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THE WEATHER OF 1785: AN INTERDISCIPLINARY APPROACH TO METEOROLOGICAL RECONSTRUCTION USING FORENSIC SYNOPTIC ANALYSIS

By

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B.A. Lyndon State College, 1975

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A THESIS

Submitted in Partial Fulfillment of the

Requirements for the Degree of

Doctor of Philosophy

(Interdisciplinary in Meteorology)

The Graduate School

The University of Maine

May 2004

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By Louis K. McNally, III

Thesis Advisor: Dr. Kirk A. Maasch

An Abstract of the Thesis Presented
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The purpose of the work is to discern differences and similarities in synoptic-scale meteorology by reconstructing the weather of the year 1785 on a daily basis. This is accomplished by compiling data from both homogenous and non-homogenous observational records, and from historical anecdotal evidence as recorded in diaries, archives and contemporary publications. Through this reconstruction, it is possible to infer some characteristics of the global circulation of 1785.

With forensic techniques, I develop meteorological parameters from anecdotal evidence. These data are combined with meteorological observational records to produce a database from which semi-diurnal weather maps can be constructed. Sources include individual diaries, newspapers, military journals, travelers' journals, ships' protests, and other archival data. These data cover the eastern part of North America from Hudson's Bay to the Caribbean Islands and the western Atlantic Ocean east to Bermuda. The results are presented both in table and summary formats.

Although the year 1785 does not stand out as particularly anomalous in studies of average annual temperature. the much colder weather discovered in this higher-resolution work becomes evident. The transition seasons of spring and fall are greatly shortened, and winter patterns prevail for most of the year. Ice storms are common in Virginia, and rivers remain frozen into June. The edge of the polar cell is much closer to the northeastern United States than in modern-day weather patterns, aiding in the development of vigorous storms. Individual weather events can be identified which are not in evidence with annual or monthly averages.

As the climate of 1785 is considered by some to be analogous to that in the Little Ice Age, some inference can be made about the general circulation patterns then. The results may shed new light on what weather people might have faced in early times, when weather records are unavailable, and may present an idea of future weather, should the climate turn cooler.

Understanding these results will provide new context for investigating historical events. Application of the techniques used here to other years may allow researchers a new method by which climate change on a regional scale may be interpreted.

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Along the way, I have had the pleasure of meeting many fine researchers and librarians, in many countries, each of whom eagerly shared my enthusiasm for history, meteorology, and the joys of digging for material buried in archives for centuries. There are so many to thank, but those who stand out include the staff at the Athenaeum Library in Portsmouth, the Case Western Reserve Library in Cleveland, the Bermuda Archives, the Archives of Antigua and Barbuda, the Newport Historical Society, The Maine Maritime Museum, the Maritime Museum of Nova Scotia, the Peabody Institute Library, the Maine Historical Society, the New York State Archives, the Archives of Guatemala, and the American Philosophical Society. Without the assistance of these people, some of whom attended to my requests rapidly and in person during my travels, this work would remain quite incomplete.

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CHAPTER 1

INTRODUCTION

1.1 Previous Work

Over the last 25 years, a number of reconstructions of weather and climate have been performed. These include work by Ludlum (1963, 1966, 1968, 1970), Lamb (1972, 1977, 1992), Douglas, et al (1978), Baron (1980, 1992), Wilson (1985, 1992), Kington (1988), Catchpole (1992), Ball (1992), Ogilvie (1992), Pfister (1992), Camuffo and Enzi (1992), Pavese, et al (1992) Borisenkov (1992), Wang and Zhang (1992), Wang, et al (1992) Gong, et al (1992), Murata (1992) and Jones and Bradley (1992) among others. Each has developed his or her own methods by which weather or climate information is extracted and analyzed. Only Ludlum, Douglas, Kington and Wilson use weather maps as their focus. This study uses the applied techniques of forensic synoptic analysis (McNally, 1994) to arrive at weather maps from which interpolated values may be attained.

In order to assess the effects of climate change on an individual location, one must have an understanding of how the day-to-day weather affects us. By using daily weather data instead of climatic averages for this study, a more precise assessment of direct effects can be made. Although proxy evidence and long-term averages can give an inference to effects on long time scales, it is the weather, the individual unit of the climate, which affects us most directly. Thirty-year norms used currently for comparative analysis can certainly obscure a specific event. Individual storms and events that are lost even in monthly and annual averages stand out clearly in my research method, allowing us all a look behind the climate averages and into their importance at a new resolution. By using an historical approach to the weather, both individual weather events and their effects on day-to-day human activity are clearly revealed.

1.2 Outline of Study

In this study, diaries and various historical observational data are used for the reconstruction of meteorological maps on a synoptic scale for the northeastern portion of North America for the year 1785. The results will show that even small amounts of observational data and anecdotal comments can be used to arrive at a general representation of the weather patterns at the regional synoptic scale. Apparently unrelated non-homogenous data sets, travelers and trappers journals, ships logs and protests, and other sources, like newspaper reports, can be successfully combined to reveal the workings of the atmosphere. Using these data, a complete synoptic analysis of the year, at semi-diurnal resolution, can be reconstructed, using the techniques of forensic synoptic analysis (McNally, 1994). New insights in to the effect of the weather on local and regional historical events may also be gained.

Inferences can then be made regarding the position of the polar front and the flow at upper levels of the atmosphere. Using proxy data from studies of other locations from around the world, along with the results acheived in this study, a general outline of the prevalent flow in the northern hemisphere in 1785 can be obtained. This results in an estimation of the size and position of the polar cell. Similarities to and differences between the circulation of 1785 and that of other post-volcanic eruption years, and of the theorized circulation at the onset of the last glaciation are outlined.

The general area of study encompasses northeastern North America. Observational data include six compilations of regular weather observations using the instruments of the time, eight general observational diaries with various temporal resolutions, and seven diaries that contain anecdotal, or non-meteorological observational evidence. A number of individual comments are culled from eighteen other diaries as well, although their temporal resolution is very irregular. Some of these additional diaries are recorded at specific locations, while others represent the travels of immigrants and soldiers. Additional anecdotal and historical information was gathered from five newspapers from 1785 and early 1786. Four ships logs, thirteen ships protests, and three Hudsons Bay Company factory records in Canada are also used.

It is important to note that the observations used, whether strictly observational or anecdotal, represent a human-based proxy for reconstruction of the weather and, ultimately, the climate. The current state of climate change research for years before 1860 concentrates almost exclusively on the geophysical proxy, e.g. ice cores, lake and ocean sediments, tree rings, etc., to arrive at some inference of the climate or its trend. The method used herein extracts weather information directly from the source, the observer. To bridge the gap between long-term proxy paleoclimatological data sets and todays weather, we must know the weather of the past. Perhaps a connection can be developed between the two, resulting in a continuous analysis at much finer resolution, extending from today back as far as the connections with proxy data can be correlated.

By extracting the semi-diurnal resolution of weather in the late 18th century, a beginning is established towards this goal. With few exceptions, weather records in North America only extend back 150 years or so. Series are even shorter away from the coast towards the west and north. The importance of successfully reconstructing data from 1785 will prove that the length of the record can be extended, providing a stronger base from which to launch research into climate change. In addition, as the 1780s were cooler than today in North America, we can get a better idea of what we might face for weather today if a cooling trend were to develop.

The use of the surface analysis at the synoptic scale was selected as the analytical format to address a number of concerns. To achieve a common method of presenting results, and to bypass the concentration on time-series analysis, Pfister (Pfister, 1992) suggests that historical weather maps be the preferred method of presentation of documentary reconstructions of the weather in the same way that Loomis did over a century ago (Shaw, 1932). Spatial analysis is the key to relating individual data sets to the larger regional and global system. The fact that the weather map will work as both an international language and a framework for comparative analysis was not lost on these scientists. The weather map is accepted both as a method for achieving results and as a successful tool for analytical connections to other data sets, enabling results at both temporal and spatial scales. The use of this method of analysis results in a format which is directly comparable to todays data and is most expeditious and of immediate value when comparing todays weather with that of the past. To these ends, the format of weather maps at the synoptic scale and inferred upper air analyses were selected for the analysis of the data.

A presentation of the results is also included as a narrative summary of the year. Historians, researchers, and scientists who may be interested in the weather at a particular point in time, can use this descriptive summary. For example, in order to assess the effect that the weather might have had on a particular historical event, this summary provides a general insight to the weather at any given moment, without the need for complete meteorological reconstruction. In this light, and with a view to the interdisciplinary aim of the work, the summary section will serve historians and researchers in other disciplines as a significant and valuable resource. All observations are also collated into data sets for further research. Both these data and the Summary of the Year appear in the Appendices.

1.3 Significance

The driving force behind the work presented here is to bridge the gap between historical and modern data, and to provide a new framework for their comparison. However, additional benefits can be derived from the results. Currently, important conclusions about our changing climate are being drawn from high-resolution data, which extend back over the last 130-150 years IRRI (1989), Houghton, et al, (1990, 1996), IPCC (1995), Mintzer (1992), United States Deprtment of Energy (1994), Strzepeck and Smith (1995), Eddy (1995), Kerr (1995), Glantz (1996). Global warming concerns, and the predictions of environmental change connected with them, are also based on data collected over this relatively short stretch of time. With the daily resolution obtained in this study, significant comparisons can now be made between current information and historical data at a much finer resolution. Analysis of other years will extend the time frame during which trends can be seen, well beyond the current 150 years or so, to as far back in time as both anecdotal and observational data can be discovered. It follows that these weather data, when compiled into norms representing the climate. the oldest historical (weather) data could then be directly correlated with concurrent paleoclimatic proxy sources of similar temporal resolution, providing a continuous record of daily weather at an unprecedented resolution and temporal scale. This allows analysis of the effects of individual weather events on all manner of historical events, reinforcing interdisciplinary study.

An additional benefit is the ability to infer the circulation at upper levels of the atmosphere from the results with the same forensic synoptic techniques used on the regional surface scale. By combining these inferences with those extracted from work in other locations, we can reconstruct the prevalent flow in the northern hemisphere in 1785 and answer questions about size and position of the polar cell at that time. With these same techniques and additional data sources, we can assess global circulation at other times in the past. By comparing todays circulation with circulations theorized for the onset of the last glaciation, we could perhaps arrive at a circulation pattern associated with a general cooling in the hemisphere, one to which we could look to determine if a cooling period is underway either now or in the future. Furthermore, as the results of the work deal with individual weather events, we might find in them more than just a circulation pattern that would indicate a change in the climate. By looking at weather events which are recorded on a daily basis in a cooler time, their presence may serve as early indicators of change. There may be a more valid and rapid way to identify change than waiting for its identification in comparisons of 30-year norms.

Another benefit of this work will be to re-establish the importance of the skills used in preparation and plotting of meteorological data. Today, much of the work and many of the techniques in use herein is already supplanted by automated methods. This has forced a new generation of operational meteorologists to be exposed only to modern computer-generated and displayed information. without having to learn or use the analytical techniques from which the information is produced. By presenting forensic synoptic analysis as a viable tool for climate research. these plotting and analysis skills can be assured a successful transfer to a new generation of climate researchers.

Of equal significance is the identification of the importance of extracting more than just historical information from old diaries, newspapers, and ephemera. This should be brought to the attention of researchers. Historians research and pore over old ephemera in search of answers to individual questions. If they were aware of the importance that any mention of the weather represents, as this study will show, the acquisition of this important information would increase both our database and the knowledge it could reveal.

CHAPTER 2

PREVIOUS RECONSTRUCTION TECHNIQUES

2.1 Introduction

In this chapter. I outline the major advances in reconstructive meteorological analysis over the last half-century, and compare or contrast the various methods to mine. The progression begins with David Ludlum's (1963. 1966, 1968, 1970, 1976. 1982) work. which is generally centered on a specific event in history or major weather event. Although Ludlum is primarily an historian, he remains cognizant of the importance that weather plays in military campaigns, but he stops short of actual synoptic analysis. Next is the work by C. S. Douglas, with H. H. Lamb and C. Loader (1978), on the Spanish Armada storms of 1588, which brings in the concept of adjacent air mass analysis and basic testing for accuracy. Douglas, et al, has the synoptic reconstruction as the primary focus. Both Ludlum and Douglas work primarily with military records, although some contemporary diaries also are used.

Next, I outline John Kington's (1988) work in reconstruction of the daily weather of the 1780's over Europe. Following these, Cynthia Wilson's (1985, 1992) work is addressed. She has been successful in reconstruction of weather information from outposts ("factories") of the Hudson's Bay Company over east-central Canada. This valuable work is essential for reconstruction of New England weather patterns in the summer.

Each of the techniques above has a specific purpose or result in mind, and is successful in its own right. My technique, outlined in the next chapter, draws upon some of the techniques described below, but with additional steps. The purpose of my work is to present useful information for both historians and weather analysts, whether for a particular event, specific location, region, date, or time series. Without the groundbreaking work done by the researchers named above, my work would be impossible.

2.2 Ludlum Techniques

Ludlum's technique involves direct application of the weather information to a particular event under review. New insights and understanding may be gained for the particular event once the proper meteorological information is presented together with the historical record. The procedures used for gathering the meteorological information are based on the particular event. In other words, the event itself becomes the reason for acquiring information. The presentation of the results, therefore, is also in the historical context, and deals specifically with the interaction of effects and consequences on that particular event, and only in that specific point in time.

As an example, Ludlum (1976) makes mention of events in the Revolutionary War whose success or failure turned on the weather. Because of the importance of weather to a military campaign, military records are a rich source of information from which weather information can be gleaned. In 1785, General Joseph Buell (Buell, 1785) noted the weather as it affected his march from Connecticut to Fort Pitt. This shows the importance the military placed on meteorological information even in peacetime, and provides data for analysis with implications to us far beyond its original use and intention. Ludlum addresses the Battle of Bennington in the American Revolutionary War as an excellent example of the effect that weather conditions can have in the outcome of a military campaign. This particular battle has all the earmarks of a turning point in the war for independence, and might not have had this effect had it not been for the weather.

British soldiers persisted from the start of the war to employ outdated tactics in the field. Light infantry forces, using newer field tactics, were deployed in India during the Revolutionary War, and were unavailable to British commanders in the American Colonies. The British were forced to present themselves in battle order, providing excellent targets for the guerilla style of combat favored by the Americans. Extending this practice from the conventional field skirmish to the march had already resulted in disarray during the retreat from the Battle of Concord, and yet the British kept to their habit of marching in formation in the roadway. Hessian mercenaries under the command of General Burgoyne in Vermont also used this procedure.

For example, in 1777, while attempting to move his forces southward to Albany, Burgoyne required additional horses and wagons to cross the land between the Lake Champlain watershed and the Hudson River valley. Sending out an expeditionary force of Hessians to requisition the materiel from the country folk resulted in disaster that was predicated and amplified by the weather. When the mercenaries came in contact with American forces near Bennington, Vermont, the former chose to build earthwork defenses, while the latter chose to wait until more militia could be mustered. Ludlum notes that the onset of heavy rains not only allowed time for the Americans to increase the size of their force, but also ruined the trench work that the Hessians had been preparing. A British relief column was also bogged down by the rains and thus delayed, which allowed the American forces to engage the Hessians first, defeat and capture them, and then rout the relief column late in the day.

In another example, Ludlum notes that later that year, after fog had prevented the British attackers from completing their mission, a decision was made to retreat back to the north for the winter. The commander of the Hessian soldiers, General von Reisdesel, still under British command, wrote, as in Ludlum (1982): The progress was slow beyond belief, not more than a mile an hour. It was a dolorous march. Rain was falling heavily. The road, bad enough before, was a bog. The tired men could hardly drag their feet out of the mud. The wagons stuck fast and were unable to go on." From that point on, the ceaseless attacks of the more mobile American forces of General John Stark, and their ability to eventually overtake and cut off the British forces resulted in the surrender of General John Burgoyne at Saratoga.

There is no question among historians that the Battle of Bennington and the surrender of Burgoyne at Saratoga were major turning points in the Revolutionary War. Ludlum points out the importance of weather in the outcome of the war. Ludlum focuses strictly on these mentions of heavy rains, fog, etc., which affect the military campaign under review, but they could still be used as observations for further analysis and expansion to the synoptic level. Ludlum's broad meteorological analysis and its application to a specific historical event and location is still important.

