A Monthly Temperature Series for Durham from 1784

Matthew Eglise

Thesis submitted for the degree of

Doctor of Philosophy

Department of Geography

University of Durham

November 2003

Abstract

The geographer and climatologist Gordon Manley produced a monthly temperature reduction for Durham University Observatory from 1801 to extend the series back from the start of meteorological observations at the Observatory in the 1840s. He produced his extended series shortly before he died in 1980, and left it in a provisional state, with limited notes regarding his construction of the monthly means based on temperature observations from sites around the North East of England. Papers that Manley left have been examined to ascertain how he arrived at his reduction, and his methods have been fully documented and analysed. Errors in the derivation of his monthly means have been corrected, and methods that he used refined to improve their accuracy. New techniques for the reduction of means from archived data have been studied. A selection of these were implemented to improve the accuracy of the new series, and further temperature observations that Manley did not use in his version have been evaluated and introduced. Observations from South Cave, near Hull, from 1794, and from Brandsby, near York, from 1784, provide the extension of the record back from 1801. Substantial sets of monthly means from Braithwaite, near Keighley, and Jesmond, near Newcastle upon Tyne, in addition to shorter sets from other sites around the North East of England and the Borders, have been incorporated into the reduction from 1801 to improve the representativeness of Manley's series. The completed series, from January 1784, has been analysed and compared with other temperature series for the British Isles, and the potential for a daily version of the monthly series has been investigated, based upon the data sources currently available.

Table of Contents

List of Figures

List of Tables

Declaration

No part of this material has previously been submitted in this or any other University.

Acknowledgements

The author wishes to acknowledge the assistance of staff at the following libraries and institutions:

Ackworth School, Ackworth, Pontefract

Akhurst School, Jesmond, Newcastle upon Tyne

Bootham School, York

Cambridge University Library

Local Studies Library, Kingston-upon-Hull

National Meteorological Library and Archive, Bracknell

Newcastle upon Tyne Literary and Philosophical Society

North Yorkshire County Record Office, Northallerton

Palace Green Library, University of Durham

Scottish Borders Archive and Local History Centre, Selkirk

The Royal Society Library, London

York City Archives

York Reference Library

Yorkshire Philosophical Society

Thanks are due to the British Atmospheric Data Centre for providing access to the Meteorological Office Land Surface Observation Station Data.

Also, to Joan Kenworthy and Nick Cox for encouragement

Carol & Jeff Eglise, Andrew Green, Emma Travis and Justin Mahoney for support

Carol Gray and Jane Addey for generosity

and Gordon Manley for inspiration.

Conventions

Within the text of this thesis, a number of conventions have been followed. A brief explanation of these is included here, to put into context the choices made and for what reasons.

Temperatures

In a work that examines temperatures across the last three centuries, a variety of thermometer scales are referred to. When describing and analysing temperatures, the original units are used in preference to the modern adoption of degrees Celsius, as is discussion of Manley's notes, which always use degrees Fahrenheit. For discussion of the completed monthly series, and comparison of it with other modern series, degrees Celsius are used.

Hours of Observation

Manley used a shorthand to describe multiple observation times per day, and this has been used here where appropriate. For example, the hours of 9 am, noon, and 9 pm are expressed as 9/12/21.

Reference to Archives

When referring to temperature series, Manley adopted a label that may have been the site of observation, or the name of the observer, e.g. Brandsby cf. Losh. Discussion of his work uses the same description that he used, although modern series are always referred to by the location of the observations.

Manley's Letters

Gordon Manley's letters to Joan Kenworthy, reproduced in Appendix A, are referred to collectively as Manley 1978-, and individually by the date of the letter in the style that Manley used. For example, his letter of March 1st 1979 is referred to as Manley 1.iii.79.

Miscellaneous

The word 'data' has been treated as plural throughout.

The 'North East' of England is referred to without hyphenation.

There was once a man called Manley at Durham who
found, about 1938, that he was a Curator of the Observatory
– a sadly neglected institution, for a variety of reasons!
Within it he found that there were 90 years of daily met.
observations, on one site, with but little surrounding change.
So he did a very great slog, & published a temperature
series for 1847-1940 in Q.J. Roy. Met. S. for 1941.

There was once a man called Manley at Durham who

found, about 1938, that he was a Curator of the Observatory

– a sadly neglected institution, for a variety of reasons!

Within it he found that there were 90 years of daily met.

observations, on one site, with but little surrounding change.

So he did a very great slog, and published a temperature

series for 1847-1940 in Q.J.Roy.Met.S for 1941.

Gordon Manley, 1902-80

Introduction

I.1 Introduction

Ascertaining the course of climate change in the past and into the future requires a firm understanding of historic patterns of climate over different timescales. Various techniques are available to researchers for gathering evidence of how air temperatures have fluctuated, both before the instrumental period by looking at proxy data, and when observations are available from thermometers. Since instruments were first constructed in the early seventeenth century, they have been applied to the measurement of air temperature by observers with many different motives. Knowledge of temperature was required for the calibration of astronomical instruments; some people are concerned with the connection with human health and disease; more recently there has been greater understanding of how temperature is changing. Nevertheless many observers took readings for long periods without necessarily appreciating how valuable they might be for future researchers.

Large-scale cycles of temperature change linked to the periodicity of the Earth's movement in space are well documented and are reinforced by proxy evidence of historic temperature, but the length of time that industrialisation has had to influence global air temperature is much shorter, and it is on the century-level scale that many analyses of climate change are performed, over the past 350 years. In order for these to be effective, accurate records of the temperature over this period are required. The scientific community is now very well aware of the value of long-term records, and the importance of maintaining consistency within those observations, but this has not always been the case. Within this thesis a number of different sets of observations are presented, some for as little as two years in length, whereas others maintained the same observer for over 30 years. There is evidence that consistency of observation was of importance, but in many sets of data available there is no evidence passed to us concerning the details of exposure and how this may have changed over time. Many statistical techniques, some used in this thesis, have been developed and described to re-document historic temperature observations such that they can be analysed, discussed and combined with others. It is this merging of observations that can allow the composition of short records into a continuous homogeneous temperature series that can withstand rigorous statistical analysis and comparison with similar records nationally and internationally. Many such composite temperature records exist, and as more sources of observations are found, they can sometimes be extended, and new statistical techniques applied to improve their quality. These records are usually based upon a single long-term series of observations that is known to be of good quality and can be reinforced and extended by other sets of data nearby. Such a reduction is that for Durham, first analysed by Manley in the early 1940s (Manley 1941b) based upon readings made at the Durham University Observatory from 1847.

Throughout his career, Manley noted the existence of temperature data in North East England before the start of the observations at Durham University Observatory, and in retirement he began to assemble these into a reduction for Durham beginning in 1801. These 46 years of 'new' data were never formally published and the methods he used were unknown, but the detailed analysis of the Durham University Observatory data from the late nineteenth century (Kenworthy, Cox and Joyce 1997) provided an impetus for Manley's reduction to be analysed and published. In addition, further sources of observations for North East England, and indeed for Durham University Observatory itself, have been discovered since Manley's death in 1980 (Kenworthy 1985) which can be used to extend what Manley did.

This thesis examines Manley's reduction and fully documents the work that he did in obtaining temperature series, assessing their consistency and combining them in the most effective ways he deemed possible. It also introduces and analyses new data available, and presents new ways of extending the series for Durham back to 1784. The completed reduction is compared with others in the United Kingdom, namely the Central England temperature series, also initially constructed by Manley from 1698 (Manley 1953) and then from 1659 (Manley 1974), and subsequently reduced to daily means from 1772 (Parker, Legg and Folland 1992). Comparison is also made with a reduction for Lancashire from 1735 (Manley 1946), again by Manley. This thesis aims to revise and fully document the composition of a third series based upon Manley's work so that a further reduction is available for the study of monthly mean temperatures across the instrumental period in England.

On a national scale, the reduction for Durham will provide an extra series for the analysis of temperature in England when combined with the Central England temperature series, the longest reduction currently available in this country. Differences between 'Central England' and the North East of England may therefore be analysed to examine how climate change may be affecting the relationship between the two areas. Other long records can be added from Edinburgh (Mossman 1796, 1797, 1802) and Armagh (Butler and Johnston 1996), not based upon Manley's work, and from Utrecht, Paris, Uppsala and other European reductions to gain an understanding of the patterns of temperature across the United Kingdom and further into continental Europe.

I.2 An Overview of the Climate of North East England and Durham

Durham University Observatory is situated on the outskirts of the city of Durham, 25 km south of Newcastle Upon Tyne and 13 km west of the North Sea coast. Figure I.1 shows the location of Durham in relation to the relief of the region.

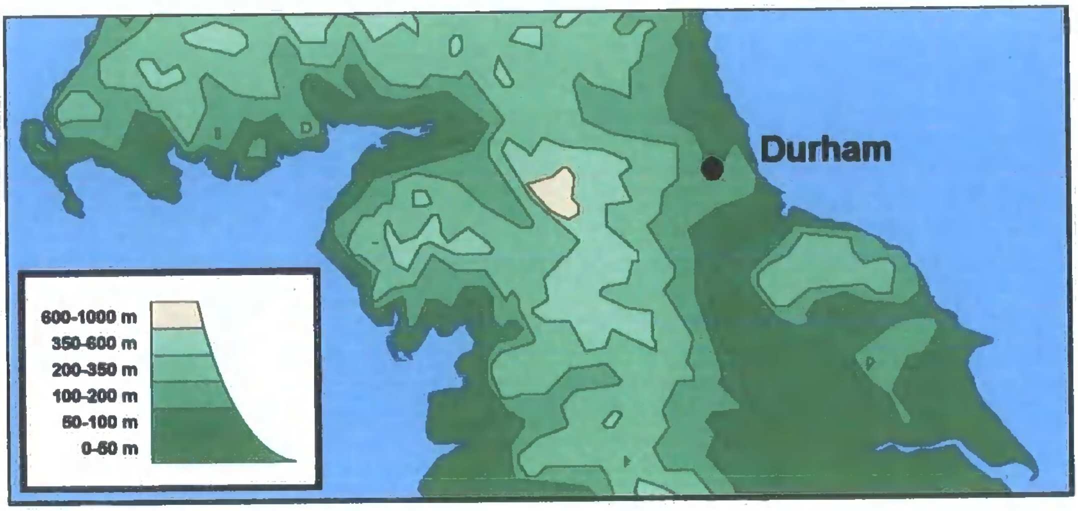


Figure I.1 The relief of North Eastern England.

The meteorological site of the University Observatory is located on the south-facing slope of a ridge within the valley of the River Wear, at 102 metres above sea level, on the outskirts of Durham city. The River Wear is situated to the north east, east and south east, 60 metres below the observatory, but at its closest is less than 1 km away, as shown in Figure I.2.

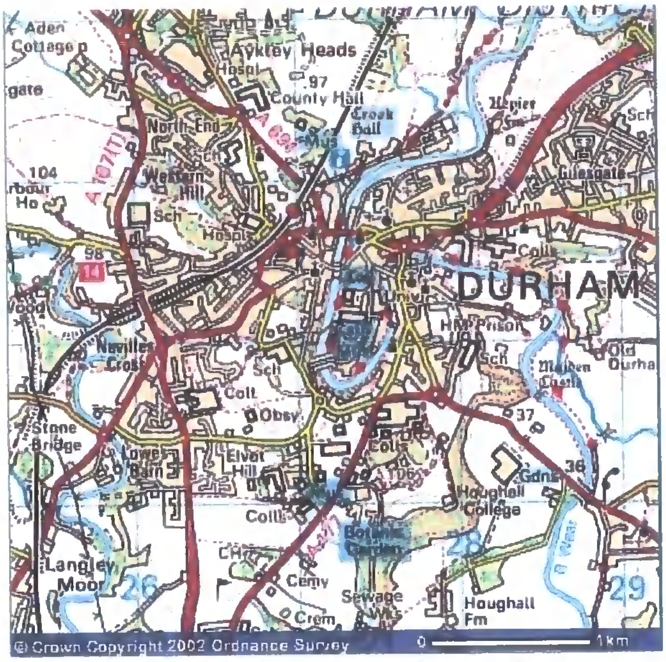


Figure I.2 A map of Durham City, showing the University Observatory (marked Obsy in lower left quadrant). (Reproduced from Ordnance Survey map data by permission of Ordnance Survey, © Crown copyright)

To the west, the ridge continues for 0.5 km before dropping to the Browney valley. Manley described the exposure as being 'on a decidedly well-exposed ridge open to winds from all quarters' (Manley 1941b). Temperature inversions in the Wear valley below the Observatory cause minima at the observatory to be a little lower than expected (Manley 1941b), but the exposure was considered by Manley to be 'well representative of the more breezy and open inland localities in N.E. England'. Nevertheless, the highly variable exposure across the region is demonstrated by temperature in the Wear valley to the south east where a distinct frost hollow is observed, indicated by minima recorded at the Houghall station 3 km from the University Observatory. The exposure at that site is well known, and gives mean extreme minima up to 2°C lower than at the Observatory (Manley 1941b, 1952a). The minima there are seen to be the lowest in the region (Wheeler 1997), and among the lowest in England.

The North East of England is roughly wedge-shaped in profile, rising from the North Sea coast in the east, to the Pennine hills in the west of the region, which dividing it from the area of North West England. The Northumberland, Durham and East Yorkshire coastlines are generally have quite a high incidence of fairly shallow cliffs, whereas much steeper cliffs are evident along the North Yorkshire coast around Scarborough and Whitby. The largest expanse of high ground in the region is that of the Pennines, but the North York Moors and the Yorkshire Wolds are large areas, although not as high, and are more consistent in their relief. As might be expected, temperature at surface level is highly correlated with altitude: see the map in Figure I.3.

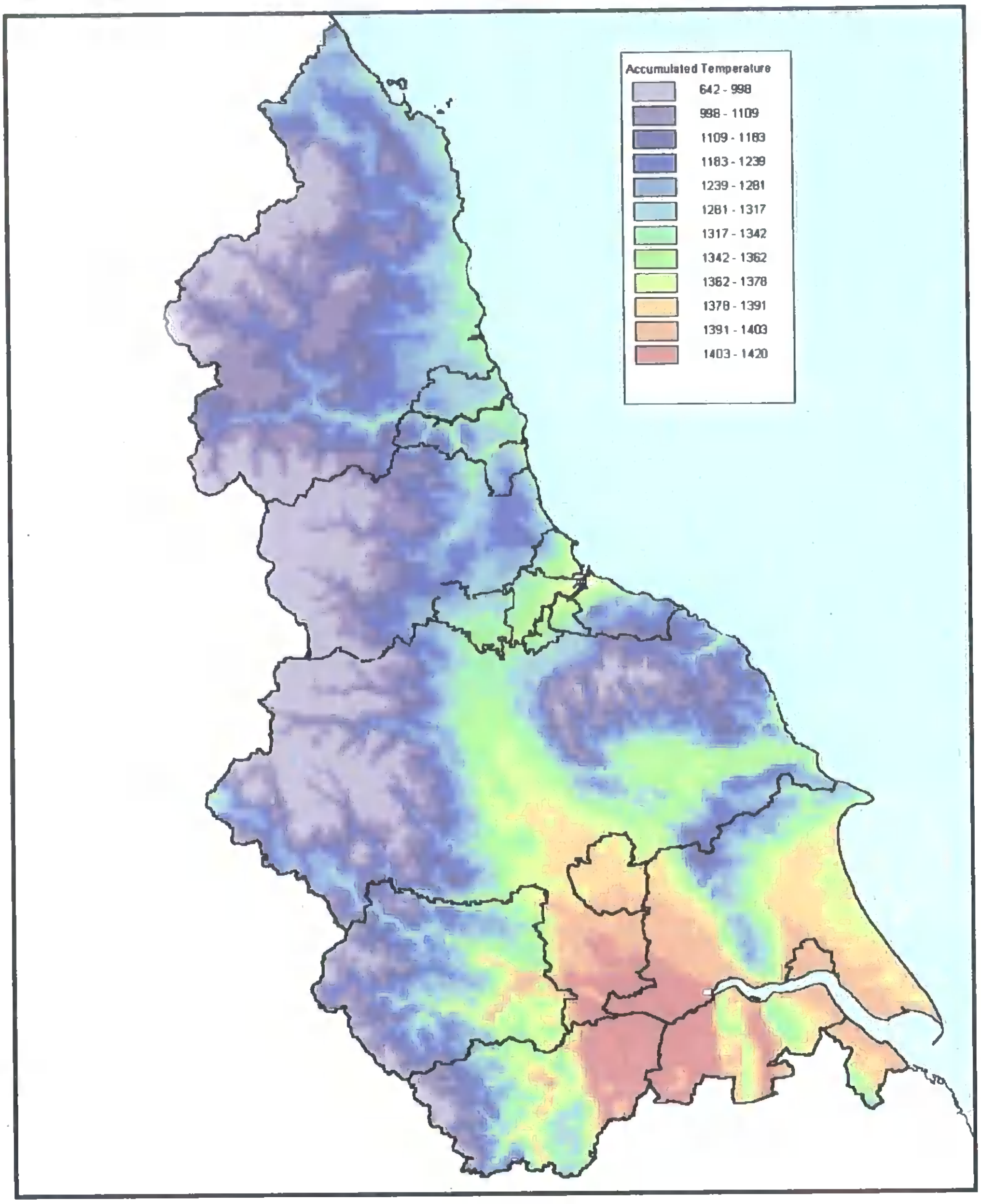


Figure I.3 Temperature for North East England, expressed as mean cumulative temperature for January to June, for the period 1941-1970, °C. Black lines show administrative boundaries (after Defra 2000, data from the Meteorological Office).

Within the region, the area that experiences warmest temperatures is the southern Vale of York, which is lower in altitude, and is sheltered from sea breezes by the Yorkshire Wolds and from westerly airflow by the southern Pennines. The climate of Durham benefits similarly, although to a lesser extent, by its location between the northern Pennines and higher ground between Durham and the coast to the east between Seaham and Hartlepool. The area of relative warmth in the Figure can be seen to extend north from the Vale of York to the Wear valley. Were Durham much closer to the coast then it is likely that it would be affected more by coastal influences, such as those seen at stations such as Tynemouth (29 metres above sea level). The sea surface temperatures in the North Sea close to the coast are the coolest around the British Isles (Manley 1935), remaining between 3 and 14°C, whereas off the south west coast of England, they range from 8 to 18°C through the year. Evans (1967) gives the January mean sea surface temperature, close to the coast, as 3.2°C, and the July mean as 12.6°C. The main reason for this is the sheltered position that the North Sea occupies, with the bulk of the British Isles shielding it from the warming North Atlantic Drift. This lower temperature for the North East assists in keeping maritime influence less important than is the case in other regions, and indeed can reduce the maxima along the North Sea coast by up to 10°C (Wheeler 1984) as a result of the cooling sea breezes, which can reach speeds of up to 25 knots (Wheeler 2002). In winter, air flow from the east, typically associated with high pressure in the northern North Sea, tends to cancel the warming proximity of the North Sea and can lead to extremely low temperatures, for example −13.5°C at Sunderland, directly on the coast, on January 11th 1982. The expected temperature regime of the North East compared to Central England would be one of cooler temperatures, based upon the latitude and these North Sea influences, but an examination by Wheeler (2002) of temperature at Sunderland has shown some higher annual means than for Central England during the 1990s, whereas this was not the case previously.

Because of the strong east-west altitude gradient across the region, and the clear relationship between temperature and altitude, it can be said that the temperature regime at each station is generally dominated by its altitude, unless that station is on the coast, in which case maritime influence will be dominant. In later chapters, a selection of stations observing temperature in the 1990s are studied, each being at a certain altitude and being more or less influenced by the sea. Stations directly on the coast have been avoided, although under some conditions sea breezes will inevitably extend further inland and will influence temperature at sites further inland.

Durham falls somewhere in the middle of the range of stations examined, making it a good typical station, approximately representative of the region in its altitude and mean annual temperature. This representativeness of Durham is discussed further in chapter 8.

Temperature reductions made up from historic observations, by their nature, have a marked degree of uncertainty, reflecting inaccurate early instruments, unknown exposure and the methods of recording the original readings. The geographical area over which the original observations are spread also introduces inaccuracies, despite careful reduction of those means based upon their climatological relationship with the 'target' station (Durham in this case). As such it can be more meaningful to consider a reduced series to be representative of an area, or even a region, rather than a specific meteorological station; examples are temperature reductions for Lancashire and Central England. In this thesis, temperatures reduced for Durham cannot be expected directly to represent Durham University Observatory itself, at least not to the 0.1°C precision that they are presented here. When compiling his sets of historical series for use in extending the Durham series, Gordon Manley would have been mindful of the geographical extents of North East England, but he was also constrained by existing temperature reductions; namely Lancashire, Central England and Edinburgh. Even if England were climatologically identical across its area, Manley would have not been able to use data from the west of the Pennines, from the Scottish Borders approaching Edinburgh or the area of England south of the Wash, for all these places had been incorporated in the Lancashire, Edinburgh and Central England temperature series respectively. As is discussed in later chapters, Manley was conscious of the need to keep Durham an independent series, such that it could be compared with neighbouring reductions. In fact, he was not able to do this, but one aim of this thesis is to restore independence to the Durham reduction such that there are no overlaps with other series for England or Scotland.

Durham is located in the well-recognised region of North East England. Stations within this area also share common features, although clearly there can be no definitive division of England into regions for climatological analysis, and there will generally be a smooth transition between the

North East and its neighbours, especially to the north and to the south, but less so to the west where the Pennines act as a line of demarcation in climatological terms. The United Kingdom Meteorological Office defines regions on the basis of climatological conditions that these regions have in common. The area defined by 'North East England' in this thesis overlaps five of the Meteorological Office regions, but with the majority of the North East covered by two of these regions. Meteorological Office districts are also defined, where the 'England East and North East' region covers the majority of the area covered in this study. Other definitions exist for the purposes of analysis, such as that used by Wheeler and Mayes (1997), whereby their 'North East England and Yorkshire' region has the Humber estuary as its southern-most part, compared to the Meteorological Office district that stretches as far south as the Wash. In addition to this, the Meteorological Office has a 'general region' of simply 'England North', which has as its southern edge a horizontal line approximately from the Dee estuary to the Wash. Furthermore, for synoptic forecasting purposes they use 'Northern England' and 'Yorkshire and Lincolnshire', which together cover the majority of the area here. In this thesis, the boundaries of North East England are the same as Manley's; from the Humber in the south east; Keighley in the south west; the Pennines to the west and the Firth of Forth to the North, thus including part of south east Scotland.

1.3 Thesis Structure

After an introduction to Gordon Manley and his work on the Central England, Lancashire and Durham reductions, the following chapters look at the background to the problem that is faced when reducing temperature observations to be representative of a given place or region. The use of the thermometer in meteorology is discussed in chapter 2, along with an examination of the conditions under which thermometers were observed. The observations that are available for North East England are discussed in chapter 3; some of which Manley was aware of and some of which he was not. Manley spent a great deal of time working on his temperature reduction for Durham University Observatory, producing large quantities of rough notes, and writing a series of eleven letters to Joan Kenworthy. These are analysed in chapter 4, to form a complete understanding of what Manley had available, what he did, and what mistakes he made, all hitherto unpublished. His methods are examined, and in chapter 5 they are expanded to introduce new techniques and increase the accuracy of those that he used. A major component of this is a study of the climate of Durham in relation to other sites around North East England and the Scottish Borders, using temperature data from the 1990s.

Manley was aware of the existence of additional meteorological observations in the south of the region, from South Cave, near Hull, and Brandsby, near York, but did not use them to extend his series further back than 1800. In chapter 6, this extension is discussed, and created, and with the incorporation of data from Durham University Observatory, found after Manley's death, from 1843, this brings the period of the reduction from 1784 to 1849. Analysis of the completed reduction is discussed in chapter 7, reviewing techniques and comparing the completed series with temperature data from the Central England temperature series, and from Edinburgh. Potential improvements are also examined, in view of the quality of data available for the North East, which is less plentiful than for regions further to the south, for example. In chapter 8, the completed reduction is discussed in the context of other temperature series: how well it can represent 'Durham' given the climate of the region, the location of its constituent observations, and the methods used to build monthly temperature means representative of Durham before the University Observatory was founded.

Chapter 1 – Gordon Manley and the Durham University Meteorological Record

Contents of this chapter

1.1 Introduction

Since the early 1840s, meteorological observations have been made at the Durham University Observatory. Over the course of the first decade, the initial sporadic readings taken to correct the astronomical equipment were enhanced to observations made every day at regular times. Observation continues there today, but over the last 150 years the timing of observation and exposure of the different thermometers has changed. When working in the Department of Geography at the University, and afterwards, Gordon Manley made efforts to standardise the data that were available to him and to attempt to extend the record back to the eighteenth century from the use of temperature records from other stations in the North East of England. Since he died in 1980, this theme has been continued within the University, with the precise documentation and digitisation of what he did from the 1850s onwards (Kenworthy, Cox and Joyce 1997). Manley's work on extending the series backward was never completed, nor were his methods and data sources ever published. From examining his letters and notes, it is possible to determine what he was working with and how he worked on the extension. In addition to this, further data sources have been discovered that may be used to extend the temperature record of the Durham University record still further from the provisional series left by Manley in 1980.

1.2 Gordon Manley

Gordon Manley was born in 1902 on the Isle of Man, but soon moved to Blackburn and from an early age was interested in the weather, taking meteorological readings locally. He took a degree in Engineering at Manchester University, graduating in 1921, and then studied geography at Gonville & Caius, Cambridge , until 1923. Two years later he moved to Kew to work for the Meteorological Office, but was to spend only a year there before moving to Birmingham to become an assistant lecturer in Geography at the University. In 1928, he gained his first appointment at Durham University (a lecturer in Geography as at Birmingham) although, as head of a new Department, his responsibilities were greater. He taught biogeography and North American geography as well as climatology, and became Curator of the University Observatory in 1931. While he was at Kew, he had taken measurements with, and maintained, the meteorological instruments and upon arriving in Durham he set about reorganising the instruments there, some of which he believed to be incorrectly sited or faulty (Manley 1941b). He was elected a Fellow of the Royal Geographical Society at this time, and in 1932 a Fellow of the Royal Meteorological Society.

Manley made various studies of the local climatology while in Durham, particularly of the North Pennines, and during 1932 and 1933 he published a series of papers on the subject in both the *Durham University Journal* (Manley 1932a, Manley 1933a) and the *Meteorological Magazine* (Manley 1932b and Manley 1933b). These papers stemmed from time spent setting up a station, and examining the observations taken from it, at Moor House, upper Teesdale. He used these results to publish a study of local meteorology of Cross Fell (Manley 1939b), notably the helm wind. He took an interest in the local history and archaeology of the county and its surroundings, and on finding sets of maps of the county in the Durham University Library published papers on those (Manley 1931) and on other surveys of the area (Manley 1934a, Manley 1934b and Manley 1936). He also developed an interest in local snowfall, from both historic records and the contemporary situation (e.g. Manley 1937, Manley 1939a, Manley 1941a) and this interest continued until well into his retirement when he worked on developing a snowfall record for the

North East of England.[1] From 1938 to 1940, he was involved in setting up and making observations at a station on Dun Fell, which at 847 m provides the longest unbroken mountain record in England. Many climatologists tend to concentrate on the examination of temperature extremes, and Manley was no different in this respect, although throughout his career he favoured temperature minima, quite possibly stemming from his years spent in the coldest part of England, and his early expedition in 1926 to East Greenland.

In his position at the Durham University Observatory, Manley became interested in the meteorological record kept for the previous 90 years[2] and which comprised, and still does, the second longest continuous record at a British university observatory (after Oxford University[3]). During the latter part of his time at Durham, he scrutinised the temperature records held there and published a standardised series, correcting for the various exposures that had been used throughout its history (Manley 1941b). For this paper and two others, he was jointly awarded the Buchan Prize, together with Dr T.E.W. Schumann. He would later expand upon this series by extending it using other local temperature archives.

Manley left Durham in 1939 after gaining an external M.Sc. from Manchester University, and returned to Cambridge, where he was appointed demonstrator in Geography. His continuing interest in the climatology of the North of England was reflected in the bulk of his writing over the next decade. He became President of the Royal Meteorological Society in 1945 and helped bring into existence the meteorological journal *Weather*. The extension of temperature series was touched on in his publication on the Durham University Observatory record, but he took this

---

[1] Many other papers were published by Manley, both at this time and later in his career on these subjects. A complete bibliography of all his known papers and articles (with the exception of those published in regional newspaper such as the *Manchester Guardian*) may be found in Sheail, Kenworthy and Tooley (1985).

[2] Manley suspected that records had been kept at the University Observatory before the earliest observations that he had available, these starting in 1847 in quarterly format and 1849 in daily format. The Observatory itself had opened in 1841, but the first two ledgers from 23rd July 1843 to 30th April 1850 were not eventually discovered until after his death.

[3] The Oxford Radcliffe Observatory started recording in 1815, and the Royal Observatory at Greenwich in 1841.

further in a paper on the climate of Lancashire (Manley 1946), analysing temperature series for the surrounding area and adjusting them so as to be representative of a certain station or region. In this instance, the area he covered was that of the 'Lancashire plain' – an area that he knew well in both its geography and its climatology, and was able to establish a temperature series starting in 1735, making it the longest derived temperature series in the British Isles at that time.

His longest appointment was at Bedford College, London as a Professor in Geography from 1948 to 1964, during which time he wrote *Climate and the British Scene* (Manley 1952a). After this, he moved to the new University of Lancaster to head the Department of Environmental Studies[4], but was to stay there for just 3 years to 1967 when, at the age of 65, he retired. Back in the Cambridgeshire countryside, he continued his research, remaining a Research Associate at his old Department at Lancaster. His retirement was an active one for he also became Visiting Professor of Meteorology at the Texas A and M University and remained so until 1970. His revised work on the Central England temperature series was published during this period (Manley 1974) to lengthen his earlier 1953 paper and include data up to 1974. It was this work that brought him recognition worldwide. He was awarded an honorary degree of Doctor of Science by the University of Durham in 1979.

For the twelve years of his retirement, Manley continued to work on his temperature series, returning to concentrate again on Durham in 1978, and was assisted in this task by a personal grant from Shell Oil. The majority of the next two years were spent productively, extending the record back to 1801 using a variety of sources for his data.[5] As no Durham University Observatory readings were available to him before 1847[6] (or from 1850 as daily observations), he had to adapt data from other sources to be representative of conditions at the Observatory. Manley found that values derived from his various archives varied widely and put much of this

---

[4] later Environmental Sciences

[5] These sources, and his methods, are discussed in chapters 3 and 4.

[6] For 1847 and 1848, Manley only had an annual mean for 1847, and quarterly means and extremes for the last quarter of 1847 and the whole of 1848.

down to instrumental error and inconsistent reading: observers of the early nineteenth century might not have imagined a scientist studying their data over 150 years later, requiring accuracy to 0.1°F! Manley drew up a series of tables, but stated that each was merely a step towards the final version. His last table was written out on November 5th 1979 to cover the period 1801 to 1847, and to join seamlessly with the data available for the University from 1847.

Gordon Manley died in hospital on 29th January 1980, at the age of 78. More detail on his life can be found in Lamb (1981) and Tooley & Sheail (1985), with a review of his general work on the Durham extension in Kenworthy (1985).

1.3 The Meteorological Record

The University of Durham was founded in 1833. Astronomy was not initially included as a subject to be pursued. The interests of one man, Temple Chevallier, provided the driving force behind the establishment of astronomy at Durham, and afterwards the building of the University Observatory.

The Reverend Temple Chevallier came to Durham in 1835, initially as Professor of Mathematics but added 'Astronomy' to his title in 1841. It is clear that this was among his interests from a much earlier date, because in 1839 he had discussed the acquisition of some land for the siting of an observatory from the Dean and Chapter of Durham Cathedral, who then, as now, owned a substantial amount of land around Durham City. The Bishop of Durham, Bishop Maltby, assisted the cause by writing to Lord John Russell on several occasions stating reasons for the initiation of astronomy as a subject at Durham (Rochester 1980). It followed that an observatory would be necessary from which to undertake research, and that this would be an excellent means of furthering the reputation of the University of Durham and of science in general. Eventually, some land on a ridge to the west of the cathedral was granted under a lease, and Chevallier raised funds to erect a building and furnish it with astronomical instruments. Many of these came as a donation from T. J. Hussey, of Hayes in Kent, in 1839 and two years later, the observatory building was completed. Even before the construction was finished, astronomical work was undertaken and a certain amount of meteorological observation was being made.[7]

Initially, no emphasis was placed on meteorology as a subject in its own right; as in common with other observatories, readings were only taken to assist with the astronomical work. It was important to take readings of air temperature when making observations with the telescopes because temperature affects the way in which light is refracted. Temperature readings at

[7] Early journals of astronomical observations show data from 1840, with associated sporadic temperature readings being taken from this time also. These journals were found at the Observatory in the early 1980s.

observatories were generally undertaken on an *ad hoc* basis and readings taken only at night when observation was taking place. However, it was clear that meteorology was seen as an important ancillary subject at Durham from an early stage and Chevallier himself was among those who founded the British Meteorological Society.[8] In 1840, the curators of the Observatory had stated that assistant observers should have an opportunity to study for a short period at the Royal Observatory at Greenwich: given that meteorology was advancing there under Glaisher at that time, this would have been influential in gaining support for the subject. The prominence of meteorology became more obvious when temperature readings were taken during the day, as well as at night to adjust the astronomical readings. The earliest ledgers of astronomical observation appear to have been used as rough notebooks, and they contain sporadic readings of temperature, but proper meteorological records began to be kept in journals apart from the astronomical observations from around 1842. The precise date when this started is unclear because no meteorological readings of any great significance have been found for this early period, although some second-hand sources suggest that the meteorological records were being kept from 1841 (Whiting 1932), or 1842 (Baxter 1956). There is some uncertainty over whether these references are to astronomical observations only (Kenworthy 1985).

Until the 1980s, it was understood that the first serious meteorological readings began in 1850 when R. C. Carrington was the observer. His is a meticulous meteorological record, with entries daily at 9 am and 9 pm, and contains a full range of values for pressure, temperature, humidity, rainfall, wind (direction and speed) and cloud cover. A subsequent catalogue of some of the contents of the basement of the University Library led to two journals being discovered from mid-1843.[9] Even so, there must have been some structured recording of the temperature before to this since the *Durham Advertiser* carried monthly summaries together with a note on the extremes for that period, in common with a number of other local newspapers of the time. It is not clear whether the temperature readings were taken continuously by the observer, Arthur

[8] Later to become the Royal Meteorological Society.

[9] This catalogue was produced in 1982 and led to two journals being found from July 1843 to April 1850. The contents and nature of these are detailed in chapter 5.

Beanlands, and were only sent to the newspaper on an irregular basis, or whether these published summaries were all that was ever recorded. The data printed in the *Durham Advertiser* comprise the months of June, September and October 1842, plus all months for 1843. These data included the means calculated from the mean maxima and mean minima for the month.[10]

At first, the thermometers were probably sited against the north wall of the building, adjacent to a small area of flat roof created by virtue of the fact that the upstairs offices occupied a slightly smaller space than the downstairs living quarters. The thermometers were held directly outside the window to the transit room so were readily accessible to the observer (Manley 1941b). There was no screening of them until October 1851, when a surround was put up around the instruments which was referred to as the 'north shed'. A substantial proportion of Manley's 1941 paper on the temperature series in Durham focuses on the differences between the thermometer values recorded in this north shed, and those taken previously. He also studied the differences between these and the Glaisher stand which was erected on the lawn in front of the observatory (i.e. to the south) in 1860. Readings were taken from the north shed thermometers until 1871, passing through the hands of four successive observers (Marth, Marshall, Dolman and Plummer). J. J. Plummer, presumably after examining the relationship between the earlier north-shed readings and Glaisher stand readings, placed maximum and minimum thermometers in the north shed to ascertain the precise nature of the differences (Baxter 1956).

[10] Chapters 3 and 4 describe and analyse these data. In addition to data from 1842 and 1843, Manley found temperature observations reported in the *Durham Advertiser* in 1845 (Manley 27.xi.79) but did not incorporate these into his extension.

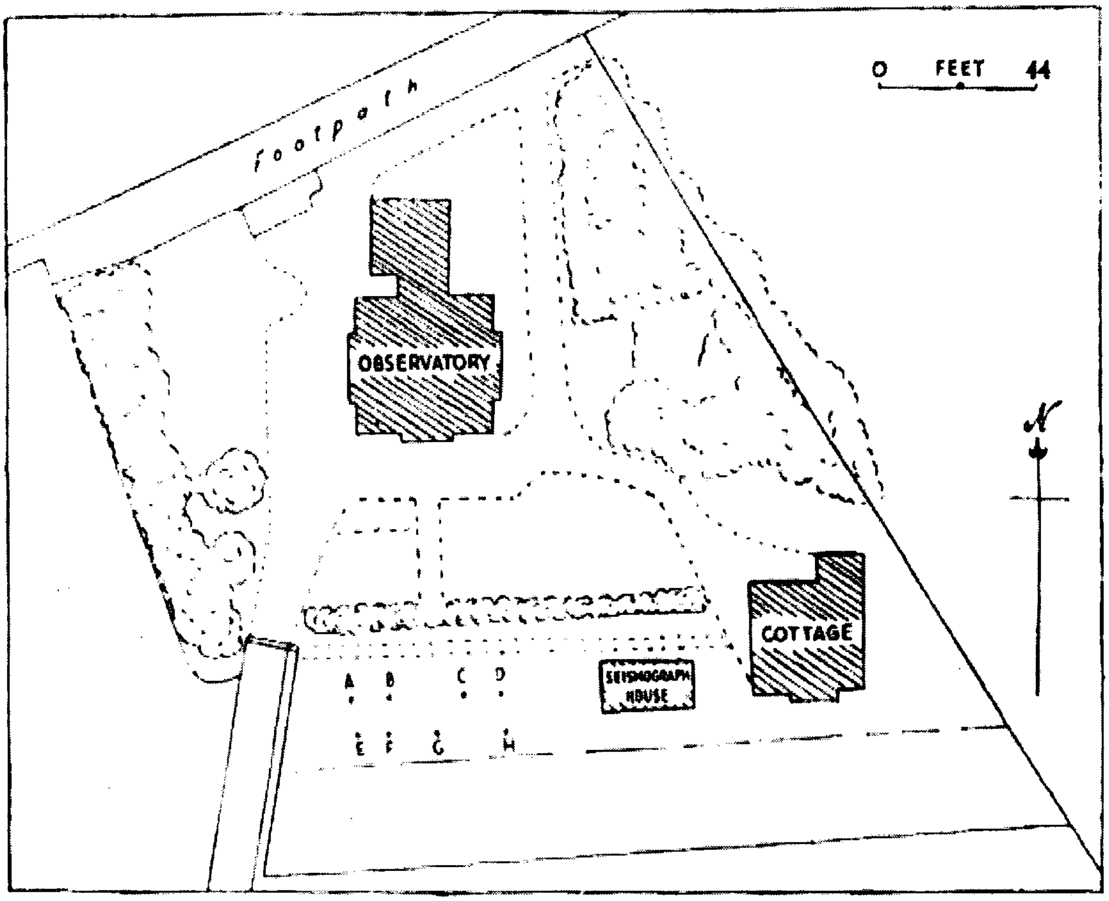


Figure 1.1 A plan of Durham University Observatory in the 1950s. The sites marked A and B are the two Stevenson screens (Manley 1941b).

The first Stevenson screen was installed at the Observatory in 1900[11], and once more the observer (Carpenter) ensured that a comparison was made between the new stand and the previous one over a period of a year. Manley was of the opinion that this time of overlap was not long enough to provide a good assessment of the characteristics of each screen. He described the 12 month overlap as 'not adequate' and 'excessively difficult to interpret' and was also uncertain of the accuracy of the self-registering thermometers throughout this transitional period (Manley

[11] The precise date of the installation of the Stevenson screen is thought to be March 1st but this was not clear because its first use was not recorded in the ledgers. The occasion of its introduction was deduced and subsequently confirmed by the Meteorological Office (Manley 1941b).

1941b). He devised a procedure for calculating reinforced or 'adopted' means for the entire 'Glaisher period' in an effort to smooth out any inadequacies in the readings, taking into account the changes in the hours of observation which came about in 1885. Regarding the overlap between the Glaisher and Stevenson screens, Manley used data from Ushaw[12] and Rounton[13] to corroborate the readings taken at Durham (Manley 1941b). By these methods, Manley published a series of 'adopted' means for Durham University for 1847 to 1940.

Since 1941, meteorological observation at the Observatory has continued, although astronomical observations are no longer carried out, having ceased around 1939. The building itself was vacated by the observer once a cottage was built in the grounds in 1932, mainly due to the encroachment of damp into the ground floor rooms (Baxter 1956). The joint professorship of Mathematics and Astronomy did not return to Durham until 1985, and the building is currently used by the gamma ray section within the Department of Physics at the University. In 1936, a Dines pressure tube anemometer was installed in the space vacated by the main telescope and was in good working order until the meteorological station was automated in 1999 and readings from the Dines anemometer ceased. Throughout this period, a succession of observers continued to take meteorological readings to supplement the long record that had been built up by that stage. The most recent observer, Audrey Warner, took the readings from 1969 to 1999, and the instruments have now been replaced by an automatic weather station, which ran for one year before the manual observations ceased.

---

[12] Ushaw is the site of one of the constituent colleges of the University of Durham and is 5 km north west of the Observatory. Manley used data for 1885 to 1940.

[13] Rounton is 10 km north east of Northallerton. Manley used data for 1883 to 1920 to support the Glaisher/Stevenson transition.

1.4 Manley's Aims and Unfinished Work

During his lifetime, Gordon Manley worked on the extension of three important temperature series. He spent a good proportion of his time, both while employed and while in retirement, researching the whereabouts of meteorological archives throughout the United Kingdom.

> *'The task of bringing our earlier sources of meteorological observations into an arrangement which will facilitate the quest of scientists has for forty years provided me with an occupation of increasing fascination and complexity.'* (Manley 1981)

The variable fashions of geography over the years failed to influence Manley, and it was this lack of diversion which led to his continuation of research into temperature series long after the use of computers had shifted the focus of climatology into mathematics (Craddock 1980). He was very keen to turn the long Durham University Observatory series into a reliable and continuous temperature record, and was fully aware of the fact that even in the slightly dubious state in which he found it, it was the second longest British university record which had been kept at one site. The fact that the two longest records in the country were in the south seemed to frustrate him somewhat, and he was very keen to build series for the North West and North East of England.

Manley was concerned that the archives that he knew of, and discovered, should be carefully preserved and the data in them put to use. Looking at his notes made while producing these series, it is clear that he was always disheartened when a record proved to be unreliable for some reason, and was therefore not suitable for use in one of his temperature extensions. For example:

> *'Reluctantly discarded owing to early irregularities and doubtful exposure'* on the record kept at Keighley by Abraham Shackleton (Manley 1953)[14]

[14] This comment relates to the user of this record in Manley's Central England temperature extension, but he would later use this series in his Durham extension.

'I have examined his MS. as a south-country inland set for that period would have provided useful reinforcement; but there are far too many gaps due to absence' on the record kept at Selborne by Gilbert White (Manley 1953)

'Life is complicated by Sir J. Brisbane, who at Makerstoun in Berwickshire had a superbly equipped observatory, but DID NOT OBSERVE ON THE SABBATH' (Manley 9.ix.79) [15]

He was very interested in the contents of weather diaries from a historical and personal point of view, publishing a number of papers solely on their contents, for example on the journals of Thomas Barker at Lyndon (Manley 1952b, 1969a), John Dalton (Manley 1944, 1968) and Constantia Orlebar (Manley 1955).

Manley generally concentrated on working on series for areas which he knew well, from a climatological and personal point of view. His relationship with County Durham was a long one and he spent much time there, returning frequently in his retirement while working on the series for North East England; indeed it was for Durham that he first produced a standardised temperature series, smoothing out irregularities and uncertainties in the data. He was well aware of the example set by the longer 'senior' series kept at Greenwich and Oxford, and this led on to his first extension of a temperature series for Lancashire, where his links stemmed from his childhood and his return to the University in Lancaster in 1964.

Work on a series for London occupied a short spell of Manley's life although it was never published. He compiled a daily series for 1723 to 1811 and was later to use the information, and details of other records for the London area, to create his series for central England. His work on this was initially published in 1953, seven years after the completion of his Lancashire series, and was, to a certain extent, an amalgamation of the Lancashire and London sets of data that he

---

[15] Chapter 3 discusses why Manley did not use this record.

had worked on previously, for his definition of Central England spreads from its south eastern corner in London to its north western corner in the southern Lake District. His continued research into weather journals led him to produce in 1974 an updated paper on Central England temperature (Manley 1974). Not only did he extend the series forward to 1973 based upon the choice of stations he had opted for in the earlier paper, but also backward to 1659. The main set of data that Manley used to provide values for the earlier period was data for London for 1670 to 1697 on which he had worked previously (Manley 1961). Before 1670, he used largely non-instrumental data to infer temperatures to the nearest degree, or half-degree later in the period. In addition to these improvements, he published the temperatures in degrees Celsius, as opposed to the Fahrenheit scale, although it was with some objection to the new system of measurement that he did this.

By the time Manley returned to this work on the Durham series in the late 1970s, he was aware that there were a number of weather archives available for the North East of England, but that there were surprisingly few compared with the number available elsewhere. There are many reasons for this, not least the slow spread of scientific practice away from London and the major southern and Midland cities, and he knew that the Durham extension could not be as long as the other series available. Nevertheless, this did not dishearten him: one of the main reasons for his working on the series was his connection with Durham and the fact that the data were 'there'. Continuing this standardised series forward was straightforward, but extending it backward proved more difficult. He spent much time travelling from his home in Cambridge to Durham, Newcastle and York to locate series which had been printed in newspapers, or were available in libraries. He visited the Newcastle Literary and Philosophical Society Library on several occasions, copying down readings from the journals of James Losh[16], but also obtained some of his material by post from libraries that were able to photocopy or otherwise reproduce the pages

[16] Detailed information on this, the major archive for the extension running from 1801 to 1833, can be found in chapter 3.

of the archives he required. He obtained temperature records for Keighley and South Cave in this way, among others.

Manley's widow, Audrey, deposited many of his papers in the Cambridge University Library so that they could be consulted and it is from these that valuable clues may be obtained as to the progress of his work and what he had available (Manley 1938-). When she died, the remainder of his papers were lodged with the Department of Geography at the University of Durham.[17] In addition to these collections, much can be derived from the letters he wrote to Joan Kenworthy who at the time was Principal of St. Mary's College at the University of Durham. These letters cover the period from January 1978 to November 1979 and provide the only formal 'writing up' of his work on the Durham extension (Manley 1978-). Although they do not go into detail of the calculations he made, or exactly why he chose to perform certain steps rather than others, these documents give a valuable indication of the chronology of his work, which the papers held in Cambridge do not provide because his rough notes are not dated and have been catalogued in only a rough chronological order.[18]

[17] This collection is extensive and comprises 10 boxes of manuscripts, and hundreds of prints, slides and negatives (Tooley 1993), but does not include any work on Durham.

[18] Manley used a distinctive convention when dating his letters. For example, the date 27th November 1979 would be written 27.xi.79. This convention is used when referring to his letters in the text.

1.5 An Opportunity to Complete Manley's Work

Manley's final table of values for Durham was for 1801 to 1847, in his letter dated 27.xi.79. While this is complete, with no gaps, there remained improvements which could be made to it, some of which were recognised by Manley and some which were not. He made it clear that the table in this form was not finished by the following comment:

> *'I feel the work shouldn't be wasted and it will be quite a time before I can get it all completed and written up. So, this isn't yet for publication, merely retention.'* (Manley 5.xi.79)[19]

There is evidence in his notes and letters to suggest that he was still researching the existence of other temperature series which may have been suitable for inclusion in the series to improve the quality. He had also relied upon other temperature series to bolster the calculated values during certain periods, in that for the years 1833 to 1842 he used his own Lancashire series and the temperature data published for Edinburgh by Mossman (Mossman 1896, 1897, 1902). He was keen to remove any reliance upon these, so that the final Durham series might be compared with other series in the country to investigate regional differences:

> *'Edinburgh is not only a long way off but I want to avoid using it if I can, to keep "Durham" independent.'* (Manley 3.vi.79)

Two major advantages are available to researchers returning to look at the Durham extension, which Manley did not have in the late 1970s: namely those of computing power and time. Manley must have been aware that he might not live to complete work on the temperature series and it would appear that he was purposefully depositing a record of what he was doing with Joan Kenworthy so that someone could later pick up where he left off.

[19] This comment relates to the table included in a slightly earlier letter November 5th 1979, for 1801 to 1850.

Some errors have been found in the recalculation of the data while examining Manley's methods and checking his results. It is known that he did not use a calculator, and it is certain that a good proportion of the errors were brought about by this fact. He was, as discussed above, of a fairly old-fashioned character and was not easily swayed by modern methods, particularly in the field of automation:

> *'I know nothing about adding machines, but reckon I'm quicker, especially now I've got to do it one-eyed; transferring from MS page to press-buttons seems to me rather more effort.'* (Manley 27.ix.78)

Not only can the use of computers be helpful in calculating the data itself, but also in analysing the series after it has been compiled. Manley was trained to do all this by eye but would not have been able to engage in some of the more sophisticated methods which are now available to statistical analysts.

The most significant development which has occurred since the late 1970s with regard to the data that Manley used has been the discovery of some of the journals of meteorological readings taken during the early years of the Durham University Observatory. This has been published in preliminary form (Kenworthy 1985) but little analysis has been carried out upon it to investigate its suitability for incorporation into the series. In addition, Manley intended the data set for South Cave, near Hull, to be included in the extension. This series extends back to 1794 and despite being 150 km south east of Durham, is in a similar climatological region[20] and overlaps the existing period of data by enough to provide a good extension to the series. Extra data for the series observed by Cholmeley at Brandsby, North Yorkshire, can also be incorporated into the

[20] i.e. west of the Pennines and fairly near the coast. Durham and Hull are grouped in the same north eastern *district* used by the Meteorological Office for dividing the British Isles. The district is divided in two at roughly the level of Teesside to form two separate Meteorological Office *regions*.

series, because data have now been found for the period from 1784 to 1791[21] and for 1854. Some further fragments for Scarborough and Whitby have been found for parts of 1815, 1818 and 1819.

There were also a number of non-instrumental diaries available to Manley which, as in a similar way he did for his Central England extension, he may have gone on to incorporate into the series to extend it backwards still further. Such archives as those kept by Timothy Whittingstall, for Lanchester (1636 to 1670), by Christopher Sanderson at Eggleston-in-Teesdale (1682 to 1689) and by Abraham Sharp near Bradford (starting in 1701) might prove useful in extending the series back from 1794.[22] Such non-instrumental sources have not been considered for use in this study, on the grounds that means derived from them have a much lower accuracy than those from instrumental diaries.

There is also an opportunity to build upon the monthly data by creating a daily series compatible with it. Manley was keen to create daily temperature series where such data existed and where it could be proved valuable, in his London fragment for example, and a daily series has been produced for his Central England temperature series by researchers at the Meteorological Office (Parker *et al.* 1992). It is clear that Manley had intended his extension to Durham to be published, but was unable to make this goal. He wrote of 'the paper' that would be produced as a result of his research (Manley 27.ix.78) and, while many of his notes are difficult to decipher and understand, the best part of the material which he had available is accessible. Manley was determined to complete the task and it was a matter of pride that he should complete a series for the area of England he knew so well. He encountered many difficulties, most of which still present themselves to the researcher of the present day. In his own words, upon turning to look at the Durham extension, said:

---

[21] Manley had monthly data for Brandsby available for 1811 to 1830 and relied upon this series heavily in his extension.

[22] Of these three diaries, only the location of the Sanderson manuscript was known to Manley.

'*... start on some HARD PERSISTENT SLOG. Take a deep breath: be careful: and I'll vow to praise!*' (Manley 27.ix.79)

1.6 Summary of Chapter One

This chapter has introduced Gordon Manley, giving background to his life and major achievements. It is mainly his work on temperature series that is of interest in this thesis, and this has been highlighted. Further detail on Gordon Manley can be found in Lamb (1981), Tooley & Sheail (1985) and Kenworthy (1985).

Chapter 2 – Background to the Thesis

Contents of this chapter

2.1 The Beginnings and Growth of Recording Climatic Factors

2.1.1 The Thermometer

The thermometer was first invented as the air thermoscope in the early seventeenth century by a number of different figures: Galileo, Sanctorius, Drebbel and Fludd have all been credited with the invention (Middleton 1966).[23] Their thermometers measured temperature via the pressure of air within a vessel that caused the level of water at an open end to rise and fall as the air temperature fluctuated. It was not until the middle of that century that a thermometer was described that used liquid as the medium sensitive to temperature. This was developed at the Academia del Cimento in Florence and was an elegant glass instrument, with the tube coiled round in a rising spiral, possibly in an attempt to improve the sensitivity of the apparatus. It was not long before knowledge of the thermometer spread north of the Alps, but makers of such instruments in the Low Countries used straight stems, possibly recognising the scientific value over the decorative. Later in the seventeenth century, the glass parts of the thermometer were mounted on a wooden board that was sometimes covered in paper with a scale marked upon it. The bulb lay snugly in a depression in the wood. For these early thermometers, the liquid used was some form of spirit; generally 'spirit of wine', a relatively impure ethanol.

[23] Middleton (1966). All references for sections 2.1 and 2.2 are derived from this work unless stated otherwise.

The thermometer is thought to have been brought to England from Florence by Robert (later Sir) Southwell. He showed an example to Robert Boyle (1627-1691) and the instrument aroused interest among the fellows of the Royal Society very shortly after its foundation in 1660. A certain amount of discussion was entered into concerning the possible applications of the new thermometers and on October 7th 1663 the fellows discussed the acquisition of four thermometers to be placed, and read, in cellars. Two weeks later, Robert Hooke brought several thermometers for the fellows to examine. They first ensured that all the instruments read the same, in this case the reading was 'the figure 8', although exactly what scale was being used is not clear.

Hooke then set about designing and making his own thermometers and again used spirit of wine, but this time coloured with cochineal for ease of reading. He stated that the spirit responded quickly to heat and is not easily frozen. He graduated his thermometer by placing the bulb in freezing distilled water[24] to find a single fixed point from which to make further graduations on the scale. At first, thermometers had been graduated by comparison with an existing instrument at a variety of different temperatures, but the use of a single fixed point from which to graduate a thermometer became more frequent. However, even this method had its uncertainties, because the constancy of the freezing point of water was not confirmed for several decades after it was first used as a fixed point. The other marks on the thermometer were made at regular intervals up the scale but would vary between different makers. Hence it would be very difficult to compare measurements made using different thermometers.

Many other scientists looked at refining the materials used to make thermometers and the scales used to read off the measurements. Different liquids were researched by the Florentines and mercury was tried. They showed that mercury did 'receive the heat first'. Boyle also considered using 'well-refined quicksilver', as did Edmund Halley, but all these experiments found that mercury expanded less than spirit did with the same rise in temperature. In fact, Halley had

[24] Freezing water will not give the true freezing point of water - melting ice should be used instead.

decided upon using air as his medium, quite unaware of Hooke's more advanced research into coloured spirit. Isaac Newton also published a paper, in 1701, that described a linseed oil thermometer.[25] There is no evidence that Newton used it for meteorological observation, but he did specify certain temperature ranges on his scale that would be reflective of the seasons.

2.1.2 Thermometer Scales

In the late seventeenth and early eighteenth centuries there were almost as many different scales as there were thermometer makers, and in order to make comparable readings it was seen that a common standard was needed, at least within each country. The method of dividing up the length of the thermometer stem into degrees was debated with the use of both one and two fixed points finding favour in different areas. The first thermometers had generally used one fixed point as already mentioned, but the use of two fixed points would enable the difference between the two to be divided into a fixed number of units. Moreover the method of finding the fixed points also varied although the freezing and boiling points of water were generally used. What separated the different scales was the number of divisions between the two fixed points. By the middle of the eighteenth century there were three main systems for graduating thermometers: Fahrenheit, Celsius and Réaumur. The Réaumur scale was unlike the other two in that it used only one fixed point and was later to be considered less satisfactory for this reason. It divided up the thermometer into 80 degrees. Daniel Fahrenheit's thermometer scale was divided into 180 divisions between the freezing and boiling point of water. Anders Celsius devised a scale that was divided into 100 units, although his scale ran from 0 at the boiling point up to 100 at the freezing point. It was Carl Linnaeus who inverted the scale into the one we use today.

Before these scales had been described, there was some consolidation and one particular scale emerged which found favour among those observing the weather. This was known as the Royal

[25] This paper did not bear his name and it not until some years later that this work was attributed to him.

Society scale and was based upon one fixed point where the scale existed largely to the positive side of zero. The hottest weather would perhaps fall at –5 degrees on this scale. Temperate conditions would perhaps be indicated by 45 degrees and the freezing point was 65 degrees. We know about this scale and its use from the secretary of the Royal Society, Dr James Jurin (1684-1750) who issued an invitation to learned gentlemen to take readings with thermometers marked with the Royal Society scale and send them back to London where the information could be studied. He recommended the use of thermometers made by Francis Hauksbee[26] of Crane Court in London (Jurin 1723). Jurin also took temperature readings himself, his own interest linked to his interests in public health and medicine (Kington 1997).

Some of these Hauksbee thermometers still exist – mostly attached to barometers – and there was some debate during the mid-eighteenth century over the reliability of the instruments. Van Swinden found that when two Hauksbee thermometers were compared, there was a difference of the equivalent of up to 10°F between the two, and that the freezing point of 65 was sometimes far from this figure, although it is not certain by how much. Nevertheless, Jurin received many reports based upon readings taken by such thermometers.

[26] This was the younger of two men named Francis Hauksbee. He was the son or the nephew of the elder. They were both in the trade of instrument making. The surname is sometimes spelt Hawksbee (e.g. Manley 1974).

2.2 Thermometers and Exposure Practices

The first instrumental meteorological readings taken with a thermometer are thought to have been observed by Antonio Terillo in Parma from 1654 (Middleton 1966). He had two thermometers, both situated indoors, one of which was sited beside a north-facing window, and the other beside a south-facing window. These thermometers, presumably graduated using two fixed points, were marked into 50 degree scales, where 13½ was the freezing point of water. Terillo stated that the coldest air he had observed had brought the reading to 7 on the scale. He observed three times a day and compared the readings between the thermometers facing north and south.

While the number of observations made with thermometers for meteorological purposes increased, the observers themselves did not seem clear about what they were measuring. In order to take a true measurement of the air temperature it is necessary to keep the thermometer well ventilated, away from the influence by radiation or convection from other obstacles such as walls or pavements. Screens were used to shield the thermometer from the direct rays of the sun, but the design of some of the early screens allowed radiation from the back of the screen onto the instruments, or from nearby objects by inadequate screening all round. Until the mid-eighteenth century, it was usual for the thermometer to be placed indoors, in a room where a fire was rarely, or preferably never, lit. These 'cool-room' readings can be used where the characteristics of the room are known but are far from ideal. Early recorders of temperature were often those connected with medicine, and were more interested in observing indoors where the sick and frail would actually be. They also had an interest in publishing and comparing their results with others taken from around the country.

The encouragement of meteorological practice in the United Kingdom was facilitated in the 1860s by Robert FitzRoy as the Head of the Meteorological Department of the Board of Trade, from 1854. He presided over the publication of national daily synoptic maps (Kington 1997).

This led to the encouragement of further sites that would report their readings via telegraphy each month or quarter in a trial of the production of more sophisticated charts.

The spread of meteorological observers across the United Kingdom was a slow one, initially being confined to London and south east of England, although with some notable exceptions. One reason for this was the location in these areas of many 'scientifically-minded' persons who would consider making such readings, no doubt attracted and motivated by the various philosophical societies of London. Despite this, there were a number of notable early observers from further afield who were making meteorological observations. The valuable series recorded by Thomas Barker at Lyndon, Rutland, spans 1733 to 1798 with a break from 1764 to 1776, where records are presumed to have been taken but are now missing.

Table 2.1 shows the early instrumental weather diaries that survive to the present. The list is drawn from Manley (1974) and was used in compiling his Central England temperature series.

Table 2.1 Early observers of instrumental temperature readings (from Manley 1974)

Observer	Period	Location
Locke/Oates	1666-67; 1692-1703	Oxford; Ongar (SW Essex)[27]
Hooke	1671-72	London
Conyers	1673-80	London
Downes	1680-94	London
Derham	1699-1706[28]	Upminster (SW Essex)
Stukeley	1722-24	London
Huxham	1724-26	Plymouth
Nettleton	1724-27	Halifax
Hauksbee	1724-29	London
Short	1727-56	Sheffield
Jurin	1728-50	London
Hooker	1729-65	North Kent, and later at Tonbridge
Barker	1733-63; 1777-98[29]	Lyndon (Rutland)
Beighton	1737-39	Midlands
Milward	1755-74	Exeter
Barrington	1770-1823	Mongewell (Oxford)
Hughes	1771-1813	Stroud (Gloucestershire)

[27] Locke started making observations in Oxford, and following a gap of 25 years, Oates continued the observations at Ongar.

[28] Derham's rainfall series extends to 1716, and he quotes thermometer readings for 1709 (a severe winter):hence a further temperature manuscript may be in existence.

[29] From 1771 to 1798, monthly means are available, and are especially useful when the daily means end in June 1789.

It is thought that Derham was the first English observer who took instrumental readings outdoors (Manley 1974); this was with a thermometer made by Patrick, hung on a north-facing wall.

The first outdoor temperature readings taken with a fully screened thermometer appear to have been made in 1729 by Professor Johann Friedrich Weidler in Germany. He placed two thermometers, which were probably made by Hauksbee, out of doors, approximately 30 feet north of his house beneath a lightly constructed shed. He compared his outdoor readings with those taken indoors and noted that they differed by up to 25 degrees (with reference to his scale this equates to around 12°C). A further test was carried out by the Reverend Henry Miles who noted a winter's-day drop of 19°F between 8 am and 9 am outdoors (most probably due to the passing of a cold front), but this equated only to a 2°F drop on his indoor thermometer (Miles 1747).

The method of taking readings outdoors began to prevail, among both observers and others. Réaumur stated in 1730 that a thermometer should be situated outside, to the north of a building, out of the sun at all times and where no radiated heat could affect the readings. However, many of these early outdoor readings seem to have been taken by those who did not care for the inconvenience of going outside to read the instrument and who sited the thermometer against a wall or on the other side of a window such that it could be read from indoors. Such a thermometer exposure would undoubtedly be affected by radiation from the fabric of the building. Roger Pickering's thermometer was observed under just this sort of exposure:

> *'the thermometer and hygrometer are placed in a little shed, made for their reception, against my study window, where I can see the graduation thro' the glass; and by lifting up the sash, can take them in as occasion requires'.* (Pickering 1744)

Many saw the benefits of screening outdoor thermometers, although these screens were not often standardised and suffered from many weaknesses. Even at the major observatories such as Kew and Durham University Observatory the use of 'sheds', basic screening held against a north wall, was used until well into the nineteenth century (until January 1860 at Durham).

The thermometers at Durham University Observatory were sited in a screen that was directly attached to the north wall of the Observatory, often referred to as the 'North Shed'. There was protection on either side by louvred boards and a solid board for the roof. The thermometers were held 3 feet 6 inches from the wall of the building, and 4 feet 6 inches above a small flat roof (Plummer 1873). When Plummer became curator of the Observatory, a Glaisher stand was being used to screen the thermometers, but he carried out an examination of the North Shed exposure by replacing maximum and minimum thermometers in the North Shed and taking the observations in parallel with the Glaisher stand exposure.

The Glaisher stand was first used at the Royal Observatory at Greenwich in 1841.[30] It was a stand, rather like a lectern, with a hinged lid that shielded the thermometers from the sun's direct radiation. However, because there was no screening to the left or right of the thermometers, the screen was only effective where the observer remembered to rotate the whole stand at the appropriate times of day. It also offered little protection to reflected radiation from nearby objects – especially the ground. The Glaisher stand was well-used by many observers in the United Kingdom, following the lead at Greenwich, but it did have critics.

There were still a large number of different types of screen, notably among the more casual observers, and especially overseas where the standards in each country were different depending upon the prevailing meteorological conditions (Parker 1994). By the late nineteenth century, the Royal Meteorological Society drew up a list of necessary conditions for thermometer exposure (Mawley 1897). It opted for the Stevenson screen that had already been in some use but was

[30] It is thought that the Glaisher stand was actually not designed by James Glaisher, but by Sir George Airy, the Astronomer Royal at the time (Middleton 1966).

refined with extra shielding on the roof and base to prevent further any reflected radiation from nearby objects, or from the ground.

The Stevenson screen, first described by Thomas Stevenson, used louvred boards all around the shelter to allow the free movement of air throughout. The size of a Stevenson screen generally reflects the amount of equipment needed to be housed inside it[31], and many modern screens are larger than those that would have been in place in the nineteenth century due to the use of automatic recording instruments. The greater size of such screens increases their thermal inertia which may have an effect upon the temperature readings carried out inside. Following on from the Royal Meteorological Society's recommendation, the Stevenson screen was adopted at British observatories, in 1878 at the Radcliffe Observatory in Oxford, for example. However, some observatories did not adopt the new screen for several decades. The curators of Durham University Observatory delayed until 1900 and continued to observe using the Glaisher screen for an overlap of one year to make a comparison between the two exposures.[32]

Many comparisons were carried out between the exposures afforded by Glaisher stands and Stevenson screens. One comparison was made by Gaster at Stratfield Turgis[33] in the East Riding of Yorkshire in 1869 (Gaster 1882). He found that when comparing a Glaisher Stand with a Stevenson screen the latter shielded the thermometers better from excess incoming radiation in spring and summer, and from the loss of outgoing radiation at night. The Stevenson screen that he used was of the older style so had less protection against this night-time radiation loss, and in his analysis this loss slightly outweighed the gains made during the day. Table 2.2 shows his results.

---

[31] Larger screens are used in the tropics.

[32] Manley would later dismiss the results of this comparison as being 'excessively difficult to interpret' (Manley 1941b).

[33] At the time of observation, this was Strathfield Turgiss.

Table 2.2 The monthly mean maximum and minimum temperatures recorded in a Glaisher Stand minus those taken in a Stevenson screen at Stratfield Turgis (°F) (Gaster 1882)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Max.	-0.2	-0.3	0.3	0.1	0.7	0.8	0.7	0.5	0.4	0.1	0.0	0.2	0.27
Min.	-0.4	-0.3	-0.1	-0.4	-0.3	-0.5	-0.3	-0.3	-0.4	-0.3	-0.4	-0.2	-0.32

Margary performed a similar type of analysis with a Glaisher stand and Stevenson screen over 35 years from 1881 to 1915 (Margary 1924). His site was at Camden Square in North London, so is not an ideal one due to the urban effects that are likely to influence the data. His results were similar to Gaster, although he showed that his Stevenson screen was better protected against night-time radiation loss when compared with his Glaisher stand than Gaster's. Table 2.3 gives his results.

Table 2.3 The monthly mean maximum and minimum temperatures recorded in a Glaisher Stand minus those taken in a Stevenson screen at Camden Square (°F) (Margary 1924)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Max.	-0.2	-0.2	-0.1	0.2	0.4	0.7	0.7	0.6	0.4	0.1	-0.2	-0.2	0.18
Min.	-0.4	-0.5	-0.5	-0.6	-0.6	-0.5	-0.6	-0.6	-0.6	-0.6	-0.4	-0.4	-0.52

These two comparisons show how the temperature at one site, even when taken under similar conditions to another, can still show deviation. When thermometer differences and errors are taken away, the local exposure is left as the most important factor. The Camden Square exposure would be quite likely to show the effects of urbanization: the influence of reflected radiation during the day, and the release of absorbed insolation at night. In fact, this site holds the record for extreme daily maxima for April and May in the United Kingdom, 29.4°C on 16th April 1949 and 32.8°C on 22nd May 1922. Such effects cause both mean maxima and mean minima to be higher than would be seen from the surrounding countryside under the same prevailing conditions. This is especially so in the parks of London, such as St. James's, where wind can be sufficiently obstructed by nearby buildings to give calm conditions and the sun has opportunity to warm up the lower levels of the air without disturbance. Maxima at sites among buildings may actually be lower than in open spaces due to the lower insolation arising from the shade cast by buildings. At Old Street in the City of London, the mean monthly maxima are lower than those observed in Regent's Park, as shown in Table 2.4, although these effects may not be apparent at all such pairs of sites.

Table 2.4 Mean Monthly maxima and minima at Old Street and Regent's Park in London for three hot summers at the turn of the twentieth century (°F) (Manley 1952a).

		August 1899	July 1900	July 1901
Old Street	*maxima*	75.3	76.8	74.3
	minima	59.3	59.9	58.2
Regent's Park	*maxima*	76.3	78.1	75.8
	minima	57.0	56.8	55.8

In addition to this, the minima at a more built-up site will be higher than those in the open where night-time radiation loss is greater to the greater visible area of sky. The table shows that at Old Street the daily range is less by approximately 4°F across these three months. Manley also notes that the effects of urbanisation are not constant throughout the year even in a city as built up as London, and will depend upon the prevailing weather conditions. For example under a light north wind, the night-time minima in the north of the city will resemble those of the countryside further north (Manley 1952a).

Under other conditions, the difference can be quite marked, as is shown in Table 2.5, which compares the mean monthly maxima and minima at St. James's Park in central London with

Rothamsted (128 m above sea level, 37 km NNE) and East Malling (33 m above sea level, 47 km ESE).

Table 2.5 Mean monthly maxima and minima at three sites in London: to the north of the city and to the south (°F) (Manley 1952a).

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
St. James's Park	maxima	7.4	7.7	10.3	13.2	17.1	20.4	22.3	21.9	19.2	15.4	10.5	8.3	14.5
	minima	2.5	2.6	3.8	5.7	8.8	11.7	13.8	13.5	11.5	9.1	5.2	3.4	7.6
Rothamsted	maxima	5.8	6.1	9.0	11.8	15.6	18.8	20.9	20.8	18.0	14.0	9.0	6.7	13.0
	minima	0.3	0.0	1.6	3.4	6.2	9.0	10.9	10.9	9.2	6.7	2.9	1.3	5.2
East Malling	maxima	6.8	7.1	9.8	12.4	16.3	19.5	21.6	21.5	18.9	15.1	10.2	7.8	13.9
	minima	1.2	1.2	2.4	4.2	6.9	9.8	11.9	11.6	9.5	7.0	3.6	2.1	5.9

The aspect and slope of a site can have a strong influence, particularly during the night or the winter months where excess air drainage can give rise to low minima. Such an effect is shown between three nearby sites around Durham city, at the Durham University Observatory (102 m), Ushaw College (181 m, 6 km WNW of the Observatory) and Houghall College (50 m, 1.5 km south east of the Observatory). Although the daily means of these three sites do not differ appreciably, the maxima and minima do show a difference, and especially the average extreme monthly minima. Table 2.6 shows these characteristics at each site.

Table 2.6 Monthly mean temperatures between the Ushaw, Durham University Observatory and Houghall sites around Durham city 1925-1940 (°F) (after Manley 1952a - annual means have been added)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
	Mean Maxima												
Ushaw	42.4	42.6	47.3	50.8	56.5	63.0	66.6	66.5	61.1	53.2	46.8	42.4	53.3
Durham	43.1	43.7	48.3	51.6	57.1	63.7	67.8	67.2	61.9	54.7	47.9	43.1	54.2
Houghall	44.0	44.7	49.3	52.5	57.9	64.7	68.6	68.1	63.0	55.7	48.8	43.9	55.1
	Mean Minima												
Ushaw	32.6	32.9	35.3	37.7	42.3	47.2	51.8	51.1	47.5	41.8	37.3	33.9	41.0
Houghall	31.1	32.0	33.7	41.0	46.4	50.9	50.9	50.0	46.0	40.0	35.6	32.1	40.8
	Mean Extreme Minima												
Ushaw	23.2	23.8	26.3	29.2	32.4	38.5	44.5	43.7	38.3	31.3	28.8	25.2	32.1
Durham	20.9	21.5	24.1	26.6	29.2	36.5	41.6	40.3	35.6	29.1	25.9	23.5	29.6
Houghall	16.9	18.6	20.3	23.8	26.4	33.3	39.2	37.3	31.7	26.6	22.7	19.7	26.4

This table excludes the year 1941 when Houghall experienced the lowest temperature recorded in England of –21.1°C. It does not include monthly mean minima at Durham University Observatory because the hour of reading the minimum thermometer differed from that at the other two stations. Manley also refers to a number of individual nights at these sites when the minimum temperature at Houghall was up to 25°F lower than that at Ushaw (on January 5th 1941). The relationship between observations at these sites is shown in Figure 2.1, where the mean of the extremes for Houghall is noticeable as being especially low in relation to either Durham or Ushaw, despite the mean minima being more similar.

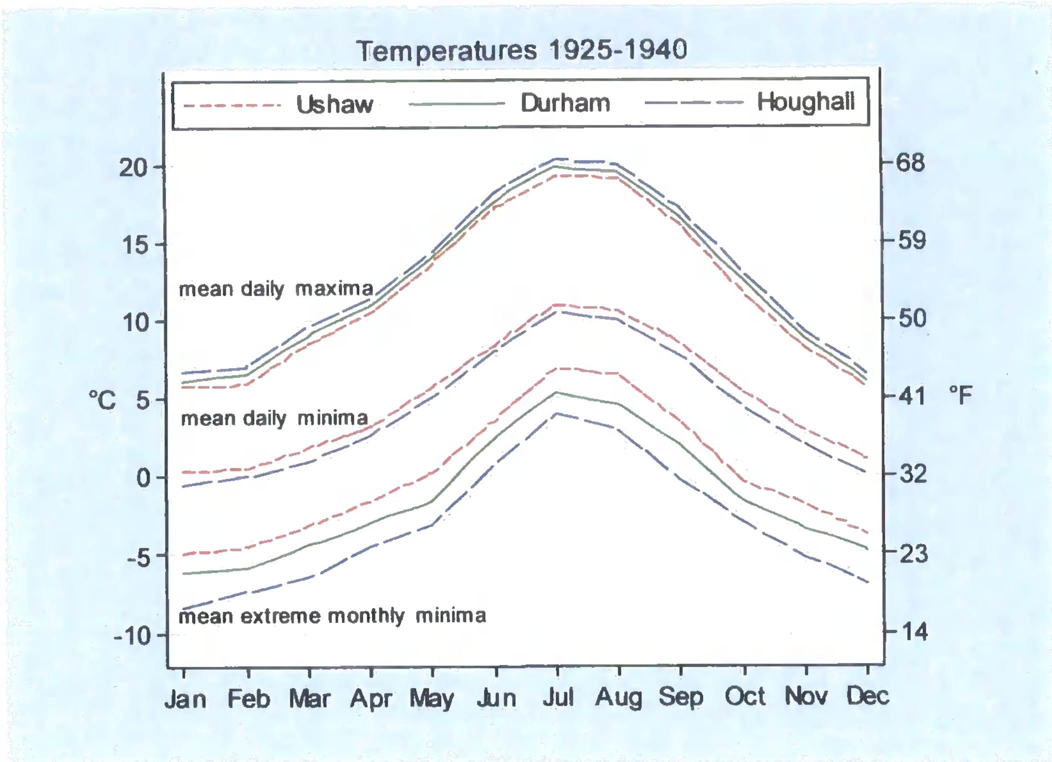


Figure 2.1 The pattern of mean daily maxima and minima, and extreme monthly minima at Durham, Ushaw and Houghall, 1925-1940 (°C).

In addition to the local relief, the local ground cover can make an appreciable difference to the exposure. The recommended ground type around a Stevenson screen is shortly trimmed grass but the type of soil in the vicinity can also affect the thermometer readings. Although heat is lost from the ground surface at night, this is partly balanced by conduction of heat downwards through the upper levels of the soil. A sandy soil with its open texture will be much less conductive than a clayey loam with a dense, often water-laden composition. Manley (1952a) demonstrated this by his comparison of temperature readings at Lynford near Thetford, on well-drained sandy soil, and Cambridge with its gravelly loam. It is in the Breckland area, of which Thetford is central, that night-time temperature is often among the lowest in south east England (Mayes and Sutton 1997). Table 2.7 shows a sequence of night minima for May 1941.

Table 2.7 The minimum temperature recorded at Lynford, near Thetford, and on a Cambridge University Farm in Cambridge in May 1941 (°F) (after Manley 1952a – means have been added).

	4th	8th	9th	10th	11th	16th	18th	Mean
Lynford	15	18	19	17	15	24	27	19.3
Cambridge	28	30	29	29	27	31	38	30.3

This pattern of lower minima above open soils will not be so great in months when large amounts of rainfall have fallen, because the excess water will block the pores of the soil and prevent the effect of greater radiative loss from being so marked. Smaller diurnal ranges and lower insolation will also reduce this effect in winter.

2.3 Issues and Problems when Constructing a Temperature Series from Archives

2.3.1 The Original Manuscript

The first stage in deciding whether a particular archive is suitable for use within a series is physically to find the original, or a facsimile of it. Many temperature series recorded in the past are available to us only in a summarised form, perhaps as monthly means. The practice of observers submitting their temperature readings to local newspapers necessitated their reduction to such means because the entire set of daily data would be too lengthy for the casual reader to interpret. Similarly, data presented at societies would have been done by voice at a meeting, followed by a transcript of the speech for publication in the proceedings. It is not always clear how such monthly or annual means were calculated, especially where the underlying readings were observed at fixed hours rather than using maximum or minimum thermometers that were reset each day. Also, there may have been errors in the calculation. In such cases it is invaluable to be able to view the original manuscript and recalculate the means to be sure of the original method. Where a daily series is being compiled, finding the location of the originals is even more important. This difficulty can severely limit the scope for creating series at this level. The daily Central England series composed by Parker *et al.* (1992) makes use of fewer records than Manley's original monthly version.

In some cases, the original record of observations cannot be traced. Evidence may point to the existence of the record, and it may even be the case that a letter, or mention in a scientific journal implies its location, but the library or archive seems no longer to possess it. It is rare that a record is known to have been destroyed. An example of this is the manuscript kept by John Dalton at Kendal from 1787 to 1844 which was destroyed during air raids in the Second World War. The only source we now have for this record is in the monthly means shown in his published papers.

Where an original manuscript is found, examination of the text, and perhaps volume numbers where the observations span several books, can give an indication of the existence of further data. Cholmeley's record from Brandsby in North Yorkshire skips several periods, and the existence of the missing data are supported by the volume numbers that also miss certain numbers (Cholmeley 1783-). Copies of these have not been found. Barker's record from Lyndon is split across two collections, with the period from 1748 to 1763 preserved at the library of Lancing College and the remainder from 1777 to 1789 held at the Royal Society. There is a paper published in the Society's *Philosophical Transactions* for 1771-1798, and there is no reason to believe that he did not continue to observe for the period between the two original sets of manuscripts. Manley suspected there to be three further volumes, for the period before to 1748, for 1763 to 1776 and for 1789 to 1798 (Manley 1952b).

Most manuscripts are compositions of several meteorological factors, temperature, rainfall, wind speed for example. Others, such as Derham's from Upminster, consist of separate journals for each component. The temperature series runs from 1699 to 1706, but rainfall journals are available until 1798, suggesting that temperature may have been recorded up to this date, too.

2.3.2 Interpretation

The readability of archives varies widely from one observer to another. Whereas James Losh's journals (recorded at Jesmond, Newcastle upon Tyne) were carefully tabulated with temperature readings clearly visible for each time of observation, Thomas Short's manuscript (for 1727-55, recorded at Sheffield) consisted of much prose with temperature readings embedded within the text. This makes digitisation of the readings particularly time-consuming. Some manuscripts give more information concerning the exposure and details of the thermometer than others. It was common to present a front page to each journal that described the site of the observations, the observer's name, and perhaps details of the thermometer location and type. David Hastings' manuscript (recorded at Alnwick, Northumberland) shows a representation of the thermometer that he used from 1739 to 1741. This is especially useful because the scale he used was non-standard but instead was marked into points such as 'frost' or 'temperate'. Temperature readings would be along the lines of '1 below frost' or '4 above temperate'. Whether the thermometer was kept outdoors or indoors is usually specified, and sometimes the type of exposure is given, such as a north wall exposure. Some manuscripts are not explicit about the exposure, but certain features of it can be inferred from comments among the readings. It was common for a thermometer to be hung on a wall outside a room such as a study, as described by Pickering (1744) in section 2.2 above.

In some manuscripts, the identity of the actual observer and who transcribed the information are not clear. This uncertainty is especially strong for the James Losh manuscript where the handwriting is seen to change several times over the period of observation. It is known that he, like other contemporary observers, was a lawyer who travelled, and it is therefore certain that he did not always read the thermometer himself. Whether he actually wrote in the journals himself is less clear; even statements in the first person do not necessarily imply the identity of the transcriber. This then brings a further potential source of error, from a set of observations to another person who would copy them up. The occasion of an observer being replaced by another brings uncertainties about the objectivity of the readings, as do the changing predilections of the observer over time. Examining the tendency for an observer to favour certain readings over another, such as whole numbers or halves, can assist in this process.[34] A further problem is the interpretation of the handwriting if it is not particularly neat. Some sections of Francis Cholmeley's manuscript (recorded at Brandsby, North Yorkshire) are especially hard to read.

Separate categories of manuscripts that present their own unique challenges are the non-instrumental diaries. These can be particularly useful when used to infer temperature, but a lot depends upon the content of the diary. Comparisons can be made with the present temperature

[34] A final-digit analysis of the James Losh manuscript is presented in section 3.2, as is a discussion of the various changes in handwriting.

regime for the area where any quantifiable comments are made, such as days when sleet or snow is observed to fall, or the thickness of ice upon familiar bodies of water. There may also be contemporary instrumental diaries that can be used for comparison. Some of the non-instrumental diaries require an additional level of interpretation, such as the record kept by William Elmsall at Sheffield from 1708 to 1740. He used a set of symbols to describe the general character of the weather for each day.

2.3.3 Techniques of Analysis and Reconstruction

Some of the large variety of techniques used to reconstruct climatological series depend upon the climatological variable being examined, and some do not. Manley made use of a number of different methods when addressing temperature data, and these will be detailed in the next section. Those used by others when examining series for their usefulness, for combining series and reducing them to be representative of a given site, and in analysing the completed series will be covered in this section.

Choosing which series to use is often a case of selecting which ones to reject, because reconstructions of past climate are generally limited in their scope by the quality of archives available. The choice of which series to use is governed by the area which is being studied. For Manley's Lancashire and Central England series, the number of archives available within these broad areas is high, such that he was able to extend the latter series into the seventeenth century. Where the series is based upon a single site, such as Mossman's reduction for Edinburgh (Mossman 1896, 1897, 1902), then series outside of the immediate area may only be used if they are corrected for the distance that they are from the central site. This then introduces a further uncertainty to the final series. Some climatological factors fluctuate more rapidly across distance than others: for example air pressure varies slowly, whereas wind speed and direction can vary rapidly, being much more variable over distance. Temperatures, in theory, should be similar, especially when recorded under modern conditions where exposure is standardised. Varied documented types of exposure, plus uncertain undocumented situations, make interpretation of temperature readings difficult. The general approach in this case is to compare the series with another nearby. Reference can be made to any documented station history to place extra confidence in the readings. Some sites, such as the pressure series observed at Lund (Bärring *et al.* 1999) have an excellent history available. Any site changes were less important from a geographical point of view for this series, although pressure readings do need to be corrected for altitude and air temperature, so any location changes may have an effect upon the observations.

Where station history is not available, or the details given are suspicious, statistical tests may be applied to the series in an attempt to try and gain further information on the data. Simpler tests use an examination of the mean and standard deviation to see how the series changes over time. If a knowledge of the general climatic trends is available for that time period, then this can be accounted for in the analysis. If a surrounding series is available, the two can be compared to try to locate any change-points in either of the series, although events around the same time in both series could confuse matters. For example, an upward or downward trend of the mean might be acceptable, but a sudden jump in the mean from one year to the next could indicate a change in instrument, site or recording practice. Similarly, a change in the variability of the data might indicate such changes. These changes, when they can be identified to result from a single point in the data, are known as change-points, and can sometimes be detected by eye on a graph. A change-point shows that the series is inhomogeneous around that point, and lacks stationarity. Objective statistical tests can be applied to such series, for example the SNHT test described by Alexandersson (1986). Bärring *et al.* (1999) found that by using this test, they were able to independently locate change-points in the series which corresponded to those already suspected from more basic analysis. In this instance, because good station history was available any change-points found that were not supported by the station history were disregarded. Jones *et al.* (1999) also used this test to detect change-points in pressure data. An analysis of a less well-documented series might benefit from the use of a change-point test. Lanzante (1996) describes a test which aims to detect a change-point in the mean, and also mentions the difficulty in applying a test for a change-point in the variance, giving Downton and Katz (1993) as one example. Lanzante's method uses a non-parametric technique in an attempt to increase the resistance, and reduce the extent to which the test is affected by the presence of outliers. The test is based upon another, described by Siegel and Castellan (1988), and Lanzante applies it iteratively to a series to determine whether a discontinuity is significant in relation to the background noise. This test was applied to two separate time series of monthly pressure data to detect change-points in the series.

Another method of giving weight to a series is to combine it with another. This is widely used in climatic reconstructions, especially where the series is modelling the temperature over a wide area. A number of series might be chosen from various points across the area. Various ways of weighting the series may be implemented, the simplest being that of equal weighting, effectively giving the mean of the different series for each point to the composite series. While this is the most common method of combining series, it makes an assumption that the temperature difference between two series is constant for the various points, each month for example. This is unlikely to be exactly correct, yet for many purposes the assumption is not dangerous. Trewin and Trevitt (1996) show that when developing composite temperature records, the differences for each month are not equal. They examine the relationship between several pairs of sites, and the associated differences each month for the pairs. Traditionally, temperature data are regarded on a monthly basis, which can lead to the misrepresentation of extreme events that occur early or late in the month.

Combining series by taking the means across a different number of separate series can cause an undesired side-effect in the variance of the final series. As two typical temperature series are averaged, the variance of the combined series is reduced, and if a composite series is to be representative of a given site, the previous level of variance may need to be re-established. When compiling their daily Central England temperature series, Parker *et al.* (1992) adjusted Manley's previously completed series for the variance that will have differed from that for the series after 1878, which was altered by them to use three stations at all times. They use a technique based upon research published by Yevjevich (1972) that estimates the effective number of stations for a series, with regard to variance, which may be different from the actual number of stations for this statistic. Before 1878, they used just one station to construct the series, so that the effective number of stations is 1, but after this period for, three stations, the effective number of stations ranges from 1.08 in January to 1.17 in July. They therefore reduced the variance of the period before 1878 to be comparable to that using the modern-day continuation of the series calculation that uses three series.

A series may be rejected where a number of missing values are apparent from the data. Researchers have used differing thresholds to determine whether a series, or portion of it, should be rejected on the grounds of incompleteness. For example, Manley's threshold was high at around 15 missing values required in order to reject a month as incomplete.

Alternatively, techniques may be applied which attempt to reconstruct missing values within a series. This may be done for a single series or for a series before its combination with another. In the former case, there must be enough confidence in the derived values for them to be used as the final values for the series. Given that the missing values are derived from an analysis of the character of the points to either side, such techniques depend upon a high-quality series to start with, and not too many missing values whose presence may degrade the confidence in portions of the series for its ability to act as a calibration period. Filling gaps in a series may be done in a subjective manner, given that approximately one thirtieth of any potential inaccuracy in the estimation of the value will be reflected in the corresponding monthly mean. Such subjective estimation was the kind that Manley appeared to use and would be based upon the values for the few days surrounding it, and also the general trend for the month in question. Valero *et al.* (1996) describe a more advanced method, applied both to single missing values, and to consecutive blocks of absent data. They use harmonic analysis in combination with the annual mean to estimate the likely value for blocks of missing points. For individual missing values, they calculate a mean on a shorter scale, for each season, to weight each month and determine how each month contributes to the annual mean for the given year. They also explain how their series corrected by the infilling of data can be compared with another overlapping series to form a composite series.

Leite and Peixoto (1996) also examined estimating values using a monthly temperature series from Lisbon in Portugal from 1856 to 1994. They used an autoregressive model to estimate the 1901-1995 series based upon 1856-1900. Applying the same model backwards from the 1950-1994 series back to 1856, they took the mean of the two sets of estimates to compare this with the actual observed values. The results, in this example, proved to be inconclusive, with the predicted monthly maximum temperature giving 17.5°C for 1947 when the observed maximum was 17.2°C in 1948. They do, however, state that the technique can predict a missing value to within 0.2°C, and would be more accurate were more than one series to be used, perhaps using several from a wide area.

Extending a record from one site using those from elsewhere has been addressed by Craddock (1979), taking a number of different records surrounding a key site, and combining them to extend that of the key site. Using rainfall data, Craddock based his research upon Oxford and described three methods used to examine the data between two sites, based upon plotting graphs of the relationships. With a similar aim, Jones *et al.* (1999) integrate sets of pressure data from a total of 51 separate stations to create monthly pressure maps for Europe. Three of these sites, from Edinburgh, London and Dublin, are located in the British Isles, with the 60 point grid (on a 10° latitude by 5° longitude basis) extending from 35 to 70°N and from 30°W to 40°E. For each grid point, the estimate is derived from the nearest neighbours according to their distance from the point. Each set of station data was assessed for homogeneity and had gaps filled using methods described above. The stations were compared by plotting the differences between each station and its neighbouring sites.