The methodology I used in this study is similar in terms of acquiring the information, but differs in that the information is acquired for an entire year. It is also reduced to observational code (usable plotting symbols), and is then plotted on the synoptic map for further analysis before assessing the effects on a single event or location. This methodology does not preclude the application of certain observational information to any one event, nor does it dilute the observation on a temporal or geographic scale. The same analytical concepts used by Ludlum can be used here to resolve the effects of the weather on a particular event, but can also allow for the development of the synoptic chart for further study of the movement of weather systems both before and after that specific event. Ludlum has also been instrumental in addressing the major weather events over the last two centuries with work on winters, storms, hurricanes and tornadoes. Each of these works extracts weather information from diaries and news reports of the day to describe an individual storm, with some attention is paid to seasonal averages and long-term climatological change. His work is without doubt the most comprehensive undertaken in the paradigm.

2.3 Douglas/Lamb/Loader Techniques

The Climatic Research Unit at the University of East Anglia pursued an important study in forensic synoptic analysis, providing further proof of the value of military records for meteorological reconstruction. The study of the Spanish Armada Storms of 1588 (Douglas, et al. 1978) uses many of the techniques included in my work. Of great importance is the fact that the weather maps were reconstructed on a synoptic scale first, prior to any historical analysis. This represents a significant advance over previous studies.

Initial collection of the data performed by Douglas included acquisition and translation of ships' logs from the State Papers of Spain and certain letters and discourses from the Irish State Papers. Pertinent references to wind, weather, and the like were collected and tabulated by date and location. S. G. Aston from the Meteorological Office at Aldergrove, England, and S. J. G. Parrington from the Meteorological Office at Belfast, Ireland then undertook an initial synoptic meteorological analysis.

After this level of analysis was complete, H. H. Lamb was called upon for further analysis. At this time, he included observational information from Tycho Brahe (La Cour, 1876) in Denmark, which was unavailable to the initial analysts. A procedure for acceptable accuracy similar to one established by C.K.M. Douglas of the British Meteorological Office in England during World War II was applied. This method uses observations of the adjacent air mass to resolve the general accuracy of the initial analysis. Lamb used the Armada data to resolve the Danish data, assumed to be an adjacent air mass. The criteria were twofold: accurate representation of the wind direction (within 20 degrees) in Denmark (56% of cases), and accurate representation when a major trough or storm is present within 250 kilometers (16% of cases). Overall results of 72% accuracy were achieved. Then, second order results were attained by synoptic analysis of the initial area including the new adjacent information. Lamb achieved an assumed level of 90% accuracy. The reasoning is that if 72% accuracy can be achieved beyond the fringe of the Armada observations, then the accuracy within the range of observations must be higher.

One difference in the methodology I use is that each of the individual observation sets must be analyzed first for their ability to represent the weather at each location before they are used to resolve the synoptic-scale meteorological scenario. This additional assessment would most likely increase the accuracy of the final result. One similarity to Lamb's technique, however, is that no attempt is made to teleconnect" with another location until the initial analysis is complete. Although the reconstruction of the air mass to the west is tenuous at times, it can be estimated in a prove/disprove mode. Then, as with Lamb's technique, it is possible to test an adjacent air mass to the west of New England with Canadian data from the Hudson's Bay Company posts. The appearance of the forecast airmass on subsequent days can also prove or disprove the initial analysis.

One other important and valuable feature of the Douglas, et al study is the interpretation of the logbook entries as meteorological events. It is not discussed in the work just how this part of the analysis is derived. Specific data points for plotting are not presented. This is a shortcoming of their procedure in that reconstruction by others would be difficult. I have eliminated this by presenting all data for each location. This will facilitate reconstruction both of my region in finer resolution, and of adjacent areas in the future. It is implied, however, that the concepts of air mass analysis and movement, frontal development, and common storm movement theories are used to transcend the logbook entries and arrive at the final meteorological interpretation.

In my methodology, the techniques of air mass analysis, frontal development, and storm movement are the criteria by which meteorological data are extracted. The value of codification of the observations (reduction of historical data to meteorological terms) for further testing and future analysis is clearly shown. Although Douglas, et al, use weather maps as a final presentation tool, as shown in Fig. 2.1, reproduction or recreation by others would have to involve the entire procedure outlined above. Here is summary of the order of the procedures for the technique used by Douglas, et al:

- Collection of Data (Douglas, Loader)
- Translation
- Tabulation
- Initial Analysis (Aston, Parrington)
- Adjacent Air Mass Test (Lamb)
- Additional Weather Extracted from Logbooks
- Analysis (Douglas)

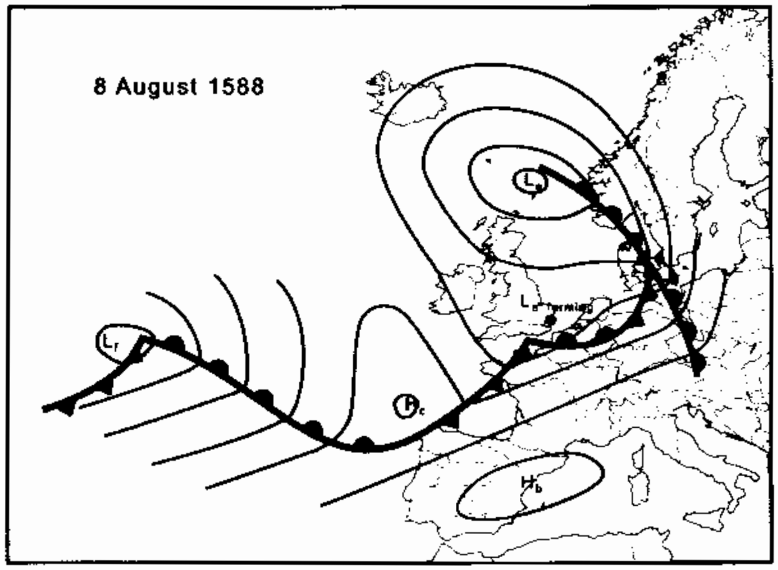


Figure 2.1: Final weather map from Spanish Armada reconstruction by Douglas, et al.

2.4 Kington Techniques

Kington (1988) reconstructed the weather of the 1780's in Europe using a much wider and denser network of educated and trained observers than that available in North America in 1785. Over 100 different data points are available on the European continent during the decade (Fig. 2.2). To begin his process, Kington acquired and then collated the data, with respect to each source's methodology of observation. Different observation techniques were in use at the time. The majority of Kington's data comes from professional societies with some additional data from diarists. Reduction of these different data to a similar meteorological form is required. Special attention is paid to the temperature, so data from each source must be reduced to comparable scales. With the exception of the different temperature scales, wind and weather observations by 1785 were becoming standardized.

For temperature data, thermometric observations were measured on the many different contemporary scales. Each set of temperature data was converted to Celsius. Most other observations (weather, sky condition, etc.) were taken in accordance with the rules set forth by either the Royal Society of London, the *Société Royale de Médecine* in France,

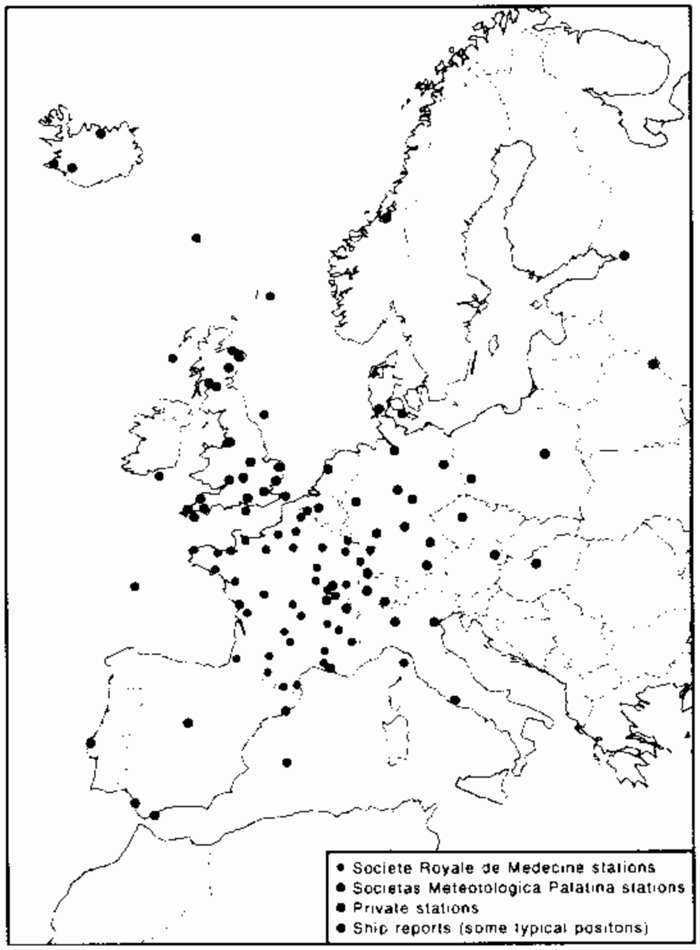


Figure 2.2: Kington's network of available data in 1785.

or the *Societas Meteorologica Palatina* in the German state of the Rhineland Palatinate. There are many similarities in the methods used by each group's members for observing each parameter, not the least of which is the scale used for wind speed.

The origin of this scale can be traced to 1667, when the Accademia del Cimento in Florence was disbanded after providing the earliest documented network of meteorological observations. In the same year, the first Curator of Instruments of the Royal Society of London, Robert Hooke, proposed a method of observing the weather, and devised instruments for the purpose. In 1723, the Society's Secretary, James Jurin, pursued an observational

Table 2.1: Comparison of *Societas Meteorologica Palatina* (SMP) Scale and Beaufort Scale of Winds with land criteria.

SMP Number	Latin Descriptor	Beaufort Descriptor	Category	Beaufort Force	Approximate Speed (knots)
0		Smoke rises vertically	Calm	0	0
		Smoke drifts with wind. Wind vanes do not respond	Light air	1	2
1	Arborum duntaxat folia	Leaves rustle	Light breeze	2	5
		Leaves and twigs in motion	Gentle breeze	3	9
2	Ramos minoris agitat	Small branches move	Moderate breeze	4	13
		Small trees in leaf sway	Fresh breeze	5	18
3	Ramos majoris agitat	Large brances move	Strong breeze	6	24
		Trees move	Near gale	7	30
4	Ramos avellit	Twigs and boughs break	Gale	8	37

network where journals were kept. These included the time of the observation, the barometric pressure in inches and tenths, temperature, wind direction and strength, sky condition, weather, and melted precipitation.

In these records from the Society, we find the first reference to the wind speed on a scale of five points. from 0-4. where 0 indicates a calm state, 1 is light air", 2 is moderate" wind, 3 is a strong wind", and 4 is a most violent" wind. The observations I use from North America contain the same scale of 0-4. It is probably no coincidence that Admiral Francis Beaufort used this as a basis for his scale, the Beaufort Scale, developed in 1805 and still in use today. Doubling the criteria of Jurin's scale (0.1,2,3,4) will result in the Beaufort scale numbers (0,2,4,6.8) for estimating and measuring the speed of the wind (Table 2.1). As the same descriptive terms are used, comparison to the Beaufort scale results in successful extraction of useable wind data from the diaries used herein. See Table 1 for an assessment of wind strength from the original scale and comparison with Beaufort.

The *Societas Meteorologica Palatina*. founded in 1780 by Karl Theodor, Prince-Elector of the Palatinate and directed by Johann Hemmer. provides Kington with data for much of Europe (Desaive, et al., 1972). In addition to precise requirements for the siting of the thermometer and barometer, there was a requirement that wind speed be estimated as well. This was accomplished using a scale remarkably similar to the one originated by Jurin. With two completely separate data sets using the same scale, I then assume that most observers in 1785, including those in North America, would be using this scale of 0-4, originated by the English. In fact, virtually all of the wind speed observations in North America are recorded in similar fashion.

The *Société Royale de Médecine* in France, Kington's other major source of data, only observed wind direction. In Germany, however, the *Societas Meteorologica Palatina* also undertook regular observations of other meteorological parameters. These data are comprehensive enough to be converted into modern-day plotting symbols. Some inference as to the origination of the weather plotting symbols in use today can be found in the records kept by the Society. Fig. 2.3 reveals the comprehensive nature of observation in Europe during the year 1785. Kington then constructed his plotting symbols to allow the meteorological charts to be valid at 1400 hours local time. In order to take into account the change in a parameter (most often the weather and sky condition) from earlier or later in the day, an additional plot was included to the lower right of each station model.

Once all information is plotted on base maps, Kington's meteorological analysis proceeded in four parts. Firstly, the available temperature, wind, weather and cloud data are examined to assess air mass homogeneity. Identification of air masses and distinguishing any obvious differences among them (warm or cold, moist or dry) is the initial aim of this step.

Secondly, the area of greatest discontinuity between assumed air masses is analyzed to identify evidence of frontal boundaries and their relative locations.

Thirdly, the pressure pattern is analyzed, further refining the positions of fronts. Kington's methodology for constructing a synoptic weather map is similar to methods used today through the plotting stage. Once the information is successfully plotted, however, common

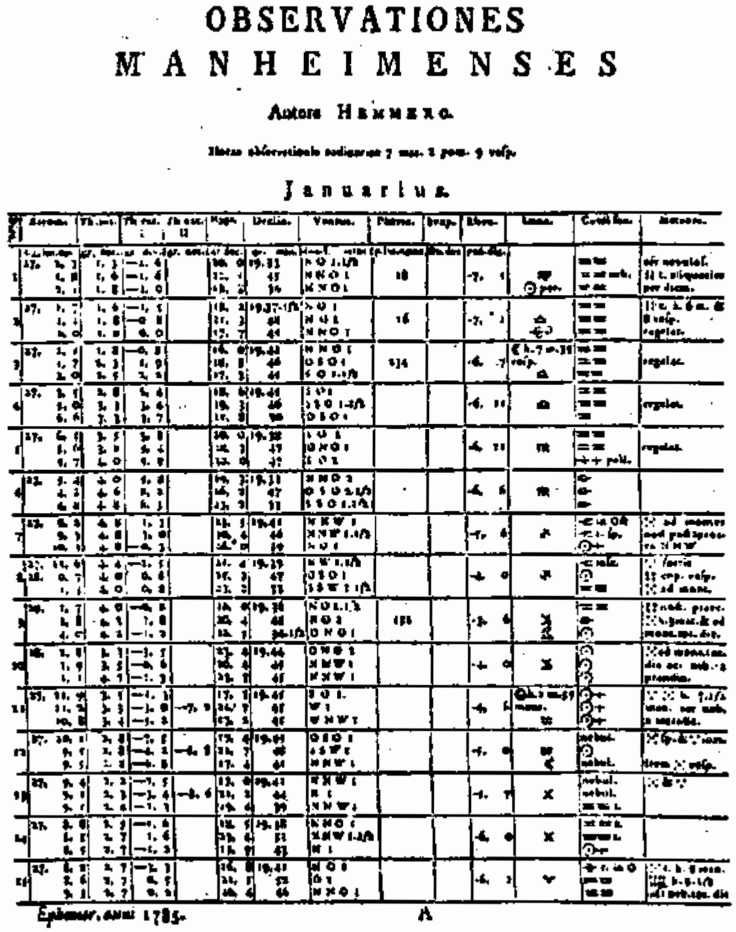


Figure 2.3: Example of European observation, Johann Hemmer, Mannheim, 1785, from Ephemerides, *Societas Meteorologica Palatina.*

practice is for the pressure analysis to be resolved first. There would then follow analytical treatment of temperature, cloud cover, and precipitation to complete the synoptic chart. The lack of pressure information in both his data and mine precludes this procedure, and pressure analysis is basically confined and restricted to trend analysis.

Fourthly, synoptic continuity in pressure system movement and development are taken into account. This process includes an assessment of the general speed and direction of air masses and the progression of low pressure areas from wave-stage systems through maturity and occlusion. Final presentation is in the form of daily weather maps. See Fig. 2.4 for an example of aerial coverage and results. Here is an outline of the procedure used by John Kington:

- Acquire data
- Reduce observations to similar scales
- Codify into usable meteorological parameters
- Analyze for temperature, wind, and cloud
- Analyze for largest discontinuity
- Analyze for pressure patterns and fronts
- Analyze for synoptic continuity
- Plot on weather maps

2.5 Wilson Techniques

Wilson (1985, 1992) undertook a synoptic analysis approach with weather records from the Hudson's Bay Company posts in an attempt to reconstruct particular seasonal differences for the abnormally cold years of 1815-1871, and the unusual warmth of the spring of 1818. Company records are also available for the year 1785. These records include data for many meteorological parameters, yet little in the way of barometric pressure analysis is possible, due to the lack of barometer readings in the database. Therefore, Wilson chose to use wind information as prima facie evidence of pressure patterns with certain caveats.