When a series is judged to be complete, it may be compared against other completed ones available. Correlations and linear regressions of the two series are standard ways of judging the differences between two sets of data by examining the relationship between the two data. The regression calculation yields a coefficient of determination, r^2, which will be between 0 and 1: a value of 1 indicates a perfect fit, in the sense that given a predictor x a straight line $a + bx$ predicts a response y exactly. In this thesis, the response is the temperature of interest. Note however that this need not mean that $y = x$, as a need not equal 0 and b need not equal 1. Multiple regression can be applied when several predictors are available to determine the best combination of those predictors for fitting the target data set, plus some constant. A feature of the regression is that the weight for each combination may be negative as well as positive (or zero), as may the constant (or intercept, when plotted graphically).

2.4 Temperature Series: Manley's Construction of Temperature Series from Archives

2.4.1 Three Series

Manley produced three main temperature series, each having different characteristics and each compiled using different sets of techniques. He wrote four main papers on these, all of which appeared in the *Quarterly Journal of the Royal Meteorological Society*, between 1941 and 1974. He worked on extensions to all of these series, although only two of these, for 'Lancashire' and 'Central England', were actually published.

As has already been noted in chapter 1, when he arrived in Durham, later becoming a curator of Durham University Observatory, Manley noticed the varied exposures under which the temperature recordings had been made, and started to standardise the data available such that they would be comparable to the readings being taken at the time, using maximum and minimum thermometers within a Stevenson screen (Manley 1941b). Although the main purpose of this work was not to extend the series back in time, there was some doubt over when the Observatory had actually started recording temperature readings on a formal basis. Until 1981, some of the early ledgers lay unknown, presumed never to have been compiled, so that the earliest daily data that Manley had access to started in 1849. He took the series back to 1847 based on quarterly means for 1847 and 1848, and the annual mean for 1847. He stated that his motivation for doing this work was the Radcliffe Observatory in Oxford for which a temperature series was available from 1815. He noted the quality of the Oxford series, stating it to be 'more reliable than any other in southern England'[35] and resolved 'to place the records from the [Durham] University Observatory on a similar basis'.

[35] Manley (1953). For this section, references will be drawn from Manley's four papers discussed here and sources should be clear from the context. Any references derived from other works will be marked in the usual manner.

His extension for 'Lancashire' was not based upon a single site, as at Durham, but instead for a representative area of England; 'the Lancashire plain', an area bounded by the Irish Sea, the western edges of the Pennines and Peak District, the Solway and the Mersey (Manley 1946). It therefore occupies a large area, but one for which Manley was sure that the overall climatic conditions were similar enough to model in one series. He chose this area, partly because he was very much acquainted with it and the local climate, but also because there was an opportunity to make use of archives of temperature data in a similar way to the two major extensions for the British Isles that had been completed at that time. Robert Mossman's series for Edinburgh began in 1764 and Manley was confident about this 'exceedingly thorough' series (Mossman 1896, 1897, 1902). He noted that the habit of observing temperature was 'widely developed' in the northwest of England, especially due to the exchange of information through bodies such as the Manchester Literary and Philosophical Society.[36]

For his Lancashire series, Manley took several modern-day stations that would give a good approximation to the area he was concerned with, and would be likely to continue well into the future as observation stations. For this, he chose Leyland, Hutton, Southport and Stonyhurst, four stations fairly well spaced across the plain, and at a variety of altitudes from Southport on the coast to Stonyhurst at 115 m. The mean of these stations would give the modern average, and he extended the series backward endeavouring to use several stations at all times. He was able to maintain at least two concurrent stations at all times until 1784 and was particularly aware of several significant temperature records – namely those of the Dalton brothers in Kendal and Manchester. He took the series back to 1753, and was frank about the inherent errors that would have been present in the early years of the data. Asking the question 'why extend an already bold series of monthly means (from 1781) back into the shadowy mid-eighteenth century', he stated that it was a 'highly dangerous' exercise and had been driven by a possible extension back to 1750 when there was a known advance of the Scandinavian ice-sheet. He called it a 'provisional indication', 'until something better can be found', and 'a stimulus for others to look

[36] Manley was himself a member of the Manchester Literary and Philosophical Society.

for other series or for others to improve upon my methods'. In eventuality, he would go on to improve upon these methods himself in his major piece of climatological jigsaw-solving, the Central England temperature series.

After twenty years of assembling data, Manley published a temperature series in 1953 that would be representative of the centre of England (Manley 1953). The area that this covered spread between, and included, the two existing temperature series of 'Lancashire' and 'London' and was centred geographically near Oxford (as the major station providing data to the series). Climatologically, the centre was further to the north or north east, due to his reluctance to base the series too heavily upon the data from London that were plentiful but quite often showed the effects of urbanisation. He was motivated to produce this series by the extension produced by Labrijn for Utrecht in the Netherlands back to 1743 (Labrijn 1945). Manley noted that, due to its low relief and consistency of climate inland, producing a series for the Netherlands was less prone to error than one for England with its variety of altitudes and more exposed position on the western edge of Europe.

The existence of four long series for Lyndon (near Rutland), Derby, Stroud and Exeter led Manley to believe that the best approach to finding a set of means applicable to Central England would be to use all possible series and bring them to a comparable standard representative of a certain area. Ideally, he would have extended the Radcliffe Observatory data directly but he noted the lack of good series close to it, both temporally and spatially. He did use Oxford as far back as the series extended[37], for 1815, in conjunction with Lancashire and took the mean of the two. Extending the mean back to 1698 from this point, he always reduced his station data such that they were comparable to this combined Oxford and Lancashire mean.

[37] Manley did not use the directly published means for the Radcliffe Observatory, but adjusted them so as to be comparable with the series set out by Knox-Shaw and Balk (1932).

By 1974, some further series had come to light and Manley also wished to bring his central England series up to date so he published a revised version (Manley 1974). In updating the series, he used the same combinations of station data as before, but made corrections based on the fact that the data from the Radcliffe Observatory at Oxford would have been subjected to urban influences. These corrections amounted to 0.1 or 0.2°C. He refined some parts of his existing series, by incorporating several series from London for 1670 to 1697, and adjusted his corrections to Derham's series from Upminster. The uncertain period from 1707 to 1722 was supplemented by series from Thornhill (William Elmsall), London (anon., probably Rawlinson), Richmond (Smith) and Westminster (Gadbury). These were all non-instrumental but provided Manley with extra information with which to give confidence in the means he had already calculated. Lastly, he extended the series back to 1659, again using non-instrumental records and with reference to data from Utrecht.

2.4.2 Manley's Choice of Stations

For each of his temperature series, Manley chose a single station or a combination of stations with which to model the air temperature. For his Durham series, this was just the Durham University Observatory, whereas for the Lancashire and Central England series this was ¼(Leyland + Hutton + Stonyhurst + Southport) and ½(Oxford + Lancashire) respectively. The issues raised by using a combination of stations were addressed by Manley in similar ways in all three of his papers on these two series.

Manley studied isotherms based on ground-level observations in order to determine whether the stations he was using were fully representative of the region concerned. For Central England, this region (as described above) extended roughly from London to the Solway, and the Severn

Estuary to the Wash.[38] In reality, the coverage of an area, and the stations he chose to represent that area, were governed by the data that were available. The geographical centre for the Central England series is somewhere a little to the north of Oxford, but the climatological centre based upon an analysis of the daily extremes and means of the final series is somewhere between Shrewsbury and Birmingham (Manley 1953).

For the Lancashire stations, he performed a check using modern data, taking 20 stations and several years of data to compare each of them with the modern equivalent of ¼(Leyland + Hutton + Stonyhurst + Southport). For Central England, he took modern means for a variety of different stations across the region: Cheltenham, Rugby, Oundle, Shrewsbury, Giggleswick (near Settle), Buxton, Welshpool, Marlborough, Huddersfield, Cullompton, Hereford and Macclesfield.[39] He compared these means with his modern equivalent of the central England and found the results varying by expected amounts based upon their relative positions. For example, some of the smaller differences were at Hereford (-0.2°F) and Welshpool (-0.3°F) whereas some of the larger differences were at stations farther afield: Giggleswick (+2.0°F) and Buxton (+3.2°F largely due to its altitude). In addition to this, he looked at the Meteorological Office summary for their 'Midland counties' area that was also similar to his 'central England' (the Midland counties ranging between 0.4°F cooler in Dec-Jan and 0.4°F higher in Jul-Aug). He took this process of looking at modern means a little farther back by comparing a temperature record taken at South Kyme, near Sleaford, between 1800 and 1869, with the Oxford/Lancashire set from 1815, the earliest year for which data from the Radcliffe Observatory were available.

Manley performed a further check by checking his Oxford/Lancashire assumption against the London series, and also against ½(Greenwich + Edinburgh), and found the anomalies between the series to be fairly constant through the years, again giving confidence in the choice of this

[38] Also including Plymouth and Exeter but because these stations are near the coast, Manley assumed them to exhibit similar characteristics to stations further north.

[39] For the first three stations he used data for 1931 to 1950, and for 1906 to 1935 for the others.

combination of station data. The anomalies for the Greenwich/Edinburgh combination were actually quite small and Manley stated that these two records could be used as a good approximation to Central England.

When considering records for inclusion in a series, Manley always considered the geographical location of the site, and its position relative to the 'climatological centre' of the region. If the site were not central, he would try and pair it with one or two others to bring this centre closer to the region's core. The geographical and climatological centres are closer for the Lancashire series, where the characteristics of the plain are fairly homogeneous and predictable based upon coastal, latitudinal and altitudinal effects. From his analysis of the isotherms for the Lancashire plain he was confident in pairing a series from Manchester and another from Kendal. For Central England, he was concerned about the use of data from Plymouth and Exeter but did include them in the series. The use of the Exeter values was particularly important because they stretched from 1755 to 1774, at a time when few records elsewhere have survived. For 1762, were he not to have used the Exeter data, then the Lyndon series would have been the only one available for that year.

In addition to all this, Manley was well aware of the climate of these two regions for which he was building up series. There is evidence from his Lancashire paper that he visited each of the sites where temperature had been recorded.

2.4.3 Ascertaining Exposure

In order to make corrections to archived data, it is necessary to know what sort of thermometer was used: the scale and any sort of calibration or comparison made with other instruments, where the thermometer hung in terms of its aspect and proximity to other objects, whether there was any screening, and also the times of day of reading. Much of this information is not recorded, and even the times of reading are uncertain from the journals and diaries left by observers.

Some recorders were more specific than others about their exposure. For example, the scene of the record observed by John Dalton at Kendal is described as being 'under a pretty large gooseberry tree'. Manley remarks with amusement that he is unsure of the definition of 'a pretty large gooseberry tree'. In fact, from his investigation into letters written by the observer, he concludes that the thermometer was actually kept 2 feet or so from the ground and 'was not strictly underneath the bush'. The manuscript itself is very detailed and the observing hours are given for the three readings each day.

If the exposure was unknown, or open to question from ambiguities in the manuscript, Manley would analyse the data to attempt to find key characteristics that would indicate certain types of exposure. For example, high daytime maxima, particularly in summer, might indicate strong urbanisation effects, especially if combined with higher than expected evening temperatures for the same occasions. Outside urban areas, such a feature might be a symptom of poor shielding of the thermometer, particularly when supported by comments in the manuscript that the day was sunny. The features of an urbanised exposure would also be exhibited to a certain extent in the night-time minima. Should these be relatively high, it could be that a nearby wall was radiating heat. If the diurnal curve was skewed, favouring relatively higher temperatures in the morning or evening, Manley might conclude an exposure on an east- or west-facing wall respectively. He compared the features of a temperature series with that for others for which he knew the exposure, such as the Kew record where the thermometer was held against a north wall. This sort of exposure would have been approaching the optimum[40] for the mid to late nineteenth century until the Stevenson screen replaced the Glaisher stand. The diurnal range observed from a stand would be higher throughout the year, especially in the summer months, than that seen when a thermometer is held again a wall, largely due to the greater radiation loss from the stand thermometer at night, and the protection given by the brick or stone surrounding the wall-mounted instrument. For Marshall's Kendal record, Manley compared the absolute and mean extremes to see the differences between the two. He concluded that in this case, the exposure was a shaded north wall due to the relatively constant and unexceptional minima.

The most difficult situations occur when the thermometer itself was of an uncertain origin or scale. Such thermometers were used more frequently in the late seventeenth and early eighteenth centuries. If the exposure is cited, then this makes an analysis of the data easier. For example, Derham's series observed at Upminster from 1699 to 1706 was made with a thermometer that had an unknown scale. Manley took the extremes for the whole record, from 58 as the minimum to 186 as the maximum, and compared this with modern data for the same area. The manuscript did detail the fact that the exposure was against a north-facing wall, so he was able to build that fact into the comparison. For Upminster, he analysed the prevalence of sleet and snow days in the Derham record (i.e. the air temperature being around or below 34-36°F) and compared this with the present occurrences of sleet and snow. Manley also took the mean difference between the 5am and noon readings for this record, and found them similar to those for the Glaisher stand at Greenwich. Similarly, John Dalton's temperature record from Kendal was taken with a home-made thermometer, with an undocumented response.

If Manley was aware of the exposure, from notes in the manuscript or elsewhere, he would compare it with known exposures elsewhere to be sure that there was not a further local characteristic which could contribute to the temperature trends. Where the exposure was a north

[40] For the purposes of these analyses, the optimum exposure would be that equating most closely to that observed from within a Stevenson screen.

wall, or Glaisher stand, the analysis is made easier by the existence of several verified sites using these exposures such as Kew and Rothesay for north wall exposures, and Oxford, Camden Square and Greenwich for Glaisher stand exposures. Other stands were used from time to time, including the Lawson's stand implemented by Vernon for his Manchester record.[41]

Manley had access to a number of different comparisons between Glaisher stand and Stevenson screen exposure (Margary 1924 for example), and North wall to Glaisher stand exposure (Plummer 1873 for example). He used these studies to adjust a record to one representative of a different kind of exposure, or to compare reported exposure with known records of the same kind elsewhere. Within each type of exposure, there will be other influencing factors such as varying degrees of urbanisation, surrounding slopes, ground cover, aspect, etc., as previously detailed in section 2.2.

The prevailing weather type for each day, if specified, can give a valuable indication of the likely temperature. Sometimes this information is limited to a passing comment such as 'clear' or 'cloudy' but may also include wind speed and direction, and rainfall, which can indicate the type of airflow. Manley used this information particularly when analysing a record kept using an indoor thermometer. For the Lyndon record, taken by Barker, he looked at the differences between the indoor and outdoor record where it overlapped. He looked particularly at days when snow or sleet was observed to fall, when the difference between the two readings was in the region of 9°F. This difference was less with higher temperatures, becoming 'small' in summer (Manley 1952b). He plotted a graph of indoor against outdoor temperature which he noted fell roughly upon a straight line, and could then read off the graph to find the equivalent indoor or outdoor reading given one or the other. For other purely indoor readings, Manley compared them with local outdoor readings. An example of this was the indoor Hutchinson record in Liverpool that he checked against the outdoor record taken by Dobson, also in Liverpool. For another indoor record at Middlewich (taken by Vernon), Manley states that the temperature is

[41] A description of the Vernon stand is given in Parker (1994).

seen to drop to freezing point at times, something fairly uncommon among such exposures, although the monthly means were still generally higher than expected, and he concluded therefore that the room was well aired. Another check upon any temperature record, but one that is particularly suitable for indoor records, is an examination of monthly means between successive years over the period of the record. This helps identify any changing trends in the exposure, such as increasing use of an 'unused' room, particularly when any underlying trend displayed in contemporary outdoor temperatures is eliminated from the indoor ones.

2.4.4 Correcting the Readings

Once the exposure of a temperature series is ascertained, the homogeneity must be examined. Undocumented changes to the thermometer, exposure or hours of reading can all make observations inaccurate if such events are not accounted for in the temperature data. Manley was able to check the temperature readings taken at Durham by comparing the means derived from the fixed hour means with those derived from the maximum and minimum readings for each day. In this way, he found a different mean in the latter set of data for 1922 to 1933 and upon further research found that the maximum thermometer had its mercury thread broken at the beginning of this period and was able to correct the data for this. In the case of Durham, Manley reinforced the means derived from the maximum and minimum readings by using those obtained from the fixed hour means from 1900 onwards (excluding 1916 to 1919). There were further problems with the Durham record in that the hours of reading the maximum and minimum thermometers varied with the maximum read in the evening (9 pm) and the minimum read in the morning (10 am) until October 1885, after which both were read and set in the evening. However, he determined from examining the observations that the maximum was read at 2 pm from April

1855 to June 1858, and applied corrections for this. He did not see it necessary to make adjustments for the change in reading of the minimum thermometer from morning to evening.[42]

Sometimes a variety of causes are behind changing means over a period, and Manley made two separate sets of corrections to the early years of the Hutchinson record taken at Liverpool. He suspected that the site had a fairly urban exposure and this was exhibited in the readings taken at midday. He therefore weighted the mean taken earlier in the day at 5 am, in preference to this noon observation. In addition to this, the diurnal range was greater than the Kew north wall but less than the Greenwich Glaisher stand exposure. He applied corrections mid-way between these two exposures.

Where the daily data from a manuscript is provided for fixed hours of observation, Manley converted the means to be representative of a mean taken on maximum and minimum thermometers and the mean taken from those. The first stage in this is to convert the fixed hour means to 24 hour means: the temperature resulting from the means of continuous observations throughout the day. Manley had three separate sets of conversion factors that had been derived based on hourly observations at other sites, for Greenwich, Kew and Rothesay. These sets of corrections are similar despite the exposure for each site being different (Greenwich upon a Glaisher stand and Kew against a north wall, for example). Sometimes Manley would use the corrections taken near to the site being examined, or perhaps the mean of two sets of corrections. At other times where the exposure of a site was known to be a north wall, for example, he would use the most appropriate set of corrections, Kew in this case.

Where Manley was integrating the data from one site with that for another, or for an area such as the Lancashire plain, he adjusted the temperature readings for the altitude at which they were

[42] He argued that minima for the period to 8 am will be lower than that ending at 9 pm; if the period ends at 9 am then this difference will be smaller, and even more so by 10 am.

taken. He used the standard lapse rate figures to convert all temperature data for this series to the equivalent of 50 feet above sea level.

Other factors influencing the exposure such as slope, general aspect of the site and soil type were considered by Manley in a general sense. As mentioned above, he often visited the sites, even if the building in which the observer lived had long since been demolished. This gave him a good idea of how the aspect of the site might influence the temperature, or whether the character of the surrounding land would influence the readings. Should a site be in a hollow, or on a ridge, then he would bear this in mind when adjusting the series and comparing it with others. How temperature might be affected by the general aspect of the site and the soil type was discussed in section 2.2 above.

Manley also looked at the exposure in detail to ascertain whether other undesirable symptoms would be exhibited, such as when the thermometer was not at the standard 4 feet above the ground. He knew that Dalton's record at Kendal was recorded on a thermometer positioned 2 feet from the ground. He looked at the characteristics of the temperatures recorded by Hutchinson with a thermometer at roof level, although any features would probably be overwhelmed by the urbanisation influences at this particular site. A further difficulty in temperature readings in the eighteenth century is the switch from the Julian to the Gregorian calendar in 1752 when the 3rd to the 13th of September were skipped. Manley checked the dates given in the diaries because not all observers could be assumed to follow the new style of dating. He assumed that their readings followed this pattern, were it not specified, thus making the month 19 days long. A precise knowledge of the transition between the old and new style calendar is more important when comparing a British series with one from the continent, where the Julian calendar was adopted at different times.

2.4.5 Checking the Corrected Series

Where a corrected record suggests some uncertainty, perhaps in the earlier years, comparison against other records can be performed to look for differences in trends and overall character. Manley tried to compare series with those nearby, but for the earlier series this was not always possible because fewer records were available. He had to compare the readings made by Hutchinson at Liverpool with those by Barker at Lyndon in Rutland. He looked at the monthly means for each site and checked that the relationship over successive months and for each specific month from year to year was constant.

When combining records for use in a series such as Lancashire, he would examine the characteristics for each of the constituent records, comparing them between themselves from month to month and year to year to check for anomalous months when a recording or transcription error might have been present. He did the same thing for modern data, recorded at approximately the same sites as the older data. For his Lancashire series, Manley studied the weather type to see how prevailing conditions influenced the relationship between the various stations. He stated that all the sites he looked at exhibited similar qualities in easterly, windy months under which circumstances the underlying potential sources of error could be investigated such as thermometer or observation error. If he suspected that a record was prone to some error, he would occasionally still use it but assign a much lower weight to it when combined with another record. He did this for his Central England series when combining the Lancashire and Lyndon means, assigning a greater weight to the Lyndon record for the period from 1753 to 1759. After this period (when the Lyndon record was no longer available) from 1764 to 1770, he used the Lancashire, Greenwich, Edinburgh and Exeter means with equal weights. This decision was also influenced by the fact that the geographical centre of these four locations lies approximately in the English Midlands.

Where Manley suspected problems with a series he would sometimes consult the returns made to Somerset House, under the supervision of Glaisher, on a quarterly or annual basis. However, Manley had concerns over the quality of these data, given that the means were adjusted based upon the fact that the standard method of observation was the Glaisher stand. The conversion factors he used for the Glaisher stand were based on his own thermometer exposure at Greenwich, but Manley argued that these were not applicable to other sites in the United Kingdom, particularly as some sites were using other forms of exposure entirely.[43]

Minor records that are not directly being used in a series can be used as checks upon the longer records. Manley used a variety of shorter series (Applegarth, Carlisle, Bolton, Seathwaite and Whitehaven) to give him greater confidence in, and to adjust, Dalton's Manchester record when examining it for use in his Lancashire series. In a similar way, he used the Lyndon record as a check against the Lancashire data from 1771, despite it being too far away geographically to be incorporated into the series. From 1775 onwards, he used a brief record from Branxholm on the Scottish Borders as a check. If a record was lengthy but presented problems such as irregular reading hours or missing days, it can still be used as a check on individual days or months. Such a case was the use of the Mongewell record from 1773 to 1823 to act as a check upon the overlap between Lyndon and his combined Oxford and Lancashire mean when working on the Central England series. In addition, he checked his Durham series against a composite mean of Greenwich and Aberdeen, Durham being approximately half way geographically between the two, and also against Oxford and Stonyhurst for overall trends. He compared the early years of the Lancashire record against Edinburgh and London, and against the nearest continental stations where the data he had calculated were based on particularly uncertain sources. For the later years of the Lancashire series, he compared his work with Oxford, Durham and Edinburgh for the entire period that each record overlapped with his. This meant that he could compare Lancashire with the Oxford series from 1815 and found 'close agreement from 1840'. Manley went through the same process for his central England series, although there were few lengthy

[43] For example, the record kept at Seathwaite was observed using a thermometer held against a north wall, and Vernon's at Middlewich (Cheshire) were taken with a Lawson stand, similar to a Glaisher stand but with more shielding against the sides and roof.

English series that he had not directly incorporated into his record and so he resorted to comparisons with Edinburgh and Utrecht in the Netherlands.

2.4.6 Bridging Gaps

Manley used a number of different series which formed the major components of his reductions. At times, these major series did not overlap and he was forced to try and bridge the gaps using another record, or combination of records. This process is easier when the bridging records overlap the series already used, so that a comparison may be made between their relative characteristics and the bridging series adjusted to fit in better with the other two. The central England series had a gap between the end of the Lyndon record in 1798, and the start of the Oxford record in 1815. For this period he used a number of different records: he would compare the bridging series when it overlapped the existing one, taking the departure from the mean for each month from several years before the gap to several years after it. He did the same for a number of other series to build up a picture of how the temperature varied over the intervening period in relation to the two major records. In the case of the central England period from 1799 to 1814, he used data from his Lancashire series, from the Royal Society records, and from the Edinburgh, Stroud, Derby and Salford areas, comparing their means for the gap with Oxford for 1821 to 1840 (or to the end of each series, whichever was later). He did have objections about using each of these individual records on their own. Edinburgh being far north, and the Royal Society being far south, did not make ideal records on their own, in his opinion, but could be averaged to give a good approximation to the Midlands. Manley remarks that the Stroud record (by Hughes) is 'quite useful' but contains only a morning observation until 1803, and the Salford record (by Hanson) is 'extremely urban' and only covers 1807-1818. The Derby record, observed by Swanwick, is a long one, from 1793 to 1838, and Manley may have made more extensive use of it were it not for 'long spells of erroneous readings of constant magnitude'. He took the mean of all these different sets of anomalies to arrive at an overall 'Midland anomaly' for these sites spread across the English Midlands.

Manley looked at some further records to give additional confidence in this period, particularly one recorded by Cary on the Strand in London. This series, according to Manley, is 'extremely urban' and after reducing the record to monthly means, he weighted the 8 am reading by a factor of 3 compared with the noon reading and used it to form a combined anomaly with the Lancashire differences (already calculated) and a third set from South Kyme in Lincolnshire to give another 'Midland anomaly'. He used this second set of differences as a check upon the values already derived.[44]

This process is possible when records exist reasonably nearby, but when there were are no such manuscripts, Manley interpolated temperature values from further afield. For his Lancashire series, he considered the temperature recorded by Rutty in Dublin, and also the differences between the London and Edinburgh series. These two are both too far away from the Lancashire plain to be used directly in his reduction. For 1755, Manley was faced with a lack of any local records and resorted to a London series recorded by Ayscough and Cuff. He acknowledged that this would have been heavily influenced by urban effects, and in order to try to remove these he compared the differences between the Kew and Old Street records between 1883 and 1911, one 'rural' and one 'urban'.

2.4.7 Non-Instrumental Diaries

Manley referred to a number of non-instrumental diaries, particularly when compiling his Central England series that was extended back into the seventeenth century when the ownership of thermometers was much less common.

[44] The South Kyme record, kept by an unknown observer, started in 1800, so Manley's second 'Midland anomaly' used only the Strand and Lancashire data up to 1799.

When examining non-instrumental observations, Manley compared what instrumental data were available with the comments made by the non-instrumental observer, with regard to frost, or snow, or the turn of the seasons. An example of this is found in his updated Central England record of 1974. A record for Thornhill near Sheffield, kept by William Elmsall for 1708 to 1740, had come to his attention. This record is non-instrumental, but Elmsall kept a detailed symbolised recording of the weather wherever he was, sometimes travelling around the surrounding counties. Manley compared these comments with the journal kept by Oates at Chesterfield for 1715 to 1731, which is also non-instrumental, and two records that do have temperature readings from Halifax (by Nettleton, 1724 to 1727) and another from Sheffield (by Short, 1727 to 1756). He took the number of days of frost reported by Elmsall and compared this with modern-day Wakefield giving an assessment of 56 against 59 days respectively.

2.4.8 Summary of Manley's Methods

Manley used many different techniques to compile his temperature series for Durham, Lancashire and Central England. Further techniques have been used elsewhere, and the choice of what methods to employ when analysing and combining temperature observations to form a composite series will depend upon those individual series, and the area or station being modelled. Chapter 3 considers the data available for the reduction of a temperature series for Durham, and chapters 5 and 6 examine and apply different techniques to these observations.

2.5 Summary of Chapter Two

In this chapter, the emergence of the thermometer and its use in meteorological readings has been summarised. The theory of combining discrete temperature series into single reductions, capable of representing areas was discussed and the methods that Manley applied when performing these combinations were introduced. Using examples from his Central England and Lancashire reductions, the different techniques that Manley used were identified, together with his habits and his use of observations that were not based upon instrumental readings but on remarks of the daily state of the weather or date of plants or crops coming into flower.

Chapter 3 – The Data

Contents of this chapter

3.1 Data Sources Available for North East England, Yorkshire and the Scottish Borders

3.1.1 Introduction to the Series

When compared with other areas of Great Britain, the North East of England is not strongly populated with long-term, primary-source meteorological records. In some senses, this is to be expected, as the centres of learning, science and industry were concentrated further to the south at the time recording got under way, during the late seventeenth and eighteenth centuries. On the other hand, development in the North East could hardly be considered sluggish. Rather, academic questioning and what we would now consider 'science' were slower to gain a foothold in the region in Georgian times, quite possibly because of what might now be termed a 'brain-drain' towards the south and the drive that this produced. Reasons for this are beyond the scope of this discussion, but it was not until 1792 that the first scientific or philosophical body was inaugurated in Newcastle upon Tyne, the largest city in the region. This was the Newcastle Literary and Philosophical Society, which continues its activities to the present. Other such societies in the region included the Scarborough Philosophical Society and the York Philosophical Society, which is also still in existence. In its annual report for 1832 an emphasis was placed upon meteorology:

> '*A third subject of extensive interest, to which several Members of the Society have for some time past paid attention, and which it now appears practicable to prosecute in a systematic manner, is that of Meteorological observations ... the Council have, therefore, constituted a Meteorological Committee, and engaged it to make an Annual Report of its proceedings and progress.*'

It is probable that such associations were in existence on a less formal basis before this time, perhaps offering a subscription library service, and occasional lectures and meetings for members. The beginning of recording of meteorological details was preceded by the arrival of precision instruments from the continent, notably the thermometer and barometer. It became popular to record details of the weather in personal diaries at the end of the eighteenth century, and many observations of local conditions are found that may be compared with more numeric observations to build a picture of climatic conditions of the times. Much of this material is of limited use when preparing temperature series, as the precision of the instruments was doubtful at the time, but even readings taken sporadically from an inaccurate, indoor thermometer may be used to give confidence in other readings taken nearby. Such methods were employed by Manley in the construction of his Central England and Lancashire temperature series.

Meteorological readings are originally associated with those taken by astronomers as a matter of course when calculating instrumental bias, which would be affected by temperature. Indeed, the impetus for meteorological readings at Durham University came from just such a source. However, the earliest known instrumental readings that are available for the region are not associated with an observatory. The oldest known instrumental record was kept by David Hastings, a watch and instrument maker in Alnwick, between 1740 and 1746. He used a thermometer that was graduated with high degrees being associated with cold, and low degrees with heat, and also recorded wind direction, air pressure and a remark on the general weather. An explanatory page from the front of his ledger shows the graduation of the thermometer, as shown in Figure 3.1.

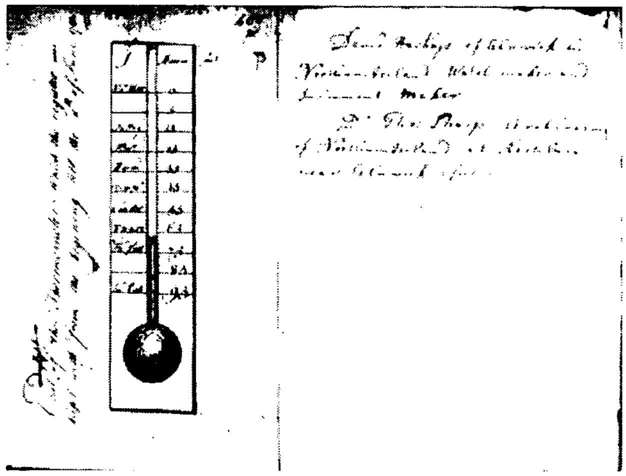


Figure 3.1 A page from the front of David Hastings' meteorological journal showing the thermometer that he used and its scale (Hastings 1740).

Some diarists would have a vested interest in the weather as farmers or ship-owners, and it is records from the upper classes of society which survive, mostly doctors and lawyers for example. Several diarists were members of the Quaker community, for example William Ogden (1795-1870) of Sunderland, and Luke Howard (1772-1864) of Ackworth in South Yorkshire.

When Gordon Manley drew up his temperature series for Central England, he was far more fortunate in both the quantity and the quality of records available, in part because of the much larger physical area that this series can be said to cover. London comes within his definition of Central England, as does Oxford.

It is necessary to define here what is meant by the North East of England. To a certain extent, the bounds of Manley's 'North East' were determined by the quality and distribution of meteorological records, but in general the area may be described as covering the English and Scottish lowland east of the Pennines and the Cheviots, from the north bank of the Humber in the south to the south bank of the Firth of Forth in the north. In this study, where 'North East England' is referred to, Yorkshire and South East Scotland are implicitly included. As discussed in the introduction, there are a number of different methods for dividing the United Kingdom into areas for climatological study (e.g. Wheeler and Mayes 1997; Gregory 1976; and the Meteorological Office regional and district areas). In chapter 8, any restrictions that the area imposes are discussed.

The sources of data that cause the area to be wider than expected are those from Edinburgh, South Cave (Hull) and Braithwaite (Keighley). Manley incorporated these three sites for their unique characteristics. He described the Edinburgh series as being 'very carefully reduced' (Manley 27.ix.78). The record from South Cave has a very early start date of 1795, and Braithwaite both has an early start (1809 but extending to 1794 with irregular readings) and is a long series covering all years to 1857. Manley did not himself lengthen his series into the eighteenth century, due to a lack of time available to him, so these latter two records will be relied upon when extending the series backwards.

Each series will be considered in turn and its features summarised, giving details of the site and observer, and how it fitted into Manley's construction of a temperature series for North Eastern England. Manley referred to each site by its location, but on occasion he used the observer, or site of a nearby town if the site was obscure. This convention will be retained, using the same names as Manley.

Details of the other series that Manley used are limited. He first listed possible stations in a letter dated 27.ix.78, but knew about many of them beforehand, encountering them while compiling his Lancashire and Central England extensions. A rearranged and updated table for reference when considering the Losh/Durham overlap was included in a letter of 5.xi.79. The dates shown in Table 3.1 are those for which data are now known to exist. This may be as a result of information given in Manley's papers, or from investigations that have led to the discovery of new observations for known series, or new series entirely. All these series comprise at least monthly means.

Table 3.1 Temperature Data for North East England. Series marked with an asterisk were not known to Manley in whole or in part.

Dates	Location
1740 to 1746	Alnwick (David Hastings). An instrumental record, but observed using a non-standard thermometer.
1783 to 1808[45]	Brandsby, 18 km north of York (Francis Cholmeley). Several readings per day.
1794 to 1814	South Cave, 8 km west of Kingston-upon-Hull. (Manley only had copies up to the end of 1804)
1799 (Oct) to 1857	Braithwaite, now part of Keighley. Until 1809 the readings were taken indoors only (Abraham Shackleton).
1801 to 1824	York (Jonathan Gray). Manley appeared to have these data from notes made in his manuscripts, but they have not been found either in his material or in searches of libraries.
1802 to Sept 1833	Jesmond, Newcastle upon Tyne (James Losh)
1811 to 1830	Brandsby (Francis Cholmeley). Monthly means.
1831 onwards	York (John Ford)
1817 to 1825	New Malton, 22 km north east of York
1824 to 1850	Ackworth, 5 km south of Pontefract (Luke Howard)
1831 to 1837	Wykeham, 10 km south west of Scarborough (Robert Nendrick Hodgson)
1835 to 1838	Abbey St. Bathans
1837, 1839, 1840 to 1842	Allenheads, 21 km SSW of Hexham (Rev. William Walton)
1840 to 1841	Yarm
1841 to 1846	Kelso
1842	Middlesbrough
1842 to 1849	Makerstoun

45 Manley did make a reference to a series from 1784 in a letter to Joan Kenworthy (Manley 27.xi.79). This probably refers to the early Brandsby data, but there is no evidence to suggest that he obtained, analysed or used these observations.

The archives that Manley had at his disposal can be displayed graphically, as shown in Figure 3.2.

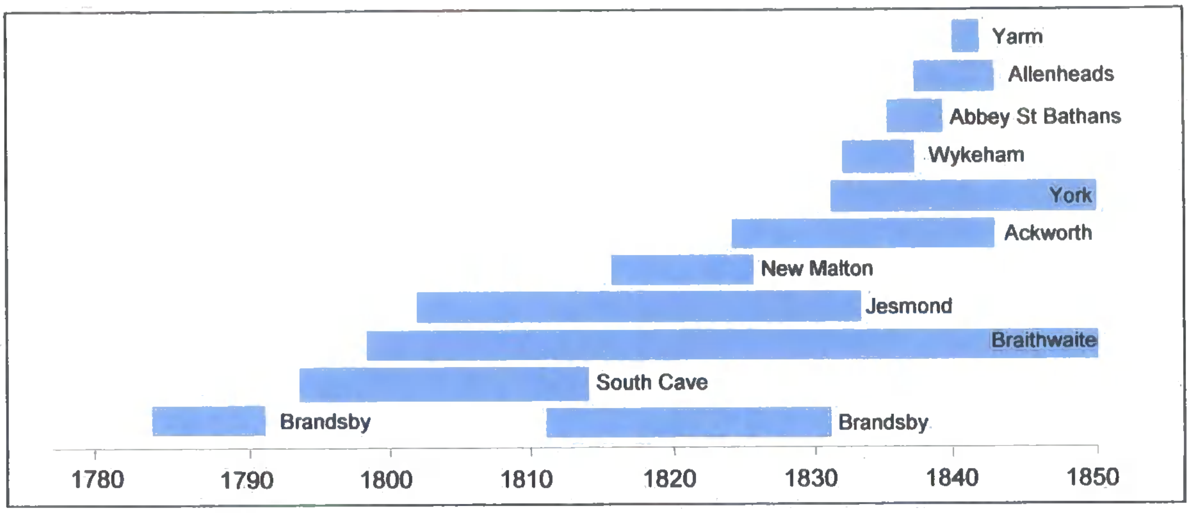


Figure 3.2 How the temperature series that are available for North East England overlap.

The map in Figure 3.3 shows the geographical location of recording of each of these archives.

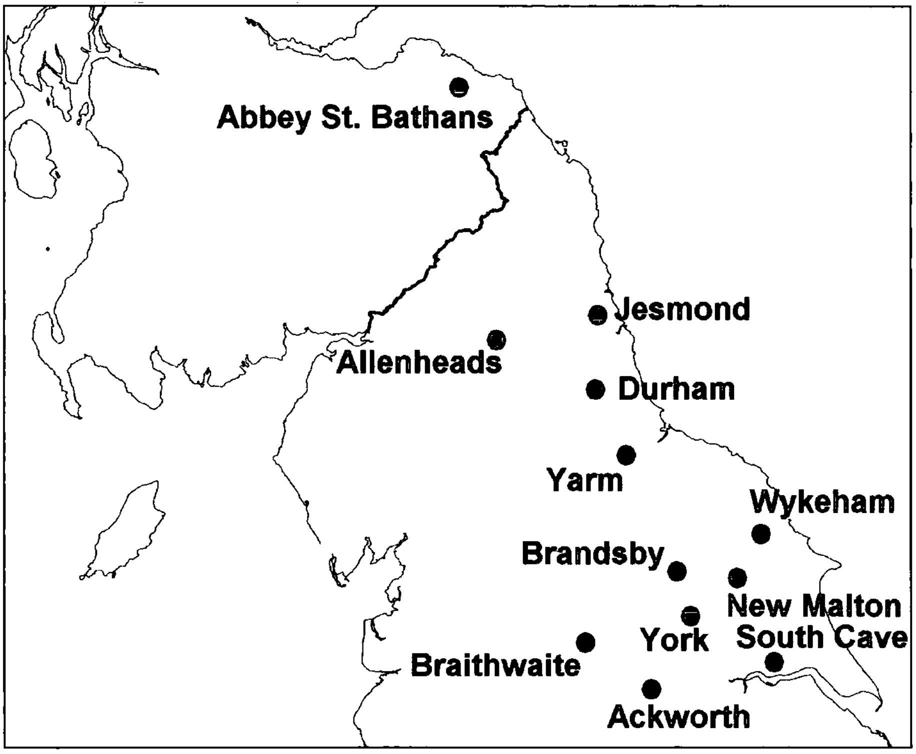


Figure 3.3 Location of Manley's archives of data. Circles represent the location of series. Although he knew of all these data, he did not use them all in his reduction.

The meteorological observations for the North East of England are located in various libraries and archives in the area and elsewhere. Table 3.2 shows where the source for each data set used in this study was located. Some temperature observations were used by Manley, but the source for these, for various reasons, can now not be located. Where this is the case, Table 3.2 shows the places where the information has been unsuccessfully sought. For these records, it is assumed that the original journals, or copies of them, have been lost, at least for the time being.

Table 3.2 Sources of data used in this study, and their locations.

Observation	Location of original manuscripts, or copies
Alnwick (David Hastings)	Original journals held at the British Museum (Hastings 1740-1746). Photocopies of microfilm available at Cambridge University Library among Manley's boxed notes (Manley 1938-).
Brandsby (Francis Cholmeley) early daily set	Microfilm North Yorkshire County Archives (Cholmeley 1783-)
South Cave (Henry Barnard)	Original journals (two volumes) at Hull Local Studies Library (to 1815). Also microfilm of journals from start of record in 1794 to 1804 (Barnard 1794-).
Braithwaite (Abraham Shackleton)	Original journals at Cliffe Castle Museum, Keighley (Shackleton 1799-). Photocopies available at Cambridge University Library among Manley's boxed notes (Manley 1938-).
York (Jonathan Gray)	Neither original, nor copies of original manuscript found. Reference to its existence at Yorkshire Philosophical Society Library in 1979 (Manley 1938-), but no longer present there, at Yorkshire Museum, York City Library, or York City Archives. Manley's transcripts of monthly means available in his boxed notes at Cambridge University Library (Manley 1938-).
Jesmond (James Losh)	Original journals at Newcastle Literary and Philosophical Society Library (Losh 1802-).
Brandsby (Francis Cholmeley) later monthly data	Monthly means on microfilm at North Yorkshire County Archives (Cholmeley 1811-). Daily means not referred to in Manley's work, and not found.
York (John Ford)	Original not found at York City Library, York City Archives, York Philosophical Society or Bootham School (site of observation). Transcription of monthly means found in York City Archives (Ford 1831-).
New Malton	Originals not found. Transcription of monthly means in Dove (1838, 1853).
Ackworth (Luke Howard)	Monthly means available in Howard (1842a, 1842b) from 1824 to 1841, although Manley appeared to have data until 1850. Daily means not referred to in Manley's work, and not found.
Wykeham (Robert Nendrick Hodgson)	Manley appeared to have monthly means for 1831 to1837 available (Manley 1938-). Original not located, but may consist of daily means.
Abbey St. Bathans (Rev. John Wallace)	Summary of observations in *Transactions of the Berwickshire Naturalists' Club*, sourced from the Scottish Borders Archive and Local History Centre.
Allenheads (Rev. William Walton)	Original observations at the library of The Royal Society, London for 1837 and from 1939 to 1842 (Walton 1836, 1840, 1841)
Yarm (unknown observer)	Original observations at the National Meteorological Library and Archive, Bracknell.

Each series of data available in the North East will be discussed and analysed.

3.1.2 Brandsby

The village of Brandsby is 18 km north of York on fairly flat, low land 5 km south of the Hambleton Hills upon which Ampleforth College stands at the southern edge of the North York Moors.

There are two sets of temperature readings that were recorded at Brandsby; the later of these was known to Manley and was used when compiling his series for Durham and covers 1811 to 1830. It is not clear whether Manley had daily means available, but only monthly means for these years have been found. However, the source for these monthly data does include comments that also appear in Manley's notes, implying that this was the same copy that he worked from. Both sets of observations are recorded on microfilm at the North Yorkshire County Archive (Cholmeley 1783- and Cholmeley 1811-).

The second, earlier, series covers the period from December 29th 1783 to September 4th 1791, and also for parts of summer and autumn 1806, 1807 and 1808, ending on December 31st 1808. This record is split across several volumes of ledgers, and the front page of each is titled 'Cholmeley of Brandsby archive'. It is mentioned that the site of the recording is at Brandsby Hall and it is known from parish records (Bulmer 1890) that the Italian-style Hall was built in 1745 upon a site previously used for a mansion belonging to the de la River family since the latter part of the 13th century. The Cholmeleys acquired the estate during the reign of Queen Elizabeth when an heiress to the de la River family married Roger Cholmeley. Table 3.3 summarises observations available in the archive.

Table 3.3 Temperature observations recorded at Brandsby.

Dates	Comments
December 29th 1783 to September 4th 1791	Generally 3 or 4 readings per day, at assorted times. Sometimes as many as 7 readings per day, although half way through 1786 this drops to 2 readings a day often at 6 am and 10 pm, or 8 am and 11:30 pm. Drops to one reading a day for the last month, generally at 8 am. Various comments are given such as 'first swallow heard' etc. Only temperature is recorded.
May 1st to October 31st 1806 (most of August missing)	Written in slightly different handwriting from the previous journals, with comments in the weather for most days on the right hand side of the ledgers, which were not present before. 'Vol III' is marked on the front page.
July 12th 1807 to December 31st 1808 (with breaks of a month or so every few months)	Same handwriting and style as 1806. 'Vol V' is marked on the front page.
January 1811 to December 1830	Average temperatures given for each month to the nearest 0.5°F, with a few observations missing.

There are also brief records within this set of observations for Scarborough and Whitby for the summers of 1815, 1818 and 1819. Nine months of data from March 12th to December 15th 1854 appear to have been recorded at Brandsby (Brandsby Hall was still owned by the Cholmeleys at this time), although no times of observation are given, and the handwriting is different from before.

On none of these ledgers are there any details of where the thermometer was kept and read, although on the first page of the oldest journal for 1783 is given an indication of the scale of the thermometer, clearly graduated in degrees Fahrenheit, as shown in Table 3.4.

Table 3.4 The scale of the thermometer used for recording temperature at Brandsby at the start of the record in 1793.

Temperature Observation	Reading
Boiling Water	212
Summer Heat	76
Temperate	56
Freezing	32

The series from 1783 to 1808, and from 1811 to 1830, both appear to have been recorded by a Francis Cholmeley. Along with the microfilms of the meteorological register are held copies of correspondence and estate records of income and expenditure and from this information it can be seen that a Francis Cholmeley died in 1808, around the same time that the first archive finished. It is possible that the first set of data to 1791 was recorded by the same Francis as this, but the later data from 1811 were maintained by his son. There was also a Francis Cholmeley, possibly the father and grandfather of the previous two respectively, who in 1770 built the present village church at his expense (Bulmer 1890).

The record is held on microfilm, and its date of reproduction in 1981 means that Manley could not have used it. It is known from his letters than Manley was in Northallerton consulting the Brandsby record on October 3rd 1979.

The data recorded from 1783 to 1791 were observed and recorded to the nearest whole degree Fahrenheit. It is possible to examine the frequencies of the final digit of his readings to find any bias in his observations and therefore make an assessment of the accuracy of the readings. An analysis of the data recorded until 1791 shows a much greater frequency of the temperature being observed to the nearest even degree (2°F, 4°F, 6°F etc), as shown in Figure 3.4, with the observer slightly favouring a final digit of 0 (0°F, 10°F, 20°F etc). It is possible that the thermometer used was graduated in two-degree intervals and the same observer recorded the readings throughout the period, keeping this habit constant. No temperature was recorded to a half-degree precision.

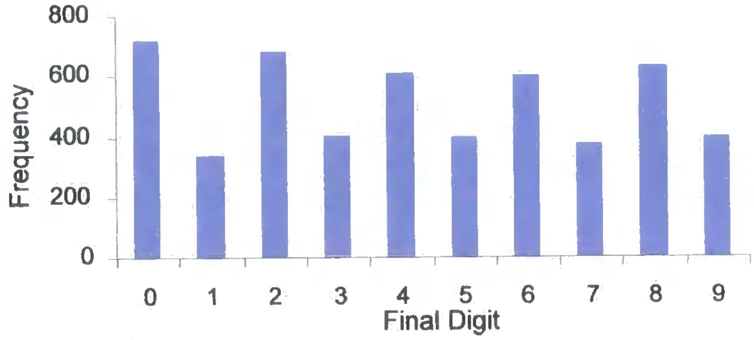


Figure 3.4 An analysis of the frequency of final digits for the Brandsby temperature data from 1783 to 1791.

When a chi-square test is applied to these results, the calculated value for chi-square is 375.0, with the critical value at the 0.01 level of significance, for 9 degrees of freedom, being 21.67. The null hypothesis of a uniform distribution, each digit occurring with equal frequency, is therefore rejected firmly, so that the frequencies are clearly affected by observer idiosyncrasies.

It is thought that Francis Cholmeley recorded meteorological details after 1830, because he was vice-president of the York Philosophical Society in 1833 (reported in the annual report for the society for that year) and he became a trustee in the following year. In 1835, the report gives rainfall details for several places in and around the city of York, including Huggate (in York city), Middleton (to the east of York), Moat Hall (to the west of York), Ackworth[46], Kirkthorpe (near Wakefield) and Brandsby.

3.1.3 Braithwaite

Little is known about a record that was kept by Abraham Shackleton, one km NW of Keighley, although the modern town has expanded past the area that used to be the village of Braithwaite where the readings were taken; it gives its name to an estate of houses now. Manley had photocopies of microfilms of the original readings, which are now held at the Cambridge University Library (Manley 1938-), although the originals and the microfilm copies are held by the Cliffe Castle Museum in Keighley (Shackleton 1799-). From the beginning of the record in October 1799 only indoor temperatures are recorded, for each month. The mean for the month is given, in Fahrenheit, and also the maximum and minimum temperatures for that month. It is not clear exactly how the mean was derived but there is no reason to suspect that it was not just a straight arithmetic mean of the daily values. No other climatic factors, nor comments on the general weather, are given.

From January 1809 to the end of the series in September 1857 both indoor and outdoor temperatures are given. It is possible that at the some time towards the end of 1857 or in early 1858 the observer died, because the means have not been calculated for any month in 1857 and there are only comments on the weather up to December 1857.

[46] Ackworth is the site of the record kept by Luke Howard.

3.1.4 Allenheads

The village of Allenheads is at an altitude of 427 metres above sea level in southern Northumberland about 21 km SSW of Hexham. The Reverend William Walton FRS[47] recorded temperature, both indoors and outdoors, as well as air pressure, rainfall and wind direction. His original manuscripts cannot be traced, but summaries of his readings are held by the library of the Royal Society in London as they were sent there by the author a year at a time over the course of the late 1830s and early 1840s (Walton 1836a, 1836b, 1840, 1841a, 1841b). His data cover the years 1837, 1839, 1840, 1841 and 1842. For 1837 and 1842, only monthly means are available, but for the other three years daily data are present.

Walton's summaries for temperature show that he took the measurements at 9 am and again at 3 pm using a thermometer sited indoors, attached to his barometer, and also a thermometer out of doors, although the exposure of this latter instrument is not given. He also included some remarks about the weather type, and several pages of summary information about the year. He calculated monthly means for both thermometers for each year.

He was particularly interested in rain gauges, and included in the rear of his 1841 pamphlet (Walton 1841b) details of several different designs of gauges and their characteristics of capture, depending upon the angle of rainfall and the size and shape of the gauge opening.

The readings for indoor and outdoor temperatures, shown in Figure 3.5, are particularly useful for comparison with the indoor and outdoor readings observed by Abraham Shackleton at Braithwaite. Unfortunately there are no comments stating where the indoor thermometer was located, whether it was in an unheated room, for example. The range between the two exposures in winter is up to 11.2°F, in January 1841.

---

[47] One of the proposers for Walton's presentation as a Fellow of the Royal Society was Robert Hodgson, the observer of the temperature series at Wykeham.

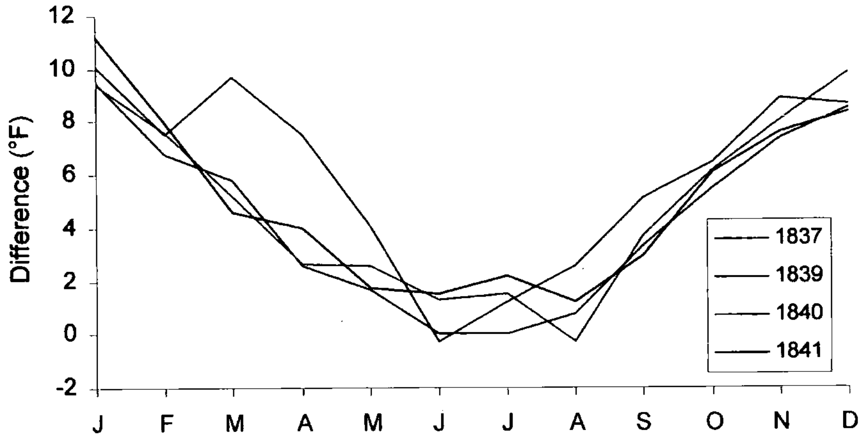


Figure 3.5 Difference between indoor and outdoor temperatures at Allenheads (°F).

A letter in the library of The Royal Society from Luke Howard[48] is addressed to a W. H. Sykes and tells of his opinion that Walton should be encouraged to continue observing and submitting his results to the Royal Society:

> *'... as he appears to be a faithful and accurate observer and such documents (tho' not entitled to a place in the Transactions) are most valuable materials for future use in estimating the various climates of these islands'.*

[48] Luke Howard was the recorder of the meteorological record at Ackworth.

3.1.5 York

There are two series of temperature readings that were recorded in the city of York. The first of these was recorded by Jonathan Gray (1779-1837) of Gray's Court. He was a figure of some reputation in York, holding a number of official appointments in the city, including Under Sheriff of the County of Yorkshire in 1803. He was the treasurer, and a vice-president, of the York Philosophical Society in 1833. His family was generally well known in the city and was the subject of several books and a thesis (Tebbutt 1994, Cobb 1989, Gray 1927). The original observations by Gray have not been located, although Manley has a transcript of them from 1800 to 1824 among his papers at Cambridge University Library (Manley 1938-).

Jonathan Gray started to record details of the weather in 1800, but it is known from his diaries and correspondence that he was usually away travelling, and often on 'tours', including one after Wellington's victory at Waterloo. Many of his papers comment on the weather in the places that he visited, and he was particularly appreciative of Durham which he said 'is the most pleasant city I ever saw'.

He started to take meteorological readings in 1800, and it is known that Manley had access at least to monthly means from 1801 until 1824. However, a search at the York City Library indicated that his work may have been lost. Gray also recorded rainfall, and a copy of his rainfall observations for 1811 to 1824 is available in the library of the Royal Meteorological Society.

Much of the information on the two York temperature series is known from the work of William Baines (obituary in the *Yorkshire Evening Post*, 1987), a local meteorologist and historian who wrote many articles on the subject, and was a regular contributor in the *Yorkshire Evening Post* on weather issues. The York City Archives has a bound ledger with monthly temperature summaries for York from 1832 to the 1960s. Various facts are recorded, including for each month the highest maximum temperatures, lowest minimum temperatures, mean of maximum thermometer and mean of minimum thermometer, as well as rainfall, sunshine and barometer averages. It appears that the author of this compilation was Baines, although this is not certain. The source for the temperature means from 1832 was undoubtedly John Ford, the observer of the second York series. The original observations taken by Ford have not been located despite searches at several institutions.

John Ford (d. 1875) attended Ackworth School near Pontefract[49], and was in 1834 Principal of the Friends' School in Lawrence Road in York (just east of the castle) and then later at Bootham school, just north west of the city centre, when the school moved there in late 1846. He was involved, as was Jonathan Gray, in the York Philosophical Society and in 1841 became Curator of Meteorological Instruments. It took some years for the Society to purchase its own equipment and install it in the Museum Gardens, and it is probable that Ford continued to use his own instruments and report observations to the Society. When the instruments were eventually installed in the gardens in 1873, a member of the museum staff took daily observations and sent the results to the Meteorological Office in London by telegram (Baines 1971). The site of the York readings was transferred to Archbishop Holgate's School in 1964, 4 km east of the city centre.

On May 4th 1841, Ford gave a lecture to the York Philosophical Society titled *Meteorological Observations made at York*, which detailed the same means for 1841 as given by William Baines in his monthly summaries. Ford then published the monthly means each year in the Society Reports for Bootham School. In some of these summaries there are details of rainfall compared with other local sites such as Ackworth. Ford's original readings cannot now be found. York City Library once held a broadsheet pamphlet of 1840 means, presumably more detailed than monthly data, but this also seems to have been lost. Despite not having the original data, some information is known about the exposure of the thermometers at the various sites from Clarke (1891).

[49] Luke Howard taught at Ackworth School.

'Until about 1870, the thermometers were in a shaded spot, shielded by boards, open towards the North. At Lawrence Street (until 1855)[50] *this appears to have been in the open garden*[51]*. At Bootham it was near a garden wall, and within 30 feet of the E corner of the two-storey school-rooms. About 1870, they were placed in a Stephenson screen near the old locality. Since this was removed, in 1876, to a more open spot in the garden, 90 yards from the house, the values have agreed closely with those of the Y.P.S. The extreme maxima and minima used to be slightly lower, the latter because of there being no falling surface, down which the cold air slides, as at the Y.P.S. stand. The former may arise from its more open position. Probably the extremes at Bootham would have been slightly greater had the instruments occupied a more open place.'* (Clarke 1891)

3.1.6 Ackworth

Ackworth is a village that is strictly known as High Ackworth. Low Ackworth and Ackworth Moor Top are located nearby. Ackworth School, in High Ackworth, was founded by Quakers, and Luke Howard (1772-1864) taught there. He lived at Ackworth Grove in the village.

Luke Howard's name has been mentioned in connection with several of the other meteorological observers in this chapter, for he was a very keen meteorologist. He was born in London and was brought up by his parents as a Quaker. It is thought that his interest in the weather and climate began during the summer of 1783 when much of the skies of the Northern Hemisphere were affected by volcanic dust thrown up by the volcanic eruptions of Eldeyjar in Iceland and Asama Yama in Japan (Heidorn 1999). In 1802 Howard presented a paper to the Askesian Society titled

[50] The move actually took place in November 20th 1846 (Bootham 2002).

[51] The school was next to the river Foss, and the garden may have led down to the river. It was the river which forced the move to Bootham because many boys were becoming ill with water-borne diseases such as typhus, and a few died (Bootham 2002).

On the Modification of Clouds[52] describing and identifying clouds into the distinct groups that we still recognize today. He published *The Climate of London* in 1818-19 describing the climate of the city microclimate, and was elected a Fellow of the Royal Society in 1821. Heidorn describes Howard starting his Meteorological Register in 1806, and that this was regularly published in the *Athenaeum Magazine* from 1807. Summaries of Howard's temperature readings are printed in his book *A Cycle of the Seasons of Britain* (Howard 1842a) from 1824 to 1841, presented to the Royal Society by the author. This gives monthly means, and individual monthly maxima and minima for 1842 are available in a separate letter to the Society (Howard 1842b). The book also shows the mean barometer readings, and rainfall. Examination of his published papers shows that he lived in Tottenham, North London, at least during the period from 1815 to 1823 for which he published mean temperatures and pressures (Howard 1823) and for this period he provided detailed descriptions of the instruments themselves and their 'methods of observation' (Howard 1842a). It seems probable that when Howard moved back to Ackworth from Tottenham he would have brought his recording practices, and possibly his instruments, with him.

There is no record of any means for dates before 1824 at Ackworth, but Manley did have access to means for 1824 to 1850, and 'possibly 1852'. It is not clear where he obtained his means after 1841.

[52] In current English the word 'Modification' might be better substituted by 'Classification'.

3.1.7 South Cave

The record at South Cave begins at the beginning of 1794, and continues with few breaks until the beginning of 1815. The observer was Henry Boldero Barnard (1755-1815) who built Cave Castle at South Cave, the site of the observations. Barnard lived there with his wife, Sarah Elizabeth Gee, and their four children. His temperature observations consist of, at most, a single reading each day. This reading is almost always in the morning between 8 am and 10 am.

Barnard was obviously keen on horse racing as there were days during the year, approximately half a dozen each year, when he was at either Pontefract or Beverley.

The manuscript is divided across two bound journals, the first containing the years up to 1810, and the second those thereafter. At the front of the first journal is a note written by Barnard:

Cave Castle South Cave 1st of January 1794

NB. The Barometer and Thermometer used in these observations was sent me by the late celebrated Mr Smeaton the Civil Engineer. It was made under his immediate inspection by Messrs Nairne & Blount, Cornhill London. The Thermometer is by Fahrenheit scale, and is placed out of doors on a north west wall and in a sheltered situation, about eleven feet from the ground where the sun only comes in an afternoon. The Barometer is in the house upstairs in a large open passage or lobby.

That division in the scale is noted, immediately above which the mercury stands. The wind and the time the observation is made, is to the quarter or point in which it is. AM is before 12 o'clock or noon - PM: after that time.

The summer of last year (1793) was a remarkable dry one, the crops of corn very bad, and the grass ground so burnt up that hay was never known at so high, or cattle at so low a price. In the young plantations most of the new planted trees died for want of rain particularly Beech Larch and Scotch Pine. Hitherto (1st January 1794) neither frost or snow, but the cattle grazing in the pastures and requiring scarce any other food than what they get there, the Glastonbury Thorn in full flower this day.

Hen. B. Barnard
1st January 1794.

The manuscript is very neat, and easy to read. It is written on both sides of the paper in ruled tables having columns for the date, time of observation, barometer reading, thermometer reading, wind direction, and a brief comment on the type of weather that day, observed at the end of the day. After each year is a summary headed 'Naturalists calendar etc etc extracted from the foregoing register'. There are notes for a selection of days as a summary of notable features of the year, e.g. 'Ice House filled', 'Young geese at the farm', 'Planted potatoes', 'Intensely hot', 'Finished reaping beans'. There are generally two pages of such summaries.

Figure 3.6 shows an extract from Barnard's journal for the beginning of 1796.

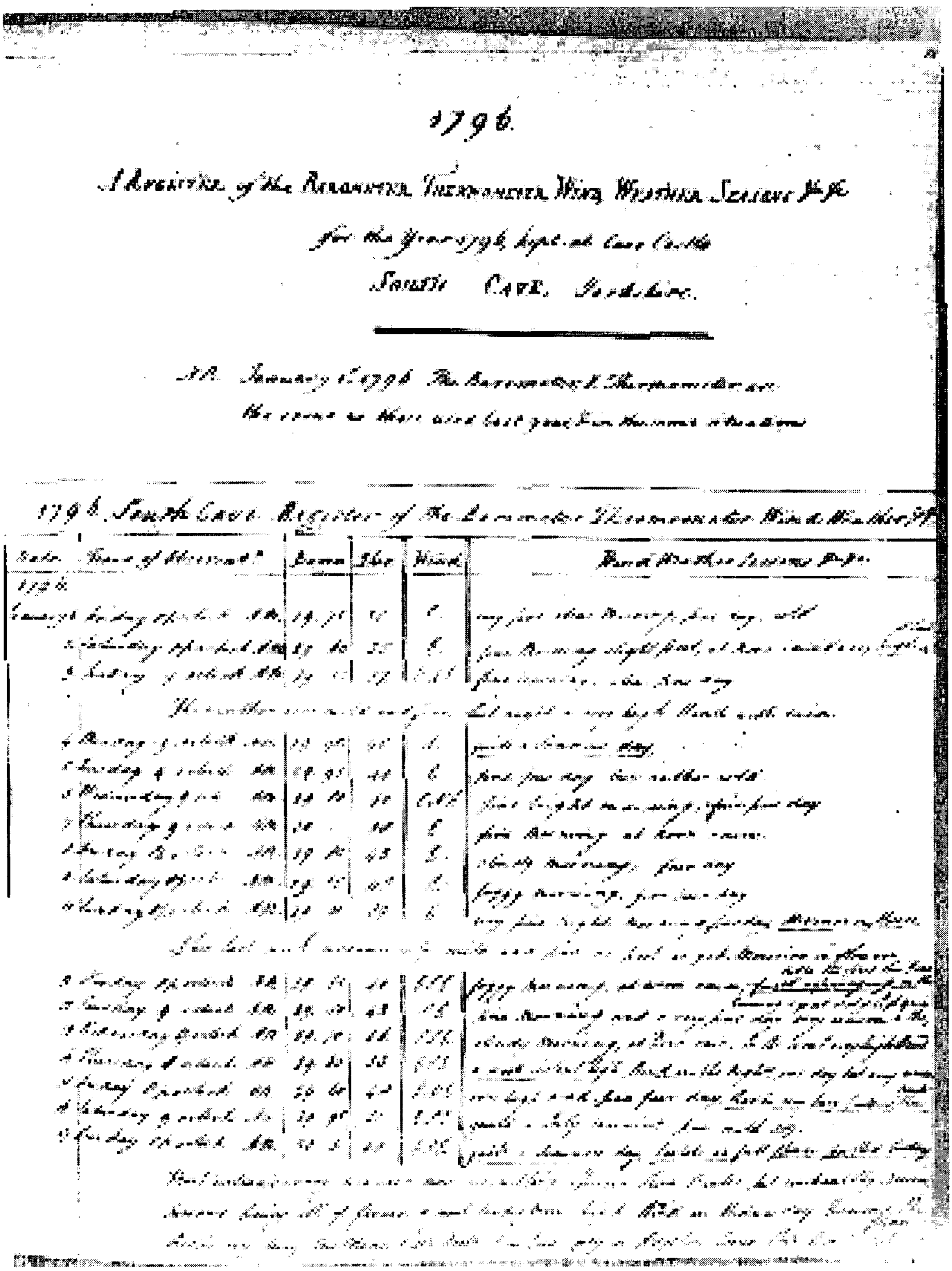


Figure 3.6 An extract for January 1st to 17th from Barnard's journal at South Cave.

Each year is prefixed by a small illustration, and a comment on the location of the barometer, and thermometer, which do change during the record. The location of the thermometer remains outside, against a north west wall, 11 feet above the ground, until 1798.

> *'...the barometer in the same place, the thermometer in the same aspect, but lower, about 6 feet from the ground'*

In 1803, the thermometer was moved from its outdoor location to one, according to the comment, inside.

> *'...and are placed in the house in the hall. The thermometer very near the door which is almost always open, nearly the same as the open air'*

However, in 1805, this exposure is detailed further.

> *'...the barometer is placed near the door in my dressing room, the thermometer in an open passage near the cloister'*

Comments in 1806 and 1808 further explain this exposure.

> *'...thermometer in open passage near the cloisters about 3 feet from the ground'*

> *'...the thermometer out of doors in the Cloister and sheltered by the Cloister roof, it is placed about three feet from the ground'*

The thermometer was moved for the last time in 1809 to a higher position in the cloister.

> *'...about five feet from the ground'*

It is not clear from the manuscript whether in 1805 the thermometer was actually moved or whether 'near the door' did refer to the cloister area. The movement of the thermometer from its outdoor location to the indoor one may have been motivated by the occasional covering of the instrument by snow, as reported in February 2nd, 9th, April 5th 1799 for example. Moving it to the cloister may have been more convenient than having it eleven feet above the ground, or indeed outdoors at all. Throughout the record, both barometer and thermometer remain the same ones, donated by Mr Smeaton. Table 3.5 summarises the changing exposure of during the record.

Table 3.5 Exposure of the thermometer at South Cave.

Period	Exposure
1794-1798	Outdoors at 11 feet, north west wall
1799-1802	Outdoors at 5 feet, north west wall
1803-1804	Indoors, 'near the door'
1805-1808	Cloisters, 3 feet
1809-1815	Cloisters, 5 feet

An analysis of the observations around freezing point gives confidence in the exposure of the thermometer with regard to its accuracy at the lower end of the scale. It is difficult to ascertain accuracy at warmer temperatures because the observations were all taken early in the day.

Tables 3.6, 3.7, 3.8 and 3.9 show comments on the state of the weather, alongside temperature, wind and pressure readings for days where the thermometer is reading around freezing point (32°F).

Table 3.6 Extract from Barnard's journal for February 1797 – thermometer on a north east wall, 11 feet from the ground

Date	Temp.	Wind	Barom.	Comment
13	43	E	29.55	rainy morning. Afterwards fair and fine
14	35	E	29.15	cold raw day, with slight showers of snow and sleet
15	30	N	29.65	a hard frost and very cold, snow drops in full flower
16	31	N	30.20	very fine day, a frost
17	30	ENE	30.25	bright frosty day, very cold
18	29	ENE	30.25	bright frosty day, very foggy in the morning
19	32	E	30.30	cold frosty day, the weather for the last week in general bright and frosty. Forced asparagus cut today, the first this year.
20	38	E	30.30	foggy morning, quite a summers day
21	28	E	30.30	frosty morning very fine day. Gooseberry trees budding
22	32	E	30.30	frosty morning, very fine day
23	37	E	30.30	very fine day. Crocus in flower and many daisys
24	34	E	30.30	fine day
25	37	WNW	30.30	fine bright day

Table 3.7 Extract from Barnard's journal for January 1800 – thermometer on a north wall, 5 feet from the ground.

Date	Temp.	Wind	Barom.	Comment
19	38	E	29.10	cold gloomy day with rain
20	34	N	29.10	the ground covered with snow this morning
21	24	N	29.35	very hard frost, bright clear day
22	28	N	29.70	hard frost, very cold, in the evening a high wind
23	31	E	29.60	very high wind
24	34	ESE	29.15	fine mild pleasant day, appears to thaw
25	34	ESE	29.65	a slight frost, in the evening rain
26	44	SSW	29.20	the snow gone, a thaw, fine mild warm bright day

Table 3.8 Extract from Barnard's journal for February 1803 – '...the thermometer very near the door which is almost always open, nearly the same as the open air'.

Date	Temp.	Wind	Barom.	Comment
3	44	NNW	29.70	the ground covered with snow, a thaw at noon
4	35	N	30.15	more snow this morning, a hard frost, bright fine day
5	34	N	29.90	a frost, gloomy day, and unpleasant
6	38	N	29.30	several showers of snow. Cold frosty weather during the last six days with a little snow
7	36	N	29.50	a thick snow this morning. Cold frosty day with snow
8	35	N	29.90	a hard frost, slight showers of snow
9	30	N	30.25	cold frosty day
10	35	N	30.30	cold frosty day
11	32	E	30.40	intensely cold, a hard frost. Forced asparagus on the table
12	32	E	30.30	a hard frost intensely cold
13	35	E	29.70	a thaw, the snow going gradually away. Frosty snowy weather during the last week and intensely cold
14	38	NW	29.70	a thaw, damp and unpleasant day
15	41	NW	29.20	showers of rain very high wind in the evening

Table 3.9 Extract from Barnard's journal for March 1806 – thermometer in cloisters, 3 feet from the ground.

Date	Temp.	Win	Barom.	Comment
9	41	NNW	29.55	wintry day, showers of snow and hail and rain
10	34	N	28.75	the ground covered with snow this morning
11	33	N	29.10	the snow very deep this morning, snowy wintry day
12	30	N	29.10	a hard frost, cold wintry day the snow thick
13	29	N	28.95	very snowy
14	33	N	29.15	very snowy wintry day
15	30	N	29.40	a hard frost, cold wintry day
16	34	NE	29.40	cold wintry day. The first lamb of my flock dropped.

Each of these four different exposures shows the temperature to be closely matched to the comments on the weather. The 'indoor' exposure in 1803 does not give temperatures higher than might be expected from 'intensely cold' weather. 'Frost' is noted with morning temperatures of 30 to 35°, which could be considered a little high. However, the thaw is reported on the day that the thermometer reads 35°F. On balance, the thermometer 'indoors' does not appear to yield temperatures that are higher than might be expected outdoors. The observations made where the thermometer is outdoors, and outside but in the shelter of the cloisters, in the table for 1806 above, also appear to be reasonably representative, with snow lying between 29 and 34°F.

Although the observations begin on January 1st 1794, the last reading before a long gap comes on April 2nd. Barnard was taken ill 'with a violent fever', and the readings do not resume again until November 19th 1794. The observations cease in January 1815. There is a temperature reading on the last day, January 19th, but no wind observation.

Cave Castle was sold by the Barnard family in 1925, and is now a hotel and golf club.

3.1.8 Wykeham

The small village of Wykeham is 10 km south west of Scarborough in North Yorkshire, and it is here that observations were made by Robert Nendrick Hodgson, the headmaster of the village school. Manley had monthly means for 1831 to 1837 (except May 1835, and September, October and December 1837). The temperature readings were taken at 6 am, noon and 6 pm, and it is thought that the site changed from Wykeham to a house in the hamlet of Ruston, 2½ km south west of Wykeham (Manley 1938-). Manley analysed the data and believed the move to have taken place in late Autumn or Winter 1836; he gives two different theories in two separate papers. Manley probably had access to the daily data because he mentions the coldest day, 21st January 1835 at 17°F, and warmest day, 10th June 1835 at 83°F, for the record, although Hodgson could have supplied these with summaries of his own means. It is possible that the source may be local newspapers where a monthly summary would be sent by the observer for publication in the first week or so of each month.

It is known that Hodgson later moved to London. Records from the Royal Society state him as Rector at St. George's Church, Hanover Square.

3.1.9 Abbey St. Bathans

A short series of monthly means is available for the small village of Abbey St. Bathans, 19 km WNW of Berwick-upon-Tweed and at 202 m above sea level). The readings were taken at 'The Manse' in the village by the Rev. John Wallace and summaries are available for 1835 to 1838. There are four daily observations for temperature, at 9 am, 10 am, 3 pm and 10 pm, and also at these same times for a Leslie's hygrometer, and a barometer. He also printed columns for the temperature of spring water from a nearby well, the relative humidity and rainfall for each month.

Means for each month are provided for the 10 am and 10 pm temperatures, and also for the 9 am and 3 pm readings. For each year he calculated similar means, and all these results were published in successive years in the *Transactions* of the Royal Society (Wallace 1835, 1836, 1837, 1838). It seems as if Wallace planned to cease the observations in 1838 as with the copy of the means for this year was printed a summary of the four years to 1838. He included the 'mean height of the thermometer' for each of those years, printing the mean of the 10 am/10 pm pair in preference to the other, which is in general between 0.2 and 3°F lower than the 9 am/3 pm mean. Wallace took the mean of the two observations in order to derive his daily mean. Figure 3.7 shows the relationship between indoor and outdoor monthly means for the four years of his record.

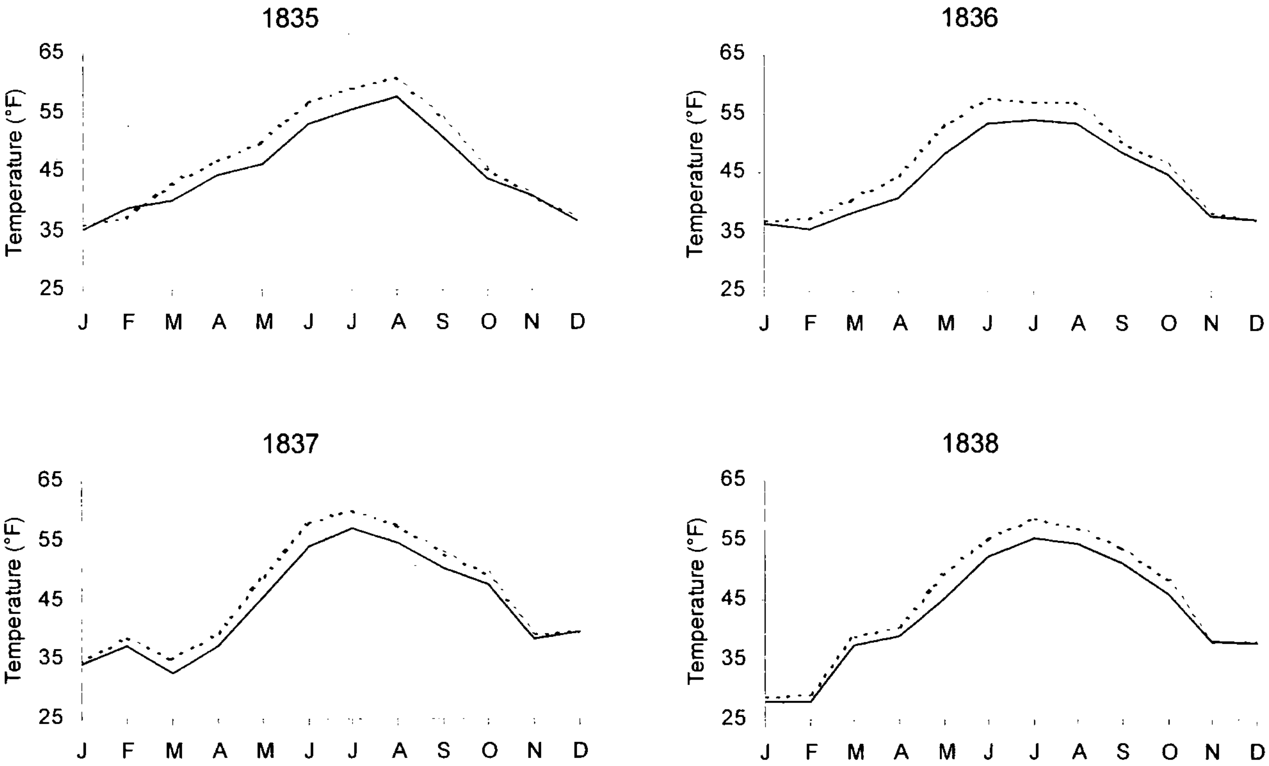


Figure 3.7 A comparison between the monthly means taken at 10 am/10 pm (broken line) and 9 am/3 pm (solid line) for the four years of the record at Abbey St. Bathans (°F).

3.2 James Losh's Record at Jesmond

The longest and most complete series of data for the North East of England, and the most important for the extension of the Durham series, comes from an record kept by James Losh, a lawyer from Jesmond, about 3 km to the north east of Newcastle upon Tyne city centre. He took temperature readings three times a day from 1802 to 1833, as well as wind direction, air pressure and a few words about the prevailing weather condition. The original journals are held at the Library of the Newcastle Literary and Philosophical Society (Losh 1802-).

3.2.1 James Losh

Losh was an eminent man of early nineteenth century Newcastle and we therefore know more about him than most of the other observers whose work Manley used. His weather journals contain a lot of supplementary information about the weather, and he kept a personal diary for several years of his movements and activities, which was later published by the Surtees Society in two volumes (Hughes 1962, 1963). He is often mentioned in books on the local history of Newcastle upon Tyne and his life has been the subject of a recent doctoral thesis (Smith 1996).

Losh was born in 1762 in Woodside near Carlisle and moved to Newcastle in 1797 after reading law at Trinity College in Cambridge. Much information about his life comes from his connections with the Literary and Philosophical Society of Newcastle which he joined in 1799, a year later becoming a vice-president of the Society, at the age of 38. A year after this, he started his first record of his observations of the weather. He took an interest in meteorology long before this, but becoming involved with scientists and scholars in Newcastle at the Society may have prompted him to record what he measured in a similar fashion to other men of the period.

Losh's house, Jesmond Grove, was large with extensive grounds. Maps of the area at the time show the buildings set beside the Ouseburn, running into the Tyne to the south east of Newcastle.

The main building was demolished in 1927 after eleven years as a boarding house for the Church High School. Figure 3.8 shows a photograph of Jesmond Grove, thought to be in the mid-1920s.

Figure 3.8 Jesmond Grove.

A building, formerly known as Jesmond Cottage, stood several hundred yards to the west of Jesmond Grove and still stands. Despite its humble name, it is a very grand property with tall chimneys and many windows. It is now the main building of Akhurst School - a private primary school. A driveway leads to the rear of the school, with two large stone posts at its entrance. These were probably original gateposts for Jesmond Grove. The whole area surrounding the school has been built over with detached 1930s houses, filling in the gaps between the few older residences that still remain. Figure 3.9 shows the area from maps drawn in 1895 and 1914, showing very little development between these two years.

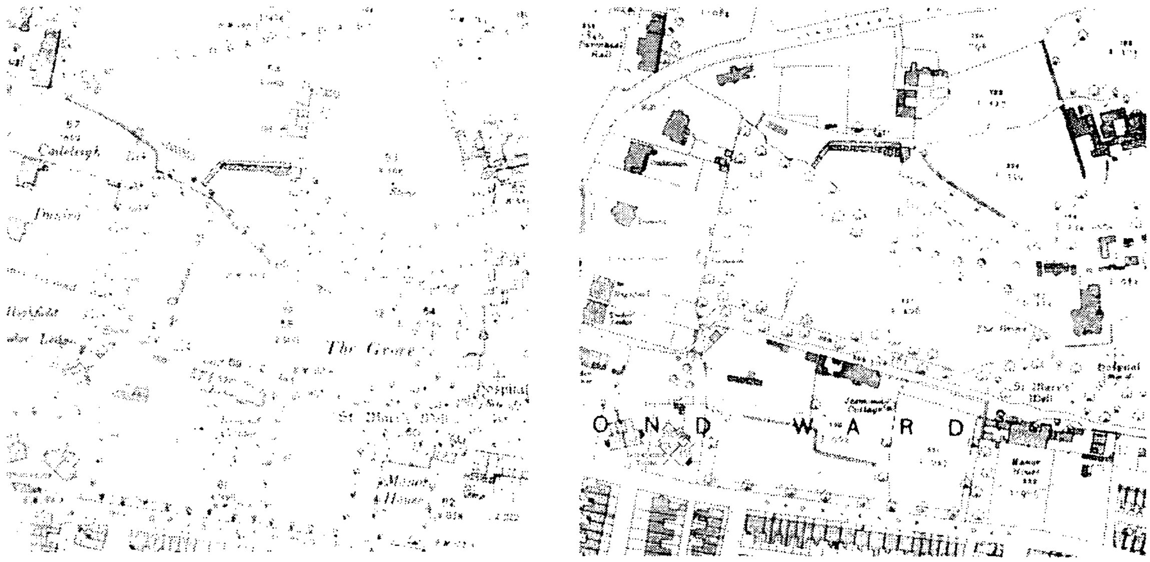


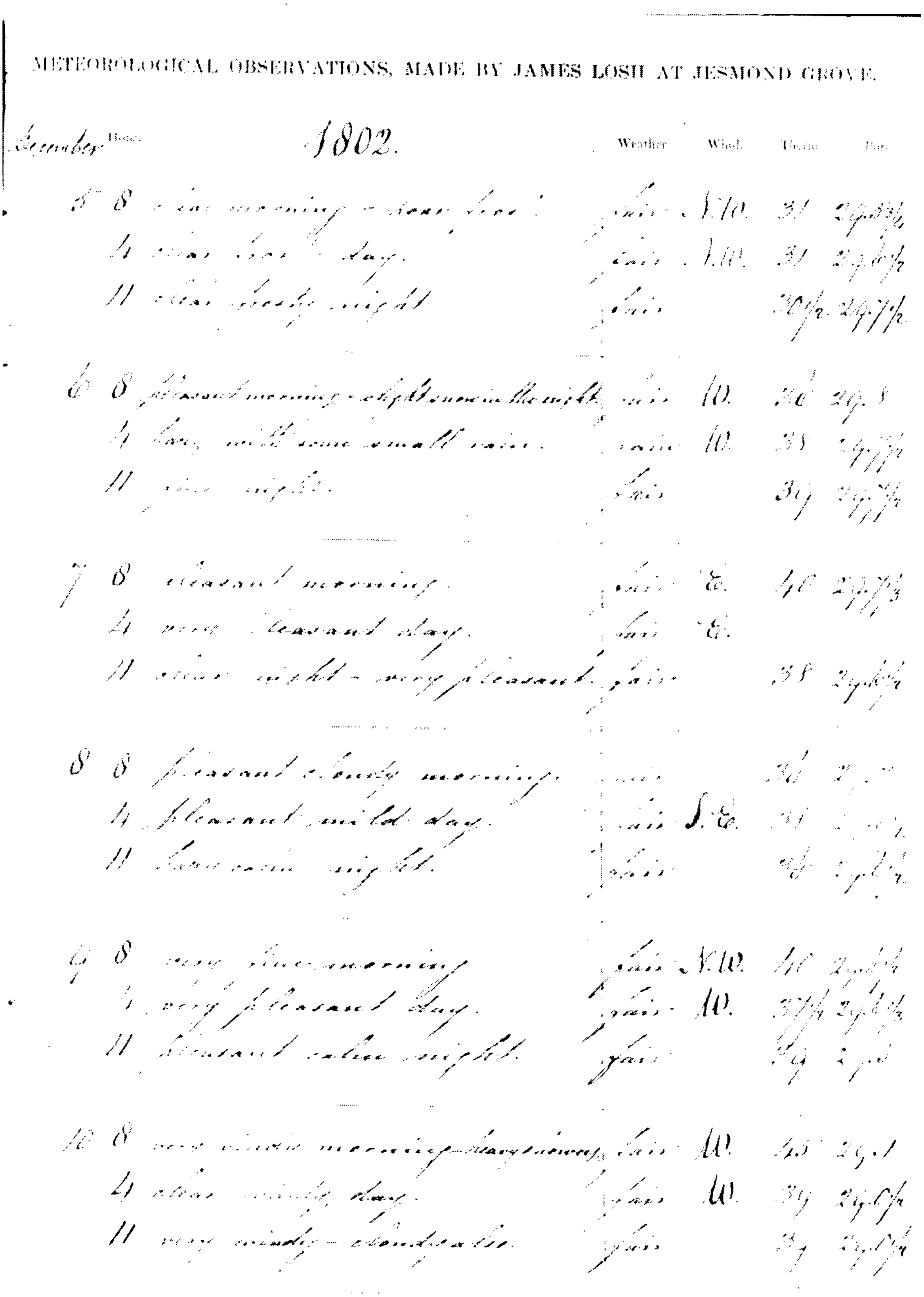
Figure 3.9 Maps of East Jesmond 1895 (left) and 1914 (right).

Few older houses remain in the area: the Jesmond Manor House was demolished in 1929. The Banqueting Hall, a short distance to the east, and Jesmond Dene House to the north are exceptions. Both of these were owned by Lord Armstrong and presented to the City of Newcastle upon Tyne in 1883, about fifty years after being built, along with the picturesque Jesmond Dene area and Armstrong Park which are now used as recreational areas, and contain nature trails and woodland walks. St. Mary's Chapel and the nearby well still remain, surrounded on all sides by the back gardens of surrounding houses. The chapel is in ruins but is the earliest in Newcastle, dating from the twelfth century. Losh makes reference to the chapel and well in his register.

It is probable that the thermometer was outside Losh's study window, as was the custom at the time, and was probably attached to a hook on the wall with no screening. From here, the observer may only have had to lean out of the window to check the temperature but it may have been influenced by heat held in the stone walls. This possibility shows up in the readings when, notably in winter, the evening temperature taken at around 11 pm is several degrees higher than that in the early afternoon. This phenomenon could happen in open air, more likely in the winter months with the lower diurnal range than in summer, but perhaps not to the extent demonstrated in Losh's readings. The house was situated in a slight valley, and etchings show slightly higher ground to either side, but this would generally lead to cooler night-time winter temperatures as cold air settles into the hollows.

3.2.2 The Manuscript

The readings were taken with little major variation over almost 31 years although changes in times of observation occur from time to time. On various days, no readings were made, and often the times of observation were rearranged, but on the whole, if a reading was missed at 10 pm , it would be replaced by one later, often at 4 am. Changing hours are relatively easy to correct for when calculating monthly means, and it is this, and the fact that his location of observation never changed, that make the record particularly valuable. The last observation came on the afternoon of September 28th 1833, the day that he died. Figure 3.10 shows a page from his manuscript for December 5th - 10th 1803, and Figure 3.11, a representation of January 1st 1807.



METEOROLOGICAL OBSERVATIONS, MADE BY JAMES LOSH AT JESMOND GROVE.

December 1802.

Day	Hour		Weather	Wind	Therm	Bar
5	8	fine morning – hoar frost	fair	N.W.	31	29.3¾
	4	[illegible] day.	fair	N.W.	31	29.6½
	11	clear frosty night	fair		30½	29.7½
6	8	pleasant morning – slight [illegible] in the night	fair	W.	36	29.8
	4	hazy, with some small rain.	rain	W.	38	[illegible]
	11	fine night.	fair		39	[illegible]
7	8	pleasant morning.	fair	E.	40	29.7¾
	4	very pleasant day.	fair	E.		
	11	clear night – very pleasant.	fair		38	29.6½
8	8	pleasant cloudy morning.	fair		36	[illegible]
	4	pleasant mild day.	fair	S.E.	[illegible]	[illegible]
	11	fine calm night.	fair		[illegible]	[illegible]
9	8	very fine morning	fair	N.W.	40	[illegible]
	4	very pleasant day.	fair	W.	37½	[illegible]
	11	pleasant calm night.	fair		[illegible]	[illegible]
10	8	very clear morning – [illegible]	fair	W.	43	29.1
	4	clear windy day.	fair	W.	39	29.0½
	11	very windy – [illegible]	fair		[illegible]	[illegible]

Figure 3.10 December 5th to 10th 1802, as recorded by James Losh.

Day	Hour	Observation	Weather	Wind	Therm.	Bar
1	9	Clear calm and keen frost	Fair	NW	31	30.5
Thursday	3	Very bright and calm day	Fair	NW	33	30.5½
	11	Clear and calm frosty night	Fair		33	30.5½

Figure 3.11 A typical page from Losh's manuscript: January 1st 1807.

The format shown in Figure 3.11 appeared on every right-hand page of the six hard-covered volumes, each containing a number of ledgers bound together. Unfortunately the bindings are in a rather poor condition and many pages have become detached from the spine but the data on the pages have been well protected. The left-hand page of each sheet was reserved for comments such as 'first lily in flower' or 'first day of corn harvest' and it is here that extremely valuable comments on the state of the thermometer are to be found. On February 26th 1802, the thermometer used by Losh was broken, sometime between 4 pm and 11 pm. Purchasing a new, good quality thermometer in the early nineteenth century would have been a time-consuming affair and Losh would have not wanted a large gap in his meteorological record. The manuscript is supplemented with data taken by Major Thain at Walker (in Newcastle upon Tyne), generally at 10 am. Losh must have obtained a thermometer from a friend temporarily while he awaited the delivery of his new one, for on May 21st 1802, a new one arrived:

> *'I put up a very fine new thermometer this morning in a north aspect. I find that my old one agrees with it very exactly.'*

It is possible that the new thermometer was delivered on April 15th and his employees, of whom there were many to tend the crops and look after the house and garden, took readings with it while Losh was away on business, but Losh would surely have recorded this if it was the case.