Wilson notes that wind information can be corrupted or adjusted by local topographical effects, obstructions, proximity of forest, and by local effects such as lake breezes and valley winds. Most of these barriers to using wind information can be overcome with a familiarity with the site of the observation and the effects to which wind information might be subject (see Chapter 3). Wilson also acknowledges the necessity of at least semi-diurnal analysis. Her point is that the average synoptic scale meteorological phenomenon, such as an air mass or a depression, will occupy sufficient aerial coverage as to overcome a scarcity in geographic

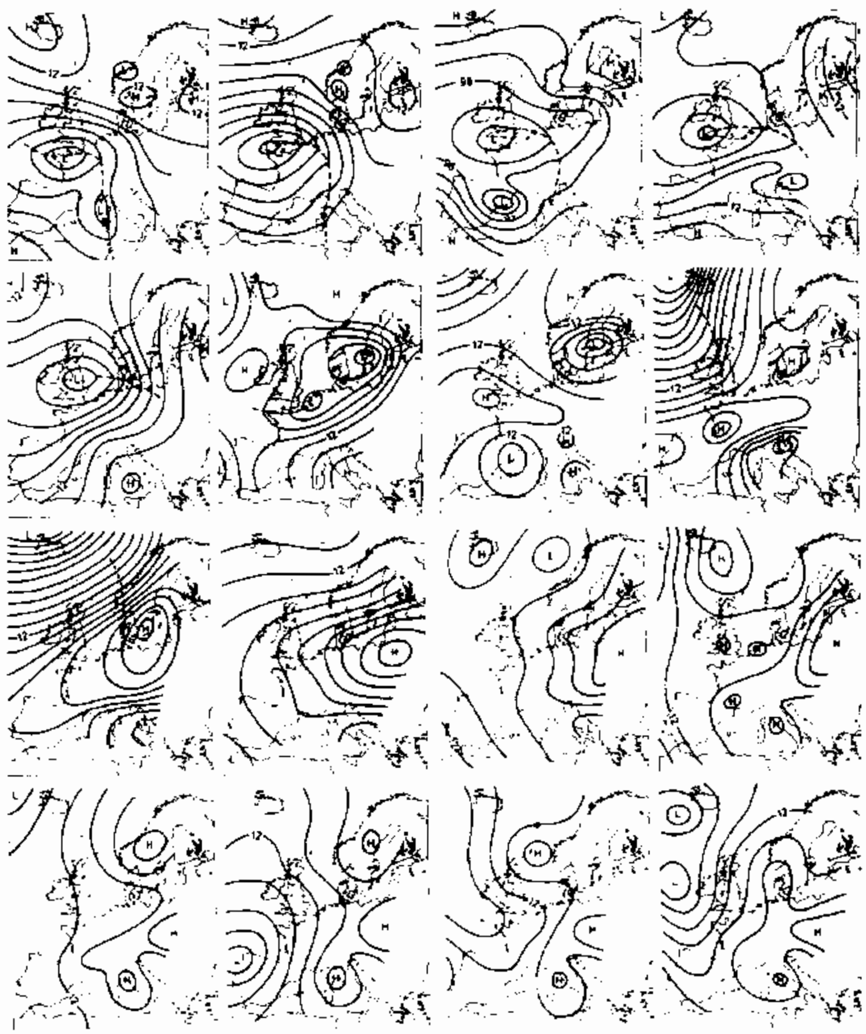


Figure 2.4: Sample of John Kington's weather maps from 1785.

coverage of stations used. These features become more visible to the analyst when using the twice-daily observations.

Techniques for the actual analysis in my work resemble those in Wilson, by following accepted methods of synoptic analysis (Petterssen, 1940, 1941, Saucier, 1955). While I do use data similar in structure, propinquity, and coverage, her use of the wind as a primary tool in resolving flow is applied to resolve air masses themselves. This method does not assess air mass qualities (moist/dry, warm/cool). My analysis includes air mass qualities at an earlier stage. Next is the resolution of sharp frontal discontinuities, as identified by differences in temperature, precipitation and cloud cover in addition to any information provided by the wind alone.

The importance of the meteorological reconstruction over the area of Hudson's Bay to analysis in New England cannot be understated. Wilson's work has significant relevance to summer weather reconstruction, and thus to my study. Many diarists in 1785 do not make observations at all during the warmer months. Mid-summer observations in New England in 1785 often include long stretches of fair" weather. This is probably due to the fact that most diarists were involved in outdoor or agricultural activities, taking little note of small scale localized events. It is important to fill in these areas of sparse data.

As the polar front (and the concomitant Alberta storm track) remain active throughout the northern hemisphere summer, it is critical to find these weaker systems affecting north-eastern North America that may have originated in central Canada. With these identified, something can then be inferred about the upper airflow at the time. The position and size of the polar cell can also be estimated. Most important is the fact that an analysis of air masses and the synoptic situation from central Canada can become a baseline for extrapolation to the east and south into New England during periods of fair" weather there. Thus summer reconstruction in New England becomes possible.

Wilson's technique involves the reduction and plotting of all pertinent information, whether direct or proxy, on a base map. Morning and evening data are separately compared to each day's base map with transparent overlays. Cloud and precipitation fields are worked in first, followed by analysis of temperature, wind fields, maximum gradient area, wind shear, and, finally, pressure tendencies. Frontal zones are next resolved, followed by the pressure analysis, taking into account the development and movement of the pressure systems themselves, using the rules developed originally by Palmen (1928), and expanded upon by Lamb (1969). In addition, Wilson compares results with the temperature and pressure curves that could be reconstructed from the initial series.

Here is a summary of Cynthia Wilson's procedure:

- Acquire data
- Remove local effects from wind data
- Reduce to twice-daily observations
- Analyze for clouds and precipitation
- Analyze for temperature
- Analyze for wind fields
- Analyze for maximum gradient and shear
- Analyze for pressure and fronts
- Prepare synoptic maps
- Compare with reconstructed temperature and pressure curves

Wilson's work has been instrumental in the treatment and development of the Hudson's Bay Company data as viable meteorological information. Although Wilson's work is 30 years later than 1785, the techniques for extraction of meaningful data from documentary evidence from the Hudson Bay area remain applicable for use in 1785, as original data used is similar. The reconstruction and use of this Canadian data fills an important role in analyzing times of sparse data in New England during summer months.

CHAPTER 3

METHODOLOGY

3.1 Outline of Methods

Regular meteorological observations from diaries and other sources were decoded and extracted as needed, and reduced to tablular form for plotting on working weather maps, using standard plotting techniques and station-model criteria wherever possible. Wind direction and sky cover were plotted according to WMO standards, and wind speed was reduced to the five categories in use by contemporary American observers, ranging from calm to strong (as opposed to the European calm to gale). Barometric pressure and temperature were plotted without adjustment for elevation, reduction or calibration, with strict attention instead paid to both temperature and barometric pressure trend. Few thermometric observations could be positively identified as outdoor, but indoor observations were assumed to have been taken in accordance with standard procedures of the time, i.e. "in a room which faces the north, where there is seldom if ever any fire in the fireplace" (Jurin, 1732).

Trend analysis (change over time) of a meteorological parameter, combined with point-in-time analysis (comparison with concurrent observations), bypasses the need for calibration of the few available instrumental observations. This method also presents a more coherent view of the atmosphere in motion. The combination of these methods for synoptic analysis is a new approach, and is usable with any homogeneous data set from any locale in the world. More importantly, it may be applied with equal success to both the sparsest data sets and non-homogenous observations, without regard to instrumental calibration.

Anecdotal, or non-meteorological, observations and comments about the weather, such as those in newspaper reports or travelers' journals, were reduced to meteorological observational form using the technique of forensic synoptic analysis (McNally, 1994). These additional data were combined with previously processed observations to develop the basic data set for plotting and resolving the synoptic situation on the working weather maps. Any additional comments, which might not immediately successfully resolve weather data, were separated out and later tested for propinquity with the completed analysis. If they successfully represent additional weather information, they are included on the working maps and used to further refine the resolution of the synoptic analysis.

Once all data (observational and anecdotal) are plotted on the working weather maps, synoptic analysis was carried out in the same manner as that which is used today for the preparation of synoptic-scale surface analyses. The techniques used for plotting and synoptic analysis of observational data have been accepted and used by operational meteorologists for decades. However, the development of the techniques for extracting usable meteorological information from anecdotal and non-observational sources, combined with the application of these data into the modern synoptic analytical process has not yet been carried out for the late 18th century time frame for the North American continent. Finally, the semi-diurnal resolution, which is used as the baseline scale of analysis, is much finer than previously available. The length of one year, 1785, is used to show the viability of the work to resolve individual weather events and address times of sparse observations. Without this level of resolution (diurnal), individual events, such as a single storm, which do not appear in smoothed or averaged analyses could not be identified and studied.

Until now, identification and comparison of individual climate types was a common method for analyzing historical weather data (Lamb, 1972). This method provides much insight for locations around Western Europe, the region for which it was developed, but it is also limited to those locations. The methods described herein are, by way of contrast to Lamb's methodology, applicable to any location under review. It is not necessary initially to develop individual climate types for North America in order to achieve results. With an understanding of both the general circulation of the atmosphere and regional synoptic weather patterns, my methods are viable for analytical purposes for any geographic area regardless of climate type. Therefore, reconstructions can be undertaken without the need for a location-specific paradigm. This approach does not, however, preclude the probability that certain climate types can be extracted in the future, allowing for easier correlation and comparison with other works and methods (Kington, 1975a, 1978, Bradley and Jones, 1993).

3.2 Selection of Synoptic-Scale Area

The general central area of this study comprises the northeastern part of the United States of America, from Augusta, Maine southward to Orange County, Virginia, and westward to the Hudson River Valley in upstate New York. This locus was selected both because of the geographic and temporal coverage of the data availability, thus enabling the resolution of synoptic scale meteorological systems over most of the year (Figure 3.1). Although the data are sparse in adjacent regions, particularly to the west and south of the central area, there are some observations included from three Hudson's Bay Company posts in Canada, newspaper reports about storms as far south as the Caribbean Islands, weather conditions in Europe, and reports from ships' papers (logs and protests) from as far away as northern Hudson Bay and the west-central north Atlantic.

As the initial analysis is undertaken at the individual air mass or single storm level (basically a single high or low pressure system), the geographical coverage must encompass at least the area of these individual synoptic systems. The vigorous nature of the weather in North America, from 40 to 45 degrees of North Latitude and on the eastern side of the continent, has led to numerous mentions of weather conditions in a number of diaries and meteorological registers, thereby providing sufficient coverage for synoptic scale reconstructions. The area selected presents additional opportunity for analysis due in part to its position at the intersection of many regular storm tracks and its proximity to the Polar Front. Figure 3.2 shows examples of historical storm tracks from Loomis.

Figure 3.1: Locus of Study.

Synoptic scale storms, excepting localized events such as air mass thunderstorms and tropical systems which are steered by different mechanisms. form and move (or track) along the edges of differing air masses. In the study area. air masses originating from all points of the compass can be found throughout the year, and arrive over the area from across the continent and adjacent ocean (Figure 3.3). Each air mass has its own specific characteristics of maximum and minimum temperature. humidity and visibility. and with specific wind direction, wind speed, and precipitation type and intensity at their borders.

These characteristics can be easily seen and recorded by observers of the weather in registers common to the time. Some of these observations also include measurements from contemporary instruments. The basic characteristics of an air mass or storm can also be recorded in general language or anecdotal form, as in a diary entry or newspaper report, and when extracted with an eye to meteorological parameters, can provide additional usable data. The combination of the influence of many varied air masses clashing nearby and

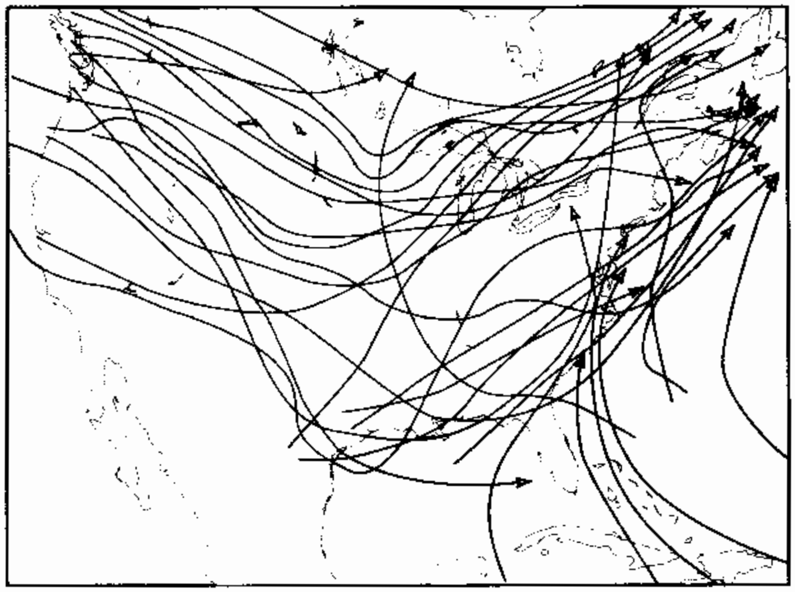


Figure 3.2: Historical storm tracks, Loomis Papers, from Fleming (1990).

plentiful observations of the vigorous weather this causes, results in an excellent mix of temporal and geographic coverage.

The rate of change in the observation of air mass characteristics and passage of obvious storm systems over a particular point with respect to earlier or later observations with the same instrument carries much weight in the analysis. Even simple references such as "dry" can have a great bearing on the identification of a change of air mass when juxtaposed temporally with a mention of "humid". The difference between weather parameters on successive days, as inferred from commentary, or anecdotal evidence, can be as effective an observational and analytical tool as actual quantitative meteorological observations from a contemporary instrument. Other than general knowledge of the placement of some instruments (e.g. a thermometer on the sash of Ezra Stiles's robe, or on the north wall of an unheated upstairs room for James Madison), I do not undertake a calibration of the few instruments used. The lack of widespread quantitative and calibrated data is not a barrier to the execution of a reconstructive synoptic analysis when "trend analysis" as outlined above is used.

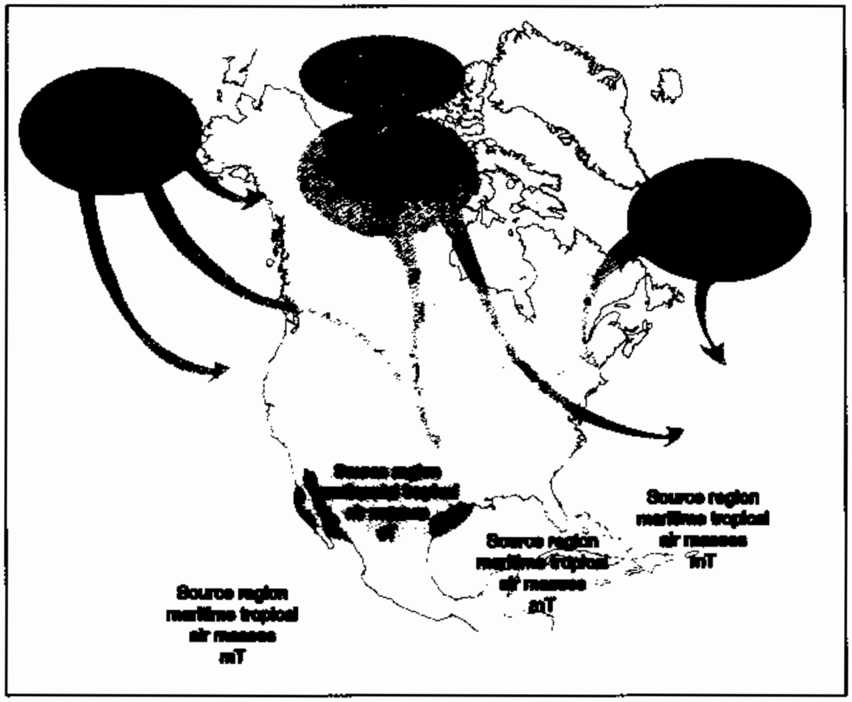


Figure 3.3: Air masses of North America. The polar front would be found at the southern edge of a continental polar (cP) air mass, the Arctic front at the southern edge of a continental Arctic (cA) air mass.