James Losh's brother William, one of 5 brothers of his, lived in Newcastle and also had a thermometer outdoors. Unfortunately, no records of this instrument can be found, and he may not have even written down observations, merely using it for interest. On March 10th 1803 James was at his brother's house where he observed that the temperature of the thermometer, at the same aspect as the one at Jesmond, read nearly two degrees higher. On February 2nd 1806, he makes an observation that the thermometer of William Hopper, living not 100 yards away from Losh himself, and therefore perhaps an employee, and in a westerly aspect gave a reading two degrees less.

The thermometer was again taken down on May 26th 1806 as it was in need of repair and was taken into Losh's dressing room. We assume that the repairs needed did not affect the accuracy of the readings as a comment on August 21st states

> *'This day the thermometer was again fixed in the open air in a north aspect - for some weeks it has only been exposed to the open air when inspected.'*

Some potentially worrying comments are noted in the summer of 1808, on May 13th and June 27th, where the thermometer is said to be in the sun. It is not clear whether this is because trees had been cut to allow the sun to reach the previously shaded thermometer, or whether it was common for the sun's rays to touch the instrument for a time during midday, the aspect being northerly, and this could raise the reading taken. However, the temperature recorded for the May date does not seem to be raised substantially above that of surrounding days. The day in June has a midday reading of 80 degrees compared with an average of 59 degrees for days either side. Aside from this, it was sometimes a practice in the nineteenth century to place a thermometer in full sun as a (false) measure of the power of the sun.

A further comment is noted for June 1817 when Losh states that his thermometer is not graduated higher than 71 degrees. This makes any temperatures higher than this rather more open to errors of observation. Obviously the observer would have been careful to read off the correct temperature but without graduations this could prove difficult for situations around and above 80 degrees. Having said this, the accurate recording of temperature was important to Losh and on occasions he would reinforce a suspicious reading with a second thermometer. One such situation was on February 5th 1818:

> *'February 1818 has been a cold and upon the whole a disagreeable month. At the beginning of it we had some very severe frost, and during the remainder of it, with very few exceptions, there has been a hoar frost every morning, though the thermometer has scarcely ever be so low as the freezing point, at the times when I observed it - Indeed it was certainly often freezing when the thermometer was at 33 or even 34, and thinking my own thermometer might be incorrect, I tried another also, which showed the same result.'*

He compared the temperature at his house with that at Benton and Point Pleasant in Newcastle on January 24th 1815 when there was an exceptionally low air temperature in the region of around 8 degrees. The difference in temperatures around the urban Tyneside area was of interest to him, here for June 1818:

> *'During the hot part of this month the thermometer was always 3 and sometimes 4 degrees higher in the shade at Newcastle than at Jesmond.'*

Unfortunately, he gives no details of where in Newcastle this measurement is taken but it would probably have been at his brother William's house, as this is mentioned elsewhere in the journal.

The summers of the years 1825 and 1826 were particularly hot, and many parts of the country suffered from drought. Losh's account of October 1825 and his summary of the year describes the situation and his solution to it:

'The month of October has been remarkably pleasant and favourable for the country. The weather has been mild with occasional refreshing showers, but no heavy rain, and only sufficient to refresh the country and encourage vegetation - Indeed wells and springs of all kinds are still more affected by the drought, and less abundant than they have been for many years past, and the ponds in this district are so completely dried up, that the waterworks both of Gateshead and Newcastle have failed to supply their customers sufficiently with water, and very great inconvenience has been suffered in consequence.'

and also,

'The heat was greater and longer continued this year than in any summer during my recollection, but as far as I could judge from my own feelings (and also from general observation) it did not produce the same relaxing effects which sultry weather in England generally does. The drought was severe for a time, and taught many persons (and whole districts) the great importance of an ample supply of water - I, among others, profited by this experience, and in consequence, I made a well (and put in a pump) which promises to secure me perfectly from want of water in future.'

And at the end of 1826:

'1826 has been remarkable for the heat and drought which commenced earlier, were more intense, and continued longer, than in any year within my recollection. I have before observed that many old persons mention a season similar to last summer about 60 years ago: but I have neither been able to make out the particular year, nor to obtain any detailed account of it.'

He was a keen observer of the weather itself, not only of the statistical observations of it. On June 19th 1804 a comment reads

'I observe tonight what I have often before taken notice of, that the thermometer rises in a great wind, when the air does not feel warm.'

Losh was a rather sensationalist observer as many of the notes in the manuscripts are those relating to extremes of temperature, and he was more interested in this measurement than wind direction or barometric pressure. Comments about untimely high temperatures are often made, particularly if the thermometer rose after the 'maximum' reading had been taken at around 2 pm.

In addition to the details about the climate of Jesmond, some of the monthly and yearly summaries give interesting insights into life nearly two hundred years ago. A comment that Losh made for January 1814 is particularly interesting:

> *'The whole of the past month has been one continued frost - although the thermometer sometimes rose for a few hours above the freezing point yet there was never anything like an effectual thaw. The snow was a great thickness on the ground, and still continues so. In many places it drifted to a very great depth and whole lines of roads blocked up, but the average thickness appeared to be about 18 inches. The river Tyne has been for sometime frozen over so that a person might walk several miles, partly above and partly below the bridge at Newcastle. Many tents with liquor, fruit etc were upon the ice, and a great number of people were constantly skating or walking about upon it. The ice was I understand from 7 to 9 inches thick. This very uncommon frost has been general all over the kingdom, and was in the neighbourhood of London preceded by a very remarkable fog and darkness for several days. The snow is so thick that flowers cannot be seen.'*

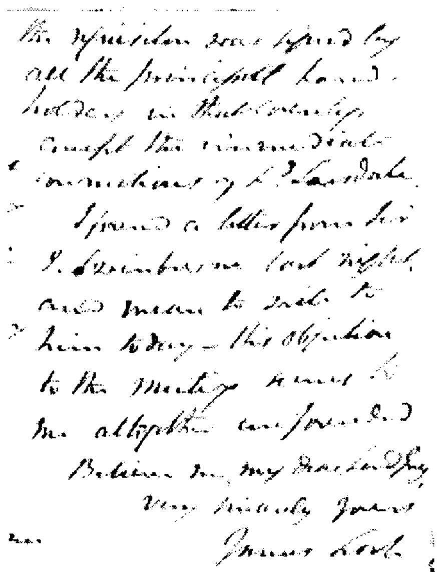
3.2.3 Who Took and Transcribed the Readings?

It is improbable that Losh actually took the hourly readings himself and it is also unclear whether it was he who copied the data into the ledgers; there is no information contained in the ledgers to indicate who took the readings and who transcribed them. By examining mistakes in the ledgers it is thought that on many occasions, if not all the time, the readings were taken and written on a separate piece of paper or notebook, being transferred to the ledger at a later time or date. On some occasions the order of the observations, normally wind, temperature, pressure, is different and the possibility of errors in this transcription cannot be ruled out. Occasionally, signs point to reasons for several days of data to be missed out. Between August 20th and September 4th 1810 there are no readings but August 19th has a single reading at 6 am. This could suggest that Losh was called away on business unexpectedly, taking the reading as he left early that summer's morning, but neglecting to tell one of his employees to check the thermometer during his absence. This is speculation of course, but can give clues to the practice of the running of Losh's estate and his day-to-day life.

Being an eminent lawyer and local politician as well as being involved on many committees, Losh would have spend much time away from his home, and this shows from summaries made at the end of each month. He always uses the first person singular in these short, usually single-sided accounts, of the preceding month and again at the end of each year. References are made to the weather in other parts of the country where he has been, London and Carlisle or mentioned extensively. He must have had friends and associates Europe-wide for he often compares the trends on weather, drought and wet spells with those in southern France. We know from reference to his diary that Losh was away from Jesmond Grove much of the time, and yet the readings generally continue without any breaks.

The handwriting used in writing up the daily readings changes at several points during the thirty years of records. From the beginning of the record until the end of 1827, the handwriting for the readings is the same as the handwriting of the notes on the facing pages. Figure 3.10 shows a page of the manuscript illustrating this handwriting. For the whole of 1828 the writing changes that is used to record the readings. The notes are still written in the old hand but the readings are written down in a much tidier fashion than before. From the beginning of 1829, and until the end of the record, the handwriting on both sides changes to a new style, both in the same hand. This writing is much untidier than that in preceding years; the numbers in particular are hard to distinguish.

Figure 3.12 shows an extract of a letter written by James Losh to Lord Grey on October 14th 1819. The handwriting in this letter is different from any exhibited in the meteorological manuscripts. One conclusion from the evidence available is that the letter is indeed in Losh's own hand, and he would have delegated an employee the task of taking the readings and then transcribing them into ledgers. The letter may also have been dictated. Losh would probably have supplied a summary of the month for the scribe to include, and it is possible that a different person took the readings from the one transcribing, but until the end of 1827 all entries were written by one person alone. This person continued writing in the notes while another wrote in the temperature readings for 1828. From 1829 a single person again, but different from before, carried out all the writing. It is possible that Losh's wife, Cecilia, was one of the transcribers, but the lack of any confirmed samples of her handwriting means this speculation cannot be confirmed.



… the requisition was signed by
all the principal land-
holders in that county,
except the immediate
connections of Lord Lonsdale.
I found a letter from Sir
J. Swinburne last night,
and mean to write to
him today – this objection
to the meeting seems to
me altogether unfounded.
Believe me, my dear Lord Grey,
very sincerely yours
James Losh

Figure 3.12 Extract of letter from James Losh to Lord Grey, probably in Losh's own handwriting.

In view of all the evidence, it seems a likely conclusion that Losh read from the thermometer from time to time, and may have left details for the transcriber to include text in the manuscript. A man curious enough about the weather to be concerned about the creation and maintenance of a thrice-daily meteorological record would surely have taken an interest in the readings of his thermometer, although not, it seems, in his other instruments as much. Perhaps this is because, as Manley thought, the thermometer was attached to the wall outside Losh's study making impulsive reading possible.

An analysis of the frequency of half-degree observations has been carried out to corroborate the theories of changing observers. There often appear clusters of these, and they are much more frequent early in the record. The frequency to which the observer(s) favoured taking a reading to the nearest whole or half degree has also been checked.

By examining the temperature readings, it is possible to identify trends in human nature. This sort of analysis can reveal changes in observer, because people have a tendency to take readings in a certain manner. It is for this reason that many observers in modern observatories allow no-one else to make the readings in case an error is introduced. It is often the case that observers will favour multiples of ten, such as 20°, 30° etc, and those such as 25° and 35° also occur more often. The observations from the manuscript show the whole multiples of ten favoured in preference to the final digits 9 and 1. To a lesser extent the digit 5 is favoured in preference to 4 and 6, as shown in Table 3.10.

Table 3.10 Final digit analysis for the Losh temperature data. All readings taken to a fraction of one degree have been excluded.

Final Digit	0	1	2	3	4	5	6	7	8	9
Before 1828	3275	2014	2671	2579	2405	2912	2566	2410	2537	2130
1828	121	92	124	88	117	97	77	105	108	92
After 1828	598	414	626	493	493	450	380	499	477	376
Total Occurrence	3994	2520	3421	3160	3015	3459	3023	3014	3122	2598

Shown graphically, this can be seen more clearly, as shown in Figure 3.13.

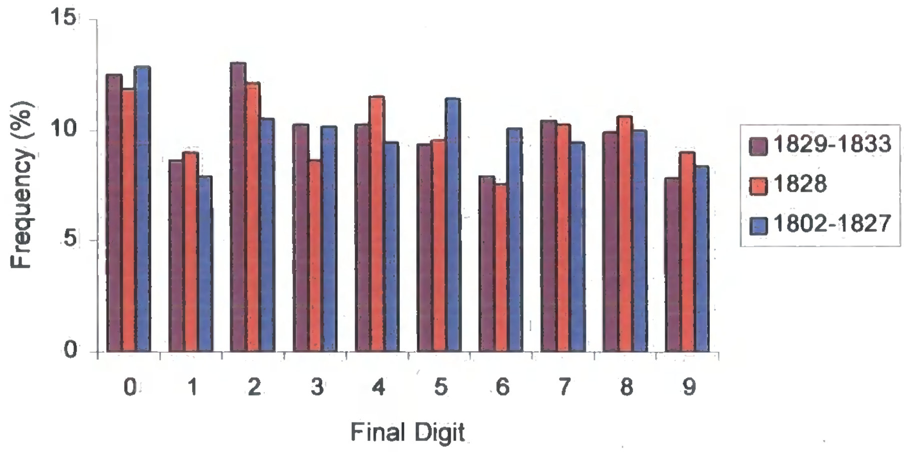


Figure 3.13 Percentage occurrence of final digits in Losh's temperature observations.

A chi-square test can be applied to this distribution in a similar way to that applied to the Brandsby data above. The statistic for the overall occurrence of digits yields a calculated value for chi-square of 521.5. The critical value, at the 0.01 level of significance, is 21.67, therefore, as with Brandsby, the null hypothesis that these readings occur by chance is rejected. When the test is applied to the three distinct periods above, the calculated values for chi-square are 461.5, 21.2 and 129.0 respectively, indicating the same conclusion for the periods before and after 1828, with the occurrence of digits for years before 1828 the least likely to have occurred by chance. For 1828 itself, the value for chi-square of 21.2 is only slightly less than the critical value of 21.67 for the 0.01 level of significance, but on this basis the null hypothesis that these readings occur by chance must be accepted. At the 0.05 level of significance, however, with a critical value of 16.92, the null hypothesis would be rejected.

Between 1827 and 1830, when the handwriting of the person recording the readings changes, there appears to be no obvious change in the occurrence of the different final digits in the data. The proportions remain fairly constant, suggesting that the person writing in the journal may not actually have taken the instrumental readings.

It can also be seen that although most readings were observed to the nearest whole degree, there are many occurrences of the readings being taken to the nearest half-degree. These appear more frequently towards the beginning of the manuscript, but not as often as would be expected from an observer taking readings purely objectively, as shown in Figure 3.14. The spread of final digits is not great enough to introduce significant errors into the monthly readings as they will be smoothed out by the averaging process, yet they still can cause some concern when looking at individual days.

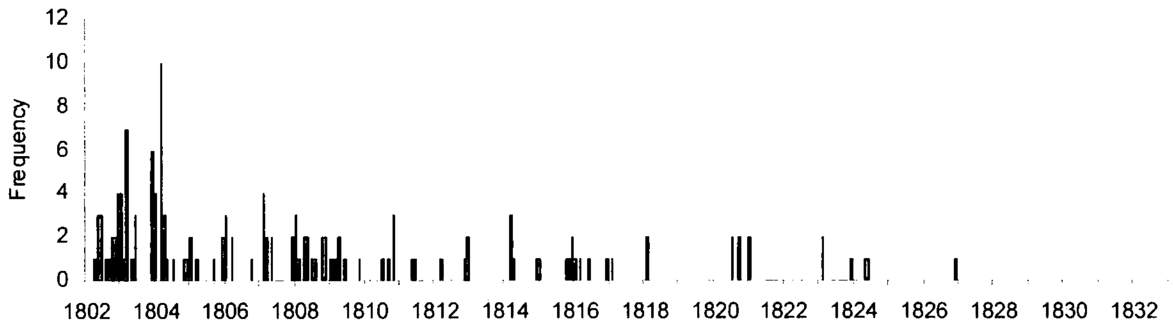


Figure 3.14 Frequency, by month, of occurrence of the temperature readings for each month that were taken to a half-degree accuracy.

The two people who wrote up the readings in 1828, and from 1829 to the end of the record, did not transcribe any half-degrees, although it can be seen from the graph that the frequency of this happening was decreasing anyway.

3.2.4 Summary of Data Series

Temperature observations available for the North East of England are generally very well made, some with more details of exposure than others. The records from South Cave, Jesmond and Brandsby each contain details of exposure that are invaluable in the interpretation of the readings. Even the shorter records, from Allenheads for example, were taken with great care, and their observations can usefully be employed in reductions of temperature for Durham as performed by Manley, described in chapter 4, and improved and updated versions, discussed in chapters 5 and 6.

3.3 Summary of Chapter Three

In this chapter the many sets of observations available for North East England and the Scottish Borders have been introduced. It is not an exhaustive list, but it contains and discusses all the data which are known of, and which would be useful in constructing a series for Durham University Observatory before 1843. A digest of data series for the region is not available elsewhere in publication. It is hoped that this list can be improved by the discovery and inclusion of other data sources which are suspected to exist. Further observations for York were available to Manley but now appear lost, despite much searching around their last known locations. The source for some data was discovered quite by accident, whereas for others the location was well known. Much time was spent digitising the data, and all is available on the CD-ROM attached to this thesis for further analysis.

Chapter 4 – Manley's Preliminary Work

Contents of this chapter

4.1 Material Known to Manley

4.1.1 Letters

During the last few years of his life, Gordon Manley sent a series of eleven letters to Joan Kenworthy (Manley 1978-). The first of these, which includes information on his climatological activities relating to the North East, was written on January 30th 1978, and the last on November 27th 1979, with Manley dating them in the style 27.xi.79, for example. The content of these letters relates mostly to his work on the 'Durham' extension, although some concentrate on other matters, and they also contain some general conversation.

At the time of writing these letters, Manley was living in retirement in the village of Coton, near Cambridge, and Joan Kenworthy was the Principal of St. Mary's College at the University of Durham. Their association had begun when she held a tutorial fellowship for 1959-60 at Bedford College, University of London, where he was then Professor of Geography.

The letters give a good indication of the chronology of the material with which Manley was working: which temperature records he hoped or intended to use, provisional temperature data etc. It can be seen from the letters that Manley worked in a very structured manner. He set out exactly what progress had been made, but rarely said how he got to the result. Information can be gained concerning his methods from the papers deposited at Cambridge, yet there is no indication of any chronological order among them.

It is a pity that he was not able to complete a 'final' version of his Durham extension, but he has left enough clues and evidence to allow reconstruction of what he did so that it can be fully appreciated. His letters indicated that he hoped that others would participate in meeting the challenges he identified.

A transcription of sections from Manley's letters that are relevant to his research, from early 1978 to late 1979, may be found in Appendix A. Where a word cannot be read, it is marked by the characters ***.

4.1.2 Manley's Progress – Evidence from his Letters

Within the 22 month period covered by his letters, Manley worked on the extension of the Durham temperature series back to 1801, his standardisation of the latter parts of the series already having been completed to 1940 (using his 'adopted means'). He updated the latter part of this series to 1978, making an adjustment to the method used (Manley 1.iii.79, 1980). Until 1958, he used the daily maxima and minima, together with the readings at 9 am and 9 pm, at which time the later reading was discontinued. In this year the maximum and minimum thermometers were read and set at 9 am as opposed to 9 pm.

His first few letters discussed the existence of manuscripts for northeast England. He knew that the local historical journals, such as *Archaeologia Aeliana*[53], had references to meteorological data, and also that local newspapers had a practice of printing temperature data. In 1.vii.78, he mentions the *Newcastle Journal* and the *Newcastle Courant* where he was looking for

[53] *Archaeologia Aeliana* was the journal of the Newcastle Archaeological Society.

temperature data printed as monthly or yearly summaries for the benefit of readers. He later said that the 1840s were lacking in temperature information. He also made the comment that

> '*I am still defeated by the task of extending the Durham Univ. Obsy. Record further*'
> (Manley 1.vii.78)

Three months later, he seemed to be more optimistic about the prospect of extending the Durham record. He wrote a detailed letter putting into context his work on the adopted means, and on creating a long series for the North East of England. On his previous work he says:

> '*...it did provide a "University" record to accompany the senior one (Oxford, Radcliffe Obsy. since 1815), and to lie in between Oxford and Edinburgh. It has since been regarded as a "base" for "North East England"*' (Manley 27.ix.78)

Over the previous few months, he had been looking at how it might be possible to use a set of other manuscript temperature archives that he had known about for some time. He knew also that, although the Observatory would not have started serious astronomical observations until 1843, when measurements were made to determine its latitude (Whiting 1932), meteorological readings were being taken before this date. Indeed, the first observer was Rev. Temple Chevallier (also Professor of Mathematics and Astronomy at the University), who held this position from June 16th 1840, together with his assistant John Stewart Browne. It is assumed that Manley was aware of the variety of early astronomical observation journals which were kept at the Observatory, and are held now at the Palace Green Library of the University of Durham. These show various readings from 1840, with observations made generally at night to help with the calibration of the instruments. There are few readings that would be of any use to extend the series.

> '*If Chevallier had sent in his year complete, much effort would be saved. Incidentally he was reading instruments now and then as early as 1841, which must, I think, have been the year the building was complete.*' (Manley 3.vi.79)

Living some distance away from the North East, Manley was keen to get help in his search for data. On several occasions in his letters he asked Joan Kenworthy whether she could help him.

> *'But now comes the question that you might take an interest in! How to extend backwards!'*

> *'Would you like to see if you can get any of the monthly or yearly summaries for the University Observatory out of the files of the Durham Advertiser?'* (Manley 27.ix.78)

He asked whether Joan Kenworthy would be able to research any temperature information published in the *Durham Advertiser*, a weekly paper covering Durham City and the surrounding area. She located, in a limited range of papers kept in the *Durham Advertiser* offices, means for part of 1842 (from May 15th 1842), and for most of 1843 (to December 27th), as weekly summaries rather than the annual ones that Manley had assumed. The Durham Advertiser started publishing in 1814, and he speculated whether there was any earlier data (Manley 3.vi.79). Manley assumed that the *Durham Advertiser* was printing monthly summaries (Manley 8.viii.79), as Manley asked whether it would be possible to revisit the Durham City Library to obtain several notable months between 1844 and 1846, presumably to corroborate observations from other series that he had.

Manley was aware of a number of other meteorological readings for the North East, including the 'Losh' record in Jesmond from 1802, which he had known about 'for many years' (Manley 27.ix.78). On the data recorded by Losh:

> *'Now Losh has almost 32 years of these monthly tables, very well entered, and NO ONE HAS EVER TOTTED THEM UP!'* (Manley 27.ix.78)

He had been to the library of the Newcastle Literary and Philosophical Society, where the original manuscripts are stored, on at least one previous occasion to look at the daily extremes for any evidence of remarkable exposure, although he found these to be 'unexceptional'. He also made a comment about the hours of observation, and on the relationship between data observed in Jesmond and in Durham:

> *'The mean temperature, based on good readings at 9h/14h/23h gives a pretty close approximation to the conventional max+min/2'*
>
> *'Durham (336 ft) is probably about 0.6 °F cooler than Jesmond (ca. 150 ft)'* (Manley 27.ix.78)

However, his assumption that the readings were taken at these hours was correct for less than 20% of the record, something that he would later realise and correct.

> *'Now the real nuisance is before that. For 1802-1811, he used different hours, and left a number of "odd days" out, I completed one or two "sample" months... I'll have to come up again sometime when I can ... to add a few more years for temperature.'* (Manley 9.ix.79).

These hours do apply for the period from 1812 to 1818, for which Manley already had means available to him as a result of Losh making his data available to Nathaniel John Winch (1768-1838), a botanist, studying climate of the area[54]. Winch calculated monthly means from Losh's observations, and published them in a paper titled *Geographical Distribution of Plants in the Counties of Northumberland, Cumberland and Durham* (Winch 1819). Winch sent a copy of these means to Losh, who submitted them to the Newcastle Literary and Philosophical Society who in turn published them in their *Transactions*. Heinrich Wilhelm Dove[55], who produced a

---

[54] Winch was also secretary to the Newcastle Infirmary, and in 1805 the Sheriff to the city of Newcastle upon Tyne. During his lifetime he amassed a herbarium of 20,000 plants (FENSCORE 2002)

[55] When Dove died in 1879, the journal *Nature* in its obituary referred to him as the 'father of meteorology'.

world map of mean monthly temperature, obtained these means and published them also (Dove 1838, 1853).

Manley was sure that he could extend the series backward to at least 1794.

> *'Between one thing and another, I think one can continue the old Durham "adopted means" with but little adjustments: - and perhaps extend them to 1794-1978!*
>
> *But I really don't see any sound way of adding anything to Durham before 1794, and even is a big stretch, the chief reason to attempt it is the exceedingly severe winter of 1795 and the very mild 1796'* (Manley 27.ix.78)

From his letters and papers, it can be seen that Manley's approach was that the Losh record should form the central basis of his extension for the Durham series from 1847. Much of his work consisted of finding other records which could be used to fit the period between the end of the Losh observations and the beginning of the earliest Durham data, as he knew it to be, in 1847[56]. He saw the period from 1833 to 1847 as a 'gap' that had to be 'bridged'. He was less concerned with finding data that could be used to supplement the Losh observations from 1802 to 1833, but was interested where the 'bridge' series overlapped such that comparisons could be made between them.

> *'In order to provide an "overall control" for the "N.E. England" temperatures, over the gap from the end of Losh to the beginning of Durham Obsy, there are "North East England (inland)" records that permit a "bridge" at either end. The best is Ackworth, 1824-1852. There's also York (1831 onward) but I'm having great difficulty finding any York before 1841. There's an earlier York set, 1801-1824, that inadequately overlaps Ackworth. To the north, Edinburgh is too far off. Kelso also lies inland, and is possible, but I've only found 1841-45 so far.*

[56] For 1847, Manley calculated the monthly means using quarterly records submitted by James Glaisher on behalf of the *Registrar-General's Quarterly Return of Births, Marriages and Deaths.*

Keighley (Braithwaite) is another v. fine Quaker record for which the thermometer obs. seem good from 1809-1857: but it is 750 feet above sea level, and quite a long way from Durham, altho' generally in better accord than York or Ackworth. Inland from Hull there are some fragments, notably one that might enable a few odd years to be added that covers 1794-1814[57]*.'* (Manley 27.ix.78)

He spent the first three months of 1979 working on extending the reduction for Durham University Observatory by continuing his 'adopted mean' calculation[58]. During this time he also worked on his Moor House temperature series in Upper Teesdale, but from June 1979 he appeared to spend considerably more time on extending the Durham meteorological series, principally to deal with the gap between the Losh archive and the existing Durham series (i.e. 1833 to 1847).

In the ensuing months he visited Newcastle twice more (reported in 8.viii.79 and 9.ix.79) to obtain the mean monthly temperatures from the Losh ledgers, adjusting them and combining them with other series: by November 5th he had made an extension representative of Durham as would be expected under Stevenson screen exposure. In his letters, he outlined the records available for spanning the 'gap' between 1833 and 1847 and showed that he had reached a tentative initial version for these years.

Several of the later letters include rough tables on what data he considered to be available and useful for his 'gap'. In March 1979, his list included records from Cumbria.

[57] The series Manley refers to from 1794-1814 is that observed at South Cave, 17 km west of Hull.

[58] The calculation of adopted means is a method of reinforcing one set of observations at one site with reference to another set of observations at that same site. Usually whereas temperature at a site is calculated from the mean of the daily extremes, this mean plus a component of the fixed hour observations is often taken as the daily mean (e.g. Glaisher 1867, Manley 1941b). This is discussed further in chapter 5 with analysis of the Durham data from 1843.

Ackworth 1824-1852

York 1841 onward (possibly from 1832, uncertain and troublesome)

Makerstoun 1842-1849

Kelso 1841-1846

Braithwaite above Keighley, 1809-1859, rather high up and more distant

Kendal 1823-1851, homogeneous, wrong side of Pennines

Carlisle 1835-1850, homogeneous but potentially useful

(Manley 1.iii.79)

Three months later, he outlined a different set of series that he considered viable, still including Kendal in this list, but dropping Carlisle.

1) Ackworth 80 miles SSE : Luke Howard's series running from 1824-1850 (perhaps 52)

2) York 60 m SE by S : John Ford 1841-1852 (and later) but with a break in 1845 (change of location) and 1848 (instruments). [There are also averages for each of the months for the period 1832-33].

3) Kendal 60 m SW : Samuel Marshall: a full series 1823-60 almost homogeneous

4) Keighley (Braithwaite) : Abraham Shackleton ms 1798-1857 65 miles SW

5) Edinburgh 100 m NW a very carefully reduced table (1764-1896), but pretty distant

'There are also some shorter records in the Border Counties – none right through the gap; and one in Yorkshire for 1831-40 that I haven't yet examined[59] *(if I can find it). Also I might run Allenheads to earth on my next visit to Newcastle: it covers 1836-1876*[60]*. Ackworth is a less perfect record than I hoped; York is troublesome; Kendal is across the Pennines. Edinburgh is not only a long way off but I want to avoid using it if I can, and keep "Durham" independent.'* Manley (3.vi.79)

[59] It is not clear what this series is for 'Yorkshire' 1836-1876. He may mean 'York'.

[60] Observations at Allenheads have only been found for 1837 and 1839-1842 (Walton 1838, 1840, 1841, 1842, 1843). In his next letter, dated 8.viii.79, he stated that only '1842 and perhaps 1844' were available.

The method that Manley used to determine whether to use these series was to examine anomalies from the mean for sections of the series either side of his 1833-39 'gap'. Before the gap, he considered Losh and Brandsby means, comparing these with means for Keighley, Ackworth, Lancashire and Edinburgh. After the gap, he considered data from Durham University Observatory for 1847-1856. He took the mean of these two sets of anomalies to give a set of means for 1833-1839.

> '*I've been slogging out the departures for each month for each of the above series, to north, south, and west of Durham and I get the "provisional monthly means" on the enclosed sheet. But: they're pretty dicky; the deduced values from each of the series quite often departs from the others, sometimes one can suspect instrumental faults.*' (Manley 3.vi.79)

He revisited Newcastle (Manley 9.ix.79) to calculate monthly means for 1802-1829 (excluding certain months he already had, and 1812-1818). It was on this visit that he noticed that the hours of observation are not the same throughout the record. This letter was the last that he sent before compiling monthly means for 1833-1847, when he began to place less reliance upon the observations technically out of the North East region (i.e. those he used in his 'Lancashire' series).

> '*The possible "overlaps" to Durham (independent of Edinburgh) are to be found in the records from Ackworth, Keighley, York; (Applegarth (Dumfries), Carlisle, Kendal beyond the Pennines) and partly from Makerstoun (Berwickshire)*'. (Manley 9.ix.79)

Over the next month, Manley completed the reduction of monthly means for 1801 to 1850. The period 1802 to 1833 was based upon Losh's observations, together with reference to decadal means from Brandsby. He also stated his assumed hours for Losh's times of observation.

> *'The table 1801-1850 herewith is made up of:- the reduction to Durham, for 1802-1832, of Losh's MS from Jesmond (Newcastle), 3 readings daily, mainly 8h/16h/23h for 1802-1805. Then 9h/15h/23h for 1806-1811; thereafter, 9h/14h/22h.'* (Manley 5.xi.79)

He later corrected these assumptions once more to his final version[61].

> *'I found that Losh, through 1812-1818 Jan, observed at 9h/14h/23h, not 9h/14h/22h. I had taken his figures from those already published by one of these characteristic North-East-Coast botanists (called Nathaniel Winch, who used them in a paper of his in 1819). This makes a tiresome little adjustment; and I also spotted the need for a little amendment in 1833.'* (Manley 27.xi.79)

Edinburgh and Lancashire still formed part of the extended series, for 1833-1839, despite his various comments that Edinburgh is 'much more distant' and 'of which I have some little doubts'. Despite saying 'I want to avoid using it [Edinburgh] if I can', he seemed resigned to drawing upon it, stating that for Edinburgh and Lancashire

> *'I think they must be used to provide an "overall control", that is the fluctuations of the decadal means, and perhaps the annual means at Durham, after all reductions have been made, showed "fit" with Lancashire and Edinburgh.'* (Manley 5.xi.79)

His last digest of the observation sets available to him was outlined in his letter of November 5th 1979, and is a virtually complete list of all the series that have data at some point between 1833 and 1839.

1) *Durham Advertiser: a) close estimates based upon bits of about 5 months in 1842. b) nearly all of 1843*

---

[61] The hours of observation that Manley assumed were quite general, with some years providing a better fit to his assumption than others. Section 5.2 shows how close his assumptions were.

> 2) *Published means for the five-year mean for Jan. Apr. July. Oct. for 1843-47 (found in Phillips' "Yorkshire", 1853)*
> 3) *Yarm for 1840 and 1842: obs. At 8h 12h 16h 20h daily capable of reduction*
> 4) *North Shields 1842: Middlesborough 1841 and 1842: Allenheads 1841 and 1842 (dubious)*
> 5) *York 1832 onward; careful, but in sheltered position; change to more open site end 1846. At Yorks. Philosophical Society*
> 6) *Ackworth 1824-1850. Occasionally suspect.*
> 7) *York 1800-1824: 8 am only; and very sheltered. Wykeham, inland from Scarborough 1831-1836*
> 8) *Keighley 1800-1857: 10 am only and "indoors" until 1809.*
> 9) *Kelso said to begin 1832 but not found until 1842*
> 10) *Makerstoun nearby, 1841-1855, but local change in 1849*
> 11) *Abbey St. Bathans 1835-1839, (Hawick & Cresswell-Twizell in Northumberland in 1840s rejected.)*
>
> *West of Pennines Kendal 1823-1869, Carlisle 1802-1824, Applegarth (Dumfries) 1827-1851, All these have been incorporated in my "Lancashire" reduction.* (Manley 5.xi.79)

The set of archives that Manley knew of was still expanding as he worked in late 1979. He had mentioned the data from Hull (South Cave) on several previous occasions and visited there just before November 27th. He mentioned in his letter of November 5th 1979 that the series from Brandsby ran from 1811 to 1830, but made no mention of any other component of this data. In his final letter (November 27th 1979) he makes the comment

> *'I went back via Hull. They're going to provide us with microfilm to photocopy 1794-1803.*
>
> *After that another visit to Northallerton County Record Office will enable me to "top off" to 1784.'* (Manley 27.xi.79)

This reference to 1784 is probably to the earlier section of the Brandsby series, from late 1783 to September 1791, although Manley was not explicit about this. Nowhere in any of his other letters, nor in his papers, did he mention the existence of this earlier series. It was presumed that his earliest record was that from South Cave, starting in 1794. Microfilm photocopies of this latter series are present among Manley's boxed notes, and they are annotated by him; hence he clearly received them before his death in January 1980. There is no evidence from the notes that he worked on the data other than calculating monthly means, for which a sheet shows his summation of the single daily observations, the number of observations per month, and his calculated mean.

Over the course of the letters, Manley indicated more frequently the pace of his work and the motives behind his inclusion of the tables he was working on. He was never explicit in his reasons for this, but in a letter in autumn 1979 he included the 1821-32 Losh data with the comment

> *'anyhow this is all for reference ... don't bother to reply, it can wait.'* (Manley 9.ix.79)

and then in his next letter

> *'... I feel the work shouldn't be wasted and it will be quite a time before I can get it all completed and written up. So, this isn't yet for publication, merely retention!'* (Manley 5.xi.79)

His last letter of November 27th 1979 was marked 'personal' and included the 'final' version of his Durham data, along with the comment

> *'Hence this provision on my part of a copy of the earlier table that I sent, revised for those years, this is merely an insurance, in case of loss!'* (Manley 27.xi.79)

He also sent a copy of this table to Professor W. B. Fisher, then head of the Department of Geography at Durham University. It has been assumed that Manley was some way from completing the extension and reduction for the Durham University Observatory, when considering his comments on publication shown above. However, he was already looking towards the end of finishing the work on temperature:

> *'Rainfall I must next start on, and the obs. around 1848-1850 are quite a dreadful puzzle ... But I want if possible the annual summaries for 1844,46,47,48 and 49, if they were published in the Advertiser'* (Manley 27.xi.79)

Manley wrote with handwriting that can be quite difficult to read, and he often used coloured pens in his notes to write over existing text or calculations to add updates or alternatives, meaning that the original copies must be examined to make sense of what he was doing, rather than photocopies. Even then it is not always clear in which order text was written, and certain words and numbers remain unintelligible.

4.1.3 Papers

After Manley's death, his widow Audrey deposited a collection of papers in Cambridge University Library regarding all aspects of his work (Manley 1938-). The manuscripts were initially uncollated, but were grouped together by Gillian Sheail by subject into six large cardboard boxes. Box number three relates to Durham, although there are many general notes and references to Durham archived in the others. The great majority of the work material within the 'Durham' box is handwritten, and very difficult to read and interpret given Manley's practice of using a sheet of paper to its full potential. While this is admirable, it makes deciphering a sheet of notes in small handwriting, and up to four different colours of ink superimposed upon each other, very difficult, in terms not only of reading but also of setting each fragment in chronological order. Nevertheless, much information can be extracted from Manley's papers regarding archives which he was considering using and trials of possible corrections. Among all the workings and writing, nothing is crossed out, but many sections have comments such as 'this trial gives unsatisfactory results'. Some of his notes are very useful, whereas others prove to be just rough workings that were later superseded. On the back of a large brown envelope, he gives some corrections applicable to the Losh series, in order to bring the means calculated from the fixed hour readings to the 24 hour mean, then to the mean of the daily extremes, and finally to a mean appropriate for the difference in altitude between Jesmond and Durham.

Suggested Smoothed Calculations

to the Losh means

a) a 'mean of day' for Losh, and then M+m/2,

and then to Durham (a further –0.5): all in °F

Smoothed			
-1.0	*J*	*-1.0*	
-1.2	*F*	*-1.1*	*But from the yearly*
-1.8	*M*	*1.2*	*means Lancs/Edin*
-2.8	*A*	*1.5*	*it looks as if these*
-2.5	*M*	*1.7*	*corrections should*
-2.0	*J*	*1.7*	*(overall) be 0.5° more*
-2.0	*J*	*1.7*	
-3.0	*A*	*1.7*	
-3.0	*S*	*1.6*	
-2.5	*O*	*1.5*	
-2.0	*N*	*1.0*	
-1.2	*D*	*1.0*	
		16.7 (1.4)	

On a separate sheet of paper, Manley considers the fixed hour observations of the Losh record, and how Losh tended to follow patterns of observation hours over the years of his record.

During 1811 Losh observes at 9 15 23 until May 15

May 16 9 14 22 ... but mainly 23

But this is rather irregular, quite often 16h, same 15 to 18; usually 23

in June-July, early Aug

Dec. mainly 9 14 23 : but Aug, Sep, Oct, Nov. 9 14 22

On several occasions, Manley noted down 'to do' lists on new pieces of paper. Although they are not dated, details in them can be cross-referenced to progress that he indicated in his letters, and a sense of when he wrote the notes can be derived.

To do next

1) Tabulate 1802-1830 From Losh/Brandsby

*(Keighley pretty ***) (***[62] also Keighley) (Lancashire or Kendal)*

2) Add 1800/1801 from Early York, and perhaps Edinburgh

Later, bring in Hull (S. Cave). (Lancs?)

Manley was about to tabulate the period for 1802 to 1830, so he must have been writing this list at some point between the two letters dated 9.ix.79 and 5.xi.79. He went on to show how he derived 1801, although not 1800, despite stating that this needed to be done in his list.

Evidence from Manley's notes was gathered to determine the methods he used. In general he worked on distinct groups of years at a time, and he was quite explicit about what he was working on in his notes, even if the actual methods and calculations appear quite unclear. Each period has been examined in turn, widening and narrowing the bounds of each set of years in order to find the length of time over which Manley applied a certain correction. This sort of work can be considered easier using computer software to apply corrections to sets of data, something which Manley did not use. Frequently, a potential set of corrections yielded results almost matching Manley's final series, but not close enough for a good match. The corrections

[62] It is not clear what these two words are.

were rejected and his notes re-examined for any further clues. A certain amount of judgement has been applied to determine if the anomalies from a set of corrections are due to arithmetical errors on Manley's part, or resulted from his 'tweaking' of the values in an intuitive manner.

4.2 Manley's Methods and Results

4.2.1 Introduction

Given that Manley's notes are in no particular order, the handwriting at times is very difficult to read, and he often wrote over his tables of calculations, something that would have made sense to him at the time of writing, but makes deciphering the order of his work is very difficult. Traces of his methods from each set of years can be discerned, however, and generally it has been possible to piece together the evidence to arrive at the method that he used, although it is not always clear why he chose that method and rejected others.

From his notes, it is apparent that Manley spent some time checking the hourly corrections at Greenwich, Kew and Rothesay against each other to see how the overall corrections for certain hours of observations compared. Figure 4.1 shows a section from just one of the sheets where he compared the adjustments.

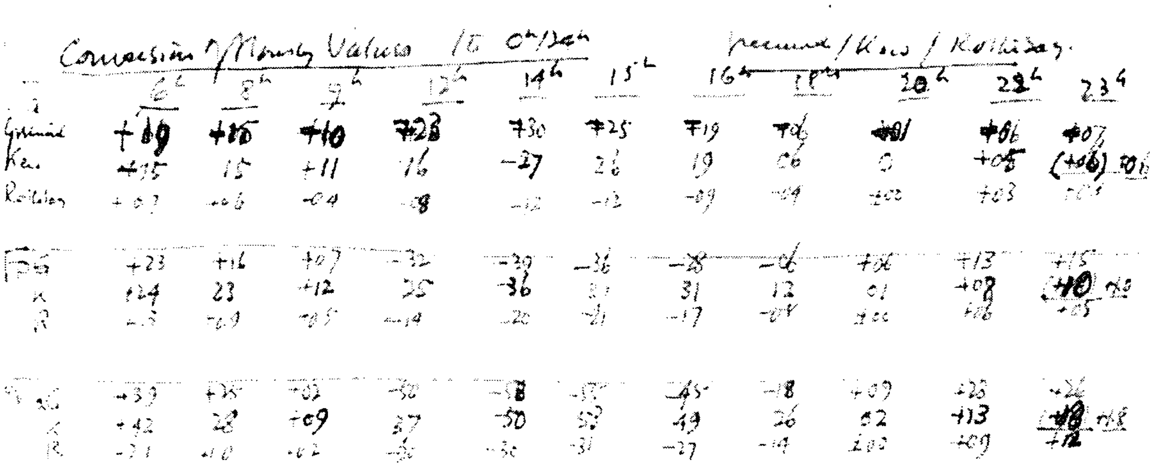


Figure 4.1 Manley's comparison of adjustments to fixed hour means from corrections based on observations at Greenwich, Kew and Rothesay (°F).

Manley grouped sets of years together to form manageable chunks, whenever a common set of observations could be used as their source. In some cases, later in the period, he started off with a single year in isolation, reflecting the shorter periods for which each of the sets was available. He brought the monthly means together for his final versions of the tables, which he sent with his letters to Joan Kenworthy dated 5.xi.79 and 27.xi.79.

In the following sections, each set of years that he treated in a similar way will be described in terms of Manley's handling.

4.2.2 1802-1805

Manley based the period 1802 to 1805 largely on James Losh's temperature series from Jesmond, where for this part of his record the observations were generally made at 8 am, 4 pm and 11 pm.

A note from Manley's papers shows the corrections he made to this period based upon the hours of observation from the manuscript. He often wrote such corrections in units of tenths of a degree Fahrenheit.

'1802-05

9/14/22 <u>Deduct</u> to give 24h :-

-05	*-06*	*-11*	*-20*	*-21*	*-25*	*-18*	*-20*	*-16*	*-10*	*-06*	*-03*

8/16/23 add/subt

+01	*+01*	*+02*	*-02*	*-09*	*-08*	*-05*	*-01*	*00*	*+04*	*+01*	*+03*

To bring 8/16/23 to

equivalent of 9/14/22 add

+06	*+07*	*+13*	*+18*	*+17*	*+17*	*+13*	*+19*	*+16*	*+14*	*+07*	*+06*

From York it certainly <u>looks</u> as if 1802-1805 emerges about <u>0.9°F</u> below what one would expect from <u>1807-1810</u>. This corroborates the Edin/Lancs suspicion and leads one *to think that there is something wrong with the 8/16/23 reduction, which has the effect of being too great'*

and from the same sheet

'Kew8/16/23 are below 9/14/22 by

05 06 08 10 10 10 10 11 12 11 08

05 year –09

Greenwich 06 07 13 18 17 17 13 19 16

16 07 06 year -13

This illustrates the difference made by a screen added to the wall

Nevertheless we need to add even more to the 1802-05 obs.

to get results that will fit with Lancs/Edin/York. Suggest

an average of 2.0 on the year ranging approx 1.2 to 2.6?'

However, and this was very typical of the way that Manley worked, he calculated a set of corrections and applied them, but then decided that the results that they gave were not correct.

'1802-1805 Nov. Basis 8-16-23 here: but the results come too low by about 0.5

or even 0.8 over the year

(1806 might be reasonable over the year

- hard to say)

1807 to 10 might be reasonable though'

The corrections that Manley used for this set of times, first to means representative of 24 hour readings, then to the mean of daily extremes, with his altitude corrections, are shown in Table 4.1. Also included are the corrections based on reference to the later decadal means of the Brandsby series from 1811 to 1820.

Table 4.1 Initial corrections that Manley applied for Durham to the period 1802-1805 to fixed hour means derived from observations by Losh (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hours & Altitude	-0.2	-0.2	-0.2	-0.2	-0.6	-0.9	-0.8	-0.4	-0.3	0.3	0.0	0.0
Decadal Means	0.4	0.4	0.5	0.7	0.8	1.0	1.0	1.0	1.0	0.7	0.5	0.4
Total	0.2	0.2	0.3	0.5	0.2	0.1	0.2	0.6	1.7	0.4	0.5	0.4

These corrections are general because Manley made slight deviations from the second line above, depending on whether he thought the correction was right. In general, the deviation is only 0.1°F but Manley made no note that explained why he made these deviations. Elsewhere, there are comments simply referring to individual monthly means being 'too high' or 'too low'. The full set of corrections from the basic Losh data to Manley's final series is shown below in Table 4.2.

Table 4.2 Final corrections made for Durham to means derived from fixed hour readings from observations made for 1802-1805 (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1802	0.2	0.0	0.0	0.0	0.0	0.1	0.1	0.5	0.8	0.9	0.6	0.4
1803	0.2	0.1	0.3	0.7	0.2	0.1	0.2	0.7	0.6	1.0	0.5	0.4
1804	0.2	0.1	0.3	0.5	0.2	0.0	0.3	0.5	0.7	1.0	0.5	-0.3
1805	0.2	0.2	0.3	0.6	0.2	0.1	0.2	0.7	0.4	1.1	0.5	-0.3

4.2.3 1806-1811

For the six-year period from 1806, Manley used Losh's observations as the basis, together with some reference to the Brandsby decadal means. He initially derived a series reduced for the altitude at Durham based upon the Brandsby data alone, but did not base any of his years upon this, choosing instead to make use of the Losh observations with an adjustment based upon the adjusted Brandsby means. For these years, the temperature readings at Jesmond were generally taken at 9/15/23, although it seems that Manley made an incorrect initial assumption that the readings were taken at 9/14/23. The corrections that he made in his final version did reflect the hours that observations were made for the majority of this period. The data from Brandsby do not actually start until 1811, but it appears that Manley extended back to 1806 the corrections derived from the decadal means from those data.

> *'1811/1830*
>
> *Take out the Brandsby monthly means, from 9/14/23 to M+m/2*
>
> *Derive Durham from them and see if it fits tolerably with Durham derived from Losh'*

Table 4.3 shows the set of corrections that Manley used to gain values representative of Durham University Observatory.

Table 4.3 Corrections applied for Durham to Losh's fixed-hour observations for the period 1806-11 (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hours & Altitude	-0.6	-0.8	-1.3	-1.9	-2.1	-1.4	-2.1	-1.9	-1.7	-1.1	-0.8	-0.4
Decadal Means	0.1	0.1	0.2	0.7	0.3	-0.7	0.3	1.3	0.3	0.3	0.3	0.1
Total	-0.5	-0.7	-1.1	-1.2	-1.8	-2.1	-1.8	-1.6	-1.4	-0.8	-0.5	-0.3

4.2.4 1812-1818

Manley did not calculate monthly means for the period from 1812 to 1818, but relied upon a derivation of the means for the period by a contemporary. Nathaniel John Winch, as described above, wanted to examine the trends in climate over recent years and calculated monthly means from the observations for the 1812 to 1818, as shown in Table 4.4.

Table 4.4 Winch's published means, taken from Losh, for 1812 to 1818 (°F). All of these means were calculated to the nearest ¼°F.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1812	36.5	40.75	37.5	42	51	56.75	57.75	58	55.75	49	42	37	47
1813	36.75	43.25	45	47	52.75	56.5	60.75	58	56.5	47	40	39.75	48.6
1814	28.5	35.75	38.5	50.25	47.75	53	60.5	60.5	56.25	48	41.75	38.5	46.6
1815	33.5	43	43.5	46.5	53.5	57.25	58	59	56.5	50.25	43	33	48.1
1816	37	36	37.5	41	48.75	54.75	56.25	56.75	52	44	39.25	36.75	45.1
1817	40.5	43	41.5	46.25	49	57.75	57.25	55.75	55.25	44	45.75	35	47.6
1818	38	32	38.5	42	51	62.25	63	58	55.5	53.5	48.75	40.75	49.5

Manley inserted these calculated values straight into the extension with an adjustment for the conversion to the mean of the daily extremes, and altitude, with some additional corrections presumably based upon his impression that some of the means were too high or too low. No supporting evidence exists in his notes of why he made these corrections, but the entire set of amendments can be derived by taking the difference between Winch's means, and Manley's final version of his reduction, as shown in Table 4.5.

Table 4.5 Total corrections made by Manley to Winch's means reduced from the Losh observations from 1812 to 1818 (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1812	-1.1	-1.2	-1.5	-2.1	-1.9	-2.2	-1.8	-1.8	-1.1	-1.2	-1.4	-1.0	-1.5
1813	-1.2	-1.1	-1.5	-2.0	-2.0	-2.1	-1.8	-1.8	-1.2	-1.2	-1.4	-1.0	-1.5
1814	-1.1	-1.2	-1.5	-2.1	-2.0	-2.1	-1.7	-1.9	-1.0	-1.2	-1.5	-0.9	-1.5
1815	-1.1	-1.1	-1.5	-2.1	-2.0	-2.1	-1.6	-1.7	-1.0	-1.1	-1.4	-0.8	-1.5
1816	-1.2	-1.2	-0.7	-0.7	-2.1	-2.3	-1.6	-1.8	-1.0	3.8	-1.3	-1.0	-0.9
1817	-1.1	-1.1	-1.5	-1.9	-1.9	-2.3	-1.7	-1.8	-1.0	-1.3	-1.3	-0.9	-1.5
1818	-1.2	2.8	-1.6	-1.2	-2.3	-2.5	-2.0	-1.1	-0.3	-1.5	-1.4	-1.1	-1.1

Some of the corrections for individual months, shown in Table 4.5, are substantially different from the overall trend shown across those months for other years, and for the year as a whole. Manley's correction to Winch's mean for February 1818 was 2.8°F, compared with the average for February, excluding that year, of -1.15°F. A similar correction was made to October 1816. It is probable that Manley was exercising his judgement that Winch had made an error in his calculations, but there is no confirmation for this from his notes. After calculating his means for 1812 to 1818, Manley seemed uncertain of their accuracy and planned to make adjustments. It is not clear whether the adjustments from Table 4.5 that differ from the monthly corrections for other years were made as a result of his reference to observations at Brandsby.

> *1811-1820* *For the years 1812-18, I have relied too much on the Dove reduction.*
> *Might be reasonable to adjust by Brandsby a bit.*
> *But it would be preferable to take out from original MS. [Note I have done Oct 1817 and June and July 1818 and Nov 1818: check]*

4.2.5 1819-1820

From 1819 to the end of the availability of Losh's observations, Manley's corrections are more straightforward as he assumed all readings to be taken at 9/14/22. 1819 and 1820 are grouped together because Manley, when using decadal means from Brandsby to check the data, used 1811 to 1820, then 1821 to 1830, these two groups of years together being the complete availability of the Brandsby data. Manley's final corrections are given in Table 4.6 below.

Table 4.6 Corrections applied for Durham to Losh's observations for the period 1819-20 (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
To 24 hr means	-0.5	-0.6	-1.1	-2.0	-2.1	-2.5	-1.8	-2.0	-1.6	-1.0	-0.6	-0.3	-1.3
To daily extreme mean	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
For altitude	-0.5	-0.6	-0.6	-0.4	-0.5	-0.4	-0.8	-0.4	-0.6	-0.6	-0.6	-0.5	-0.5
Decadal means	-0.4	-0.2	-0.1	-0.1	0.1	0.2	0.4	0.1	0.7	0.1	-0.3	-0.4	0.0
Total correction	-1.2	-1.2	-1.6	-2.3	-2.3	-2.5	-2.0	-2.1	-1.3	-1.3	-1.3	-1.0	-1.7

4.2.6 1821-1830

This period is very similar to that for 1819 to 1820; the Brandsby correction is different because Manley used the decadal mean for 1821-30 for this section. Table 4.7 shows the corrections in full.

Table 4.7 Corrections applied for Durham to Losh's observations for the period 1821-30 (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
To 24 hr means	-0.5	-0.6	-1.1	-2.0	-2.1	-2.5	-1.8	-2.0	-1.6	-1.0	-0.6	-0.3	-1.3
To daily extreme mean	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
For altitude	-0.5	-0.6	-0.6	-0.4	-0.5	-0.4	-0.8	-0.4	-0.6	-0.6	-0.6	-0.5	-0.5
Decadal means	-0.2	-0.3	-0.1	0.0	0.1	0.3	0.4	0.3	0.3	-0.1	-0.2	-0.4	0.0
Total correction	-1.0	-1.3	-1.6	-2.2	-2.3	-2.4	-2.0	-1.9	-1.7	-1.5	-1.2	-1.0	-1.7

4.2.7 1831-1832

Until 1830, Manley relied upon observations from Losh's record, with some adjustments made by reference to the record at Brandsby. For 1831 and 1832 there are no Brandsby data available, and as a result of this Manley made no final correction to this period of Losh data, just adjusted them to a daily extreme mean, and then applied a correction for the difference in altitude between Durham and Jesmond. Table 4.8 summarises these adjustments.

Table 4.8 Corrections applied for Durham to Losh's observations for the period 1819-20 (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
To 24 hr means	-0.5	-0.6	-1.1	-2.0	-2.1	-2.5	-1.8	-2.0	-1.6	-1.0	-0.6	-0.3	-1.3
To daily extreme mean	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
For altitude	-0.5	-0.6	-0.6	-0.4	-0.5	-0.4	-0.8	-0.4	-0.6	-0.6	-0.6	-0.5	-0.5
Total correction	-0.8	-1.0	-1.5	-2.2	-2.4	-2.7	-2.4	-2.2	-2.0	-1.4	-1.0	-0.6	-1.7

Manley did imply in his notes that he might use further observations in addition to those from Losh's readings in his notes, using Keighley, York and Kendal observations, but he did not do this in the final version of his reduction that accompanies his final letter.

4.2.8 1833-1839

The section of Manley's reduction from 1833 to 1849 used more diverse techniques of construction, and different series. Therefore, the periods are divided into shorter groups of years when the different sets of observations were each available. In his notes, Manley wrote an early version of what was available to him for these years, which he also reproduced in slightly different versions in his letters dated 1.iii.79, 3.vi.79 and 5.xi.79.

> *'Can do*
>
> *1831-2 from Losh, and Yorkshire/Keighley, York and Kendal?*
>
> *[1833-39 revised Yorkshire or Borders]*
>
> *1840 from Yarm (+ Yorkshire , Borders)*
>
> *1841 Middlesbro' + Yorkshire*
>
> *1842 Yarm, Middlesbro' (fragments of Durham)*
>
> *1843 Mostly Durham (check from Borders and York)*
>
> *1844 a little Durham (check from Borders and York)*
>
> *1845 a little Durham. Rest from Borders and York*
>
> *1846 Mostly from Borders + York*
>
> *1847 The Revised Durham; check by Makerstoun/York*
>
> *1848 Durham, check by Makerstoun/York*
>
> *1849 Durham, check by Makerstoun/York*
>
> *We have 1841-49 Makerstoun and York as a 'block', from which we might interpolate the values!*
>
> *Having Durham for 1843, 48 and 49'*

For 1833 to 1839, Manley used a single technique of reducing the monthly means. His notes give an early version of the data he had available.

'<u>1833 to 1839</u> off Ackworth-Keighley (?Kendal) – (Abbey St. B.) (Wykeham)

[York for what it is worth] (rather short of Borders region)

(some reference to Abbey St.B/MAK)

Largely by building out deviations from average from previous or ensuing years

Keighley, altho' only one obs. Daily seems consistent, and covers 1847-1856'

For his final version, Manley used a technique of calculating means forward from one set of observations, and another set back from a later set. He described the calculation of this part of the extension in his letter dated 5.xi.79.

> *'... I worked out a series of the most probable "monthly anomalies" applicable in N.E. England, a few miles inland from the coast. I extended one set forward, from the earlier Losh/Brandsby series 1801-1832; and another set backward, from the later Durham series 1847-1856. The agreement wasn't too bad and I've taken the mean.'* (Manley 5.xi.79)

The 'most probable monthly anomalies' comprised records from Keighley, Ackworth, Lancashire and Edinburgh. It is notable that Manley decided to use the Lancashire and Edinburgh series after earlier insisting on their exclusion, and also given that he did not mention them in his earlier summary of what data he had available for these years as shown above. For the years 1833 to 1839, he calculated two sets of means, taking the mean of the two to arrive at his final estimation. The first set was derived from means extended forwards from 1824 to 1832, and the second set extended backwards from 1846 to 1832.

Considering the first extension, Manley began by taking a set of means for 'Durham' for the years 1824 to 1832. For this, he used the Losh and Brandsby data. Table 4.9 shows the data he adopted.

Table 4.9 Manley's means for 'Durham' reduced from Losh and Brandsby observations, 1824 to 1832 (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year
Mean	36.0	38.4	40.9	44.7	50.0	55.8	59.1	57.3	54.2	50.0	42.0	40.1	47.4

His next step was to refer to the monthly means of Keighley, Ackworth, Lancashire and Edinburgh, also for 1824 to 1832. These are shown in Table 4.10.

Table 4.10 Monthly means for Durham for 1824 to 1832, for Keighley, Ackworth, Lancashire and Edinburgh (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Keighley	35.8	37.0	40.5	45.6	52.2	58.8	61.6	58.3	55.4	49.4	40.4	39.0	47.8
Ackworth	35.8	38.9	42.3	47.1	51.9	58.6	62.0	60.0	56.1	52.2	42.1	40.2	48.9
Lancashire	35.7	38.8	42.3	46.7	52.5	58.0	60.7	59.0	55.1	50.3	41.9	40.3	48.4
Edinburgh	36.2	38.7	40.4	45.3	50.4	56.7	59.0	57.2	53.1	49.0	41.1	39.8	47.2

Manley then examined the data for 1833 to 1839, again for the Keighley, Ackworth, Lancashire and Edinburgh series, calculating the differences between the 1824-32 and the 1833-39 sets, shown below in Table 4.11.

Table 4.11 Differences for Keighley, Ackworth, Lancashire and Edinburgh for the period from 1824 to 1832 (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1833	-2.2	0.8	-2.7	-1.0	5.8	-0.9	-0.3	-2.7	-1.3	-1.3	1.0	1.8	-0.3
1834	0.3	2.2	2.2	-1.0	1.8	0.2	0.3	1.4	0.5	-0.3	1.7	1.8	0.9
1835	0.0	1.5	-0.2	-0.8	-1.5	-1.8	-1.3	1.9	-0.3	-3.3	0.3	-1.5	-0.6
1836	0.2	-1.2	-1.0	-2.2	0.0	0.0	-2.8	-2.3	-3.0	-3.6	-1.7	-1.0	-1.6
1837	-0.2	0.7	-6.0	-6.6	-2.6	-0.2	-0.2	-1.5	-1.5	-0.2	-1.1	0.5	-1.6
1838	-6.0	-7.8	-1.5	-4.2	-3.3	-1.5	-0.8	-0.7	-0.3	-1.6	-2.9	-0.4	-2.6
1839	0.0	-0.6	-3.0	-2.5	-1.6	-0.8	-1.5	-0.7	-0.8	-1.8	2.7	-2.0	-1.1

This table of differences ('anomalies') was then applied to his Durham data for 1824-32 (Table 4.9 above). This process resulted in the means shown in Table 4.12.

Table 4.12 Manley's estimated means for Durham for 1833-39 extended from earlier data (1824-32) (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1833	33.8	40.2	38.2	43.7	55.8	54.9	58.8	54.6	52.9	48.7	43.0	41.9	47.2
1834	42.3	40.6	43.1	43.7	51.8	56.0	59.4	58.7	54.7	49.7	43.7	41.9	48.8
1835	36.0	39.9	40.7	43.9	48.5	54.0	57.8	59.2	53.9	46.7	42.3	38.6	46.8
1836	38.0	37.2	39.9	42.5	50.0	55.8	56.3	55.0	51.2	46.4	40.3	39.1	46.0
1837	35.8	39.1	34.9	38.1	47.4	55.6	58.9	55.8	52.7	49.8	40.9	40.6	45.8

This is the first set of means referred above. Manley then calculated a second set of means based on later data (1832-46) in a similar way, using the Keighley, Ackworth, Lancashire and

Edinburgh series, and applied the deviations to 'Durham' data for the period 1847-56. The mean of the two sets was the final version that Manley inserted into his extension.

4.2.9 1840-1841

For the derivation of monthly means for 1840 and 1841, Manley referred to several shorter archives of data. The exact combination of data that he used is not certain, but for 1840, he certainly made use of an archive from Yarm, for which only 1840 and 1842 are available. His approach was to start with the record, reduce it to be applicable to Durham conditions of exposure, as detailed above, and then to adjust the set of means based on previous decadal means. In his notes, Manley refers to the use of the Keighley, Ackworth, Lancashire and Edinburgh data as an overall control on the Yarm record, but gives no adjustments that resulted from this. For 1841, he probably used a set of data recorded at Allenheads that was available to him in 1841 and 1842. The combination of the Yarm and Allenheads data, adjusted with reference to Keighley, Ackworth, Lancashire and Edinburgh, probably resulted in his means for 1840 and 1841 and allowed him to bridge the gap onto data printed in the *Durham Advertiser*, detailed in the next section.

4.2.10 1842-1843

For 1843, Manley used a set of data printed in the *Durham Advertiser* early in January 1844. The maxima and minima were printed in the newspaper, and he inserted means into his extension unaltered, calculating the monthly means directly as the mean of the daily extremes. Data for 1842 were not complete however, so for the three months when no *Durham Advertiser* daily extreme means were printed (June, September and October) Manley used the fixed hour means observed at 9 am and 9 pm. Various notes among his papers show corrections to observations made at these times to bring the mean to be representative of one calculated from the daily extremes. Table 4.13 shows the means that Manley derived for 1842 and 1843.

Table 4.13 Monthly means for Durham derived from summaries published in the Durham Advertiser for 1842 and 1843 (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1842	32.0	37.5	42.0	44.0	51.3	57.0	58.0	61.5	54.2	42.2	40.0	45.5	47.1
1843	38.2	33.0	40.9	46.0	47.0	51.3	57.7	57.9	57.8	45.8	40.4	45.3	46.8

4.2.11 1844-1846

Manley used a similar technique for 1844 to 1846 as for the period from 1833. A note shows the data that he had available for these years.

'We have York 1832-46 equal to later York plus a correction. Ackworth and Keighley.
[Borders 1834 to 1850 or 55]
might provide a pattern of N.E. anomalies'

He did also consider the Ackworth observations, after comparing them with means from York.

'The run against Ackworth is not consistent. Moreover Ackworth only overlaps for 4 year (1847-50) with Durham, and then looks a bit inconsistent against York or Wakefield'

He used monthly means from Keighley, Ackworth, Lancashire and Edinburgh once more, to arrive at an estimate for the three years from 1844 to 1846, adjusting these with reference to the later York observations, providing a period sufficient for the calculation of a reliable decadal mean. It is possible that for the entire 1833-46 period, Manley calculated a single stretch of data using the Keighley, Ackworth, Lancashire and Edinburgh data, but later broke it up into sections when the *Durham Advertiser* data came to light. He made a reference to temperature data in the *Durham Advertiser* for 1845 (Manley 27.xi.79), but it seems that he either did not obtain the data, or did not use it.

4.2.12 1847

For 1847, Manley calculated the deviations for 1848 and 1849 (for Durham) from the York and Edinburgh series, in order to obtain means for 1848 and 1849 in a similar way to the process that he adopted for 1833 to 1839. He then took the mean of these two years, and for each month derived a mean anomaly, which he then applied to a 'Durham average' that seemed to be calculated from 1847 to 1856, to arrive at an estimate for 1847. Figure 4.2 shows some of the rough notes that he used to arrive at his means for this year. The means that he finally arrived at were a little lower across the year than those shown here.

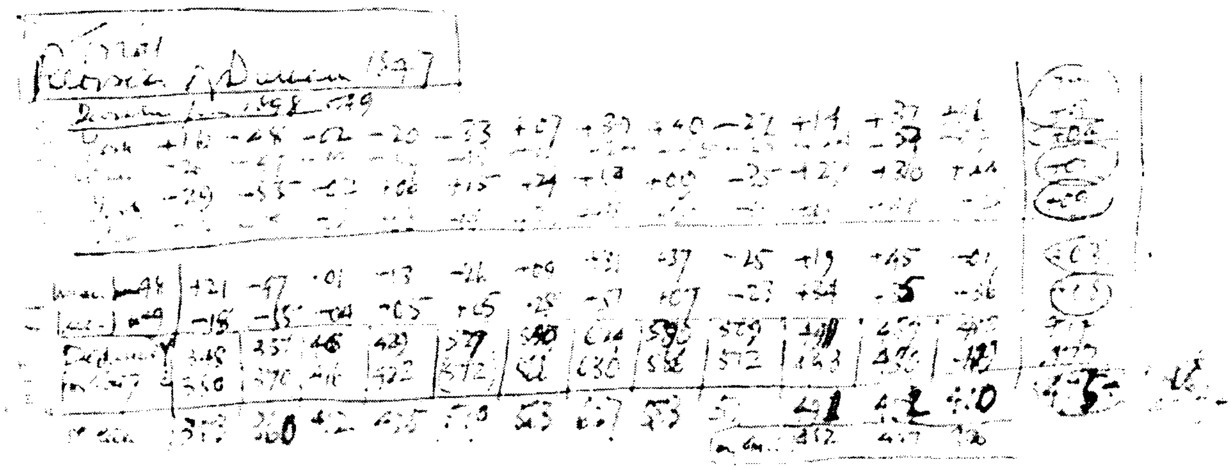


Figure 4.2 Manley's trial of 1847 for Durham.

As detailed in the next section, Manley had an annual mean for 1847 that had originated with actual Durham observations (Glaisher 1848a). He may have referred to this mean in order to lower his monthly means derived from the notes above and thus to arrive at his final version.

4.2.13 1848

Although Manley was not aware of the existence of original journals of observations from Durham University Observatory from 1843, which included daily observations for 1848, he did have some monthly and quarterly means that had been published by Glaisher in the Registrar-General's *Quarterly Returns of Births, Marriages and Deaths* published in London. These means included an annual mean for 1847, and quarterly means and extremes for the last quarter of 1847 and the whole of 1848 (Glaisher 1848a). No notes have been found that describe exactly how he used these quarterly means, but it is probable that he used a similar technique for 1848 as for 1847, by calculating a mean from other observations, and then adjusting the results by reference to these quarterly means for Durham.

4.2.14 Summary of Methods

Through extensive examination of Manley's letters and notes, it has been possible to gain an appreciation of the methods he used, and how he arrived at the monthly means sent in their provisional form to Joan Kenworthy and W. B. Fisher. An analysis of the efficacy of these techniques and suggestions for improvement are made in chapter 5, and the extension of the reduced means using observations that he had available, but had no time to use, is pursued in chapter 6. In some cases it has not been possible to ascertain his precise method, and in other cases his method has been seen to be sound, but to suffer from an imperfect transcription of observations and their hours from the original manuscripts. The nature of some errors that he made is examined in the next section.

4.3 Errors Made by Manley

4.3.1 Introduction

As Manley worked on his temperature extension in the late 1970s, it is apparent from his letters that he was aware that he did not have the time to devote to the process that he had for his Central England series. He was keen to deposit copies of his work with Joan Kenworthy and W. B. Fisher at the Department of Geography at the University of Durham, and appeared to be working with haste. It is not surprising, therefore, that he cut some corners while creating his means, saving himself some time making long calculations to derive corrections on a daily basis as observational hours of each series changed. Moreover, his transcription and calculation of means from the original sources, regardless of the method he later applied to refine those means, was at times incorrect.

Among his notes (Manley 1938-), he left most of the original data in their uncorrected form straight from the journals or microfilms. For each of these series, where available, the original was sought, and daily means re-transcribed from these. The purpose of this was to check Manley's transcription and calculation based on his own methods, to refine his calculations by considering new techniques that operate on a daily basis, and to gain extra information from the original data, such as details of exposure, or comments made by the observers regarding the weather on a daily, monthly and decadal level.

Manley used the observations made by James Losh at Jesmond to form the basis of the early years of his extension; hence the recalculation of means was central to the study of any errors made in Manley's work. It is thought that most of the remaining observations that he used were used by him in an original monthly format. Daily observations for Brandsby and York have not been found, but for the former his monthly means were checked against the originals and were seen to match exactly. Similarly, his use of monthly means from Keighley, Ackworth, Lancashire and Edinburgh all match those from their original sources.

During the course of his work, Manley did correct some of his own errors after realising that he had made an incorrect assumption in an earlier calculation. Two versions of Manley's monthly temperature series for Durham exist in letters sent from him to Joan Kenworthy. The first is shown in his letter dated November 5^{th} 1979 (Manley 5.xi.79) and the second on November 27^{th} 1979 (Manley 27.xi.79). The two versions differ in only a small number of months, but these are when Manley realised a mistake had been made, and had therefore corrected it. In his latest version, some of his corrections were caused by his assumption that the hours of observation of the Losh record differ from the prevailing majority hours for that period.

4.3.2 Study of Errors Made

As described above, Manley did make assumptions concerning the hours of observation for the Losh data that he later corrected. When he visited the Newcastle Literary and Philosophical Society Library to study Losh's ledgers of observations, he wrote down the three readings per day in long columns on foolscap notepaper, so it is easy to see where errors have occurred. Given that Manley was rushing to complete the copying of the temperature readings, it may be expected that some errors would have occurred in his transcription from the original. Also, the handwriting in the ledgers is also quite difficult to decipher at times, especially during the period from January 1829 to the end of the record in September 1833, when some figures are quite ambiguous. Figure 4.3 shows a section of one of the pages of notes that Manley calculated monthly means from the Losh series.

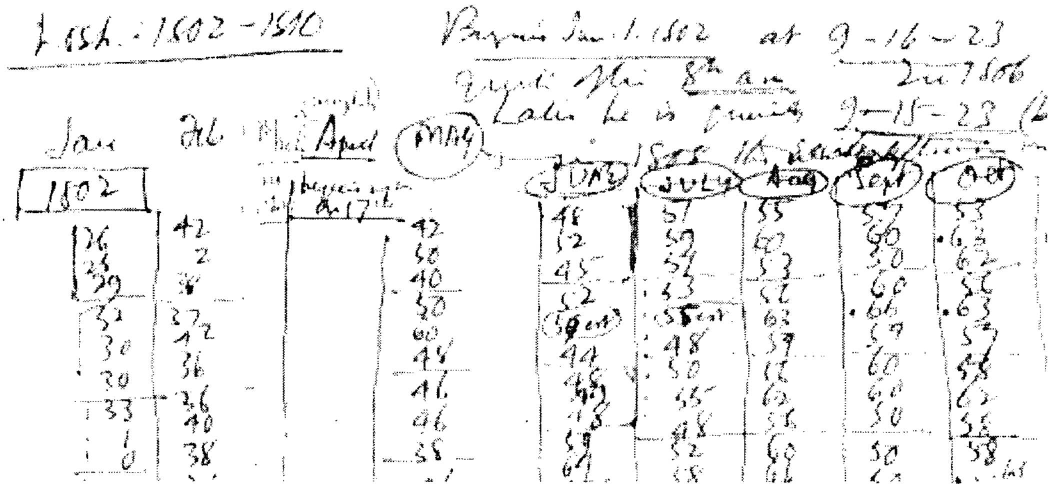


Figure 4.3 A sample sheet of notes Manley took while transcribing the Losh observations and calculating the monthly means.

It is possible to detect from these sheets, which exist for all years of the Losh record, whether Manley made any mistakes in transcribing data from the original manuscript. An analysis of Manley's version against the original observations does show deviation. At the end of each of these calculation sheets, Manley derived the mean from the observations noted down using a manual long-division process, rather than using a calculator, as mentioned in chapter 1 (Manley 27.ix.78).

Also, he appeared to have a non-standard method of rounding results. He did not habitually follow the modern convention of rounding up to the nearest whole, anything equal to, or greater than one half. Instead, he followed a system, in general use (e.g. Jeffreys 1939), that involved rounding down even decimals but rounding up odd decimals (for example, 7.5 would be rounded up to 8 but 6.5 would be rounded down to 6). There are some variations on this technique that are in use in some texts (e.g. Linacre 1992), but these are generally not used by statistical and data calculation software packages, which tend to follow the rule of always rounding up where the final digit is a 5. Any errors that Manley made are mostly arithmetic mistakes, shortcuts made while generating monthly means from the Losh data. The kinds of errors he made can be divided into four different categories. A sample was taken from the first four years of Losh's observations, and the errors grouped into these sections, as shown in Table 4.14.

Table 4.14 Types of Errors made by Manley in his calculation of means from Losh's observations.

Error	Examples
Day not transcribed	1804: January 31st, March 20th, July 24th, August 1st, September 27th
Incorrect value transcribed	Various discrepancies
Incorrect sum total for month	Many discrepancies
Incorrect result for division	February 1802 – 2835/78 is expressed as 37.7 but it should be 36.3

Manley copied daily values from the ledgers onto his sheets of paper, and then added up the columns and divided by the number of readings in total. In his transcription of daily values, he occasionally missed out a day, so that the total number of readings was fewer than it should have been. In such cases, Manley was aware that he had omitted the values, because when calculating the mean, he divided by the number of readings actually present on the sheet. It would appear that he wrote down these values while in the library, and then did the calculations afterwards, when the omitted data were not available.

The readings that Manley copied onto his sheets from the manuscript were checked against the original copies to ascertain whether he had made any mistakes. Of the four years examined, 15 readings, just over 1%, differed.

Manley added all readings for that month to derive a total that he could then use to calculate the mean. In adding this total, he made a substantial number of mistakes. Of the 48 months studied, 23 had errors of this type.

The final stage that Manley performed was to divide the sum of all daily readings for a month by the number of observations. Even where the sum for the month and the number of readings are correct, Manley's mean based on these values is occasionally wrong.

Manley did also make adjustments to the monthly means, for no written reason. For example, November 1802 calculates as 3676/90, which he wrote as 40.8 (correctly) before adjusting it and circling the figure as 40.9. Of the 48 months studied of the Losh record, the various errors may be broken down as shown in Table 4.15. Note that the total number of months exceeds 48, because some errors were derived from more than one reason. For example, Manley may have adjusted a mean, but that mean was erroneously derived in the first place.

Table 4.15 Summary of errors made by Manley with the calculation of monthly means from the Losh record from 1802 to 1805.

Problem	Months
Months with correct mean	17
Months Manley ignored	2 (March and April 1802)
Months where mean was calculated correctly, and subsequently adjusted	4 (September 1802, November 1802, July 1803, December 1803)
Months with total miscalculated	24
Total miscalculated, and number of readings incorrect	10

The study of these four years from Losh's observations show that Manley did make some errors, and these would have an effect upon his monthly means provided in his letters. It is possible that he might have revisited the original readings and recalculated all these means before publishing. For the reduction of monthly means in chapters 5 and 6, all the original sources for the observations were re-examined and means recalculated.

4.4 Summary of Chapter Four

In common with chapter 3, this chapter presents much information for the first time. One of the central themes of this thesis is to examine the methods that Manley used in the creation of his original data for Durham University Observatory as until now it has not been possible to place confidence upon the reduction without knowing the details of its composition. Some errors were found, and these have been documented to allow his own reduction to be analysed in its own right, apart from the enhancements and extension presented in chapters 5 and 6.

Chapter 5 – Improvements

Contents of this chapter

5.1 A Temperature Series for 'Durham' Using Modern Data

5.1.1 Improving Manley's Series for 'Durham'

Manley's series for 'Durham' was constructed at a time of his life when it is reasonable to suppose that he was aware that he might not have many years left to devote to the construction of the temperature series. As discussed in chapter 1, he made comments concerning the unfinished nature of the reduction and noted that some of his methods could be improved. The construction of series can be reworked in a number of ways, some of which would have a more substantial effect on the final temperature readings than others. A variety of different approaches will be discussed in this chapter together with an appraisal of what effects the techniques have. The aim of this section is to show how the series can be improved within the main body of data available for the North East of England which Manley was using from 1802, rather than extending the series backwards from this period.

5.1.2 Combining Series to Investigate Characteristics of Temperature in the North East

Where a number of series overlap across a period, and each is sited some distance from the station being modelled, series may be combined in order to form a composite series. The advantages and limitations of this are detailed in section 5.3. Manley employed the technique in his Central England (referred to as the CET series; Manley 1953, 1974) and Lancashire (Manley 1946) reductions. It is unlikely that temperature recorded in the eighteenth and nineteenth centuries was observed under such strict conditions as are laid down at the present. The site of the thermometer may mean that the readings are adversely affected (for example, by the thermometer receiving direct insolation at certain times of the day or year). The methods of observing the thermometer may not have been ideal, and the instruments themselves may have had inadequacies in their response to air temperature. This section will explore the use of this technique in some of Manley's, and other, temperature reductions.

When combining data for sites in order to create a composite temperature series, it is not necessarily obvious which sets of data should be combined, and whether unequal weights should be applied to each set. When creating the Lancashire series, Manley used just a single series where only one was available, but for the portion of the series from 1924 until 1945[63], he used the series listed in Table 5.1.

[63] This was the most recent section of the reduction for this series at the time that Manley was writing. He assumed that these four stations, combined in equal weights, would provide the best combined characteristics of all those available.

Table 5.1 Stations used by Manley in creating a contemporary series for 'Lancashire'.

Site	Weight	Altitude
Southport	0.25	5 metres
Leyland	0.25	23 metres
Hutton	0.25	20 metres
Stonyhurst	0.25	115 metres

The mean created from the composite of these series was then modified using the adjustments shown in Table 5.2.

Table 5.2 Corrections applied to the contemporary composite series for 'Lancashire' (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Adjustment	0.2	0.3	0.3	0.4	0.2	0.2	0.2	0.2	0.2	0.1	0.1	0.0	0.2

These adjustments were derived from the mean for the period 1906-35. Manley's premise for his Lancashire temperature series was that it should be 'appropriate to a level of 50 ft above the sea, inland on the plain' (Manley 1946). He stated that an approximation to the 'Lancashire' mean could be obtained by taking the Hutton mean and adding 0.1F° or the Leyland mean and adding 0.3F°.

When compiling his temperature series for Central England, Manley used the mean of the Oxford series and his own Lancashire series. Therefore his series and weights are half of those in Table 5.1, with Oxford having a weight of 0.5.

The temperature series calculated by the Hadley Centre uses four series in order to form its composite at the present. These series have been chosen for their expected longevity as meteorological stations, as well as for their geographical positions. The stations and their weightings are shown in Table 5.3.

Table 5.3 Stations used in the Central England Temperature Series published by the Hadley Centre for the United Kingdom Meteorological Office (Parker et al.. 1992).

Site	Weight	Altitude
Rothamsted	0.33	128 metres
Malvern	0.33	62 metres
Squires Gate	0.167	10 metres
Ringway	0.167	69 metres

The premise for the use of these series is that they are geographically spaced across the region designated as 'Central England' by Manley. The sites are also chosen for their lack of severe local urbanisation and areas where the local characteristics are not relatively extreme such as frost hollows, coastal sites and upland sites (Parker *et al.* 1992). Nevertheless, Ringway is the site of the Manchester International Airport, and Parker describes its location as 'not ideal'. The relationship between temperature at Ringway, Malvern and Squires Gate was made against observations at local rural sites[64]. Negative corrections of up to –0.2C° are currently being applied to the final reduced series to counter the effects of urbanisation (Parker *et al.* 1992) after a comparison with local rural stations.

A further series for 'Central England' was composed by Jenkinson *et al.* (1979) which used the series shown in Table 5.4. This combination was used from 1974 onwards, but before this point, for the bulk of their reduced series, just three series were used (Oxford, Ross on Wye and

[64] Temperature data recorded at these local rural sites were not of sufficient quality to use in the series reduction itself because of missing days.

Sheffield). Parker *et al.* (1992) rejected the use of these sites on the grounds that they inadequately represented Manley's definition of Central England.

Table 5.4 Stations used in the Central England Temperature Series published by Jenkinson et al. (1979).

Site	Altitude
Ringway	69 metres
Finningley	10 metres
Wittering	80 metres
Cardington	29 metres

5.1.3 Availability of Modern Data for the North East of England

The network of stations where meteorological data are recorded is extensive across the British Isles. The North East of England has many such stations from where data are sent to the Meteorological Office and archived. Such data are accessible to the public via the British Atmospheric Data Centre (BADC), which acts as a central repository for atmospheric and climatological datasets, and as a storage centre for data generated from the Natural Environment Research Council (NERC). Data provided by the BADC are available on the internet, and locations across the North East have been examined for temperature observations made over the last decade. A majority of the meteorological stations only record rainfall, whereas others also record temperature, and the format of the temperature data also varies. The temperature readings have generally been digitised by the Meteorological Office in the same format in which they were recorded. The two formats used for temperature readings for the data used in this study are referred to as 'Daily Climate' (a manual message format) and 'National Climate Message' (an electronic message format).

Climate stations reporting 'Daily Climate' to the UK Meteorological Office use a paper form termed Met Form 3208b. It allows for up to 31 daily observations, with one set of readings per day. The reading time for this form is flexible with sites reading at either 9 am or 10 am, but all the stations examined in this study observed at 9 am. Temperature is recorded on this form as a spot reading at 9 am, and also as maximum and minimum readings observed and reset at 9 am. Of the data recorded on the 3208b, only the maximum and minimum temperatures are used for this study. The mean temperature for the 24 hour day is subsequently calculated as the mean of this maximum and minimum, i.e. the mean of the daily extremes.

The other format for data collection used for series in this study is the NCM (National Climate Message) format. This is based upon an electronic transfer of the data with the main message being at 9 am each morning. Some stations also send a message at 9 pm, in which case this contains additional climate data such that, for example, the maximum and minimum thermometers are read at both 9 am and 9 pm for these stations. In this study, where two messages are sent each day, the two messages are taken together and the 24 hour maximum and minimum are calculated.

Preference has been given to data available over the last full decade (the 1990s) because the Meteorological Office has made available data only until July 2000 at the time of writing. Therefore the nine year period from 1991 to 1999 has been used for this study wherever possible. In certain circumstances, these years are not available, in which case nine years of the most recently available segment of the series has been used instead and adjusted as detailed below. Some series have more than nine years available, but rather than have a different number of years for each station, affecting variability, a standard of nine years was chosen where possible.

A drawback of using the 1990s is that this decade is noted for its above-average temperatures. It is well documented that the Central England temperature series, as calculated by the Hadley Centre, shows a marked warming for this decade when compared with the previous decades.

This warming tends to be concentrated during winter, which shows milder temperatures whereas, to a lesser extent, the summer temperatures are depressed. Because these characteristics are exhibited by each of the individual series being looked at, and it is only the relationship between the series that is being examined, the potential difficulties with this decade should not pose a problem, although where data are not being provided from the 1990s then a correction is made.

5.1.4 Sites Chosen for this Study

The rationale for creating a 'modern series for Durham' is to show how data from various stations can be manipulated to create a new series which is representative of temperature conditions at the Durham University Observatory. Data for the recent past have been used and various local series used to compare with known temperature actually recorded at the Durham University Observatory for the same time period (1991 to 1999). Once the best approximation to the Durham data has been found for modern station data, the findings can be applied to eighteenth and nineteenth century data that are available to find temperature representative for Durham at that time. Given that the temperature characteristics do vary over an area, particularly one potentially stretching across a triangle from Keighley to Hull to Edinburgh, the best choice of stations is not obvious. Table 5.5 shows the availability of data in the eighteenth and nineteenth century, and hence the requirement for sites that are near to these locations. The manipulation and presentation of temperatures in this section is performed in degrees Celsius.

Table 5.5 Complete years for which data are available for sites in the eighteenth and nineteenth centuries, to 1843.

Historic site	Period
Abbey St. Bathans	1835 – 1838
Ackworth	1824 – 1841
Allenheads	1837 – 1842
Brandsby	1784 – 1790, 1811 – 1830
Keighley	1800 – 1843
Jesmond	1802 – 1832
New Malton	1817 – 1825
South Cave	1794 – 1814
Wykeham	1831 – 1836
Yarm	1840 – 1841
York	1831 – 1843

For each site for which data are available in the eighteenth and nineteenth centuries, a corresponding site has been selected which recorded data in the 1990s, with the sites as close together as possible. The historic sites are detailed in Table 5.6 below, with the associated modern site, and the relative position between each other and between the modern site and Durham University Observatory. Appendix E shows the relative locations of the contemporary and historic sites in a set of maps.

Table 5.6 Historic sites where temperature has been recorded and their most appropriate modern equivalents.

Historic site	Altitude (m above sea level)	Modern site	Ordnance Survey Grid Reference	Altitude (m above sea level)	Location: Modern vs Durham	Location: Modern vs Historic
Abbey St. Bathans	202	Whitchester	NT721589	255	129.5 km NNW	5 km SW
Ackworth	Approx. 50	Ryhill	SE402148	78	127.4 km S	5 km WSW
Allenheads	427	Westgate	NY915385	333	35.3 km W	8 km SE
Brandsby	29	Ampleforth	SE598789	95	70.8 km SSE	6 km S
Keighley	229	Bingley Samos	SE088350	262	108 km S	6 km SSE
Jesmond	46	Newcastle	NZ258648	52	23.3 km N	3 km S
New Malton	Approx. 25	High Mowthorpe	SE888685	175	95.8 km SE	10 km ESE
South Cave	2	Leconfield Saws	TA031428	6	124.8 km SE	16 km NE
Wykeham	Approx. 50	High Mowthorpe	SE888685	175	95.8 km SE	9 km SW
Yarm	Approx. 30	Hartburn Grange	NZ407185	31	26.9 km SSE	6 km NNE
York	Approx. 17	Askham Bryan	SE551477	32	98 km SSE	6 km SW
		York Heslington	SE631512	19	97.8 km SSE	3 km SE

It is possible that other stations in the North East could contribute temperature data that would more closely match that of Durham, but for this study only sites that have a location and exposure close to that of an eighteenth and nineteenth century series have been considered.

If data for the 1990s were not available, and the reasons for including the site were strong, then a different recent segment of the series was used. Two different sites were chosen initially to represent York, as both Heslington and Askham Bryan presented strong cases for being suitable[65]. Temperature data are available for both of these sites across similar periods, and both are located within 6 km of York city centre, with Heslington closer to the historic site. The York Heslington station ceased recording temperature in 1979, whereas at Askham Bryan it continues to be observed, although more readings are missing for the Askham Bryan record. In view of these factors, it was decided to start this study with both of these series as being potentially suitable, and determine during the analysis which is the most suitable. For other sites, the choice of a modern station was more obvious.

The relationship between Durham and the other sites was checked using a method of linear regression, predicting means for Durham based on each individual site. These calculations were performed using observations and corrections in degrees Celsius throughout. The results of the regression may only therefore be applied to measurements in degrees Celsius. Regression was also applied to the Central England temperature series to predict temperature at Durham. All sets of series gave fairly strong positive correlations, with Bingley Samos giving the weakest r^2 of 0.72[66]. Table 5.7 summarises all coefficients, and the root mean square error for each regression.

---

[65] The results of the data combination show that the Askham Bryan series is more useful in forming part of the composite series for Durham in all cases where 'York' data are available, as described below.

[66] Regressions will be summarised by r^2, the coefficient of determination, a figure of merit which may be used to compare both simple and multiple regressions.

Table 5.7 Results of applying linear regression to estimate daily means at Durham using each one of the modern sites.

Series	r^2	RMSE (°C)
Newcastle	0.979	0.74
Hartburn Grange	0.973	0.84
Westgate	0.962	0.99
Askham Bryan	0.959	1.04
High Mowthorpe	0.958	1.04
Ryhill	0.957	1.05
Ampleforth	0.957	1.10
Whitchester	0.950	1.16
Leconfield	0.939	0.26
York	0.912	1.51
Central England	0.903	1.58
Bingley Samos	0.717	2.70

Figure 5.1 shows a selection of graphs, showing values of r^2 for daily means by month. These graphs compare Durham to Newcastle, Askham Bryan and Westgate, and also to the Central England temperature series for 1991 to 1999.

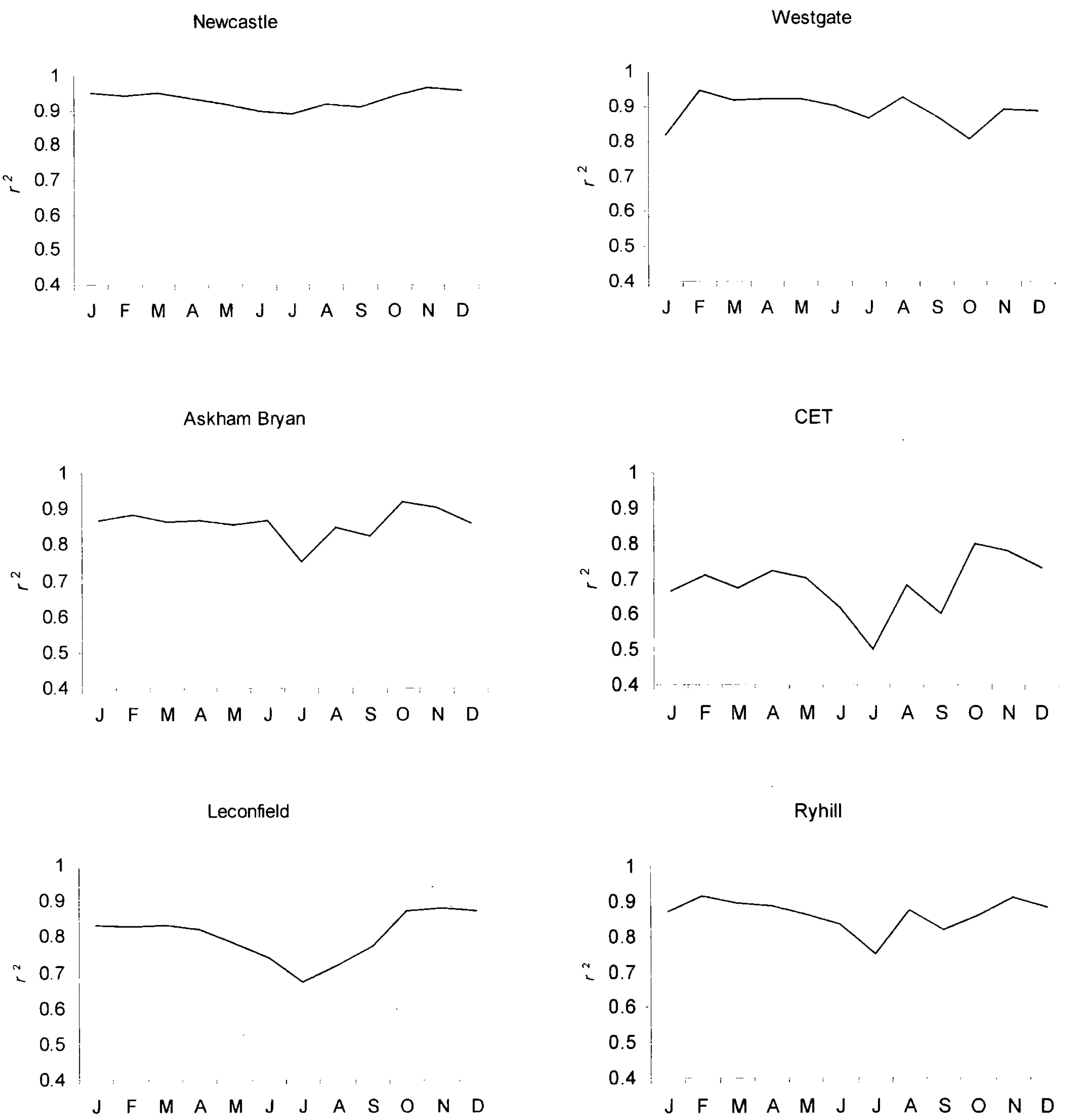


Figure 5.1 Graphs showing r^2 for daily means, by month, from Durham University Observatory against other series in the North East, and the Central England series, 1991-1999.

To a certain extent, these results show that the correlation is stronger where the site is closer to Durham, with the sites having strongest correlations being Newcastle, 23 km to the north and Hartburn Grange, 27 km towards the south. The sites furthest from Durham – Whitchester, Ryhill and Leconfield Saws – all exhibit weaker overall relationships with temperature at Durham. The correlation for Bingley Samos was notably weaker than for other series, possibly reflecting the combination of its distance from Durham and higher altitude. However, Westgate shows a stronger relationship, but it is much closer to Durham at 35 km to the west. For the sites that are closest to Durham, the value of r^2 for each month is consistently strong throughout, but as the overall r^2 weakens, the consistency between months begins to break down. For example, the range of correlation coefficients for Askham Bryan, in the upper half of the table, ranges from 0.92 to 0.75. The strength of correlation for Leconfield is weakest in mid-summer, reaching a trough in July, but the pattern of r^2 is smooth. Leconfield and Ryhill are almost equally distant from Durham, but the relationship for Ryhill is slightly weaker, with an overall value for r^2 of 0.86 as opposed to 0.80 for Leconfield. The pattern throughout the year at Leconfield is much smoother, with a weaker relationship in mid-summer reaching a trough in July, whereas at Ryhill the summer trough is interrupted by a stronger relationship in August temperature at Durham. The results of this analysis of r^2 might be more consistent if a greater number of years were taken for the comparison, but for these data the overlap between sets of observations was nine years. These results are discussed further in chapter seven.

5.1.5 Preparation of the Modern Data

Several of the modern sites do not have the full set of temperature data for 1991 to 1999 available. In addition, some series have slightly different formats to the data, and have some missing values. Table 5.8 shows what data are available and in what format for the sites.

Table 5.8 The availability and format of modern data in North East England. [67]

Site	Data Format	Years Available	Years Used	Missing Data
Ampleforth	dly3208	1959-1971	1962-1970	1.0%
Askham Bryan	dly3208	1959-1999	1991-1999	2.3%
Bingley Samos	ncm	1982-1999	1991-1999	1.2%
Hartburn Grange	dly3208	1969-1990	1982-1990	0%
High Mowthorpe	dly3208	1959-1999	1991-1999	0.1%
Leconfield Saws	ncm	1991-1999	1991-1999	6.4%
Newcastle	ncm	1982-1999	1991-1999	0%
Ryhill	dly3208	1994-1999	1994-1999	1.2%
Westgate	dly3208	1994-1999	1994-1999	0.2%
Whitchester	dly3208	1980-1988	1980-1988	0%
York Heslington	dly3208	1965-1979	1965-1973	0%

For each series, the daily mean was calculated from the standard formula of the mean of the 24 hour maxima and minima, where the thermometer is read and reset at 9 am. Monthly means were then calculated from these daily means. Each series has its monthly means adjusted by a constant amount according to their altitude relative to Durham, which is taken to be equivalent to 0.6°C per 100 metres. Table 5.9 shows the corrections made for altitude.

[67] The table shows the years that are available using the most convenient data format that the BADC holds. In certain circumstances, extra data are held by the Meteorological Office. Where the data are available until 1999, the site is still taking observations at the time of writing, although the BADC only holds data to July 2000, again at the time of writing.

Table 5.9 Corrections for altitude made to the modern data series. The values are added to each series to reach its equivalent for Durham (°C).

Site	Altitude Correction
Ampleforth	-0.05
Askham Bryan	-0.46
Bingley Samos	1.04
Hartburn Grange	-0.46
High Mowthorpe	-0.47
Leconfield Saws	-0.62
Newcastle	-0.33
Ryhill	-0.16
Westgate	1.5
Whitchester	0.99
York Heslington	-0.54

Some of the series do not have data available for the chosen 1991-1999 period, so these were adjusted with reference to the Central England temperature series. A correction was made for each month by comparing the monthly mean for Central England for 1991-1999 with the mean for Central England for the years that data are available for the series. For example, the series at Ampleforth is only available for 1959 to 1971, so the latest nine full years of the series were used (1962-1970). For each month, the correction was calculated as the difference between the Central England average for that month for 1991 to 1999, and the average for the same month for 1962 to 1970. Table 5.10 shows the corrections made to each of the series where such adjustments were necessary.

Table 5.10 Values for the Central England series for each month for the years that the modern series are for, plus the corrections necessary to bring these latter modern series to the standard of 1991-1999 (°C)

	CET Monthly Means						CET Monthly Corrections relative to 1991-99				
	1991-99	1962-70	1982-90	1994-99	1980-88	1965-73	1962-70	1982-90	1994-99	1980-88	1965-73
Jan	4.5	3.32	4.01	4.6	3.41	4.13	1.18	0.49	-0.1	1.09	0.37
Feb	4.78	3.13	3.61	5.25	3.11	3.68	1.65	1.17	-0.47	1.67	1.1
Mar	7.07	5.01	5.9	6.92	5.54	5.51	2.06	1.17	0.15	1.53	1.56
Apr	8.66	7.80	7.86	8.63	8.08	7.58	0.86	0.8	0.03	0.58	1.08
May	11.63	11.26	11.27	11.48	10.91	11.18	0.37	0.36	0.15	0.72	0.45
Jun	14.24	14.62	14.14	14.23	14.01	14.24	-0.38	0.1	0.01	0.23	0
Jul	16.86	15.46	16.74	17.17	16.2	15.64	1.4	0.12	-0.31	0.66	1.22
Aug	16.62	15.27	16.03	17.1	15.76	15.59	1.35	0.59	-0.48	0.86	1.03
Sep	13.91	13.49	13.58	14.12	13.72	13.53	0.42	0.33	-0.21	0.19	0.38
Oct	10.31	10.94	10.82	11.05	10.16	11.00	-0.63	-0.51	-0.74	0.15	-0.69
Nov	7.22	6.26	6.69	7.7	6.83	5.94	0.96	0.53	-0.48	0.39	1.28
Dec	4.63	3.67	5.56	4.65	5.19	4.7	0.96	-0.93	-0.02	-0.56	-0.07

These corrections with reference to the CET series were applied to temperature data from each of the eleven sites and multiple linear regression was applied to the daily data to see which combination best matched the means for Durham for 1991-1999.

To ensure that the modern sites were used to best approximate conditions at the historic place of observation, an adjustment was made to reflect any difference in altitude between the modern site and its historic counterpart. These corrections were applied across all months equally.

As described above, linear regression performed between individual sites and Durham generally yielded good positive correlations, assisted by the fact that temperature data could be taken from identical years for both series being studied. However, data are not available for all series for the same period, namely for Hartburn Grange, Ampleforth, Whitchester and York Heslington as described above, because these stations were not observing data in the 1990s. The York Heslington series could also be discarded on the basis that the Askham Bryan series displays a much better correlation with Durham, and is therefore considered a better proxy for the York historical site.

To attain the best sets of series to be combined in order to estimate temperature at Durham, Bingley Samos and York were removed from the group as these have the two weakest correlations when taken as single predictors for temperature at Durham. In addition, Hartburn Grange, Ampleforth and Whitchester were removed because these sites have no data available in the 1990s and regression is likely to be less reliable when comparing temperatures with those observed at Durham in a different decade. This rationalisation exercise resulted in six remaining sites of Newcastle, Westgate, Askham Bryan, Mowthorpe, Ryhill and Leconfield Saws, all well distributed series with good quality data available. Multiple linear regression was then applied to each combination of these six series to determine which combinations, and with what weighting, displayed the best estimation of the Durham daily means. There are 63 different combinations of at least one station, with values for r^2 ranging from 0.9877 to 0.72. The best sets of combinations, all with values for r^2 greater than 0.978, all use the Newcastle series as their main component and are shown in Table 5.11.

Table 5.11 The optimum combinations of series used to estimate temperature at Durham, using a method of multiple linear regression.

Predictors	Overall r^2	1st Series	1st Weight	2nd Series	2nd Weight	3rd Series	3rd Weight	4th Series	4th Weight	5th Series	5th Weight
New West Ask Lec	0.9877	New	0.5462	West	0.2147	Ask	0.1539	Lec	0.0852		
New West Ask Mow Lec	0.9877	New	0.5558	West	0.2192	Ask	0.1630	Mow	-0.0387	Lec	0.1013
New West Ask Ryh Lec	0.9875	New	0.5461	West	0.2077	Ask	0.1401	Ryh	0.0249	Lec	0.0808
New West Ask	**0.9873**	**New**	**0.5682**	**West**	**0.2013**	**Ask**	**0.2273**				
New West Ask Mow	0.9873	New	0.5600	West	0.2001	Ask	0.2146	Mow	0.0220		
New West Ask Ryh	0.9871	New	0.5652	West	0.1869	Ask	0.1869	Ryh	0.0577		
New West Ask Mow Ryh	0.9871	New	0.5619	West	0.1870	Ask	0.1835	Mow	0.0092	Ryh	0.0550
New West Ryh Lec	0.9863	New	0.5431	West	0.2127	Ryh	0.1154	Lec	0.1280		
New West Mow Ryh Lec	0.9863	New	0.5530	West	0.2157	Mow	-0.0349	Ryh	0.1229	Lec	0.1432
New West Lec	0.9862	New	0.5505	West	0.2605	Lec	0.1913				
New West Mow Lec	0.9862	New	0.5497	West	0.2600	Mow	0.0028	Lec	0.1897		
New Ask Ryh Lec	0.9861	New	0.6914	Ask	0.1545	Ryh	0.1263	Lec	0.0266		
New Ask Mow Ryh Lec	0.9861	New	0.6953	Ask	0.1567	Mow	-0.0130	Ryh	0.1286	Lec	0.0314
New Ask Ryh	0.9859	New	0.6888	Ask	0.1717	Ryh	0.1363				
New Ask Mow Ryh	0.9859	New	0.6876	Ask	0.1705	Mow	0.0033	Ryh	0.1354		
New West Mow Ryh	0.9856	New	0.5687	West	0.1796	Mow	0.0606	Ryh	0.1874		
New West Ryh	0.9855	New	0.5971	West	0.1776	Ryh	0.2227				
New Ask Lec	0.9855	New	0.7133	Ask	0.2551	Lec	0.0308				
New West Mow	0.9847	New	0.5716	West	0.2390	Mow	0.1878				
New Ask Mow Lec	0.9855	New	0.7022	Ask	0.2454	Mow	0.0328	Lec	0.0187		
New Ask Mow	0.9853	New	0.6981	Ask	0.2596	Mow	0.0401				
New Ask	0.9853	New	0.7141	Ask	0.2835						
New Ryh Lec	0.9848	New	0.6955	Ryh	0.2234	Lec	0.0791				
New Mow Ryh Lec	0.9848	New	0.6959	Mow	-0.0013	Ryh	0.2238	Lec	0.0796		
New Mow Ryh	0.9844	New	0.6890	Mow	0.0524	Ryh	0.2542				
New Ryh	0.9843	New	0.7125	Ryh	0.2840						
New West	0.9832	New	0.7198	West	0.2857						
New Mow Lec	0.9828	New	0.7372	Mow	0.1356	Lec	0.1304				
New Lec	0.9824	New	0.7991	Lec	0.2067						
New Mow	0.9819	New	0.7480	Mow	0.2544						
New	0.9787	New	1.0117								

It can be seen from Table 5.11 that the values for r^2 are all high, showing good positive correlations across the top 31 combinations. However, some of these combinations use up to 5 predictor series, and in some cases the weights of some predictors are small. The combination with the best balance between the number of predictor sites and high weights for each site was judged to be the Newcastle, Westgate and Askham Bryan set (shown in bold type and underlines in the table). The smallest weight in this combination is that for Westgate at 0.2013, whereas if a fourth predictor of Leconfield was added, it increased the value of r^2 by only 0.0004 and had a weight of 0.0852. Table 5.12 summarises the results of the linear regression and details of the sites. The value of the intercept for the regression is -0.2362.

Table 5.12 Weights applied within the single optimal combination of series used to represent Durham, derived from the results of multiple linear regression.

Site	Weight	Location relative to Durham	Altitude (m above msl)
Newcastle	0.5682	23.3 km N	52
Westgate	0.2013	35.3 km W	333
Askham Bryan	0.2273	98 km SSE	32

In all the combinations with high values for r^2, Newcastle features as the most prominent series, reflecting the similar climatology between Newcastle and Durham, and the geographical proximity of the two sites. Analysis of the residuals gives residuals a standard deviation of 0.586°C. The greatest positive and negative residuals are 2.0°C (occurring on April 20th 1997) and –2.4°C (occurring on April 9th 1997).

The calculated monthly means for Durham from the combination of Newcastle, Westgate and Askham Bryan, when the associated weights are applied, agree exactly with the true means for Durham to an accuracy of 2 decimal places.

The combinations of series with the closest match to the Durham monthly means tend to be well distributed around the North East of England. As might be expected, when the locations of the component series are plotted on a map, it can be seen that they are dispersed roughly around Durham. Figure 5.2 shows the sites with sized circles to represent the relative contributions of each series for the best set of predictors from the linear regression.

For all the best combinations of series, Newcastle features as the dominant predictor site, with the best 31 combinations all including it. Indeed, the 31st combination, ordered by the results of the linear regression, uses the Newcastle site alone to predict Durham, and this is followed by all other combinations that do not use Newcastle.

Regarding the best match of Newcastle, Westgate and Askham Bryan, although Askham Bryan is 98 km to the south, its weight is much lower than that of Newcastle, situated just 23 km north of Durham. When the altitude of each site is considered in relation to its contribution to the composite series, the mean is 99 metres, compared with the altitude of Durham at 102 metres.

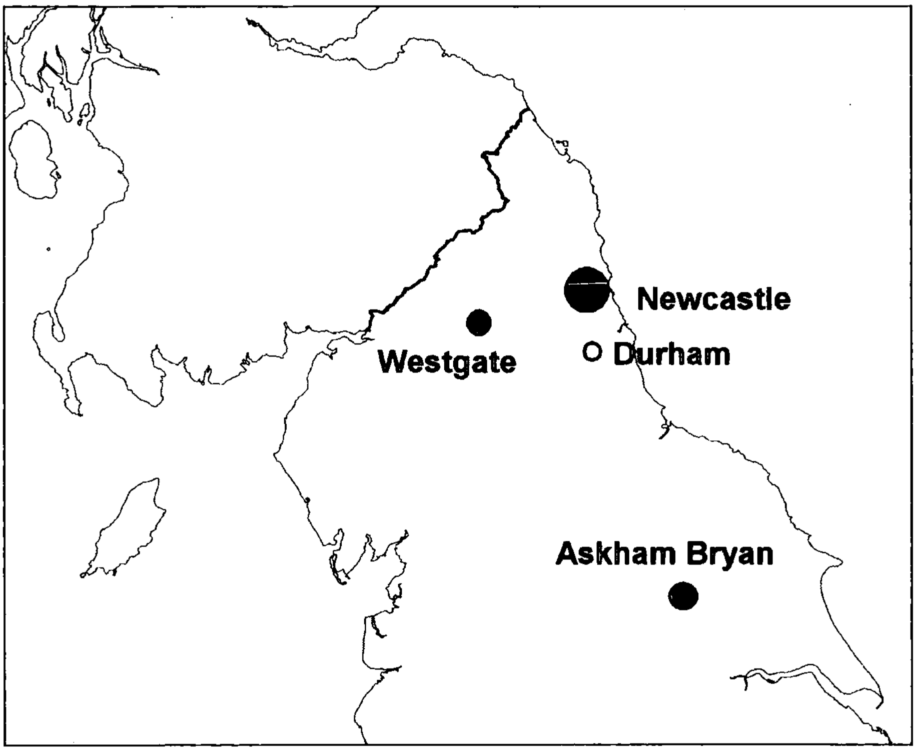


Figure 5.2 Map showing the relative positions of the component series for the composite series with the closest match to the Durham monthly means. The filled circles show the relative contribution of data from each series, with the location of Durham shown for reference.

5.1.6 Combining the Historic Series

The composite series using Newcastle, Westgate and Askham Bryan is shown to give the closest approximation to temperature at Durham of all the modern series studied. However, when considering the best series to use for combining during the eighteenth and nineteenth centuries, not all of the series paired to the modern stations are available. The entire set of historic data was examined, Figure 3.2 showing the periods that each archive has full monthly data available, but for clarity in this context it is reproduced in Figure 5.3 with the modern site names shown.

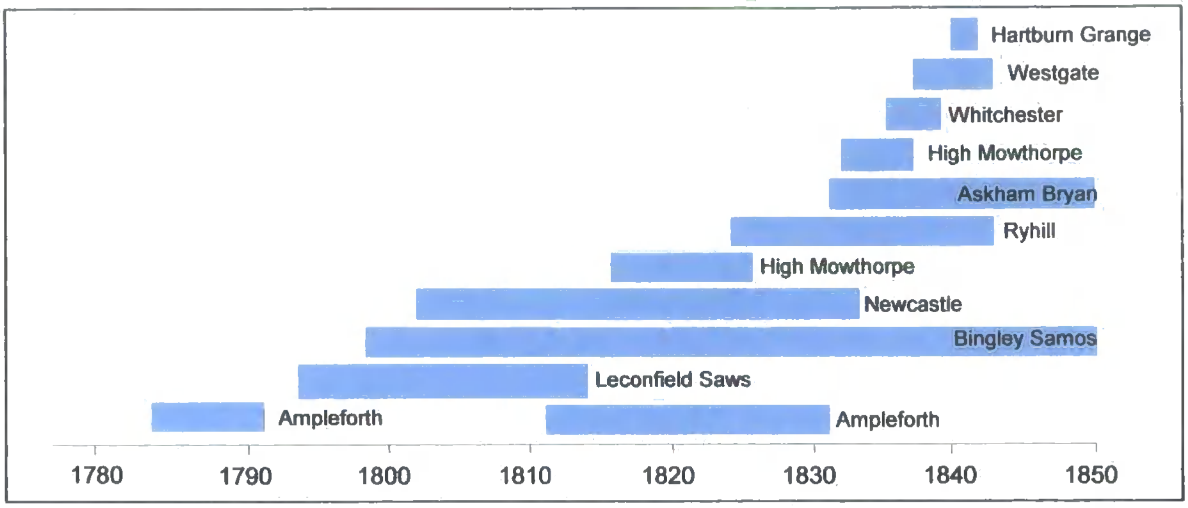


Figure 5.3 Availability of data for construction of a composite series from data taken at modern sites close to the historic locations. The modern site names are shown in this figure.

For each year, a set of up to five series is available. Each of these sets were taken and the linear regression method of finding the most suitable combination of these series was applied to the eighteen discrete sections between 1784 and 1843. Table 5.13 shows the results, with each adjacent pair having a different set of series available.

Table 5.13 Combinations of various modern series which best match the annual pattern for Durham for each distinct period where the historic monthly data are actually available (°C).

Period	Series Available	Best Combination of Series and Weight	Intercept	r^2
1784-1790	Ampleforth	0.977	0.105	0.957
1791-1793	no data			
1794-1799	Leconfield Saws	0.926	0.604	0.939
1800-1801	Leconfield Saws	0.837	0.400	0.942
	Bingley Samos	0.107		
1802-1810	Leconfield Saws	0.207	-0.396	0.982
	Bingley Samos	not used		
	Newcastle	0.799		
1811-1814	Leconfield Saws	0.207	-0.396	0.982
	Bingley Samos	not used		
	Newcastle	0.799		
	Ampleforth	not used		
1815-1816	Bingley Samos	0.043	-0.618	0.980
	Newcastle	0.974		
	Ampleforth	not used		
1817-1823	Bingley Samos	not used	-0.115	0.982
	Newcastle	0.748		
	High Mowthorpe	0.254		
	Ampleforth	not used		
1824-1825	Bingley Samos	not used	-0.356	0.984
	Newcastle	0.712		
	High Mowthorpe	not used		
	Ampleforth	not used		
	Ryhill	0.284		
1826-1830	Bingley Samos	not used	-0.356	0.984
	Newcastle	0.712		
	Ampleforth	not used		
	Ryhill	0.284		

table continued on next page

table continued from previous page

Period	Series Available	Best Combination of Series and Weight	Intercept	r^2
1831-1832	Bingley Samos	not used	-0.284	0.985
	Newcastle	0.714		
	High Mowthorpe	not used		
	Askham Bryan	0.284		
	Ryhill	not used		
1833-1834	Bingley Samos	not used	0.841	0.966
	High Mowthorpe	0.496		
	Askham Bryan	not used		
	Ryhill	0.447		
1835-1836	Bingley Samos	not used	0.841	0.966
	High Mowthorpe	0.496		
	Whitchester	not used		
	Askham Bryan	not used		
	Ryhill	0.447		
1837-1838	Bingley Samos	not used	0.454	0.965
	Whitchester	not used		
	Askham Bryan	0.453		
	Ryhill	0.478		
1839	Bingley Samos	not used	0.322	0.978
	Westgate	0.530		
	Askham Bryan	0.433		
	Ryhill	not used		
1840-1841	Bingley Samos	not used	0.322	0.978
	Westgate	0.530		
	Askham Bryan	0.433		
	Hartburn Grange	not used		
	Ryhill	not used		
1842	Bingley Samos	not used	0.322	0.978
	Westgate	0.530		
	Askham Bryan	0.433		
1843	Bingley Samos	0.029	0.636	0.959
	Askham Bryan	0.893		

For each of the eighteen periods, between zero and five series are available. The combination of series which gave the highest coefficient of determination was chosen for each period, and in several cases the series selected were the same for neighbouring periods, thus reducing the number of distinct adjacent periods to thirteen. It was observed that in most cases the optimum number of series to be combined for the linear regression was two, with a third series sometimes giving a marginal improvement in the regression coefficient but the weight applied to this new series being small, at less than 0.1. An example of this is shown in Table 5.14, where for the period 1802-1810, data for Leconfield Saws, Newcastle and Bingley Samos may be combined. The table shows the marginal difference that the addition of a third series makes, due to the dominating effect of the Newcastle series and the unsuitability (with an individual r^2 of 0.9787) of the Bingley series (with an individual r^2 of 0.7167).

Table 5.14 Results of multiple linear regression applied to the 1802-1810 period for estimating Durham temperature.

Series Used	Leconfield Weight	Newcastle Weight	Bingley Weight	Intercept	r^2
Leconfield Saws Newcastle Bingley Samos	0.1945	.7920	.02209	-.4211	0.9829
Leconfield Saws Newcastle	0.2067	.7991		-.3960	0.9824

The common series running through the entire period are Leconfield Saws, Newcastle, Ryhill and Askham Bryan, but there are years when only one of these series is available. From 1815-1817 Newcastle is joined by Bingley Samos, and from 1818-1823, Newcastle is joined by High Mowthorpe. Where Newcastle and Bingley are combined, Bingley contributes a weight of just 0.04 to the regression equation, but if Ampleforth were substituted as the only other available series, it would contribute just 0.03 to the regression equation and introduce Ampleforth for the first time in this part of the reduction, and for only a small number of years. Hence it was decided to leave Newcastle and Bingley Samos as the optimum combination for 1815-1817.

Each distinct period from 1784 to 1850 provides good fits between Durham and the other sites, with some being better than others. With reference to the individual values of r^2, the overall fit for each period is best where there are a number of sites available, and where the Newcastle data are available, as might be expected from its proximity to Durham. Following this, periods where Westgate is available demonstrate a good fit. Figure 5.5 demonstrates that where only one series is available, the fit is weaker, particularly given that from 1784 to 1791 only Ampleforth is available, and the fit between this and Durham is not as strong as for some other single series. Where only Leconfield is available, the correlation is weaker still. From 1800, where there are at least two series available, then the fit is stronger. Figure 5.4 shows how the fit of the regression of the different sets of series against Durham varies over the period being studied.

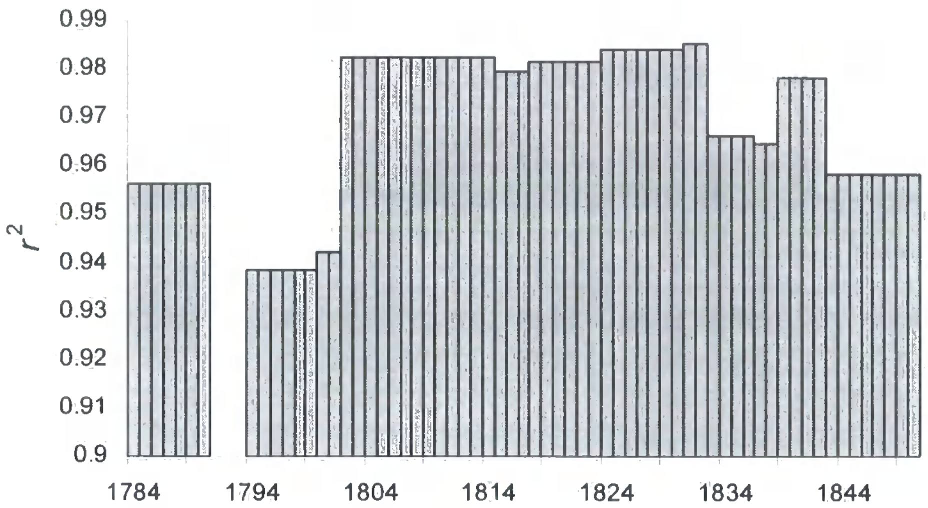


Figure 5.4 The coefficient of determination, r^2, for 1784 to 1850 when the optimum combinations of series are chosen to estimate temperature at Durham.

From 1833, data from Newcastle ceases to be available, and High Mowthorpe appears in the optimum combinations for four years from 1833 to 1836 where it is paired with Askham Bryan and then Ryhill. Bingley Samos data are available for these years, but unlike 1817-1823, the use of Mowthorpe is seen to contribute strongly to the strength of the regression giving a value for r^2 of 0.9661 against 0.9585 where Bingley is used to pair Askham Bryan. On this basis, High Mowthorpe was retained for 1833 to 1836.

From 1837 to 1842, Askham Bryan continues to be available to the end of the period being studied, but it is then paired with Westgate, which slightly exceeds Askham Bryan in its contribution to the regression equation. Bingley Samos data are available, but their use leads to a much weaker overall correlation with Durham. From 1843, Westgate ceases to be available, leaving only Askham Bryan and Bingley Samos available.

Table 5.15 shows the periods of historical record used to estimate temperatures at Durham. Correlation between these thirteen periods and Durham indicate which of the historic series would be best combined from 1784 to 1843 in order to estimate temperature at Durham.

Table 5.15 The full set of distinct adjacent periods for which series may be combined to estimate temperature at Durham, from 1784 to 1843.

Period	Series Available	Best Combination of Series and Weight	Intercept	r^2
1784-1791	Ampleforth	0.977	0.105	0.957
1792-1793	no data			
1794-1798	Leconfield Saws	0.926	0.604	0.939
1799-1801	Leconfield Saws	0.837	0.400	0.942
	Bingley Samos	0.107		
1802-1814	Leconfield Saws	0.207	-0.396	0.982
	Newcastle	0.799		
1815-1817	Bingley Samos	0.043	-0.618	0.980
	Newcastle	0.974		
1818-1823	Newcastle	0.748	-0.115	0.982
	High Mowthorpe	0.254		
1824-1830	Newcastle	0.712	-0.356	0.984
	Ryhill	0.284		
1831-1832	Newcastle	0.714	-0.284	0.985
	Askham Bryan	0.284		
1833-1836	High Mowthorpe	0.496	0.841	0.967
	Ryhill	0.447		
1837-1838	Askham Bryan	0.453	0.454	0.965
	Ryhill	0.478		
1839-1842	Westgate	0.530	0.322	0.978
	Askham Bryan	0.433		
1843 onwards	Bingley Samos	0.029	0.636	0.959
	Askham Bryan	0.893		

5.2 Refining Manley's Mean Calculations for the Losh record

5.2.1 Manley's Assumptions

Manley relied on the Losh series for 1802 to 1833 almost exclusively. He did not combine the record directly with any other temperature series in order to form a composite series as he did in his Lancashire reduction, for example. Section 5.1 above showed that when looking at the exposure and location of the series available for the eighteenth and nineteenth centuries, the Newcastle proxy is used for each year that the Losh data are available, but it is always combined with other series.

In order to compose the best quality series representative of Durham for 1802 to 1833, the monthly means must first be calculated as accurately as possible. Manley made assumptions when calculating the monthly means for the Losh data as follows:

a) that any missing value would be estimated based upon the surrounding hourly values within that day, and for the days either side
b) that the readings were taken at constant times each day for substantial blocks of the record

The discussion in this section concentrates on the Losh record as an example, but the principles of filling gaps and making adjustments according to the times of observation will apply to all temperature data sets that are used in this study.

5.2.2 Missing Values in the Losh Record

Whether Manley filled gaps within the Losh record depended upon the length of the gap. He ignored any larger period without readings and calculated the monthly mean using just those values present. The threshold for deciding whether to ignore a month or to estimate values for the gaps did vary but he generally discarded a month if it had more than fifteen days where readings were missing for entire days. If just one reading a day was missing, then he would generally accept more than fifteen such days before discarding the month. His estimates for the missing readings were based on looking at the days either side, and other readings for that same day. For example, January 1802 has three gaps in the temperature readings. These are shown in bold and underline type in Table 5.16, with Manley's estimates substituted.

Table 5.16 January 1802 of the Losh record at Jesmond. Readings in bold and underline type were missing from the record and were estimated by Manley (°F).

Date	Times				16	8/16/23	34	38	39
1	9/16/23	26	28	29	17	9/16/23	39	40	40
2	9/16/23	32	30	30	18	9/16/23	40	40	42
3	9/16/23	32	31	30	19	8/16/3 am	46	46	34
4	9/16/23	26	28	30	20	9/17/22	38	32	36
5	8/16/22	32	32	34	21	8/16/22	41	36	**32**
6	8/16/23	34	31	40	22	9/16/23	34	**36**	30
7	9/16/23	31	32	39	23	8/16/23	36	41	42
8	9/16/22	38	38	34	24	8/16/23	42	42	43
9	8/16/23	34	33	33	25	8/16/23	43	45	43
10	10/16/23	31	32	30	26	8/16/23	43	46	45
11	10/16/23	29	29	28	27	8/16/23	38	44	42
12	8/16/23	28	27	26	28	8/16/23	45	47	48
13	8/16/23	26	25	**24**	29	8/16/23	45	42	38
14	10/16/23	24	24	28	30	8/16/23	35	42	44
15	9/16/23	23	22	24	31	8/16/23	44	48	46

In total, the Losh record has 425 days (3.6%) where at least one value is missing, 95 of which have no readings at all. Figure 5.5 shows the distribution of the gaps in the Losh record.

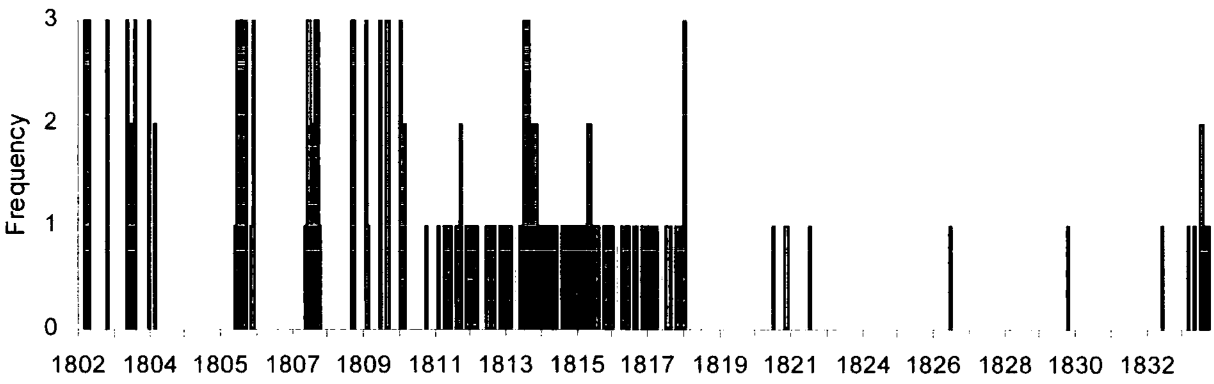


Figure 5.5 The number of missing readings in the Losh record per day.

5.2.3 Methods for Filling Gaps

Different methods can be used to fill gaps in a series. Whether gaps are filled, and if so how they are filled depend upon the nature of the gap and of the series. Three main methods for the filling of gaps in a series are explored here.

a) Climatological estimation – a missing hourly reading is the average of the readings for the same hour/day in all other years that are available for the record.

b) Interpolation – a curve is plotted of the daily/monthly readings to either side of the missing value and the graph may then be used to find the missing value. Alternatively, this may also be done algebraically. A daily mean could be interpolated, and the values which do exist for that day, if any, can be combined to deduce the missing value. This method is only suitable for plotting the daily values because there would not be enough data to draw a diurnal curve, although it might be possible to use a diurnal curve from present-day data for a site close to the series being studied for missing values. The combination of this diurnal curve and the monthly curve above could be combined to find a suitable value.

A second interpolation technique termed a 'method of first difference' could be used to take the series of daily means with a missing value and calculate the difference between each successive pair. The value to the left of the missing value can be estimated by continuing rightwards the series. This is added to the value on the left of the missing value as an initial estimate for the missing one. The same is done for the right-hand side, and the mean of the two estimates taken as the missing value.

A third interpolation method, known as kriging, combines the interpolation within the monthly curve and the missing value where it exists in other years (i.e. climatological estimation).

c) Parallel estimation – the missing value is compared with similar values at other stations. The other station could be from a site close by at the same time, or the same site at a later date. A weighted combination of surrounding stations could also be used.

Two different techniques have been tested to ascertain whether the estimation of missing readings is feasible for the temperature data used in the reduction and extension of the Durham series. The first technique considers the estimation of monthly means where an entire month or even a year is unavailable. The second method is used to estimate means for a single day where one or all of a day's individual readings are unavailable.

5.2.4 Trial of Filling Gaps by Climatological Estimation – the Valero Method

Two methods of filling gaps have been discussed in chapter 2 from papers by Valero *et al.* (1996) and Leite and Peixoto (1996). The Valero method was applied to a section of the Durham data where monthly temperature values had been taken out of the series and the method tested to see how well these 'missing' values were estimated. This method can address the problem of complete months of data missing, or where a month has so many missing values that it has to be discarded. Where there is a small proportion of values missing within a month, these can be filled using other methods, or ignored, as appropriate.

Valero *et al.* (1996) divided missing monthly values in a series into two separate types – first, where monthly means are missing for a complete year, and second, where isolated monthly means are missing. It is this second method that is applied here, and the aim is to estimate the annual mean from the monthly readings by using a weighted average from the monthly means that do exist. The monthly weights are obtained by examining means five years either side of the year in question, and for these ten years the following statistics are calculated:

$\bar{y}_{ik}$ mean for the month over the year

$\bar{X}_k$ mean of all ten annual means

$\bar{a}_{ik}$ monthly weights where $\bar{a}_{ik} = \dfrac{\bar{y}_{ik}}{\bar{X}_k}$ i.e. monthly weight = $\dfrac{\textit{mean of the month over a year}}{\textit{mean of all ten annual means}}$

For the year k, the annual mean is calculated from the following formula:

$$X_k = \sum_{i=1}^{12-m} \left(\frac{y_{ik}}{a_{ik}} \right) / (12 - m)$$

where m is the number of missing months for year k

For the case where only one monthly value is missing for a year, the formula simplifies to:

$$X_k = \sum_{i=1}^{11} \left(\frac{y_{ik}}{a_{ik}} \right) / 11$$

The missing monthly mean(s) can then be calculated from:

$$y_{ik} = X_k a_{ik}$$

Taking the set of means in Table 5.17 as an example, assume that means for 1806 are not available. This set of means is Manley's final reduction for Durham.

Table 5.17 An original, gap-free, set of means for the trial of a gap-filling exercise described in Valero et al. (1996).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1801	39.0	40.0	43.0	45.5	51.0	56.0	58.5	61.0	56.5	49.5	40.0	33.5	47.79
1802	35.7	38.0	41.2	46.2	46.5	55.0	54.8	60.5	55.5	49.5	41.5	37.7	46.84
1803	34.0	36.5	41.2	47.0	47.6	53.8	60.7	58.5	51.5	47.6	39.2	36.5	46.18
1804	39.8	34.5	37.7	41.0	52.6	57.5	58.0	57.0	57.8	51.2	42.3	35.6	47.08
1805	36.3	37.0	41.4	44.0	46.0	52.5	60.5	60.5	57.0	45.5	39.5	37.1	46.44
1806	35.3	36.6	38.5	42.0	50.0	56.0	59.0	59.8	55.0	49.3	44.1	41.1	47.23
1807	37.4	36.5	35.7	43.4	50.1	53.4	60.2	60.8	48.3	50.8	35.6	37.1	45.78
1808	36.1	36.0	38.0	40.0	52.2	55.9	61.2	61.4	52.6	43.5	42.4	36.8	46.34
1809	32.7	42.1	42.3	41.1	53.3	54.5	57.2	58.1	52.1	51.6	41.5	39.1	47.13
1810	37.0	37.5	38.8	45.0	57.6	47.1	58.1	58.5	54.7	49.8	41.2	37.0	46.86
1811	33.8	38.1	44.9	46.7	51.3	54.4	58.7	57.8	55.5	53.8	45.2	36.9	48.09
Ten year mean	36.18	37.62	40.42	43.99	50.82	54.01	58.79	59.41	54.15	49.28	40.84	36.73	46.85

The years 1801-1805 and 1807-1811 are considered for their means. Given that the mean of the annual means for these ten years is 46.85, the monthly weights are as shown in Table 5.18.

Table 5.18 Monthly weights for 1801-1805 and 1807-1811.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Weight	0.772	0.803	0.863	0.939	1.085	1.153	1.255	1.268	1.156	1.052	0.872	0.784

The estimated means for 1806 are therefore the product of these weights and the ten year mean. These are shown in Table 5.19, along with the actual means for 1806, and the differences between estimates and actuals.

Table 5.19 Estimated monthly means for 1806.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Estimate	36.17	37.62	40.43	43.99	50.83	54.02	58.80	59.41	54.16	49.29	40.8	36.73	47.50
Actual	35.3	36.6	38.5	42.0	50.0	56.0	59.0	59.8	55.0	49.3	44.1	41.1	47.23
Estimate - Actual	0.87	1.02	1.93	1.99	0.83	-1.98	-0.2	-0.39	-0.84	-0.01	3.26	-4.37	0.27

The estimates are generally higher across the year than the actual observed means. The variation from one year to the next within this example is too great for this technique to provide accurate estimates for missing values for any month in a year where data exist either side. It is possible that accuracy could be improved by examining more years either side than the five chosen for this study, but it could not then be used within ten years of the start or end of the available series. Even with five years being taken either side, the technique could only be used for the Losh series from 1807 to 1827, and many of the other series in this study are much shorter. For this reason, and also given that the estimates are not sufficiently accurate, missing values for entire months will not be estimated during this study.

5.2.5 Trial of Filling Gaps by First Difference Interpolation

Where values for one or more readings a day are missing, a technique of interpolation can be applied to estimate the missing readings. An example of this technique is shown in Table 5.20, with data from the Losh series for December 1802. This month was chosen as a winter month with several missing values, and where the hours of observation are all identical for the readings that are present so as to eliminate any extra interference.

Table 5.20 Monthly means for December 1802 reduced from Losh's observations. Values estimated, where gaps were present, are marked in bold and underline type (°F).

Date				Mean
1	34	34	36	34.67
2	32	37	37	35.33
3	43	41	41	41.67
4	41	40	36	39
5	31	31	30.5	30.83
6	36	38	39	37.67
7	40	**40.5**	38	**39.5**
8	36	38	36	36.67
9	40	37.5	39	38.83
10	45	39	39	41
11	40	38	36	38
12	35	40	46	40.33
13	39	38	37	38
14	34	40	38	37.33
15	35	40	43	39.33
16	36	40	41	39
17	36	37	31.5	34.83
18	35	41	43	39.67
19	45	47	48	46.67
20	46	**50.5**	45	**47.17**
21	38	36	34	36
22	32	32	30	31.33
23	30	33	30	31
24	30	32	29	30.33
25	27	36	34	32.33
26	33	34	36	34.33
27	34	36	34	34.67
28	34	33	31.5	32.83
29	32	41	40	37.67
30	40	40	38	39.33
31	42	**42.5**	44	**42.83**

The values in bold and underline type are those that have been estimated. The daily mean was calculated from the mean of values on either side of the day with the missing value. The missing daily mean was therefore interpolated from the difference between the mean for the day on each side of the missing value, and also the ones adjacent to those. The mean of these two means thus generated was taken to replace the missing value. In each case, two other observations within the day with the missing observation are available, so the daily mean could be calculated from the other two observations alone. At a glance, the estimated values look plausible based upon the reading to either side, but it is very difficult to tell by eye whether they are valid or not. In effect, the estimated mean could deviate quite substantially from the 'actual' value because, for a typical 30-day month in the Losh record, the estimated would need to deviate from the 'actual' by 9°F to affect the final monthly mean by 0.1°F. An alternative technique would be to extend the interpolation by taking the differences for a number of values either side of the missing day instead of just one as in the example above. When a day with a missing reading has a day adjacent to it which also has a missing reading, the technique becomes less reliable. Of the 425 days in the Losh record with missing values, 215 of these are adjacent to other days with missing values. This technique also performs best when the natural variability of the data is low, i.e. in the winter months. During the summer, the climatic variability between days, and hence the statistical deviations from one day to the next, will be greater and lead to estimated values that are less reliable. The small impact that infrequent estimated values will have on the monthly means led to the decision not to use gap-filling techniques for individual readings for the temperature series used in this reduction and extension of the Durham series.

5.2.6 Time of Reading

An analysis of the Losh record shows that the constancy of times of reading improves with time, but Manley's assumptions are still very generalised. The Losh record comprises over 90 different combinations of reading times, although most deviate little from the prevailing majority readings and therefore only small corrections are needed. The main four sets of times, 9/14/22, 8/16/23, 9/15/23 and 9/14/23, make up 91% of the readings, with the 9/14/22 combination contributing 53% of the total set. Figure 5.6 indicates the frequency of each set of observation times. In each case Manley assumes that the readings were all taken at the time that is most frequent for each set of years. It is possible that he would have been more accurate in his assessment of the times of observation, but was not able to visit Newcastle as often as he would have liked to examine the journals. Unfortunately, Joan Kenworthy had not been able to assist as much as he had hoped in the early months of her Principalship of St. Mary's College at the University of Durham.

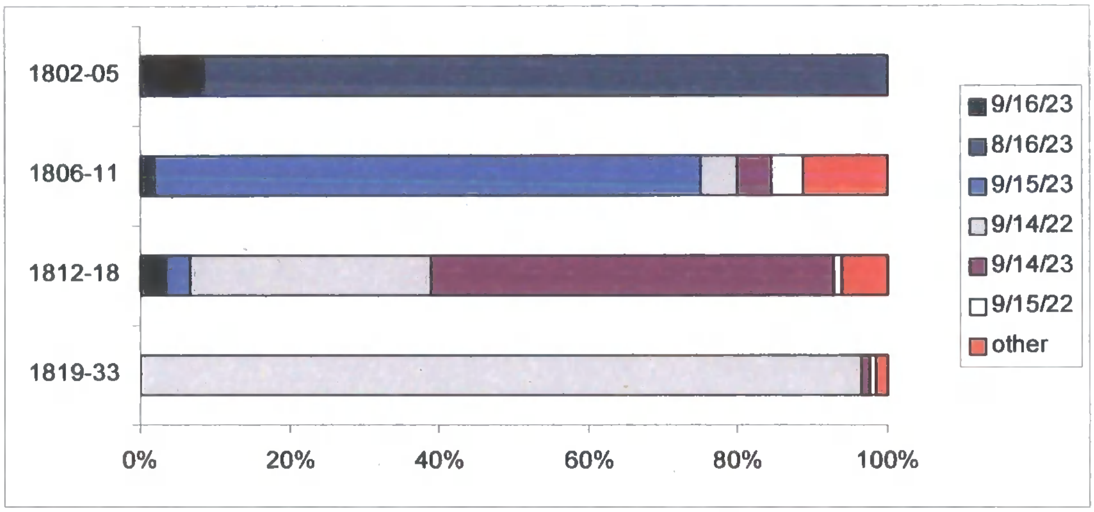


Figure 5.6 Manley's grouping of the years according to times of reading.

A more detailed analysis, year by year, shows that 1817 and 1818 should have been included in the last set of groupings, for 9/14/22. In fact, when Manley realised that he had wrongly assumed the hours of reading for 1812 to 1818 to be 9/14/22 instead of 9/14/23, he correctly included 1818 in the 9/14/22 section. This meant that he only amended the years 1812 to 1817.

To illustrate the effect of Manley's assumptions, the table for January 1802 is shown again below in Table 5.21. Days when the time of reading are different to Manley's assumption are shown with an arrow against that day. Manley assumed that for the period 1802 to 1805 readings were taken at 8/16/23. For the majority of the time they were, but it can be seen that January 1802 has many variations from this assumption.

Table 5.21 January 1802 of the Losh record. Days are arrowed where the reading times are different from those assumed by Manley.

Date	Times					Date	Times				
1	9/16/23	26	28	29	←	16	8/16/23	34	38	39	
2	9/16/23	32	30	30	←	17	9/16/23	39	40	40	←
3	9/16/23	32	31	30	←	18	9/16/23	40	40	42	←
4	9/16/23	26	28	30	←	19	8/16/3am	46	46	34	←
5	8/16/22	32	32	34	←	20	9/17/22	38	32	36	←
6	8/16/23	34	31	40		21	8/16/22	41	36	32	←
7	9/16/23	31	32	39	←	22	9/16/23	34	36	30	←
8	9/16/22	38	38	34	←	23	8/16/23	36	41	42	
9	8/16/23	34	33	33		24	8/16/23	42	42	43	
10	10/16/23	31	32	30	←	25	8/16/23	43	45	43	
11	10/16/23	29	29	28	←	26	8/16/23	43	46	45	
12	8/16/23	28	27	26		27	8/16/23	38	44	42	
13	8/16/23	26	25	24		28	8/16/23	45	47	48	
14	10/16/23	24	24	28	←	29	8/16/23	45	42	38	
15	9/16/23	23	22	24	←	30	8/16/23	35	42	44	
						31	8/16/23	44	48	46	

The calculation of the monthly means from the Losh data can be improved by using the actual observation times rather than Manley's assumed times. If this is done, the monthly means are altered. These are shown in Table 5.22 for 1808 as an example. The daily correction is derived from Glaisher's observations and resulting calculations from Greenwich (Glaisher 1849, 1850, 1867).

Table 5.22 Differences between Manley's calculated means and those derived from a more accurate correction for the hours of observation for 1808 (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Manley's Correction	36.29	36.25	38.23	39.93	55.02	56.1	62.79	58.87	51.85	44.15	42.55	37.02	46.59
Daily Correction	36.29	36.25	38.32	39.96	55.11	56.82	63.22	59.94	52.1	44.18	42.63	37.02	46.82
Difference	0.0	0.0	0.09	0.03	0.09	0.72	0.43	1.07	0.25	0.03	0.08	0.0	-0.23

1808 shows the greatest deviation between Manley's method of calculating the monthly means, and a more accurate approach where the hours of observation are corrected on a daily basis. Manley's assumptions are less satisfactory when the actual hours of observation are further away from his assumptions, and in August 1808 the readings are generally at 9/17/23. Manley's assumption of 9/15/23 shows a net two hour difference across the day and in the summer this difference has a greater effect upon the daily, and hence monthly, means. Figure 5.7 shows the differences for each month for the whole Losh series from 1802 to 1833. The peak in August 1808 can be seen clearly.

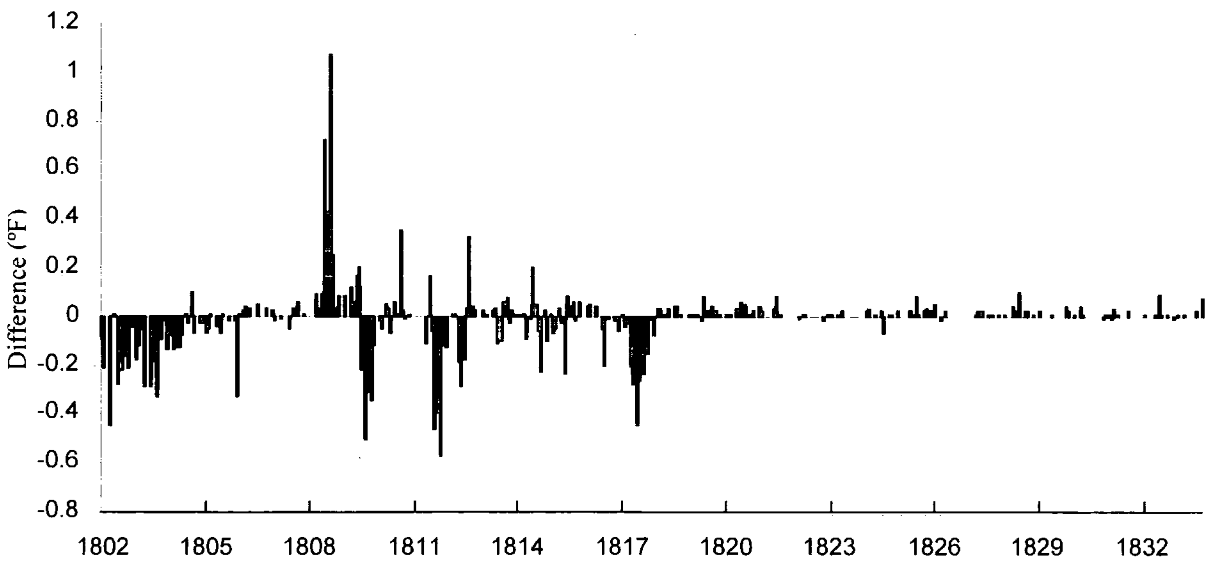


Figure 5.7 Differences between Manley's calculated means for the Losh series and those derived when a more accurate model is used for the correction for hours of observation (°F).

The monthly differences between Manley's method and the more accurate method range up to 1.07°F (0.6°C). 27% of the monthly readings have differences between the two methods of 0.1°F (0.06°C) or greater. The improved method will therefore be used when combining the Losh means into the final series for Durham.

5.2.7 Hourly Corrections

As discussed above, daily means are generally calculated from the mean of the daily extremes for each day, and the monthly means are derived from these (this mean sometimes being denoted as the Mm mean to signify its relationship to the mean of the maximum and minimum observations). The early temperature observations were made using a standard thermometer, rather than a maximum or minimum, and as such the daily extremes must be calculated from perhaps only a single temperature reading per day.

James Glaisher published corrections to be applied to fixed hour readings to bring them to a 'true mean' for the day, reduced from hourly observations at Greenwich (Glaisher 1849, 1850, 1867). This 'true mean' is taken to be the mean resulting from continuous observation throughout the 24 hour day. A further correction then needs to be made to derive the mean of the daily extremes. This mean is usually higher than the mean from typical twice-daily observations, because the latter tend to be made at 9 am (when the observed mean is still lower than the daily mean) and then late in the evening at 9, 10 or 11 pm (when the observed mean is again lower than the daily mean). Glaisher's tables show that when the temperature is observed at 10 am and 10 pm, the mean obtained is practically the same as the 'true mean'. This is the case for Greenwich, and it is assumed that the same applies to Durham.

Glaisher's publications gave two different methods of calculating the true mean for the day. The first method, published in 1849 and 1850 for example, shows corrections to be made for Greenwich itself. His second method, published in 1867, notes that the diurnal curve at Greenwich is on average flatter than at lower latitudes and more curved than at higher latitudes. It therefore provides corrections based upon the diurnal range to enable the use of the tables at places other than at Greenwich.

Other sets of corrections have been published for the United Kingdom, for Rothesay and Kew for example, but Manley was of the opinion that the Greenwich corrections were the best ones to use (Manley 1938-). When Glaisher's table from his 1867 publication is used with reference to the diurnal mean at Durham, the corrections throughout the year are substantially smaller than for Greenwich. The diurnal range for Durham, as calculated from the means of the daily extremes for 1931 to 1940, is shown in Table 5.23. This period was chosen as a typical period within the record.

Table 5.23 Mean diurnal range for Durham, calculated from observations of the daily extremes from 1931-1940 (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Diurnal Range	5.3	5.3	6.5	7.0	8.0	8.9	8.4	8.6	7.8	6.8	5.3	4.6	6.9

The corrections for Durham for two of the more common hours of observation are shown in Table 5.24, along with those adjustments for Greenwich itself.

Table 5.24 Corrections to be applied to the mean of fixed hour readings for Durham and Greenwich, the corrections for Durham being derived from Glaisher (1867) (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Durham 9 am 9 pm	0.4	0.4	0.5	0.3	0.1	-0.2	0.0	0.2	0.4	0.4	0.4	0.3	0.3
Durham 10 am 10 pm	0.1	0.3	0.1	0.0	-0.1	-0.2	-0.1	-0.1	-0.1	0.0	0.2	0.2	0.0
Greenwich 9 am 9 pm	0.7	0.9	1.0	0.6	0.2	-0.4	-0.1	0.4	0.7	0.7	0.7	0.7	0.5
Greenwich 10 am 10 pm	0.4	0.4	0.2	0.0	-0.3	-0.5	-0.4	-0.1	-0.2	-0.1	0.4	0.3	0.0

It can be seen from Table 5.24 that corrections are smaller for Durham with its lower diurnal range, and it is expected that this regime would be applicable to temperatures observed under current conditions of exposure. The mean correction for Durham is 0.2°F lower than that for Greenwich, which is likely to be greater than the error inherent in early thermometers being used for observations in the eighteenth and nineteenth centuries. Given that such instruments tended to yield greater daily extremes than modern instruments[68], the corrections for Greenwich may actually be more useful. Manley made no allowance for the differing diurnal variation between

[68] Calibration tests of the thermometers at Durham around 1847 showed that the dry-bulb instrument was registering 32.5°F at freezing point, with the maximum and minimum thermometers giving 32.7°F and 31.5°F respectively.

Greenwich and Durham, although it is not mentioned anywhere in his material that this was due to the former's corrections being more like the daily extremes for early temperature observations.

The diurnal range was compared between contemporary data from York (Heslington) for 1965-1979, and readings from the York manuscript from 1832 to 1846, as shown in Table 5.25. It can be seen that the diurnal readings between these two sites are different by, on average, almost 7°F (3.9°C). Part of this difference will result from the climatic differences between the two periods studied, but much of it is likely to be due to the suppressed daily range for the York readings caused by lower than expected readings from the York maximum thermometer, and higher readings from the York minimum thermometer.

Table 5.25 Differences between the daily range at York (1832-1846) and Heslington (1965-1979) (°F).

	1832	1833	1834	1835	1836	1837	1838	1839	1840	1841	1842	1843	1844	1845	1846	15 years
Heslington	11.0	12.4	16.0	14.9	15.2	15.6	13.7	13.6	13.6	13.8	14.9	13.9	15.6	14.8	14.5	14.2
York	7.2	6.7	7.2	6.6	6.8	7.7	7.6	7.0	7.6	7.5	7.8	7.7	6.9	7.5	7.3	7.3
Difference	3.8	5.6	8.7	8.3	8.4	7.9	6.1	6.6	5.9	6.3	7.1	6.1	8.6	7.3	7.1	6.9

Regarding the correction of the 'true mean', there are several different sets of corrections available. Glaisher, in his earlier papers, gives corrections for finding the 'daily extreme' mean from fixed hour readings that had previously been converted to the 24 hour mean. In 1867, he gave a different set of corrections, although Manley used the previous set. Table 5.26 shows these two sets of corrections to derive the mean for the daily extremes, and also the approximate correction that is obtained when the diurnal mean at Durham is compared with the mean of the fixed hour observations from 1867 to 1882, which can be taken to be a good estimate of the true correction to be applied between the two styles of temperature measurement. This assumes that observations at 10 am and 10 pm yield a mean very similar to the mean of the 24 hour day. This period was used because fixed hour readings were taken at 10 am and 10 pm, whereas before this the hours varied.

Table 5.26 Corrections for the 24 hour mean to derive the mean of the daily extremes, from the Glaisher papers, and calculated for Durham (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Earlier Glaisher Paper	0.5	0.8	0.9	0.7	0.5	0.3	0.1	0.6	0.3	0.8	0.7	0.4	0.55
Later Glaisher Paper	0.2	0.4	1.0	1.5	1.7	1.8	1.9	1.7	1.3	1.0	0.4	0.0	1.08
Durham 1867-1882	-0.08	0.30	0.47	0.66	0.69	1.03	1.34	0.97	0.65	0.37	-0.14	-0.21	0.50

The three sets of corrections shows in Table 5.26 are presented in Figure 5.8.

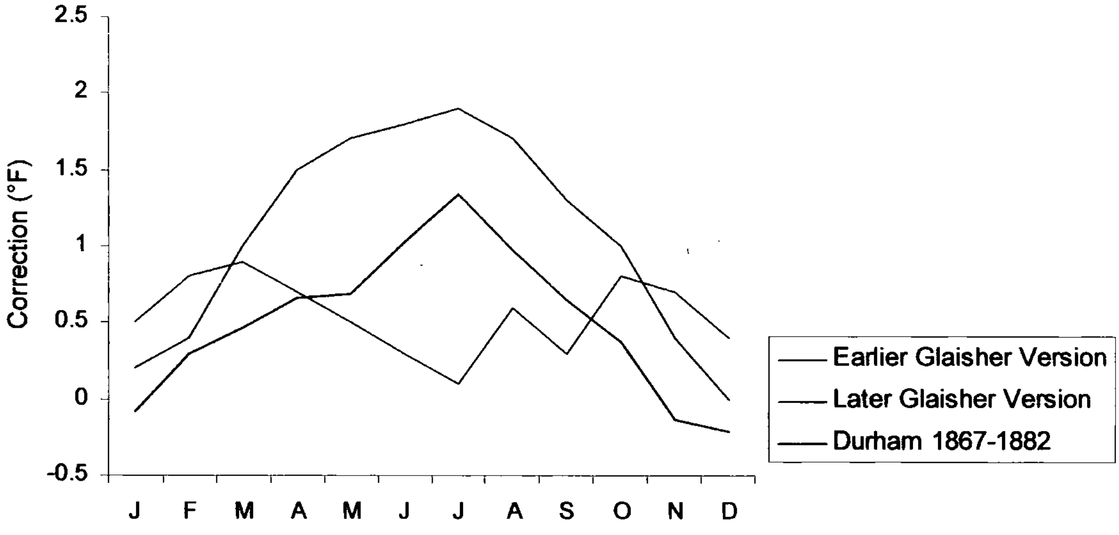


Figure 5.8 Comparison between Glaisher's corrections for Greenwich, and those derived for Durham from 1867 to 1882 (°F).

In his notes, Manley cited the set of corrections from the earlier Glaisher paper, although he did not always apply them. It can be seen from Figure 5.6 that Glaisher's early means do not follow the same pattern as that obtained directly from Durham data for 1867-1882. The curve for

Durham follows a similar pattern to that from Glaisher's later Greenwich paper, but with a mean 0.7°F lower. The annual curve for corrections for Durham gives a mean of only 0.05°F lower than that which Manley used; hence his corrections were accurate when considered across the year as a whole. In addition to this, the curve for the earlier Glaisher corrections is not as smooth as would be expected from corrections associated with mean monthly temperature. It is possible that Manley assumed that the corrections which Glaisher published were those to correct the 24 hour mean to the mean of the daily extremes, whereas they were not.

An added complication in Manley's own adjustments is that in his paper on Durham (Manley 1941b), he gave a set of corrections to be applied to fixed hour readings (at 9 am and 9 pm) which were typical of bringing means for these hours of observation to the mean of the daily extremes, as shown in Table 5.27. Further studies of the calculation of his adopted means showed that he made additional adjustments to these corrections for many months between 1850 and 1910 (Joyce 1996).

Table 5.27 Corrections made by Manley to bring fixed hour means to approximate daily extreme exposure (Manley 1941b) (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Correction	0.4	0.6	0.6	0.4	0.0	0.0	0.2	0.4	0.5	0.5	0.5	0.3	0.37

Manley stated that

> *'These last figures represent the average amount by which the means of 9 h. and 21 h. observations at Durham is thought to require correction in order to bring it to the mean of the maxima and minima, 21 h. – 21 h. Both in trend and magnitude they are not unlike those published long ago by Glaisher for the adjustment of fixed-hour observations.'*

The corrections Manley used in his Durham paper were much smaller than those he was using for his reduction of data for Durham from 1802 that he worked on in the 1970s. These latter corrections, equivalent for fixed hour observations at 9 am and 9 pm, are shown in Table 5.28, and were the sum of the corrections derived from Greenwich, plus an adjustment to bring the resulting 24 hour mean to the mean of the daily extremes.

Table 5.28 Corrections made by Manley, for his reduction for Durham from 1802, to bring fixed hour means to approximate daily extreme exposure (Manley 1941b) (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Greenwich 9 am 9 pm	0.7	0.9	1.0	0.6	0.2	-0.4	-0.1	0.4	0.7	0.7	0.7	0.7	0.5
From 24hr to Mm mean	0.5	0.8	0.9	0.7	0.5	0.3	0.1	0.6	0.3	0.8	0.7	0.4	0.6
Total Correction	1.2	1.7	1.9	1.3	0.7	-0.1	0.0	1.0	1.0	1.5	1.4	1.1	1.2

It can be seen that the lower line in Table 5.23 is different from Table 5.22 above, indicating that Manley deliberately decided not to apply the same regime of corrections to his later Durham reduction as he did for his earlier work. This presents a problem in that the available means from 1850, which Manley published in 1941, will have different adjustments applied to them than Manley's later work on the earlier period.

Figure 5.9 shows the two different sets of adjustments that Manley applied, using fixed hour means at 9 am and 9 pm to illustrate an example.

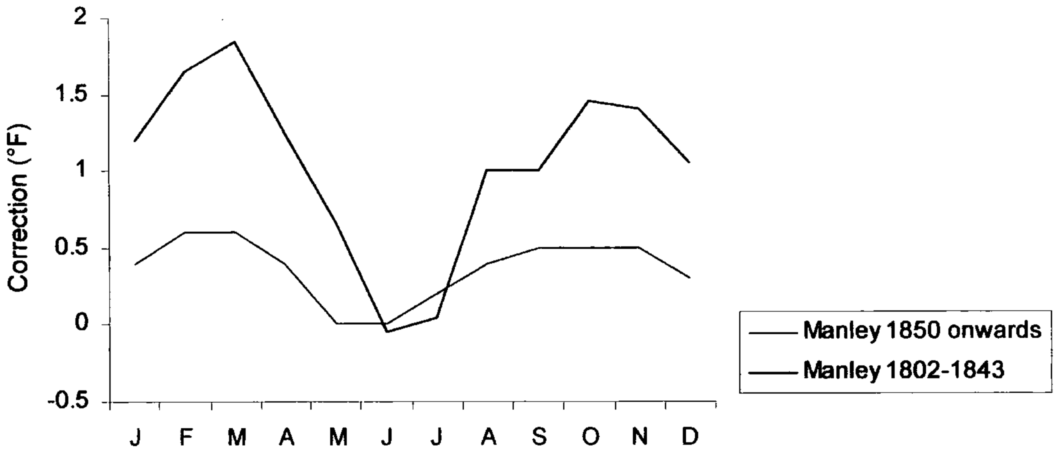


Figure 5.9 A comparison between monthly corrections applied by Manley (°F).

For the purposes of this study, the corrections employed by Glaisher at Greenwich will be used, on the premise that these were the ones which Manley used, and they are reasonably close to those derived by adjusting the corrections based upon the diurnal range at Durham. The exaggerated diurnal range apparent from early thermometers is likely to go some way towards bringing the two curves shown in Figure 5.10 above closer together.

The corrections that Manley was using in his reduction from 1802 to 1843 are shown to be too high for both the correction from fixed hour observations, and also the adjustment to the mean of the daily extremes. Figure 5.10 summarises the total corrections applied by Manley, and also the corrections that ought to be applied according to a study of actual data from Durham (1867-1882), using observation hours of 9 am and 9 pm as an example.

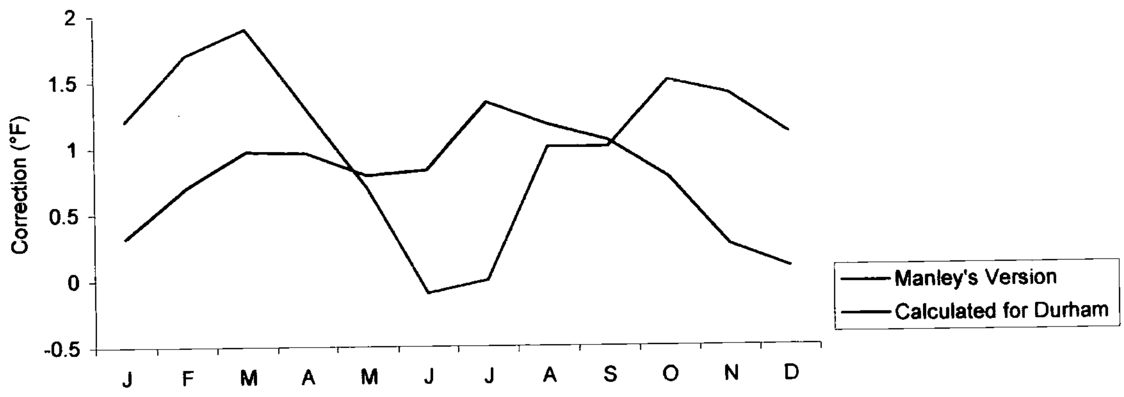


Figure 5.10 Comparison between corrections to observations applied by Manley, and those more appropriate for Durham (°F).

Given this discrepancy, the corrections to be applied within this study for the daily extreme mean will be those calculated from the Durham data for 1867 to 1882. The mean of these corrections is slightly lower across the year than those Manley employed, as published by Glaisher, and hence they will tend to lower the higher fixed-hour corrections.

5.3 Improving Manley's Choice of Series for the Extension from 1802 to 1843

5.3.1 Manley's Choice of Series

As has been discussed in chapter 4, Manley had a number of series of temperature data available, but chose not to use all of these data. By examining his letters and notes, it has been possible to ascertain exactly which series he used for each part of the reduction, although he did not leave any of this information fully documented. Table 5.29 shows how the series that Manley chose contribute to his final reduction.

Table 5.29 A summary of the series and methods used by Manley when calculating his reduction for Durham from 1802 to 1850.

Period	Series/Method
1802-1805	Losh 8/16/23; Brandsby decadal means
1806-1811	Losh 9/15/23; Brandsby decadal means
1812-1818	Losh direct from Winch
1819-1820	Losh 9/14/22; Brandsby decadal means 1811-20
1821-1830	Losh; Brandsby decadal means 1821-30
1831-1832	Losh
1833-1839	Anomalies extended back from Keighley, Ackworth, Lancashire and Edinburgh
1840-1841	Anomalies extended back from Keighley, Ackworth, Lancashire and Edinburgh, plus Yarm
1842-1843	Actual Durham data from the *Durham Advertiser*
1844-1846	Anomalies extended back from Keighley, Ackworth, Lancashire and Edinburgh, plus York
1847	York, Edinburgh deviations from the known Durham means from 1848-9 extended back to 1847
1848-1850	York, Edinburgh deviations from the known Durham means from 1848-9

When Manley was determining which series to use, he calculated annual and decadal means to ascertain whether the characteristics of a given series were appropriate to be used for the reduction, but he did not perform any statistical analyses upon these series, nor is there any evidence of him plotting any graphs of data. He had a number of other series available to him that he did not use, and tended to concentrate on the same set of series. 31 years of the reduction rely upon the Losh series, and another 16 are influenced by the Edinburgh series. He only used the series observed at Braithwaite (near Keighley) for part of its record from 1833 to 1846 whereas it is available from late 1799. He also used the York series from 1844 to 1847 but not the earlier portion of this series from 1831.

This section will identify weaknesses in Manley's choice of series for 1802 to 1850 and suggest improvements for this period. Chapter 6 discusses the extension back from 1802.

5.3.2 Disadvantages of Manley's Choice of Series

There are two main weaknesses which can be identified with the series that Manley used. First, his reduction for Durham relies upon the Lancashire and Edinburgh series. The use of these series within the Durham data, even if only for a short period, means that Durham is not independent of these other reductions, and to achieve independence for the Durham series was one of Manley's early intentions (Manley 3.vi.79). Questions are then raised about the validity of any comparisons between the three series.

The second issue with Manley's choice of series is that the total number of records he used during the entire period varies considerably as is shown above. This can lead to questions concerning the variability across the final series, as discussed in section 2.3. He also used a variety of different techniques for constructing the series as Table 5.30 shows. These different techniques can mean that consistency across the period is not maintained.

Table 5.30 Different techniques used by Manley in his reduction for Durham.

Period	Method
1802-1811	A single series modified with reference to decadal means from another series
1812-1818	A single series
1819-1830	A single series modified with reference to decadal means from another series
1831-1832	A single series
1833-1839	Anomalies from four series extended backwards
1840-1841	Five series combined
1842-1843	Actual Durham data
1844-1846	Five series combined
1847-1849	Anomalies from two series extended backwards
1850 onwards	Actual Durham data

5.3.3 Improving the Series Used

The results of the investigation into a modern series for Durham (section 5.1 above) show that there is an optimum choice of records to form the composite series based upon their individual characteristics. These series will be used to replace those that Manley chose. The new set based upon the study of 'modern' data is shown in Figure 5.11. Some series are only used for a portion of their full length; therefore the portion of the series which is used is marked with diagonal shading, and the vertical lines indicate a new combination. This section will focus upon the study of the observations available from 1802 onwards, i.e. the period that Manley worked on.

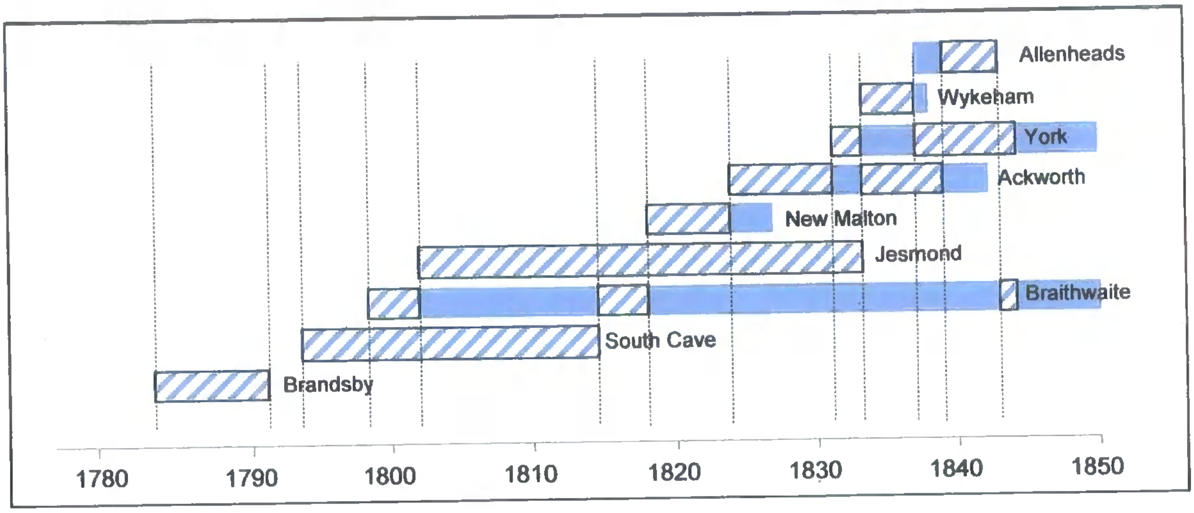


Figure 5.11 Series available for construction of a composite series for Durham where linear regression has been applied to identify optimum combinations of modern sites close to the historic locations, 1784-1843. Diagonal stripes show the portion of each series to be used.

It can be seen that the number of series remains constant through most of the period from 1800 to 1843, after which temperature data actually observed at Durham are available[69]. Unlike Manley's reduction, each series is considered throughout the time that it is available, and therefore the series can actually be extended back from 1802 by use of the records from Brandsby and Braithwaite. The Braithwaite record was known to Manley but was not used back this far when the temperature was only taken indoors. He did have temperature data from South Cave available, but was not able to include the means into his series. It is probable that he would have used the South Cave data just from the start of their availability in 1794 to 1801 when the Losh observations start, rather than overlapping the two series as this was the general practice he followed with the other periods. Manley did not use the observations from the earlier Brandsby record, probably because, although he was aware of them, he did not have the observations themselves when he was writing up his tables of reduced observations in late 1979.

[69] Observations for Durham were discovered after Manley's death. They begin in July 1843, as detailed in section 5.4; hence this section creates a reduced monthly series until June 1843.

There are several stages involved in producing a homogeneous set of monthly means, from 1802 to 1843, from the various temperature series available for the North East. Each set of observations must be analysed to ensure that the exposure is representative of that site, and any gaps in the record accounted for. In addition to this, corrections must be made for any changes in the hours of observation within that series, and then to a standard mean based upon the hours of observation. This is taken to be the true mean for the day as if temperature were sampled continuously throughout the day. For this study, reference to external series has been made as a check on the 'representation' of the series, generally comprising a comparison with the Central England temperature (Manley 1974, Parker *et al.* 1992) to ensure that differences between the series are reasonably constant. Before this can be done, the temperatures within the data set must have an adjustment made to account for the mean representing the mean for the 24 hours, as opposed to the standard mean of the daily maximum and minimum. The corrections from the observed hours to the 24 hour mean, and then to the daily mean, are made with reference to James Glaisher's observations at Greenwich, as described in the section above. Manley noted that these observations as opposed to others available at Kew or Rothesay gave better results for Durham University Observatory (Manley 1938-). The entire set of corrections is shown in Appendix B, and those made to derive the mean of the daily extremes are shown in Table 5.31. The second line of 'improved' means is derived from a study of actual Durham temperatures as discussed above, and will be applied in this section in preference to the larger corrections used by Manley.

Table 5.31 Typical corrections made to 24 hour means to derive the daily mean based upon the maximum and minimum observations (Glaisher 1867) (°F)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Manley's version	0.5	0.8	0.9	0.7	0.5	0.3	0.1	0.6	0.3	0.8	0.7	0.4	0.55
Improved version	-0.08	0.30	0.47	0.66	0.69	1.03	1.34	0.97	0.65	0.37	-0.14	-0.21	0.50

When the analysis of the individual series is complete, it is then necessary to make a correction for the altitude of the original site, which must be adjusted to the general temperature expected at Durham University Observatory, at 102 metres above mean sea level. Each distinct period from Figure 5.12 was taken, and the monthly means adjusted by a correction to bring the effective altitude of that station to that of Durham University Observatory and standardise the temperatures from the series on this basis. These corrections are shown in Table 5.32.

Table 5.32 Corrections necessary to bring monthly means to those appropriate for the altitude at Durham University Observatory.

Site	Altitude	Correction to bring to Durham
Abbey St. Bathans	202	1°F (0.6°C)
Ackworth	approx. 50	-0.5°F (-0.3°C)
Allenheads	427	3.5°F (2.0°C)
Brandsby	29	-0.7°F (-0.4°C)
Braithwaite	229	1.4°F (0.8°C)
Jesmond	46	-0.7°F (-0.4°C)
New Malton	Approx. 25	-0.9°F (-0.5°C)
South Cave	2	-1°F (-0.6°C)
Wykeham	approx. 50	-0.5°F (-0.3°C)
Yarm	approx. 30	-0.7°F (-0.4°C)
York	approx. 17	-0.9°F (-0.5°C)

When there is more than one set of observations to be used for the given period, the mean of the monthly values is taken to find the mean exposure for that month, according to the optimum differences discussed above.

Observations made at South Cave and Braithwaite are used for the improvements to Manley's reduction, and are studied in detail in chapter 6 because they are, as far as the series which he used are concerned, 'new' information that he did not have. Table 5.33 summarises the series to be used for each section of the 1802 to 1843 period. For simplicity, each period starts on January 1st, and ends on December 31st.

Table 5.33 Optimum combination of temperature series contributing to the reduction from 1802 to 1843. The value for r^2 is shown for each set of series as a predictor for temperature at Durham.

Period	Sites	r^2
1802-1814	South Cave, Jesmond	0.982
1815-1817	Braithwaite, Jesmond	0.980
1818-1823	Jesmond, New Malton	0.982
1824-1830	Jesmond, Ackworth	0.984
1831-1832	Jesmond, York	0.985
1833-1836	Wykeham, Ackworth	0.966
1837-1838	York, Ackworth	0.965
1839-1842	Allenheads, York	0.978
1843 onwards	Braithwaite, York	0.959

The temperature series used in the reduction is reasonably constant, with Braithwaite, Jesmond, York and South Cave and Ackworth forming the 'backbone' of the reduction, and Wykeham, New Malton and Allenheads providing the second series when the main series are not available. In 1843, observations from the Durham University Observatory are available, although not fully until August, so 1843 is included in the tables above. The reduction using the various series will therefore be continued until July 1843. From January 1843 only two series are available because the Allenheads observations finish at the end of 1842, to leave just Braithwaite and York available.

Each series can then be combined using the weighting determined from the regression equations to yield an estimate for the temperature at Durham University Observatory. Each component series was checked to ensure that there were no problems with the temperature readings. Chapter 6 gives an analysis of the South Cave, Brandsby and Braithwaite observations, used for the extension back from 1802, and chapters 3 and 4 an analysis of the Losh observations. The York, Wykeham, Ackworth, New Malton and Allenheads observations were then examined to correct any problematic aspects that they exhibit.

5.3.4 York

Observations from York are available from 1831 to 1860, taken by John Ford (Ford 1831-). The section of this series that concerns this study was observed only at Walmgate, in York city centre at Bootham School (until December 1846 when the school moved to Bootham)[70]. Only monthly means are available, although several different measures of the thermometers are available. The observation that is of most use in this study is the calculated mean of the maximum and minimum thermometers. In order to avoid any doubt of the calculation of this set of means, it was compared with the maximum and minimum means for each month, and was seen to be the same. No adjustments need be made to the hours of observation for this series because the means are already those for the daily extremes. As a check for any changes in exposure, Figure 5.12 shows the monthly means from 1831 to 1843, compared with those for Central England. The graph shows a good agreement between these sets of means in terms of trends in the relationship, although there are several months where the relationship between the series moves away from a small difference. It is generally the case, however, that when the difference does diverge in this way, it is not for an isolated year but is seen as part of a trend within a few years, and the difference is not unreasonable. No adjustments were made to correct for any trend in these differences..

[70] The York observations are discussed further in section 3.1.

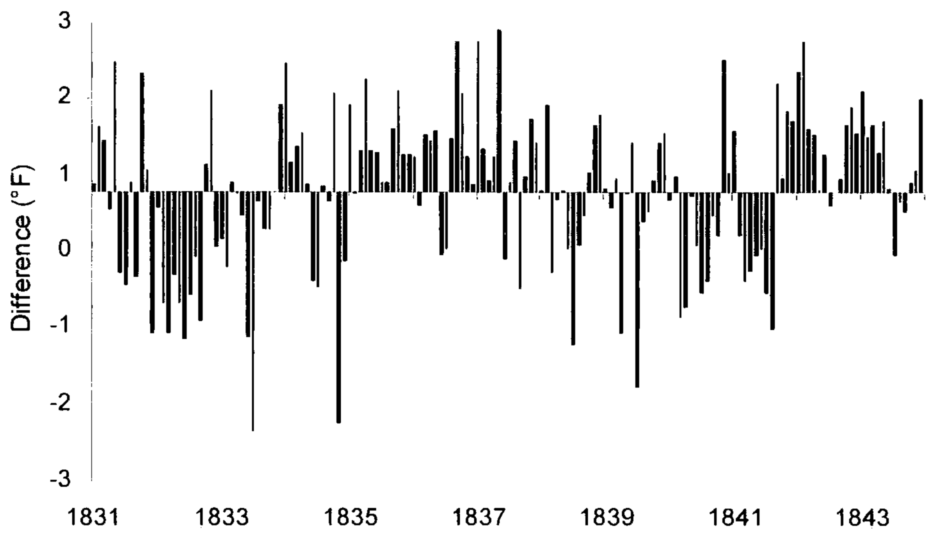


Figure 5.12 Difference between the York and Central England monthly means (°F).

The monthly means from 1831 to 1843 are shown in Appendix D. They require no adjustments from the original means of maximum and minimum thermometers.

5.3.5 Wykeham

At Wykeham, observations were made by R. N. Hodgson, from 1831 to 1837 (Manley 1938-). There are a few months missing from this series: September, October and December 1837. Three observations were made each day, at 6 am, 12 pm and 6 pm. The original source for these monthly means has not been found, with only handwritten copies of the observations among Manley's boxes of notes in Cambridge. It is not clear whether Manley had the daily means available, or whether he calculated the monthly means himself. It is assumed that the means were calculated directly from the 6 am, 12 pm and 6 pm observations, without any adjustment to the daily mean from this. Corrections derived from Glaisher's observations at Greenwich (Appendix B) were used for the adjustment to 24 hours means, and then to the mean for the daily extremes. Figure 5.13 shows a comparison between these corrected monthly means, and those for Central England for the same period.

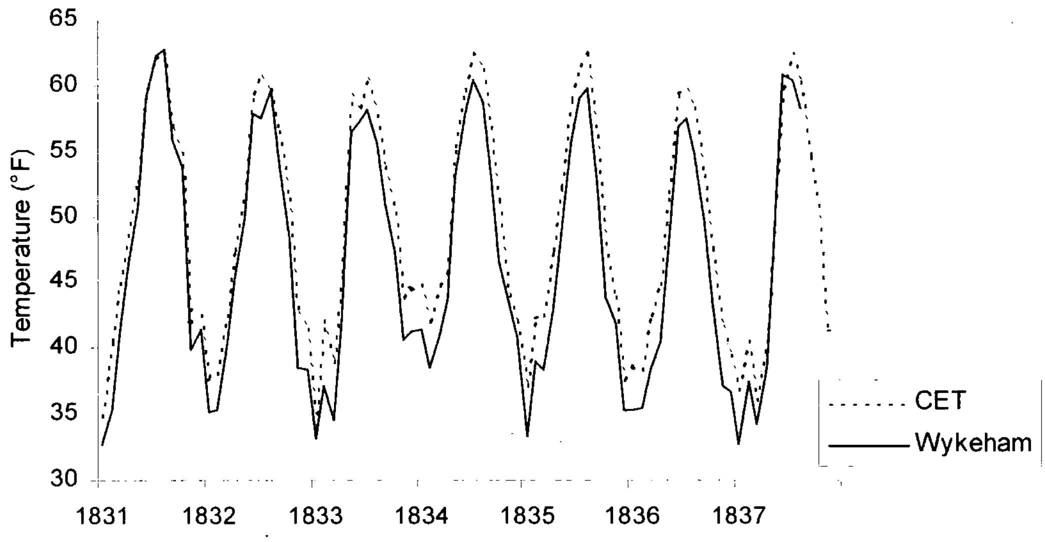


Figure 5.13 Comparison between the Wykeham (solid line) and Central England (broken line) monthly means (°F). Wykeham means have been corrected for the hours of observation.

If the corrections for the times of observations are not applied, which are always negative, then the comparison between Wykeham and Central England shows the latter series to be cooler than Wykeham for many months, which is unlikely. When corrections are applied, Wykeham is cooler in all but four months where the difference is no more than 2.0°F (1.1°C). Appendix E shows the monthly means for Wykeham, reduced from three daily readings. September, October and December 1837 are missing, presumably also from the original manuscript. The monthly means are shown in Appendix D.

5.3.6 Allenheads

Observations were made at Allenheads in 1837 and from 1839 to 1842. The manuscript (Walton 1836a, 1836b, 1840a, 1840b, 1841) contains daily means, observed at 9 am and 3 pm, both indoors and outdoors. The outdoor means were reduced to monthly values, using corrections derived by Glaisher at Greenwich, and then on to means representative of the mean of the daily extremes. There are no missing observations. Figure 5.14 shows the monthly means plotted against Central England temperature for 1839 to 1842. The difference between the two series remains reasonably constant, generally from 3 to 6.5°F (1.7 to 3.6°C).

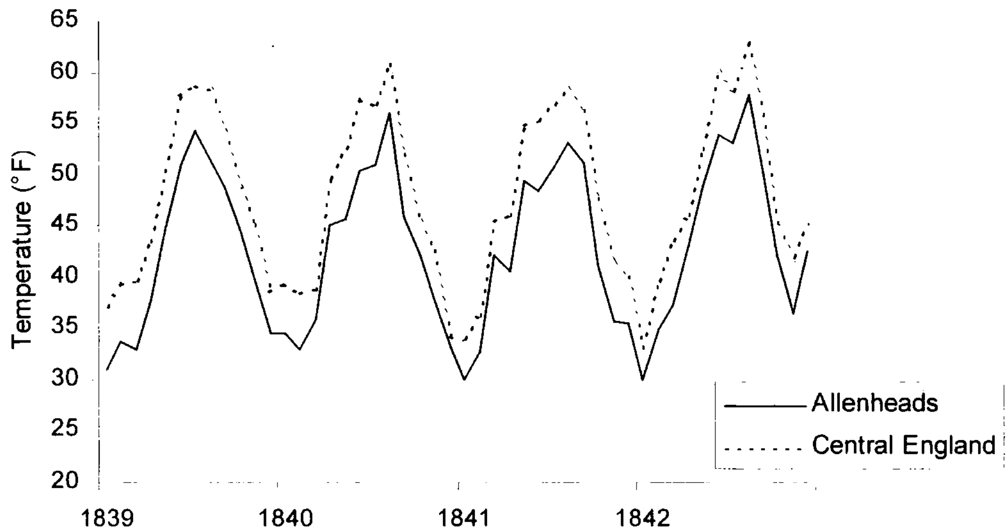


Figure 5.14 Comparison between Allenheads (solid line) and Central England (broken line) between 1839 and 1842 (°F). Allenheads means have been corrected for the hours of observation.

The monthly means are shown in Appendix D, corrected for the hours of observation.

5.3.7 Ackworth

At Ackworth, observations were made by Luke Howard and are available from 1824 to 1842 (Howard 1842a) with the monthly means already having been calculated. For 1842, however, the means do not appear to have been calculated on the same basis, and these have therefore been rejected. As a check, the pattern of exposure was examined against the Central England series for the same years of 1824 to 1841. Figure 5.15 shows the results of the comparison with the solid line representing Ackworth and the broken line representing Central England.