It is important to have some general knowledge of the individual towns, settlements, routes and destinations referred to in the data, as well as an overview of the historical events that may affect the accuracy and propinquity of the observations (Mitchell 1951). Experience in weather map plotting and contouring, and the synoptic scale analysis thereof is combined with experience in forensic synoptic analysis. This requires achieving successful reconstruction of the weather using few data points, sparse information and triangulation to resolve weather-related events. These events may include aviation accidents, marine incidents, unusual precipitation events, and the scenes of crimes. The combination, then, of data availability and geographic coverage for spatial resolution of synoptic scale features determines the area involved, and my familiarity with the region's meteorology, topography, geography, economy, politics and history helps me to understand the context of the observational and anecdotal data. My experience in forensic and operational meteorology allows the analysis to be completed. This interdisciplinary approach is a fundamental requirement for the research and analysis.

Beginning with the initial analysis area, the ability to determine the source of various meteorological entities, such as warm and cold fronts, air masses, and storms on the periphery thereof, allows estimation of the synoptic situation beyond the extent of the initial analysis both temporally and spatially. This estimation can be verified with fewer data points, as inference can be initially drawn regarding the type of air mass. For example, analyzing the estimated qualities of the adjacent air mass in terms of the broader pattern and flow, both before and after a point in time, can prove or disprove both the position and characteristics of the adjacent air mass. This is one of the procedures used by Douglas, et al (1978) and discussed in Chapter 2.

Additional inferences may be gained at various levels of the middle and upper atmosphere through the application of accepted rules of forecasting, applied in the forensic mode as "hindcast" information. For example, it is well known that the thickness of the atmosphere from the surface to the 500 millibar level, the temperature of the air at the 850 millibar surface, the location and track of relative vorticity maxima at the 500 millibar level, the location, speed, and orientation of the jet stream at levels above 500 millibars, the closure of low pressure systems, and the direction and speed of the wind at the 700 millibar level are all used together to successfully forecast heavy snow (Showalter, 1944., Oliver and Oliver, 1945, 1953, George, 1949, Saucier, 1955). Therefore, given a heavy snow event, it is possible to infer that these atmospheric parameters would be present at that time, thus providing information about otherwise unobserved upper level parameters.

The position and strength of the 500 millibar level flow and its orientation as troughs, ridges, and zonal flow can be interpreted from surface data (Harman, 1991) and is used to teleconnect with areas of even more sparse data, such as the Northwest Territories of Canada and the Atlantic Ocean, in order to achieve a broader result. Additional teleconnections to estimate a global flow are presented in Chapter 5, using climate studies centering on results from various paleoclimatic methods. These estimations, when taken together, can give an idea of the global circulation at the time.

3.3 Data Extraction and Reduction

Various sources were researched and acquired to develop a database of observations and comments. Through forensic synoptic analysis techniques, I have shown that even a single data point can have relevance for a meteorological reconstruction (McNally, 1994). A total of 76 sources were found with viable observations or mentions of the weather. These ranged from individual comments to complete registers of regular instrumental observations. Twenty "major" diaries were sorted into three categories: regular instrumental (at least daily observations), regular anecdotal, (comments at nearly daily frequency), and occasional anecdotal (8 or more comments for the year). Table 3.1 outlines the locations of these various "major" diarists. Other data were acquired from many sources, and were received in all manner of form ranging from original editions of newspapers (Fowle's New Hampshire Gazette) to journals (George Washington and Martha Ballard). Some observational sets were already collated into tables, rendering the data immediately usable. Others were not, and pertinent references to the weather had to be extracted. For some anecdotal data, the information can only be used later in the procedure when comparison with adjacent observations can validate their propinquity.

Although there are fewer data points available in 1785 for this study versus European data, enough information was found for successful reconstruction at the synoptic (regional) scale. In Kington's work for the 1780's (Kington, 1988), 88 regular observing stations and an additional 24 anecdotal, or non-observational sources (diaries and ships' logs) are used. My study has access to only 6 regular instrumental observers, an additional 8 regular anecdotal registers, 6 occasional anecdotal diaries and another 42 anecdotal observation points. These include sparse observations from 22 diaries (see Table 3.2), 4 ship's logs, 13 ships' protests, and 3 diaries from the Hudson's Bay Company. Additional references to the weather, were

Table 3.1: Major Diarists and locations. Regular instrumental diaries are denoted as RI, regular anecdotal as RA, and occasional anecdotal (8 or more comments) as OA.

Source	Location	Type
Adair	Philadelphia, PA	RI
Allen	New London, CT	OA
Alling	Hamden, CT	RA
Ames	Dedham, MA	RA
Ballard	Augusta, ME	RA
Cranch	Haverhill, MA	OA
Cushing	Waltham, MA	RI
Gilman	North Yarmouth, ME	RA
Hasey	Lebanon, ME	RA
Holyoke	Salem, MA	RI
Kemble	Mount Kemble, NJ	OA
Lewis	Morristown, NJ	OA
Madison	Orange County, VA	RI
Patten	Bedford, NH	RA
Sanborn	Hawke, NH	OA
Sewall	Augusta, ME	OA
Stiles	New Haven, CT/Newport, RI	RI
Washington	Mount Vernon, VA	RA
Wigglesworth	Cambridge, MA	RI
Wight	Medway, MA	RA

Table 3.2: Listing and locations of diarists with sparse comments (less than 8 comments for the year).

Source	Location
Banks	Yorke, ME
Batchelder	Hampton Falls, NH
Belknap	Dover, NH
Bentley	Salem, MA
Buck	Bucktown, ME
Coffin	Newbury, MA
Deane	Portland, ME
Hanson	Gardiner, ME
Hazard	South Kingston, RI
Huntington	CT
Johnson	Newbury, VT
Jones	Templeton, MA
King	Suffield, CT
Lane	Stratham, NH
Libbey	Scarborough, ME
Longfellow	Gorham, ME
Perkins	Sanbornton, NH
Smith	Falmouth, ME
Thompson	Woburn, MA
Tudor	Cambridge, MA
Weare	Yorke, ME
Williamson	Central Maine

found in 5 contemporary newspapers and 2 books. See Appendices for complete listing, and Fig. 3.4 for map showing locations.

Some initial preparation work was performed on selected sources. In some cases, the actual information was recorded in a "code" designed by the diarist. Figure 3.5 is an example from the Nathaniel Ames diary from Dedham, Massachusetts. In such a case, the coded observations must be assigned meteorological parameters and put into table form before becoming viable for further use in the next steps in the procedure. In another case, data had to be extracted visually. An example of this raw data is shown later in Chapter 6 in (Figure 6.1). Parts of the facing page of data (one reversed) appear in the same frame of microfilm, the facing pages having been pressed together for so many years. In this case, information from the opposite page must be removed or ignored in order to reveal

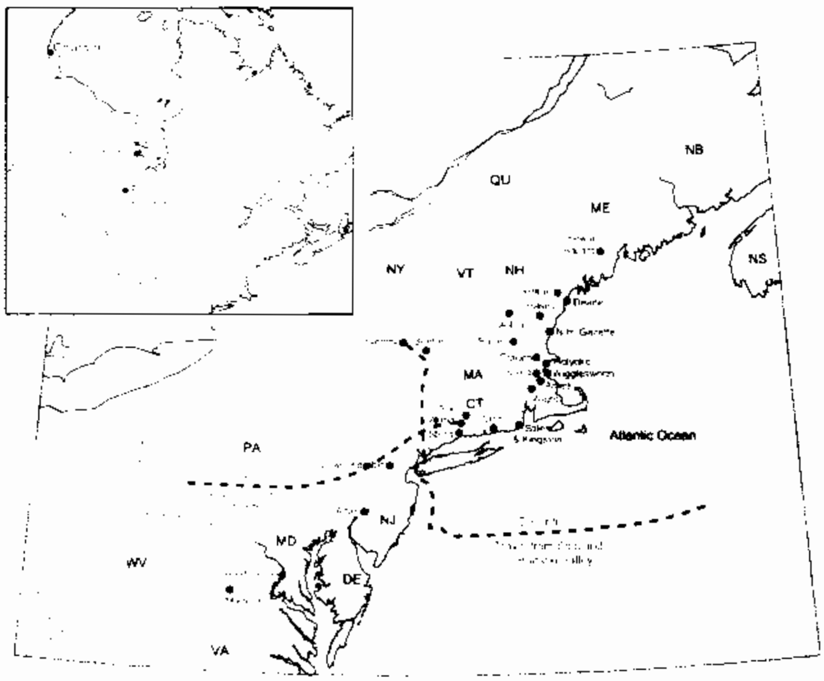
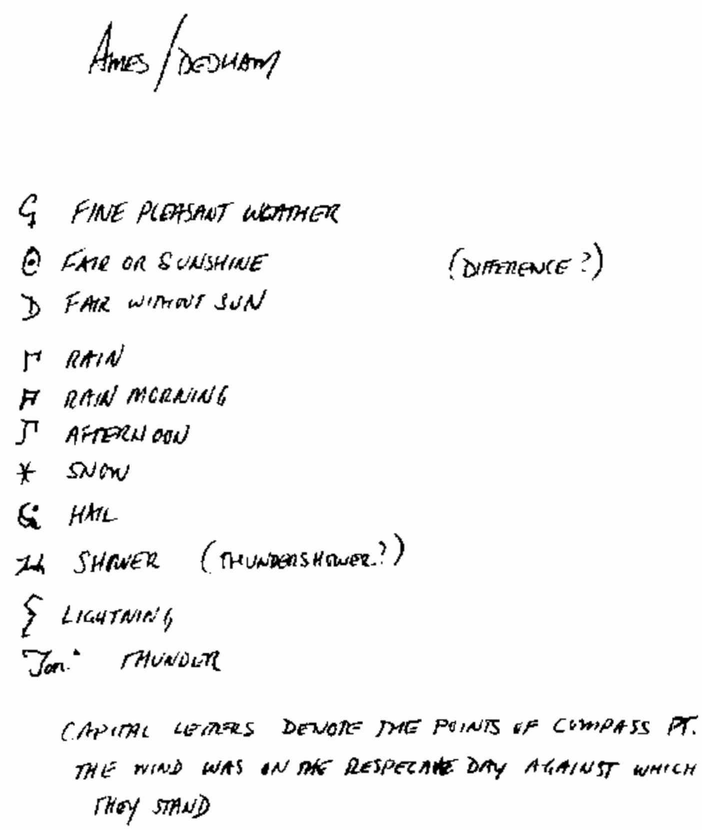


Figure 3.4: McNally network of observation sites, 1785.

information on the original page under review. An example of this is presented in Chapter 6. Some information is barely recoverable. Figure 3.6 is an example of a page from Adair's diary.

Historical and anecdotal data, or non-observational references to the weather, were extracted from their sources and arranged by site and date. Newspaper information must be dated and set to the proper location. Data from ships' logs and protests were tabulated by location and date. In each case, the meteorological information is extracted and recorded by date, time and location, and placed in a table for each observer or source. The raw data on meteorological parameters thus are readily available for future research.

Once reduced to table form, the actual preparation of the data from the remaining diaries and weather observation registers is similar to that used by Kington (1988), Douglas, et al (1978) and Wilson (1992), but with some important differences. First, the raw data are



Ames / Dedham

FINE PLEASANT WEATHER
FAIR OR SUNSHINE (DIFFERENCE ?)
FAIR WITHOUT SUN
RAIN
RAIN MORNING
AFTERNOON
SNOW
HAIL
SHOWER (THUNDERSHOWER ?)
LIGHTNING
THUNDER

CAPITAL LETTERS DENOTE THE POINTS OF COMPASS PT. THE WIND WAS ON THE RESPECTIVE DAY AGAINST WHICH THEY STAND

Figure 3.5: Transcribed page from Nathaniel Ames diary. Dedham, MA, 1785. Note diarist's code used for weather description.

sorted by time of day and location. As mentioned above, some of the data are in usable form immediately, and some have been provided after use in other research (Baron, pers. comm.). All these data, parsed and analyzed for Baron's work on content analysis (Baron, 1980), have been completely re-extracted from the originals. Certain data that might have been overlooked or deemed not useful for content analysis were comprehensively reworked and reduced to meteorological format and importance. This work was carried out on both the instrumental and anecdotal data sets.

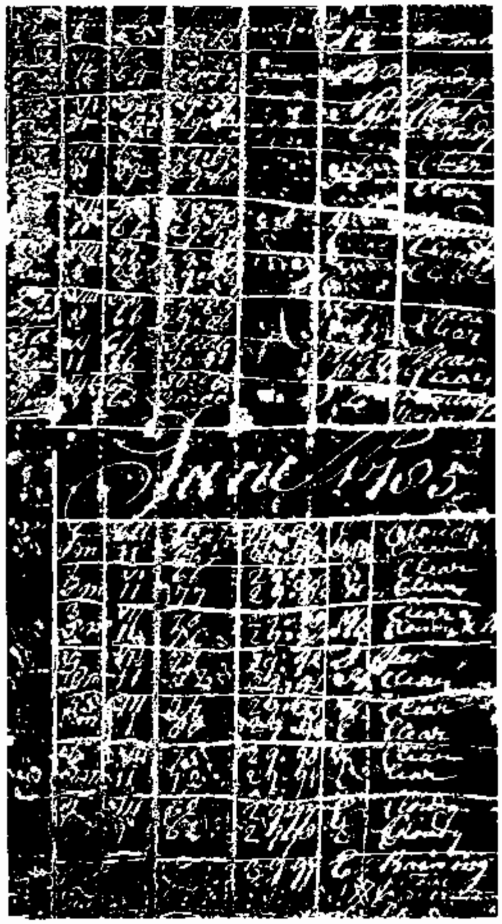


Figure 3.6: Page from Adair diary. Note additional marks from ink on facing pages in lower right-hand corner.

Next, all data are compiled into monthly tables by observer, so that other researchers can easily access information for a point in time or specific location for further research. This provides a valuable product beyond the synoptic and macro scale analysis presented herein. In addition to their value within the area of the study, the raw data are in a standardized format, reducing the time needed for comparative plotting or analysis if additional data are uncovered for adjacent areas or for a broader regional analysis. As additional sources are discovered within the area of this study, these data can also act as a template against which new data can be verified.

3.4 Locus Verification

After extracting and tabulating the raw data, an initial analysis is then undertaken to verify the locus of each observer and possible local topographical idiosyncrasies. Travel to the location was undertaken where possible to further familiarize myself with the area of the observation. This on-site perambulation permits further insight into localized effects.

As an example, a wind observation was discovered in Jacob Cushing's diary (1785) from Waltham, Massachusetts, which, on its own merit, would imply a different synoptic situation from the surrounding data from nearby Cambridge, Medway, and Dedham. When all other observations are calm, Cushing reports a southerly wind. In most cases, without any local proof, this could be reason enough to discard the data as an outlier or mistake. Further analysis, however, can help to verify that the observation is the result of local effects.

After a very hot day on 21 June 1785, cooler air arrives in the evening. Winds in all locations in Massachusetts and Connecticut are reduced to calm with the exception of Cushing's observation in Waltham, Massachusetts. The development of fog, noted in combination with the calm conditions, supports an assumption of a high pressure area overhead, and subsidence in lower levels of the atmosphere. Thus any wind would be the result of local effects. As cold advection is present and it is otherwise calm, there is support for cold air drainage from higher elevations and/or along a river valley. Now, if one were to assume that Cushing was located where the center of Waltham is today, a southerly breeze immediately stands out as potentially bogus data (Figure 2.6). Any breeze in the center of town would have to be from either the higher ground to the northwest or from the west along the river.

Travel to the locus revealed that the modern center of town has its share of churches (Cushing was a minister) and graveyards. The oldest graves nearby, however, date back only to the 1840's. Today, Waltham is centered near the mills that were built well after 1785 in an area of the Charles River which provides easier shore access for roads and rails, and was easy to dam. In fact, after consultation with local police and historians, I found an additional area of much older buildings and gravesites a few miles to the east. Although the immediate environs are surrounded by a housing development dating from the 1920's to the 1960's, a small area remains near the main road with late 18th century houses and, in fact, a cemetery with the gravesite of the diarist Reverend Jacob Cushing himself (Figure 3.7). As it was common at the time for a pastor to be buried in his churchyard, and noting the presence of the cluster of period buildings, it is logical to assume that this was the center of town in 1785, where Cushing's observations were taken.

The cemetery is, in fact, on a hill to the south of the main road. Any land breeze consistent with cold air drainage on the night of 21 June or early morning of 22 June 1785 would have been recorded as a south wind by the observer along the main road below. Thus the value of actual on-site review becomes clear, and the observation can be considered valid. Each suspect observation must be resolved for its accuracy before the next step in the analysis.

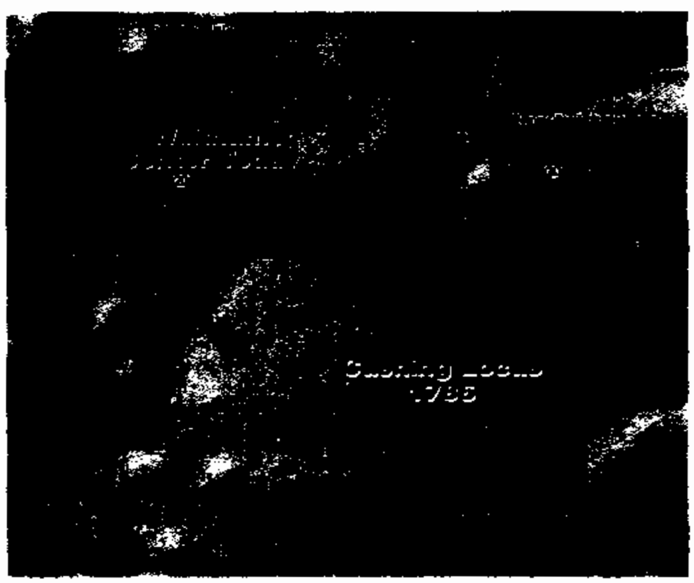


Figure 3.7: Center of the city of Waltham, Massachusetts today, and locus of Cushing's 1785 Waltham observations. Arrows indicate direction of cold air drainage and thus localized wind direction.

3.5 Individual Diary Analysis and Plotting

After suspect observations are reconciled, each diary or source is analyzed on its own as a whole by month, paying attention to obvious temperature changes, precipitation events, change in wind direction, passage of storms, and specific comments that might reveal the presence or absence of a meteorological parameter (high pressure, low pressure, storm, front, etc.). These major events are extracted and highlighted. Figure 3.8 shows an example of this part of the analysis for George Washington's diary. Anecdotal data are assessed for their ability to represent meteorological features. For example, an observation of the Aurora Borealis would imply a clear or partly cloudy sky. These anecdotal non-meteorological observations are parsed out and included in a table of their own for later use.

The analysis of each diarist is undertaken separately, as each has his or her own way of stating specific weather conditions. Thus each source can be tabulated with internal consistency. The benefit of this procedure is that any future diary or source can be processed with this methodology without regard to any adjacent area or data set. In fact, a single diary can be analyzed in this fashion to reveal the presence of many meteorological parameters (McNally, 1994).

Next in the process, the raw data are resolved for each diary or source to the semi-diurnal scale, meaning a morning and an afternoon observation. This can be accomplished in most cases due to the number of observations made by the regular observers during the day. Morning results are fewer, but could be used for any future attempt to teleconnect with the work done for Europe by Kington. One would have to use data from early in the day in New England to compensate for the time differential of 6 hours between there and the studies done in Europe, which are centered around 1400 hours local time, which is 1 hour ahead of Greenwich Mean (Zulu, Military or Universal) Time. Thus, when available, the morning observations as close to 0800 hours as possible are used. These diurnal results are then tabulated for each diarist's location.

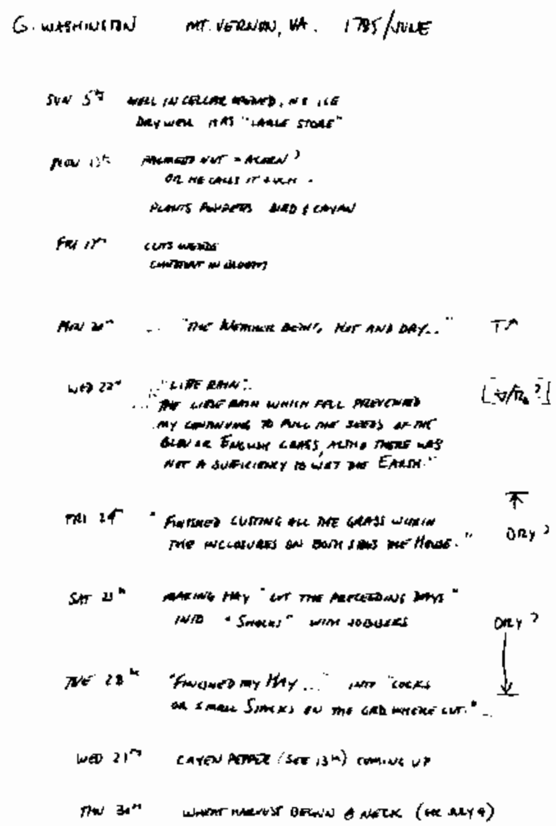


Figure 3.8: Example of transcribed monthly analysis by observer. Note initial extraction of meteorolgical data in right-hand column.

Next in the procedure. all observations and notations, now collated by location and observer, are placed into an additional table by day and month. Figure 3.9 illustrates an example. This is the point at which the actual plotting can begin. The analysis of each source for propinquity and reliability is already complete, so the information that is now plotted onto the base map has relevance both to the current point in time and to adjacent observations. Plotting both the actual weather information (as Kington and Douglas have done) and the historical notes already assembled (as Ludlum and Wilson have done) on the same base map brings a new and heretofore unused level of resolution from which the next steps can be attempted. All processed and tabulated raw data and comments are now plotted (Figure 3.10).

Table 3.3: Monthly tabulated data for January 1785 from Holyoke, Salem, MA. Note initial synoptic analysis notes in right-hand column. "x" indicates change during the day. Wind observations are assumed to be morning and afternoon.

	AM Temp		PM Temp		Wind		Comment
1785	in	out	in	out			
1-Jan	21	14	23	13	N		Cold. Stormy. some Snow. Cloudy. Moist Air. Stormy
2-Jan	23	24	27	20	E	NE	Some Snow. X Stormy. Hail & Rain. Moderate. Moist Air
3-Jan	32	32	35	36	SE	W	Rain. Moist Air. X Fair. X Moderate. Cold
4-Jan	22	7	25	14	W	WSW	Serene. Dry Air. X Very Cold X
5-Jan	21	15	25	24	SW		Fair. Cloudy. Moist Air. X Snow
6-Jan	20	15	26	20	N		Cloudy. Fair. X Cold. Cloudy
7-Jan	17	7	26	15	NW		Serene. Dry Air. X Calm. Cold.
8-Jan	25	25	30	31	SW		Cloudy. X Moist Air. Fair. Cloudy. Moderate.
9-Jan	29	30	36	40	W		Cloudy. X Fair. Warm. Moist Air. Cloudy.
10-Jan	25	21	35	33	N		Cloudy. Moist Air. X Snow & Rain. Snow
11-Jan	33	30	36	41			Some Snow. Moist Air. Cloudy. Moderate. Fair. Pleasant. Cloudy
12-Jan	28	24	36	39	SW	SE	Cloudy. Moist Air. X Moderate X
13-Jan	31	27	25	14	NW		Cloudy. X Very Cold. Some Cloud. Fair. Serene.
14-Jan	17	13	25	24	SW		Cloudy. X Cold. Fair. Cloudy.
15-Jan	22	19	29	32	SW	NE	Fair. Cloudy. X Moist Air. Moderate. X Stormy. Snow. Rain.
16-Jan	20	22	22	15	NW		Cloudy. Some wind. X Very Cold. Serene. Moist Air.
17-Jan	16	10	24	24	NW		Cloudy. Cold. X Moist Air.
18-Jan	32	39	40	43	SW		Serene. PLeasant. X Warm. Cloudy. Rain
19-Jan	42	37	42	34	NW		Serene. Dry Air. Pleasant. X
20-Jan	25	17	33	33	NW	SE	Serene. PLeasant. X Cloudy. X
21-Jan	37	37	46	42	S		Thick Fogg. Much Rain. X Warm. Moist Air. Thaw.
22-Jan	44	40	45	46	SW	W	Cloudy. X Thaw. Moist Air. Moderate.
23-Jan	31	27	37	28	NW		Serene. Dry Air. X Pleasant. Moderate.
24-Jan	32	31	31	37	SE		Cloudy. X Very High Wind. Moist Air. Thaw.
25-Jan	45	48	46	43	SW	NW	Rain. X Warm. X Rain.
26-Jan	32	21	35	23	NW		Serene. Dry Air. X Moderate. Pleasant.
27-Jan	28	25	27	22	NE		Cloudy. X Moist Air. Cold. Some Wind.
28-Jan	33	17	34	24	NW	S	Fair. X Pleasant. X Moist Air. Cloudy.
29-Jan	35	32	35	35	SW		Snow. X Moist Air.
30-Jan	25	12	27	15	W		Serene. Dry Air. X Cold
31-Jan	18	10	27	18	W?	W	Serene. Dry Air. X Cold

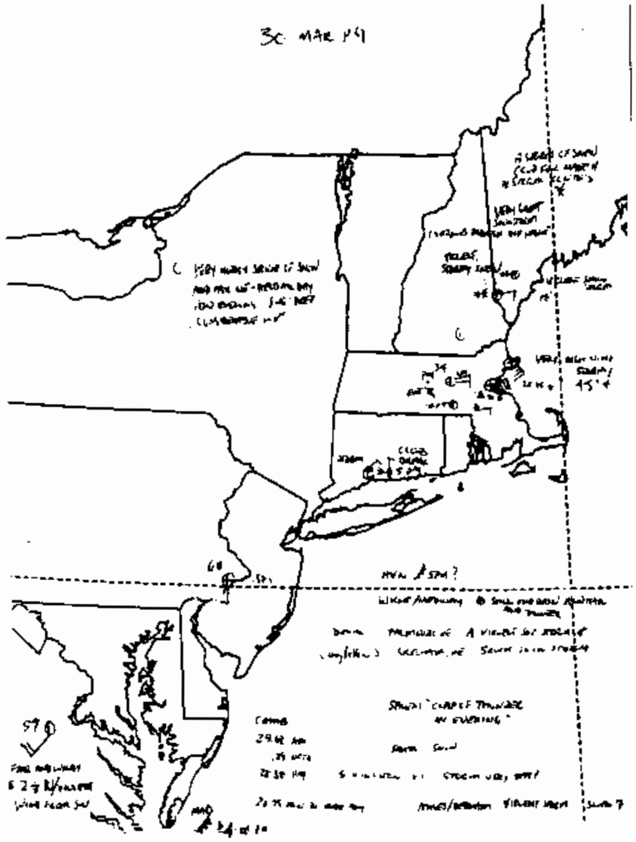


Figure 3.9: Sample of historical and meteorological data plotted together.

3.6 Working Map Analysis

The afternoon or early evening charts are used for the start of the eventual synoptic analysis because more anecdotal observations relate to the weather during the day. This, combined with regular observations, increases the data resolution for that time period. The wind direction is also more closely representational of the geostrophic wind during the afternoon, (excepting local effects such as a sea breeze), when the mixing between the surface and the upper level winds is greatest. This provides the best representation of the general flow above. Therefore, the afternoon maps are plotted first. In the case of observations that are recorded thrice daily or more, the trend of each parameter is noted in the plot. .

The morning maps are plotted next. As the observations are more irregular in the morning hours, these separate maps are plotted with respect to both the prior day's afternoon map and the afternoon map of the day itself. By this method, the speed of frontal passages can be more accurately estimated, as well as more accurately establishing the onset, length, or end of precipitation. Additionally, anecdotal information regarding the previous night, such as an observation of frost or distant lightning, can be taken into account and plotted closer to the actual time of occurrence. This provides better resolution rather than attempting to show such data on a single day's map, as Kington(1988) has done. With the completion of the morning working maps, diurnal resolution is now available for the synoptic analysis.

3.7 Reconcile Suspect Observations

At this point, any suspect observations must be reconciled. As an example, a brief look at the data for 31 January 1785 shows temperatures falling into the teens (Fahrenheit) in New England, and to near freezing to the south. Winds are calm or light northwesterly, skies are clear or nearly so, and barometric pressure rising at both Philadelphia, Pennsylvania and Cambridge, Massachusetts. This would imply a placid situation with a weak polar high pressure system advecting into the area. The single observation of "stormy" from Sandy Hook, New Jersey immediately stands out (Figure 3.10).

Indeed, within 24 hours, a major snowstorm affects New England. Working backwards to the clearing on the afternoon of 29 January 1785, reveals the passage offshore of the previous storm. The fact that Sandy Hook is still reporting "stormy" on the 31st, and without any other storm nearby, implies that the previous storm has cut off from the upper flow and stalled. The intensity of the next approaching coastal low does not explain the heavy snow that then falls in the Boston area. However, intensification of an occluded or cutoff low from just offshore, evidence of which is only implied in the Sandy Hook observation could explain the extra intensity. Additional proof that the Sandy Hook observation is valid is developed from ships' protests in Bermuda (Ships' Protests, 1785). These document the activity of the offshore system. Ships' protests are discussed in Chapter 6.

This scenario is common in the "storm graveyard", or end of the storm track, which today would be found well off Newfoundland, or in rare cases, as far south as the Gasp Peninsula of Quebec, Canada and the adjacent Gulf of St. Lawrence. The implication that the "storm graveyard", which is also associated with the edge of the polar cell, is displaced that far southward is discussed in Chapter 4. The immediate benefit at this stage of the procedure is that the apparent outlier observation from Sandy Hook is indeed valid. The benefit to the overall analysis is also recognized when a similar event occurs from 24 to 26 February 1785. The storm in that case only reaches Cape Cod before occluding and stalling, thus implying that the former event is itself not a singular case.

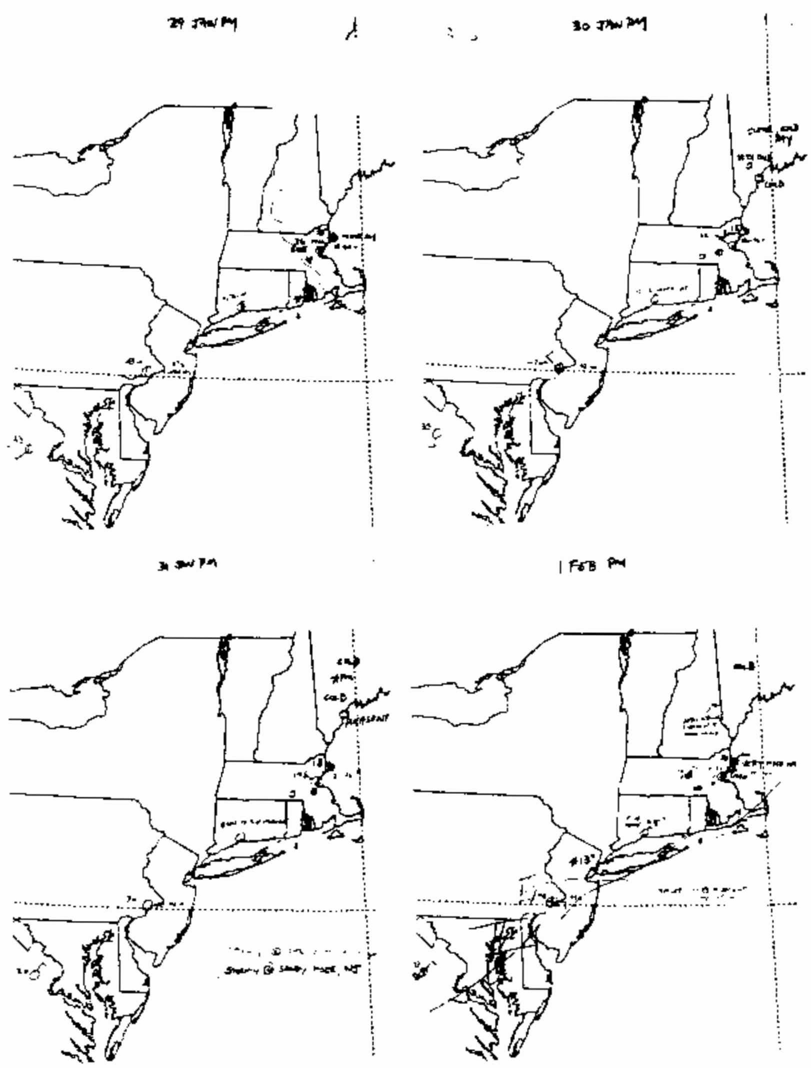


Figure 3.10: Maps from 29 January to 1 February 1785.