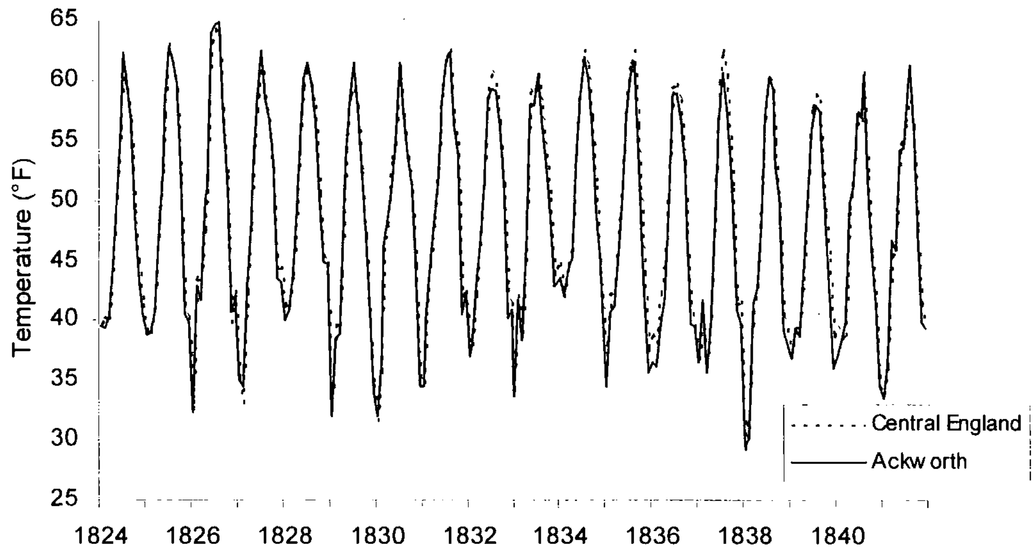


Figure 5.15 Monthly means for Ackworth (solid line) and Central England (broken line) for 1824 to 1841 (°F).

It can be seen that the agreement between Ackworth and Central England is generally good, and this can be further examined by plotting the differences between the two series, as shown in Figure 5.16. There is a noticeable trend towards a greater difference between the series in the late 1830s, with the Central England series rising to about 1°F warmer than Ackworth before the difference drops down to a mean of 0.5°F as for the 1820s.

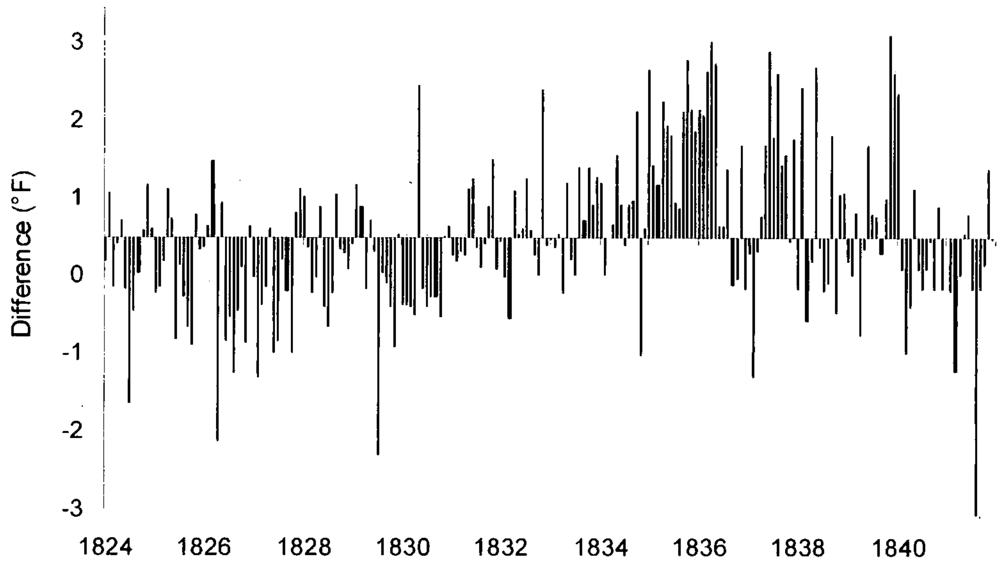


Figure 5.16 Difference between the Ackworth and Central England monthly means for 1824-1841 (°F).

The small difference and the fact that there is no overall trend do not indicate a substantial instrumental problem, but as a further check, the Ackworth monthly means were also compared with those observed at Ryhill, 5 km WSW, in the 1990s to examine whether the observations at Ackworth are typical of the region. The overall mean of the observations is different because of the different sets of years being studied, but the value for r^2 when comparing the two sets of data is 0.988. On the basis of these checks, the means for Ackworth were acceptable as being representative of the site, and it is assumed that the means were calculated by Howard using the daily extremes. The monthly means are shown in Appendix D.

5.3.8 New Malton

Very little information is known about the observations at New Malton, with the monthly means published in Dove (1838). The means are available from October 1817 with no breaks until December 1825, but it is not clear how the means were calculated. Because the period that the observations cover is completely overlapped by the Jesmond and Brandsby series, the three sets of data can be examined together to try to ascertain information about the exposure at New Malton. Also, Brandsby is just 8 km west of New Malton, so the temperature regime should be similar. When all the series are plotted together, they are seen to follow each other closely, but with a greater, seasonal difference between New Malton and Central England. Figure 5.17 shows the differences between the New Malton and Brandsby observations, and the New Malton and Central England temperatures.

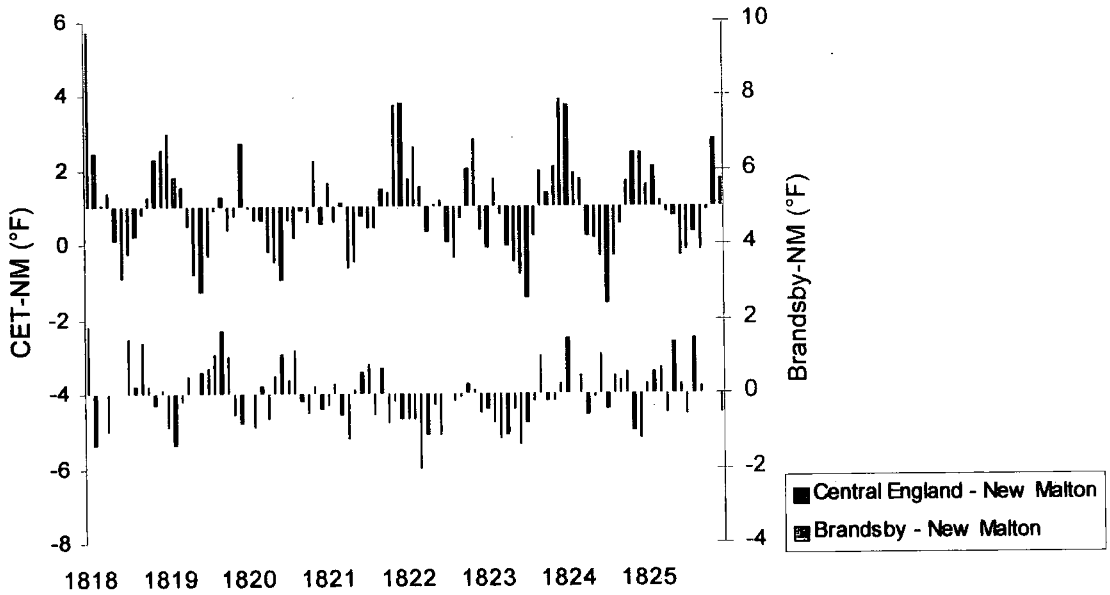


Figure 5.17 Differences between the New Malton and Brandsby observations, and the New Malton and Central England temperatures (°F).

As expected, the difference between New Malton and Brandsby monthly means is small. When compared with Central England, the pattern is similar, but within these eight years there are recurring peaks in the difference in winter. The mean of these peaks is 2.7°F, and when the differences are examined between New Malton and Jesmond, a similar pattern is seen, but with the overall mean of the differences being lower, reflecting the expected cooler temperatures in Jesmond when compared with New Malton. In this case, the mean of the winter peak difference between Jesmond and New Malton is 2.3°F. These peaks could be explained by sheltered exposure in winter at New Malton, or an alternative method of monthly mean calculation matched by a similar regime at Brandsby. For there to be such similarities in exposure, the conditions at Jesmond would need to be closer to that for the Central England data, with no clear evidence of sheltered winter exposure. Because so little is known of the exposure at New Malton, in the absence of any strong evidence of anomalous exposure or thermometer faults, when compared with other series, the monthly means as published in Dove (1838) were left uncorrected.

Monthly means for New Malton are presented in Appendix D.

5.3.9 Brandsby

Temperature data for Brandsby are available in two separate groups. The first set of observations is daily from 1783 to 1791 and the second set monthly from 1811 to 1830. It is this second set which is relevant for the reduction to Durham University Observatory for 1802 to 1843, although the results of the linear regression show that the series is not required. Nevertheless, a brief discussion follows on this latter portion of the series on the basis that the early daily data are used in the extension (chapter 6) and the exposure between the two sets is seen to be similar. Less is known about the latter exposure than the first set, but it might be assumed that the two sets were observed as a continuous series, with the period in between having been lost. If this is the case, then the known conditions of observation for the period to 1791 could be applied from 1811. It is known that both sets of observations were made at Brandsby Hall.

The earlier Brandsby series consists of several observations daily, at varying times. It is not known how the monthly means from 1811 to 1830 were calculated, although these appear in the microfilm along with the earlier means, suggesting that they were calculated soon after being observed. The means are calculated to the nearest half a degree Fahrenheit, and comments are made against the means if there are any missing days for those months. There are a few months when monthly means are not available at all, as detailed in Table 5.34.

Table 5.34 Months in the later Brandsby temperature series where a mean is not available.

Year	Month
1813	November
	December
	January
1814	January
	February
	March
	April
	May
	June
1815	August
1816	November
1818	May
1818	June

The monthly means were adjusted from the 24 hours format to be representative of means derived from the daily extremes, on the assumption that the observation regime was similar in the later series as for the earlier. Means derived from the earlier set, corrected as described in chapter 6, can be plotted along with the later set, as a check against the relative exposure, as shown in Figure 5.18.

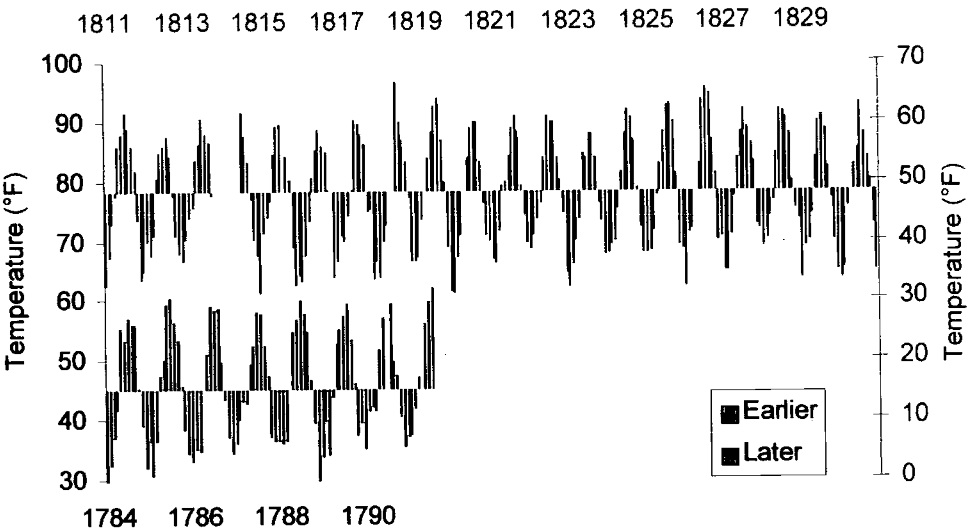


Figure 5.18 The earlier Brandsby monthly means, 1784-1791, with the later set superimposed on a separate axis (°F).

The comparison between earlier and later Brandsby data shows a good match between the two exposures, suggesting no substantial difference between the position of the thermometer between 1791 and 1811.

5.3.10 Creating the Composite Series

With monthly means for each series having been calculated, the composite series was created by taking means for each month from January 1802 to July 1843, for the series to be combined as described above. This is straightforward for most months, except for a few where a mean is missing for one of the series. Table 5.35 shows when this is the case.

Table 5.35 Months between 1802 and 1843 where observations are missing that would be used in the new reduction.

Year	Month	Missing Series
1802	*March*	*Jesmond*
	September	*South Cave*
1805	*July*	*South Cave*
1808	*July*	*South Cave*
	August	*South Cave*
1811	*July*	*South Cave*
1813	*July*	*South Cave*

For each of these months, there are still two series that may be used to form the mean in the absence of the third, and linear regression was applied to obtain the best combination of the two remaining series, and the monthly mean for Durham calculated accordingly.

5.3.11 Adjustment of Variance

The reduced series from 1802 must adhere to the same conditions of exposure as Durham University Observatory as closely as possible. As such, it is different from the Central England series, for example, in that the modelled station is a single site, rather than an area. Where temperature observations from a number of separate stations are combined, the variance of the combined series may be less than for the individual series, and an adjustment may need to be made for this. Manley did not use this technique in his original composition (Manley 1953), but the daily version of his series composed by Parker *et al.* (1992) ensured that a correction was made as the number of series varied between one and three. Corrections for the Durham series would be effectively to increase the variance by applying a factor to the individual monthly means. An investigation was performed to check whether an adjustment for the monthly

Durham means was appropriate, starting with an examination of the method adopted for the Central England series.

Parker *et al.* (1992) examine two correction factors to apply to the daily Central England data. The first is an estimated correction based upon the standard deviations of two portions of the daily series, in their case for two 30-year segments, and is termed b_1. Because it is taking two actual portions of data, this correction aims to examine the shift between the two sets of data that includes any change in variance, plus any other differences such as observation practice and exposure[71]. The second correction factor, b_2, examines solely the change in variance induced by the number of series incorporated into the reduction. Parker *et al.* (1992) then combine these two adjustments to reach the corrections for each month:

$$b_i = \frac{\overline{b}_1}{\overline{b}_2} b_{2i}$$

Adjustments made to the composite series for any systematic changes in exposure, hours of observation or instrumental error have already been corrected for, where possible, and therefore the first corrective factor (b_1) was not used. Instead, the factor b_2 (referred to hereafter as b) was calculated for each group of months where the number of combined series was not one.

The first step in the process is to find the effective number of stations that are used, and this is likely to be different to the actual number of series (Yevjevich 1972). The statistic for the effective number of stations, n', is defined as

$$n' = \frac{n}{1 + \bar{r}(n-1)}$$

[71] Parker cites the shift from Glaisher stand to Stevenson screen exposure in their choice of segments of 1848-1877 and 1878-1908.

where n is the number of stations, and $\bar{r}$ the mean linear correlation coefficient between each individual station. Generally, for the Durham reduction presented above, there are two stations, with $n = 2$, there will be one pair of correlations, and hence $\bar{r}$ will be the same as this single correlation coefficient.

The adjustment factor to be applied to the monthly means, b, is therefore

$$b_i = \sqrt{\frac{1+2r_i}{3}}$$ where the number of stations is three (1802-1842)

$$b_i = \sqrt{\frac{1+r_i}{2}}$$ where the number of stations is two (1843)

To adjust the variance of a set of data by the value b, it is necessary to multiply each temperature anomaly for that month from the annual mean by the square root of b.

The variance of the new reduced data for Durham was examined and compared with that for the Central England temperature series for the same period, 1802 to 1843. This is shown in Figure 5.19.

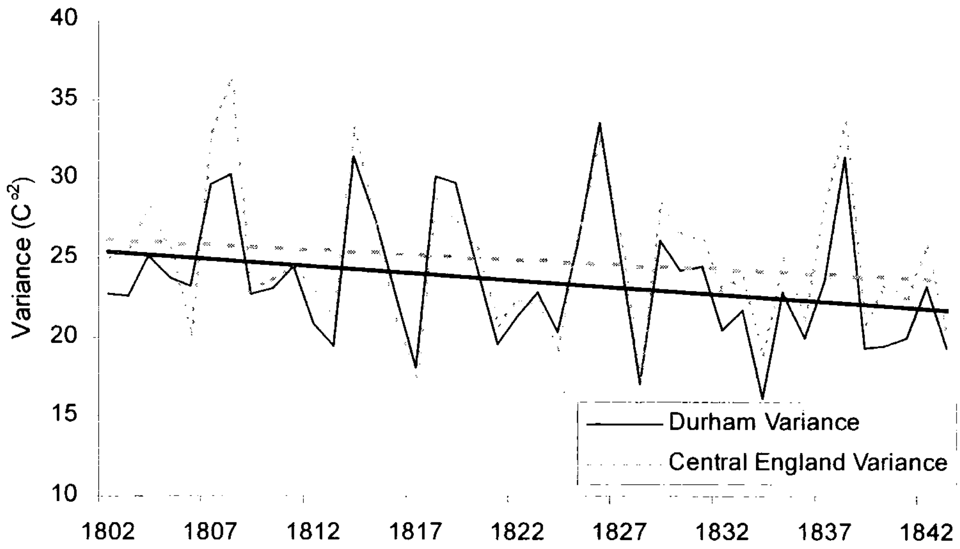


Figure 5.19 Variance for the Durham reduction (solid line) and Central England temperatures (broken line), 1802-1841 (C^{o2}).

The pattern of variance between the two series is seen to be closely matched, with the magnitude of variance greater for Central England, as would be expected from the higher temperature that it exhibits (a mean difference of 0.78°C between 1802 and 1843). The variance of the Durham temperature data is suppressed below what would be expected from the long-term trend between 1802 and 1809, with these data being derived from the Jesmond and South Cave temperature series. What is not seen however is an overall difference between the variance of the two series that might be corrected by applying adjustments to the monthly means for Durham.

To check the suitability of the variance correction method, two periods were studied. From 1802 to 1814, the Jesmond and South Cave data are used for the reduction, and during this period the difference in variance between the reduced Durham series and CET reaches a peak at around 1809. From 1824 to 1841, the Jesmond and Ackworth data are used for the reduction. For the early section of this period, from 1825 to 1829, the variance between Durham and CET is very similar, but from 1830 the Durham variance is lower than CET by approximately 2°C^2. Tables 5.36 and 5.37 shows how the values of n' and b vary for each month for these two periods.

Table 5.36 Values of n' and b, 1802-1814.

1802-1814	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
n'	1.21	1.37	1.22	1.34	1.09	1.25	1.20	1.56	1.27	1.08	1.19	1.25
b	0.91	0.85	0.90	0.86	0.96	0.89	0.91	0.80	0.89	0.96	0.92	0.89

Table 5.37 Values of n' and b, 1824-1841.

1824-1841	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
n'	1.02	1.06	1.12	1.23	1.09	1.02	1.18	1.02	1.04	1.06	1.11	1.03
b	0.99	0.97	0.95	0.90	0.96	0.99	0.92	0.99	0.98	0.97	0.95	0.99

In order to correct these two periods for variance, the values of b were applied to the reduced Durham means as described above. Figure 5.20 shows the resulting variance of the reduction from 1802 to 1843, together with the variance of the unadjusted data. The unadjusted data are shown in a broken line, with the adjusted data in a solid line.

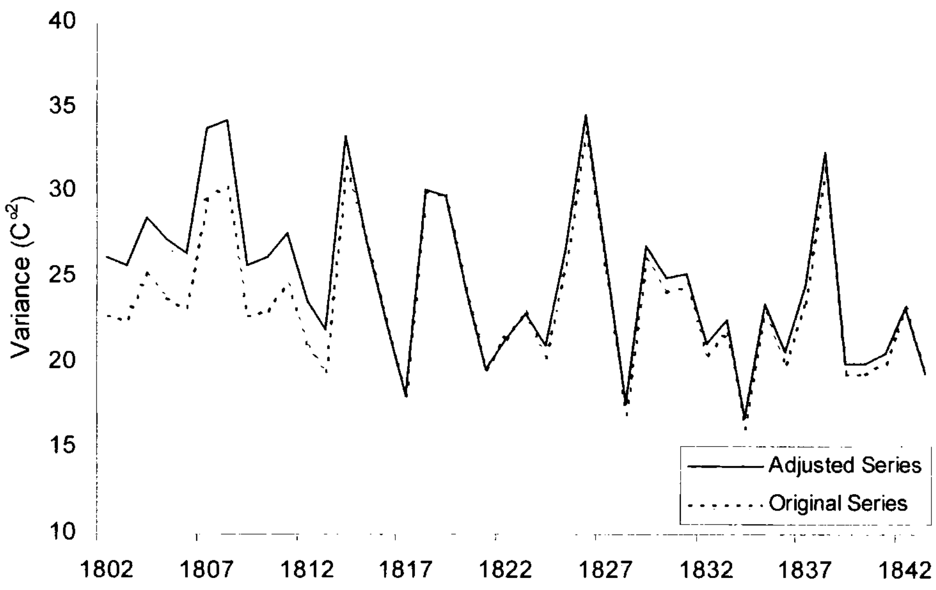


Figure 5.20 Adjusted (solid line) and unadjusted (broken line) temperature data reduced for Durham and adjusted to amend the variance to that of a series observed using just a single station, 1802-1843 (C^{o2}).

The variance for the period from 1802 to 1812 has been increased the most, by a mean increase of 3.3C^{o2}. It can be seen from Figure 5.21 that the variance for this period is much greater than the long-term mean variance for the entire period for 1802 to 1843. When this period is compared with the variance adjustment for 1824 to 1842, it can be seen that the earlier period is anomalous in the scale of the adjustment it required. Given that this period is composed of temperature data from Jesmond and South Cave it is possible that one or the other of these series has a fault within its observations. Availability of Jesmond data continues after 1814 and the variance adjustments in this section are much lower, whereas South Cave is only used as late as 1814. To examine the benefit of applying the variance adjustment to this earlier period, the variance of the Central England temperature series was added, as shown in Figure 5.21. The CET variance is shown as a heavy black line, with the adjusted Durham series variance shown in a broken line.

Figure 5.21 Variance for the reduced Durham series (broken line) and Central England series (solid line), 1802-1843 (C^{o2}).

The variance for the adjusted Durham temperature series between 1802 and 1814 is seen to be higher than that for the same period of the Central England series. In addition, the variance for the Central England series across the entire period from 1802 to 1843 displays no substantial downward trend (with a regression formula of $y = -0.064x + 26.25$; y being temperature and x being the number of years from 1802) compared with that for the adjusted Durham series that displays a slightly stronger downward trend (with a regression formula of $y = -0.167x + 28.45$; Central England temperature acting as a predictor for Durham temperature). On this basis, the variance of the Durham temperature series was not adjusted based upon the numbers of constituent series used in the reduction.

5.4 Introduction of Data Observed at Durham from 1843

5.4.1 Two New Journals

During a catalogue of the basement of the University Library in the early 1980s, two further volumes of meteorological observations were discovered. Manley assumed that these had been lost, and that R. C. Carrington made the first set of surviving observations from January 1st 1850. Manley knew from the publication of temperature observations in the *Durham Advertiser* that meteorological work was being pursued before 1850 but was unable to locate the original ledgers. The first of the two volumes covers July 23rd 1843 to December 31st 1847 (Durham University 1843-), and the second from January 1st 1848 to April 30th 1850 (Durham University 1848-).

The journals contain observations for the barometer, attached thermometer, external thermometer, minimum and maximum thermometer readings, wind direction, and rainfall. Readings of the instruments was made at 9 am and 9 pm, and there was also a spell of incomplete hourly observations around the autumn equinox in 1846. The maximum thermometer was read at 9 pm, and the minimum at 9 am.

Comments against certain days, written by the observer, indicate monthly means, and estimates for missing readings, which are fairly infrequent. There are also observations about the general state of the weather such as one on September 12th 1843 stating 'foggy', and some observations have a '?' besides them.

When calculating the monthly means, which are shown for the 'spot' readings at 9 am and 9 pm, and for the minimum and maximum observations, the observer did check those made previously, for some have question marks against them and a revised observation. On November 16th 1843, the minimum was initially written as 45.3, but was amended to 35.3 with '??' against it. On the next day, it is possible that the maximum observation was not made and a figure is written in as '43 say'.

On December 13th 1844, against the 9 pm reading, a comment is made in the margin stating a potential problem with one of the thermometers

> *'The Mercury in the Max thermometer was touching the steel and hence it appears at this temperature to be 2 degrees higher than the large thermometer.'*

Again at 9 pm on January 10th 1845, the maximum thermometer was 'in contact with float', and at 9 pm on November 5th 1845 the 'maximum thermometer had float apparently in contact'. This occurred again on November 15th and December 24th. It seemed that a new maximum thermometer was acquired on January 4th 1846, from which point comments on the float ceased, and another new maximum thermometer was used for the first time on July 15th 1847 – because the end of March the maximum readings were observed only to the nearest whole degree and very occasionally to the nearest half-degree. Even after the new thermometer was used, there are still odd comments about both maximum and minimum thermometers being 'in contact'.

From August 4th 1845 to the morning reading on the 8th, there are no observations. In the margin is written a comment concerning this gap

> *'A break occurs here in consequence of a mistake either on my own part or on that of Mr. Veale (observer pro tem), who supposed that I had not gone away, and was not informed of my absence until the Friday the 8th inst.'*

From October 1846, wet and dry thermometer readings were made every day at both 9 am and 9 pm. Between February 15th and 20th 1848, the maximum thermometer was 'out of order' and estimates were made based upon the observer's own impression of the day's temperature. On May 3rd 1849, the maximum thermometer was replaced once more, with the comment stating the make of the previous thermometer as an 'Adie'. No observations were recorded on the evening of October 22nd 1849, nor the following morning, and on the next day the neat writing of R.C. Carrington begins. On the 26th, the maximum thermometer was again 'out of order' and no reading was recorded.

There are some periods from the journals where the observer appears to have been away, or unable to take readings, and others have performed the task. Near the end of the second journal, from December 24th to January 2nd, a comment is made by Carrington concerning his substitute

> *'The observations taken by Mr Cruddas[72] watchmaker btwn the 24th & the 2nd of January were found full of mistakes and unfit to be retained.'*

There seems to be a great concern made throughout the journals for good observation practice, despite the observer's prime role being astronomical rather than meteorological. Towards the back of the second journal is an analysis of the accuracy of the thermometers, made by surrounding the standard and maximum thermometers in a bag of melting snow, and placing the minimum, wet and dry thermometers directly in melting snow. The results are as follows.

Standard	*32.4*
Maximum	*32.7*
Minimum	*31.5*
Woodenscale Min.	*30.0*
Wet	*32.5*
Dry	*32.5*

[72] The handwriting in the journal is not clear concerning this name, although the Cruddases were a fairly prominent local family. One of the buildings at St. John's College, Durham, is named after a Dora Cruddas.

The second of the more recently discovered journals runs until April 30th 1850, and yet the first one which Manley knew of begins on January 1st 1850. For some reason, Carrington copied the first four months of 1850 to a new ledger, possibly to mark his arrival with a new journal, or perhaps because he considered the previous readings to be of inferior quality, although there is no direct evidence for this. It is uncertain why these two ledgers were placed apart from the later set.

5.4.2 Monthly Means

Because the two new journals include observations at 9 am and 9 pm and the maximum and minimum readings, a variety of means may be calculated. The monthly mean is at the present time conventionally taken as the mean of the maximum and minimum observations, but there is some doubt expressed in the manuscript concerning the accuracy of the maximum thermometer (the test using melting snow yielded an observation of 32.7°F). Manley used the 9 am and 9 pm observations, in addition to those from the maximum and minimum thermometers, to create 'adopted' monthly means, detailed in his 1941 paper on the Durham temperature series (Manley 1941b).

Means from the daily values in the manuscript were all recalculated to check the derivation of the monthly means, and some errors were found in the means given in the manuscript, and hence also those reproduced in Kenworthy (1985).

Table 5.38 shows the monthly means calculated from the manuscript using 9 am and 9 pm readings, plus an adjustment for these times of day according to Glaisher's corrections (Appendix B), and those derived from the maximum and minimum observations. The means shown are those as recalculated from the daily values, rather than the means given by the observer.

Table 5.38 Calculated means from the two journals for Durham University Observatory from July 1843 to December 1849 (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1843 9/21							58.5[73]	58.8	57.6	44.3	40.3	44.1
1843 M/m							57.7	58.3	58.3	45.8	41.9	45.3
1844 9/21	37.9	33.2	38.7	48.0	48.4	55.6	57.6	55.2	54.3	46.7	42.4	34.0
1844 M/m	39.1	35.0	40.3	49.0	48.6	54.8	56.7	55.5	55.2	47.8	44.2	35.3
1845 9/21	35.9	31.9	35.4	43.5	46	58.1	55.5	54.7	50.9	47.2	42.9	37.6
1845 M/m	37.7	34.1	36.6	44.5	46.9	57.4	55.9	55.2	51.4	48.6	44.6	38.6
1846 9/21	40.6	42.3	40.0	42.6	51.9	64.5	60.6	60.1	56.8	47.0	42.6	32.8
1846 M/m	41.2	42.9	40.4	43.2	51.5	63.6	60.7	59.7	56.8	48.2	43.9	33.2
1847 9/21	34.2	34.9	39.8	42.3	51.4	55.7	61.8	57.3	50.3	47.7	44.2	39.8
1847 M/m	34.7	35.4	40.7	41.5	51.6	55.5	61.5	56.5	50.7	48.1	45.2	40.0
1848 9/21	33.1	39.7	39.5	43.1	56.4	55.5	59.0	54.5	53.1	46.6	40.2	38.9
1848 M/m	33.2	40.6	40.6	43.7	55.5	55.3	58.3	54.0	53.3	47.6	40.9	40.1
1849 9/21	37.4	40.8	40.8	41.1	50.0	53.8	57.7	57.7	53.1	44.7	41.2	38.1
1849 M/m	37.7	41.9	40.7	41.3	50.2	53.7	57.2	57.8	53.5	45.5	41.1	38.1

The relationship between means derived from 9 am and 9 pm observations, and from the maximum and minimum observations can be seen more clearly in the graph shown in Figure 5.22. The mean representative of the daily extremes can be derived from the fixed hour readings, bringing them first to the mean for the 24 hour day, and then to the maximum/minimum mean. These correction factors are those used in the rest of this chapter, and in chapter 6, and are shown in Table 5.39.

[73] Observations began on July 23rd 1843, so the means for this month are likely to be slightly lower than expected were the full month available.

Table 5.39 Corrections to bring monthly means from a mean observed at 9 am and 9 pm to one observed using the maximum and minimum readings for the day (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
24 hour mean	0.7	0.85	0.95	0.55	0.15	-0.35	-0.05	0.4	0.7	0.65	0.7	0.65
Max/Min Mean	-0.08	0.30	0.47	0.66	0.69	1.03	1.34	0.97	0.65	0.37	-0.14	-0.21

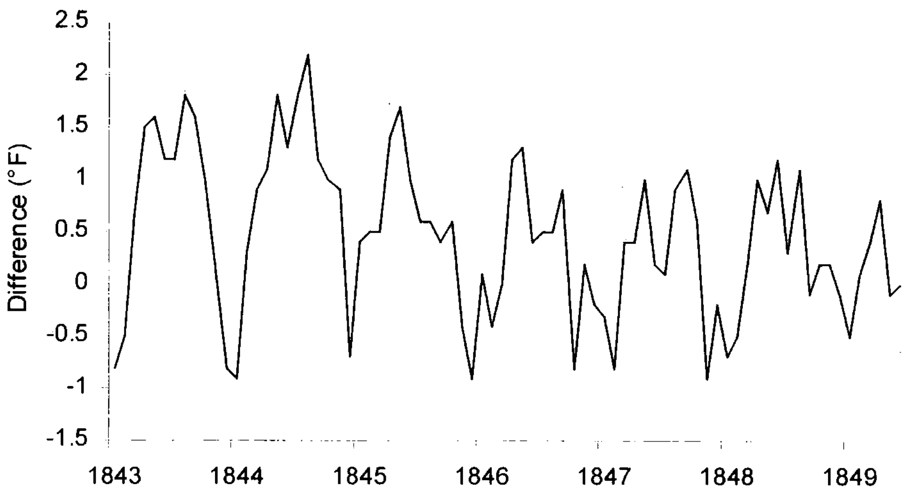


Figure 5.22 Differences between the mean calculated from the actual maximum and minimum daily observations and the 9 am and 9 pm observations (°F).

It can be seen from Figure 5.22 that the mean derived from the maximum and minimum readings is higher than the fixed-hour mean during the first half of this portion of the record. This could be due to problems with the maximum thermometer as described above. Manley was aware of problems with the maximum and minimum readings when he reviewed the means from 1850 onwards, and it was because of this that he implemented his adopted means. When Manley took data from the *Durham Advertiser*, he made no adjustments to the means, although this was probably due to a lack of time. The means derived from the two early journals will be subjected to the same process of creating adopted means as Manley used in his later reduction.

5.4.3 Adopted Means

Manley's adopted means were calculated by

$$A = \frac{1}{2}M + \frac{1}{2}(F + K)$$

where A is the adopted mean, M is the mean derived from maximum and minimum readings, F is the mean derived from fixed hour readings at 9 am and 9 pm, and K is an adjustment factor as shown in Table 5.40.

Table 5.40 Corrections made by Manley to bring fixed hour means to approximate daily extreme exposure (Manley 1941b) (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
K	0.4	0.6	0.6	0.4	0	0	0.2	0.4	0.5	0.5	0.5	0.3	0.37

Table 5.40 is therefore Manley's assumed corrections to bring the mean of the fixed hours to the mean of the daily extremes, and he made the comment that these adjustments 'in trend and magnitude are not unlike those published long ago by Glaisher for the adjustment of fixed-hour observations'. These corrections can be compared with the line from Table 5.39 above that shows the Max/Min adjustment. In the calculation of adopted means from 1843, Manley's corrections were used. Adopted means from July 1843 to December 1849 are shown in Table 5.41.

Table 5.41 Adopted means derived from the fixed hour and daily extreme means for Durham from 1843 to 1849 (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1843							58.6	59.8	58.6	45.8	41.7	45.2
1844	39.1	34.9	40.6	49.3	49.1	55.6	57.7	56.2	55.3	48.2	43.8	35.1
1845	37.1	33.6	37.3	44.8	46.7	58.1	55.6	55.7	51.9	48.7	44.3	38.7
1846	41.8	44.0	41.9	43.9	52.6	64.5	60.7	61.1	57.8	48.5	44.0	33.9
1847	35.4	36.6	41.7	43.6	52.1	55.7	61.9	58.3	51.3	49.2	45.6	40.9
1848	34.3	41.4	41.4	44.4	57.1	55.5	59.1	55.5	54.1	48.1	41.6	40.0
1849	38.6	42.5	42.7	42.4	50.7	53.8	57.8	58.7	54.1	46.2	42.6	39.2

These adopted means differ, as might be expected, from Manley's reduction for Durham made in the late 1970s, but interestingly the deviation between his reduction and the mean derived from the new journals using the *maximum* and *minimum* observations is zero. The *adopted means* compared with Manley's reduction are shown in Figure 5.23.

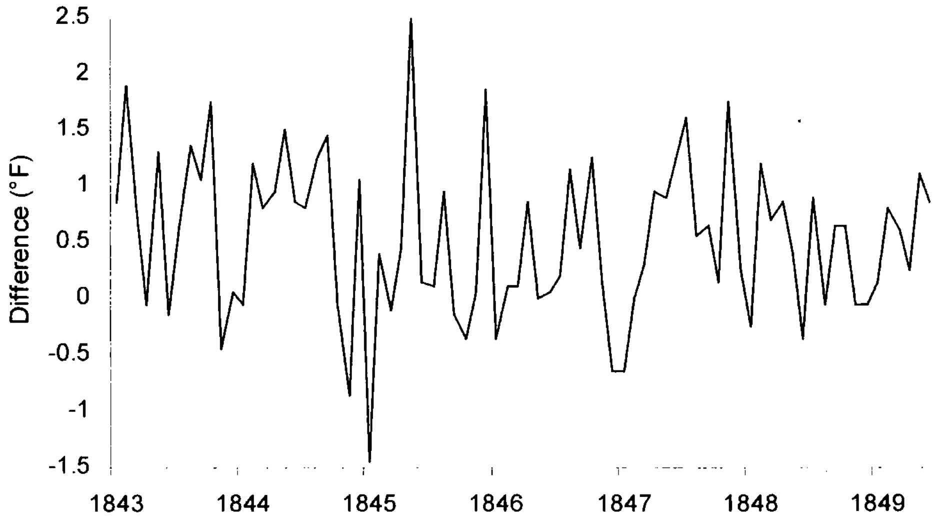


Figure 5.23 Differences between the adopted means and Manley's reduction for 1843-1849 (°F).

The principle of the adopted means is to smooth the mean of the daily extremes. Figure 5.24 shows curves for the daily extreme mean and the adopted mean. Any divergence between these two curves can be seen on this graph, and in Table 5.42 which shows the differences between the two sets of observations, for which the overall mean difference is 0.6°F (0.3°C).

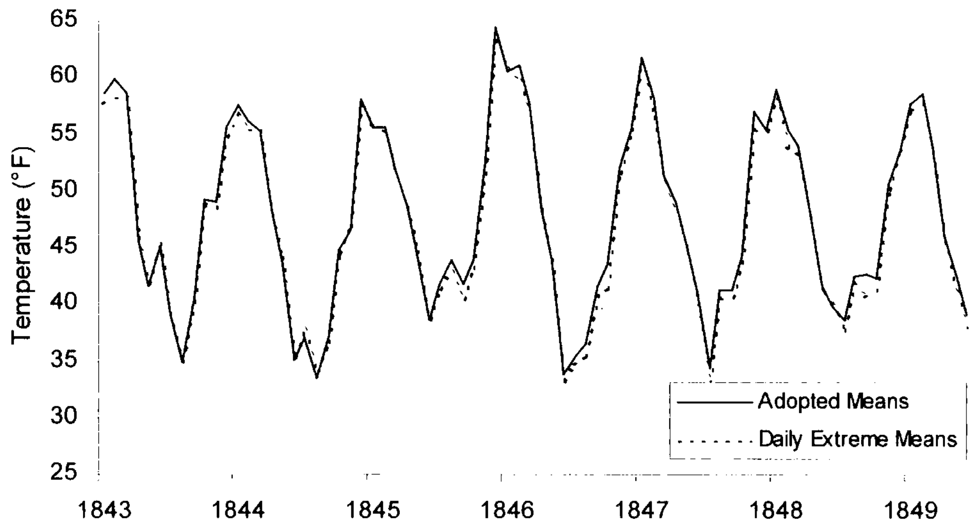


Figure 5.24 Adopted means (solid line) and mean derived from the daily extremes (broken line) for Durham from 1843 to 1849 (°F).

Table 5.42 Differences between the adopted means and the daily extreme means for Durham from 1843 to 1849 (°F).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1843							0.9	1.5	0.3	-0.1	-0.2	-0.1
1844	0.0	-0.1	0.3	0.3	0.4	0.8	1.0	0.7	0.1	0.4	-0.4	-0.3
1845	-0.6	-0.6	0.6	0.3	-0.3	0.6	-0.3	0.5	0.5	0.0	-0.3	0.0
1846	0.6	1.1	1.5	0.6	1.1	0.9	0.0	1.4	1.0	0.2	0.1	0.6
1847	0.7	1.2	0.9	2.1	0.4	0.1	0.4	1.8	0.6	1.1	0.4	0.8
1848	1.1	0.8	0.8	0.6	1.6	0.1	0.8	1.5	0.8	0.4	0.7	-0.2
1849	0.9	0.5	2.0	1.1	0.4	0.0	0.6	0.9	0.6	0.6	1.5	1.1

As a check on the integration of the adopted means with the monthly means the annual means for Durham from 1802 to 1940, together with means for the same period from the Central England record, are shown in Figure 5.25.

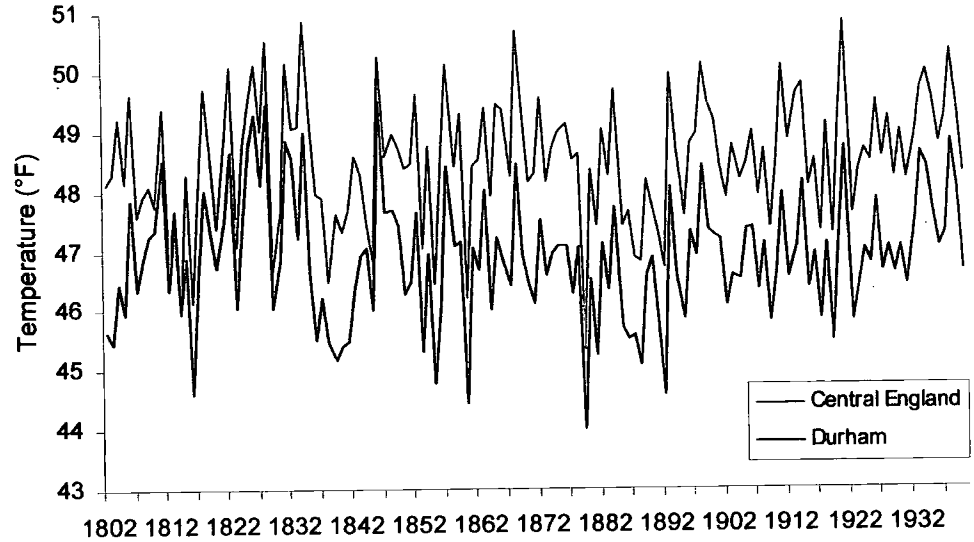


Figure 5.25 Annual Durham and Central England temperatures, 1802 to 1940 (°F).

It can be seen from Figure 5.25 that the difference between the two temperature series does change during the period. Figure 5.26 shows differences between the means for 1802 to 1940.

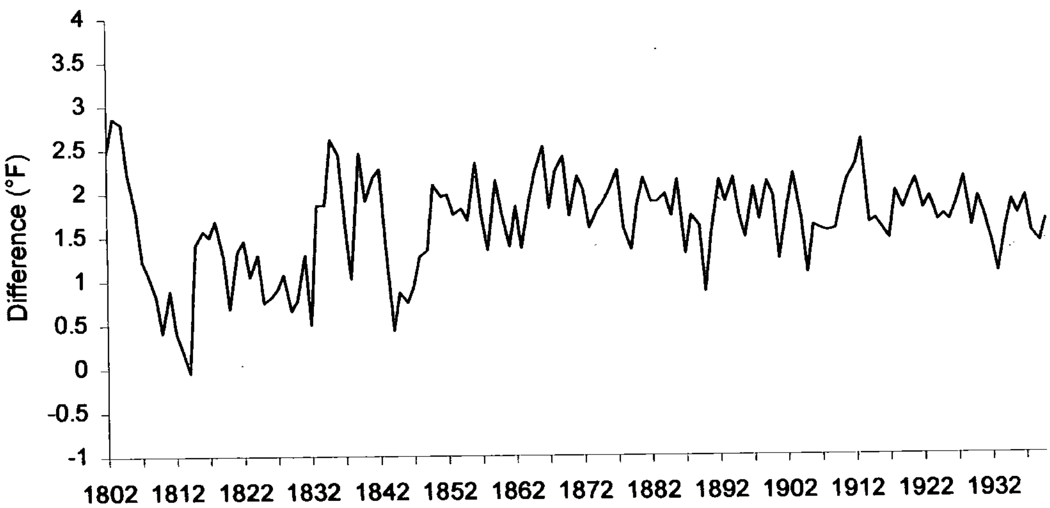


Figure 5.26 Annual differences between Durham and Central England (°F).

There is a distinction between the differences before around 1850, and after 1850, which is unexpected because the means calculated for 1843 to 1849 use the same method as that afterwards. The calculated means from the 'new' Durham journals covers only a short period but appears from Figure 5.26 to follow the same pattern as the means from 1802 rather than those from 1850. These results, and further comparison with other long-term series, will be discussed in the next chapters.

5.5 Summary of Chapter Five

A mechanism for creating mean temperature for Durham University Observatory has been introduced in this chapter. By analysing the relationship between a number of sites across the North East of England and the Scottish Borders, it has been possible to use the technique of multiple regression to derive weights to be applied to observations from Westgate (in Weardale), Askham Bryan (near York) and Newcastle. These stations were chosen deliberately as being close to sites where historical observations were made, thereby creating a method for the combination of this historic data such that it best represents 'Durham'. A discussion of the results showed a general tendency for these stations to be dispersed well across the region.

Once a framework was in place for the assembly of data, attention was paid to the quality of this data by improving Manley's corrections with more refined techniques of correcting for the times of observation for the historic readings and a study of filling gaps in these records. Each of the series to be used in the new reduction was studied in more detail to ensure there were no problems with the data, possibly resulting from the exposure. Finally, data actually observed at Durham were introduced to the new reduction from mid-1843.

Chapter 6 – Extension Back To 1784

Contents of this chapter

6.1 Scope for Extending the Series Backwards

The data that Gordon Manley had time to reduce only enabled him to begin his extension for the Durham series in 1802 with the start of the series observed by James Losh, at Jesmond. Manley had a copy of the temperature readings from a series observed at South Cave, near Hull[74], and although it was his intention to use it, he died before he was able to do so.

When Manley's reduction for Durham begins in 1802, the Losh data are largely used on their own, with adjustments for the location of Jesmond relative to Durham, and to bring readings observed three times a day to a mean representative of the true daily mean. It was previously thought that the set from South Cave was the only series Manley knew of that could be used to extend backwards from the Losh series (Kenworthy 1985). Two extra sets of data have been discovered for Braithwaite and Brandsby[75], which may be used to reinforce the period from 1794 to 1801, and also to extend the series back further to 1784. Manley was aware of the earlier

[74] The exposure and background to the South Cave series (Barnard 1793-1815) are studied in more detail in section 3.1.

[75] The Braithwaite (Shackleton 1799-1857) and Brandsby (Cholmeley 1783-1808) series are examined further in section 3.1.

portion of the Braithwaite series, for it is present as a photocopy of the original manuscript in his boxes of notes at Cambridge University Library (Manley 1938-). It was also thought that he was not aware of any other series that could be used, but an interesting comment that Manley made in a letter to Joan Kenworthy on November 27th 1979 (Manley 27.xi.79) refers to him visiting Northallerton to 'top off to 1784'. The association was not previously made between this comment, and the later 1811-1830 monthly means for Brandsby, which are held in the North Yorkshire County Archives in Northallerton. While searching for the daily source for these monthly means, which have not been found, the earlier set of observations was discovered, on microfilm, in Northallerton, for December 29th 1783 to September 4th 1791.

The South Cave and Brandsby temperature series were observed daily, and the hour of this observation varies throughout the record. A daily mean was calculated, from the assorted observation times, to be comparable to that observed for the day as a whole. In order to do this, Glaisher's Greenwich adjustments were used, although Glaisher only published adjustments applicable to observations made on the hour, whereas the South Cave and Brandsby series include observations on the quarter-, half- and three quarter-hour. Glaisher's hourly corrections were therefore interpolated from one hour to the next to derive these fractions of hours (almost always for the half-hour). Appendix B shows the complete set of corrections used.

The Braithwaite manuscript contains only monthly summaries: a mean, plus the highest and lowest observations for that month. There are no explanatory notes associated with this manuscript, as there are with the other two, so conditions of exposure can only be guessed. This series is unique among those for the North East: it not only provides an indoor data series, as the South Cave observations do, but also gives a very long overlap of these indoor readings with those outdoors. This gives an opportunity to make full use of the indoors-only observations early in the record.

All calculations in this section were performed using the data in their original degrees Fahrenheit scale, converting any externally referenced temperatures to degrees Fahrenheit also, where necessary.

6.2 Data from South Cave

Although Manley was aware of the data recorded at South Cave (Barnard 1794-1815), he was not able to include it in his extension before he died. The series consists of a single reading each day, from January 1st 1794 to January 19th 1815, with the time of observation being almost without exception in the morning, and generally between 8 am and 9 am.

Across the set of data, Figure 6.1 shows the frequency of the different times of observation. The morning observation times of 8:00, 8:30, 9:00 and 9:30 make up 88% of all readings. The observation for each day was adjusted with reference to Glaisher's corrections from Greenwich to give a mean representative of the 24 hour day, and then a further adjustment made to the mean of the daily extremes.

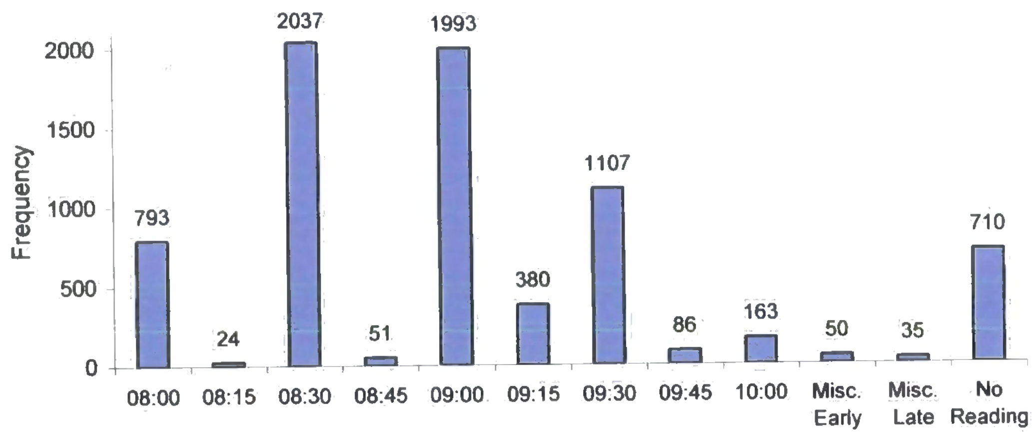


Figure 6.1 Comparative frequency of hours of observation for the South Cave record.

The series is largely complete with 10.4% of days (710 observations) missing a reading, although the missing days tend to be found in groups. The longest gap is from April 3rd to November 18th 1794, when Barnard was taken ill. Other periods where there are missing readings occur in April 1795 (9 days), August/September 1797 (13 days), August/September 1798 (36 days), August to November 1801 (85 days) and September/October 1802 (34 days). Where there are missing observations, a judgement must be made; whether to calculate the mean for the days that are present for that month, or to mark the month as being absent from the data. Where the whole month is missing, then this latter option must be taken, but many months have just a small number of missing observations. Figure 6.2 shows months where readings are missing, with values on the graph corresponding to the number of gaps missing for each month.

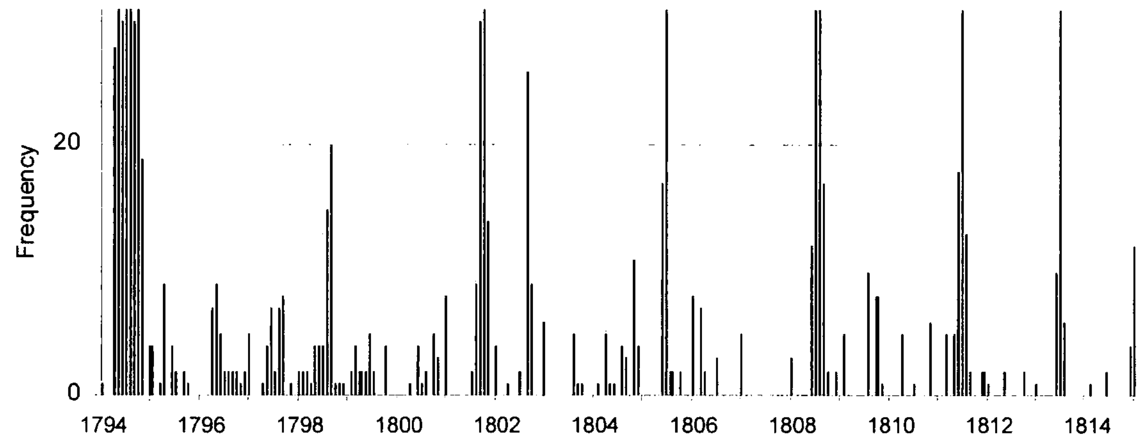


Figure 6.2 The number of missing observations, by month, in the South Cave record.

A threshold was selected at 20 missing values per month to signify that the month will be marked as being completely missing for the purposes of calculating a monthly mean. This threshold will cause eight months to be rejected as being 'missing' – a cluster of months with between 15 and 20 missing observations will therefore be included in the calculation of the monthly means. Where a month is marked as being missing, the monthly value will be missing in the series for South Cave.

There is evidence from the original manuscript of the temperature record indicating that the thermometer was moved from an outdoor to indoor exposure in 1803. The indoor exposure was described in the manuscript as being 'nearly the same as in the open air'. An analysis of the yearly means is shown in Table 6.1, with comparison with the Central England temperatures for the same years. Certain years in the South Cave record have a substantial number of observations missing, the observer being away for periods, so the annual means were adjusted to indicate this.

In the majority of years where periods of observations were missed, the gap was in the summer, giving an annual mean lower than would be expected. Figures in parentheses in Table 6.1 show the annual mean for Central England that has been calculated to exclude the associated missing period in the South Cave data.

Table 6.1 Annual Means for South Cave and Central England (°F). Values in parentheses are adjusted for missing readings in the South Cave data.

Year	South Cave Mean Temperature	Central England Mean Temperature	Difference
1795	47.9	47.6	-0.3
1796	48.1	48.2	0.1
1797	47.8	48.2	0.4
1798	49.4	49.3 (48.4)	-0.1 (-1.0)
1799	46.5	46.2	-0.3
1800	48.9	48.6	-0.3
1801	48.3	49.3 (48.3)	1.0 (0.0)
1802	49.7	48.1 (47.3)	-1.6 (-2.4)
1803	50.9	48.3	-2.6
1804	49.9	49.2	-0.7
1805	45.8	48.2 (46.7)	2.4 (0.9)
1806	48.2	49.6	1.4
1807	45.6	47.6	2.0
1808	43.6	47.9 (44.8)	4.3 (1.2)
1809	46.3	48.1	1.8
1810	46.7	47.8	1.1
1811	46.7	49.4 (48.3)	2.7 (0.6)
1812	45.8	46.8	1.0
1813	45.6	47.7 (46.6)	2.1 (1.0)
1814	45.0	46.0	1.0
Mean			0.8 (0.25)

Table 6.1 shows that the differences between South Cave and Central England means do fluctuate throughout the period. These can be seen more clearly in Figure 6.3.

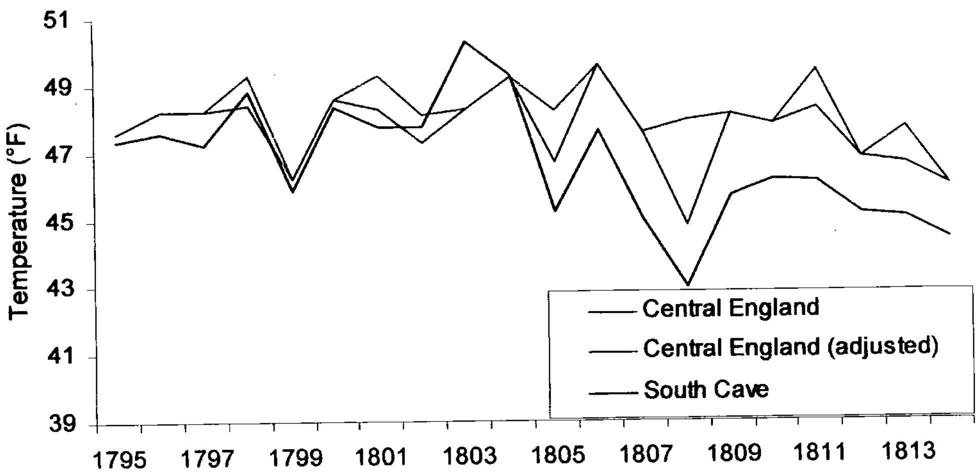


Figure 6.3 Annual means for South Cave, Central England, and the Central England series, adjusted for those days in the South Cave record where observations are not available (°F).

Where missing observations from the South Cave record are removed from the calculation of Central England means for that same year, the differences are smaller, and the mean of these averages is 0.25°F. Given that South Cave is further north of the 'Central England' area, it would be expected that South Cave would be cooler, and a comparison between the Central England and Leconfield Saws[76] in the 1990s shows a difference of 0.68°F. The small difference between these two comparisons shows that the South Cave record must have had a good, reasonably representative exposure at the decadal level for the area around Hull/Leconfield.

Despite the overall mean agreeing well with Central England, the South Cave observations do fluctuate across the period. A comparison of the pattern against documented evidence from the original journals for exposure is shown in Table 6.2.

[76] Section 5.1 explains the Leconfield Saws site, and shows its location relative to South Cave.

Table 6.2 Thermometer exposure at South Cave, and its effect upon the annual means compared with Central England annual means.

Year	Adjusted Difference between South Cave and Central England	Exposure
1795	-0.3	
1796	0.1	Outdoors at 11 feet, north west wall
1797	0.4	
1798	-1.0	
1799	-0.3	
1800	-0.3	Outdoors at 5 feet, north west wall
1801	0.0	
1802	-2.4	
1803	-2.6	Indoors, 'near the door'
1804	-0.7	
1805	0.9	
1806	1.4	Cloisters, 3 feet
1807	2.0	
1808	1.2	
1809	1.8	
1810	1.1	
1811	0.6	Cloisters, 5 feet
1812	1.0	
1813	1.0	
1814	1.0	

The agreement is good between the South Cave/Central England differences and the exposure type (Table 6.2). The South Cave exposures can be divided into three sections: outdoor exposure from 1795[77] to 1802, indoor exposure from 1803 to 1804, and sheltered outdoor exposure from 1809 to 1814[78]. The table shows there to be little difference between the two 'cloister' exposures, and also no substantial difference between the two outdoor exposures, such as can be gained from such short periods of data. When the thermometer was moved indoors, a marked difference can be seen, although this shift occurs early in 1802, as opposed to 1803 when the ledger reports the thermometer being moved. Barnard's comment at the beginning of 1802 was 'in the same situation' as the previous year (i.e. outdoors, 5 feet above the ground). It would seem improbable that Barnard strictly moved the thermometer only on January 1st, but his notes during the year do not mention any actual dates. Similarly, the change from indoor exposure to the cloisters appears to have taken place before January 1st 1805, when it is first mentioned in the manuscript.

Rather than picking an arbitrary date from each year to denote the change of exposure (whereby the annual means might be correct, but monthly means would be affected), the mean difference for each exposure group was examined to find roughly when the change was made. Taking means for the 'outdoors', 'indoors' and 'cloisters' differences, it is possible to find the portion of each year that should to lie in each group. The mean for each exposure was calculated when there is no concern over the exposure used: for example the 'cloisters 3 feet' exposure runs from 1805 to 1808 (with a mean difference of 1.38°F) and 'indoors' exposure in 1803 (with a mean difference of -2.6°F). Using this technique, the exposure actually moved indoors after 7.14% of the year (1802) had passed, i.e. on January 27th. Similarly, the change to the site in the cloisters, occurred after 50% of the time into 1804, i.e. on July 2nd [79]. This technique is crude, but in the absence of any documentary evidence from the manuscript, and given that the differences in Table 6.2 indicate the exposure changing at times other than those explicitly specified by Barnard, it is the best option available.

---

[77] The South Cave observations start in 1794 but because this year is incomplete, it has not been included in this analysis.

[78] The record actually ends on January 19th 1815.

[79] 1804 was a leap year.

In order to smooth the means for the Barnard record, means can be calculated for each type of exposure, and these are shown in Table 6.3. The years 1802 and 1804 have been excluded from the table because the exposure type is not constant throughout those years.

Table 6.3 Weighted means resulting from each type of exposure at South Cave (°F).

Exposure Type	Years Examined	Weighted Mean
Outdoors at 11 feet, north west wall	1795-1798	48.3
Outdoors at 5 feet, north west wall	1799-1801	47.9
Indoors, 'near the door'	1803	50.9
Cloisters, 3 feet	1805-1808	45.8
Cloisters, 5 feet	1809-1814	46.0

The differences for each exposure type could be weighted by the number of years in each group, and a mean obtained for the differences that would be applied to each annual mean. However, this would then introduce reliance upon the Central England series within the data, which is unacceptable for this study. Alternatively, the means can be smoothed without reference to an external series. When the means for each group are multiplied by a weight according to the number of years within that group, indicating the prevalence of that form of exposure in the overall series, and the resulting total is divided by the number of years with a single exposure type, a smoothed mean is obtained of 47.1°F. The means that result for each group in Table 6.3 above can then be compared with this, to give a correction for that group. These corrections, and the years to which they apply, are shown in Table 6.4. The years 1802 and 1804 have the annual correction applied to them pro rata, depending upon the number of days which fall into each group. When applying the correction on a daily basis, this adjustment would therefore change on January 26th 1802, etc.

Table 6.4 Smoothing corrections to be applied to the South Cave observations

Period	Correction (°F)
1794-1798	-1.2
1799 - January 26th 1802	-0.8
January 27th 1802 – July 1st 1804	-3.8
July 2nd 1804 – 1808	+1.3
1809 - January 19th 1815	+1.1

If there are gaps in the daily record, but fewer than 20 per month, the mean is calculated from the observations that are available. Because the observations that are present could be anywhere within the month, the further they are towards the beginning or end of the month, the greater the potential to affect means calculated for that month. For example, when only twelve observations are available for a spring month, and these run from the 1st to the 12th of the month, the resulting monthly mean will, without adjustment, generally reflect a cooler temperature than occurred for that entire month, because the warmer portion is omitted. This problem is a side effect of the arbitrary, as far as the climate is concerned, division of the year into twelve roughly equal portions, and indeed the points at which years and months begin. In order to correct for this positioning of observations that are present within a month, every other year for the South Cave record was examined to see how, on average, the temperature for that month follows a pattern. An average for these dates for every other year in the record (when observations are available for those dates) can be calculated, and the mean of the available observation in the month studied compared with this. A difference results from this comparison, which is used to add or subtract from the mean of available observations. This then enables a correction to be determined.

Taking November 1794 as an example, observations are available only for the eleven days from 19th–24th and then for the 25th-30th of the month. The mean of observations across the entire South Cave record for the days 19th-24th and 25th-30th of November (excluding 1794) is 38.684°F, and the mean for all November observations (again excluding 1794) is 41.296°F. The difference between these two figures shows that these eleven days in the month of November gives a lower mean than if the whole month were available, in this case a lower mean of 2.6°F. Therefore, a correction must be made to adjust the temperatures observed to be closer to those expected, and the monthly mean increased by 2.6°F. This correction brings the observed monthly mean for November 1794 from 41.2°F to 43.8°F.

This method of adjusting the monthly means for missing days has an advantage that it is not dependent upon other series for its reference. The South Cave record consists of 20 full years of data, which is probably sufficient for such a technique to be used, but a record of shorter length might not be deemed to have enough observations in other years to yield comparative means. An alternative to this technique would be to apply linear interpolation over the gap and derive replacement daily means where any are missing, but due to the long periods without data, this method is not so useful. For example, for August and September 1798 there is a gap from August 17th to September 20th. Linear interpolation would estimate means between the readings on the 16th and 21st of 57.3°F and 64.1 °F. For September, the daily means available are towards the end of the month, but because the final mean available in August is lower than the first available in September, the interpolated means for September would increase the overall mean for that month. Similarly, the estimated mean achieved via interpolation for August would be increased from the mean of available observations, despite those available readings all being at the beginning of the month. This is counter to what one would expect from the annual curve of temperature.

A further alternative to this technique would be for reference to be made to a contemporary series that runs for the same dates as those that are missing, but the only records overlapping South Cave are those which are also being used in this study (Jesmond, York, Brandsby and

Braithwaite) and for 1794 to 1798 there is no overlap to any series in the North East of England. Traditional methods of correcting temperature series for gaps often rely upon overlapping contemporary series (e.g. DeGaetano *et al.* 1995, Eisheid *et al.* 2000) but none are available that have observations geographically close to South Cave. Reference could be made to the Central England or Edinburgh series, both of which do run for the same period as South Cave, although then this would bring an element of dependency upon the Durham University Observatory series upon these 'external' data. The adjustments derived from this method are not minor, particularly given that a high threshold for not rejecting a month as being completely missing yields months where, at worst, just eight days are available at either the beginning or the end of that month[80]. Were the threshold used for discarding months as being incomplete much lower, at five missing days for example, then such large adjustments would not be necessary and the method could be deemed unimportant. There would be more gaps in the monthly record, however, so there is a trade-off between series completeness and series accuracy. In the winter months, and to a lesser extent in June and July, where the temperature across the month is more constant than the rest of the year, the corrections are smaller.

Table 6.5 shows those months when a monthly reading to be used has gaps (i.e. between 1 and 20, inclusive), and what the correction is calculated to be. For this exercise, all means have been kept at three decimal places for the calculation, although the final mean is displayed to one decimal place.

[80] For a February in a non-leap year, if 20 days of observations are missing, the remaining eight may be found from the 1st-8th, or from the 21st-28th.

Table 6.5 Adjustments made to South Cave monthly means to correct for missing observations.

Year	Month	Days Present	Mean of days present (°F)	Mean of all days in month (°F)	Correction	Original Mean (°F)	Corrected Mean (°F)
1794	Jan	1-7;11;13;27-31	30.429	35.837	5.418	30.0	35.4
1794	Nov	19-23;25-30	38.684	41.296	2.612	41.2	43.8
1795	Apr	1-14;24-30	44.518	45.081	0.563	46.5	47.0
1796	Apr	1-5;8-21;25-27;30	44.644	44.891	0.247	51.1	51.4
1796	May	2-12;16-26	49.869	50.195	0.326	48.5	48.8
1796	Jun	1-9;12-13;17-30	54.087	54.164	0.076	54.8	54.8
1797	Jan	1-10;14-17;20-31	35.550	35.564	0.013	38.8	38.8
1797	Jun	1-2;4-14;18-20;24-30	54.221	54.206	-0.015	53.9	53.9
1797	Aug	1-24	58.930	58.637	-0.292	59.4	59.1
1797	Sep	7-13;16-30	54.683	55.390	0.707	55.0	55.7
1798	Aug	1-16	59.037	58.593	-0.444	61.1	60.7
1798	Sep	21-30	53.574	55.370	1.796	55.4	57.2
1799	Jun	1-6;8-12;16-21;23-30	54.176	54.210	0.034	53.8	53.9
1800	Oct	1-6;9-22;26-31	49.019	48.940	-0.080	47.8	47.7
1801	Jan	1-12;17-26;31	35.765	35.562	-0.202	39.2	39.0
1801	Aug	1-22	58.734	58.423	-0.311	64.2	63.9
1801	Nov	15-30	39.790	41.393	1.603	37.9	39.5
1802	Oct	10-31	47.202	48.753	1.551	52.0	53.6
1803	Jan	1-25	35.521	35.539	0.018	39.4	39.5
1803	Aug	1-10;14-29	58.408	58.493	0.085	62.1	62.2
1804	Apr	1-10;16-30	45.019	45.091	0.072	46.0	46.1
1804	Nov	1-12;24-30	41.904	41.251	-0.653	42.6	41.9
1805	Jun	1-13	53.460	54.283	0.823	50.8	51.6
1806	Jan	1-13;17-21;27-31	35.773	35.575	-0.198	38.9	38.7
1806	Mar	1-16;24-31	40.400	40.405	0.006	39.4	39.4
1807	Jan	1-6;12-31	35.680	35.755	0.075	34.5	34.6
1808	Jun	6-23	54.211	54.215	0.004	53.6	53.6
1808	Sep	17-29	54.532	55.411	0.880	53.9	54.7
1809	Feb	1-14;20-28	38.630	38.222	-0.408	40.1	39.7
1809	Aug	1-15;26-31	59.001	58.831	-0.170	54.9	54.7
1809	Oct	1-13;20-25;28-31	49.210	48.857	-0.353	49.5	49.1
1810	Apr	1-24;30	44.821	45.214	0.392	43.4	43.8
1810	Nov	1-5;12-30	40.890	41.229	0.339	42.8	43.1
1811	Mar	1-13;15;20-31	40.244	40.200	-0.043	44.2	44.2
1811	May	1-2;7-27;29-31	50.378	50.055	-0.322	51.8	51.5
1811	Jun	1-12	53.146	54.200	1.054	53.9	55.0
1811	Aug	14-31	58.322	58.772	0.450	55.9	56.3
1813	Jun	1-20	53.870	54.282	0.412	52.0	52.4
1813	Aug	7-31	58.782	58.872	0.090	54.8	54.8
1815	Jan	1-19	35.930	35.782	-0.148	33.2	33.1

In addition to those months where no data are available at all, months where there are greater than 20 missing observations have not had their mean calculated from the data. These months are April 1794, with 28 missing readings, and September 1802, with 26 missing readings. Appendix D shows the full set of South Cave monthly means, corrected for the hour of observation, for missing observations, and smoothed to bring the exposure across the record to a common standard as described above. The single reading per day has been reduced to the 24 hour mean by use of the corrections published by Glaisher for Greenwich (shown in Appendix B), and then on to that representative of the daily extremes.

The figure at the beginning of this section can then be replotted to show how the comparison between South Cave and Central England is affected by the corrections described above. This is shown in Figure 6.4, where it can be seen that the agreement between the two series, particularly at the beginning of the comparison period, is much more consistent from year to year.

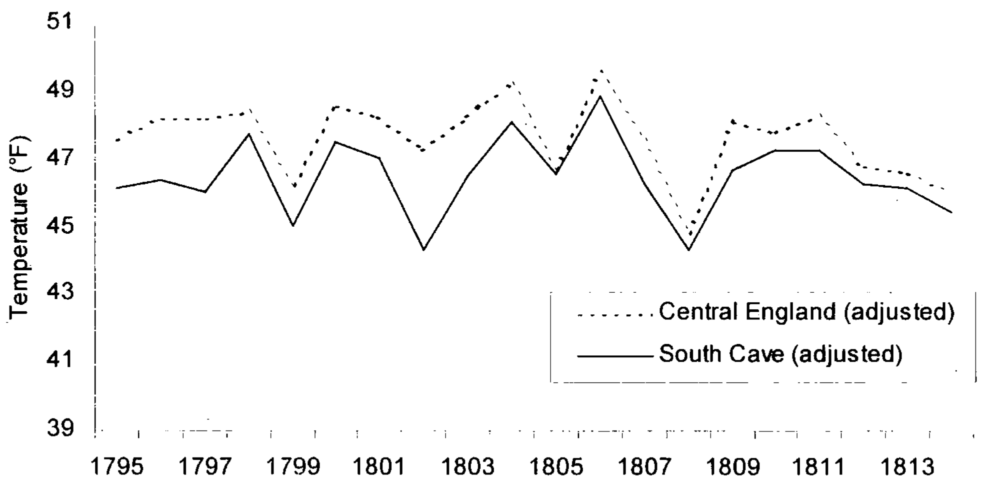


Figure 6.4 Annual means for South Cave the Central England series, both series adjusted for those days where observations are not available (°F).

6.3 Data from Braithwaite

6.3.1 Exposure

The monthly series observed by Abraham Shackleton at Braithwaite (Shackleton 1799-), near Keighley in West Yorkshire, began in October 1799, and until January 1809 was observed using a thermometer placed indoors. From January 1809, a thermometer was sited outdoors and in addition to the indoor observations, the series continued to December 1856. Nothing is known in detail of the exposure of these thermometers, although it was a common practice to place a thermometer in an unheated room. The idea behind this was that air temperature affected the health of people. Homes did not have the benefit of central heating, and rooms housing the poor would frequently be unheated. It is not correct, however, to assume that the exposure was similar to a thermometer situated outdoors, and with a series that does not have daily data available it is difficult to check statistics such as the daily ranges throughout the year to ascertain the characteristics of the exposure.

The manuscript shows three temperatures for each month, designated MH, GH and LH, presumably Mean Height, Greatest Height and Least Height respectively. It is not certain that the mean height column is derived from a mean of all observations, but there is no evidence to suggest that it was not. It was common in the eighteenth century for a single reading to be taken per day, and the monthly means in this record can be examined to see if they are indicative of the location of Braithwaite. Several methods may be used to check the overall trends and means for the Braithwaite series. A comparison with the Central England series (Parker *et al.* 1992) is useful to act as reinforcing evidence for the means and trend, although it is not desirable to place too much emphasis on comparison with Central England, or indeed any other external series, in case an element of that series is inadvertently incorporated. For comparison with Braithwaite, the overall trend exhibited by Central England has been used, plus the overall means at decadal level, rather than yearly or monthly means.

As a further check, means from a 'modern' site close to Braithwaite can be adjusted to means representative of early nineteenth century exposure[81]. Once this is done, the modern series can be relied upon as exhibiting good exposure and observation practices for a location similar to Braithwaite.

Looking at the outdoor exposure of the Braithwaite record, the annual means of the series can be plotted against the Central England means for those same months. This graph is shown in Figure 6.5, and it can be seen that the overall pattern shown by the two lines is good. However, regression lines plotted for each series would be expected to be parallel, to show a constant relationship between the two series, but this is not the case, indicating that the exposure of one of the two series is progressively changing over this period. The formulae for the regression lines are $y = 0.0456\,x + 46.123$ for Braithwaite, and $y = 0.0033\,x + 48.265$ for Central England, with y being the predicted temperature at Durham, and x being the number of years from 1809.

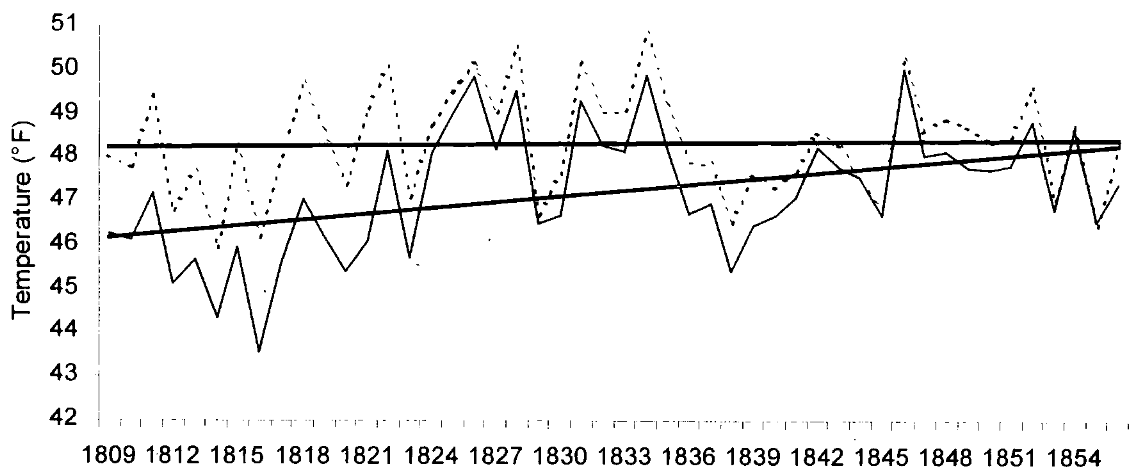


Figure 6.5 Graph showing the Braithwaite indoor annual means (solid line) compared with those for Central England (broken line). A regression line is shown for each series (°F).

[81] Means for the 'modern' period, i.e. the 1990s, show substantially warmer temperatures than those for the early nineteenth century.

In order to investigate this further, the differences between the two series can be plotted. Figure 6.5 shows these, and clearly indicates a change in relative exposure at some point between 1822 and 1824.

Figure 6.6 Differences between the Braithwaite outdoor monthly observations and those for Central England over the same period (°F).

Figure 6.6 above can be expanded by looking at the monthly differences between the two series for just the three years from 1822 to 1824, as shown in Figure 6.7.

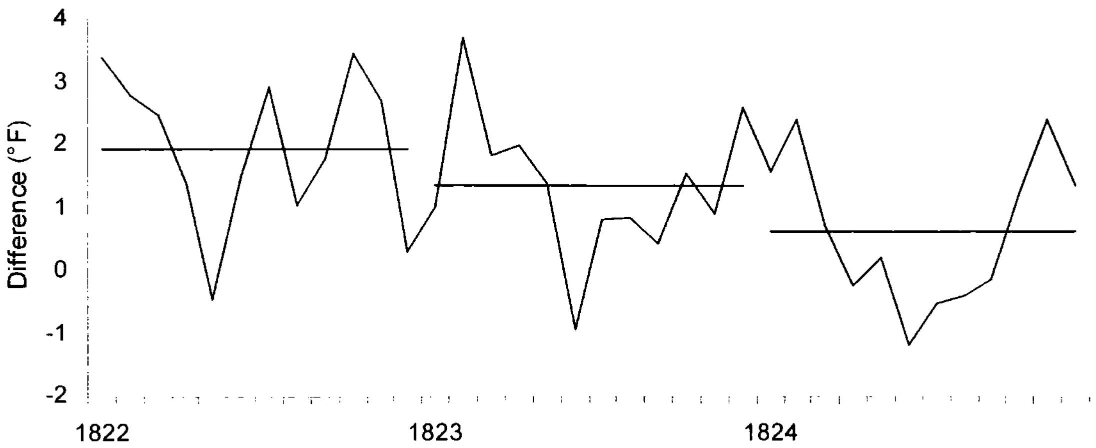


Figure 6.7 Differences for each month between Braithwaite outdoor and Central England temperatures. The horizontal lines represent the mean difference for the years 1822, 1823 and 1824 (°F).

The plot of monthly differences between the two series does not yield any sudden breakpoint that might represent a change of instrument, or a change of exposure, assuming that this changing difference can be attributed to movement in the Braithwaite observations as opposed to the Central England data. A peak and trough can be seen occurring in 1823, but the magnitude of these is not substantially greater than those for 1822, or 1824. It is possible that the exposure was changed gradually, for example the thermometer being moved towards the house, although this seems unlikely. A further explanation might be that the thermometer developed a fault that took three years for it to move from one standard to another. A more plausible reason for this movement might be a staged shift over a few years from one time of observation to another. This could be explained by temperature being observed later in the day in the later part of the record than in the earlier, and hence the monthly means being lower at the start. The difference between Braithwaite and Central England would then be greater.

A change-point test (Lanzante 1996), based upon the Wilcoxon-Mann-Whitney test, was applied to the data, but was unsuccessful in detecting the actual change-point. It is not clear why this test was not able to find this possibly because of a gradual change in the movement of the monthly means, but because the plot of differences between Central England and Braithwaite shows a clear lack of homogeneity, the correction process was continued.

Because no evidence is available in Abraham Shackleton's manuscript concerning exposure, the temperatures through the early portion (1809-1823) of the record were adjusted to bring them to a standard comparable with the later portion (1824-1856). With the exact change-point between the two standards of exposure being unclear, each year from 1822 to 1824 was adjusted by an amount different from the rest of the earlier portion from 1809 to 1821. In order to determine the correction required, these years were compared with the difference between Braithwaite and Central England for 1824-1856. Table 6.6 shows the annual means for each of these periods, and the comparison between each of these, and the 1824-1856 mean difference.

Table 6.6 Mean differences between the Braithwaite and Central England annual means for periods where this difference is substantially different from the long-term average, 1824-1856 (°F).

Period	Mean Difference	Variation from 1824-1856
1809-1821	2.2	1.5
1822	2.0	1.3
1823	1.4	0.7
1824-1856	0.6	-

When these variations are applied as additive adjustments to each period, the lower monthly means from 1809 to 1823 are therefore raised, and a plot of differences between Braithwaite and Central England is flatter, as shown in Figure 6.8.

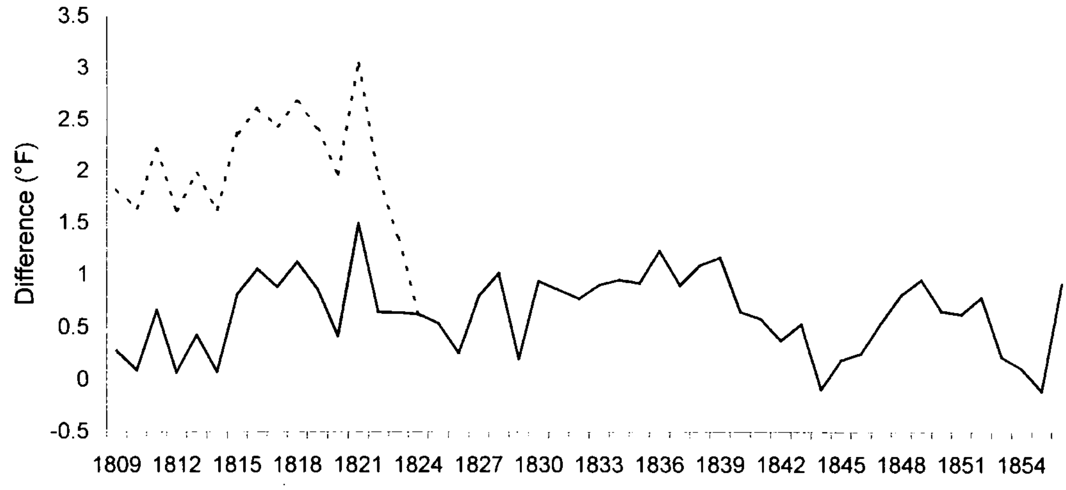


Figure 6.8 Differences between the Braithwaite indoor monthly observations and those for Central England, with the period from 1809 to 1823 adjusted for the abnormally cool exposure (°F).

As a final check on the early period for the Braithwaite record, the graph in Figure 6.4 is replotted with the adjusted monthly means from 1809 to 1823, shown in Figure 6.9. The formula for the Braithwaite series regression line is now $y = 0.0051\ x + 47.577$, with y being the predicted temperature at Durham (the equation for Central England being the same as before, with a slope of 0.0033), and x being the number of years from 1809.

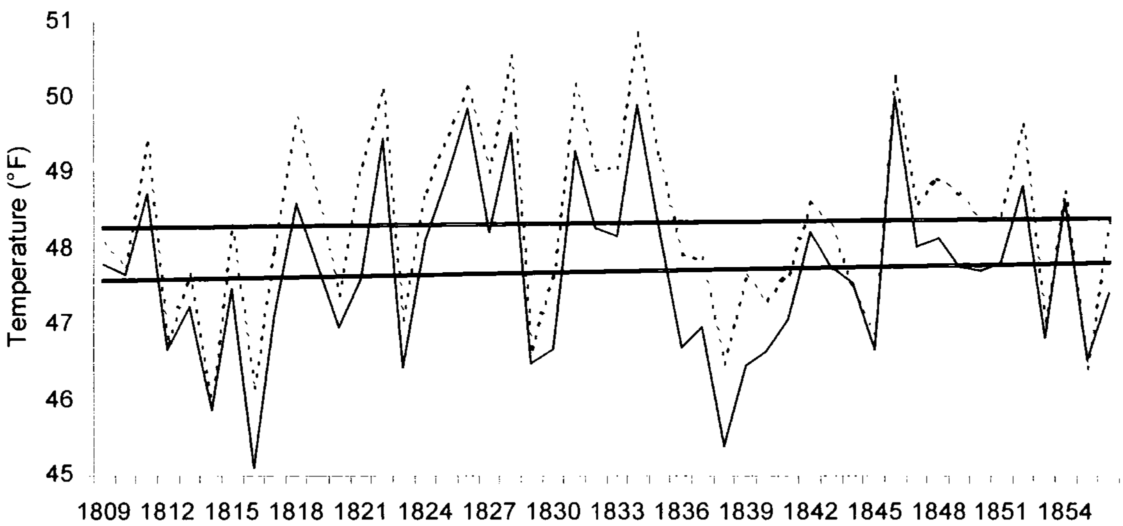


Figure 6.9 The Braithwaite outdoor (solid line) and Central England (broken line) temperature series with regression lines plotted (°F).

In order to investigate why the Braithwaite and Central England series differences are high between 1809 and 1824, the differences can be matched with known diurnal air temperature warming patterns from Glaisher's observations at Greenwich. The first step is to reduce the differences by a correction to bring the effect of altitude on the Braithwaite observations (229 m above mean sea level) to a similar exposure as Central England (50 m)[82]. This correction is 1.8°F (1.0°C). Assuming a 'perfect' thermometer, much of the remaining difference could be interpreted as that related to changing hours of observations. Table 6.7 shows how these differences might be interpreted, assuming a single observation per day. These changing hours

[82] Manley stated that his Central England reduction represented conditions at 100 to 200 feet above sea level (Manley 1974). An altitude of 50 m has been assumed here.

certainly look plausible, and may be the reason why the Braithwaite record gives high monthly means in its early years.

Table 6.7 Possible hours of observation in the Braithwaite outdoor temperatures (°F).

Period	Braithwaite/Central England difference	To adjust to 50 m above msl	Remaining difference	Approximate hour of observation
1809-1821	2.2	1.8	0.4	9:45
1822	2.0	1.8	0.2	10:00
1823	1.4	1.8	-0.4	10:25
1824-1856	0.6	1.8	-1.2	10:55

To look at the overall exposure of the Braithwaite outdoor thermometer, the corrected outdoor observations may be compared with the temperature observed at the modern site of Bingley Samos (6½ km SSE). The monthly mean temperature for Central England for 1809-1856 and 1991-1999 were compared, and this correction applied to monthly means for Bingley Samos from 1991 and 1999. These Bingley Samos means were then compared with the adjusted Braithwaite means, as shown in Table 6.8.

Table 6.8 An analysis of the adjusted Braithwaite outdoor observations relative to corrected, modern, observations for Bingley Samos, 6½ km SSE (°F).

Month	Bingley Samos 1991-1999	CET 1809-1856	CET 1991-1999	CET Difference	Braithwaite 1809-1856	Braithwaite compared with Bingley Samos	Correction
	A	B	C	D (i.e. C-B)	E	E-(A-D)	F
Jan	37.6	36.8	40.1	3.3	35.6	1.4	-0.7
Feb	38.2	39.0	40.6	1.6	37.2	0.5	0.3
Mar	41.1	41.6	44.7	3.1	40.2	2.1	-1.1
Apr	44.7	46.2	47.6	1.4	45.5	2.2	-1.1
May	49.7	52.2	52.9	0.7	52.2	3.1	-1.6
Jun	54.4	57.8	57.6	-0.2	58.1	3.5	-1.8
Jul	59.3	60.2	62.3	2.2	60.5	3.3	-1.7
Aug	58.8	59.4	61.9	2.6	59.6	3.4	-1.7
Sep	53.9	55.4	57.0	1.6	55.4	3.1	-1.6
Oct	47.6	49.3	50.6	1.2	48.2	1.9	-1.0
Nov	41.7	42.8	45.0	2.2	41.5	2.0	-1.0
Dec	38.2	39.4	40.3	1.0	38.4	1.2	-0.6
Year	47.1	48.3	50.1	1.7	47.7	2.3	-1.2

These results show that the adjusted Braithwaite outdoor means are still 1.2°F (0.7°C) higher across the year than would be expected from the similar modern exposure at Bingley Samos. There could be very many reasons for this. The most likely reason is that Abraham Shackleton's thermometer continually read too high by this amount, when smoothed across the year. Alternatively, this could be because the monthly means do not actually reflect true monthly means at all, but the means of observations made at a certain time of day. This 1.2°F difference could be a result of the mean being taken from observations of the thermometer made at about 8:05 (and also at 20:40, and assuming that only one observation per day was made). As mentioned above, there is no evidence for this, and the Bingley Samos data might yield a relatively low exposure anyway due to a geographical feature such as a slight hollow causing depressed temperature (but from an examination of the site this is not seen to be the case). As a result, it was decided to adjust the Braithwaite outdoor means by a smaller amount than these corrections show, but one that is still in keeping with the pattern that they follow. The data were therefore adjusted to bring them to the mean of the Braithwaite and adjusted Bingley Samos sets, i.e. to adjust all months by one half of the adjustments in Table 6.9 (1.2°F per year on average). This adjustment is column F in the table, as an addition of these corrections to the monthly means.

To test that the total of all the corrections are reasonable, it can be checked against the expected difference between Braithwaite and Central England according to the altitude difference between the two. The mean difference between the Braithwaite and Central England record across the period 1809 to 1856 is 1.4°F (0.8°C) after the correction is made for smoothing, then a further 1.2°F (0.7°C) for the adjustment with reference to Bingley Samos. This total difference of 2.6°F (1.5°C) is in good accord with the expected difference of around 1.8°F (1.0°C) expected, given the relative altitudes.

Appendix D shows the full set of outdoor temperature observations for Braithwaite, adjusted for the abnormal temperature from 1811 to 1823, and for the generally high observations that may be seen from the comparison with Bingley Samos in the 1990s.

6.3.2 Indoor Observations

It is not necessary to use most of the indoor record as part of the temperature extension, because outdoor means are available for 1809 to 1856. The period from 1799 to 1808 will require the indoor record to be used, and as such it can be compared against the outdoor record as a check upon its exposure. The long overlap between the outdoor and indoor observations allows a good comparison to be made between the two exposures, so the monthly means from the manuscript were adjusted to be comparable to a mean calculated from the daily extremes. The differences between the indoor and outdoor thermometers are not constant throughout the series, however, and Figure 6.10 shows how the relationship changes.

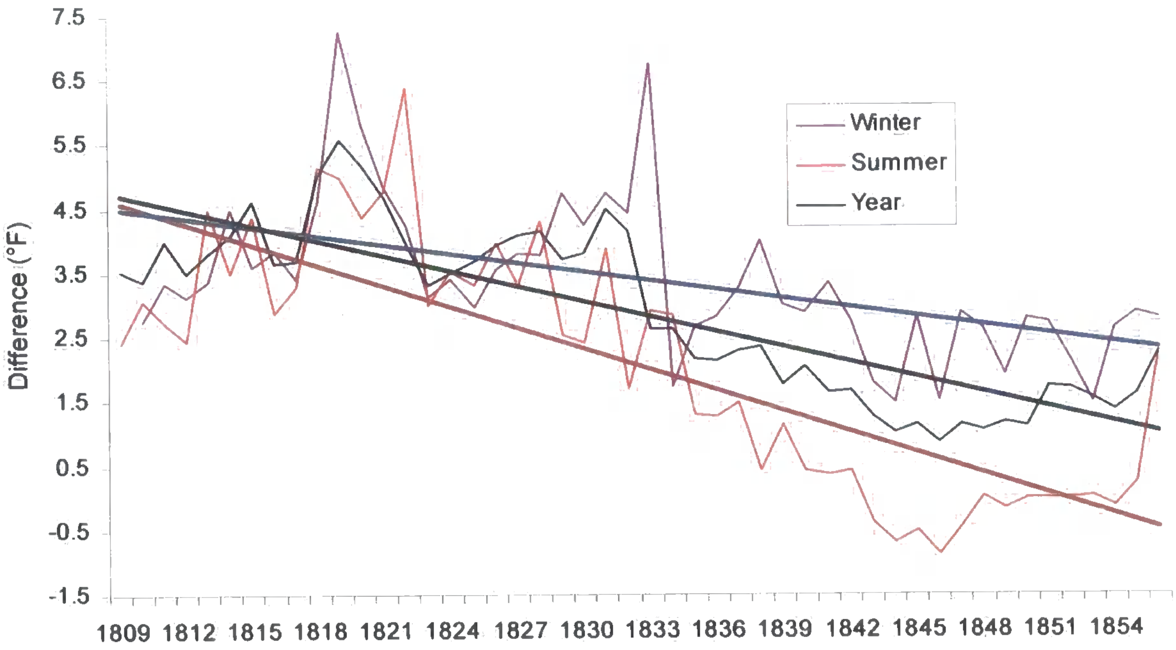


Figure 6.10 Differences between indoor and outdoor temperatures in Winter and Summer with the yearly average. Regression lines are shown for each (°F).