3.8 Synoptic Analysis

In 1785, as is true today, it is important to note that it is the major weather event that receives the most attention. Today, a major storm or flood receives proportionally larger media coverage than the everyday weather. This is especially true when the event impacts a large urban area where both major media outlets and population maxima are co-located. Little additional public attention is drawn today to an early frost, although the actual climatological records and an occasional footnote by the regular observer would be recorded. For example, a major freeze in critical growing areas for economically sensitive crops receives disproportionate publicity, and it is only the investors and arbitragers who risk loss on the futures exchanges who might give some special notice. Given that most people are insulated from their environment with adequate shelter, the most intense events are the ones that become the most newsworthy.

In eighteenth century North America, however, the weather was of absolutely critical daily importance. The slightest aberration could have major consequences on the farm-based household, as is true today, with ramifications easily reaching the few learned observers in their towns and villages. The dutiful observers of the late 1700's note the slightest variance from normal, resulting in comprehensive information. However, both regular scientific records and diaries kept by individual townsfolk and farmers show more comment during stormy weather than when the weather was less vigorous. This relatively comprehensive coverage received for major events in 1785, like today, presents the most realistic starting point for the reconstruction of the year.

Whether today or yesterday, weather which might appear as "usual" or "expected", does not receive the attention that the major storm does. However, I assume that the weather in question, with well-established parameters and a lack of unusual characteristics, would most likely be encountered in the center of an air mass (or area of high pressure). This would be the weather found between the storms and major events, and does represent longer periods of time. The persistence of meteorological conditions within a well-established air mass would be noted less, but can be assumed to be more constant than in a more volatile situation. It is no less important to extract the weather information to reconstruct conditions during these periods of time, but the data are more sparsely distributed.

Just as the analysis of a modern-day weather map begins with the areas of densest data, it is reasonable to apply this plan to the available information from 1785 or any other reconstruction. As the density of data for the major events of 1785 is much more plentiful, it is thus both reasonable and preferable as a starting point for plotting the working map. Therefore, as opposed to beginning with 1 January 1785, major events are the beginning point for the synoptic analysis.

With major weather events the temporal starting point, it is important to begin plotting by using the area with the finest possible spatial resolution of data. The area around Boston, Massachusetts, having already been well settled before 1785, is the best area to evaluate the plotted information. In 1785, a number of villages and towns had already become established with agriculture well underway. Each of these towns was at a stage where churches were also established, with resident literate ministers recording births, deaths, marriages and social events. Indeed, some of our minister-diarists were already filling in for each other in the pulpits of neighboring towns. Travel to and from Boston was undertaken regularly from the outlying towns, and was considered commonplace. Analysis of the plotted data begins in the region around Boston.

The major events range in duration from hours (frontal passages) to days (mature storms), but will set the stage for the continuation of the work. The analysis then continues by including adjacent areas with the next densest network of instrumental and observational data. The region stretching southward and westward from suburban Boston, Massachusetts to southern Connecticut at New Haven is analyzed next, rounded out with the data from the overall settled region from south coastal Maine to the Chesapeake Bay. Within this area, there exist sufficient observational and instrumental sets of data in addition to numerous anecdotal sources and historical support for expansion of the reconstruction.

The synoptic analysis is carried out using the most pertinent data first, followed by the additional parameters in order of their importance to the particular synoptic situation. For example, the temperature trend may be more important in arriving at the correct meteorological representation of a cold frontal passage than a study of the pressure on any given day. After the major events are resolved, obvious frontal passages, stagnant air patterns, and other changes in meteorological parameters are addressed. Start and stop of precipitation is noted, major shifts in wind speed and direction, and obvious changes in cloud cover or the character of the sky and weather receive next priority, as they would be the most accurate representations of the location of an air mass or passage of a meteorological feature. Analyzing these features first allows for the best possible analysis and best reconstruction for any given time, while still using all the techniques available.

Modern techniques are applied as frequently as possible in determining the centers of high and low pressure as well as for tracking tropical depressions, storms, and hurricanes. (see Petterssen (1940,1941), Showalter (1944), Byers (1944), Oliver and Oliver (1945, 1953), George (1949, 1953, 1960), George and Wolff (1955), George et al(1956, 1958), Saucier (1955), Petterssen (1956), Palmen and Newton (1969), Donn (1975), Bluestein (1992, 1993), Lutgens and Tarbuck (1998). After the major meteorological features are plotted and the analysis is complete, an estimation of upper atmospheric flow may be attempted. In the same way that we can use the specific parameters for forecasting heavy snow as listed above, we can also estimate the position of major and short wave troughs and ridges, thereby implying the presence of a zonal or meridional flow. For example, a storm noted in Hudson Bay on Day 1 arriving the next day in New England might imply a zonal flow, while a storm noted in Virginia on Day 1 and working up the coast to New England on Day 2 would likely imply a meridional flow. Any additional effects, such as the suspected presence of a short wave trough, are then included in the analysis, further refining the temporal scale

The following list contains selected examples of forensic synoptic techniques. These techniques are examples collected from a number of the sources cited in the text. They explain how various meteorological parameters can be assessed in a forensic mode by using surface observations as the initial point and hindcasting the parameters with which they are affiliated. These examples are generally used today for forecasting the weather, but are equally effective in the hindcasting or forensic mode.

3.9 Test of Other Anecdotal Data and Comments

The anecdotal data parsed in the first step of data reduction now can be recalled and tested against the completed synoptic analysis. These are the general references to the weather or other events, such as the Aurora Borealis observation mentioned above, which do not specifically represent an observation of a meteorological parameter. Many of these anecdotal references can, at this point, be assigned value when applied to major storms, floods, and the like. Others have no immediate reference to weather per se, and must now be viewed with respect to their relation to other notes from the same source and to the weather at the time of the note, as deduced from the synoptic analysis.

This step is accomplished by first assessing the note or observation in terms of other notes which might have been made by the same diarist. How often these notes appear in the span of the diary or record may give some indication of the importance the diarist places on the event, or of the importance of the event itself when compared to others in the diarist's experience. This analysis is only an indication, however, of the importance to the diarist and not to the synoptic situation. These comments must be compared with the weather of the moment to determine their meteorological value.

As an example, Ballard, setting out from Fort Western in Augusta, Maine, notes on 12 March 1785, that she "traveled with a candle at night". This observation, on its own, has little meteorological value. Only after assessing the entire year of her observations would one realize that she only mentions the extraordinary. One could assume that the winds were light, and a lantern was unnecessary. However, when compared with the weather map for that evening. (Figure 3.12) the fact that high pressure was indeed overhead, indicating

Table 3.4: Selected Examples of Forensic Synoptic Analysis Techniques.

1. When falling barometric pressure trend is slow, poor weather is the result, therefore reports of poor weather indicate a slow downward pressure trend. This is helpful in establishing the area of the extent of falling barometric pressure.
2. If a ridge, or area of high pressure, is located between two areas of low pressure, or storms, and the lows are moving at the same speed, the high will also move at the same speed. This is useful in establishing the speed of an approaching low in the absence of any other data other than the presence of high pressure.
3. If a ridge of high pressure is located between two areas of low pressure, and the lows are moving at different speeds, the high will move southward in the northern hemisphere. Thus a southward moving high will indicate different forward speeds for the areas of low pressure on either side.
4. A slow moving front brings a broader area of precipitation. Therefore, broad areas of precipitation (noticeable at this scale of analysis) will indicate a slow moving front. This is helpful in estimating the speed of advance of a frontal system.
5. A fast moving front brings brief precipitation, thus brief precipitation events indicate faster moving frontal systems.
6. Cold air west of a frontal system sharpens and intensifies a front. Therefore, an observation of an intensifying front would be proven out by strong cold air advection. Strong cold air advection in the absence of any other information would indicate a sharp front has passed. Look to the east and north for verification.
7. Frontolysis occurs under anticyclonic flow. Thus a dissipating weather system will indicated high pressure at upper levels of the atmosphere.
8. Persistent light precipitation indicates an occluded low pressure area. Proof is in the previous day, as occluded lows move very slowly, if at all. Persistent precipitation over more than a day or so indicates a stalled occluded low, which is accompanied by a cutoff low pressure area at 500 millibars.
9. Warm core high pressure areas move very slowly or become stationary. Therfore, persistent warm or humid weather with light winds indicated the presence of the high. Little, if any, movement in the near-term can be expected.
10. Low pressure areas increase in speed while deepening, until they reach the occluded stage, at which they slow in forward speed, and stop to dissipate. Therefore, precipitation types associated with a developing or mature storm (heavier rains and snow) can be used to move a low faster than if the lighter precipitation associated with occluded storms (light rain, drizzle, flurries) is observed. Also, a stalled storm can then be backtracked to its mature and developing stages with increased speed back in time.
11. Low pressure areas will intensify and recurve on their track if a strong short wave at 500 millibars and sharp cold air advection at the surface is present. Thus, a low which recurves towards the northeast in the northern hemisphere while intensifying indicates the presence of sharp cold air advection to the west and north at the surface, and the presence of a strong short wave trough at the jet stream level.
12. A new low pressure system will move along the warm isotherms at the surface until it reaches the 850 millibar level, at which point it will move at the speed of the upper flow. This will continue to 700 millibars, then to 500 millibars, etc. Thus a low which deviates from the track of the warm isotherm has reached and cut off into 850 millibars, and will, with its new forward speed and direction, indicate the speed and direction of the flow above.
13. Weak low pressure areas tend to move towards areas where precipitation has recently occurred. Thus, a low pressure area approaching an area of recent precipitation can be assumed to be weak, meaning it is at the wave stage and will not intensify. This, in turn, indicates a zonal flow in the upper atmosphere, devoid of short waves or any immediate strong cold advection.
14. Heavy snow (with the exception of lake-effect snows) occurs only on the northeast side of a mature or occluded low pressure system, between 0 and –2 degrees Celsius at the 850 millibar level, within the closed contours of the low at the 700 millibar level, north of the track of maximum positive relative vorticity advection, and, in northeastern North America, at 5400 geopotential meters or less of atmospheric thickness to the 500 millibar level. Thus, heavy snow in this region will indicate the presence of all of the above parameters.

light and variable winds at worst and calm conditions at best, verifies the anecdotal data as usable in meteorological form.

In all cases, suspect data can be resolved as applicable to the meteorological analysis. Refinement of the temporal or spatial scale of meteorological parameters was accomplished with these data. This reinforces the importance and value of even a single mention of environmental conditions.

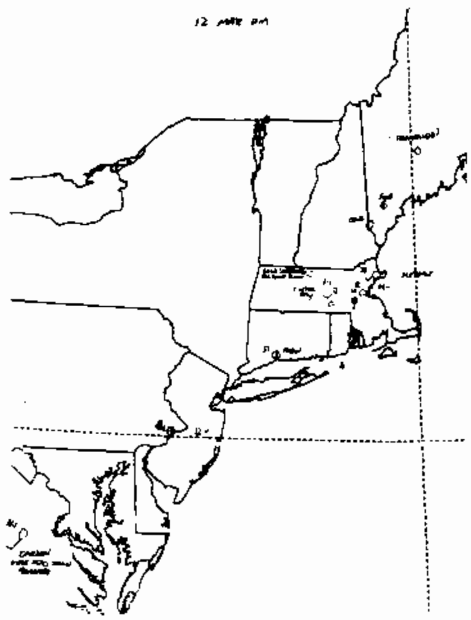


Figure 3.11: Map from 12 April 1785. Note Ballard's observation in Maine. See text for analysis.

3.10 Final Analysis and Summary

Macro scale analysis (beyond the spatial scale of the plotted and analyzed data) can be undertaken at this point, as a complete picture of the year is in hand. Without the entire year, and the anomalies discovered therein, this type of analysis would be mere speculation. For example, the prevalence of storm tracks and strong winds at this latitude says something important about the intensity of the jet stream and the proximity of the polar front to New England. This leads to the assumption that the polar cell was perhaps larger, as its edge is certainly depressed southward over this region of the continent. See Chapter 3 for these results and their use as a starting point for an assessment of circulation in the northern hemisphere..

Any additional refinements to the synoptic analysis can also be effected at this stage. For example, a long stretch of summer weather, without any important weather events mentioned, can be more accurately described when an indication of the upper flow is included. As discussed above, these would be periods of time when a large air mass might be overhead. These periods begin with the last known major event, and end when the next known event occurs. Now, with an assessment of the upper flow, otherwise unspecific weather during the period, such as a scattered shower, perhaps caused by the passage of a short wave trough, can be more accurately described. Thus times of sparse data can be more accurately described.

The relationship of weather events noted or observed at distant locations can now be related to the synoptic situation, helping to refine it further. For example, a newspaper report of a hurricane in Jamaica or a reference in a traveler's journal about his ship being beaten off the east coast by strong westerly winds can now be included in the larger picture in the same way that anecdotal comments are included in the procedure above. These distant reports can help in assessing the general upper flow in the atmosphere by tracking their results over a much larger area. Here is a summary of my methods for reconstructing the weather with forensic synoptic analysis:

- Acquire data (multiple sources and databases)
- Verify locus (travel where necessary)
- Decode coded diaries
- Re-extract data from prior works
- Extract historical and anecdotal comments for later use
- Codify data into usable meteorological format (wind scales, trends)
- Parse all information to twice-daily frequency

- Assemble each source into annual format
- Analyze individual sources for the year for major events
- Assemble all observations into daily format by month
- Combine with historical and anecdotal data for plotting
- Plot afternoon maps
- Plot morning maps
- Reconcile Suspect Observations
- Perform synoptic analysis
- Assess upper atmospheric flow
- Reanalyze for upper atmospheric influences (short waves, etc.)
- Test anecdotal data, include and refine analysis as applicable
- Analyze for macro scale
- Assess distant reports, include and refine analysis as applicable
- Reach conclusions

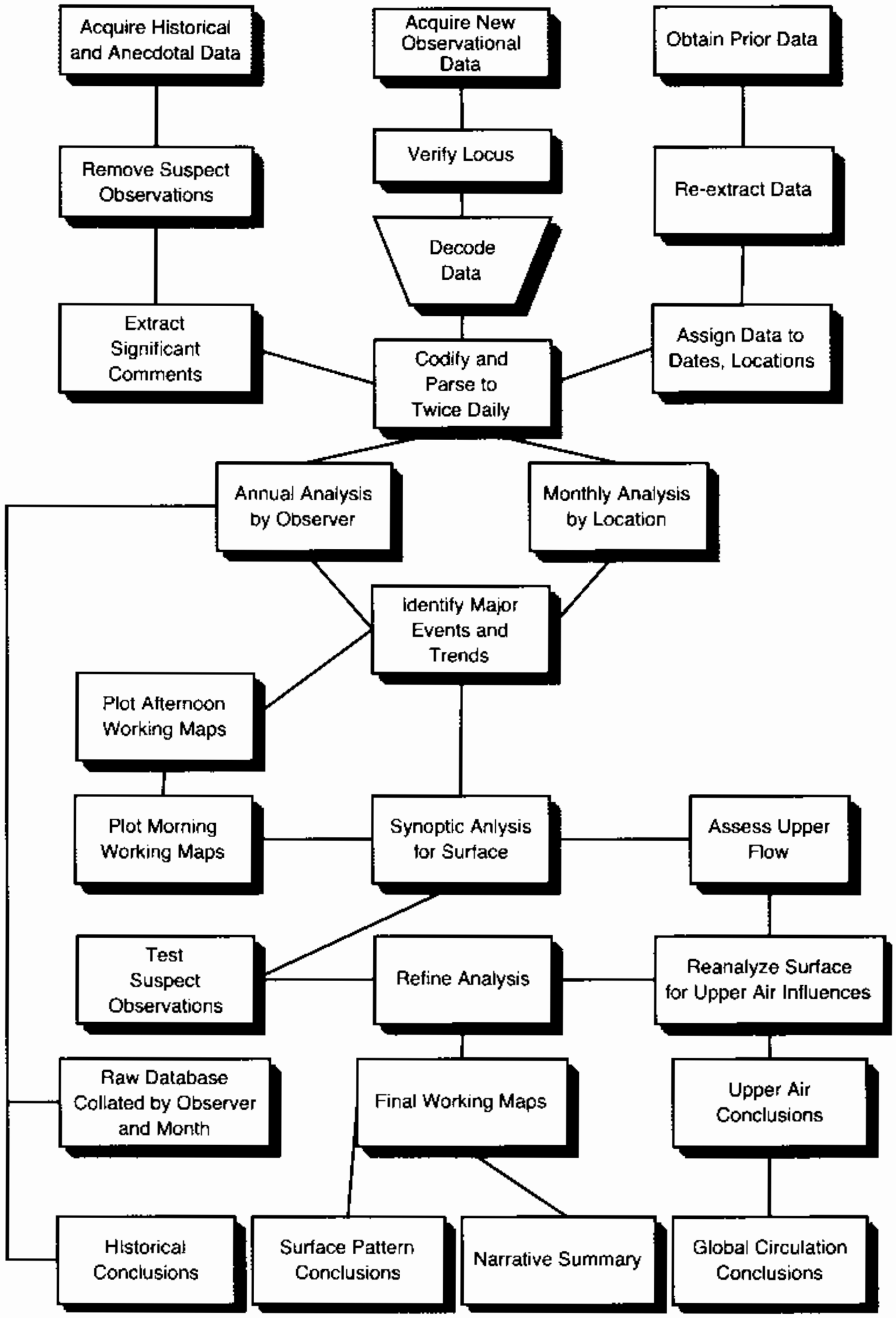


Figure 3.12: Outline of methodology.

CHAPTER 4

RESULTS

Qualitative (anecdotal) and quantitative (observational) evidence indicate that 1785 was colder than today (1994-2003). Synoptic analysis reveals a definite lag in the arrival of warm air in the spring, a lack of transition seasons, and cool-season weather patterns during the summer. Analysis of temperature curves also indicates an increase in the variability in the weather in 1785 with respect to today.

4.1 Anecdotal Evidence

4.1.1 1785 Colder Than Today

Numerous examples found in anecdotal evidence indicate that 1785 was cooler than today. Many diarists mention a "backwards spring" or a "backwards season". These terms refer to a spring season that may have included a brief warming early in the season, followed by a long cool period, which lasts well past the expected arrival of warmer temperatures. Although these are only colloquial references, they do agree with other anecdotal and instrumental evidence.

Newspaper reports also indicate that winter cold persisted well into the year, and much longer than today. From the *Independent Journal*, New York, dateline Philadelphia, 1 January 1785: "The navigation of the Delaware has been impeded for some days past by the ice, which renders it unsafe for vessels either to come in or go out." (Independent Journal, 1785). And from another edition, 9 February, dateline New York: "Yesterday arrived at their moorings in the East-River, his Britannic Majesty's Packet, the Speedy, and the Brigantine Sally, Captain Raymond, from Bordeaux. These vessels have been long detained from coming to town, by prodigious quantities of floating ice ..." (Independent

Journal, 1785). Another report from Philadelphia on 26 January relates: " ... on Sunday, between 20 and 30 sail of outbound vessels left this port to proceed on their intended voyages; since which several vessels that had been detained below by the ice, have come up to town." (Fowle's New Hampshire Gazette and General Advertiser, 1785). Ballard (1785) mentions crossing the frozen Kennebec River in Maine in late April, as well as snow up to her windows, and that the river did not open up for navigation until June.

To contemporary writers, other years in the 1780's were considered to be even colder. Thomas Jefferson (1787) noted the cold of 1780, mentioning that a temperature reading of 6 degrees (F) was registered at Williamsburg, Virginia in that year. He wrote: "I believe (this) may be considered to be nearly the extreme of ... cold in that part of the country ... as, at that time, York river, at York town, was frozen over, so that people walked across it; a circumstance which proves it to have been colder than the winter of 1740, 1741, usually called the cold winter, when York river did not freeze over at that place. In the same season of 1780, Chesapeak bay was solid, from its head to the mouth of the Patowmac. At Annapolis, ... the ice was from 5 to 7 inches thick quite across, so that loaded carriages went over on it." As these reports would be rarely, if ever, heard today, one can assume at a minimum that the winters were indeed colder.

4.1.2 1785 More Variable Than Today

Thomas Jefferson, in his Notes on the State of Virginia (1787) observes the change in his climate at Monticello thus: "A change in our climate however is taking place very sensibly. Both heats and colds are become much more moderate within the memory even of the middle aged. Snows are less frequent and less deep. They do not often lie, below the mountains, more than one, two, or three days, and very rarely a week. They are remembered to have been formerly frequent, deep, and of long continuance. The elderly inform me that the earth used to be covered with snow about three months in every year. The rivers, which seldom failed to freeze over in the course of the winter, scarcely ever do now."

Jefferson also notes, however, a change in the spring: "This change has produced an unfortunate fluctuation between heat and cold, in the spring of the year, which is very fatal to fruits. From the year 1741 to 1769, an interval of twenty-eight years, there was no instance of fruit killed by the frost in the neighbourhood of Monticello. An intense cold, produced by constant snows, kept the buds locked up till the sun could obtain, in the spring of the year, so fixed an ascendancy as to dissolve those snows, and protect the buds, during their development, from every danger of returning cold. The accumulated snows of the winter remaining to be dissolved altogether in the spring, produced those overflowings of our rivers, so frequent then, and so rare now." (Jefferson, 1787). Although his assessment of the climate was that it was generally more moderate, the variability, particularly in the spring, stood out for him.

4.2 Temperature Evidence

4.2.1 1785 Colder Than Today

Comparison of temperatures from 1785 with today (1994-2003) reveals that 1785 was indeed colder. Average temperatures (Figure 4.1) were computed from outdoor observations taken by Holyoke (Salem, Massachusetts), Wigglesworth (Cambridge, Massachusetts), Stiles (New Haven, Connecticut), and Adair (Philadelphia, Pennsylvania). The morning and afternoon readings were used as proxies for the high and low temperatures for the day, according to contemporary custom. From Thomas Jefferson in 1790: " ... my method is to make two observations a day, the one as early as possible in the morning, the other from 3 to 4 o'clock, because I have found 4 o'clock the hottest and daylight the coldest point of the 24 hours" (Foley, 1967). These temperatures were used to compute an average temperature for the day. As the shoreline was much closer to Cambridge in 1785, the lower summer temperatures at Cambridge compared with those recorded at Salem are attributed to Wigglesworth's proximity to the water, thus being more susceptible to cooling from afternoon sea breezes.

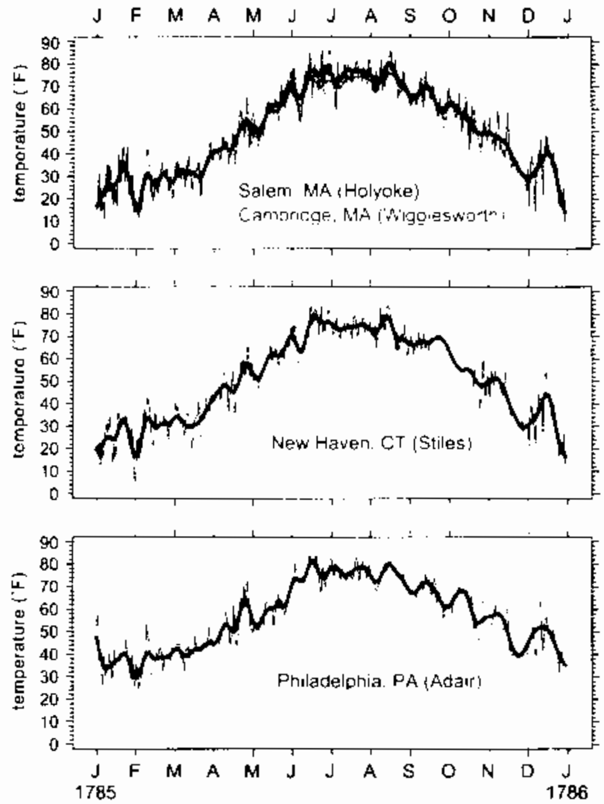


Figure 4.1: Four annual instrumental summaries for 1785.

In Figure 4.2, the observations from 1785 by Holyoke and Stiles are compared with similar locations for 1994-2003. Holyoke's record from Salem is compared with Logan Airport in Boston (BOS), and Stiles's temperature record from New Haven is compared with that of Tweed Airport in New Haven (HVN). One can see that, although the summer temperatures are remarkably similar, the winters are longer and colder in 1785 than they are today. There is also a noticeable delay in the advance of springtime warmth, as mentioned in the anecdotal evidence above.

Statistics including annual average temperature, standard deviation, variance, and annual extremes for Stiles and Wigglesworth are summarized in Table 4.1, along with the year-by-year temperature statistics from 1994-2003 for New Haven and Boston, respectively. Mean annual temperature for 1785 is lower than any recorded between 1994-2003.

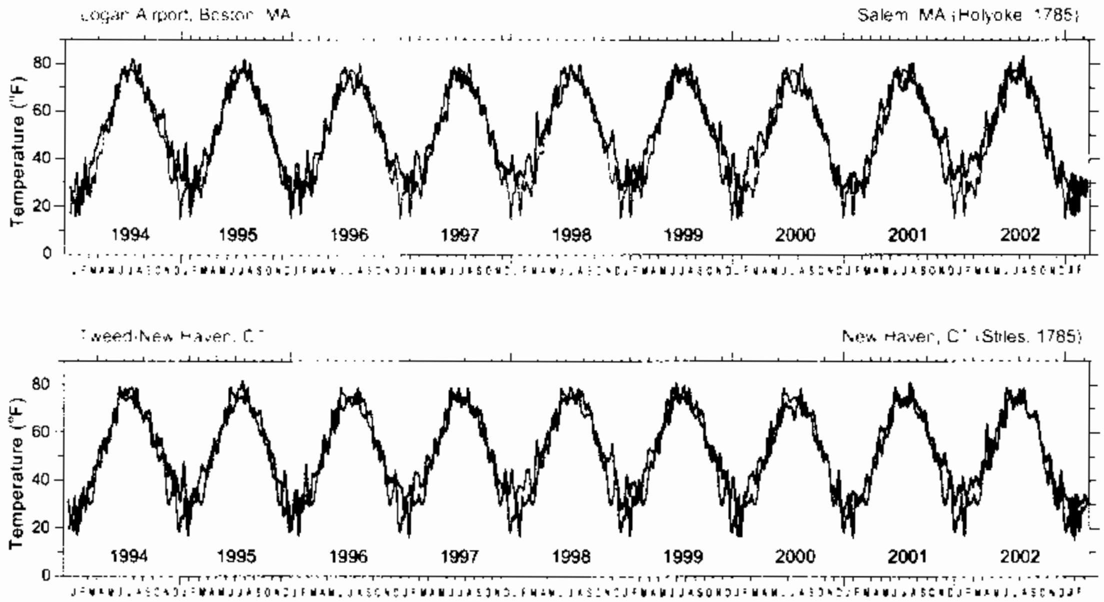


Figure 4.2: Comparison of Holyoke and Stiles' annual temperatures with 1994-2002 Boston and New Haven records (1785 repeats).

Comparison with the Global Historical Climate Network (GHCN) temperatures (Vose, et al, 1992) indicate that a slightly warmer summer and fall could be inferred when using the 1785 data from this study. See Figure 4.3. However, no smoothing was applied to my data. See references for complete methods used to adjust raw data in the GHCN.

4.2.2 1785 More Variable Than Today

Variability derived from comparison of the 1785 data with that of today also supports an increase in the variability compared with 1994-2002. The difference in range stands out in figure 4.2. Although there is some difference from year to year, summer maxima are generally similar, while winter minima are lower than those of today. The delay in spring warmth also contributes to the overall increase in variability. Variance computed from daily temperatures is higher for 1785 than any year from 1994-2002. See table 4.1 for results.

The increased variability in 1785 was reflected in reports of the day. Drought in Europe was serious, and was recorded in numerous letters and papers. Following are reports

Table 4.1: Temperature statistics for New Haven 1994-2003 and Boston 1994-2002 compared with New Haven, Salem and Cambridge in 1785. Note lower annual means and higher variance for 1785.

year	mean	sigma	var	max	min
Tweed/New Haven					
1994	52.8	17.7	313.3	86.5	5.0
1995	52.7	16.9	285.6	88.0	11.0
1996	52.9	16.9	285.6	80.5	10.5
1997	53.2	15.5	240.3	83.5	12.0
1998	56.2	14.9	222.0	82.5	19.5
1999	54.2	15.9	252.8	90.5	15.0
2000	51.4	16.1	259.2	80.0	10.5
2001	53.9	16.1	259.2	86.0	20.3
2002	52.6	15.6	243.4	83.0	25.0
New Haven					
1785	50.4	19.8	392.0	83.5	3.5
Boston/Logan					
1994	52.8	18.4	337.2	86.0	2.0
1995	52	17.5	306.0	86.5	7.0
1996	51.3	16.6	275.0	81.0	11.0
1997	51.5	16.4	270.0	84.0	10.0
1998	53.7	15.5	240.1	83.0	14.0
1999	53.6	16.6	274.6	89.0	9.5
2000	51.2	13.7	271.2	80.5	3.0
2001	53.1	16.5	272.0	85.5	19.0
2002	53.4	16.5	273.0	89.0	23.5
Salem					
1785	50.6	19.9	396.0	87.0	9.0
Cambridge					
1785	49.3	18.4	338.0	82.0	12.5

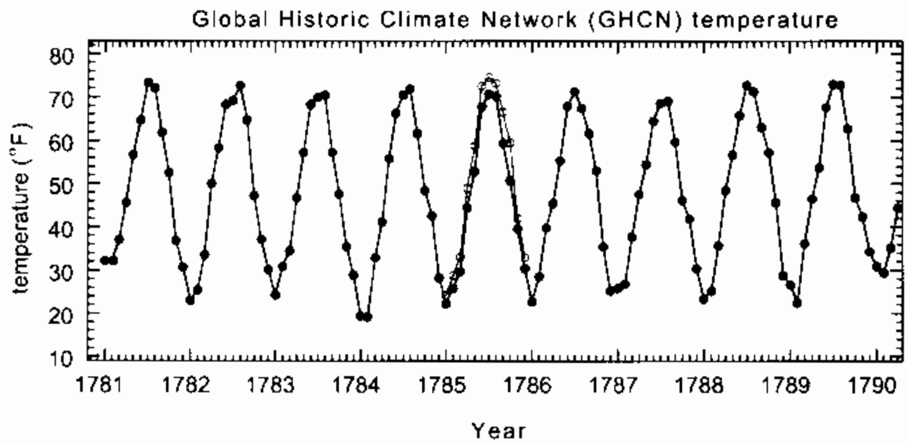


Figure 4.3: Comparison of 1785 temperature data with the Global Historic Climate Network.

published in Fowle's New Hampshire Gazette and General Advertiser. One report from France notes: (dateline London, June 8) "The accounts of the present drought in France are truly singular. In the internal provinces of that kingdom, not only ponds and lakes are dried up, so that the peasants are in want of drink for their cattle, and thereby reduced to the necessity of killing and disposing of them : But the canal of Bordeaux, between San Sangtoigne and Chateaux de Mir, is so low that barges cannot pass.- The fruits of the earth are dried up, and they have a terrible prospect of grain and the vintage, unless rain falls shortly."

Dateline Vienna, June 11: "Last week great damage was sustained in the Vineyards and the fields in this Neighbourhood, and particularly towards Krems, by the fall of a prodigiuos Quantity of Hale, in Consequence of which the Temperature of the Air was greatly chilled, but the Warmth is now restored. They write from Syria that the Weather there is still exceedingly cold, & that all the Mountains are again covered to a considerable Depth by a great Fall of Snow on the 1st." (ed. note: June 1st.)