The graph in Figure 6.10 shows three lines for the differences between indoor and outdoor temperatures. Summer temperatures are plotted as the mean of June and July differences, and winter temperature as the mean of December and January temperature[83]. The annual mean is also shown. Regression lines placed over set of data show a clear downward trend in the difference between the two sets of observations. Given that the analysis of the outdoor temperature above shows no trend relative to the Central England dataset, this must be due to movement in the indoor observations. In addition, the temperature difference remains fairly

[83] The January and December temperatures used are those the in same season: i.e. the 1810 winter mean is the average of December 1809 and January 1810.

high, yet fairly constant at the start of the record, with summer and winter temperatures exhibiting a similar difference from the outdoor readings. Towards the middle and end of the record, the divergence becomes clear, although the two seasonal plots exhibit a lot of variability.

At the start of the record, summer and winter indoor temperatures show a similar deviation from those outdoors, but this deviation is high, implying poor ventilation in summer and some artificial heating in winter. Summer temperatures show the greatest change, towards a situation where indoor and outdoor temperatures become closer to each other, i.e. the unheated room is better ventilated. In winter, however, the difference between indoor and outdoor temperatures does drop, but still remains high. The room is therefore still obtaining artificial heat, but to a lesser extent later in the record. There are a number of peaks in the plot of deviations. Peaks in summer, such as in 1822, might imply particularly high temperatures when the ventilation of the room was not especially effective. The maximum temperature shown in the manuscript for outdoor temperature in June 1822 is 74°F, which is rather higher than that observed in the surrounding years. Between 1843 and 1849, the deviation between summer indoor and outdoor temperatures drops below zero – i.e. it is warmer in these summers indoors than outdoors.

In order to ascertain necessary corrections on the indoor data, a short stretch of outdoor data was considered, given the progressive movement of the relationship between the two sets of data. The period from 1809 to 1817 shows a stable relationship between the indoor and outdoor temperatures, and it is reasonable to assume that this relationship may be extended back to 1799. Table 6.9 shows the relationship between the two exposures between 1809 and 1817.

Table 6.9 The relationship between indoor and corrected outdoor exposures at Braithwaite for each year between 1809 and 1817 (°F).

Year	Indoor Mean	Outdoor Mean	Difference
1809	49.8	46.9	-2.9
1810	49.5	46.8	-2.7
1811	51.2	47.8	-3.4
1812	48.6	45.8	-2.8
1813	49.5	46.3	-3.1
1814	48.4	45.0	-3.4
1815	50.6	46.6	-4.0
1816	47.2	44.2	-3.0
1817	49.3	46.2	-3.0
Mean	49.3	46.2	-3.2

Taking each month from 1809 to 1817 for the indoor means, the relationship can be seen in further detail, as shown in Table 6.10.

Table 6.10 The relationship between indoor and corrected outdoor exposures at Braithwaite for each month, for the years 1809 to 1817 (°F).

Month	Indoor Mean	Outdoor Mean	Difference
Jan	36.2	33.8	-2.5
Feb	40.1	38.5	-1.5
Mar	42.0	38.9	-3.1
Apr	47.1	43.6	-3.5
May	52.7	50.1	-2.6
Jun	58.8	55.8	-3.0
Jul	61.8	58.5	-3.3
Aug	60.6	56.8	-3.8
Sep	59.0	54.1	-5.0
Oct	51.1	47.2	-3.9
Nov	43.5	40.1	-3.4
Dec	39.0	36.7	-2.3
Mean	49.3	46.2	-3.2

However, it is known from the study of the outdoor readings above, that the exposure did change in some way from the start of the outdoor record in 1809 to 1824, when it remained more constant. It is reasonable to assume that the corrections applied to the outdoor readings should also be applied to the indoor set, particularly as it is suspected that this change was due to alteration in the hour of observation of the thermometer. When this is done, the relationship between the two exposures is as shown in Table 6.11.

Table 6.11 The relationship between corrected indoor and corrected outdoor exposures at Braithwaite for each month, for the years 1809 to 1817 (°F).

Month	Indoor Mean	Outdoor Mean	Difference
Jan	37.4	33.8	-3.6
Feb	41.6	38.5	-3.1
Mar	42.8	38.9	-3.9
Apr	47.8	43.6	-4.2
May	52.9	50.1	-2.8
Jun	58.8	55.8	-3.1
Jul	62.0	58.5	-3.4
Aug	60.7	56.8	-3.8
Sep	59.3	54.1	-5.2
Oct	52.0	47.2	-4.7
Nov	44.3	40.1	-4.1
Dec	40.3	36.7	-3.6
Mean	50.0	46.2	-3.8

The differences shown in Table 6.11 were applied to the indoor means for 1799 to 1808 to adjust them to exposure associated with the outdoor means at Braithwaite. The resulting means are shown in Appendix D.

6.4 Data from Brandsby

Manley used data from Brandsby in his reduction for Durham from 1802 in the form of monthly means that were available from 1811 to 1830 (Cholmeley 1811-). During this study, the source of these means was sought to check Manley's figures and also to see whether daily observations were available. These means from 1811 to 1830 were discovered at the North Yorkshire County Archive in Northallerton in the same format that Manley used, presumably therefore the same source. The document is available on microfilm, the original is no longer available. A search for daily data as the source of these monthly means in this Archive was not successful, although documents were discovered that record temperature observations from December 29th 1783 to September 4th 1791 (Cholmeley 1783-). The temperature was observed several times a day throughout this period at Brandsby Hall, the same site as for the 1811 to 1830 set[84].

The readings from 1783 (December 29th) to 1791 (September 4th) are less regular than the South Cave or Braithwaite series. The number of observations per day ranges from zero to seven, with missing days making 16.4% of the total. Missing values tend to be spread throughout the series, but several groups occur, as shown in Figure 6.11.

[84] Background information on the Brandsby record is covered in more detail in section 3.1.

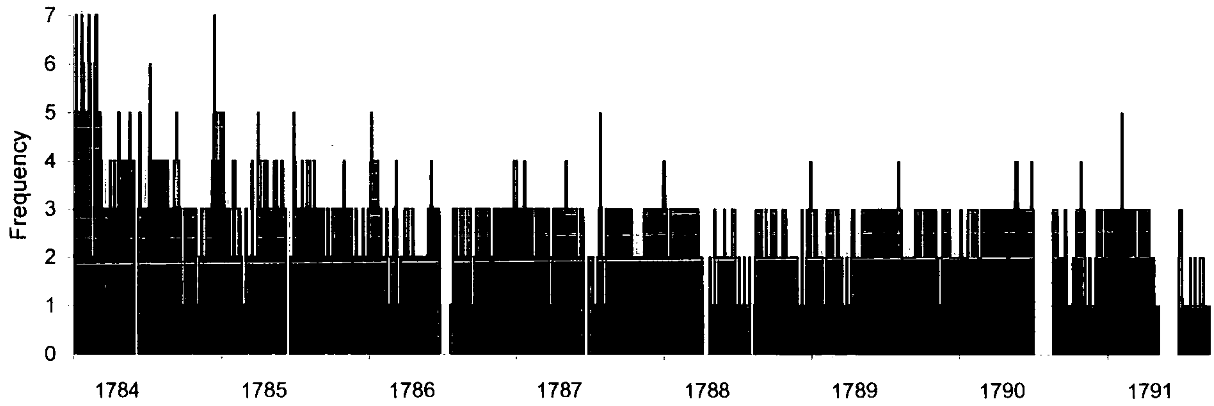


Figure 6.11 Frequency of temperature observation, and days with missing values, in the early Brandsby record 1784-1791 (°F).

Monthly means have been calculated from the daily temperature observations, using Glaisher's corrections for Greenwich to reduce the multiple readings per day to that comparable with the true mean for the day.

There is no documentary evidence from the manuscript for the position of the thermometer, so it is not possible, as for South Cave, to examine movement in the exposure over time. Where missing values are present in the original record, a decision must be made concerning their treatment. For consistency, the same method will be used as for the South Cave record, and the number of days per month with missing observations will be considered. Provided at least one of the multiple observations per day is present in this record, that day will be considered available. Figure 6.12 shows how the number of missing days within each month is distributed.

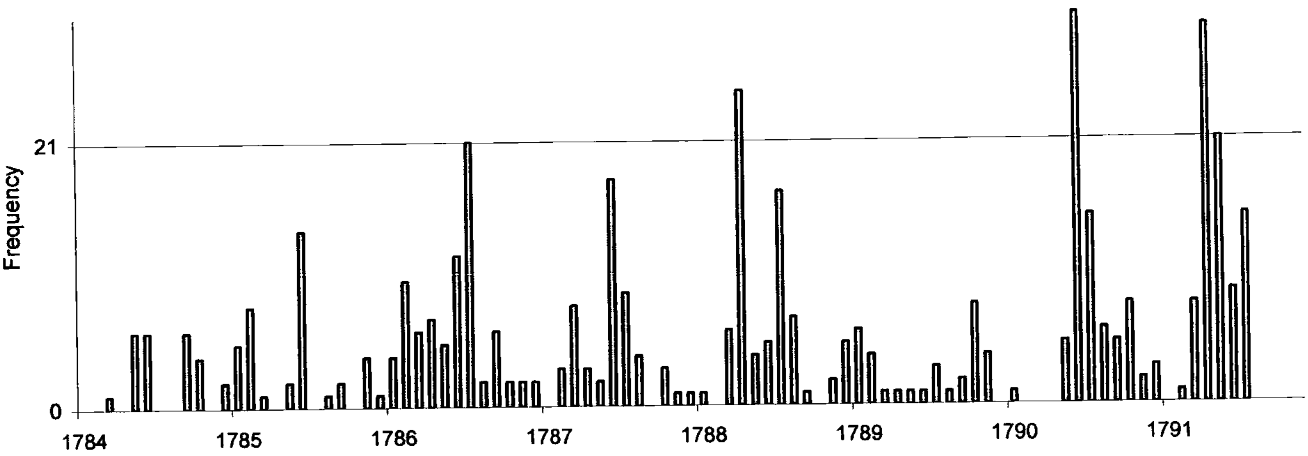


Figure 6.12 The number of missing observations, by month, in the early Brandsby record

The threshold for the number of missing days within a month is set at 21 for the Brandsby record[85], so therefore any month with more than 21 missing days' observations will be treated as missing. July 1790 has no observations at all, and April 1788 and May 1791 are treated as missing with 25 and 30 missing days respectively. Other months that have missing days' observations were corrected using the same method as for the South Cave data above. The technique looks at the pattern of temperature across that month in the other years of the record, but because the early Brandsby series consists of eight full years of data, compared with 20 for South Cave, the method should be considered less strong. Table 6.12 details months in the early Brandsby record that have between 5 and 21 missing days, and the correction adjustment to be applied to those months.

[85] Note that this is different to the threshold set for the Braithwaite record. The limit was chosen with reference to the data to maximise the numbers of days with data without compromising the quality of the final monthly means.

Table 6.12 Adjustments made to Brandsby monthly means to correct for missing observations (°F).

Year	Month	Days Present	Mean of days present	Mean of all days in month	Correction	Original Mean	Corrected Mean
1784	May	1-12;15-27	50.597	51.137	0.540	54.4	54.9
1784	Jun	7-30	56.818	56.285	-0.533	53.8	53.3
1784	Sep	1-19;26-30	52.692	52.189	-0.503	56.5	56.0
1785	Jan	1-10;13-19;22-27;29-31	34.059	34.058	-0.001	35.8	35.8
1785	Feb	1-13;15-17;19;26-28	36.256	36.537	0.281	29.8	30.0
1785	Jun	1-4;17;19-20;22-30	55.870	55.506	-0.364	59.5	59.1
1786	Feb	1-11;20-22;25-28	35.748	36.047	0.299	34.0	34.2
1786	Mar	1-6;12-23;25-31	38.048	37.683	-0.365	34.0	33.6
1786	Apr	1-6;8-17;21-25;29-30	42.796	43.399	0.603	43.8	44.4
1786	May	1-2;6-11;13-24;26-31	52.014	51.650	-0.365	50.9	50.5
1786	Jun	1-18	54.692	55.668	0.976	57.8	58.7
1786	Jul	17;23-31	57.498	58.681	1.182	57.2	58.4
1786	Sep	1-5;12-30	52.670	53.275	0.605	48.9	49.5
1787	Mar	1-5;8-18;25-31	36.434	36.749	0.315	41.8	42.1
1787	Jun	1-10;25;30	55.737	56.252	0.516	51.7	52.2
1787	Jul	1;3-4;6-7;14-30	58.768	58.661	-0.108	58.1	58.0
1788	Mar	1-10;15-23;25-30	37.728	37.448	-0.280	35.9	35.6
1788	Jun	1-5;7-22;24;28-30	55.857	55.775	-0.081	56.6	56.5
1788	Jul	1-6;8-12;19;25-26	59.376	58.360	-1.016	60.9	59.9
1788	Aug	7-29;31	57.229	57.548	0.319	57.0	57.3
1788	Dec	2-8;13-31	34.303	34.654	0.351	29.0	29.3
1789	Jan	1-7;9-11;17-31	34.401	34.398	0.000	33.1	34.5
1789	Oct	4-7;13-31	44.291	45.106	0.815	44.4	45.2
1790	Jun	1-25	55.371	55.817	0.446	56.4	56.8
1790	Aug	15-29;31	56.325	57.471	1.146	57.6	58.8
1790	Sep	1-16;18-19;21-22;24-27	54.102	53.068	-1.034	50.4	49.3
1790	Oct	3-5;8-31	44.263	44.871	0.608	46.0	46.6
1790	Nov	1-3;5;9;13-14;16-30	36.700	37.385	0.684	38.9	39.6
1791	Apr	1-12;15-17;19-20;22-25;30	42.525	43.155	0.630	45.7	46.4
1791	Jun	21-25;27-30	57.394	55.819	-1.575	57.3	55.8
1791	Jul	1-3;10-12;15-23;25-31	58.034	58.468	0.435	59.3	59.8
1791	Aug	1;6-10;13-16;20-21;23-25;29	57.251	57.115	-0.136	61.8	61.7

Despite there being no documentary evidence for changing exposure, the Brandsby means were examined for any shifts from one year to the next by comparing them with the Central England data for those same years. To make this comparison valid, the Brandsby means were first adjusted from the 24 hour mean to those representative of the mean of the daily extremes.

Table 6.13 Yearly averages for Brandsby and Central England (°F).

Year	Brandsby Mean Temperature	Central England Mean Temperature	Difference
1784	44.7	46.1	1.4
1785	45.8	47.4	1.6
1786	45.0	46.9	1.9
1787	46.0	48.7	2.7
1788	46.3	48.6	2.3
1789	46.0	48.0	2.0
1790	45.5	48.0	2.5
1791[86]	48.8	50.4	1.6

[86] This early Brandsby series ends on September 4th 1791, hence the comparison with Central England will be made from January to August only.

Table 6.13 shows a consistent pattern from 1784 to 1790 of a difference between Brandsby and Central England of between 1.4 and 2.7°F (0.8 and 1.5°C) on the annual mean, although for 1791 the comparison is less useful because the Brandsby record is not complete. The differences between temperature at Brandsby and for Central England are reasonably constant, but they are high. In order to check whether the means are higher than expected, further data for Yorkshire were examined. As discussed above, little is known about the exposure at Brandsby and there are no data series nearby, in the late eighteenth century, for the observations to be compared with. Temperature series exist for sites in North Yorkshire and for East Yorkshire that are close to Brandsby, and these may be employed to investigate the pattern of temperature in the region to assess whether the Brandsby observations need adjustment. Table 6.14 summarises the stations and their locations. In this section, degrees Celsius were used as most of the source data were available in this scale.

Table 6.14 A summary of sites for which temperature data are available in the region around Brandsby for comparison with the exposure at Brandsby.

Site	Location relative to Brandsby	Altitude (m above sea level)	Period for which data are available
Brandsby		29	1784-1790
Ampleforth	6 km N	95	1962-1970
Linton-on-Ouse	15 km SW	14	1991-1999
Leconfield	50 km SE	2	1991-1999
High Mowthorpe	35 km ESE	175	1991-1999
Askham Bryan	25 km S	32	1991-1999

Figure 6.13 shows the mean relationship between Brandsby, Central England and other stations in the North Yorkshire region. Three graphs are shown as each is drawn for a separate period for which the data are available. All modern sites are compared against Central England for the 1990s, except Ampleforth for which the most recent data available are from 1962 to 1970.

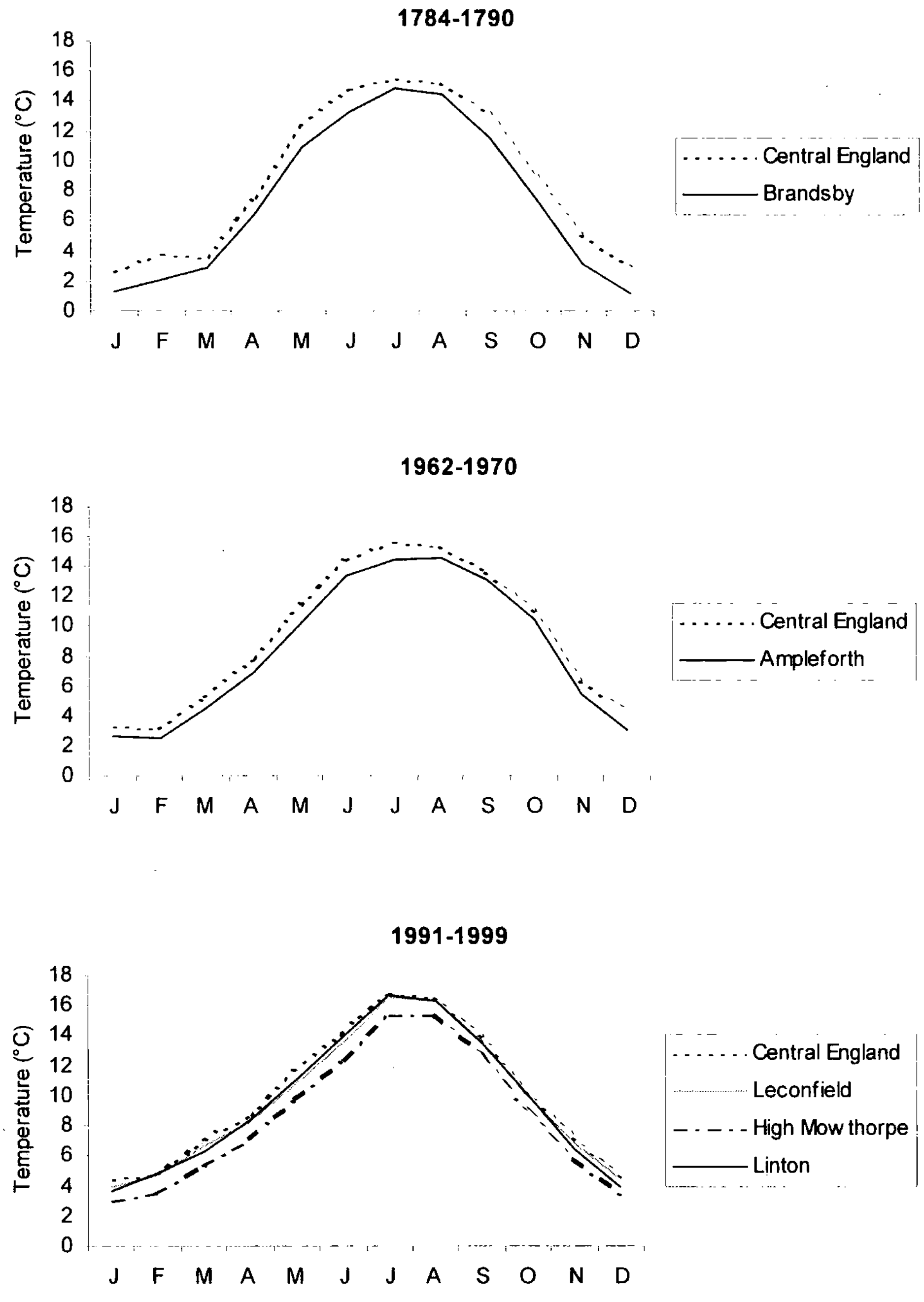


Figure 6.13 The relationship between Brandsby and stations close to Brandsby, and Central England, for the different periods for which data are available for these stations (°C).

The relationship between Central England and Brandsby for the 1780s is one of a constant but higher than expected difference, given the location of Brandsby close to sea level. The difference between Central England and Ampleforth, which is on a ridge 6 km to the north of Brandsby and 66 m higher in altitude, is in fact less, i.e. Ampleforth is generally warmer than Brandsby for the periods that were studied, when compared with the Central England temperature series. To check whether the Ampleforth means are anomalous, the monthly means for Linton-on-Ouse were also examined. These show a very similar pattern of monthly temperature to that for Central England, with a mean difference of 0.4°C compared with the 1.3°C difference for Brandsby. Linton and Brandsby are 15 km apart, but Linton is on flatter ground and is slightly lower in altitude, to the west of the Hambleton and Howardian hills. Brandsby is at the foot of these hills, which rise to the north and east of the village respectively. Although no modern observations are available for the area immediately around Brandsby, it is probable that temperature there is depressed by the effect of cooler air descending into the lower land where Brandsby is situated. Minima are likely to be lower than for the nearby Ampleforth and Linton stations. The Vale of York, where both Linton-on-Ouse and Brandsby are located, is known for the frequency of fog and frost in relation to surrounding, more upland areas, for this reason (e.g. Wheeler 1997). Looking further afield, the monthly means for Leconfield and Askham Bryan are very similar to those for Linton-on-Ouse, and hence also show a very close match to the Central England temperatures, with mean differences of 0.4°C. High Mowthorpe is a station at a higher altitude than Brandsby, and at 175 km ESE is much further away than the other sites mentioned, but the pattern of differences between it and Central England is in fact very similar to that for Brandsby, despite the latter being much lower in altitude.

From this analysis, it can be seen that observations from Brandsby result in lower monthly means than would be expected purely from its distance from Durham, its relative altitude, and from the assumption that the exposure is roughly similar to that at Ampleforth. A correction needs to be applied to the Brandsby observations, to bring them more into line with those from Ampleforth and Linton-on-Ouse. Table 6.15 shows the differences between Ampleforth and Central England, and Linton and Central England, both of which are warmer than Brandsby.

Table 6.15 Differences between the Central England temperature series (CET) and two other stations close to Brandsby (°C).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
CET-Ampleforth	0.75	0.64	0.77	0.93	1.18	1.08	1.19	0.78	0.56	0.65	0.88	1.11	0.88
CET-Linton	0.76	-0.14	0.71	0.30	0.57	0.36	0.20	0.30	0.40	0.18	0.77	0.65	0.42
Mean Difference	0.75	0.25	0.74	0.61	0.88	0.72	0.70	0.54	0.48	0.41	0.83	0.88	0.65

The pattern of differences between the two pairs of series is not smooth, with peaks in early summer and mid-winter; hence the correction was set to the same across all months, being the mean for the monthly differences. This correction of 0.65°C represents the approximate amount that the Brandsby means are cooler than the surrounding area as indicated by the monthly means at Linton-on-Ouse and Ampleforth, the latter being used as the proxy for Ampleforth when studying modern data.

Appendix D shows the full set of Brandsby monthly means for this early portion of the series, corrected for the hour of observation and for missing observations, and for the adjustment of 0.65°C described above. The various observations per day have been combined and reduced to the 24 hour mean by use of the corrections published by Glaisher for Greenwich (shown in Appendix B). This reduction step is more complex than for the other series studied, because the number of observations per day varies. Cholmeley did not keep any pattern to his hours of observation, so each day must be examined individually.

6.5 Integration of the Series Available for the Extension

6.5.1 Data Availability

The data for South Cave, Braithwaite and Brandsby can all be added to the beginning of the series for Durham. Figure 6.14 shows how these series overlap.

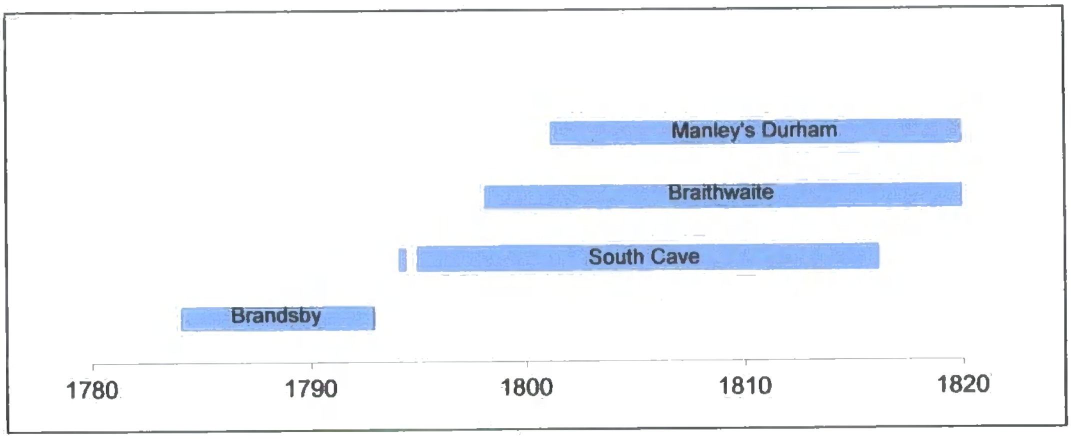


Figure 6.14 Temperature data sources available to extend Durham series, starting in 1801.

As examined in section 5.1, the optimum combination of these series can be determined from an analysis of records observed at the present that are close by and representative of the historic observations. The proportions of each of these series are reproduced in Table 6.16.

Table 6.16 Optimum combination of series available to extend the Durham series back from Manley's starting point of January 1st 1802.

Period	Series Available	Best Combination of Series and Weights
December 29th 1783 – September 4th 1791	Brandsby	Brandsby (0.71) intercept of 2.50°C
September 5th 1791 – December 31st 1793	no data	
January 1st 1794 – September 30th 1799[87]	South Cave	South Cave (0.93) intercept of 0.60°C
October 1st 1799 – December 31st 1801	South Cave Braithwaite	South Cave (0.84)[88] Braithwaite (0.11) Intercept of 0.40°C

The summary in Table 6.16 shows that throughout the period from December 1783 to the end of September 1799, where data are available, only a single series best matches the temperature at Durham. South Cave and Braithwaite are then combined until the end of 1801, with South Cave being the dominant series.

[87] A gap exists from April 3rd 1784 to November 18th 1784 when Barnard, the observer, was ill. During this period, there are no data available for the extension.

[88] The weights do not add up to 1 for this period because there is also a constant for the regression equation.

6.5.2 Combining the Series

Each set of temperature observations, once standardised as shown above, should be adjusted slightly according to the site's altitude relative to Durham University Observatory at 102 m above mean sea level. This correction is not necessary for Brandsby because the adjustment made above to account for the exposure caters for the altitude component. Table 6.17 therefore shows the altitude for South Cave and Braithwaite, and the corrections required, assuming 1.08°F (0.6°C) per 100 m.

Table 6.17 Altitude corrections to be made for series in the extension to the Durham series

Site	Altitude	Correction (°F)
Braithwaite	229 m	+1.4
South Cave	2 m	-1.1

The reduction for Durham was made by combining the three series as indicated above, and was continued to the end of 1814 to allow for a comparison with Manley's reduction of 1979, and also the revised reduction presented in chapter 5 above. When there are gaps in the South Cave record, the Braithwaite data were used alone, when available. Gaps in the Brandsby record were left blank, because there is no suitable reference series available for the North East for these years. Months when gaps were filled by reference to another series, and those when no reference data were available, are shown in Table 6.18.

Table 6.18 Months with gaps to be filled by reference to the Braithwaite series, and those where no extra data are available.

Year	Month	Treatment
1788	April	None
1790	July	None
1791	May	None
1791	October	(27 months) None
1793	December	
1794	April	(7 months) None
1794	October	
1801	September	Braithwaite (Indoor)
1801	October	Braithwaite (Indoor)
1802	September	Braithwaite(Indoor)
1805	July	Braithwaite (Indoor)
1808	July	Braithwaite (Indoor)
1808	August	Braithwaite (Indoor)
1811	July	Braithwaite (Outdoor)
1813	July	Braithwaite (Outdoor)

After applying these corrections to each series, the extension to Durham from 1784 can be completed. Following the examination of variance in chapter 5 for the period from 1802, it was decided not to adjust the variance for the period before 1802, and for part of the extension only one series is used in any case. Monthly means for the extension are shown in Appendix D.

To investigate the agreement between the reduced monthly means for the extension period, the means were plotted against Manley's own reduction of 1979, and the Central England temperature series. Figure 6.15 shows this graph.

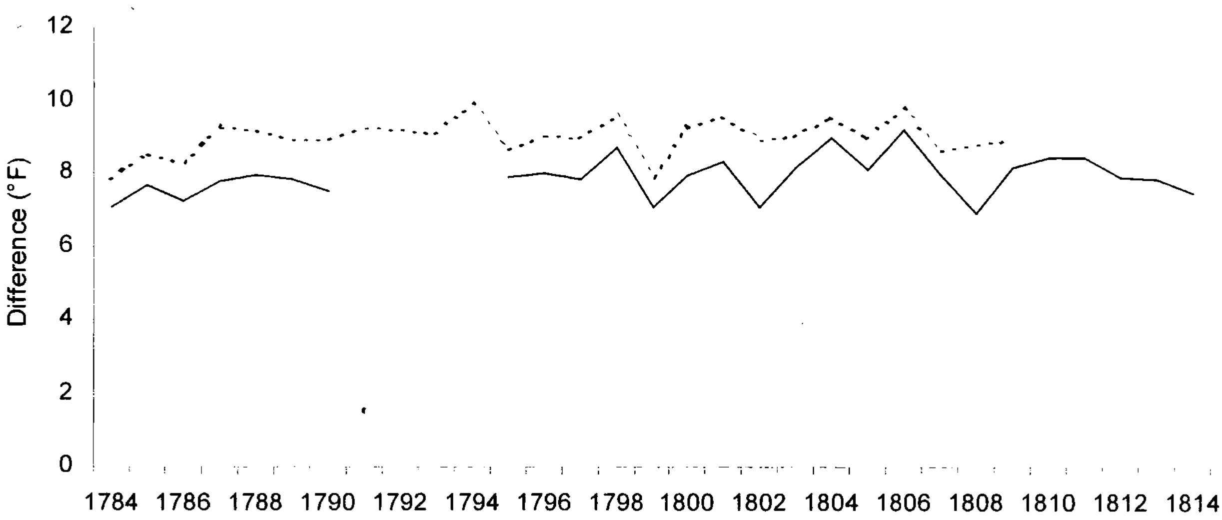


Figure 6.15 Monthly means reduced for Durham (solid line), plotted with means for Central England (broken line), 1784 to 1814 (°F).

The section of the plot showing the overlap between the new reduction and Manley's is difficult to interpret given the close agreement between the two curves. When the portion from 1801 to 1814 is split into two separate plots, carrying forward the combination for South Cave/Braithwaite to 1814 using the same weights as for the period to 1801, the agreement can be seen more clearly[89]. Figure 6.16 shows this.

[89] Missing monthly means for South Cave were filled using Braithwaite alone.

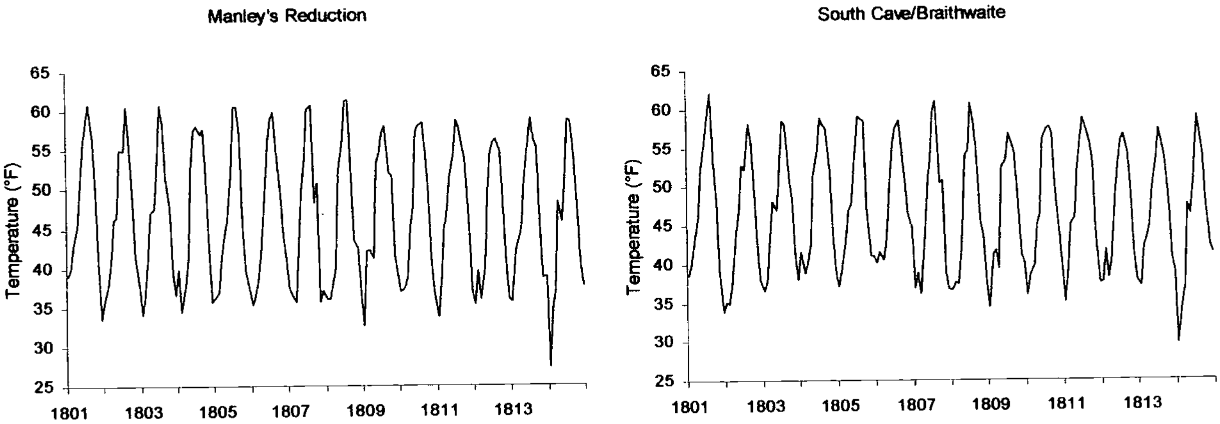


Figure 6.16 A comparison between the derived temperatures for 1801 to 1814 using South Cave and Braithwaite data, and Manley's reduction for the same period (°F).

The differences between the two graphs in Figure 6.16 are shown in Figure 6.17.

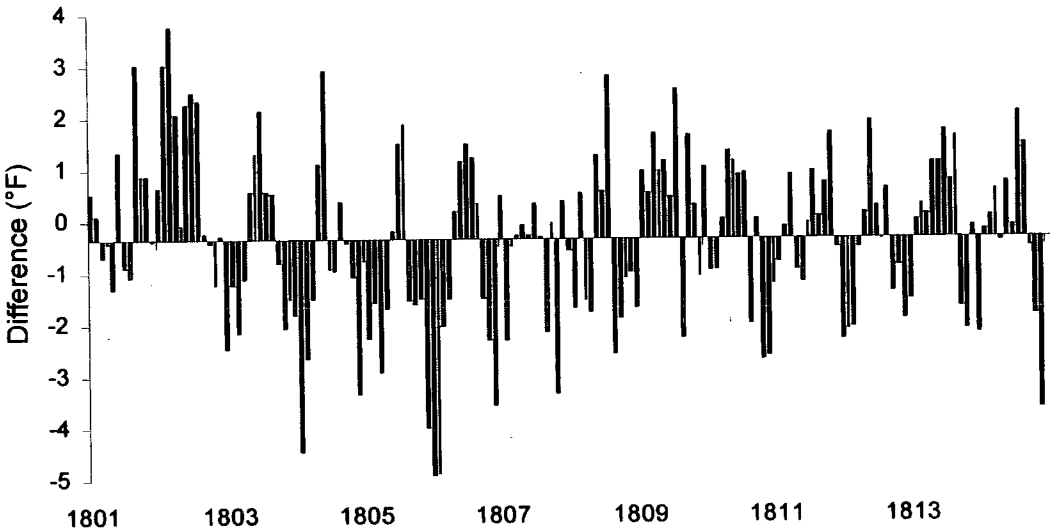


Figure 6.17 Differences between Manley's reduction for Durham from 1801 to 1814, and the projection of the new method onto this period.

In general, the new reduction agrees reasonably well with Manley's version, mirroring the minor temperature changes in addition to the major ones. There are some differences of between 3.8 and –4.9°F between the two series, although these larger deviations occur in groups and are not isolated, and some of the magnitude is due to the errors which Manley made in his original calculations.

The methods used to extend the series are different from those that Manley used, yet by extending the process onwards from 1801 it can be seen that the agreement between the two methods is good. The extended series will be analysed in more detail in chapter 7, where this extended part of the series is also compared with the reduced series using more advanced techniques than Manley used, as detailed in chapter 5.

6.6 Potential for a Daily Series

6.6.1 Other Daily Series

Given that some of the sets of data used in the reduction for Durham University Observatory were recorded daily, it follows that a complete daily construction of the temperature series may be possible. A project undertaken at the University of Durham to digitise the temperature record did aim to create a daily temperature series from the data available which had been directly observed at the University (Kenworthy, Cox and Joyce 1997). Original daily data for the Observatory is available from late 1849, although a decision was made not to calculate a daily series for the early period of the record, and the daily series for Durham therefore begins on January 1st 1876.

The Central England temperature series, based upon Manley's paper of 1953 and subsequently extended, begins in 1772[90] and is maintained by the Hadley Centre (a research unit at the United Kingdom Meteorological Office) as described in Parker *et al.* (1992). This series is constructed from a set of temperature records in a similar way to the extended Durham University Observatory series presented here, and is based upon Manley's own monthly reduction, but uses different sets of archives to maximise the potential for creating a daily series. The sets of data used in the daily Central England series are shown in Table 6.19.

[90] The monthly Central England series begins in 1659.

Table 6.19 Stations used by Parker et al. (1992) to calculate the daily Central England temperature series.

Period	Station
1771-1773	London (Kennington)
1774-1776	London (Crane Court)
1777-June 1789	Lyndon Hall, Rutland
July 1789-1811	London (Somerset House)
1812-1825	London (Greenwich)
1826-1852	London (Chiswick)
1853-1877	Oxford
1878-1930	Stonyhurst, Cambridge, Ross on Wye
1931-1958	Stonyhurst, Rothamsted, Ross on Wye
1959 onwards	Rothamsted, Malvern, Squires Gate, Ringway

6.6.2 Can a Daily Series be Created for Durham from 1784?

To examine whether a daily series can be created for the Durham temperature series, it is advantageous to divide the period that the record covers into separate sections according to the source for the temperatures, as shown in Table 6.20.

Table 6.20 Summary of the distinct periods used in the construction of the monthly temperature series for Durham.

Period	Sources
1784-1801	South Cave, Brandsby and Braithwaite
1802-June 1843	Jesmond, York, South Cave, Braithwaite, Wykeham, Ackworth and Allenheads
July 1843-1849	Durham University Observatory records
1850 onwards	Durham University Observatory records

From 1850, the monthly temperature series is not strictly homogeneous due to Manley's use of varying methods to create these means. Joyce (1996) argued that the creation of a daily series is not possible back to 1850 using the same data for Durham that was available to Manley. The aim of this project was to calculate daily means which were consistent with Manley's own adopted means, but although much time was spent in determining exactly how Manley had arrived at these adopted means, there was still doubt over his methods.

> *'The calculation of a daily mean temperature series consistent with Manley's Adopted Means was an original objective of the project To use Manley's formula for using fixed-hour observations to strengthen means derived from maximum and minimum temperatures (Manley 1941)[91] could not be justified in the light of inconsistent success at replicating the monthly adopted means. Instead a statistical approach similar to that used by Parker, Legg and Folland (1992) was used for data from 1876.'* (Joyce 1996)

The varying methods that Manley used from 1850 onwards are not an issue in creating a daily series from July 1843, using the observations from the two earliest journals. For this period a single method of creating the means was used, based upon a simple adopted mean, plus a correction to the fixed-hour component to make it comparable with the daily extreme component.

[91] Within this work, the reference is Manley 1941b.

It could be argued that the quality of these data, while being acceptable for use with a monthly series, would not be suitable for a daily series. It is known that the maximum and minimum thermometers were not completely accurate during this period, although the continuation of Manley's adopted means smooths some of this. There are numerous comments in the original journals relating to replacement of the maximum thermometer in particular.

Before July 1843, the source for the monthly temperature series is a set of records observed at sites situated around the North East of England. Some of these records were observed on a daily basis whereas for others only monthly summaries survive. Of the various sets of observations available for the North East of England, Table 6.21 shows which have daily readings.

Table 6.21 Stations in North East England where daily temperature observations are available.

Station	Period
Brandsby	29th December 1783 – 4th September 1791
South Cave	1st January 1794 – 2nd April 1795
South Cave	19th November 1794 – 19th January 1815
Jesmond	1st January 1802 – 28th September 1833
Allenheads	1st January 1839 – 31st December 1842
Yarm	1st January 1840 – 31st December 1841

The set of available daily observations detailed in Table 6.21 is shown graphically in Figure 6.18 to illustrate the spread of readings over the period addressed by the monthly record.

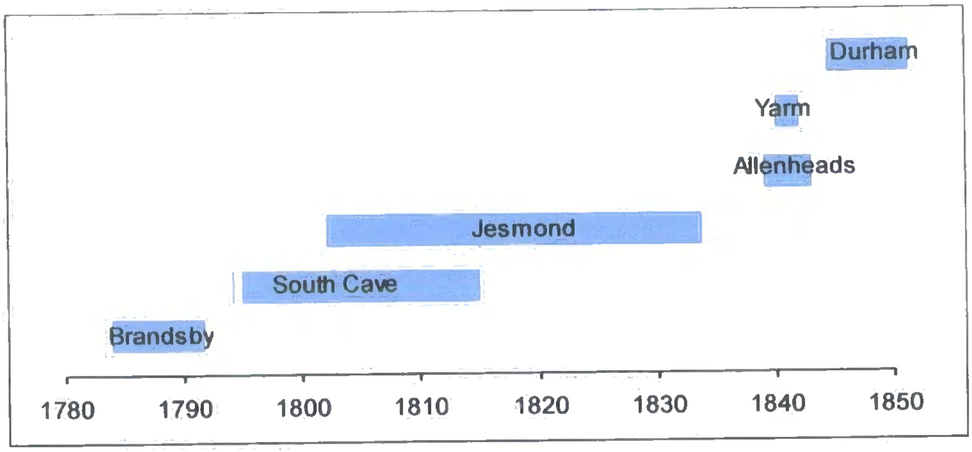


Figure 6.18 Distribution of daily temperature records for North East England.

Of the temperature data available, most were used within the monthly series. Table 6.22 shows the set of temperature records used for the monthly series from 1784 to June 1843, and whether the component series have daily observations available. Observations for Yarm were not used within the monthly series for Durham because they did not figure substantially in the results of the regression, adding little extra information to this version for the period when the data are available. In 1840 and 1841, the Allenheads and York series are combined, and give a value for r^2 of 0.9783, one of the strongest fits obtained for the exercise, when used to predict temperature data for Durham.

Table 6.22 Monthly and daily temperature series used in the extension and reduction for Durham University Observatory.

Period	Series Used	Maximum Resolution
December 29th 1783 – September 4th 1791	Brandsby	Daily
September 5th 1791 – December 31st 1793	No data	
January 1st 1794 – April 2nd 1794	South Cave	Daily
April 3rd 1794 – November 18th 1794	No data	
November 19th 1794 – December 31st 1798	South Cave	Daily
1799 – 1801	South Cave, Braithwaite	Daily (South Cave)
1802 – 1814	South Cave, Jesmond	Daily (South Cave and Jesmond)
1815 – 1817	Braithwaite, Jesmond	Daily (Jesmond)
1818 – 1823	Jesmond, New Malton	Daily (Jesmond)
1824 – 1830	Jesmond, Ackworth	Daily (Jesmond)
1831 – 1832	Jesmond, York	Daily (Jesmond)
1833 – 1836	Wykeham, Ackworth	Monthly
1837 – 1838	York, Ackworth	Monthly
1839 – 1842	Allenheads, York	Daily (Allenheads)
January 1st 1843 – July 22nd 1843	Braithwaite, York	Monthly
July 23rd 1843 onwards	Durham data	Daily

It would be possible to generate daily temperature values from the monthly means for some of the periods shown in Table 6.22. To derive a daily series based upon the same combinations of series as for the monthly version, the majority of years from 1784 to 1842 may be reproduced, with gaps between September 1791 and the end of 1793, and from April 3rd 1794 to November 18th 1794, during which the monthly series also lacks data. Gaps would also be present from September 29th 1833 to the end of 1838 and from 1843 until July 22nd. Co-incidentally, the monthly series uses all the monthly observations where daily data are available, meaning that a daily series could be based upon the same sites. A decision would be made concerning the period from 1802 to 1814 when both the Jesmond and South Cave data are available, in which case both series could be used, or just a single set of data. It can be seen from the results of the regression analysis in chapter 5 that Newcastle (the proxy site for Jesmond) is a much better estimator for temperature at Durham than Leconfield (the proxy site for South Cave), with values for r^2 of 0.9787 and 0.9385 respectively.

Missing observations within a daily series can be more problematic than with a monthly set, because if the final series is not to have gaps, readings must be estimated. This process introduces an artificial component into the series that is not there in a monthly set, provided not too many of the daily values are missing. The creation of monthly means dampens the high variability inherent in early thermometers, particularly maximum and minimum instruments, and also smooths extreme readings resulting from poor exposure or where ventilation and sunlight exclusion around the instrument is poor. Examining the daily series available, it can be seen that there are many number of gaps and missing readings that could affect the quality of the final results. Table 6.23 details each period that the daily records cover, and the number of missing days.

Table 6.23 Coverage of daily temperature data for the Durham University monthly series.

Series	Start	End	Days in Period	Missing Days
Brandsby	29th December 1783	4th September 1791	2806	460
South Cave	1st January 1794	2nd April 1794	91	17
	19th November 1794	31st December 1801	2589	289
Jesmond	1st January 1802	28th September 1833	11588	95
Allenheads	1st January 1839	31st December 1841	1095	0

For the period covered by the monthly temperature series, 83.6% of days have at least one daily record available. When missing observations are considered, this proportion drops to 79.7% to reflect the missing readings apparent in each of the series shown in Table 6.23. The early

Brandsby record is the most affected by missing readings, with 16.4% of days without an observation. The daily Allenheads record is complete for the three years that it covers.

The quality of observations is an important factor to be considered when attempting a daily series. The stations used in the reduction for Durham have all been assessed as above and are considered suitable for combining to form a reasonable approximation to a daily series. Observations made earlier in the eighteenth century might not be considered adequately accurate for the creation of a daily series, indeed for the daily Central England series, Parker *et al.* (1992) did not attempt to extend the daily temperatures back before January 1772, whereas Manley's reduction starts in 1659 (although not all based upon daily readings).

Of the available data for a daily reduction, the South Cave is situated the furthest away from Durham. For the monthly reduction, the process of forming means smooths the variability from day to day inherent in the record, but in forming a daily series it would be preferable to have composite data that were observed at stations closer to the target station.

A daily series for Durham University Observatory could be created from known data observed around North East England. The daily series would begin at the same time as the monthly series, but with currently available data, there will be several major gaps in the daily series from September 1791 to December 1793, from September 1833 to December 1838, and from January 1842 to July 1843. Within the periods covered by available daily observations there will be a many number of gaps in the Brandsby and South Cave components which would need to be estimated if they were to be eliminated. A daily series using these records would not be based upon the same set of data as the monthly reduction, which has more sets of observations to draw upon, and the reliability of the daily series would therefore be questioned. Only a single record is available to form the daily reduction for the majority of the period that the monthly record covers. A compromise could be sought between those series containing daily information whereby only those would be used to form the monthly series, but this would lead to a less optimised monthly reduction. Also, it would not be possible to make direct comparisons between the daily and monthly series.

As discussed above, a daily series for Durham University Observatory is only currently available from January 1876. The benefits of creating a daily series from late 1783 would be fully realised if this daily reduction for Durham observations could be extended back to July 1843.

6.6.3 Future Work on a Daily Reduction for Durham

In view of the above arguments, daily reduction for the period that the monthly reduction covers was not proceeded with. However, if daily versions of any of the monthly archives are discovered, or indeed any new sources of daily observations are found, then a daily reduction might become feasible. Of all the sets of observations that are currently available, it is perhaps most likely that the York record will be discovered. The data available for York are thought to exist only from monthly summaries, probably transcribed from the original ledgers, by William Baines in the 1980s. The original journals seem to have been lost, or at least they cannot be traced at their previous known locations. It is also possible that the later Brandsby set of data may be located in its full format. The source for these data within this study was a set of microfilms held at the North Yorkshire County Archives at Northallerton (Cholmeley 1811-). These films were photographed in 1980 but it is known that Manley viewed these data before this, possibly from the original copy where daily observations may be available. There is also the earlier set of data at York (from 1801 to 1824) observed by Jonathan Gray. Manley certainly had access to monthly observations, although as with the later set of York means, the original for these appears to have been lost, despite much searching at libraries and archives, both locally and nationally. Were these three sets of observations discovered, then the coverage of daily observations across the monthly period would be much better, as shown in Figure 6.19.

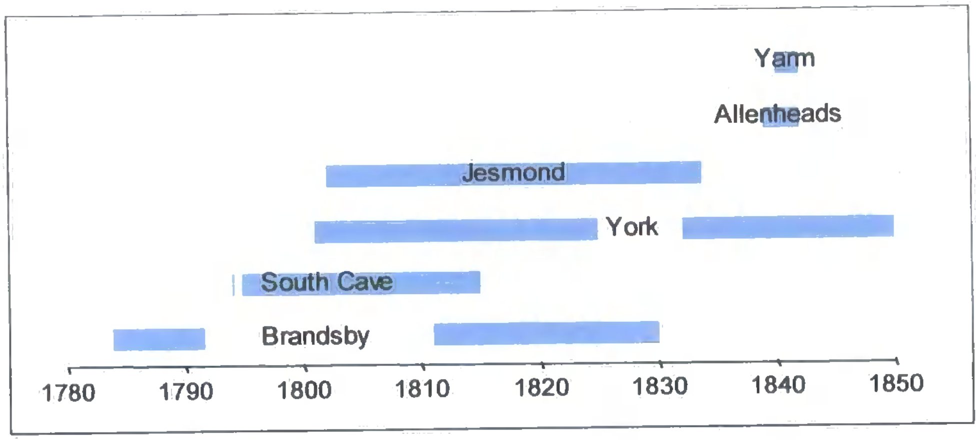


Figure 6.19 Coverage of daily temperature observations, assuming the existence of the later Brandsby series, and both York sets.

6.7 Summary of Chapter Six

Following the construction of a revised reduction for the period that Manley was working with, from 1802, this chapter examines extending the extension back from this date. Observations are available from South Cave, Brandsby and Braithwaite that together enable the reduction for Durham to begin in 1784. Each of these series is analysed in some detail to ensure that the temperatures are not affected by any suspected changes in exposure over the period. The South Cave observations in particular exhibited some movement in exposure, and the Braithwaite readings contained both outdoor and indoor means; the latter were amended to bring them into agreement with the former for the early part of the period. As for chapter 5, multiple regression revealed the best combination of these series for the periods that they are available. The potential for a daily series based upon the same data sets as the monthly series was discussed and it was determined that such an exercise would be possible, but with more gaps then the monthly version, reflecting the poorer availability of daily observations for North East England.

Chapter 7 – Analysis

Contents of this chapter

7.1 A Review of the Work Achieved

7.1.1 Investigation

A large proportion of the overall effort involved in this study has been the investigations into what Manley was working with, and how he pieced together his reduction for Durham from 1801 to 1850. This work involved careful study of his notes deposited in Cambridge University Library (Manley 1938-) for information concerning this reduction, where information concerning his work on the Durham series is found among material for other investigations of his. Integrating these notes with work summarised in his letters proved difficult given the lack of any dates on his boxed material. His letters sometimes contradict each other regarding the data he was using, with different versions of summaries and tables being presented at different times.

The way that Manley worked was very methodical, yet, even with the benefit of his knowledge of the climate of North East England, mistakes have been found in his calculations. Many of his adjustments to sets of observations were intuitive and do not necessarily follow any pattern. It has sometimes been difficult to identify whether errors are present, or whether these are facets of his calculations and were made on purpose.

Much of the original observations that Manley was using is present among his boxed papers, but there is a substantial amount that is not available, and his notes do not indicate the source for the manuscripts. In some cases it has not been possible to locate the original sets of data in order to check his calculations, and to investigate the potential for the creation of a daily reduction based upon the monthly series. Libraries throughout the North East of England, and the Scottish Borders, were searched in an attempt to locate the original copies. In some cases this was successful, for the Abbey St. Bathans series for example. National Libraries have been found to hold some data, such as the Yarm set at the National Meteorological library and archive, and letters relating to the Allenheads and Wykeham observations at the library of the Royal Society in London. For reference, the best source for each set of temperature data is shown in Table 7.1.

Table 7.1 Locations where data sources used in this study may be found.

Site and Observer	Period	Type of Material	Location and Reference
Brandsby Francis Cholmeley (early daily set)	1784[92]-1791	Microfilm	North Yorkshire County Archives (Cholmeley 1783-)
South Cave Henry Boldero Barnard	1794-1815	Manuscript (two volumes)	Hull Local Studies Library (Barnard 1794-)
	1794-1804	Microfilm	Hull Local Studies Library
Braithwaite Abraham Shackleton	1798-1857	Manuscript	Cliffe Castle Museum, Keighley (Shackleton 1799-).
		Photocopy	Cambridge University Library (Manley 1938-)
Jesmond James Losh	1802-1833	Manuscript (six volumes)	Newcastle Literary and Philosophical Society Library (Losh 1802-)
Brandsby Francis Cholmeley (later monthly set)	1811-1830	Microfilm	North Yorkshire County Archives (Cholmeley 1811-)
New Malton	1818-1825	Publication (summary)	Dove (1838, 1853)
Ackworth Luke Howard	1824-1842	Publication (summary)	Howard (1842a, 1842b)
York John Ford	1832-1867	Transcription of monthly means only	York City Archives (Ford 1831-)
Wykeham Robert Nendrick Hodgson	1831-1837	Transcription of monthly means	Cambridge University Library (Manley 1938-)
Abbey St. Bathans Rev. John Wallace	1835-1838	Publication (summary)	Transactions of the Borders Naturalists' Society (Wallace 1835, 1836, 1837, 1838)
Allenheads Rev. William Walton	1836-1842	Manuscript letters	The Royal Society Library, London (Walton 1836a, 1840, 1841)
Yarm	1840-1841	Manuscript	National Meteorological Library and Archive, Bracknell

[92] The earlier Brandsby observations begin on December 29th 1783. For the purposes of monthly means, the series begins from 1784.

Also for reference, Table 7.2 shows those sets of data that could not be located, but which are thought to have existed when Manley was working on his reduction.

Table 7.2 Sets of observations that are thought to exist, but could not be located.

Site and Observer	Period	Type of Record
York Jonathan Gray	1802-1824	Daily observations
Brandsby Francis Cholmeley (late monthly set)	1811-1830	Daily observations (monthly summaries are available)
York John Ford	1832-1867	Daily observations (monthly summaries are available)

If the data described in Table 7.2 were to be found, then improvements could be made to the reduction as presented in chapters 5 and 6. These potential enhancements are detailed in section 7.3 below.

7.1.2 The Reduction – 1802 to 1849

The period of the reduction is considered to be that which Manley was working on in the late 1970s to 'attach' onto the Durham University Observatory data that he knew existed at that time, and to start as far back into the past as he could manage. When he was working, the earliest record of which he was aware was that from Brandsby, which starts on December 29th 1783. Neither daily nor monthly means from this series have been found among his material, and the only reference to it is a single comment concerning data from 1784 in one of his letters (Manley 1978- ; 27.xi.79). He did not use this series however, probably because of a lack of time. Nor did he use the earliest set of data that has been found among his notes, that for South Cave from

1794, despite being aware of the observations. Therefore the starting point of his reduction was the beginning of the Losh record, observed at Jesmond, in January 1802. He derived estimates for 1801 that were included in tables in his letters, but 1802 was considered the starting point for this section.

In order to improve Manley's reduction for Durham from 1802 to 1849, his methods were first examined to see whether there were any problems with these, or any errors evident from his results. His practices were seen as sound, and based upon a general knowledge of the climate of North East England. However, these techniques were not particularly objective in that they were based upon his own feeling that the means he arrived at appeared to be too high or too low. There is no evidence of Manley employing particular statistical tools while working on his reduction; indeed, he did not use a calculator or computer and it is perhaps as a result of this that some errors were found in his results.

Each series that is available for North East England was considered for use in the new reduction. Manley generally built his version from blocks of years for which the major records were available, and made adjustments to those basic monthly means by referring to decadal means from other series. For the latter half of his reduction, he relied upon a combined mean from four series across Northern Britain: Keighley, Ackworth, Edinburgh and his own Lancashire reduction. This Lancashire reduction is itself a product of three other series from the area south of Lancaster. These stations, and the Edinburgh series, are further from Durham than those sites used by Manley earlier in his reduction, such as the Losh and Brandsby observations. Given the variability of climate across the North of England, less confidence should be placed in temperatures observed at places further from Durham, specifically those west of the Pennines. Observations to be used in the reduction for Durham should be located as close to Durham city as possible, essentially those east of the Pennines, south of the Firth of Forth and north of the Humber. The major problem with this period of his reduction is the incorporation of the Lancashire and Edinburgh observations, thus making Manley's final version incapable of direct comparison with them. Given that long-period temperature series for the United Kingdom are limited in their availability, to incorporate two data sets in the calculation of another restricts comparison that may be made between the two series, and hence the usefulness of the reduction. Manley did recognise this, and indeed he may have corrected for it given time.

Exposure details from each manuscript, where available, were considered in case of any adverse effects upon the resulting means. The Losh manuscript was considered in extra detail given its length and apparent quality, and also to use as a typical set of observations for temperature in the early nineteenth century. During the analysis it was found that some series were not used in the final reduction to the extent that their length or quality might encourage, due to their location relative to Durham and the ability of different series available at each point in time to estimate temperature at Durham. Analyses were performed on factors such as the handwriting and the frequency of missing readings, and the prevalence of observations made to the nearest degree or half-degree, to assist in the detection of any trends in the observations.

The sets of temperature observations were adjusted to reach monthly means characteristic of the mean observed at Durham University Observatory, where the mean for a day is calculated from the mean of the daily extremes. Some observations consisted of daily information with several readings per day, and others of monthly means alone. Fixed hour readings for the York site were not available, but daily extremes were, and hence the mean could be calculated directly. For all other series, the fixed hour readings were combined to form an approximate mean for the day, and then adjusted to bring this to the mean for the 24 hour period, as if observations were taken continuously, and then on to the mean representative of the daily extremes. For these two sets of adjustments, reference was made to the corrections published by James Glaisher (Glaisher 1849, 1850, 1867). The adjustments were altered slightly to account for the lower diurnal range in the North East of England than at Greenwich, although an allowance was made for the greater variability exhibited in the thermometers used at the time. These adjustments were made on a daily basis, rather than the annual to decadal level that Manley applied. It was seen that for most of the series, the hours of observation varied greatly from day to day, so some months would have been poorly estimated by Manley's assumptions. In his review of his final monthly means he was subjective, making comments such as 'looks too high' but without expressing why, or by how much.

The available temperature series between 1802 and 1849 were examined in relation to data from a site nearby that is either observed currently, or was so in the recent past. The purpose of this was to ensure that the exposure at the historic site was similar to exposure expected for that area. To determine the best combination of series to represent Durham, multiple linear regression was applied to the data to estimate mean temperature for Durham University Observatory. The result of this study led to an optimum set of three series to represent Durham University Observatory. The annual and monthly means of this combination were seen to be the same as the annual mean for Durham, after the means from each site were adjusted according to their altitude relative to Durham University Observatory. The mean difference for all months was 0°C. The historic counterparts of these three series are never available simultaneously for the reduction period; therefore, sets of combinations were found for each period of the reduction where a distinct set of records was available. Sets of two series were preferred to those with greater or fewer constituents on the basis that a constant number of series throughout a period limits any extra corrections needed for the varying number of data sources. It was also observed that a third series incorporated into the regression equation gave very little improvement in the overall ability of the chosen series to estimate temperature at Durham. Two series were used in preference to a single series on the assumption that the quality of data observed in the early nineteenth century was more variable than under modern conditions, so that the second series helps to damp any such characteristics. Increasing the number of series above two is unlikely to bring any further benefit to the composite series, given the correlation diagrams that were produced. Where more than a single set of data was used to form the composite, the variance of the combined data was examined to ensure that the variance was that which would be expected of a single series, given that the station data to be modelled are for Durham University Observatory and not an area such as 'Lancashire' or 'Central England'. Once the optimum set of combinations for each distinct period was chosen and adjusted, the historic observations were combined to find the monthly means for the period from 1802 to mid-1843.

Two journals of original daily observations for Durham University Observatory were found shortly after Manley died (Durham University 1843-, 1848-). Although he suspected that these existed, he was never able to consult them and continued his own method of reduction until the end of 1849 to meet data from the Observatory that was known at the time. This study, however, uses the new data, from July 1843 to the end of 1849, which was analysed and reduced to monthly means based upon Manley's system of adopted means applied by him from 1850. This system combines the mean of the daily extremes, averaged with an adjusted mean from the fixed hour readings. The fixed hour observations from the two 'new' journals are generally at 9 am and 9 pm, making the correction more straightforward. Manley's adjustments for changing hours of observation for the earlier period (as he worked in the 1970s) were drawn from Glaisher's calculations for Greenwich, yet from 1850 he used a different set that exhibits a similar pattern but with a lower magnitude. This inconsistency initiated a study of actual differences between fixed hour and daily extreme means from Durham data for the sixteen years from 1867 to 1882. This showed that the pattern of corrections that Manley used was incorrect and could be improved. The new set was used for corrections to data from the 'new' journals, and also to the period from 1802 to 1843.

7.1.3 Summary of the Correction Technique

The process of adjusting the source data into monthly means representative of Durham can be summarised into a number of separate stages. These stages will be slightly different, depending upon whether the original means are in daily or monthly format. Where daily means are available, more calculation steps are necessary, whereas where the only monthly means are available, more checking needs to be done on the means already presented. Figure 7.1 summarises the process for reference.

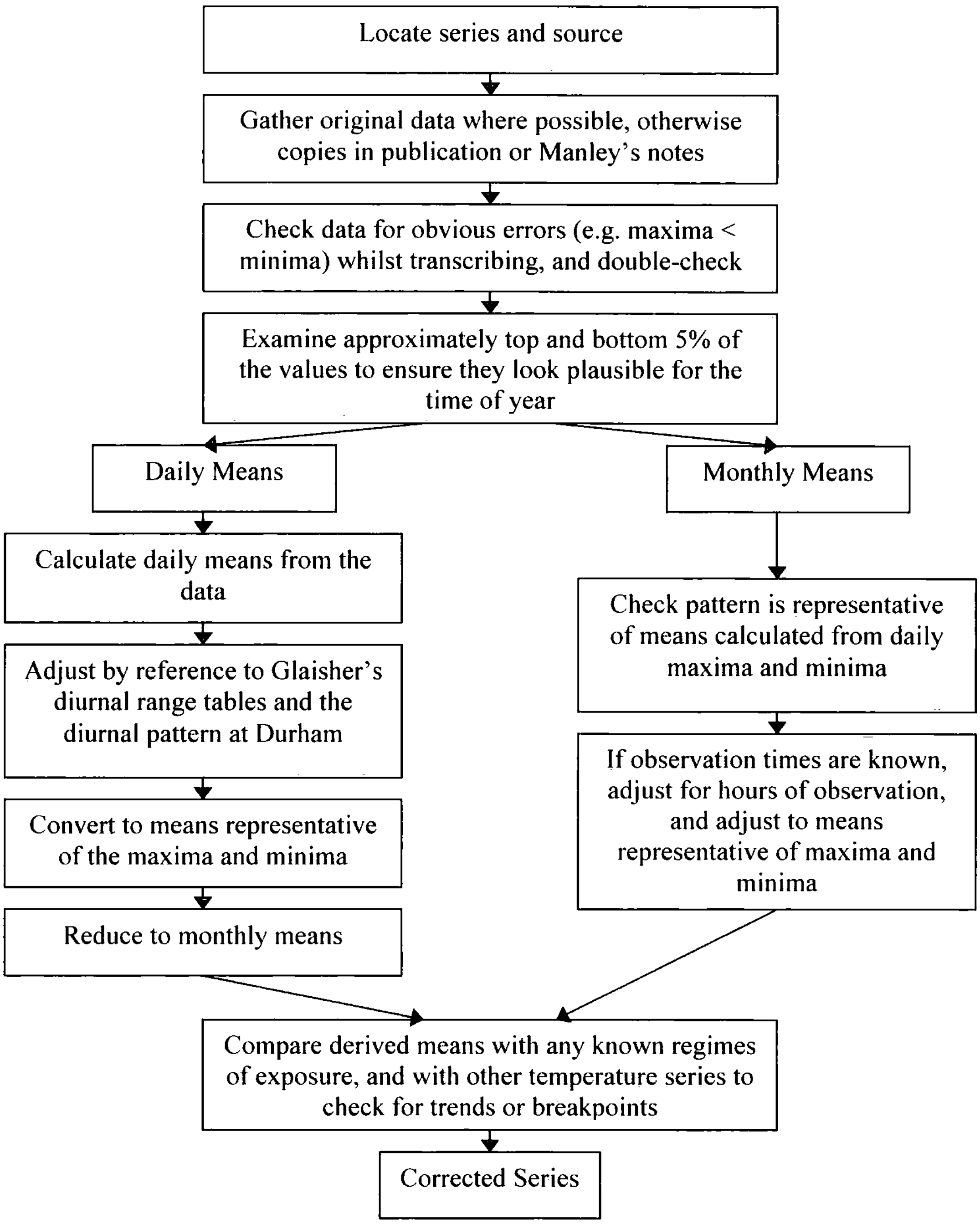


Figure 7.1 A summary of the process of deriving corrected monthly means from the source data.

7.1.4 The Extension – 1783 to 1801

The 'extension' period was considered to be that before 1802, when the earliest series that Manley used for his reduction starts, and from when he calculated monthly means that were included in letters to Joan Kenworthy.

Three sets of observations are available for this earlier extension period. As for the later 'reduction' years, each period for which a distinct set of observations is available was compared for its temperature regime with Durham University Observatory using data for the modern period at sites geographically close. The resulting analysis resulted in optimal combinations, and in each case either a single record, or pair of records, were selected to represent Durham. Only the period from October 1st 1799 to December 31st 1801 provided two available sets of observations, South Cave and Braithwaite, of which South Cave was demonstrated to be the most useful. Adjustments were made to the observations, to derive monthly means based upon the mean of the daily extremes, in a similar way to the later period.

7.1.5 Summary of Component Series

Table 7.3 details the sets of observations that were used to build the monthly temperature series from 1784 to 1849. Where a series becomes available part-way through a month, its start date is assumed to be at the start of the next month. Similarly, if a series ceases to be available part-way through a month, its end date is assumed to be at the end of the previous month.

Table 7.3 Temperature observations used in creating the monthly temperature reduction for Durham University Observatory from 1784 to mid-1843, after which Durham data are available.

Period Start	Period End	Months	Series Used and Weight[93]
January 1st 1784	August 31st 1791	92	Brandsby
September 1st 1792	December 31st 1793	16	No data available
January 1st 1794	March 31st 1794	3	South Cave
April 1st 1794	November 31st 1794	8	No data available
December 1st 1794	December 31st 1798	49	South Cave
January 1st 1799	December 31st 1801	36	South Cave (0.84), Braithwaite (0.11)
January 1st 1802	December 31st 1814	156	South Cave (0.21), Jesmond (0.80)
January 1st 1815	December 31st 1817	36	Braithwaite (0.04), Jesmond (0.97)
January 1st 1818	December 31st 1823	72	Jesmond (0.75), New Malton (0.25)
January 1st 1824	December 31st 1830	84	Jesmond (0.71), Ackworth (0.28)
January 1st 1831	December 31st 1832	24	Jesmond (0.71), York (0.28)
January 1st 1833	December 31st 1836	48	Wykeham (0.50), Ackworth (0.45)
January 1st 1837	December 31st 1838	24	York (0.45), Ackworth (0.48)
January 1st 1839	December 31st 1842	48	Allenheads (0.53), York (0.43)
January 1st 1843	July 31st 1843	7	Braithwaite (0.03), York (0.89)

The details of the various proportions shown in Table 7.3 can be seen more clearly in the graphical representation shown in Figure 7.2. The South Cave, Brandsby and Jesmond are the most prevalent across the period, with Jesmond being the most dominant, contributing to over half of all the months in the period, and South Cave contributing to just over one third of months.

[93] The sum of the weights will not necessarily be 1, because there is also an intercept for the regression equation. Full details are shown in chapter 5.

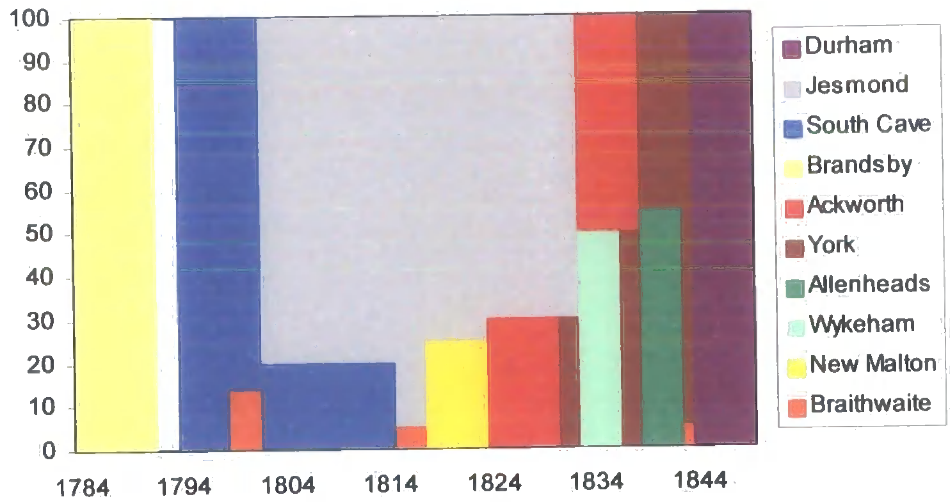


Figure 7.2 Representation of the contribution each set of observations makes towards the monthly means for Durham University Observatory, 1784 to 1843.

7.2 An Analysis of the Accuracy and Precision

The correction and combination of the various sets of observations in this thesis are, for some stages, quite lengthy. Approximations have been made to corrections, and the original source data are available to a certain degree of accuracy, which cannot be enhanced. This section examines the major stages in the process described above to allow confidence in the accuracy of the data.

7.2.1 Accuracy of Original Observations

Of the historic data, all observations were made in degrees Fahrenheit, with some to the nearest whole degree and others to the nearest half-degree. As has been discussed in previous chapters, the confidence that can be placed upon the accuracy of the historic observations varies, with some series as the long Losh and South Cave data sets probably being more accurate than others.

When only monthly means are available, such as the later Brandsby set from 1811 to 1830 and the Allenheads observations, the assumption has been made that the means were calculated intelligently, using the maxima and minima for the days, or readings very close to these. The exposure of the sites is, in many cases, almost unknown, so again assumptions have to be made. For the South Cave observations, certain details are available concerning the exposure, so these have been borne in mind when calculating the monthly means by analysing the differences in means for each exposure type. There is evidence of some observers checking the calibration of their instruments, but not from all. In no record is it possible to segregate instrumental error from exposure bias, or from calculation problems.

In view of these caveats, the confidence that may be placed upon readings observed to the nearest half-degree Fahrenheit might seem a little optimistic, but after all, these data are all that are available, and the monthly reduced means are an approximation for Durham. Nevertheless, much has been done to analyse and correct the readings where there is any suspicion of bias for calculation method, exposure or even transcription errors. Table 7.4 shows the original data used in the reduction, the general precision of the recorded observations, the known details of exposure and times of observations, and also whether daily observations or just monthly means are available. In terms of the apparent precision of the observation, the Allenheads data are the most useful, because not only are daily observations available, but the times of observations are also known. How accurate the thermometer was though is questionable.

Table 7.4 Precision and details of exposure for the sets of data used in the reduction of monthly mean temperature for Durham (all 'degrees' here are expressed on the Fahrenheit scale).

Site	Period	Type	Precision
Brandsby (early daily set)	1784[94]-1791	Daily Means	Nearest whole degree
South Cave	1794-1815	Daily Means	Nearest whole degree
Braithwaite	1798-1857	Monthly Means	Monthly maxima and minima presented to nearest half-degree
Jesmond	1802-1833	Daily Means	Nearest whole degree
Brandsby (later monthly set)	1811-1830	Monthly Means	Monthly means presented to nearest half-degree
New Malton	1818-1825	Monthly Means	Monthly means presented to nearest one-tenth of a degree
Ackworth	1824-1841	Monthly Means	Monthly means, presented to nearest one-hundredth of a degree
Wykeham	1831-1837	Monthly Means	Monthly means presented to nearest one-tenth of a degree
York	1832-1867	Monthly Means	Monthly means presented to nearest one-tenth of a degree
Abbey St. Bathans	1835-1838	Monthly Means	Monthly means presented to nearest one-tenth of a degree, but are available for four readings per day at 9 am, 10 am, 3 pm and 10 pm
Allenheads	1836-1842	Daily Means	Nearest one-tenth of a degree

Data for the modern period, generally the 1990s, have also been used in this study. In all cases, these observations are to an accuracy of 0.1°C, greater than the maximum resolution of the historic data (for which 0.5°F would equate to 0.9°C). It is assumed that temperature readings from these sites in the modern period are accurate, with no instrumental error.

[94] The earlier Brandsby observations begin on December 29th 1783. For the purposes of monthly means, the series begins from 1784.

7.2.2 Corrections

A range of different sorts of adjustments and corrections have been made to the historic and modern data. In most cases, assumptions have been made regarding how the corrections would vary through the year. In the case of the corrections for altitude, an assumption of 1.08°F (0.6°C) per 100 m has been assumed in order to adjust temperature readings at altitudes different to Durham, to 102 m. This figure of 1.08°F was derived from the Celsius correction and applied to the historic observations.

When the original observations were made at known times of day, corrections were made with reference to Glaisher's corrections derived from observations at Greenwich, modified with reference to the Durham diurnal range. These corrections are to the nearest 0.1 degree Fahrenheit for hourly corrections, but when interpolating corrections for intermediate half- and quarter-hours, 2 decimal places have been retained and applied to the source data.

During the calculation and manipulation of monthly means, precision was retained to at least 3 decimal places, before the final modification to a single decimal place, despite this level of accuracy being difficult to justify should final means be presented in this form. This retention of as much detail as possible during calculation is important to ensure that coarseness is not introduced inadvertently. The rounding to one decimal place is only done after all corrections are applied, and the monthly means have been converted to degrees Celsius. In addition to this, the reduction to monthly means from daily values will smooth any errors. All rounding in this thesis has been done using the general mathematical method of rounding numbers ending in 5 consistently upwards.

7.2.3 Conversion from Fahrenheit to Celsius

The manipulation and adjustment of historic data in this thesis has been performed using degrees Fahrenheit. When comparing this with other temperature reductions, or modern data, the monthly means for Durham have been converted to degrees Celsius. Given that at these temperatures, one degree Fahrenheit equals approximately 0.6 degrees Celsius, this conversion will introduce some coarseness into the data. Temperatures that are expressed in degrees Celsius therefore lose some of the accuracy that is present in the original Fahrenheit data. Given the uncertainties in the original historic observations, this loss of information should not be considered a problem.

7.3 Analysis of the Final Series

7.3.1 Comparison of the Durham Reduction Against Other Series

During the creation of the reduction for Durham University Observatory, comparison was made with the Central England temperature series as a check upon some of the individual series. Comparing the Durham and Central England series proves useful in that the overall temperature difference between the two series should be reasonably constant, assuming no uncertainties exist with the Central England series itself. This difference will be approximately the temperature expected by the relative altitude, and to a certain extent the latitude, between the two areas. On the diurnal level, the differences would be less predictable; hence comparison has only been made on the monthly and annual level. Figure 7.3 shows a comparison between the Durham and Central England temperature series across the overlapping period between them, up to 1940.

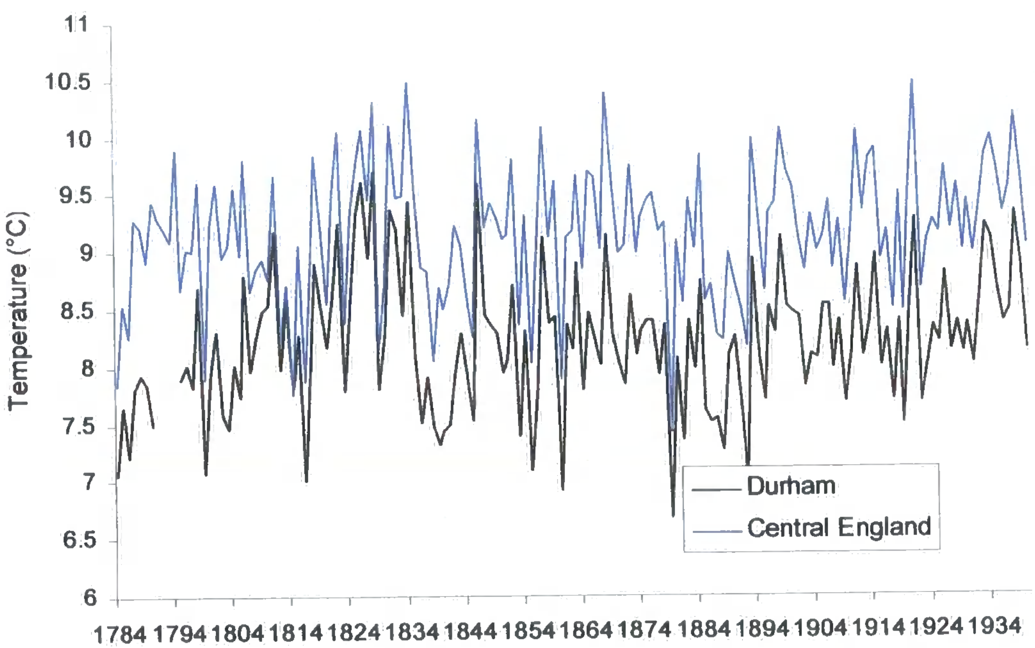


Figure 7.3 Annual means for the Durham and Central England temperature series (°C).

The relationship between the two series is best examined when the differences between them are considered. Figure 7.4 shows these differences, where the increased deviation between the two series in the early part of the series can clearly be seen.

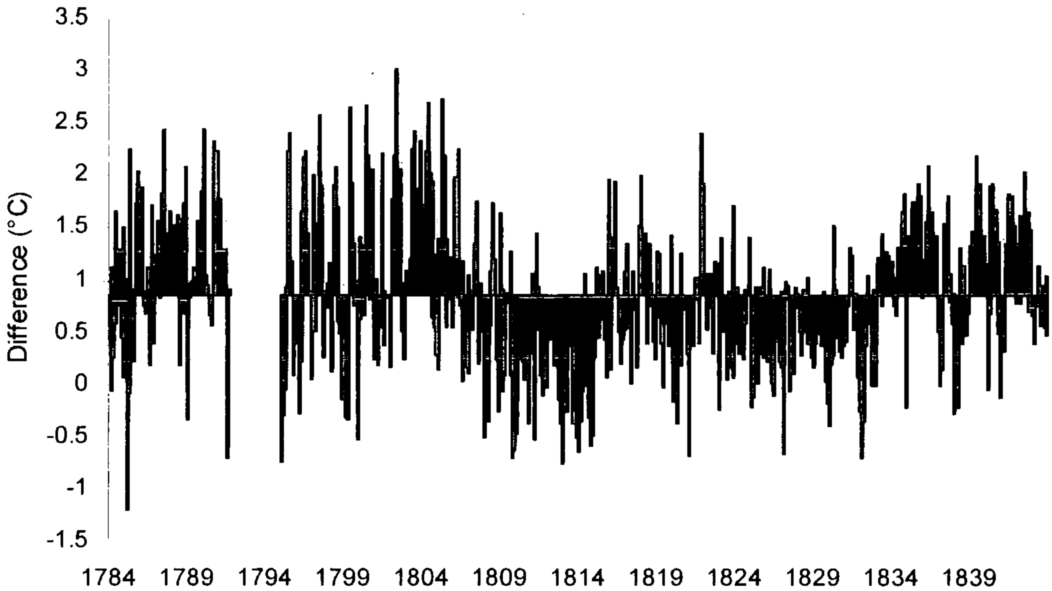


Figure 7.4 Differences between the Durham University Observatory and Central England temperature series from 1784 to 1849 (°C).

The differences between the Durham and Central England series are generally fairly constant, reaching a slight peak in 1802 and then dropping back to the mean difference of 0.85°C for the reduction period. On average, across the Durham University Observatory record from 1784 to 1849, the difference between the two series is very similar to the typical difference seen through the arguably more accurate period from 1850 onwards. Figure 7.5 shows the mean difference for each distinct period in the Durham record. The long-term difference between the Durham and Central England series is shown as a solid line across the entire period, as calculated for the years 1850 to 1940.

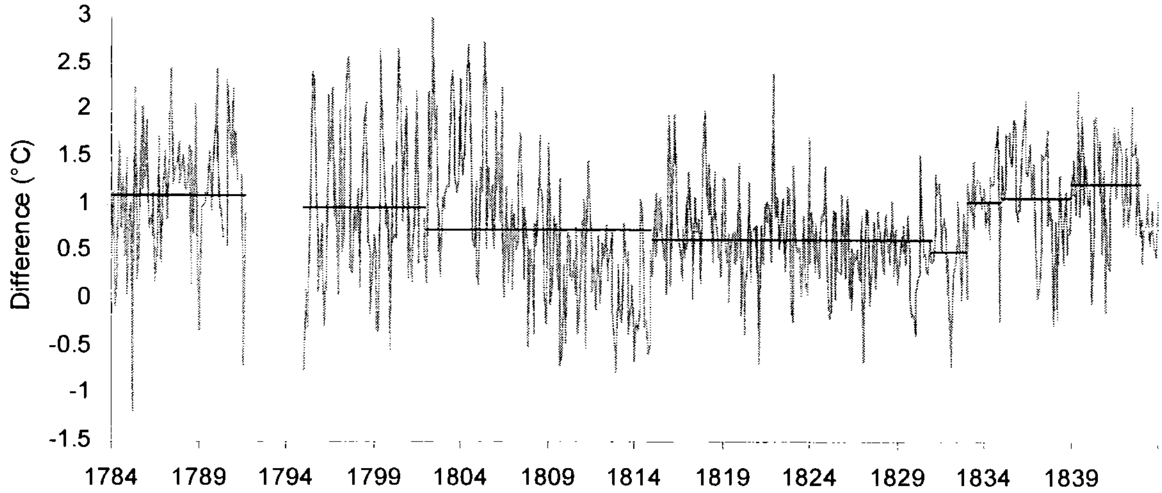


Figure 7.5 Differences between the Durham University Observatory and Central England annual means, with mean differences between the series shown for each period (°F).

It is to be expected that there will be a certain amount of variability between the Durham and Central England series corresponding to the different component series that have been used at each stage. Manley's own reduction also showed similar patterns, and on average was lower than the reduction presented here by around 0.4°C, thus making the difference between his and the Central England series slightly greater. The reduction presented here is also a little more variable than Manley's version, with the annual mean having a standard deviation of 4.96°C against 4.66°C for Manley's. Figure 7.6 shows the reduction presented here compared with Manley's version.

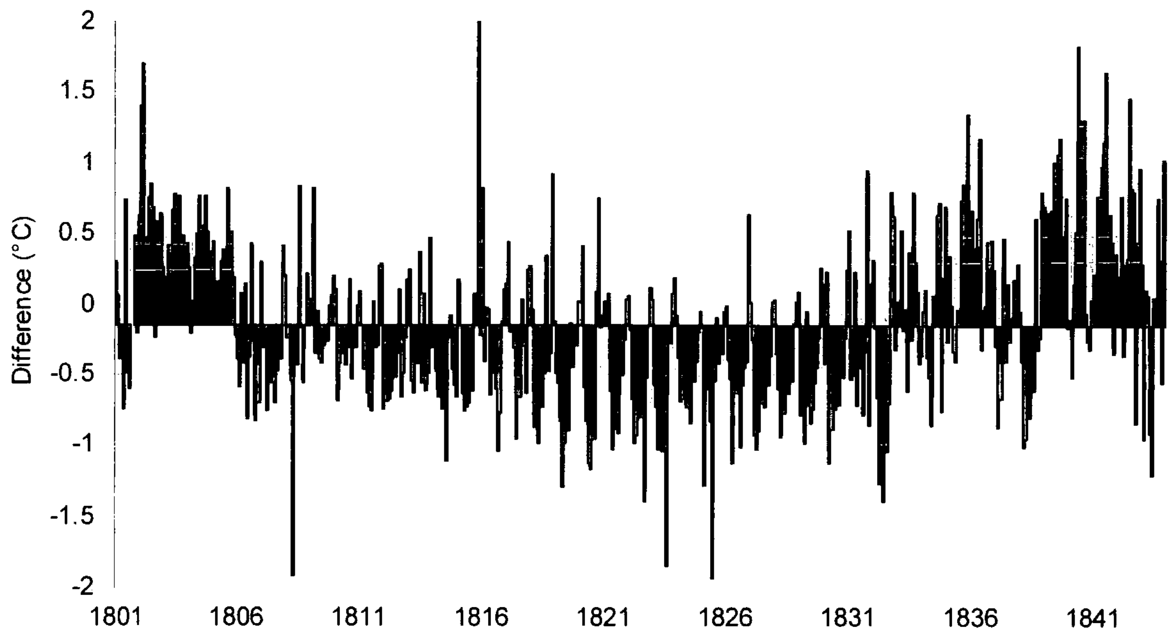


Figure 7.6 Differences between Manley's reduction for Durham University Observatory, and the version presented here. Values are shown as differences from the mean of –0.15°C).

A comparison with Mossman's temperature reduction for Edinburgh is also useful, although less so than the check against Central England. As with the comparison against Central England, the same patterns are shown in the Durham reduction when compared with the Edinburgh means, shown in Figure 7.7.

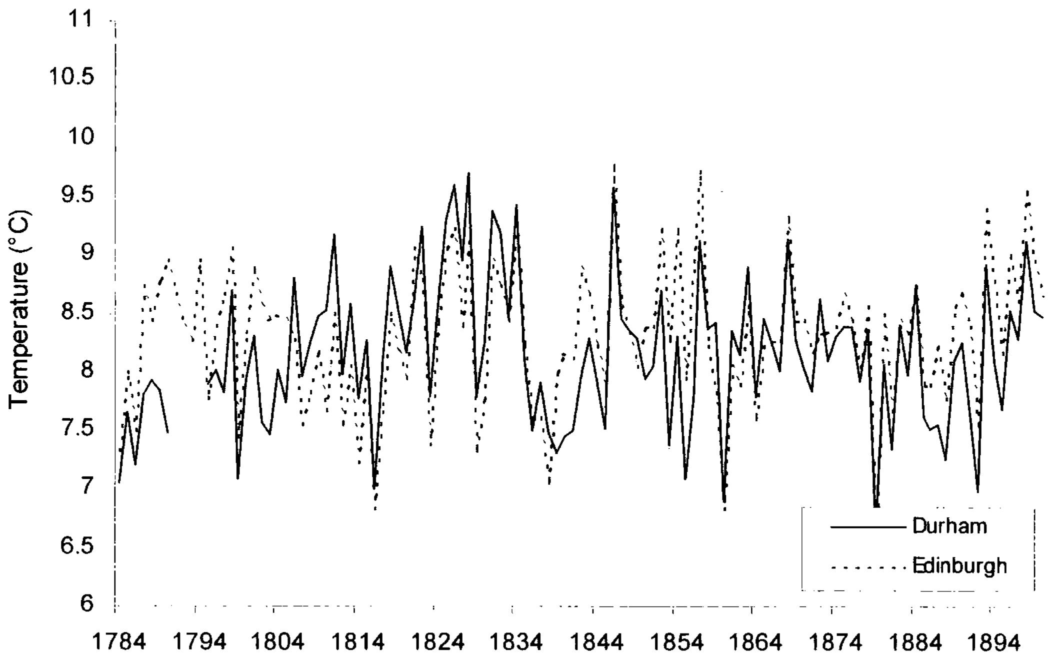


Figure 7.7 The Edinburgh (broken line) and Durham University Observatory (solid lines) annual means between 1784 and 1900 (°F).

The period from 1784 to 1802 consistently displays means that are too low in relation to the rest of the series, by approximately 1.6°F (0.9°C), when compared with the means for the period after 1850. This shows up clearly on the graphs shown above. Figure 7.8 concentrates on just the early period of the extension for Durham between 1784 and 1815, when the agreement in pattern can be seen more clearly.

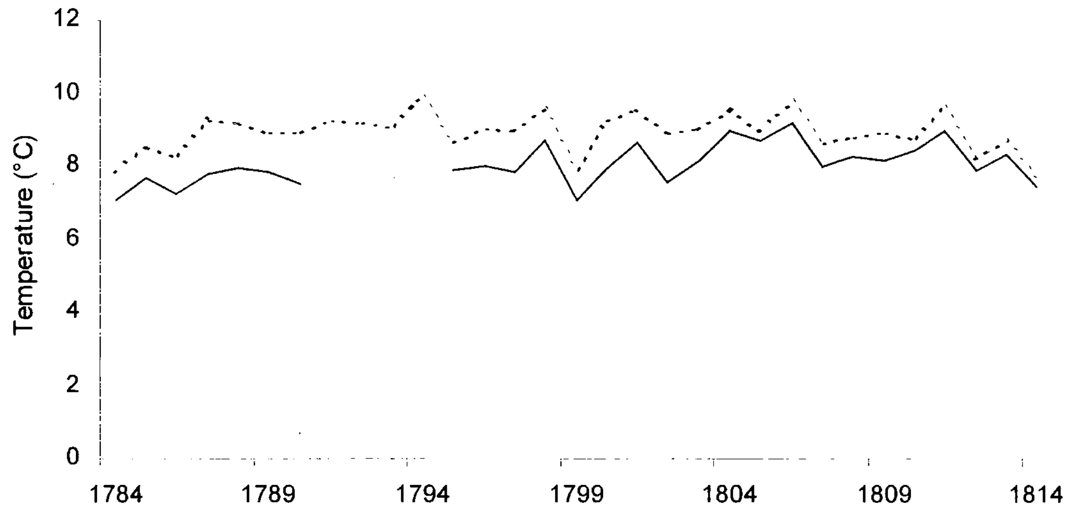


Figure 7.8 Durham University Observatory (solid line) and Central England (broken line) annual means between 1784 and 1814 (°F).

The early portion of the series from 1784 to 1791 is composed of the Brandsby series alone, with no extra sets of data to provide a balance to its location 90 km SSE of Durham. The correlation diagram between Durham and Ampleforth for data observed under modern conditions of exposure is shown in Figure 7.9, with the overall value of r^2 being 0.957.

Figure 7.9 Values for r^2 for each month for the Ampleforth temperature series used to predict temperature at Durham University Observatory.

The strength of the values for r^2 across the year between Ampleforth and Durham in Figure 7.8 reflects the poorer fit of the Brandsby data with some of the rest of the Durham reduction. The fit is poorer in early autumn than at other times of the year. For the exercise, full daily means were considered across 30 years of data, and hence this should give accurate values for r^2, which might not be the case if only monthly means were considered, or if a shorter period of data was considered.

The use of temperature observations from South Cave and Brandsby has been valuable in extending the record farther back into the eighteenth century, but the quality of data that they provide in relation to the climate of Durham is not ideal. However, in view of the quantity of data that are available for the late eighteenth century and into the start of the nineteenth century, the Brandsby and South Cave series must be seen as essential. Analysing the data before 1802 should be done with a caveat that these monthly means have been adjusted to be as representative of the temperature of Durham as possible. Further corrections could be made that are based upon the relationship between Durham and another external series such as that for Central England, but this would introduce a strong component of such a series into the Durham reduction, and it would lose its independence regarding comparison with other reductions. On balance, these estimates for monthly means at Durham University Observatory, although flawed, are perhaps as close as they may be without employing further advanced techniques as outlined in the following section. Indeed such techniques may not prove able to bring the estimates for Durham substantially towards a 'better' exposure for the Observatory.

7.4 Improvements

7.4.1 Improvements for 1802-1843

The techniques that have been used in this study have been chosen to provide good estimates for the mean monthly temperature at Durham University based upon the data available. For the construction of the temperature reduction, certain aspects of the procedure might be improved by the use of more advanced methods, although it is possible that the use of such techniques would not afford additional accuracy in the overall means. This section examines what further possibilities there might be for refinement of the data presented.

A key component of the production of monthly means was the analysis of the climate at various places in North East England and the Borders using stations that are recording temperature now, or in the recent past. Care was taken to choose those sites that are situated close to the historic sites, although in principle the modern sites could be quite unrepresentative of the local area. This is difficult to assess given the spatial resolution of stations observing temperature. Characteristics such as frost hollows may lead to poor representation for a given area, although it is expected that the data actually observed at a modern station, and reported back to the Meteorological Office, are of the highest quality. The monthly means that are calculated from the daily data will tend to smooth out any of the finer diurnal inconsistencies in the exposure of these sites. Monthly means were calculated for the modern stations using data from the period 1991 to 1999. This was chosen as a long enough period for which monthly means might reliably be calculated, and also because some of the stations did not have observations available for a longer period than this. It was considered desirable to have consistency in the number of years of data averaged, and to place foremost the location of the sites chosen. In addition to this, some of the 'modern' stations had actually ceased observing temperature and did not have data available for the 1991 to 1999 period. In this case, an adjustment was made to bring the overall monthly means for the station's available nine-year period to a mean more representative of the 1990s. This was achieved via comparison with the Central England temperature series, thus introducing a small reliance upon this later reduction. The choice of these modern stations might be improved by selecting stations that do record daily temperature, but do not necessarily report to the Meteorological Office, and which are available as data sets at the British Atmospheric Data Centre. The ideal, but very protracted, solution to this criticism would be to monitor temperature at the location, and under the same exposure, as that for which the data from the historic archive would have been derived. In most cases the location of the house or estate where temperature was observed is known, although the actual location of the thermometer and the way that it was exposed to the air is not certain.

For the historic York site, two potential modern stations were examined, and it was seen that the observations from Askham Bryan matched the Durham exposure more closely than those from Heslington. A further study might include extra paired stations for each of the other locations in an attempt to refine the choice of station.

After correlation diagrams were drawn for the individual modern stations against exposure at Durham for the same period, the correlation was seen to be good. For stations further away from Durham, the correlation gets poorer, although not purely as a function of the distance between the two sites. Leconfield, although approximately 130 km SE of Durham University Observatory, yields a mean correlation coefficient of 0.92. Ampleforth is closer to Durham, 80 km SSE, and the mean correlation is 0.24. The Brandsby series is the only set available for the period from 1784 to 1792, giving a very useful extension to the beginning of the series. It has been shown that the observations themselves were well kept, but the location relative to Durham has weaknesses. Ampleforth itself is close to Brandsby, but higher on a slope to the north at 95 metres as opposed to 29 metres. More representative modern stations could not be identified closer to Brandsby from the data available with the British Atmospheric Data Centre, but it is possible that such data do exist, or could be constructed from the network of more casual observations made by local meteorologists.

A simple adjustment was made to the data series for their relative location to Durham based upon a general 0.6°C warming per 100 m of altitude, for each month. Manley used a single figure throughout the year, but a more optimised adjustment might be reached by considering each month separately. The lapse rate does vary according to the location and the prevailing weather conditions: for example they are steeper in northern England under westerly airflow, and under low sunshine conditions (Pepin 2001).

When the different sites were combined to test the composite exposure against that for Durham, multiple linear regression was used to judge the suitability of the combination. Two sites were chosen generally as the optimum number of constituent sets of data for combination.

The historic sets of observations were all analysed carefully to ensure that any gaps or varying times of observation did not adversely affect the quality of the monthly means. When observations for a complete month were missing, no mean was estimated. Where greater than three, but fewer than 20 or 21 (depending upon the series) of the daily observations were missing, then the monthly mean was calculated, but adjusted to take account of the position of the available daily means within the month, based upon the typical progression of temperature during the month for that site. This simple method was chosen in preference to some alternative techniques that were considered (e.g. Valero *et al.* 1996) but it is possible that more advanced techniques may be employed to give a better approximation to the monthly mean. The method used here is only successful for series where a substantial number of means are available for surrounding months of that same name, i.e. a longer record.

Adjustments were made to means derived from fixed hour observations in the manuscript material to bring them to those representative of the mean of the daily extremes. Observations from York were the only historic means available before 1843 that were observed using a maximum and minimum thermometer. Daily means for other sites were calculated from all available observations (up to seven in the case of the early Brandsby set) and an adjustment made to bring this first to the 'true mean' or '24 hour' mean of the day. Glaisher published such corrections (Glaisher 1849, 1850, 1867) and although Manley believed them to give good results, they are dependent upon a higher diurnal range at Greenwich than at Durham, and so are greater. A balancing factor to this is that extremes measured upon thermometers in the late eighteenth and early nineteenth centuries are often exaggerated due to inaccuracies in the calibration of the instruments. If the exposure of the original readings could be more accurately ascertained, from a medium-term analysis of the conditions of temperature at that specific site for example, then the corrections should be reduced to be more applicable for the typical diurnal range at Durham.

The 24 hour means were adjusted to bring them to a mean appropriate for the daily extremes, and this set of corrections was derived from those actually observed at Durham for the 16 years from 1867 to 1882. This period was chosen for its consistency of hours of observation, but a longer period might be more appropriate, provided further adjustment of its constituent means was pursued.

7.4.2 Improvements For 1843-1849

The period from 1843 to 1849 has been filled using monthly means calculated from the two journals that were found in the early 1980s. Manley's method of calculating the monthly means from 1850 onwards was applied to this period to maintain consistency with the later period, but it can be seen from comments in the manuscript that there were problems with the maximum thermometer. A replacement thermometer was obtained, but this continued to provide problems. Monthly means derived for this period display a good agreement with the longer term means from later in the series, but a fuller analysis of the maximum thermometer readings might be carried out as a check on the exposure. The system of adopted means effectively places a weight of approximately 0.25 onto the maximum thermometer reading, thus reducing the effect of any errors.

It has been shown that the corrections that Manley applied to the mean of the maximum and minimum means, which was then given a weight of 0.5 for the adopted mean, did not match actual corrections calculated for Durham from observations later in the century. Manley's original corrections were used to provide consistency with the later years from 1850, but a study could be made of these corrections to ensure that his means after 1850 were not adversely affected by his choice of adjustments.

7.4.3 Improvements Before 1802

Potential improvements to the period of the reduction for Durham University Observatory before 1802 are largely similar to those discussed from 1802. This earlier section of the reduction presents further difficulties because of to the relative lack of data sources available to construct the monthly means. In general, only one series is available at any given time for this period: any increase in the observations available should substantially increase the reliability of the reduction, especially if they were to cover the two gaps that are present.

As has been discussed in the analysis above, the reduced series shows a deviation in its monthly means when compared with Central England, from 1784 to 1802. This is the period where only a single series is available, and it could be brought closer to the prevailing difference between Durham and Central England later in the period. This adjustment would create a better agreement between Durham and Central England, but would introduce an element of reliance that might be unacceptable.

A set of observations is available from Alnwick, observed by David Hastings between 1740 and 1746 (Hastings 1740-). These data were not included in this study for several reasons, mainly because although the observations were made using a thermometer, the scale was not graduated using a recognised measurement. An indication of the relative points of boiling and freezing points might allow some monthly means to be derived from this manuscript to a certain degree of accuracy. However, a gap of 37 years would be present in the series after this record ceases to be available.

7.4.4 Summary of Improvements

It is difficult to assess whether a temperature reduction is fully optimised, and uses the most accurate techniques and adjustments in its creation. Manley's own techniques have been improved, and what has been achieved is undoubtedly more than Manley could have anticipated, especially regarding the statistical analysis of the monthly means and their comparison with other series. The monthly means presented here are one of many sets that could be derived from the temperature observations, Manley creating another himself. Several versions of the Central England temperature series have also been derived, by Manley and others, each possessing their own advantages and each generally claiming to be more accurate, or representative, than the others. For derived temperature series, it is difficult for any claim of accuracy to be objectively measured. Where observations have been created for a site and a period where none previously existed, tests upon the accuracy may be criticised for being subjective and difficult to qualify, as indeed might the methods used to create that series. Some potential areas for improvement have been discussed here. Techniques might be developed that would yield a version of the monthly means that would be 'better' from some points of view. The law of diminishing returns might well be cited in this case, however, for after all results cannot be compared with non-existent observed means for Durham in the late eighteenth and early nineteenth centuries.

All the methods used to create the reduced monthly means here have been fully documented in this thesis, so that amendments to the methods or to the source data can be made in future should any new sources of observations be found, or more refined techniques be introduced. Exploration of Manley's letters and notes has allowed much greater understanding of the series he left, the methods he used and the reasons why he considered his reduction unfinished. Careful examination of his source material and the addition of data not used by him have allowed more accurate reduction, while statistical methods have been applied to test the value of the data and to develop new methods for its use.

7.5 Summary of Chapter Seven

This is a summary chapter, giving an overview of what has been covered in the previous two chapters. This is followed by an analysis of the completed series by comparison with other reductions, and suggested improvements. Inevitably, there are ways in which the accuracy and representativeness of such a reduction might be improved, although these may not yield great differences in the calculated means, and different methods are discussed in this context.

Chapter 8 – The Representativeness of Durham

Contents of this chapter

8.1 How Well the Series Represents 'Durham'

8.1.1 'Durham' and Temperature across North East England

In the introduction of this thesis, the location of Durham was introduced in relation to the rest of North East England. Temperature at Durham University Observatory is not remarkable, in view of its location in the centre of the area typically classified as North East England, and in terms of its climatology, that station represents well the immediate region. The observatory itself is situated 60 m above the Wear valley, on a south-facing slope, and hence is not affected by the katabatic flow of air that affected the meteorological station at Houghall, now closed, 1 km to the south east. The observatory ridge is somewhat exposed to winds, but the North East is generally sheltered from prevailing westerlies by its position to the east of the Pennines. The immediate area around the city of Durham is characterised by low hills, and quite shallow relief, with the contours of the land generally following the rivers Wear and Browney. There are few of the sharper differences in temperature that can be seen in the more upland areas to the west of the city, as the land rises across the Durham Dales to the northern Pennines, and to the north into Northumberland and the Cheviots.

Monthly mean temperatures have been calculated, ideally to be representative of 'Durham University Observatory'. A reduction of this type, comprising temperature observations from a radius of approximately 150 km from Durham city, might not yield a temperature series wholly representative of the characteristics and exposure of the target station. The temperature series in this study could perhaps best be described as representing 'Durham'. A set of three stations was found to provide an optimum combination of means when combined to form monthly means for Durham, using the criteria in this study. When the distances between each station and Durham are calculated, and their weights considered, a location in the vicinity of Newcastle upon Tyne is reached for the 'centre' of the reduction. When the weighted altitudes of the contributory stations are considered, a mean of 99 metres above sea level is found, very similar to the actual altitude for Durham at 102 metres. The temperature reduction for 'Durham' might therefore be expected to represent an area at least covering Durham City and Newcastle upon Tyne. This area should be smaller than that relating to 'Central England' given the smaller geographical coverage of the source data, but given the potential error in a reduction such as this, it is of no surprise that temperature is modelled as accurately for Newcastle upon Tyne as it is for Durham. Indeed the value of r^2 between monthly mean temperature at Durham and Newcastle is 0.979, where data from the 1990s are considered. Figures 8.1a and 8.1b shows isotherms of mean temperature across the British Isles for January and July.

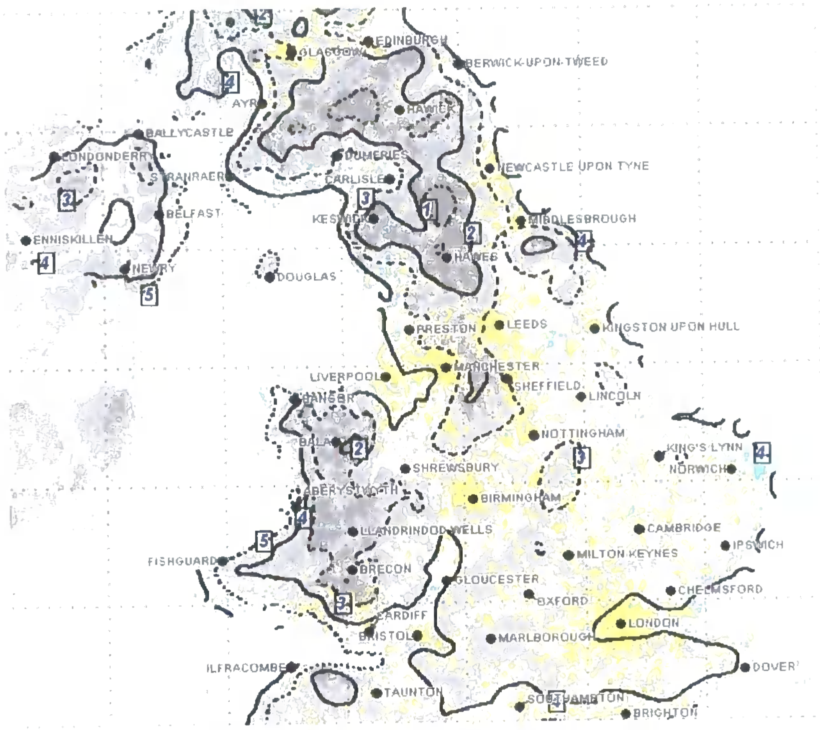


Figure 8.1a Isotherms of mean temperature for January for the British Isles (°C).

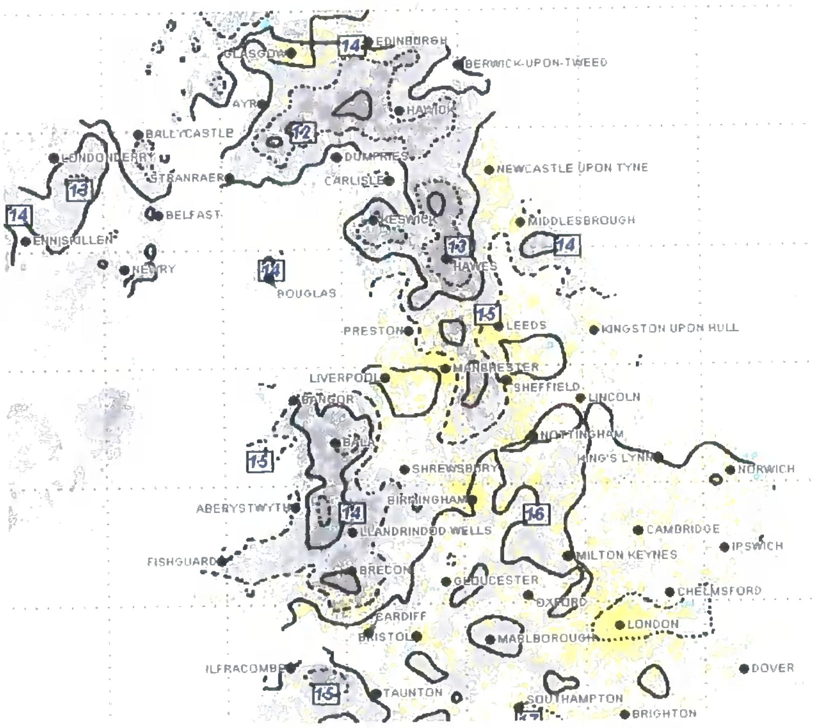


Figure 8.1b Isotherms of mean temperature for July for the British Isles (°C).

The maps in Figure 8.1 show clearly the high spatial variability of temperature as a major potential problem for the creation of a temperature series for North East England. The isotherms are markedly closer together in the North East, whereas the 'Central England' area has a much shallower temperature gradient. These differences are partly due to the more variable altitude in the North, but also to the influence of the North Sea on the climate of the region. The North East of England is roughly wedge-shaped, dropping from a ridge that is the Pennines in the west, from an altitude of up to 900 metres above sea level at Great Dun Fell in County Durham and 700 metres in the southern Pennines of South and West Yorkshire. The general dip of the land towards the coast is interrupted by the North York Moors and, to a lesser extent, the Yorkshire Wolds. The area of land between the Pennines and the sea is much narrower in the north of the region than the south; hence the distance from the sea and its influences in the southern half of the region may be much more than in the north. Surface waters of the North Sea are coolest off the Eastern coast of Scotland and North East England, ranging from around 5°C in winter to 13°C in summer, and this induces cooler temperatures in summer within the region than are seen elsewhere, particularly in areas close to the coast. Stations around the region tend to have their climates dominated by altitude or proximity to the coast. Wheeler (1997) demonstrates this in a comparison between Durham, Askham Bryan and High Mowthorpe (all used in this study) as well as other sites within the region. Askham Bryan is at a relatively low altitude of 32 metres and is shielded from easterly winds by the Yorkshire Wolds. These factors, and its distance from the sea (approximately 60 km) enable its mean maximum temperature in July[95] to reach 20.2°C, compared with 19.2°C at Durham (at 102 metres and 13 km from the sea), and 17.2°C at Tynemouth, which is at approximately the same altitude as Askham Bryan but directly on the coast. The long coastline along the east of the region affects temperature close to the coast, depressing it and decreasing the range between maxima and minima, and the incidence of frost. Table 8.1 shows the altitude and annual mean temperature for sites across the North East.

[95] Using data for the period 1961-1990.

Table 8.1 Mean Annual Temperature for stations across North East England, 1960-1991 (°C).

Station	Altitude	Mean Annual Temperature
Tynemouth	29	8.75
Durham	102	8.55
Malham Tarn	395	6.80
Moor House[96]	556	4.95

These regional differences provide much greater relative variability than those within the larger 'Central England' area, where altitudes are generally lower and the distance from the sea is greater than that for stations in the North East. Manley was partially successful in avoiding stations close to the Irish Sea for his Lancashire reduction, with the exception of Southport, which carries a weight of one quarter (Manley 1946).

The Pennines not only shelter Durham, and the North East generally, from the prevailing westerly winds but also cause the North East to experience much lower rainfall than the North West, for example. Table 8.2 shows how mean annual rainfall varies from east to west at three stations, including Durham. The mean annual rainfall for England and Wales for the period is 917 mm.

Table 8.2 Mean annual rainfall at stations in Northern England, (mm) 1961-1990.

Station	Mean Annual Rainfall
Durham	652
Bradford	873
Kendal	1323

[96] Using data for the period 1961-1980.

Wetter weather in North East England generally occurs when depressions lie in the southern North Sea, drawing moist air northwestwards across the region, with no interruption by relief before it passes over the coast (Wheeler 2002).

In chapter 5, data from modern sites were examined. Multiple linear regression was applied to these sets and the results showed how temperature at those sites is related to that at Durham University Observatory. Of all the sites studied, temperature at Newcastle upon Tyne was seen to have the strongest fit with Durham temperature, which is not surprising given their proximity both geographically and climatologically; Newcastle is 23 km north of Durham. The altitude of Durham is higher (102 m compared with 52 m for Newcastle) but this will give rise to only a small, typically constant, difference between the two sets of temperatures. Like Durham, Newcastle upon Tyne lies in a river valley, although Newcastle is situated closer to the coast than Durham, and will also experience some urban warming effects given the much larger size of Newcastle and the location of the observations, at the Newcastle Weather Centre, in the middle of the city. Table 8.3 shows how the temperature varies on average, for each month, between Durham and Newcastle.

Table 8.3 Annual Temperature at Durham and Newcastle upon Tyne, 1991-1999, °C.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Durham	3.6	4.4	6.1	7.7	10.3	12.9	15.5	15.4	12.7	9.2	6.0	3.8	9.0
Newcastle upon Tyne	4.6	5.3	6.8	8.3	10.7	13.5	16.1	16.0	13.4	10.2	7.2	4.8	9.7

Newcastle is, on average across the year, 0.7°C warmer than Durham, which is more than might be expected from the difference in temperature of 0.3°C that would be implied from the difference in altitude. However, it is difficult to identify how much of the excess would be caused by the greater proximity of Newcastle to the coast or by urban influence. It can be seen that the difference between the two series is greater in winter than it is in summer.

Following Newcastle, Westgate displayed the next strongest fit of mean temperature with Durham, with an overall value for r^2 of 0.962. Westgate is situated in Weardale, 35 km west of Durham, and on rather higher ground at an altitude of 333 m. This higher altitude causes the monthly means at Westgate to be proportionately lower than Durham, yet the pattern of temperature is similar, as indicated in the value for r^2. The relief of the land between Westgate and Durham is quite consistent, generally sloping downward from west to east, giving no substantial interruption to the prevailing eastward movement of air. At times, temperature at Durham will be influenced by its proximity to the North Sea, which will not be the case for Westgate. In addition, Westgate will be largely unaffected by any urbanisation effects, as it is only a small village.

Slightly weaker fits with temperature at Durham are seen with Askham Bryan (York) and High Mowthorpe. These stations are located 98 km SSE and 96 km SE of Durham respectively, much further from Durham than Newcastle upon Tyne and Westgate, but interestingly the values for r^2 are very similar at 0.962 and 0.959. In fact, the two Yorkshire stations are situated in quite different areas, with Askham Bryan being at an altitude of 32 m in the Vale of York, and High Mowthorpe at 175 m in the Yorkshire Wolds to the east. Table 8.4 shows monthly mean temperatures for the two stations for the period studied.

Table 8.4 Annual Temperature at Askham Bryan and High Mowthorpe, 1991-1999, °C.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Askham Bryan	3.7	4.2	6.3	8.4	11.0	13.7	16.5	16.4	13.7	9.9	6.3	4.1	9.5
High Mowthorpe	3.0	3.5	5.4	7.1	9.8	12.4	15.4	15.4	12.8	9.1	5.8	3.4	8.6

The difference in altitude between the sites would be expected to be give a mean difference in temperature of 0.9°C, which is indeed what is seen in the table above, with a slightly greater difference in summer than in winter, smoothed throughout the year.

The strong fits between the temperatures at Durham and those discussed here across North East England are encouraging as they show that the overall pattern of temperature at sites in North East England is quite consistent, even for sites up to 100 km away from Durham. Some confidence can therefore be placed on the technique employed in this thesis of using linear regression to find the best ways of combining temperature data across the North East to represent Durham, given the assumptions made concerning the accuracy of the historic readings.

8.1.2 An Examination of Some Notable Warm and Cool Periods

Checks may be made on a temperature series for extreme events that are known to have occurred from documentary sources and which may be seen in other temperature series. The monthly means for Durham should show signals from events such as mild winters and cool summers, for example, and also from notably warm spells that affected the whole country, or indeed the whole of Northern Europe.

One of the warmest spells that occurred during the temperature record was during the summer of 1846. In June and July, the temperature at Durham is known to have reached very high temperature for the season, Manley referring to a 'phenomenally hot June' (Manley 8.viii.79). On June 19th 1846, the *Durham Chronicle* confirmed the high temperatures.

It is so melting hot this week,
That, though our readers flout us,
The truth we must in conscience speak,
We've scarce our wits about us.

Monthly means for 1846 were taken from the journal of observations found at the University after Manley died, with the means calculated from an adopted mean of the fixed hour readings, and of the daily extremes. Figure 8.2 shows monthly means for 1846 for Durham compared with those for Edinburgh and Central England.

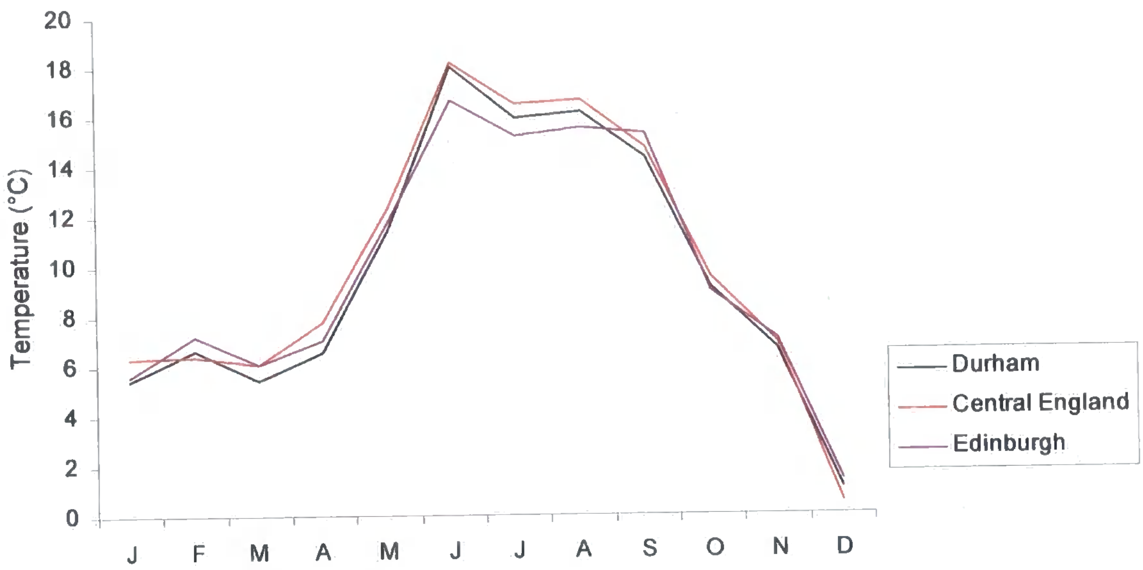


Figure 8.2 Comparison between Durham, Central England and Edinburgh monthly mean temperature for 1846 (°C).

It can be seen in Figure 8.3 that the high monthly mean in June was particularly well expressed in the Central England and Durham series, with these giving means that are almost identical. For June 1846, Durham gives a mean of 18.0°C, and Central England gives 18.2°C. At Edinburgh the mean temperature is lower, at 16.6°C. The maximum temperature at Durham for 1846 was observed on June 6th with a reading of 83.3°F (28.5°C), and then on both June 18th and June 19th there was a similar reading of 83.2°F (28.4°C). The daily Central England series gives means for these days as 20.8, 20.4 and 20.4°C respectively. When these daily maxima are used to create adopted means for the month, the daily mean can be calculated[97], and compared with Central England, as shown in Table 8.5.

[97] The daily mean was calculated in the same way as the monthly adopted mean for the month of June 1846, as the mean of the 9 am, 9 pm, maximum and minimum observations. Manley's adjustment component for the adopted mean is zero for June.

Table 8.5 Comparison of mean temperature for three notably hot days in the record for Durham, and for that day for Central England (°C).

Date	Durham	Central England
June 6th 1846	22.2	20.8
June 18th 1846	23.7	20.4
June 19th 1846	21.4	20.4

Although the monthly means for Durham and Central England both show the same value, the daily means for Durham over the three particularly hot days in June 1846 are higher than those derived for Central England. It is known that the maximum thermometer at this time at Durham could have been recording values a little too high, although the fixed-hour readings show observations that are compatible at 9 am and 9 pm with the maximum observed for that day. On June 18th, the temperature observed at 9 am was 77.8°F (25.4°C), rising to the maximum of 83.2°F (28.4°C) at some point later that afternoon. This observation at 9 am is almost equal to the maximum morning reading observed at Durham for the period from 1843 to 1849, which was 78.0°F (25.6°C) observed on July 15th 1847. These high readings were substantiated with the maximum observed readings in the morning, and for the maximum for the day for the period from 1850 to 1882, which are 80.9°F (27.2°C) at 10 am on July 15th 1868, and 92.5°F (33.6°C) for the daily maximum on July 16th 1876.

The extended temperature record at Durham shows roughly alternating warm and cool decades, as shown in Figure 8.3. Warm decades are observed in the 1800s, 1820s and early 1830s. Cool decades occur in this record in the late 1830s and early 1840s.

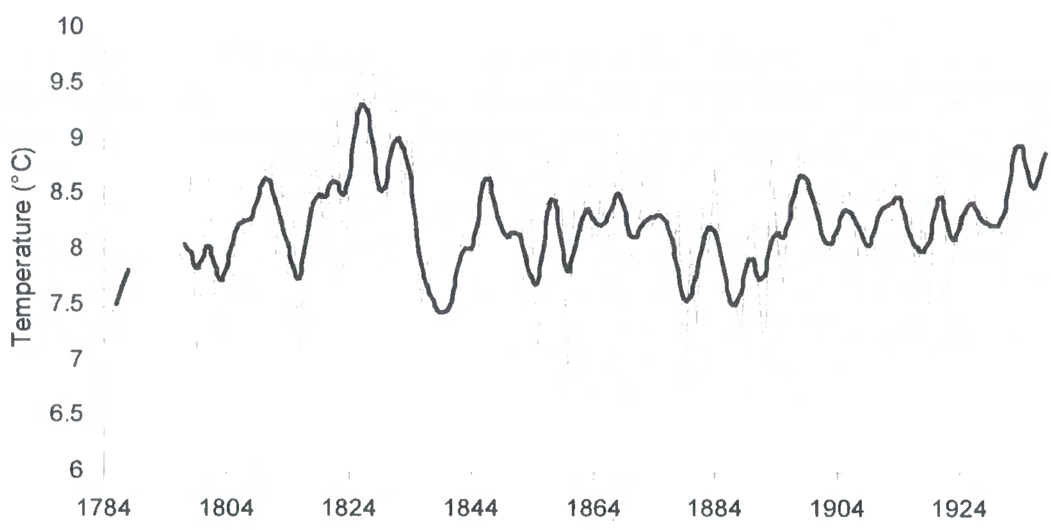


Figure 8.3 Durham temperature for 1784 to 1849 smoothed using a binomial filter with weights of 1:4:6:4:1. (°C).

The peak in 1846 can be seen in Figure 8.4 although this was a year surrounded by years unremarkable for temperature extremes. Across the entire extension, the warmest period is from 1824 to 1828, especially so in 1825 and 1826. This shows up as a peak of almost 2°C higher than the long-term mean. James Losh, in his observations at Jesmond, makes a note of the temperature during this period.

> *'1826 has been remarkable for the heat and drought which commenced earlier, were more intense, and continued longer, than in any year within my recollection.'* (Losh 1802-)

When Durham annual means are plotted from 1800 to 1940, this warm period in the late 1820s can be seen as the warmest extended period of the whole record, with no years being as warm as that observed in 1828, followed by 1826. Between 1800 and 1940, the regression line continues to show a downward trend, as shown in Figure 8.4.

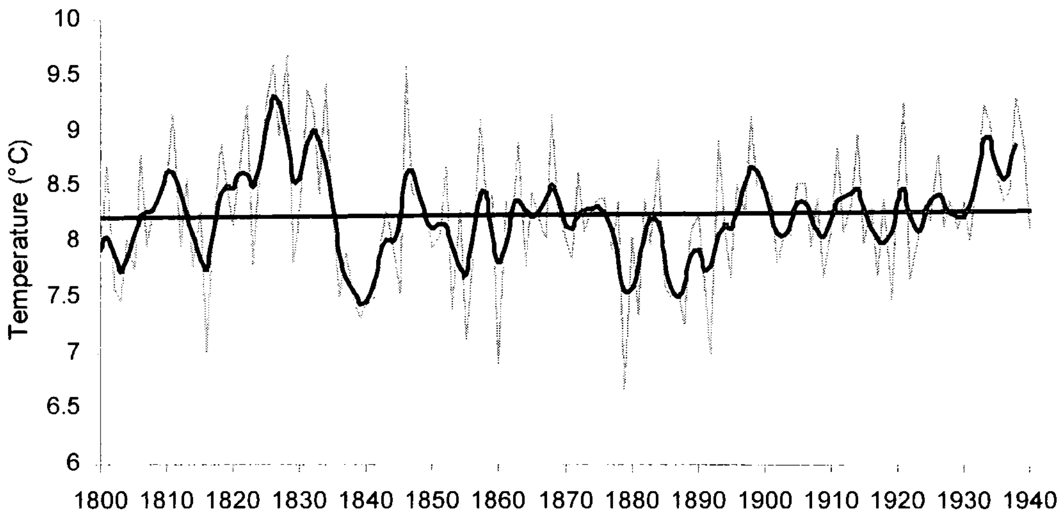


Figure 8.4 Annual temperature at Durham from 1800 to 1940, smoothed using a binomial filter with weights of 1:4:6:4:1smoothed using a . (°C).

8.1.3 Larger-Scale Conditions

A global-scale event that affected observed temperature for the period of the reduction was the eruption of the Tambora volcano in April 1815. Several separate explosions took place during this month, resulting in the largest ever recorded eruption, with a Volcanic Explosivity Index of 7 on a scale of 1 to 8 (Newhall and Self 1982). The ejection of aerosols and particles into the atmosphere is estimated to have lowered global temperature substantially (Lamb 1995), and over the course of the following year the effects of the event caused cooler temperatures over a large part of the Northern Hemisphere, to the extent that in Northern Europe and parts of North America 1816 was known as 'the year without a summer'. Figure 8.5 shows the monthly means for Durham University Observatory for 1816 in addition to those for Central England.

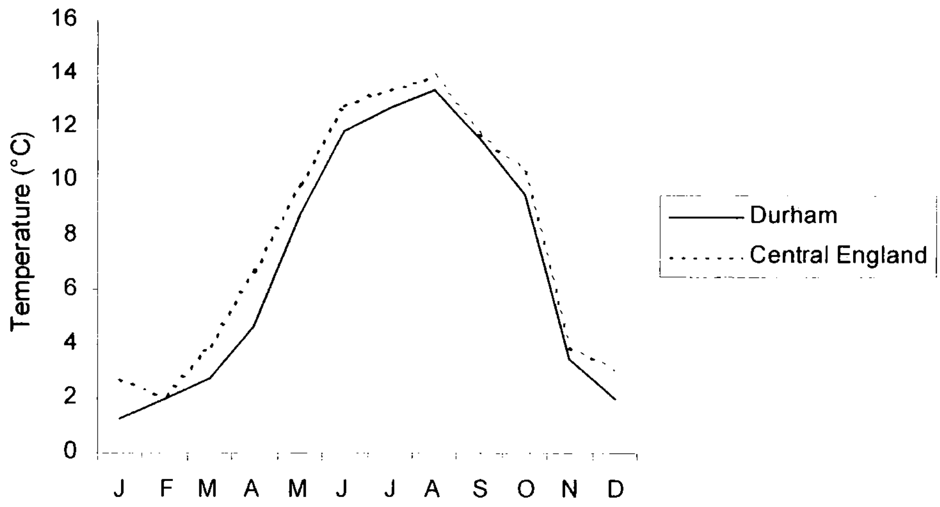


Figure 8.5 Comparison between monthly means for 1816 for Durham University Observatory and Central England (°C).

Monthly means for 1816 display a good agreement between the two series. Figure 8.6 shows the anomalies for 1816 when compared with the mean for the decade from 1821 to 1830. In this figure, the spring and summer temperatures are seen to be severely depressed in relation to the following decade. The temperature at Durham was up to 2.4°C lower in spring, and 2°C lower in late summer than the longer term mean. Means at Durham were lower in every month in 1816, although at Central England the temperature did rise slightly above the average in January and October. This pattern is reflected in the anomalies for Durham, although it would follow that the difference between mean temperature at Durham and Central England would mean that the latter series exhibits higher means.

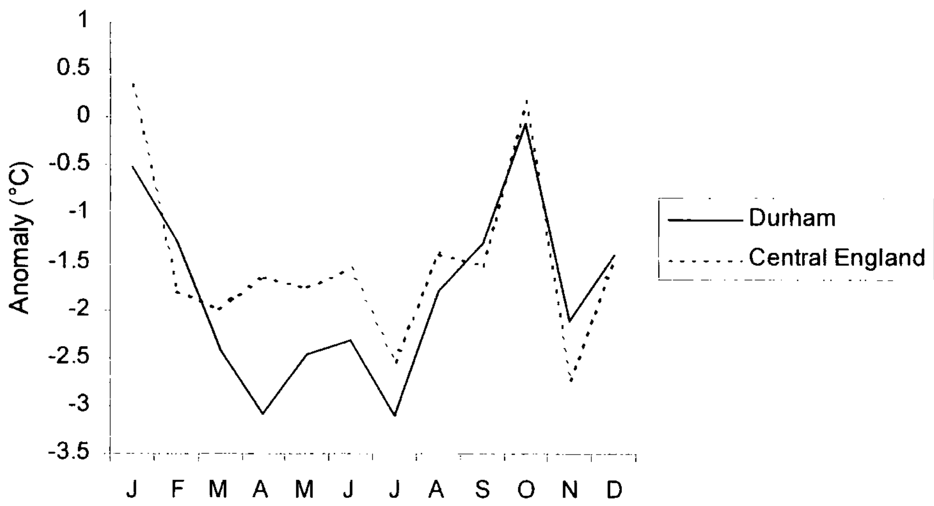


Figure 8.6 Anomalies from the mean for 1821 to 1830 for Durham and Central England in 1816 (°C).

In this section, examples have been chosen as case studies to illustrate the representativeness of Durham, showing how the series can represent temperature at regional and national scales.

8.2 The Usefulness of the Series Within Current Research

8.2.1 Of What Use is a Monthly Temperature Series?

Long-term temperature series are frequently used in the study of temperature change where such records exist. It is not necessarily the case that the longer records are the most valuable, especially where inhomogeneities are introduced in an attempt to make a reduction as long as possible, or where external factors such as urban warming influence a series. An example of this is the Toronto temperature series, where the encroachment of building around the site has caused measurable effects upon the temperature observations (Jones and Bradley 1992). Table 8.6 shows a selection of some of the long-term temperature series available for Western Europe.

Table 8.6 A selection of long-term temperature series available for Western Europe (after Jones and Bradley 1992).

Site	Record Start
Central England	1659
Berlin, Germany	1701
De Bilt, Netherlands	1706
Padova, Italy[98]	1725
Geneva, Switzerland	1753
Stockholm, Sweden	1756
Paris, France	1757
Trondheim, Norway	1761
Milan, Italy[99]	1763
Edinburgh	1764

Jones and Bradley (1992) studied a selection of the longer temperature series available for Europe, and found there to be good general agreement between the records of a warming between 1851 and 1980. However, for those records that are available as far back as 1700, the trend for warming is not present across the longer period. Across the period of the reduction for Durham, they found cool decades in the 1780s, 1800s and 1810s, and also in the late 1830s and 1840s. Monthly series provide the extra information within annual series that allow seasonal changes to be examined. Although it is recognised that warming has occurred since the mid-nineteenth century, this is largely exhibited in autumn, winter and spring (Jones and Bradley 1992).

[98] e.g. Camuffo (2002)

[99] e.g. Maugeri, Buffoni & Chlistovsky (2002)

8.2.2 The Use of Archived Data as a Tool in the Study of Climate Variability and Climate Change

Accurate daily measurement of temperature has only been possible since the invention of the thermometer in the late sixteenth century. The aim to record daily temperature to a precision equivalent to 0.1°C was not within the range of early instruments, and even with thermometers used into the nineteenth century, inherent errors in the accuracy of the instruments led to complications in the analysis of the records left by them. The recording of temperature at observatories began in the early nineteenth century, with the Radcliffe Observatory at Oxford, and Durham University Observatory being two of the oldest in the United Kingdom. In order to extend the temperature records back from this time, data must be gathered from the various archived sources left by observers who did not have the resources of the Observatories. These records are of observations using thermometers that were often made by the eminent makers in the field such as Six and Hauksbee, but in some records the exposure of the thermometer strongly compromises the accuracy of the observation. James Losh probably had his thermometer attached to a north-facing wall of his house in Jesmond. Henry Barnard moved the location of his thermometer at South Cave from outdoors, against a northwest-facing wall, to a hall indoors, then to his cloisters, seemingly never satisfied with the exposure. Abraham Shackleton at Braithwaite kept only an indoor record for the early portion of his series, for which the exposure throughout the seasons would depend intrinsically upon the ventilation of that room, of which little is known. Questions must be asked concerning the intended purpose of the thermometer observations of each of the observers in the North East. James Losh owned a farm, and was a keen observer of seasonal changes in his crop ripening and harvesting times. It is probable therefore that his interest in the weather was largely agricultural. Abraham Shackleton's indoor thermometer may have been sited there specifically to monitor the temperature indoors, under conditions that were simulating those housing the poor. Connections between air temperature and public health were made by Jurin (Kington 1997) and others, and led to observations being initiated by physicians. Indeed, Manley speculated that the publication of such temperatures in local newspapers of the early nineteenth century might have been a way of advertising their professional services (Manley 27.ix.78).

Provided the exposure of observations used to lengthen a series is known, then reducing the daily observations to monthly means is more straightforward. Of the data used in this study, such details range from the scant (such as Barnard at South Cave) to the non-existent (such as Losh at Jesmond). Given that differences induced by the exposure of a thermometer can be of a magnitude that is substantial in the context of the actual signal itself, then it is vital that the data are analysed as fully as possible to ascertain problems in this exposure. As records further back in time are considered, the availability of local stations to check against becomes less, and for this study reference has been made to the Central England series to ensure that the exposure is at least constant for records in the North East of England.

It is vital that the study of any reduced series is accompanied by an awareness of the limitations of its use that have arisen from its constituent series. For Durham, the period from 1784 to 1801 may be seen as being weaker than the following years due to its dependence upon only a single series. After 1801, the combinations of series used to form the reduction have been shown to vary in their accurate representation of the temperature at Durham, such that some periods within the reduction may be considered more reliable than others. The study into optimum combinations of series considered modern data for Durham, and yielded very close matches between the monthly means at Durham with those of the composite series. Although the series at Jesmond is the closest in distance to Durham, it does not form the dominant proportion in the periods where it is available. Investigations into the optimum combinations of series in fact give sets of sites that are spread widely throughout the region. This is advantageous in that the North East is well represented as a region, but less useful when temperature needs to be estimated for Durham City itself.

Some of the observers calculated their own monthly means from daily data, and for many of the records this is now available (e.g. Wykeham, Abbey St. Bathans and York). These means are assumed to have been calculated from the average of one or more readings per day, in the absence of any other information provided, and indeed the analysis of the data shows this to be the case where it is possible to detect such small potential differences. It was general practice to treat the mean of the day as the mean of continuous observations throughout the day (Glaisher referred to this as the 'true mean'), but current practice takes the mean of the daily extremes to represent the day. Corrections are necessary to convert a mean observed at certain fixed hours to one observed as if the mean of the daily extremes were taken, and these adjustments are dependent upon factors such as the diurnal range at the site, the hours of observation, and the synoptic conditions on the day of observation. All these corrections, if incorrectly assumed on the basis of evidence from the manuscript concerning exposure, may compromise the resulting monthly means. Care must be taken to prevent rounding and conversion errors during the various stages of calculation in a reduction, although one advantage in the conversion from Fahrenheit to Celsius is that the temperature measured to a precision of 0.1°F is almost halved when converted to a precision to 0.1°C, due to the approximate doubling of Celsius to Fahrenheit readings. A monthly mean expressed in degrees Celsius after conversion from the original Fahrenheit would therefore absorb some imprecision in the original calculation.

It is important that recognition is taken of the limitations of a temperature reduction. In view of the examination made of the individual data sources in this study, confidence in the monthly temperature series for Durham should be viewed as high, although whether a daily series could be created from this is debateable. For their creation of the daily Central England temperature series, Parker *et al.* (1992) did not extend the daily series back as far as 1659, when the monthly reduction starts, but began in 1772 with a series of daily records from London, due to the lack of daily observations made outdoors before this date. The natural variability across the North East, even between stations that are close by, can be substantial, even when using modern observing techniques, because of the climatology of those individual sites. To demonstrate this, Manley (1946) gave the example from Leyland and Hutton, two of the component series of his Lancashire series. He found these sites to be using the same hours of observation; they are 8 km apart in distance and 43 feet (13 metres) apart in altitude, and yet the observed temperature differed by up to several tenths of a degree (Fahrenheit). A combination of series spread across the region is therefore desirable for a reduction, where possible.

8.3 The Place of 'Durham' in Evaluation of Past Climate in the British Isles and Europe

8.3.1 Climate Study at the Regional Level

The prevailing concern about temperature trends on regional and global scales leads to a desire for a greater understanding of changing patterns of temperature over the instrumental period. While long-term series are valuable in such research, the availability of data observed at a single site, under homogeneous conditions can be limited, and the extension of records by reduction from nearby sites provides greater opportunities for study. As theories concerning warming are developed, it has been predicted that regional and local scale temperature changes are likely to be more complex than straightforward warming (IPCC 2001). It is fortunate that such a lengthy reduction as the Central England temperature series is available for Britain, in addition to other reduced series, and long-term unreduced, single-station series such as Oxford and Armagh. The temperature record for Durham University Observatory was recognised by Manley when he worked at Durham in the 1930s as being worthy of continuation (Manley 1941b), and although manual observation at the Observatory has now ceased, an automatic weather station has been in place since October 1st 1999. The extension of temperature records back beyond the starting dates of such stations is of extra value where that station continues to monitor temperature at the present time, and, like Durham, has a future assured in its status as a climatological reporting station.

Efforts have been made to construct temperature series at lower resolutions, at the decadal level (Jones and Bradley 1992), that stretch further back than studies within the instrumental period allow, in this example to 1400. Several of the manuscript records in this study include details on harvesting of crops, dates of plants coming into leaf, and other elements that may be taken as proxy measurements of temperature. Such observations have been used to construct temperature series at the decadal and annual level. Annual and monthly comparison at higher resolutions via such series as Central England is valuable, as is examination of temperature at the more local level.

8.3.2 Historic Climate and the Context of 'Durham'

The reduced series of monthly means presented here best considered is an extended version of the monthly and daily series for 'Durham', because the longer a record, the greater confidence that may be placed on it. On its own, the extension of 66 years covers an interesting period of roughly alternating warm and cool decades, but when considered as part of the overall record gives a series of over 218 years that enables study at the decadal- and century-level. Comparison between this set, and the longest instrumental temperature record in the world, for Central England, is valuable as a check on the latter's trends and to provide an opportunity to view differences in patterns between the North and South of Britain. Reduced series for Lancashire and Edinburgh enable a national picture to be gained of temperature trends. When the additional pieces of original, unreduced series are included, Britain can be seen to profit from a generous supply of temperature data. Several long-term rainfall records are also available, as are a number of barometric series. The consideration of all these components of meteorological measurement can be pieced together to form evidence of prevailing weather over short periods, or even synoptic maps of conditions at certain dates in history (e.g. Kington 1978, 2000), thus broadening the use of the constituent series into historical studies. The extra spatial resolution that the extended Durham series provides will allow research in this area, and others, to benefit. Future research could bring the extension of additional meteorological components into the late eighteenth century for Durham, notably rainfall and air pressure, from records left by observers such as Losh, Barnard, Cholmeley and Shackleton. Indeed, as soon as Manley had reached a provisional version of his temperature series in late 1979, he had already turned his attention to laying foundations for an extension of the rainfall record. Research has recently been published on one of the key series forming Manley's Central England temperatures using the record observed by William Derham at Upminster, Essex, to create a twelve year air pressure series from 1697 (Slonosky *et al.* 2001). A daily series, compatible with the monthly means, is available from January 1876 to the present.

Further work may allow a daily temperature series for Durham back to late 1783 using observations that are already known to exist. Careful reduction of the record for Alnwick from 1740 to 1746 would provide an excellent starting point for the extended, reduced series if other records were found that span the resulting gap from 1747 to 1783. It would be possible to provide provisional values for this period that are derived from the Lancashire and Edinburgh series, although their accuracy would need to be viewed in the correct context.

Monthly temperature data for 'Durham' is made available here from January 1784 to the present, with the exception of a small gap between September 1791 and December 1793, and from April 1794 to October 1794, for which no data have been found. The entire set of monthly mean temperatures for Durham from 1784 to 1849 is given in Appendix C.

8.4 Summary of Chapter Eight

The ability of the completed series to represent the station for which Manley's original series was based was discussed in this chapter. The climatology of the region was reviewed and related to the locations of both Durham University Observatory and those sites from where data were included in the reduction and extension. The usefulness of a series for 'Durham', when compared with those for Central England, Lancashire, Edinburgh, Armagh, and others, was discussed, particularly given the relative lack of original observations for the region. It was noted that the city of Durham, and more importantly the site of the University Observatory, has seen little industrialisation, and its variety of planning restrictions should ensure that the Observatory's temperature data continue to be comparable to that observed in the past. The wider question of whether such monthly series are of use was answered with reference to the necessity of an understanding of the climate of the British Isles as a whole, including any regional differences, before detailed conclusions on any short- or long-term temperature changes.

Appendix A – Letters from Gordon Manley

Gordon Manley wrote a series of letters to Joan Kenworthy during 1978 and 1979 (Manley 1978-). Sections of the letters relating to his work on temperature at Durham are reproduced here. His handwriting is difficult to decipher at times; therefore where a word cannot be read, it is marked with the characters ***. Sections which are not relevant to his work on temperature series have been marked with the characters ...

A.1 30th January 1978

...

Curiously enough Durham & Northumberland are rather lacking in earlier weather records; nothing " daily" of any length of any length before 1802. This is probably, in part, accidental; it would be hard to sustain the view that counting and measuring (i.e. "Science") were better developed in Lancashire & Westmoreland & Yorkshire; possibly there was more imagination over the west side, and its easy to run off into speculation about the Anglians of Northumbria and the greater Danish-Norse infiltration to the south and west that makes such a dialect difference. Still, Robert Stephenson was a more delicate imaginative chap than his father, and his mother was a Hindmarsh: a very good Tyneside name.

I've tried repeatedly in the past to find if the (reported) diary & weather notes of Timothy Whittingstall about 1636-1670, (mentioned in Arch. Aeliana, about 1924) who seems to have farmed towards Lanchester, have ever been found in MS. in the Diocesan, or other Cathedral collection (Mickleton MSS)

...

I had help from the Univ. Library last year, on things like the Bamborough Collection, and your very agreeable Librarian (whose name for this moment escapes me) also got out some Wright papers, with a bit of 18th century weather that was almost all Coventry! – not Durham at all.

...

A.2 9th March 1978

. . .

PS HULL on Monday was quite a success, a good afternoon's work on a useful record 1794-1814. But I'll have South Shields to visit, later in the year!

A.3 1st July 1978

...

Newcastle (on Thurs.) where I went by train, being a bit scared of the alterations and parking problems, I thought depressing. The Central Library (N/C Journal and N/C Courant for 1838-1840) was very efficient and helpful however, and I like the relict-Victorian air of the N/C Lit. & Phil. library near the station: they have a very fine local record, but I am still defeated by the task of extending the Durham Univ. Obsy. record further.

Friday down to York: Bootham School: great disappointment, tho' delightful archivist;

...

A.4 27th September 1978

...

There was once a man called Manley at Durham who found, about 1938, that he was a Curator of the Observatory – a sadly neglected institution, for a variety of reasons! Within it he found that there were 90 years of daily met. observations, on one site, with but little surrounding change. So he did a very great slog, and published a temperature series for 1847-1940 in Q.J.Roy.Met.S for 1941.

Reading this today it will be evident that he did an almost over-elaborate job, but it did provide a "University" record to accompany the senior one (Oxford, Radcliffe Obsy. since 1815), and to lie in between Oxford and Edinburgh. It has since been regarded as a "base" for "North East England". BUT: Manley's elaborate effort to produce an "adopted mean temperature" based on "Max+Min+9^h+21^h" readings, could not be precisely continued, more particularly because in 1958 they stopped taking the 21^h observation. Moreover, during the war, when we had two hours daylight saving I'm pretty doubtful whether the readings were really taken at 11^h by the "civil Double Daylight Saving time" and at 23^h, especially having regard to the then observer.

The problem then is how best to continue the Series, for DURHAM.

During August I began some work on this, my objects was to standardise my original Moor House (1825 ft) obs. of temperature, 1932-1946, on to the Nature Conservancy's set, 1953-1978 :- I propose to talk a bit about this at the meeting on October 14 (London). I think it worth doing because the place is so splendidly marginal for tree-growth etc. (c.f. Q.J. papers in 1936, 1942 & 1943).

Investigations soon made it clear that, now that the Durham means are based on ½(Max+Min) over the interval 9^h to 9^h, they differ a little and are actually a shade higher than if they are based on 21^h-21^h as formerly. This was a little unexpected. I think it is related to the position of the screen on the south side of a stone building.

Its only a matter of 0.1°/0.2°F on monthly means but is nevertheless a figure one shouldn't neglect if one is to argue about longer-term trends in a country as small as Britain.

It might be argued that one could "standardise" Durham through Ushaw (3m. distant - ceased 1968) and Houghall (1m.). BUT: I don't think Ushaw is strictly homogeneous and has now terminated, and Houghall is a very acute frost hollow – or was: it too changed its site, & has now terminated. Between one things and another, I think one can continue the old Durham "adopted means" with but little adjustment :- AND: perhaps extend them to 1794-1978!

...

How to extend backwards!

Observations at Durham were certainly being made in 1843 (I think the building was complete in 1841 or '42: you got "subscriptions" being invited and listed in the Newcastle Courant or the N/C Journal. But I've never found that they got to the London Scientific journals. The operative Prof. of Astronomy/Maths was "in charge" and was the Rev. Temple Chevallier. The first temperature figures I could at least estimate from were quarterly, in 1847.

BUT. It had never occurred to us that Durham then had its own newspaper, the Advertiser.

It was very common in the 1840s to find that the county weekly would carry a short table of the monthly means of temperature, very often about the 2nd, 3rd or 4th week in January & covering the previous year.

I went through the Newcastle weeklies when I was at Durham last summer, but found them very disappointing in the 1840s. I think North Shields had a record in 1841, but I couldn't locate it; neither could I get any hint at Sunderland: I've tried Darlington (a Quaker town where they did that sort of thing) many years ago without success. (Shields & Sunderland moreover are "coastal").

SO. STAGE ONE. Would you like to see if you can get any of the monthly or yearly summaries for the University Observatory out of the files of the Durham Advertiser? between its beginning in 1832 or 43, and 1847? I think a look at the (4) January issues might be enough. I think one could assume that the man wouldn't be likely to have them worked up and written until at least the end of the 1st week, and very likely the 2nd or 3rd.

STAGE TWO. It is always possible that there was a "keen local amateur" in Durham. Quite often it was a subtle means by which the local medical man (or "apothecary" perhaps) advertised himself. If so there might possibly be records in the 1830s. It would be pleasant if there were!

STAGE THREE. Now comes the big job. For many years I've known of the five or six "ledger" MS. volumes in the Library of the Newcastle Lit. & Phil. (a good Victorian building, on the corner just east of the Railway Station).

This is the daily meteorological readings, and notes, of JAMES LOSH (approx. 1770-1833). A splendid man: Trinity Cantab., and a barrister; did a lot for N/C: friendly, and a backer of George Stevenson: scientifically minded, intelligent all-round :- see bits of his diary, published as one of the latest volumes of the SURTEES SOCIETY. He has quite an interesting account of coaching down to Lancashire, I think in 1824.

He lived in Jesmond (naturally!) and probably had a good gardener, and his daily temperatures at 9^h, 14^h and 23^h are entered very neatly in columns for each month on successive pages.

On the evidence of his extremes, which are not exceptional, I think he may well have had his thermometer (outside his "study" window) on the N. wall of the house – such an exposure was common; I was at Oxford last month looking at the Duke of Marlborough's obs. ("outside his dressing room window" and "outside a passage window") between 1791 & 1800.

Now Losh has almost 32 years of these monthly tables, very well entered, & NO ONE HAS EVER TOTTED THEM UP!

With the exception of 1812-1818 (7 years) when he put some of them before his Society, who printed his paper: it got into the hands of Heinrich Dove who reprinted them in Abh. der Pres. Akad. Berlin for I think 1839; Anyhow I've got a copy.

The mean temperature, based on good shade readings at $9^h/14^h/23^h$ gives a pretty close approximation to the conventional max.+min./2 (Norway e.g. likes $8^h + 14^h + 22^h$) All that's needed is THE SLOG of the columnar totals, & hence the means for the month for 1802-1811 and 1819-1833

(I think he stopped about September). This is approx. 25×12×3, or 900 straight columnar additions. It sounds a lot, but having done a very great deal of such work it isn't so bad when one gets going. - Alas, I've never come across any later paper by Losh; whether they did get into, say, the MS. records of the Society, I don't know. Why he never totted them up in his ledgers I don't know either! They didn't print much of their early contributions.

Durham (336ft) is probably about 0.6°F cooler than Jesmond (ca.150ft).

...

From your point of view, you might be interested in the rainfall; unfortunately the early Observatory measurements need a good deal of thought before 1886. There's an Ushaw record from 1860, and Sunderland (Backhouse's record) began in 1857; Hilburn (N. Northumberland) 1852.

In order to provide an overall control for the "N.E. England" temperatures, over the gap from the end of Losh to the beginning of Durham Obsy, there are "North East England (inland)" records that permit a "bridge" at either end. The best is Ackworth, 1824-1852. There's also YORK (1831 onward) but I'm having great difficulty finding any York before 1841. There's an earlier YORK set, 1801-1824 that inadequately overlaps Ackworth. To the north, Edinburgh is too far off. KELSO lies inland, and is possible, but I've only found 1841-45 so far.

KEIGHLEY (Braithwaite) is another v. fine Quaker record for which the thermometer obs. seem good from 1809-1857: but it is 750 feet above sea level, and quite a long way from Durham, altho' generally in better accord than York or Ackworth.

Inland from Hull there are some fragments, notably one that might enable a few odd years to be added that covers 1794-1814. But I really don't see any sound way of adding anything to Durham before 1794, and even that is a big stretch. The chief reason to attempt it is the exceedingly severe winter of 1795 and the very mild 1796.

On the other side of the Pennines we do better, but after all that's Lancashire mostly, or Westmoreland! The Royal Hist. MS. Commission mentions a Hindmarsh MS. Diary near ALNMOUTH for 1833-39. I don't know what it holds, or if there are instruments.

. . .

Table included showing various available archives for NE England.

A.5 1st March 1979

...

It's a pity he doesn't work out his monthly means for us. I suppose its the Rev. (Professor) Temple Chevallier. He is referred to in odd mid-Victorian summaries of observations where I originally found reference to the beginnings of Durham about 1843. There are mentions of odd readings for individual days in 1841 but I don't think the actual building was ready and filled up until 1843. The earliest screen was in my recollection a big North-Wall affair, on a small jutting roof, i.e. its height was about that of the first floor. This was a fashion set by the renowned Radcliffe Observatory at Oxford, to read the thermometer outside the 'Transit Room'; they built the Cambridge Observatory (1823, begins) in the same fashion and we have fragments here indicating that the thermometer was outside the window (above a little jutting wing) 15'3" above the ground. Gradually they changed towards the "Glaisher Stand" type of exposure, after Glaisher began to publish his "Quarterly Returns" in 1847. (This Victorian rivalry as regards type and routine of exposure went on for a long time, and bedevils everything before 1881 or even 1900, in some cases: (and 1968 for Kew Observatory!)

Anyhow Carrington's very good and careful observations (1848-52 MS) at the Observatory were in the 'North Shed' and one can continue backwards with confidence. I feel sure, given a summary of the observations.

...

I think it would be helpful to include 1847 as I had to derive approximate values for each month by interpolation between Glaisher's '3-month' averages that he gave for his first year of publication, when he was commissioned to make the country-wide 'Meteorological Reports' for the 'Registrar-General's Quarterly Returns of Births, Marriages and Deaths'.

...

I searched the Observatory's collections forty years ago (isn't it terrible!) for any fragments of MS before Carrington began his very neatly kept MS, but without success. (I had trouble after that with the mid-1850's : drunken observer, alas!)

...

RAIN. I have found a single entry of the year's total for 1845. But if the totals are available from 1843-47 that would all help. The "North East" is ill furnished with longer rainfall records.

The outstanding events around then are: cool weather in May 1843; excessive cold end Feb. 1845 and all through a very snowy March; a tremendously hot June of 1846, probably mitigated at Durham by the sea-breeze; pretty cold in Jan. 1847; dry Dec. 1844.

EXTENSION: I've found fragments for North Shields 1841 and 1842; Middlesbrough 1842; but no real 'bridge' locally to link with Losh's 1802/1833 set. There are homogeneous series, apart from Edinburgh, rather distant, for

ACKWORTH 1824-1852

YORK 1841 onward (possibly from 1832, uncertain and troublesome)

MAKERSTOUN 1842-1849

KELSO 1841-1846

BRAITHWAITE above Keighley, 1809-1859, rather high up and more distant

KENDAL 1823-1851, homogeneous, wrong side of Pennines

CARLISLE 1835-1850, homogeneous but potentially useful

Darlington, altho' its a Quaker town, is no good. I've never tried the Teesdale Mercury at Barnard Castle! There is another fragment in Berwickshire that might "support a pattern" in 1835-39, and I might have another try at Alnwick Castle. Without doubt one can make a very reasonable "bridge" from 1833 to 1843, but if one could find something nearer Durham it would be preferable!

...

PS I've just finished "Moorhouse" 1931-1978 in one table and "corrected" Durham up to date. Present 9h/9h means are univabite dicter the virtual equivalent of my earlier "adopted means".

A.6 5th March 1979

...

After a lot of tedious comparison through other records I have done two things:-

(1) brought the Durham table of 'adopted means', 1847-1940 up to date, 1978, with adjustments for the change in observing routines in 1958. When the old fixed-hour observations at 21^h ceased, the maxima and minima were no longer for the interval 21^h-21^h, but were read at 9^h (for the interval 9^h-9^h).

(2) standardised my adjusted Moorhouse monthly means 1932/47 onto the Nature Conservancy's observations 1953-1978; the earlier observations were kept nearer to the house and this *** more differences than I suspected at the time.

...

A.7 3rd June 1979

"EXTENSION OF THE DURHAM METEOROLOGICAL RECORD"

. . .

I thought I might "report progress" in providing monthly means for Durham in continuation of the series I published that begins with 1847. The stations on which one must depend in order to get an overlap with the LOSH series from Newcastle, 1802 to Sept. 1833 are:

1) Ackworth 80 miles SSE : Luke Howard's series running from 1824-1850 (perhaps '52)
2) York 60m SE by S : John Ford 1841-1852 (and later) but with a break in 1845 (change of location) and 1848 (instruments). [York: There are also averages for each of the months for the period 1832-44].
3) Kendal 60m SW : Samuel Marshall: a full series 1823-60, almost homogeneous.
4) KEIGHLEY (BRAITHWAITE) : Abraham Shackleton MS) 1798-1857 - 65 miles SW
5) EDINBURGH 100m NW [a very carefully reduced table (1764-1896), but pretty distant.]

There are also some shorter records in the Border Counties - none right through the gap; and one in Yorkshire for 1831-40 that I haven't yet examined (if I can find it). Also I might run Allenheads to earth on my next visit to Newcastle: it covers 1836-1876. Ackworth is a less perfect record than I hoped; York is troublesome; Kendal is across the Pennines. Edinburgh is not only a long way off but I want to avoid using it if I can, and keep "Durham" independent.

However, I've been slogging out the departures for each month for each of the above series, to north, south, and west of Durham and I get the "provisional monthly means" on the enclosed sheet. But: they're pretty dicky; the deduced values from each of the series quite often departs from the others, sometimes one can suspect instrumental faults.

So: it will certainly help to have the Durham Advertiser monthly means for 1843-46, for Durham University Observatory, and it will be interesting to see whether they are reasonably close to my "provisional" estimates on the accompanying sheet.

What I have found recently while reading a very obscure little book by the redoubtable amateur E.J.LOWE of Nottingham is (1) that he dedicated his little book on "Atmospheric Phenomena" (1846) to the Rev. Temple Chevallier, Prof of Maths and Astronomy at DURHAM and (2) in a discussion of the prolonged cold winter of 1845 he quotes the monthly means for Durham for Oct 1844 to March 1845 inclusive.

This leads me to think that you might save yourself a lot of trouble with the Durham Advertiser by finding whether they have a table of monthly temperature, rainfall etc for the whole year. Quite frequently the contemporary observers sent in a table for the year, giving data for each of the 12 months Jan - Dec, and it would be printed in the 2nd, 3rd or 4th issue of January. (For instance the "Cambridge Chronicle" commonly had it between roughly Jan 20 and Feb 5 - I've had quite a bit of success with it lately, towards filling the big Cambridge gap between 1837 and 1875).

If Chevallier had sent in his year complete, much effort would be saved. Incidentally he was reading instruments now and then as early as 1841, which must, I think, have been the year the building was complete.

I find that the Durham Advertiser began as early as 1814 and this leads me to wonder if by any chance there was an earlier contributor of any kind. We don't seem to have had many "science-minded" gentry (or doctors) around Durham, but Bishop Barrington's secretary, Mr EMM, at Auckland Castle was keeping observations of some kind in 1807 and he's a possible source. (Again, it would probably be a "yearly summary"). Of course if any other Durham County contributor covered 1833-1842 it would save a great deal of rather "uncertain estimation" from the several records at a distance that I've used in the "provisional" table.

Incidentally the Durham rainfall for 1845 is given as 19.80 inches. But as the gauge is said to be 352 feet above mean sea level, was it up on a balcony roof? One will have to find out what was then considered to be the level of the Observatory ground - as the Six-Inch O.S. had not then begun for Durham.

There's a "Tyneside Natural History Society" with volumes beginning in 1846, but they are rather disappointing until later in the 1850's when their secretary collected quite a number of rainfall totals – including Durham from the observer, A. Marth (He came after the chap who got drunk). The whole story of Durham in the 1860's looks as if the Churchmen (at Durham) had "lost interest". A big change from the degree course in Civil Engineering reported in 1844 in one of the Edinburgh Journals!

...

A.8 8th August 1979

...

had a busy spell on the Losh record, which is in 6 volumes at the N/c Lit & Phil, very close to the station. [He's really rather an admirable figure (1762-1833), and a bit of his diary around 1825 has been recently published in the SURTEES Soc. volumes with narratives of coach journeys etc.] You'll find they have his statue, in a Roman toga, on the staircase!

Well: the point is that I totted up his means for every month 1830-32. He has a nice set of 3 obs. daily at 9^h, 14^h and 22^h - a not uncommon practice, that gives a mean generally a little above max.+min./2 but is readily adjusted. Anyhow I've appended what I've done on a sheet herewith. There are some signs that he was getting older by 1833 and actually he died on the last day that he made his entry (Sept 23 1833). He was up at Trinity (Cambridge), and at some later time backed George Stephenson; quite an estimable chap.

Note also that Heinrich Dove quoted his means for the years 1812-1818, for temperature, based on the sum of the 3 obs. which look as if they were kept on north wall, and I think quite probably on a thermometer that could be read outside his (study?) window. They, and the instrument, look good.

Thank you so much for your noble extraction of 1842-3 from the Advertiser. I have totted them up too; summarised herewith.

What worries me is this microfilm business. I find them quite dreadful to read when they're from newspapers, unless you have a very good reader; preferably magnifying a bit. I have therefore been cudgelling my brain to think of an alternative. I have found, at York, the complete York series (on Ford's earlier site) that ran from 1832-1846 and I know they run tolerably well with Durham; and this last week I have collected Makerstoun (Berwickshire) (a very superior "Observatory"!) 1842-

1855. South of Durham we have also Luke Howard's ACKWORTH - the Quaker school - that runs from 1824-1850 but alas its figures give reason for suspicion over 1848-50 and also about 1835-6.

Between one thing and another however, now we have 1843 (and bits of '42) for Durham. I think we could at a pinch do without most the microfilms, if it's really difficult. There are however about five extremely hot, or cold, months that would be worth while - MARCH 1845, JUNE-JULY-AUGUST 1846 (especially the phenomenally hot June) and perhaps December 1844, and December 1846. And the rainfall totals of each month, ending perhaps with the 1st of the next month - I can't remember what the regular practice was, and glancing again at your reproduction, it doesn't seem as if he necessarily went to the gauge every day. So it may be that one will just have to be a little uncertain of the exact month's total (morning of 1st, to morning of 1st of succeeding).

I had a look again at the probable "back balcony" on which they put the large sort of "meat-safe" screen, although whether they began with it - 1841/2 seems a little uncertain.

...

Otherwise Losh for 1802-11 and 1819-29 (except those I've done), and 1833 where possible. I have some fragments! Elsewhere: N. Shields 1842, Middlesbrough 1842-43, (Yarm 1842), Allenheads 1842 and perhaps 1844, Newcastle 1846 to give an idea of "patterns" - they're all rather uncertain alas. Really its a most troublesome period, fortunately the general agreement between inland N. Yorkshire - Durham - Northumberland - South Berwickshire is good.

...

Table enclosed of some monthly means for Losh 1830-33, and for Durham 1842-3

A.9 9th September 1979

...

I came up to N/C on Wednesday mornings train on a "day trip", having an idea that it might be worth while getting photocopies of the LOSH volumes at the N/C Lit & Phil, which is just outside the railway station. However (a) the train was late (b) photocopies of these weekly records would be very expensive, and only the University could do them (college too, no doubt).

So I got down to slog them, having already done 1830-32. I found that a quick copy of the temperatures would leave me able to do the adding up at my own convenience (a bit like you copying the Advertiser for 1842-3!).

Well, I went on till closing time (7 pm) and spent the night in a b&b at Whitley Bay (and a remarkably nice one too, agreeably old fashioned honest North East, no spivs or shi-shi).

Then, all day Thursday*. (Yes, you can have coffee and biscuits, so I ate my lunch while I went on slogging!) (Then I found I'd mislaid the pills which no doubt your father knows are nowadays Universally Fashionable!) So I caught the Talisman back to Cambridge (1045 pm) and have just (Sunday) completed the reduction of the monthly means for 1821 onwards. (Appended: they shouldn't be wasted!)

Losh did provide a reduction in the Society's "Transactions" for the years 1812-1818.

Now the real nuisance is before that. For 1802-1811, he used different hours, and left a number of "odd days" out, I completed one or two "sample" months and I think that after all you'd better leave me to complete them, as far as temperature is concerned.

I'll have to come up again sometime when I can (conceivably late September or early October; can't say yet) for two reasons: to add a few more years for temperature, and to have a look at what may be left of his house (Jesmond Grove). He had quite a nice little "park" - all now modern suburb I think, called "Long Benton", and if any bit of the house survives one might estimate the likelihood that he put his thermometer on a bracket outside his study window, on the north wall probably. This was current fashion, & he read the Edin. Philos. Journal (and as a lawyer I surmise he was impressed by Lord Gray of Kinfauns Castle, who was a Scots lawyer who sedulously contributed to the E.P.J.) His range of temperatures does support that kind of exposure, and his house was well up the gentle slope that declines eastward to Jesmond Dene. (Perhaps if it's a nice day you could come with me to reconnoitre the house!)

James Losh was really a rather impressive chap (1766-1833) Trinity Cambridge (a little maths I think) – then law; ultimately "Recorder of N/C". Married a Lancashire parson's daughter from near Barrow. Had I think 8 children. A very pleasant bit of his diary (about 1825/6) is published (recently) by the Surtees Society with an account of his (coach) tour over to Lancashire. (He had a son at Sedburgh I think). And if you enter the N/c Lit. & Phil. He's all solemn in a Roman Toga at the top of the stairs! as a V-P of the Society. I also recall that he was keen on colliery enquiries and development and I think he backed George Stephenson.

Anyhow if you like a bit of recreation on the 'personal' side, he's a worth while figure. WHAT a pity he never slogged out his monthly means after 1818!

He's very keen on his flowers in his garden, and he's a meticulous entrant of his readings in the big "ledgers" he had printed for him. Incidentally he took his 9 am observation as usual, on the day when, aged 71, he collapsed and died – Between one thing and another I find myself much impressed by some of our forefathers (and not forgetting that remarkable Constantia Orlebar with her very attractive meteorological journal, 1786-1808: I commented in it in Q.J.Roy.Met.S. 1956).

The general pattern displayed by Losh's observations against "Central England" is good. But getting a satisfactory "bridge" between Losh of Jesmond and Durham Observatory is going to be quite tricky. I can see how to do it, in general terms, but life is complicated by John Ford the Quaker at York, who moved his station; by Sir J. Brisbane (ex-Australia) who at Makerstoun in Berwickshire had a superbly-equipped observatory but DID NOT OBSERVE ON THE SABBATH (1840s in Scotland; even at Greenwich they did as little as they could until about 1850, when probably under the influence of the Oxford Movement and the Tractarians etc. they thought that, if after all we worshipped <u>all</u> the days of the week (instead of merely Sunday) we might as well do the meteorological observations in addition!). I can assure you that the sidelights one gets on the "Victorian mind" are remarkable – and indeed Caroline Molesworth (the engineer's daughter, and the first "Lady Fellow" of the Roy.Met.S) published her own observations about 1850 in a well printed volume, all about the same period as Charlotte Bronte, etc etc.

About the Advertiser, however. I'm very worried about the task of reading anything on microfilm, and you must have had quite a long job extracting 1842-3 week by week, or was it, possibly, month by month?

I don't know on how many "frames" the sheets of the Advertiser are film photographed. <u>But</u> if it is easy to create the relatively few issues (and the pages) on which the record is printed, do you think it would be easy to have your Palaeo-manuscript dept (or whatever it is called) – it is down at the bottom of the Science Labs site and I've used it on more than one occasion – make a photo-copy – they <u>may</u> have that cheap "copycat" facility?

I think it would be worth while getting February B and March C 1845 and June A 1846; with August D1846 and December E 1846 if possible, and after that, February F 1844 and July G 1844. [A-G represents order of preference].

I have myself used the microfilm for weekly reports of temperature and rainfall in the Manchester papers and found them pretty difficult, and from what you say of the Advertiser it might well be worse.

Our "Copycat" here does microfilm frames at 4p each, so if it were easy to locate the particular frames it wouldn't be too expensive to have a few done. (For instance <u>if</u> you could always rely on a month's summary being on, say, "page 3 of the second issue", in the subsequent months, it would be quite easy!)

But, having seen what it means, perhaps when you've a bit of time to spare you could advise – June 1846 was by far the hottest June for 150 years or so!)

Sorry to bother you, but it does help to write about what I've been doing; - incidentally, I'll use another sheet and jot down the means for the months that I've derived from Losh. They're based on his 3 fixed-hours daily, $9^h/14^h/22^h$ at his house Jesmond Grove and are probably very slightly above the mean that would be derived from daily extremes, ½ (Max.+Min.).

Table of Losh monthly means 1821-1832, plus a few odd months

It is not yet possible to suggest adjustments that should be used to provide an approximate value applicable at Durham Observatory.

The effect of the proximity of the North Sea shows in several of the colder months, and also in May-June.

The phenomenal warmth of summer 1826 is notable. Extremes at these "fixed hours" are 85°F (14^h) in 1826, and 11°F on several occasions (at 9^h). These are very close to expectation.

He did not measure rainfall. He notes wind direction, and weather of the day in general terms.

Anyhow, there it all is for reference. The possible "overlaps" to Durham (independent of Edinburgh) are to be found in the records from Ackworth, Keighley, York; (Applegarth (Dumfries), Carlisle, Kendal beyond the Pennines) and partly from Makerstoun (Berwickshire). But all present difficulties.

A.10 5th November 1979

EXTENSION AND UPDATING OF

THE DURHAM METEOROLOGICAL RECORD:

PROGRESS REPORT

. . .

I feel that I owe you a progress report after about a month of quite difficult slogging. It will demonstrate that I have incorporated your own extraction of Feb.-Dec. 1843; a number of "short spells" in 1842 that you also copied have given me a basis for "rough estimates" for about five months, May 1842 onward.

The table 1801-1850 herewith is made up of: - the reduction to Durham, for 1802-1832, of Losh' s MS. From Jesmond (Newcastle), 3 readings daily, mainly $8^h/16^h/23^h$ for 1802-1805 Then $9^h/15^h/23^h$ for 1806-1811; thereafter, $9^h/14^h/22^h$. I have adjusted these fixed-hour means to "max. + min./2", using the Greenwich hourly corrections which appear to give more satisfactory results than those for either Kew or Rothesay, Aberdeen or Eskdalemuir. These means are what I slogged out at Newcastle early in October, when I enjoyed your hospitality.

For 1812-1818 however Losh did calculate and publish his means (in a Northumberland Natural History journal, now dead. The redoubtable Prof. Heinrich Dove of Berlin got hold of them and provided them again in 1845. Something leads me to think that large errors crept in (misprints, Losh's bad arithmetic, or gaps in his record). I shall have to come up to Durham again to check his MS. for those years.

There is an overlapping series kept by a Yorkshire squire at Brandsby 13 m north of York from 1811-1830 (and afterwards; but we cannot find his MS. at the York Philosophical Society after 1830). For 1811-1830 there's a summary in the County Archives at Northallerton. Two short gaps can be filled from a Malton record (1817-1825). The Brandsby man observed at $8\frac{1}{2}^h$, 14^h and 23^h but he doesn't tell us how; but his exposure was more "open" than Losh, who I think used the east wall of his house, possibly outside his study window with a board to screen it, and several feet above the ground.

Much more distant, there is the long "Edinburgh" table (by Mossman) since 1764, of which I have some little doubts; and there is the long "Lancashire" table from 1753 compiled by Manley, of which other people may have some little doubts, or even bigger ones.

I think that they must be used to provide an "overall control", that is the fluctuations of the decadal means, and perhaps the annual means at Durham, after all reductions have been made, should "fit" with Lancashire-Edinburgh.

Having attempted a compilation of sorts off Losh and the Brandsby set the big problem has been to link all before 1833, on to Durham which so far has been all after 1846. How? Available: -

(1) Durham Advertiser: (a) close estimates based on bits of about 5 months in 1842.
(b) nearly all of 1843.

(2) Published figures for the five-year mean for Jan. Apr. July. Oct. for 1843-47 (found in Phillips "Yorkshire", 1853)

(3) YARM for 1840 and 1842: obs. at 8^h 12^h 16^h & 20^h daily, capable of reduction.

(4) North Shields 1842: Middlesbrough 1841 and 1842: Allenheads 1841 and 42 (dubious)

(Quaker record)(5)YORK 1832 onward; careful, but sheltered garden; change to more open site end 1846, at Yorks. Philosophical Society.

(Quaker: Luke Howard) (6)ACKWORTH 1824-1850. Occasionally suspect.

(J.Gray) (7)YORK 1800-1824: 8 a.m. only, and very sheltered. Wykeham, inland from Scarborough, 1831-1836.

(Quaker A. Shackleton) (8) KEIGHLEY 1800-1857. 10 a.m. only, and "indoors" until 1809

[All these are N.E.England]

[SCOTTISH BORDERS] (9) KELSO said to begin 1832 but not found until 1842, (10) MAKERSTOUN nearby, 1841-1855, but local change in 1849.

(11) Abbey St. Bathans 1835-1839, (Hawick & Creswell-Twizell in Northumberland in 1840s rejected.)

[WEST KENDAL 1823-1869, Carlisle 1802-1824, Applegarth (Dumfries) 1827-1851.
OF PENNINES] All these have been incorporated in my "Lancashire" reduction.

Well: of all those I worked out a series of the most probable "monthly Anomalies" applicable in N.E. England, a few miles inland from the coast. I extended one set forward, from the earlier Losh&Brandsby series 1801-1832: and another set backward, from the later Durham series 1847-1856. The agreement wasn't too bad and I've taken the mean.

So you can see; quite a fierce job, of "trimming" between records that just do not overlap, with the exception of rather doubtful Keighley, Kendal beyond the Pennines, and the more distant Lancashire and Edinburgh that I've wanted to avoid.

And what else? I'll have to come & collect the early rainfall (1843-1855) at Durham; I've unfortunately mislaid my earlier notes. Sunshine I've already done for 1886-1940, that's fairly easily added. Frequency of snow I've already done since 1848 (Met. Mag. Jan. 1998) and I think there's enough in the obscure Sunderland runs to attempt "Snow lying".

...

Forgive the scribble, but I feel the work shouldn't be wasted and it will be quite a time before I can get it all completed & written up.* Incidentally I've been trying Raby Castle (they had a record in 1860!) but haven't yet got any further; (* so, this isn't yet for publication, merely retention!).

...

Durham ranks after Oxford as a continuous University record in one place. (Cambridge, Glasgow & Aberdeen all broke down somewhere!)

Table of results enclosed with this letter.

A.11 27th November 1979

...

I found that Losh, through 1812-1818 Jan, observed at $9^h/14^h/23^h$, not $9^h/14^h/22^h$. I had taken his figures from those already published by one of these characteristic North-East-Coast botanists (called Nathaniel Winch, who used them in a paper of his in 1819). This makes a tiresome little adjustment; and I also spotted the need for a little amendment in 1833.

Hence this provision on my part of a copy of the earlier table that I sent, REVISED for those years. This is really an insurance, in case of loss!

I went back via Hull. They're going to provide me with microfilm to photocopy 1794-1803.

After that another visit to Northallerton County Record Office will enable me to "top off" to 1784.

Rainfall I must next start on, and the obs. Around 1848-1850 are quite a dreadful puzzle. (You kindly found me 1843 from the Advertiser; I've also found 1845). But I want if possible the annual summaries for 1844,46,47,48 and 49, if they were published in the Advertiser; and the temperatures for June 1846 would be a help as it was the warmest June on record.

...

Its surprising what a lot of tiresome little troubles have come up with regard to the Durham observatory quite apart from the "Drunken Observer" of 1854-55. It certainly reflects on the period of torpor that seems to have supervened when the initial surge of astronomy and mathematics in the hands of ordained churchmen began to be replaced by a depressing lack of energy; the redoubtable Canon Tristram (who supported Darwin, and was a firm Evangelical and an informed naturalist) couldn't carry everything in the University on his shoulders!

...

Revised table enclosed with letter.

Appendix B – Glaisher's Corrections for Greenwich

James Glaisher calculated corrections to be applied to fixed hour readings, which he published as adjustments for each hour for Greenwich (Glaisher 1848b, 1849, 1850, 1967). Certain sets of manuscript temperature readings encountered in this study include observations which are not on the hour. Corrections for such readings have been interpolated from Glaisher's results. His set, and the interpolated adjustments, are shown below.

Table B.1 Glaisher's Corrections for Greenwich, interpolated between hours (°F).

Jan	00:00	1	May	00:00	5.4	Sep	00:00	4
	00:15	0.98		00:15	5.55		00:15	4.13
	00:30	0.95		00:30	5.7		00:30	4.25
	00:45	0.93		00:45	5.85		00:45	4.38
	01:00	0.9		01:00	6		01:00	4.5
	01:15	0.98		01:15	6.1		01:15	4.75
	01:30	1.05		01:30	6.2		01:30	5
	01:45	1.13		01:45	6.3		01:45	5.25
	02:00	1.2		02:00	6.4		02:00	5.5
	02:15	1.23		02:15	6.48		02:15	5.73
	02:30	1.25		02:30	6.55		02:30	5.95
	02:45	1.28		02:45	6.63		02:45	6.18
	03:00	1.3		03:00	6.7		03:00	6.4
	03:15	1.38		03:15	6.7		03:15	6.45
	03:30	1.45		03:30	6.7		03:30	6.5
	03:45	1.53		03:45	6.7		03:45	6.55
	04:00	1.6		04:00	6.7		04:00	6.6
	04:15	1.65		04:15	6.6		04:15	6.5

04:30	1.7	04:30	6.5	04:30	6.4
04:45	1.75	04:45	6.4	04:45	6.3
05:00	1.8	05:00	6.3	05:00	6.2
05:15	1.83	05:15	5.93	05:15	5.98
05:30	1.85	05:30	5.55	05:30	5.75
05:45	1.88	05:45	5.18	05:45	5.53
06:00	1.9	06:00	4.8	06:00	5.3
06:15	1.9	06:15	4.25	06:15	4.98
06:30	1.9	06:30	3.7	06:30	4.65
06:45	1.9	06:45	3.15	06:45	4.33
07:00	1.9	07:00	2.6	07:00	4
07:15	1.8	07:15	2.08	07:15	3.53
07:30	1.7	07:30	1.55	07:30	3.05
07:45	1.6	07:45	1.03	07:45	2.58
08:00	1.5	08:00	0.5	08:00	2.1
08:15	1.38	08:15	-0.13	08:15	1.48
08:30	1.25	08:30	-0.75	08:30	0.85
08:45	1.13	08:45	-1.38	08:45	0.23
09:00	1	09:00	-2	09:00	-0.4
09:15	0.8	09:15	-2.5	09:15	-1.05
09:30	0.6	09:30	-3	09:30	-1.7
09:45	0.4	09:45	-3.5	09:45	-2.35
10:00	0.2	10:00	-4	10:00	-3
10:15	-0.18	10:15	-4.38	10:15	-3.5
10:30	-0.55	10:30	-4.75	10:30	-4
10:45	-0.93	10:45	-5.13	10:45	-4.5
11:00	-1.3	11:00	-5.5	11:00	-5
11:15	-1.55	11:15	-5.8	11:15	-5.35

11:30	-1.8	11:30	-6.1	11:30	-5.7
11:45	-2.05	11:45	-6.4	11:45	-6.05
12:00	-2.3	12:00	-6.7	12:00	-6.4
12:15	-2.45	12:15	-6.9	12:15	-6.58
12:30	-2.6	12:30	-7.1	12:30	-6.75
12:45	-2.75	12:45	-7.3	12:45	-6.93
13:00	-2.9	13:00	-7.5	13:00	-7.1
13:15	-2.93	13:15	-7.55	13:15	-7.1
13:30	-2.95	13:30	-7.6	13:30	-7.1
13:45	-2.98	13:45	-7.65	13:45	-7.1
14:00	-3	14:00	-7.7	14:00	-7.1
14:15	-2.88	14:15	-7.6	14:15	-6.98
14:30	-2.75	14:30	-7.5	14:30	-6.85
14:45	-2.63	14:45	-7.4	14:45	-6.73
15:00	-2.5	15:00	-7.3	15:00	-6.6
15:15	-2.35	15:15	-7	15:15	-6.33
15:30	-2.2	15:30	-6.7	15:30	-6.05
15:45	-2.05	15:45	-6.4	15:45	-5.78
16:00	-1.9	16:00	-6.1	16:00	-5.5
16:15	-1.7	16:15	-5.78	16:15	-5.18
16:30	-1.5	16:30	-5.45	16:30	-4.85
16:45	-1.3	16:45	-5.13	16:45	-4.53
17:00	-1.1	17:00	-4.8	17:00	-4.2
17:15	-0.98	17:15	-4.35	17:15	-3.78
17:30	-0.85	17:30	-3.9	17:30	-3.35
17:45	-0.73	17:45	-3.45	17:45	-2.93
18:00	-0.6	18:00	-3	18:00	-2.5
18:15	-0.53	18:15	-2.5	18:15	-2.03

	18:30	-0.45		18:30	-2		18:30	-1.55
	18:45	-0.38		18:45	-1.5		18:45	-1.08
	19:00	-0.3		19:00	-1		19:00	-0.6
	19:15	-0.2		19:15	-0.53		19:15	-0.2
	19:30	-0.1		19:30	-0.05		19:30	0.2
	19:45	0		19:45	0.43		19:45	0.6
	20:00	0.1		20:00	0.9		20:00	1
	20:15	0.18		20:15	1.25		20:15	1.2
	20:30	0.25		20:30	1.6		20:30	1.4
	20:45	0.33		20:45	1.95		20:45	1.6
	21:00	0.4		21:00	2.3		21:00	1.8
	21:15	0.45		21:15	2.6		21:15	2.03
	21:30	0.5		21:30	2.9		21:30	2.25
	21:45	0.55		21:45	3.2		21:45	2.48
	22:00	0.6		22:00	3.5		22:00	2.7
	22:15	0.63		22:15	3.75		22:15	2.88
	22:30	0.65		22:30	4		22:30	3.05
	22:45	0.68		22:45	4.25		22:45	3.23
	23:00	0.7		23:00	4.5		23:00	3.4
	23:15	0.78		23:15	4.73		23:15	3.55
	23:30	0.85		23:30	4.95		23:30	3.7
	23:45	0.93		23:45	5.18		23:45	3.85
Feb	00:00	1.6	Jun	00:00	6.2	Oct	00:00	2.9
	00:15	1.65		00:15	6.43		00:15	2.93
	00:30	1.7		00:30	6.65		00:30	2.95
	00:45	1.75		00:45	6.88		00:45	2.98
	01:00	1.8		01:00	7.1		01:00	3
	01:15	1.85		01:15	7.33		01:15	3.1

01:30	1.9	01:30	7.55	01:30	3.2
01:45	1.95	01:45	7.78	01:45	3.3
02:00	2	02:00	8	02:00	3.4
02:15	2.03	02:15	8.18	02:15	3.45
02:30	2.05	02:30	8.35	02:30	3.5
02:45	2.08	02:45	8.53	02:45	3.55
03:00	2.1	03:00	8.7	03:00	3.6
03:15	2.15	03:15	8.85	03:15	3.65
03:30	2.2	03:30	9	03:30	3.7
03:45	2.25	03:45	9.15	03:45	3.75
04:00	2.3	04:00	9.3	04:00	3.8
04:15	2.28	04:15	9.18	04:15	3.8
04:30	2.25	04:30	9.05	04:30	3.8
04:45	2.23	04:45	8.93	04:45	3.8
05:00	2.2	05:00	8.8	05:00	3.8
05:15	2.23	05:15	8.2	05:15	3.73
05:30	2.25	05:30	7.6	05:30	3.65
05:45	2.28	05:45	7	05:45	3.58
06:00	2.3	06:00	6.4	06:00	3.5
06:15	2.25	06:15	5.55	06:15	3.33
06:30	2.2	06:30	4.7	06:30	3.15
06:45	2.15	06:45	3.85	06:45	2.98
07:00	2.1	07:00	3	07:00	2.8
07:15	1.98	07:15	2.25	07:15	2.5
07:30	1.85	07:30	1.5	07:30	2.2
07:45	1.73	07:45	0.75	07:45	1.9
08:00	1.6	08:00	0	08:00	1.6
08:15	1.38	08:15	-0.63	08:15	1.2

08:30	1.15	08:30	-1.25	08:30	0.8
08:45	0.93	08:45	-1.88	08:45	0.4
09:00	0.7	09:00	-2.5	09:00	0
09:15	0.4	09:15	-3	09:15	-0.5
09:30	0.1	09:30	-3.5	09:30	-1
09:45	-0.2	09:45	-4	09:45	-1.5
10:00	-0.5	10:00	-4.5	10:00	-2
10:15	-0.9	10:15	-4.83	10:15	-2.45
10:30	-1.3	10:30	-5.15	10:30	-2.9
10:45	-1.7	10:45	-5.48	10:45	-3.35
11:00	-2.1	11:00	-5.8	11:00	-3.8
11:15	-2.38	11:15	-6.18	11:15	-4.13
11:30	-2.65	11:30	-6.55	11:30	-4.45
11:45	-2.93	11:45	-6.93	11:45	-4.78
12:00	-3.2	12:00	-7.3	12:00	-5.1
12:15	-3.38	12:15	-7.5	12:15	-5.2
12:30	-3.55	12:30	-7.7	12:30	-5.3
12:45	-3.73	12:45	-7.9	12:45	-5.4
13:00	-3.9	13:00	-8.1	13:00	-5.5
13:15	-3.9	13:15	-8.23	13:15	-5.35
13:30	-3.9	13:30	-8.35	13:30	-5.2
13:45	-3.9	13:45	-8.48	13:45	-5.05
14:00	-3.9	14:00	-8.6	14:00	-4.9
14:15	-3.83	14:15	-8.55	14:15	-4.6
14:30	-3.75	14:30	-8.5	14:30	-4.3
14:45	-3.68	14:45	-8.45	14:45	-4
15:00	-3.6	15:00	-8.4	15:00	-3.7
15:15	-3.4	15:15	-8.15	15:15	-3.48

15:30	-3.2	15:30	-7.9	15:30	-3.25
15:45	-3	15:45	-7.65	15:45	-3.03
16:00	-2.8	16:00	-7.4	16:00	-2.8
16:15	-2.5	16:15	-7.08	16:15	-2.53
16:30	-2.2	16:30	-6.75	16:30	-2.25
16:45	-1.9	16:45	-6.43	16:45	-1.98
17:00	-1.6	17:00	-6.1	17:00	-1.7
17:15	-1.35	17:15	-5.7	17:15	-1.48
17:30	-1.1	17:30	-5.3	17:30	-1.25
17:45	-0.85	17:45	-4.9	17:45	-1.03
18:00	-0.6	18:00	-4.5	18:00	-0.8
18:15	-0.38	18:15	-3.98	18:15	-0.6
18:30	-0.15	18:30	-3.45	18:30	-0.4
18:45	0.08	18:45	-2.93	18:45	-0.2
19:00	0.3	19:00	-2.4	19:00	0
19:15	0.38	19:15	-1.8	19:15	0.18
19:30	0.45	19:30	-1.2	19:30	0.35
19:45	0.53	19:45	-0.6	19:45	0.53
20:00	0.6	20:00	0	20:00	0.7
20:15	0.7	20:15	0.45	20:15	0.85
20:30	0.8	20:30	0.9	20:30	1
20:45	0.9	20:45	1.35	20:45	1.15
21:00	1	21:00	1.8	21:00	1.3
21:15	1.08	21:15	2.25	21:15	1.45
21:30	1.15	21:30	2.7	21:30	1.6
21:45	1.23	21:45	3.15	21:45	1.75
22:00	1.3	22:00	3.6	22:00	1.9
22:15	1.35	22:15	3.95	22:15	2.03

	22:30	1.4		22:30	4.3		22:30	2.15
	22:45	1.45		22:45	4.65		22:45	2.28
	23:00	1.5		23:00	5		23:00	2.4
	23:15	1.53		23:15	5.3		23:15	2.53
	23:30	1.55		23:30	5.6		23:30	2.65
	23:45	1.58		23:45	5.9		23:45	2.78
Mar	00:00	2.9	Jul	00:00	5	Nov	00:00	1.7
	00:15	2.93		00:15	5.13		00:15	1.73
	00:30	2.95		00:30	5.25		00:30	1.75
	00:45	2.98		00:45	5.38		00:45	1.78
	01:00	3		01:00	5.5		01:00	1.8
	01:15	3.08		01:15	5.63		01:15	1.85
	01:30	3.15		01:30	5.75		01:30	1.9
	01:45	3.23		01:45	5.88		01:45	1.95
	02:00	3.3		02:00	6		02:00	2
	02:15	3.38		02:15	6.1		02:15	2
	02:30	3.45		02:30	6.2		02:30	2
	02:45	3.53		02:45	6.3		02:45	2
	03:00	3.6		03:00	6.4		03:00	2
	03:15	3.68		03:15	6.45		03:15	2.03
	03:30	3.75		03:30	6.5		03:30	2.05
	03:45	3.83		03:45	6.55		03:45	2.08
	04:00	3.9		04:00	6.6		04:00	2.1
	04:15	3.93		04:15	6.5		04:15	2.08
	04:30	3.95		04:30	6.4		04:30	2.05
	04:45	3.98		04:45	6.3		04:45	2.03
	05:00	4		05:00	6.2		05:00	2
	05:15	3.98		05:15	5.78		05:15	1.98

05:30	3.95	05:30	5.35	05:30	1.95
05:45	3.93	05:45	4.93	05:45	1.93
06:00	3.9	06:00	4.5	06:00	1.9
06:15	3.83	06:15	4	06:15	1.85
06:30	3.75	06:30	3.5	06:30	1.8
06:45	3.68	06:45	3	06:45	1.75
07:00	3.6	07:00	2.5	07:00	1.7
07:15	3.33	07:15	1.88	07:15	1.53
07:30	3.05	07:30	1.25	07:30	1.35
07:45	2.78	07:45	0.63	07:45	1.18
08:00	2.5	08:00	0	08:00	1
08:15	1.93	08:15	-0.5	08:15	0.85
08:30	1.35	08:30	-1	08:30	0.7
08:45	0.78	08:45	-1.5	08:45	0.55
09:00	0.2	09:00	-2	09:00	0.4
09:15	-0.33	09:15	-2.5	09:15	0.15
09:30	-0.85	09:30	-3	09:30	-0.1
09:45	-1.38	09:45	-3.5	09:45	-0.35
10:00	-1.9	10:00	-4	10:00	-0.6
10:15	-2.3	10:15	-4.35	10:15	-0.95
10:30	-2.7	10:30	-4.7	10:30	-1.3
10:45	-3.1	10:45	-5.05	10:45	-1.65
11:00	-3.5	11:00	-5.4	11:00	-2
11:15	-3.88	11:15	-5.65	11:15	-2.28
11:30	-4.25	11:30	-5.9	11:30	-2.55
11:45	-4.63	11:45	-6.15	11:45	-2.83
12:00	-5	12:00	-6.4	12:00	-3.1
12:15	-5.2	12:15	-6.48	12:15	-3.2

	12:30	-5.4	12:30	-6.55	12:30	-3.3
	12:45	-5.6	12:45	-6.63	12:45	-3.4
	13:00	-5.8	13:00	-6.7	13:00	-3.5
	13:15	-5.8	13:15	-6.7	13:15	-3.53
	13:30	-5.8	13:30	-6.7	13:30	-3.55
	13:45	-5.8	13:45	-6.7	13:45	-3.58
	14:00	-5.8	14:00	-6.7	14:00	-3.6
	14:15	-5.73	14:15	-6.65	14:15	-3.45
	14:30	-5.65	14:30	-6.6	14:30	-3.3
	14:45	-5.58	14:45	-6.55	14:45	-3.15
	15:00	-5.5	15:00	-6.5	15:00	-3
	15:15	-5.25	15:15	-6.33	15:15	-2.78
	15:30	-5	15:30	-6.15	15:30	-2.55
	15:45	-4.75	15:45	-5.98	15:45	-2.33
	16:00	-4.5	16:00	-5.8	16:00	-2.1
	16:15	-4.2	16:15	-5.58	16:15	-1.88
	16:30	-3.9	16:30	-5.35	16:30	-1.65
	16:45	-3.6	16:45	-5.13	16:45	-1.43
	17:00	-3.3	17:00	-4.9	17:00	-1.2
	17:15	-2.93	17:15	-4.55	17:15	-1
	17:30	-2.55	17:30	-4.2	17:30	-0.8
	17:45	-2.18	17:45	-3.85	17:45	-0.6
	18:00	-1.8	18:00	-3.5	18:00	-0.4
	18:15	-1.45	18:15	-3	18:15	-0.28
	18:30	-1.1	18:30	-2.5	18:30	-0.15
	18:45	-0.75	18:45	-2	18:45	-0.03
	19:00	-0.4	19:00	-1.5	19:00	0.1
	19:15	-0.08	19:15	-1.05	19:15	0.23

	19:30	0.25		19:30	-0.6		19:30	0.35
	19:45	0.58		19:45	-0.15		19:45	0.48
	20:00	0.9		20:00	0.3		20:00	0.6
	20:15	1.1		20:15	0.7		20:15	0.7
	20:30	1.3		20:30	1.1		20:30	0.8
	20:45	1.5		20:45	1.5		20:45	0.9
	21:00	1.7		21:00	1.9		21:00	1
	21:15	1.85		21:15	2.25		21:15	1.08
	21:30	2		21:30	2.6		21:30	1.15
	21:45	2.15		21:45	2.95		21:45	1.23
	22:00	2.3		22:00	3.3		22:00	1.3
	22:15	2.38		22:15	3.53		22:15	1.35
	22:30	2.45		22:30	3.75		22:30	1.4
	22:45	2.53		22:45	3.98		22:45	1.45
	23:00	2.6		23:00	4.2		23:00	1.5
	23:15	2.68		23:15	4.4		23:15	1.55
	23:30	2.75		23:30	4.6		23:30	1.6
	23:45	2.83		23:45	4.8		23:45	1.65
Apr	00:00	4.8	Aug	00:00	5.1	Dec	00:00	0.9
	00:15	4.9		00:15	5.2		00:15	0.93
	00:30	5		00:30	5.3		00:30	0.95
	00:45	5.1		00:45	5.4		00:45	0.98
	01:00	5.2		01:00	5.5		01:00	1
	01:15	5.33		01:15	5.63		01:15	1.05
	01:30	5.45		01:30	5.75		01:30	1.1
	01:45	5.58		01:45	5.88		01:45	1.15
	02:00	5.7		02:00	6		02:00	1.2
	02:15	5.83		02:15	6.08		02:15	1.23

	02:30	5.95	02:30	6.15	02:30	1.25
	02:45	6.08	02:45	6.23	02:45	1.28
	03:00	6.2	03:00	6.3	03:00	1.3
	03:15	6.3	03:15	6.35	03:15	1.33
	03:30	6.4	03:30	6.4	03:30	1.35
	03:45	6.5	03:45	6.45	03:45	1.38
	04:00	6.6	04:00	6.5	04:00	1.4
	04:15	6.63	04:15	6.5	04:15	1.4
	04:30	6.65	04:30	6.5	04:30	1.4
	04:45	6.68	04:45	6.5	04:45	1.4
	05:00	6.7	05:00	6.5	05:00	1.4
	05:15	6.53	05:15	6.25	05:15	1.4
	05:30	6.35	05:30	6	05:30	1.4
	05:45	6.18	05:45	5.75	05:45	1.4
	06:00	6	06:00	5.5	06:00	1.4
	06:15	5.58	06:15	4.95	06:15	1.43
	06:30	5.15	06:30	4.4	06:30	1.45
	06:45	4.73	06:45	3.85	06:45	1.48
	07:00	4.3	07:00	3.3	07:00	1.5
	07:15	3.73	07:15	2.7	07:15	1.45
	07:30	3.15	07:30	2.1	07:30	1.4
	07:45	2.58	07:45	1.5	07:45	1.35
	08:00	2	08:00	0.9	08:00	1.3
	08:15	1.28	08:15	0.28	08:15	1.2
	08:30	0.55	08:30	-0.35	08:30	1.1
	08:45	-0.18	08:45	-0.98	08:45	1
	09:00	-0.9	09:00	-1.6	09:00	0.9
	09:15	-1.48	09:15	-2.08	09:15	0.68

	09:30	-2.05	09:30	-2.55	09:30	0.45
	09:45	-2.63	09:45	-3.03	09:45	0.23
	10:00	-3.2	10:00	-3.5	10:00	0
	10:15	-3.73	10:15	-3.98	10:15	-0.33
	10:30	-4.25	10:30	-4.45	10:30	-0.65
	10:45	-4.78	10:45	-4.93	10:45	-0.98
	11:00	-5.3	11:00	-5.4	11:00	-1.3
	11:15	-5.68	11:15	-5.68	11:15	-1.5
	11:30	-6.05	11:30	-5.95	11:30	-1.7
	11:45	-6.43	11:45	-6.23	11:45	-1.9
	12:00	-6.8	12:00	-6.5	12:00	-2.1
	12:15	-7.08	12:15	-6.75	12:15	-2.18
	12:30	-7.35	12:30	-7	12:30	-2.25
	12:45	-7.63	12:45	-7.25	12:45	-2.33
	13:00	-7.9	13:00	-7.5	13:00	-2.4
	13:15	-7.98	13:15	-7.55	13:15	-2.38
	13:30	-8.05	13:30	-7.6	13:30	-2.35
	13:45	-8.13	13:45	-7.65	13:45	-2.33
	14:00	-8.2	14:00	-7.7	14:00	-2.3
	14:15	-8.08	14:15	-7.53	14:15	-2.2
	14:30	-7.95	14:30	-7.35	14:30	-2.1
	14:45	-7.83	14:45	-7.18	14:45	-2
	15:00	-7.7	15:00	-7	15:00	-1.9
	15:15	-7.45	15:15	-6.63	15:15	-1.75
	15:30	-7.2	15:30	-6.25	15:30	-1.6
	15:45	-6.95	15:45	-5.88	15:45	-1.45
	16:00	-6.7	16:00	-5.5	16:00	-1.3
	16:15	-6.38	16:15	-5.03	16:15	-1.18

	16:30	-6.05	16:30	-4.55	16:30	-1.05
	16:45	-5.73	16:45	-4.08	16:45	-0.93
	17:00	-5.4	17:00	-3.6	17:00	-0.8
	17:15	-4.93	17:15	-3.2	17:15	-0.7
	17:30	-4.45	17:30	-2.8	17:30	-0.6
	17:45	-3.98	17:45	-2.4	17:45	-0.5
	18:00	-3.5	18:00	-2	18:00	-0.4
	18:15	-2.9	18:15	-1.63	18:15	-0.33
	18:30	-2.3	18:30	-1.25	18:30	-0.25
	18:45	-1.7	18:45	-0.88	18:45	-0.18
	19:00	-1.1	19:00	-0.5	19:00	-0.1
	19:15	-0.65	19:15	-0.13	19:15	-0.03
	19:30	-0.2	19:30	0.25	19:30	0.05
	19:45	0.25	19:45	0.63	19:45	0.13
	20:00	0.7	20:00	1	20:00	0.2
	20:15	1.03	20:15	1.35	20:15	0.25
	20:30	1.35	20:30	1.7	20:30	0.3
	20:45	1.68	20:45	2.05	20:45	0.35
	21:00	2	21:00	2.4	21:00	0.4
	21:15	2.3	21:15	2.63	21:15	0.43
	21:30	2.6	21:30	2.85	21:30	0.45
	21:45	2.9	21:45	3.08	21:45	0.48
	22:00	3.2	22:00	3.3	22:00	0.5
	22:15	3.43	22:15	3.55	22:15	0.58
	22:30	3.65	22:30	3.8	22:30	0.65
	22:45	3.88	22:45	4.05	22:45	0.73
	23:00	4.1	23:00	4.3	23:00	0.8
	23:15	4.28	23:15	4.5	23:15	0.83

	23:30	4.45	23:30	4.7	23:30	0.85
	23:45	4.63	23:45	4.9	23:45	0.88

Appendix C – Monthly Mean Temperature at Durham

The full set of monthly means for Durham is presented below, in degrees Celsius, accurate to 0.1°C. Monthly means from 1850 are widely available, from the Meteorological Office, or the British Atmospheric Data Centre for example. Daily means from 1876 are available from Kenworthy, Cox and Joyce (1997).

These means are also available on the CD-ROM, attached to the inside back cover. Several files are provided, each identical in content, but in different formats, readable by most computer applications.

Table C.1 Monthly mean temperature for Durham University Observatory (°C) 1784-1849.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1784	-1.0	0.3	2.8	5.4	12.9	12.0	14.1	13.2	13.5	7.3	4.0	0.2	7.1
1785	2.5	-0.6	2.4	8.5	10.0	15.2	15.9	13.4	11.9	7.5	3.6	1.5	7.7
1786	0.8	1.7	1.3	7.2	10.5	15.0	14.8	14.6	10.0	6.2	2.9	1.6	7.2
1787	2.4	4.3	6.0	5.9	9.7	11.4	14.6	14.2	11.4	8.4	2.8	2.6	7.8
1788	2.5	2.3	2.4		12.6	13.8	15.6	14.2	12.7	8.1	4.0	-1.0	
1789	1.8	4.2	1.1	6.4	11.5	12.9	14.3	15.0	11.9	7.6	3.1	4.2	7.8
1790	1.9	5.1	5.4	5.2	10.9	13.9		15.0	9.9	8.4	4.6	2.1	
1791	2.9	2.9	5.2	8.3		13.4	15.6	16.6	12.9				
1792													
1793													
1794													
1795	-2.4	0.7	4.2	7.7	10.0	11.0	12.8	14.2	14.8	11.1	4.4	6.1	7.9
1796	6.5	4.3	4.5	10.0	8.6	11.7	13.2	13.7	13.7	6.6	3.7	-0.5	8.0
1797	3.5	2.6	3.8	6.7	9.8	11.3	14.7	13.9	12.2	7.9	3.8	3.8	7.8
1798	2.9	2.8	5.0	9.6	11.7	15.0	14.2	14.7	13.0	9.4	4.8	1.3	8.7

1799	1.0	2.3	3.7	5.7	8.5	11.4	13.3	13.0	12.1	7.3	4.7	1.8	7.1
1800	1.4	1.6	3.3	8.6	11.0	11.2	15.5	15.5	13.1	7.6	3.3	3.1	7.9
1801	3.6	4.4	6.5	7.7	11.3	12.6	15.2	16.7	11.9	9.2	4.0	1.0	8.7
1802	1.4	1.9	3.4	7.8	7.6	12.0	11.8	15.1	13.3	9.1	4.9	2.5	7.6
1803	0.8	2.3	5.1	7.9	8.5	11.4	15.2	14.2	10.1	8.2	3.7	2.1	7.5
1804	4.1	1.6	3.1	4.7	10.9	13.4	13.9	13.7	13.6	10.1	5.4	1.8	8.0
1805	1.9	2.7	5.1	6.6	7.5	11.0	15.4	15.0	13.6	7.0	4.0	3.1	7.7
1806	2.2	3.1	3.5	6.0	9.9	14.1	15.4	15.0	13.0	10.4	7.1	5.8	8.8
1807	2.7	2.8	2.4	7.1	10.4	12.4	16.0	16.7	9.5	10.7	2.4	2.4	8.0
1808	2.1	2.5	3.6	5.0	13.1	13.7	16.7	15.5	11.6	7.0	5.9	2.5	8.3
1809	0.4	4.8	6.1	5.1	12.2	12.9	14.3	14.7	11.4	10.9	5.2	3.7	8.5
1810	2.7	3.7	4.2	7.6	9.0	14.4	14.8	14.6	13.1	10.2	5.4	2.8	8.5
1811	0.9	3.5	7.6	8.4	11.3	13.2	15.6	14.3	13.4	12.4	7.1	2.4	9.2
1812	2.6	4.8	2.9	5.1	10.1	12.8	13.8	13.8	12.5	9.4	5.3	2.5	8.0
1813	1.8	5.4	6.9	7.9	10.8	12.9	14.6	14.0	12.9	8.3	4.2	3.3	8.6
1814	-2.3	1.6	3.2	9.7	8.1	11.2	16.0	15.0	13.0	8.7	5.2	3.8	7.8
1815	0.0	5.7	6.2	7.6	11.6	13.6	13.8	14.7	13.0	9.5	3.3	0.3	8.3
1816	1.3	2.0	2.7	4.6	8.8	11.9	12.8	13.4	11.6	9.5	3.5	2.0	7.0
1817	4.0	5.1	4.6	7.0	8.7	14.0	13.4	12.9	12.4	6.2	7.6	0.9	8.1
1818	2.4	1.6	3.6	5.5	10.3	16.0	16.8	14.3	12.5	11.6	8.9	3.3	8.9
1819	3.1	3.0	6.2	8.2	10.8	13.4	15.8	16.7	12.7	8.7	3.7	0.0	8.5
1820	-0.5	3.4	4.2	9.3	11.3	13.3	14.4	14.5	11.6	7.4	4.8	4.4	8.2
1821	2.8	2.8	4.9	8.7	9.0	11.3	14.0	15.4	13.9	10.0	6.2	4.5	8.6
1822	3.8	5.4	6.7	7.8	11.8	16.0	14.9	14.9	11.4	9.5	7.0	1.7	9.2
1823	0.1	1.7	4.4	6.2	11.7	11.8	14.0	13.7	11.6	8.2	7.0	3.1	7.8
1824	3.9	3.8	4.0	7.1	9.9	13.0	15.8	14.5	12.8	8.7	5.8	3.9	8.6
1825	3.6	4.1	5.1	8.6	10.7	14.1	16.3	16.0	14.8	10.5	4.1	3.9	9.3
1826	0.2	5.7	5.2	8.8	10.7	17.4	17.4	17.2	13.1	10.7	4.2	4.9	9.6

1827	1.5	1.4	4.9	8.1	11.0	14.3	16.2	14.1	12.9	11.3	6.0	6.0	9.0
1828	4.4	4.7	6.3	7.7	11.5	14.9	15.4	14.9	13.3	9.7	7.1	6.7	9.7
1829	0.1	3.9	3.9	6.0	12.0	14.1	14.7	13.4	10.8	8.3	4.7	1.6	7.8
1830	0.2	2.1	7.5	8.6	10.5	11.8	15.7	13.2	11.6	10.1	6.3	1.4	8.3
1831	1.2	4.4	6.4	7.9	10.4	14.2	16.2	16.2	12.8	11.9	5.5	5.4	9.4
1832	3.3	4.1	6.2	8.3	10.5	14.6	14.9	14.8	13.5	10.7	5.0	4.5	9.2
1833	1.2	4.4	2.9	6.8	13.6	13.8	14.6	13.0	10.9	8.9	5.6	5.8	8.5
1834	5.9	4.8	6.1	7.0	11.7	14.2	15.7	14.8	12.1	8.8	6.9	5.2	9.4
1835	1.5	4.7	4.6	6.8	9.6	13.2	14.9	15.5	11.5	7.1	5.6	2.3	8.1
1836	2.5	2.5	4.2	5.3	9.0	13.9	14.1	12.9	10.5	7.5	3.9	3.6	7.5
1837	2.1	4.7	2.1	4.2	8.4	14.0	15.4	13.9	11.7	9.4	4.6	4.4	7.9
1838	-1.2	-0.4	5.1	5.8	9.2	13.6	15.2	14.4	11.5	9.3	3.9	3.3	7.5
1839	1.5	3.0	2.7	5.5	8.6	12.1	14.0	12.7	10.9	8.3	5.9	2.7	7.3
1840	3.0	2.4	3.8	9.0	9.5	12.2	12.3	14.8	9.4	7.0	4.4	1.4	7.4
1841	0.2	2.0	7.2	6.7	11.4	11.1	12.2	13.5	11.6	7.1	3.7	3.2	7.5
1842	-0.2	2.9	4.8	7.0	10.4	13.6	13.0	15.6	11.5	6.5	4.0	6.5	8.0
1843	3.2	1.5	4.8	7.7	9.3	11.9	14.2	15.3	14.6	7.3	4.7	6.8	8.4
1844	3.9	1.6	4.8	9.6	9.5	13.1	14.3	13.4	12.9	9.0	6.6	1.7	8.4
1845	2.8	0.9	2.9	7.1	8.1	14.5	13.1	13.2	11.1	9.3	6.8	3.7	7.8
1846	5.4	6.6	5.5	6.6	11.4	18.0	15.9	16.2	14.3	9.1	6.7	1.0	9.7
1847	1.9	2.5	5.4	6.4	11.1	13.1	16.6	14.6	10.7	9.5	7.6	4.9	8.7
1848	1.3	5.2	5.2	6.9	13.9	13.0	15.0	13.1	12.3	8.9	5.3	4.4	8.7
1849	3.7	5.8	5.9	5.8	10.4	12.1	14.3	14.8	12.3	7.9	5.9	4.0	8.6

Appendix D – Selected Monthly Mean Temperatures

Monthly Mean Temperatures appear here where large tables would disrupt the main text. Data are presented in the order in which they are analysed in the text. Where means are missing for any month, the corresponding annual mean is not given.

Table D.1 Monthly mean temperature for York (°F) 1831-1843

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1831	34.0	39.0	43.5	48.0	50.2	60.0	62.5	61.5	57.0	52.5	41.0	43.5	49.4
1832	37.0	38.8	43.5	47.8	52.3	60.5	61.2	59.8	57.4	50.1	40.5	41.3	49.2
1833	34.0	42.3	38.1	45.1	58.7	59.4	62.8	57.1	53.5	49.9	43.1	42.5	48.9
1834	42.3	40.9	43.4	44.3	54.5	60.1	62.9	60.3	56.2	49.0	46.3	42.2	50.2
1835	35.3	41.5	41.1	45.2	51.0	57.7	60.6	61.5	54.5	45.9	42.6	36.3	47.8
1836	37.4	37.7	40.9	43.5	50.4	59.6	59.7	56.8	50.3	45.4	40.3	38.5	46.7
1837	34.1	39.1	35.2	39.2	46.9	60.0	61.5	58.8	55.0	49.9	39.6	40.1	46.6
1838	28.5	30.8	41.1	42.3	50.1	57.9	61.3	59.1	54.4	48.6	38.6	37.4	45.8
1839	36.2	38.8	38.6	44.6	49.6	56.3	60.6	57.9	53.8	47.8	43.7	37.1	47.1
1840	38.7	37.5	39.7	50.2	51.8	57.3	57.4	61.0	51.5	45.3	39.9	33.3	47.0
1841	32.4	36.1	45.9	46.3	54.9	55.2	57.4	59.3	53.9	46.7	39.5	38.2	47.2
1842	30.7	36.8	41.9	44.5	51.7	58.8	57.5	62.0	54.8	43.3	40.0	43.4	47.1
1843	37.1	33.9	40.4	46.0	49.0	54.2	58.7	58.9	57.4	45.3	41.2	43.3	47.1

Table D.2 Monthly mean temperature for Wykeham (°F) 1831-1837

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1831	33.2	36.2	42.2	46.8	51.2	59.3	62.4	63.3	56.2	54.5	40.7	41.8	49.0
1832	35.7	36.1	41.0	46.1	50.5	58.1	57.6	60.2	54.4	49.2	39.2	38.8	47.2
1833	33.7	38.0	35.4	42.8	57.0	57.6	58.3	56.2	51.3	47.9	41.4	41.7	46.8
1834	41.9	39.3	41.8	44.5	53.6	58.2	60.6	59.3	53.4	47.4	44.2	41.2	48.8
1835	33.9	39.8	39.2	43.8	49.2	56.2	59.1	60.4	52.7	44.7	42.6	35.7	46.4
1836	35.9	36.3	39.2	41.3	48.0	57.2	57.6	55.4	49.9	44.2	37.9	37.0	45.0
1837	33.2	38.3	35.1	39.3	49.6	61.2	60.6	58.9			37.7		

Table D.3 Monthly mean temperature for Allenheads (°F) 1839-1842

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1839	31.6	34.6	33.9	38.4	44.9	51.3	54.3	51.9	49.2	45.3	40.4	35.0	42.5
1840	34.9	33.8	36.8	45.8	46.1	50.7	51.1	56.6	46.1	43.0	38.6	33.8	43.1
1841	30.5	33.5	43.1	41.2	49.9	48.7	50.9	53.7	51.5	42.0	36.4	36.0	43.1
1842	30.5	35.8	38.2	43.7	49.4	54.2	53.3	58.4	50.6	42.9	37.1	42.9	44.7

Table D.4 Monthly mean temperature for Ackworth (°F) 1824-1841

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1824	39.5	39.4	40.4	44.9	50.5	56.3	62.4	59.6	56.6	48.5	43.8	40.5	48.5
1825	39.0	39.1	40.8	47.2	52.1	58.2	62.8	61.6	59.8	52.3	40.5	39.9	49.5
1826	32.3	42.8	41.8	50.0	51.2	64.0	64.7	64.9	56.9	51.8	40.8	41.8	50.2
1827	35.1	34.5	43.0	48.1	52.8	58.5	62.5	58.4	56.8	53.5	43.6	43.3	49.2
1828	40.1	41.0	44.1	46.9	53.4	60.1	61.4	59.7	56.7	50.0	45.0	44.7	50.3
1829	32.1	38.5	38.8	44.2	53.8	58.5	61.5	57.7	52.4	47.3	41.0	34.0	46.6
1830	32.0	36.3	46.2	48.5	51.1	55.0	61.6	56.9	53.7	51.2	43.9	34.6	47.6
1831	34.6	40.4	44.6	48.3	51.5	58.4	61.7	62.3	56.2	53.9	40.5	42.3	49.6
1832	37.1	38.1	43.0	46.4	51.1	58.7	59.3	59.1	56.2	51.2	40.2	40.9	48.4
1833	33.7	41.7	38.5	46.1	57.9	58.0	60.4	56.3	53.0	48.7	42.9	43.1	48.4
1834	43.5	42.1	44.3	45.2	53.8	58.8	62.0	60.2	55.8	48.9	45.1	41.4	50.1
1835	34.5	40.8	41.2	45.2	50.4	57.2	60.5	61.5	54.0	45.2	41.7	35.7	47.3
1836	36.5	36.2	39.8	41.9	49.2	58.9	59.1	56.9	53.2	47.5	39.8	39.5	46.5
1837	36.5	41.7	35.8	39.7	48.1	57.0	60.6	57.6	53.0	49.3	40.9	39.7	46.7
1838	29.5	30.3	41.4	42.8	48.2	57.5	60.3	59.2	53.0	50.1	39.2	38.1	45.8
1839	36.8	39.4	38.7	44.3	50.0	56.0	58.0	57.5	54.0	47.7	42.0	36.0	46.7
1840	37.0	38.4	39.8	49.9	51.4	57.3	57.0	60.5	51.5	45.7	41.5	34.5	47.0
1841	33.5	36.5	46.7	46.0	54.3	54.4	57.0	61.4	56.3	47.5	39.9	39.4	47.7

Table D.5 Monthly mean temperature for New Malton (°F) 1817-1825

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1817										44.1	45.5	34.0	
1818	34.2	34.4	39.0	43.0	52.2	62.4	65.0	59.3	55.1	52.3	46.8	35.9	48.3
1819	36.9	37.9	42.7	47.0	53.5	57.4	61.8	62.4	54.8	48.0	38.6	31.8	47.7
1820	30.5	37.1	39.8	48.2	53.0	57.4	59.6	58.3	53.2	46.0	39.8	39.9	46.9
1821	36.8	35.2	41.1	49.7	49.4	53.4	58.2	61.1	57.3	49.3	43.7	39.7	47.9
1822	38.7	40.7	44.5	46.6	53.8	61.6	60.0	59.7	53.6	49.2	43.9	34.5	48.9
1823	31.9	35.8	40.2	44.1	54.4	54.9	58.8	57.7	52.5	45.7	42.7	36.7	46.3
1824	36.0	38.5	38.5	45.1	51.1	56.4	62.4	59.5	56.1	47.4	42.5	38.7	47.7
1825	37.2	36.9	39.8	47.5	52.1	57.7	63.1	61.0	59.3	50.5	38.5	38.5	48.5

Table D.6 Monthly mean temperature for Brandsby (°F) 1811-1830

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1811	32.5	37.3	42.9	47.7	56.0	57.8	61.6	59.1	55.8	51.8	43.7	33.4	48.3
1812	35.0	39.8	37.4	40.7	50.5	54.8	56.1	57.6	54.3	47.6	40.7	37.9	46.0
1813	36.5	40.3	43.9	45.7	53.5	56.3	60.6	58.1	56.7	47.5			
1814							61.6	57.7	53.3	46.8	40.2	37.4	
1815	31.0	41.3	43.9	46.7	54.5	59.3	59.6		54.3	50.3	38.7	32.4	46.5
1816	34.0	33.3	37.4	43.2	50.5	55.3	58.6	55.9	54.9	48.5		33.9	
1817	36.5	40.8	39.9	44.2	48.5	60.3	59.6	58.1	56.3	44.8	45.2	33.4	47.3
1818	36.5	33.8	39.9	42.7			66.6	60.1	56.8	53.3	47.2	36.4	
1819	36.5	37.3	43.4	48.2	54.0	58.3	62.6	64.1	56.8	49.8	38.7	31.4	48.4
1820	31.0	37.3	40.9	48.2	54.0	58.8	60.1	60.1	53.3	46.3	40.7	39.9	47.6
1821	37.0	36.3	41.4	49.2	50.0	54.3	59.1	61.1	58.3	49.3	44.2	39.4	48.3
1822	38.5	40.8	43.4	46.2	54.0	60.8	60.1	60.1	53.8	50.3	44.7	34.4	48.9
1823	32.0	35.8	39.9	43.7	54.5	53.8	58.1	58.1	53.8	46.3	43.2	37.4	46.4
1824	38.0	39.3	39.9	45.2	51.5	57.8	62.1	60.6	56.8	48.8	42.2	37.9	48.3
1825	38.0	38.3	41.4	47.7	53.0	58.3	62.6	63.1	59.8	51.3	39.2	38.4	49.3
1826	32.0	41.3	41.9	48.2	53.0	63.8	65.6	64.6	56.8	51.3	39.7	40.4	49.9
1827	35.0	34.8	40.9	47.2	54.0	58.3	62.1	59.1	56.3	53.3	42.7	41.9	48.8
1828	39.0	40.3	43.9	46.7	54.5	61.8	61.6	60.6	57.8	49.8	45.2	43.4	50.4
1829	33.5	38.8	39.9	44.2	53.8	59.8	61.1	58.6	52.3	46.8	39.7	34.9	47.0
1830	33.5	35.3	45.4	48.2	52.5	55.3	63.1	58.1	53.8	50.3	42.7	34.9	47.8

Table D.7 Monthly mean temperature for South Cave (°F) 1794-1815

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1794	29.3	42.7	42.8								43.5	37.8	
1795	26.7	33.0	39.9	46.6	50.7	52.5	55.8	59.1	60.0	53.2	40.1	43.1	46.7
1796	44.0	40.0	40.4	50.9	48.1	53.9	56.7	58.0	57.8	44.6	38.8	30.3	47.0
1797	38.1	36.7	39.1	44.6	50.3	53.0	59.6	58.5	54.8	47.1	38.9	38.7	46.6
1798	36.9	37.1	41.4	50.3	54.0	60.3	58.6	60.0	56.4	49.9	40.9	33.7	48.3
1799	33.3	36.2	39.0	42.7	47.8	53.4	56.8	56.8	54.7	47.4	42.5	36.8	45.6
1800	35.9	36.5	40.2	49.9	53.7	53.4	61.3	61.9	57.4	47.7	40.6	38.5	48.1
1801	38.7	40.3	44.8	46.9	53.2	55.2	60.4	63.7			39.3	33.3	
1802	34.9	34.6	37.7	44.5	46.7	52.9	52.4	59.1		50.7	43.1	37.4	
1803	36.2	37.9	44.4	48.9	47.1	52.7	58.8	59.0	51.2	49.2	41.6	37.6	47.1
1804	41.5	39.2	40.9	43.0	51.7	54.8	59.6	59.2	58.4	52.8	43.9	39.2	48.7
1805	37.0	39.5	43.7	47.9	48.0	53.1		59.7	59.7	47.7	41.0	41.4	
1806	40.5	42.5	41.6	44.6	50.5	55.4	58.4	60.0	55.9	51.8	47.1	45.0	49.4
1807	36.4	38.8	36.3	44.2	50.5	54.2	60.7	62.6	51.0	51.8	39.2	36.4	46.8
1808	36.3	37.8	37.7	42.1	55.0	55.2			56.3	46.6	44.4	37.9	
1809	34.4	41.6	42.6	39.6	52.9	53.8	57.3	56.5	55.3	51.0	41.8	40.3	47.2
1810	35.7	38.8	40.5	45.6	46.5	56.5	57.9	58.9	57.8	51.0	44.9	39.8	47.8
1811	35.1	39.4	46.2	46.5	53.1	56.4		58.0	56.5	54.6	43.9	37.3	
1812	37.8	42.4	38.6	40.8	49.5	53.0	56.2	57.9	54.9	50.5	42.1	38.0	46.8
1813	37.4	42.9	44.0	45.6	50.3	53.9		56.6	54.6	48.7	41.4	39.0	
1814	29.4	34.9	37.4	48.4	46.7	50.6	59.6	57.6	54.4	48.4	42.9	41.7	46.0
1815	34.7												

Table D.8 Monthly mean temperature for Braithwaite (°F) 1799-1856

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1799										32.9	26.9	19.7	
1800	21.0	22.1	23.1	35.8	43.8	48.5	57.8	56.3	48.4	36.2	18.3	27.7	36.6
1801	36.0	39.5	40.9	44.3	52.7	57.6	60.1	63.3	54.8	48.6	38.9	34.0	47.6
1802	33.8	37.5	37.9	45.3	50.2	57.3	56.1	62.0	57.5	51.6	42.6	40.5	47.7
1803	36.7	38.0	40.9	48.3	50.5	57.2	64.8	60.8	54.0	49.6	40.8	39.1	48.4
1804	43.2	39.4	39.9	42.0	56.9	59.7	61.8	59.5	58.3	51.6	42.8	35.7	49.2
1805	36.0	39.4	43.0	45.6	49.9	55.3	62.1	61.5	58.4	49.1	42.8	38.8	48.5
1806	38.5	37.5	36.4	39.3	50.4	58.0	58.1	58.6	51.4	51.6	45.9	43.7	47.5
1807	39.5	40.5	37.0	43.5	53.8	56.0	62.1	62.9	50.5	51.9	37.9	37.0	47.7
1808	37.5	38.3	37.6	39.9	54.5	57.5	64.1	61.3	53.3	41.6	40.1	34.7	46.7
1809	31.2	40.9	39.8	40.0	55.0	56.1	59.8	58.6	54.0	49.6	38.9	38.6	46.9
1810	35.3	37.4	37.3	45.1	48.0	59.3	59.0	58.4	56.5	47.8	39.4	37.3	46.7
1811	31.8	37.4	42.3	46.0	53.3	57.1	61.8	58.1	54.7	51.3	43.4	36.3	47.8
1812	35.3	39.9	36.3	40.0	49.7	56.6	59.1	56.8	54.2	47.0	38.9	35.1	45.7
1813	33.3	40.4	42.5	44.5	51.0	55.3	60.0	56.6	53.2	44.5	37.4	36.8	46.3
1814	25.6	33.6	35.3	47.8	47.0	51.6	61.8	58.3	56.0	45.9	38.7	37.7	44.9
1815	30.2	40.9	41.9	45.0	52.6	57.4	59.2	58.7	53.5	47.9	37.7	33.7	46.6
1816	33.8	34.4	35.6	41.0	48.7	54.6	56.5	55.7	51.6	47.3	36.2	34.6	44.2
1817	37.2	40.1	39.3	44.5	47.3	58.3	56.7	54.6	54.7	42.8	45.0	33.6	46.2
1818	36.6	34.9	37.0	41.1	52.0	61.1	64.5	58.3	54.0	51.3	45.7	35.3	47.7
1819	36.3	36.4	40.9	46.0	51.0	55.3	61.0	62.8	55.0	47.3	37.2	32.6	46.8
1820	29.6	36.2	39.3	47.7	49.7	56.4	59.5	57.3	53.5	44.3	40.3	38.6	46.0
1821	35.3	34.4	39.5	47.1	48.0	52.8	57.7	58.3	56.2	48.8	42.2	39.7	46.7
1822	36.8	41.6	44.0	46.2	55.5	61.6	57.8	58.6	52.7	48.3	43.9	34.8	48.5
1823	30.0	34.3	39.0	42.1	52.1	54.7	56.6	56.7	53.6	45.4	43.1	37.7	45.4

1824	36.6	37.8	38.7	44.9	49.9	56.3	60.7	58.5	55.7	47.0	41.1	38.8	47.2
1825	36.3	37.9	39.7	46.9	50.9	57.1	64.2	59.8	57.9	49.3	37.9	38.1	48.0
1826	30.3	40.9	40.2	47.4	53.7	65.8	63.9	61.8	55.2	49.7	37.9	40.0	48.9
1827	33.3	33.1	39.7	45.2	51.7	57.0	61.7	58.1	54.0	50.5	41.4	41.5	47.3
1828	37.8	39.1	41.7	44.2	52.7	59.0	59.4	58.8	55.4	49.0	42.6	43.1	48.6
1829	31.0	37.9	37.7	42.2	52.2	58.5	59.7	56.8	52.4	46.0	37.9	34.0	45.5
1830	29.8	34.1	41.7	46.2	50.7	54.0	61.4	55.8	51.9	49.0	40.9	33.3	45.7
1831	32.0	38.1	41.7	46.4	51.4	59.3	62.2	62.3	54.7	52.0	38.9	41.3	48.4
1832	36.0	37.3	40.5	45.9	51.2	58.1	60.2	57.5	56.2	49.3	37.9	37.8	47.3
1833	32.8	38.6	36.7	45.7	58.7	56.0	59.9	57.1	52.9	47.7	40.4	40.1	47.2
1834	40.3	39.3	42.3	44.9	52.7	57.8	61.2	61.5	55.4	49.7	41.1	41.0	48.9
1835	34.3	39.1	39.3	46.4	49.2	59.1	59.9	62.5	54.4	45.3	40.9	37.3	47.3
1836	35.8	36.6	38.3	43.2	52.4	57.3	58.4	56.8	50.9	45.0	38.4	36.0	45.8
1837	34.3	37.9	34.3	39.7	48.9	59.0	61.2	58.5	52.7	49.0	37.7	39.0	46.0
1838	26.6	29.3	38.7	40.9	49.0	55.0	59.2	57.8	54.7	48.2	36.7	37.0	44.4
1839	33.6	36.8	36.0	41.9	50.2	53.8	58.4	57.1	52.7	47.0	42.1	36.3	45.5
1840	36.3	35.8	38.5	48.9	49.4	55.5	56.2	60.3	49.7	45.0	39.1	33.8	45.7
1841	31.5	34.8	44.0	45.2	53.2	54.0	57.4	57.8	54.7	45.0	38.1	37.8	46.1
1842	30.3	36.3	40.7	46.2	51.9	59.5	58.2	61.5	55.7	44.2	38.4	44.3	47.3
1843	36.3	32.6	39.3	45.5	48.7	54.8	59.2	60.1	58.7	44.2	38.6	43.8	46.8
1844	37.8	33.3	39.0	49.4	52.4	56.8	59.7	56.5	55.0	46.3	41.7	31.3	46.6
1845	35.5	31.8	34.7	45.9	48.9	58.5	57.4	56.5	52.4	48.2	41.9	36.8	45.7
1846	40.0	41.8	40.7	43.4	53.4	66.0	60.9	61.8	58.7	47.3	42.4	32.3	49.1
1847	32.5	34.3	40.0	43.9	51.2	57.8	64.7	59.1	51.7	47.2	44.1	38.5	47.1
1848	32.0	39.8	39.0	45.7	58.2	55.5	59.7	56.0	54.7	47.2	39.4	39.0	47.2
1849	35.5	40.6	40.5	42.5	51.4	57.1	58.9	59.0	54.4	45.7	40.4	35.8	46.8
1850	31.0	41.6	40.0	45.4	48.7	58.8	59.7	58.0	52.7	44.7	42.4	38.1	46.8
1851	38.5	38.6	40.0	44.4	50.7	56.3	57.9	57.8	54.4	48.5	35.9	39.5	46.9

1852	37.3	38.6	39.7	46.5	50.2	54.5	65.9	60.3	54.2	43.7	41.1	42.8	47.9
1853	37.3	31.3	36.7	44.2	50.7	57.8	57.9	58.5	53.4	48.3	40.4	34.0	45.9
1854	34.5	38.3	43.3	47.9	49.9	54.5	59.7	60.1	58.0	48.7	39.1	38.1	47.7
1855	34.5	26.9	37.0	45.7	46.7	56.5	61.4	60.8	55.7	48.2	40.1	33.5	45.6
1856	36.0	39.6	38.2	44.9	47.4	54.5	55.9	60.5	52.7	50.2	39.1	38.5	46.5

Table D.9 Monthly mean temperature for Brandsby (°F) 1783-1791

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
1783												19.4	
1784	29.2	31.6	36.2	41.2	54.9	53.3	57.0	55.5	56.0	44.6	38.5	31.5	44.1
1785	35.8	30.0	35.5	46.8	49.6	59.1	60.4	55.9	53.0	45.0	37.7	33.9	45.2
1786	32.6	34.2	33.6	44.4	50.5	58.7	58.4	58.1	49.5	42.6	36.5	34.0	44.4
1787	35.6	39.1	42.1	42.0	48.9	52.2	58.0	57.2	52.1	46.5	36.3	35.9	45.5
1788	35.7	35.3	35.6		54.4	56.5	59.9	57.3	54.5	46.0	38.5	29.3	
1789	34.5	38.8	33.2	42.9	52.2	54.9	57.4	58.8	53.1	45.2	36.8	38.9	45.6
1790	34.5	40.5	41.0	40.7	51.3	56.8		58.8	49.3	46.6	39.6	34.9	
1791	36.5	36.5	40.8	46.4		55.8	59.8	61.7	54.9				

Appendix E – Maps Showing Location of Sites of Observation

The maps in this section show the relative locations of the contemporary and historic sites as introduced in chapters 4 and 5. The width of each map is 15 km. The historic site is marked with a black circle, and the modern site with a red circle.

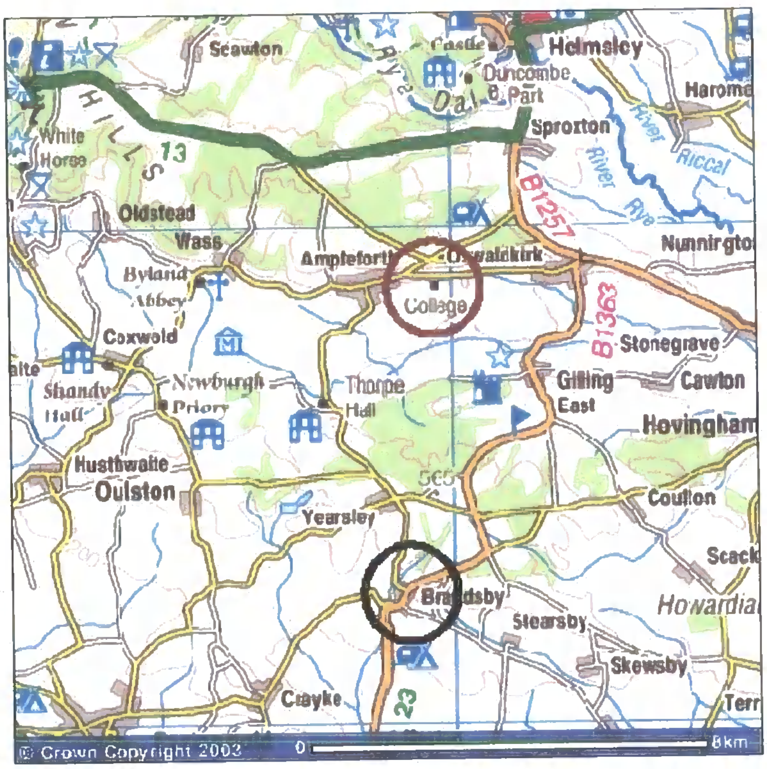


Figure E.1 Ampleforth and Brandsby

Ampleforth is 70.8 km SSE of Durham.

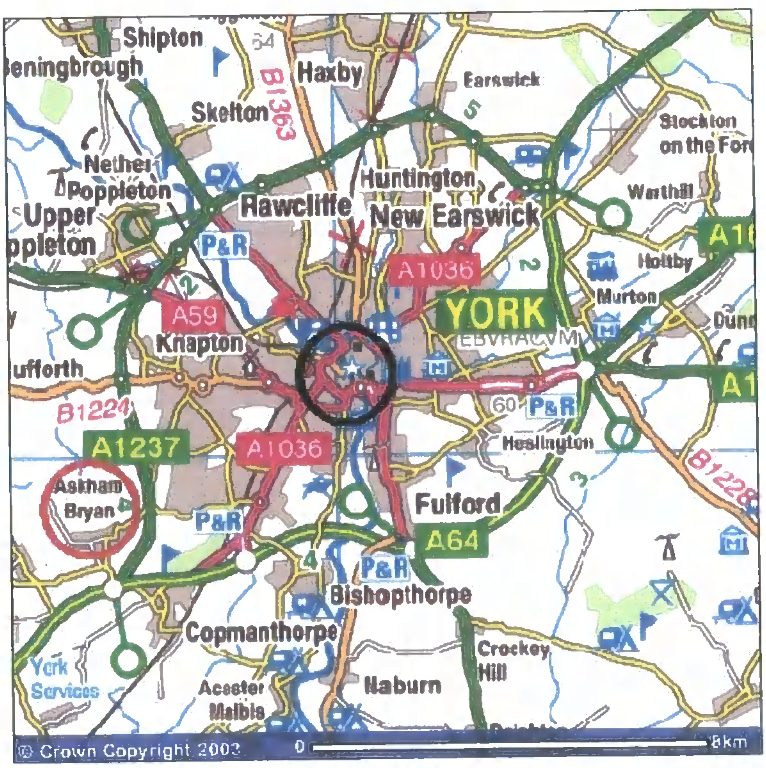


Figure E.2 Askham Bryan and York

Askham Bryan is 98 km SSE of Durham.

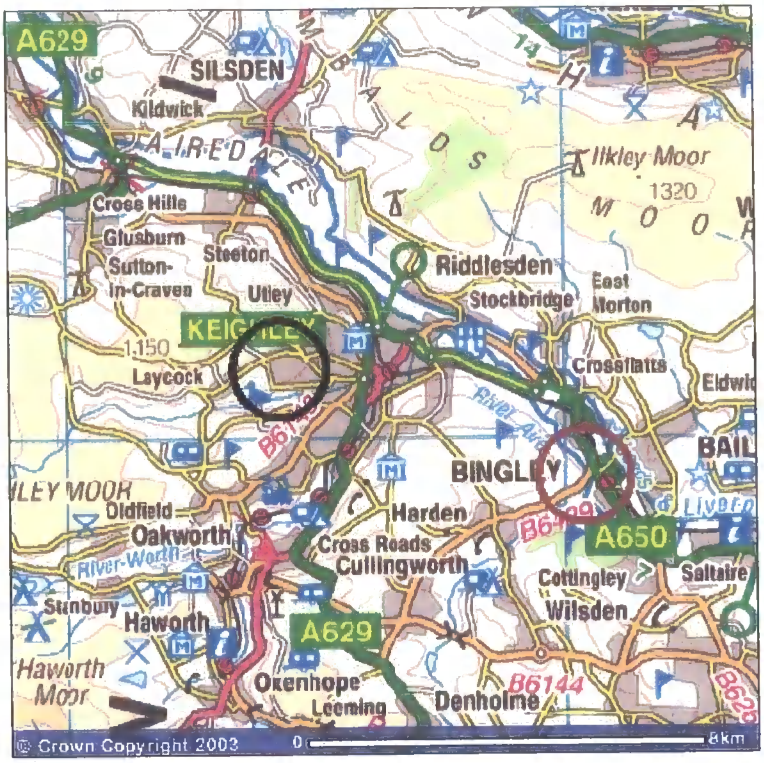


Figure E.3 Bingley Samos and Braithwaite

Bingley Samos is 108 km S of Durham.

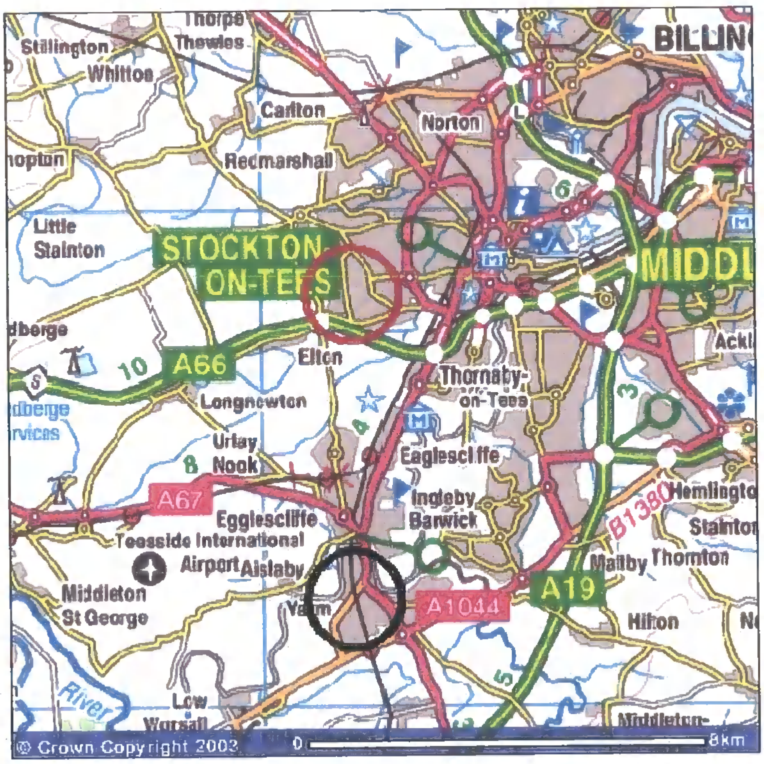


Figure E.4 Hartburn Grange and Yarm

Hartburn Grange is 26.9 km SSE of Durham.

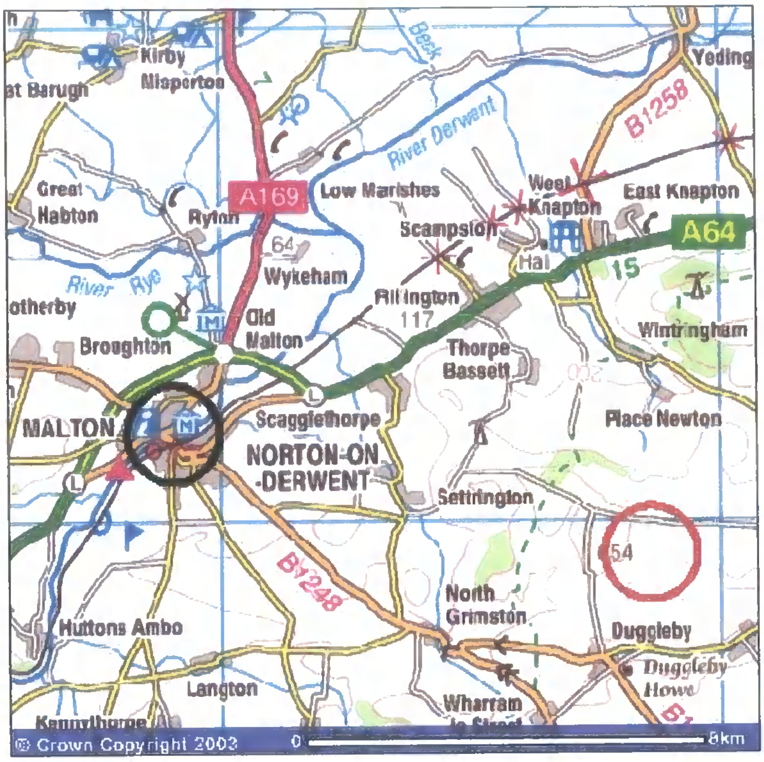


Figure E.5 High Mowthorpe and New Malton

High Mowthorpe is 95.8 km SE of Durham.

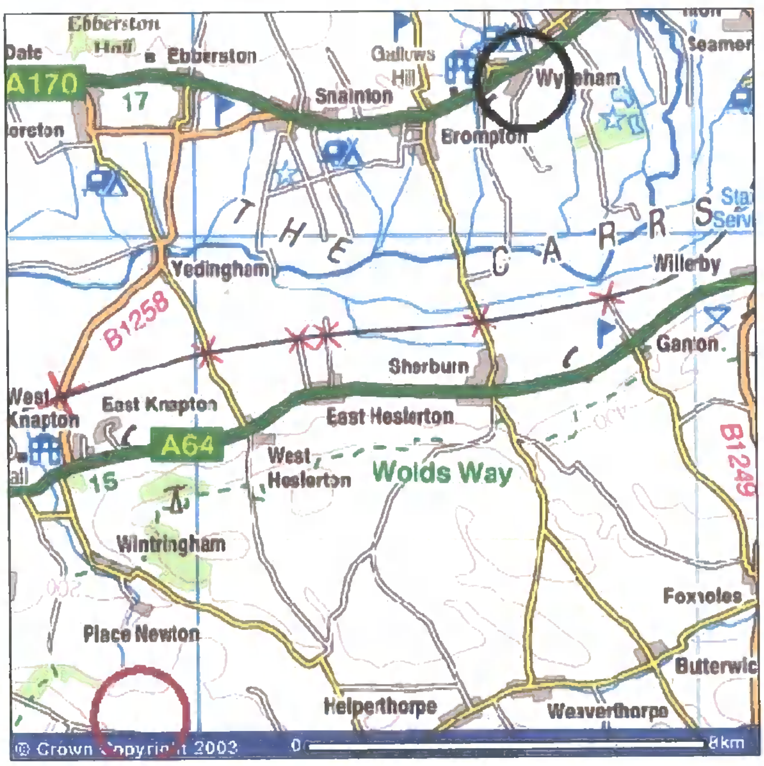


Figure E.6 High Mowthorpe and Wykeham

High Mowthorpe is 95.8 km SE of Durham.

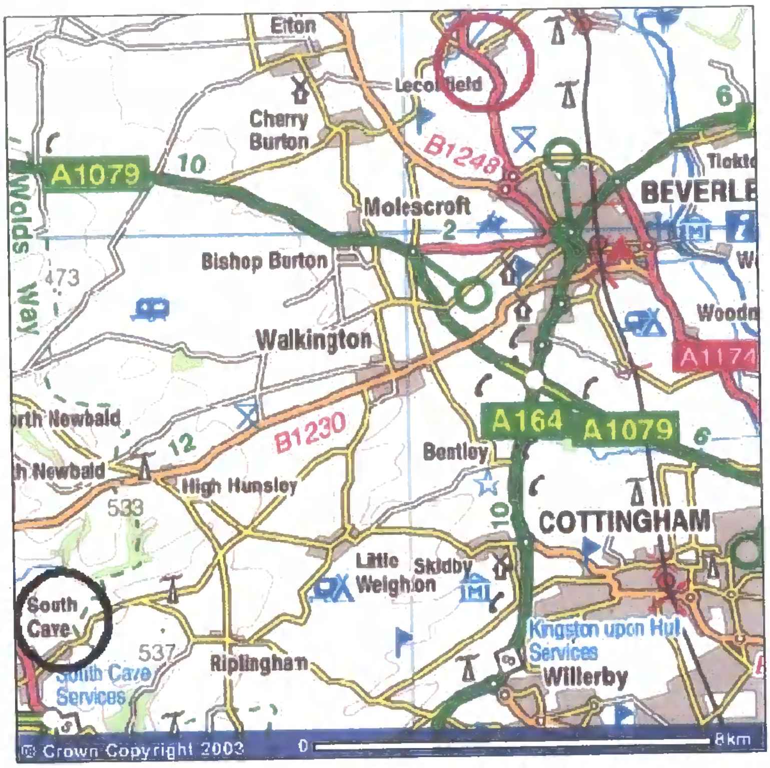


Figure E.7 Leconfield and South Cave

Leconfield is 124.8 km SE of Durham.

Figure E.8 Newcastle upon Tyne and Jesmond

Newcastle upon Tyne is 23.3 km N of Durham.

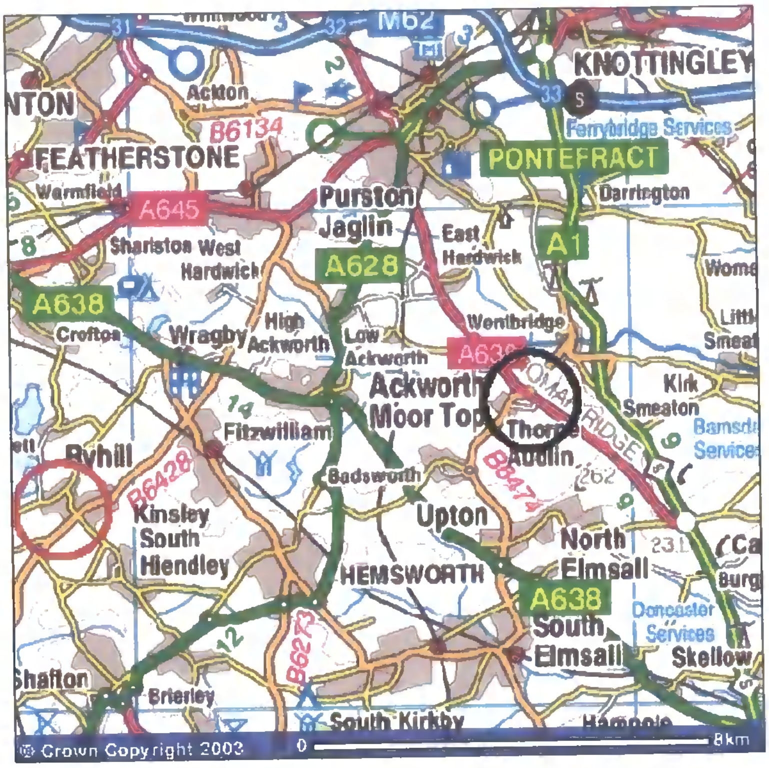


Figure E.9 Ryhill and Ackworth

Ryhill is 127.4 km S of Durham.

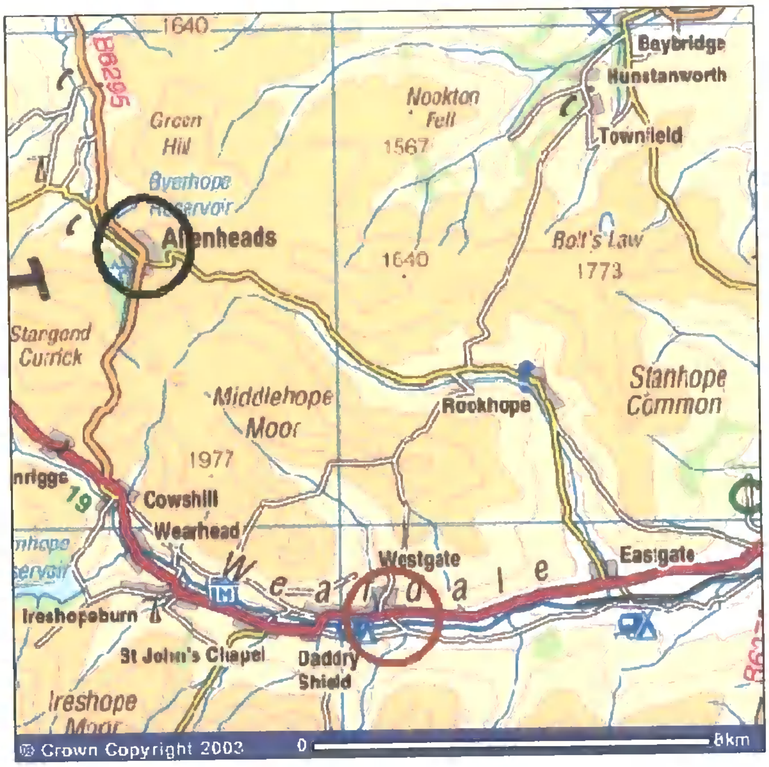


Figure E.10 Westgate and Allenheads

Westgate is 35.3 km W of Durham.

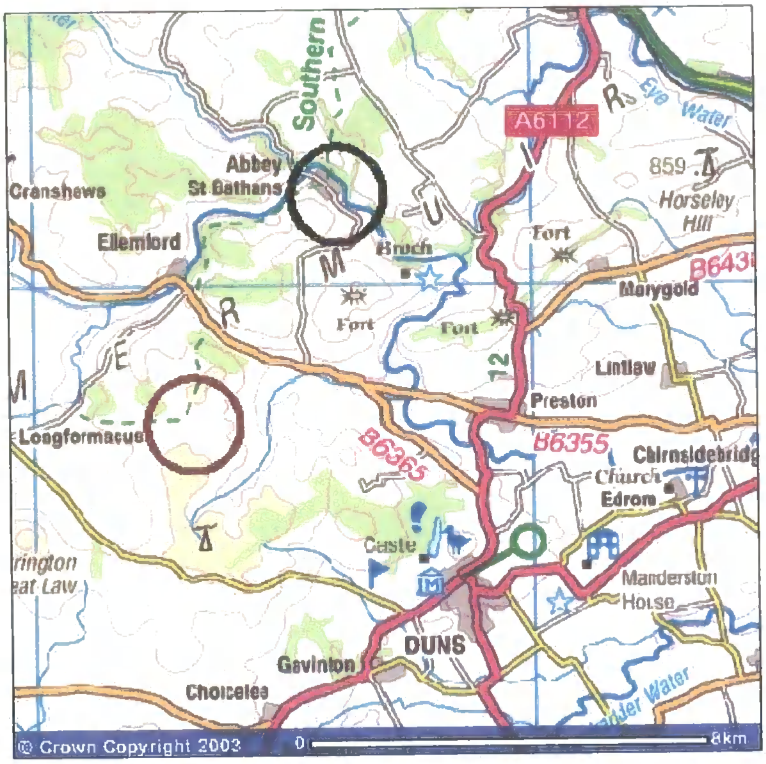


Figure E.11 Whitchester and Abbey St. Bathans

Whitchester is 129.5 km NNW of Durham.

References

Alexandersson, H. 1986. A Homogeneity Test Applied to Precipitation Data. *International Journal of Climatology* **6**, 661-675.

Alexandersson, H. and Moberg, A. 1997. Homogenisation of Swedish Temperature Data. Part I: Homogeneity Test for Linear Trends. *International Journal of Climatology* **17**, 25-34.

Baines, W. 1971. Meteorology – the first fifty years. In *Annual Reports of the Yorkshire Philosophical Society*, 1971 pp74-78

Barnard, H.B. 1794-1815, *A register of the barometer, thermometer, wind, seasons etc., kept at Cave Castle 1794 –1815*. Hull City Library, Local Studies section. Manuscript 1794-1815; microfilm 1794-1804.

Bärring, L. *et al.* 1999. The Lund Instrumental Record of Meteorological Observations: Reconstruction of Monthly Sea-Level Pressure 1780-1997. *International Journal of Climatology* **19**, 1427-1443.

Baxter, E. F. 1937. The Observatory. In *The University of Durham*, 1937. Whiting, C. E. (ed.), 59-64. Durham: Centenary Committee of the University of Durham.

Baxter, E. F. 1956. Durham University Observatory. *Weather* **11**, 218-212.

Bootham, 2002. School History, Bootham School, York, England. http://www.bootham.york.sch.uk/history (accessed January 2002)

Bulmer 1890. *History, Topography and Directory of North Yorkshire*. Preston: T. Bulmer & Co.

Butler, C. J. & Johnston, D. J. 1996. A Provisional Long Mean Air Temperature Series for Armagh Observatory. *Journal of Atmospheric and Terrestrial Physics* **58**, 1657-.

Camuffo, D. 2002. History of the Long Series of Daily Air Temperature in Padova (1725-1998). *Climatic Change* **53**, 7-75.

Cholmeley, F. 1783-. *Cholmeley of Brandsby archive: weather records 1783-1830*. North Yorkshire County Archives, catalogue references ZQGX to ZQGX 8

Cholmeley, F. 1811-. *Air temperature at Brandsby from 1811 to 1830.* North Yorkshire County Archives, catalogue reference ZQGX 12

Clarke, J. E. 1891. 50 years of York Meteorology. In *Annual Reports of the Yorkshire Philosophical Society*, 1891 pp43-76

Cobb, W. 1989. *A History of the Grays of York, 1695-1988.* York: William Sessions.

Craddock, J. M. 1979. Methods of Comparing Annual Rainfall Records for Climatic Purposes. *Weather* **34**, 332-345.

Craddock, J. M. 1980. comments made in Lamb, H. H. 1981. The life and work of Professor Gordon Manley (1902-1980). *Weather* **36**, 220-231.

DeGaetano, A. T., Eggleston, K. L. and Knapp, W. W. 1995, A Method to Estimate Missing Daily Maximum and Minimum Temperature Observations. *Journal of Applied Meteorology* **34**, 371-380.

Defra (Department for Environment, Food and Rural Affairs) 2000. Appendix A1 North East Regional Chapter. In *England Rural Development Programme 2000-2006.* London: Defra Publications.

Dove, H. W. 1838, Über die Geographische Verbreitung Gleichartiger Witterungerscheidungen. Über die Nicht Periodischen Änderungen der Temperaturvertheilung. Zweite Abhandlung. *Abhandl. K. Akad. Wissensch.* Berlin. (In National Meteorological Library, Bracknell).

Dove, H. W. 1853, *The Distribution of Heat Over The Surface of the Globe, Illustrated by Isothermal, Thermic Isabnormal, and Other Curves of Temperature.* (English translation of Dove 1838, printed for the British Association for the Advancement of Science, London. Available in the library of The Royal Society, London).

Downton, M. and Katz, R. 1993. A Test for Inhomogeneous Variance in Time-averaged Temperature Data. *Journal of Climate* **6**, 2448-2464.

Durham University 1843- , *Meteorological Observations, 23 July 1843 – 31 December 1847*, Durham University Library Archives and Special Collections OBS II Meteorological Records M1.

Durham University 1848- , *Meteorological Observations , 1 January 1848 - 30 April 1850*, Durham University Library Archives and Special Collections OBS II Meteorological Records M2.

Eischeid, J. K., Pasteris, P. A., Diaz, H. F., Plantico, M. S. and Lott, N. J. 2000, Creating a Serially Complete, National Daily Time Series of Temperature and Precipitation for the Western United States. *Journal of Applied Meteorology* **39,** 1580-1591.

Evans, F. 1967. Local Sea Fogs on the Northumberland Coast. *Proceedings of the University of Newcastle upon Tyne Philosophical Society* **1**, 162-169.

FENSCORE, 2002. http://fenscore.man.ac.uk (accessed March 2002)

Ford, J. 1831-. York City Archives, transcription by William Baines of readings by John Ford at Bootham School

Gaster, F. 1882. Report on Experiments Made at Strathfield Turgiss in 1869 with Stands or Screens of Various Patterns, Devised and Employed for the Exposing of Thermometers, in Order to Determine the Temperature of the Air. *Appendix II to Quarterly Weather Report for 1879*, 13-39. London: Meteorological Office.

Gray, E. 1927, *Papers and diaries of a York family*. London: SPCK.

Glaisher. J. 1848a, Remarks on the Weather During the Quarter Ending December 31st 1847. *Philosophical Magazine*. **32**, 130-7.

Glaisher. J. 1848b. On the Corrections to be Applied to Meteorological Observations. *Philosophical Transactions of the Royal Society* Part I, 125-139

Glaisher, J. 1849, *Philosophical Transactions of the Royal Society* **138**, 307

Glaisher, J. 1850, *Philosophical Transactions of the Royal Society* **139**, 569

Glaisher, J. 1867. *Diurnal Range Tables, newly arranged, containing corrections for temperature* etc (4th edition). London: Taylor and Francis

Hastings, D. 1740-, *Papers relating to the Royal Society (ffs 73-90v & 198-227v).* British Museum, catalogue reference MSS/BIRCH COLL.4438/PS.1003

Heidorn, K. C. 2002. *Luke Howard: The man who named the clouds.* http://www.islandnet.com/~see/weather/history/howard.htm (accessed January 2002)

Howard, L. 1823. Description of Instruments and Methods of Observations at Tottenham, 1815-23. Catalogue reference MC.3.101 at the library of The Royal Society, London.

Howard, L. 1842a. *A Cycle of 18 Years in the Seasons of Britain, Deduced from Meteorological Observations made at Ackworth in the West Riding of Yorkshire, 1824 to 1841.* London: James Ridgway. Catalogue reference 45197 (accession number) at the library of The Royal Society, London.

Howard, L. 1842b. *Monthly means of barometer and thermometer at Ackworth School, 1842*, catalogue reference MA.116 at the library of The Royal Society, London

Hughes, E. 1962. *The Diaries and Correspondence of James Losh, volume 1.* The Publications of the Surtees Society **171**. Durham: Surtees Society

Hughes, E. 1963. *The Diaries and Correspondence of James Losh, volume 1.* The Publications of the Surtees Society **174**. Durham: Surtees Society

IPCC (Intergovernmental Panel on Climate Change) 2001, Climate Change 2001: The Scientific Basis, WMO: Geneva

Jeffreys, H. 1939. *Theory of Probability.* Oxford University Press

Jenkinson, A. F. and Carr, D. 1979. *A Daily Catalogue of Central England Temperatures, 1814 to 1978.* Meteorological Office Synoptic Climatology Branch Memorandum No. 71. (Unpublished, National Meteorological Library and Archive, Bracknell)

Jones, P. D. and Bradley, R. S. 1992. Variations in the Longest Instrumental Records. In *Climate Since AD. 1500*, Bradley, R. S. and Jones, P. D. (eds.), 246-268, London: Routledge.

Jones, P. D. *et al.* 1999. Monthly Mean Pressure Reconstructions for Europe for the 1780-1995 Period. *International Journal of Climatology* **19**, 347-364.

Joyce, A. N. 1996. *Re-Creation of Manley's Adopted Means.* Report on Project Progress, October 7th 1996, University of Durham unpublished memorandum.

Jurin, J. 1723. *Philosophical Transactions of The Royal Society* **32**, 422-427

Kemp, W. P., Burnell, D. G., Everson, D. O., Thomson, A. J. 1983. Estimating Missing Daily Maximum and Minimum Temperatures. *Journal of Applied Meteorology* **22**, 1587-1593.

Kenworthy, J. M. 1985. The Durham University Observatory record and Gordon Manley's work on a longer temperature series for north-east England. In *The Climatic Scene*, Tooley, M. J. and Sheail, G. M. (eds.), 279-85, London: George Allen & Unwin.

Kenworthy, J. M., Cox, N. J. and Joyce, A. N. 1997. Computerisation and Analysis of the Durham Observatory Meteorological Record. *Final Report to the Leverhulme Trust*, Reference F/128/Q.

Kington, J. A. 1978. Historical Daily Synoptic Weather Maps from the 1780s. *Journal of Meteorology* **3**, 65-71.

Kington, J. A. 1997. Observing and Measuring the Weather: A Brief History. *In Climates of the British Isles Past Present and Future*, Hulme, M. and Barrow, E. (eds.), 137-152, London: Routledge.

Kington, J. A. 2000. The Loss of HMS Invincible and Reconstructed Weather Pattern, 15-17 March 1802. *Weather* **55**, 199-205.

Labrijn, A. 1946. Climate of Holland in the Past Two–and-a-Half Centuries. *Med. Verh. K. Ned. Met. Inst. Utrecht* **49**.

Lamb, H. H. 1981. The life and work of Professor Gordon Manley (1902-1980). *Weather* **36**, 220-231.

Lamb, H. H. 1995. *Climate, History and the Modern World*, (2nd edition), London: Routledge.

Lanzante, J. R. 1996. Resistant, robust and non-parametric techniques for the analysis of climate data: theory and examples, including applications to historical radiosonde station data. *International Journal of Climatology* **16**, 1197-1226.

Leite, S. M. and Peixoto, J. P. 1996. The Autoregressive Model of Climatological Time Series: An Application to the Longest Time Series in Portugal. *International Journal of Climatology* **16**, 1165-1173

Linacre, E. 1992. *Climate Data and Resources: A Reference and Guide,* London: Routledge.

Losh, J. 1802-. *Meteorological observations, made by James Losh, at Jesmond Grove, in the years 1802 to 1833*, volumes 1 to 6. Library of the Newcastle upon Tyne Literary and Philosophical Society

Manley, G. 1931. Some notes on the maps of the county of Durham in the University Library. *Durham University Journal* **27**(2), 127-33.

Manley, G. 1932a. The weather of the High Pennines. *Durham University Journal* **28**(1), 31-2.

Manley, G. 1932b. Meteorological records from the northern Pennines. *Meteorological Magazine* **67**, 206-8.

Manley, G. 1933a. Notes on the weather in Upper Teesdale, 1933. *Durham University Journal* **28**(4), 304-7.

Manley, G. 1933b. Further records from the northern Pennines. *Meteorological Magazine* **68**, 180-81.

Manley, G. 1934a. Saxton's survey of northern England. *Geog. Journal* **83**, 308-16.

Manley, G. 1934b. The Plancius map of England, Wales and Ireland, 1592. *Geog. Journal* **83**, 252-3.

Manley, G. 1936c. The earliest extant map of the County of Durham. *Trans. Arch. Antiq. Soc. Durham* **7**, 278-87.

Manley, G. 1937c. Systematic records of British snowfall. *Meteorological Magazine* **72**, 231-2.

Manley, G. 1938-. G. Manley Papers, Box 3 Durham, Box 6 North East England, Pennines, Yorkshire and Derbyshire, *Cambridge University MSS*, ADD 8386. Six boxes of written material: the contents have been roughly sorted.[100]

Manley, G. 1939a. On the occurrence of snow-cover in Great Britain. *Quarterly Journal of the Royal Meteorological Society* **65**, 2-24.

Manley, G. 1939b. The helm wind of Crossfell. *Nature* **143**, 377.

Manley, G. 1941a. Observations of snow-cover on the British Mountains. *Quarterly Journal of the Royal Meteorological Society* **67**, 1-4.

Manley, G. 1941b. The Durham meteorological record 1847-1940. *Quarterly Journal of the Royal Meteorological Society* **67**, 363-80.

Manley, G. 1944. John Dalton: 1766-1844. *Quarterly Journal of the Royal Meteorological Society* 70, 235-9.

[100] The use of the cited date of 1938 is approximate. The material in boxes 3 and 6 that relate to Durham covers a wide range of dates.

Manley, G. 1946. Temperature trend in Lancashire, 1735-1945. *Quarterly Journal of the Royal Meteorological Society* **72**, 1-13.

Manley, G. 1952a. *Climate and the British Scene*. London: Collins/Fontana.

Manley, G. 1952b. Thomas Barker's meteorological journals, 1748-63 and 1777-89. *Quarterly Journal of the Royal Meteorological Society* **78**, 255-9.

Manley, G. 1953. The mean temperature of central England, 1698-1952. *Quarterly Journal of the Royal Meteorological Society* **79**, 242-61.

Manley, G. 1955. Constantia Orlebar's weather book 1786-1808. *Quarterly Journal of the Royal Meteorological Society* **81**, 622-5.

Manley, G. 1961. A preliminary note on early meteorological observations in the London region, 1680-1717, with estimates of the monthly mean temperature, 1680-1706. *Meteorological Magazine* **90**, 303-10.

Manley, G. 1968. Dalton's accomplishment in meteorology. In *John Dalton and the progress of science*, Cardwell, D. S. L. (ed.), 140-58, Manchester: Manchester University Press.

Manley, G. 1969a. *Corrected temperature data 1771-1798 at Lyndon in Rutland, taken from Thomas Barker's observations*. National Meteorological Library, Bracknell (unpublished).

Manley, G. 1974. Central England temperatures; monthly means 1659-1973. *Quarterly Journal of the Royal Meteorological Society* **100**, 389-405.

Manley, G. 1978-. Letters sent from Gordon Manley to Miss Joan Kenworthy, 1978-1979. Durham University Library Archives and Special Collections, Add MS 851

Manley, G. 1980. The Northern Pennines Revisited: Moor House, 1932-1978. *Meteorological Magazine* **109**, 281-292.

Manley, G. 1981. The use of archives and written records in meteorological research. *Archives* **15**(65), 3-10.

Margary, I. D. 1924. Glaisher Stand Versus Stevenson Screen. A Comparison of Forty Years' Observations of Maximum and Minimum Temperature as Recorded in Both Screens at Camden Square, London. *Quarterly Journal of the Royal Meteorological Society* **59**, 209-226.

Maugeri, M., Buffoni, L., Chlistovsky F. 2002. Daily Milan Temperature and Pressure Series (1763-1998): History of the Observations and Data and Metadata Recovery. *Climatic Change* **53**, 101-117.

Mawley, E. 1884. Shade Temperature. *Quarterly Journal of the Royal Meteorological Society* **23**, 69-87.

Middleton, W.E. Knowles. 1966. *A History of the Thermometer and its Use in Meteorology.* Baltimore: John Hopkins.

Miles, H. 1747. *Philosophical Transactions of The Royal Society* **44**, 613-616.

Mossman, R. C. 1896. The meteorology of Edinburgh, Part I. *Transactions of The Royal Society of Edinburgh.* **38**, 681-756.

Mossman, R. C. 1897. The meteorology of Edinburgh, Part II. *Transactions of The Royal Society of Edinburgh.* **39**, 63-207.

Mossman, R. C. 1902. The meteorology of Edinburgh, Part III. *Transactions of The Royal Society of Edinburgh.* **40**, 469-509.

Newhall, C. G., and Self, S. 1992. The Volcanic Explosivity Index (VEI): an estimate of explosive magnitude for historical volcanism. *Journal of Geophysical Research.* **87**, C2, 1231-1238.

Parker, D. E., Legg, T. P. and Folland, C. K. 1992. A new daily central England temperature series, 1772-1991. *International Journal of Climatology.* **12**, 317-342.

Parker, D. E. 1994. Effects of Changing Exposure of the Thermometers at Land Stations. *International Journal of Climatology* **14**, 1-31.

Pepin, N. 2001. Lapse rate changes in northern England. *Theoretical and Applied Climatology.* **68**, 1-16.

Pickering, R. 1744. *Philosophical Transactions of The Royal Society* **43**, 1-17.

Plummer, J. J.(sic.) 1873. On Some Results of Temperature Observations at Durham. *Quarterly Journal of The Meteorological Society* **1**, 241-246.

Rochester, G. D. 1980. The history of astronomy in the University of Durham from 1835 to 1939. *Q. J. R. Astron. Soc.* **21**, 369-78.

Shackleton, A. 1799-, *Meteorological Observations.* Cliffe Castle Museum, Keighley, West Yorkshire.

Sheail, G. M., Kenworthy, J. M. and Tooley, M. J. 1985. Bibliography of papers by Professor Gordon Manley. In *The Climatic Scene*, Tooley, M. J. and Sheail, G. M. (eds.), 279-85, London: George Allen & Unwin.

Siegel, S. and Castellan, N. 1988. *Nonparametric Statistics for the Behavioural Sciences*, New York: McGraw Hill.

Slonosky, V. C., Jones, P. D. and Davies, T. D. 2001. Instrumental Pressure Observations and Atmospheric Circulation from the 17th and 18th Centuries: London and Paris. *International Journal of Climatology* **21**, 269-284.

Smith, J. 1996. *James Losh: his ideas in relation to his circle and his time.* Newcastle: Northumbria University (Ph.D. thesis)

Tebbutt, A. E. 1994. *Two York Families c.1780-c.1850.* Leeds: University College of Ripon and York St. John (B.A./B.Ed. thesis)

Tooley, M. J. 1993. Further papers of Professor Gordon Manley. *Weather* **48**(12), 428-9.

Tooley, M. J. and Sheail, G. M. 1985. The life and work of Gordon Manley. In *The Climatic Scene*, Tooley, M. J. and Sheail, G. M. (eds.), 1-16, London: George Allen & Unwin.

Trewin, B. C. and Trevitt, C. F. 1996. The Development of Composite Temperature Records. *International Journal of Climatology* **16**, 1227-1242.

Valero, F. *et al.* 1996. A Method for the Reconstruction and Temporal Extension of Climatological Time Series. *International Journal of Climatology* **16**, 213-227.

Wallace, J. G. 1997, *Meteorological Observations at the Radcliffe Observatory, Oxford: 1815-1995.*

Wallace, Revd. J. 1835, Summaries of Observations of the Barometer, Thermometer &c. at the Manse of the Parish of Abbey St. Bathans, Berwickshire. *Transactions of the Berwickshire Naturalists' Club*, p126

Wallace, Revd. J. 1836, Summaries of Observations of the Barometer, Thermometer &c. at the Manse of the Parish of Abbey St. Bathans, Berwickshire. *Transactions of the Berwickshire Naturalists' Club*, p159

Wallace, Revd. J. 1837, Summaries of Observations of the Barometer, Thermometer &c. at the Manse of the Parish of Abbey St. Bathans, Berwickshire. *Transactions of the Berwickshire Naturalists' Club*, p169

Wallace, Revd. J. 1838, Summaries of Observations of the Barometer, Thermometer &c. at the Manse of the Parish of Abbey St. Bathans, Berwickshire. *Transactions of the Berwickshire Naturalists' Club*, p194

Walton, W. 1836a, Library of the Royal Society, catalogue reference AP.20.18 *Daily meteorological observations at Allenheads near Hexham, 1^{st} January to 29^{th} February 1836*

Walton, W. 1836b, Library of the Royal Society, catalogue reference AP.21.11 *Daily meteorological observations at Allenheads near Hexham, 1^{st} May to 31^{st} October 1836*

Walton, W. 1840a, Library of the Royal Society, catalogue reference AP.23.42 *Daily meteorological observations at Allenheads near Hexham, January to December 1839*

Walton, W. 1840b, Library of the Royal Society, catalogue reference MA.113 *Daily meteorological observations at Allenheads near Hexham, January to December 1840* (also contains abstracts for 1837, 1840 and 1842)

Walton, W. 1841, Library of the Royal Society, catalogue reference AP.25.21 *Daily meteorological observations at Allenheads near Hexham, January to December 1841*

Wheeler, D. 1984, The July 1983 'Heatwave' in North-East England. *Weather* **39**, 178-181.

Wheeler, D. 1997, North-East England and Yorkshire. In *Regional Climates of the British Isles*, Wheeler, D. and Mayes, J. (eds.), 158-179, London: Routledge.

Wheeler, D. 2002, A Century of Weather in Sunderland. *Weather* **57**, 91-99.

Wheeler, D. & Mayes, J. (eds.) 1997, *Regional Climates of the British Isles*, London: Routledge.

Whiting, C. E. 1932. *The University of Durham, 1832-1932.* London: Sheldon Press.

Winch, N.J. 1819, Geographical Distribution of Plants in the Counties of Northumberland, Cumberland and Durham. *Transactions of the Natural History Society of Northumberland and Durham.*

Yevjevich, V. 1972. *Probability and Statistics in Hydrology.* Colorado: Water Resources Publications.

York Evening Post 1987. Obituary for William Baines. 14^{th} April 1987, p7.