From England, dated Falmouth, July 9: "Such weather was never known here as we have had these six months past, no more than two days rain during the whole time ; there is less grass on the ground than there was at Christmas last :-hay, which usually at this

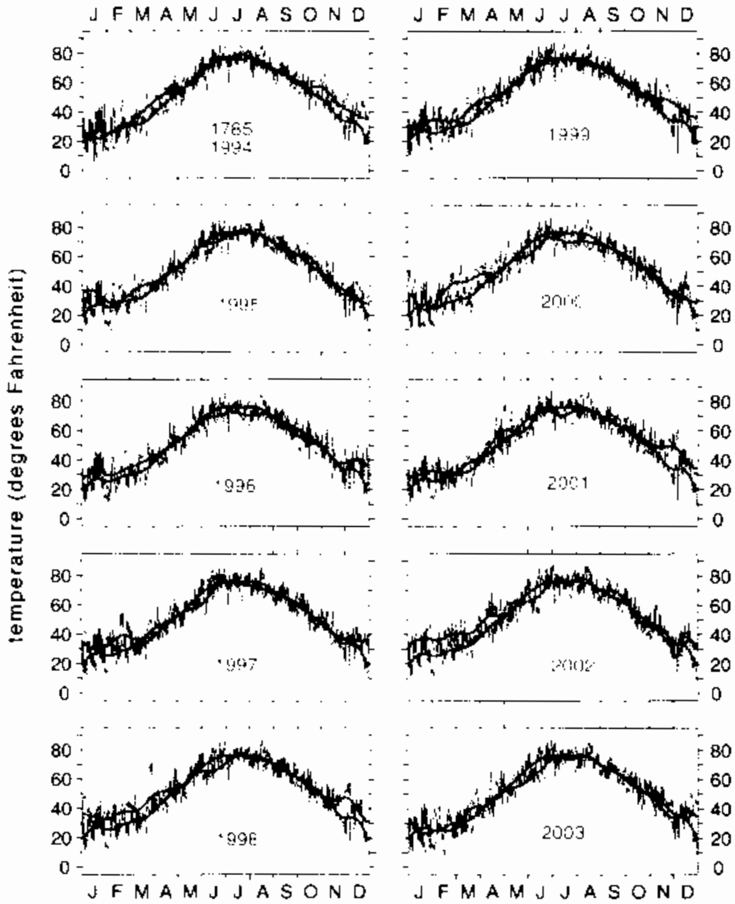


Figure 4.4: Comparison of 1785 Holyoke temperature data with the temperature recorded at Boston Logan for 1994-2003. Note lag in springtime temperatures except in 2003, and similarities in summer maxima.

season was 14d. is now 10s. per cwt. though the harvest is promising, particularly for wheat."

The letter continues: "There is not a greater instance of the extreme drought of the present season in Europe. than the following, which is selected out of a letter from a house of eminence in the commercial line at Dorltf (sic), in Holland. 'You will scarce believe that in a country like this (watery by nature) that we complain of drought ;- but such is absolutely the case at present, no rain having fell in this country for upwards of four months, and the continued easterly winds have so emptied the Rhine, Locke, Maese, and Dartez, that there are not in many places sufficient water to carry vessels over the shoals. Our wells are uncommonly low ; and as a greater phenomenon, at the Kiender Dyke (which is famed in history for the circumstance of 73 villages being overflowed by its breaking in the year 1691), the waters are so low, that the very foundation of that stupendous fabrick is now to be seen, and workmen are repairing it in many places. Such a circumstance has not occured in memory of the oldest man now in Holland.'"

4.3 Synoptic Evidence

Results from the synoptic analysis of 1785 show a number of reasons why that year was colder and more variable than the present day. The lag of springtime warmth can be identified, as well as the lack of transition seasons, and the cool season patterns that appear to be prevalent in the summer. The default pattern of a strong coastal baroclinic zone is apparent. Other differences that stand out include late, heavy snows, frequent icing, and a strong zonal flow around a persistent snow pack late into April. One interesting similarity is the depth and extent of the winter in 1994 and 2003. When comparing 1785 to the rest of the decade of the 1780's, monthly averages do not indicate that 1785 was particularly cold. In fact, 1784 was colder than 1785. The fact that these two present-day winters were similar provides insight into the environmental conditions faced by the observers and diarists of 1785.

4.3.1 Late Winter and Spring

Late, heavy snows occured in the latter part of the winter season in 1785. Snow accumulating late in the season implies both increased intensity on the storm track, and less of a continental effect in the region. Late, heavy snows also indicate that the coastal baroclininc zone was much more active at this time of the year, precluding the usual development of warm air advection patterns. Normal warm-frontal advances with the east-west warm fronts that would be expected in the spring were delayed, and do not appear until summer. This default to the baroclinic zone may have been a result of colder sea surface temperatures adjacent to a warming land mass.

Icing events noted by Washington imply that continental polar (cP) air was stronger and penetrates farther south than today. Although these icing events may have been no more frequent than today, they were stronger and later in the season. From Washington on 16 April 1785: "A great Hoar frost and ice the 1/8 of an Inch thick. What injury this may have done to fruit & vegetation, will soon be seen." And on 21 April 1785: "Ground hard crusted with frost this morning (no hoar frost)Ice the 1/8 of an Inch thick" (Washington, 1785).

Icing is caused by cold air trapped at the surface by a process called "damming". This occurs when cold polar air penetrates southward, but is prevented from retreating because of its density. The air is unable to rise over the mountains to the west and north, and is overrun by warmer air advecting from the south. The resulting precipitation falls as rain into the colder air, and freezes on contact. The fact that this occurs as late as the end of April issupporting evidence that the polar air was both stronger and colder, and penetrated farther south than it does at the present.

The fact that the polar air was present longer in the season would imply that snow cover on the ground to the north also lasted later into the year. The flow of upper air winds around and at the edge of the remaining snow pack in the spring appears to continue through the month of April. A transition season would be well established by this time today, and high pressure moving east out of southern Canada would commonly stall at the shore. This did not occur in 1785, and springtime highs (polar air masses) were larger and stronger.

The edge of the snow pack in the spring months appears not only to have prevented warm air advection, but also was lined up with the upper flow. It is possible that the upper flow was either steered or enhanced by the presence of the snow pack. Although further study is needed to prove this theory, it does follow that the polar cell may, in fact, be determined by the position of the edge of the snow pack during these transitional times of the year. A study by Namias (1963a) estimated that up to 80% of the incoming solar insolation might be lost due to persistent snow cover in the midwestern United States driven by numerous late cold outbreaks. Houghton and Lamb (Houghton, 1958, Lamb, 1955). also noted that large-scale ground cover changes, such as extensive snow and ice cover or sodden, flooded ground, are capable of "noteworthy effects upon the large-scale atmospheric circulation". Lamb tied the extent of the snow cover to a persistent cold trough in the westerlies (Lamb, 1972), which was the case in the spring of 1785 in eastern north America.

The lack of a transition season between winter and spring is evident through the end of May. Once again, the spring season would normally be well established by this time at all locations. Another result of the zonal flow in the spring months is the eastward movement of well-developed polar high pressure areas and attendant polar air masses from Canada to points offshore in the Atlantic Ocean. The smaller temperature difference between the air and the ocean allowed the air mass to move eastward, north of New England, with little to impede its progress. The resulting return flow of air around the High produced a cold onshore (easterly) flow that be at reached as far inland as Albany, New York. The more common scenario today would have a much weaker high stalling at the shore, allowing only localized sea breeze effects to develop.

4.3.2 Summer

The fact that the storm track south of the region was still active at the end of June indicates the presence of a split flow in the upper levels of the atmosphere. Because air temperatures at certain times do indicate the rapid advance of summer, and the presence of a maritime tropical (mT) air mass, it follows that any storm development south of the region would be associated with its own branch of the jet stream. Thus the possibility exists for a triple split flow, with the far northern and middle branches of the jet stream located near today's positions, and the third branch operating further south as the subtropical jet stream

The presence of a cutoff high pressure area in the summer season of 1785 is much more common today in the transition season of spring. The fact that the high was both located this far north (in southeastern Canada) and cutoff would imply that the default pattern for the mid-summer season resembles today's springtime patterns. This scenario supports an extended cool season and a much shorter summer season, as well as the continued presence of strong polar air just to the north.

The expected springtime east-west oriented stationary front, missing in 1785 finally appeard by August. Once again, we see the presence of a springtime event in midsummer. The stationary front in mid-August is one that would normally be found in either of the two transition seasons (spring or autumn). Its presence in summer supports the fact that the default pattern for summer, brief warm air advection events notwithstanding, would be more in character with today's spring or fall patterns. A stationary front at this time of year would outline the edge of colder air from the north. Some inference can then be drawn regarding both the presence and proximity of the polar front over New England.

Another indication that the polar cell is much larger and more persistent is derived from the apparent presence of the storm graveyard near enough to the region to cause some effects at the end of August. The storm graveyard is the end of the storm track, or the area in which mature cyclones reach occlusion and stall, having performed their function of mixing two or more disparate air masses completely, both horizontally and vertically in the atmosphere. Today, this event occurs in this region during the transition seasons of spring and autumn. Therefore, the size of the polar cell, or at the least the extent of its retreat in the warm season, can be implied. The polar font is well defined by the end of August and the beginning of September of 1785, signaling the beginning of early winter weather patterns, and precluding the appearance of a transition season by now.

4.3.3 Autumn and Early Winter

For reasons stated above, the transition season at the end of summer is not observed, though some mid-summer heat and tropical events are noted. There is no apparent easing of the flow into the winter. The autumn season pattern is replaced by the early winter storm track, which extends right through to the mid-winter pattern later in the year. The presence of the polar front this early in the year also precludes any late season warmth from becoming established for any length of time.

Cold air advection of the type one would normally expect in late January or early February today, i.e. Arctic or continental Polar (cP) air, is evident by the end of September. Even in widely variable years today, Arctic outbreaks of this style and magnitude do not occur until at least mid-November. These cold air events are much more well-developed and common in 1785, and imply that the snow pack to the north and west was already established, allowing the unimpeded advection of Arctic air into New England.

In order to have maritime polar air reach the region on a westerly flow from the Pacific, the entire continent must be crossed. With the polar cell well established and further south than normal, the mid-continent snow pack is also firmly established. The implication is that the flow in the center of the continent is now quite zonal, and the snow pack itself is evenly spread at the latitude of the jet stream, reinforcing its position. In this zonal flow, storm systems in the Pacific would not have the time or the pattern to occlude and stall along the west coast of the continent, and would most probably be forced inland, over the mountains, and would bring precipitable water to the high plains, producing the blizzard conditions so well documented in 1997 in the Dakotas. A well-developed westerly flow and sufficient Pacific moisture were in evidence this year as well.

4.4 Similarity to 2003

Noting the similarity of the temperature for 1785 and 2003. one might suspect that a similar pattern might occur. In fact, the similarities are quite profound. Although no reports of June snow in Syria have been found. nor are any ships reporting that they have been blown off the coast. other similarities stand out. The Following reports are from numerous sources and describe the weather in 2003. The interesting difference is that the modern-day reports not only mention the weather. but also its human and economic impact.

The comparison with Europe in 1785, and the problems with transportation are clear. An article datelined Bucharest, Romania mentions dredging of the Danube River due to low water because hundreds of barges could not pass. The water level had dropped to six feet. More dredging was required in Zimnicea. as more than 250 ships were delayed. The economic impact upstream was noted, as barges were forced to carry lighter loads, forcing up the cost of goods transported by water. The Elbe, the Rhine and the Ticino River in Italy were all well below average, and the levels of rivers in Serbia reached 100-year lows (Portland Press Herald, July 29, 2003). Because much of Europe uses these rivers for hydroelectric power, an argument was presented for more nuclear power plants by the Nuclear Policy Research Institute (New York Times, September 18, 2003).

The most startling similarity may be the heat. Britain reached an all-time record high temperature in the summer of 2003, when the thermometer at Heathrow Airport reached 100.22 degrees F., and Gravesend reached 100.58 degrees F. Transportation was disrupted as rails buckled in the heat forcing trains to slow down (Associated Press, August 10, 2003). Dozens of deaths were reported in England, and excessive heat reached Spain and Portugal. The heat was named the cause of numerous brush and forest fires (not mentioned at all in 1785). (Although a negative NAO (North Atlantic Oscillation) would be consistent with heat in northern Europe, storms would track through the south. The lack of rainfall in southern Europe is not consistent with that pattern.)

The worst toll appears to have been in France. where 14,000 people died as a result of the heat. Juxtaposed with the human toll, there are references to increased profits from beer sales, and an expectation of a spectacular wine harvest (Atlanta Journal-Constitution, October 23, 2003). Not only might we foresee some of these consequences in the future, but we might look to the anomalous pattern first seen in the winter temperatures and lag in springtime warmth in 2003 and prepare.

4.5 Summary

In summary, although the year 1785 was colder on average than the last ten years, the resulting weather patterns are quite clear and different than today's. Polar air and a strong jet stream are evident throughout the year. The persistence of the cold air into April and May precludes the timely arrival of the transition season of spring. Even with occasional appearances of summer warmth, similar in intensity to today, the general summer pattern more closely resembles spring. Summer patterns never become established, continually being replaced by cool season events. Winter patterns appear early, precluding an autumn transition season.

In the few cases where the polar air is not the forcing factor, the default pattern most obvious during the year 1785 is the rapid and frequent development of the coastal baroclininc zone and the eventual frontogenetic activity along it. The temperature difference between the land areas and the colder ocean would certainly play a role in this scheme. Additional evidence is provided by the number of weak low pressure areas which move rapidly along the frontal boundary without reaching the mature stage. By virtue of the fact that maturity is not reached, the upper flow can be implied as that which corresponds to the direction of movement of the lows. Thus the southwest to northeast upper flow in these cases are consistent with the presence of a trough to the west.

Should the trough be a single, long wave trough, the effects in Canada would be different from those discovered. Fast moving and weak lows are evident through Canada on a west-to-east upper flow at the same time. This now implies that a split flow (both in Canada and along the coastal baroclinic zone) is present at most times of the year, perhaps rejoining east of the area over the Atlantic. If the northern branches do not rejoin, and continue on independently, it would further support a pattern similar to Lamb's reconstruction. The fact that the coastal zone appears to be the most active in this colder weather pattern would seem to indicate that further research might center on this area as opposed to the mid-continent regions or a combination of the two. The continued presence of a southern storm track throughout the year supports the assupmtion of a triple split flow.

These major results appear clearly when extracted from the anecdotal, observational and synoptic data. Anecdotal and observational data indicate that the year 1785 was both colder and more variable than today, when compared to the last ten years. Monthly reconstructions do not contain the detail that individual observations and reports can provide. Working towards a synoptic analysis from these individual data provides important insight into the effects of the weather on human activity on a day-to-day basis on a scale of resolution unattainable from longer-term averages.

CHAPTER 5

GLOBAL CIRCULATION IN 1785

5.1 Introduction

In this chapter I attempt to develop an outline of the general atmospheric flow around the year 1785, in North America. The results of my reconstruction of daily weather in this year for the northeastern part of North America imply a relatively cold flow over central and eastern North America for most of the year. The source of the colder air is to the north and west, and I begin with the assumption that a north to northwest flow from north central Canada was prevalent for most of the year. By comparing proxy data from other locations around the world to identify the location of the polar front (or edge of the polar cell), it is possible to outline a general flow around the northern hemisphere resulting in one similar to that theorized by Lamb (1977), and described as a short-circuit cross-polar flow, around the edge of a displaced and possibly larger polar cell.

This flow suggests storm tracks that would provide the precipitation necessary for the development of the Laurentide and Scandinavian ice sheets. Storms would travel up the east coast of the United States and recurve northward into eastern Canada. An additional track would supply the moisture for northern Europe. This circulation, also independently described by Flohn (Flohn, 1969), is similar to that which may have been prevalent at the onset and during the dissipation of the most recent glaciation (Figure 5.1).

Wexler (1956) has suggested that a hypothetical reduction of 20% in isolation, whether from reduced solar output or from volcanic effects, would result in a circulation characterized by a broad trough over eastern North America. Lamb (1977) notes that this is similar, although weaker, to the circulation around 1800. Both are characterized by a strong and persistent trough in eastern Canada, extending down the east coast of the U.S. This would result in a prevalent cold flow to the northeastern United States from Canada. These patterns may be representative of a transitional period between major warm and cold regimes in the northern hemisphere.

Studies covering the 1780's are sparse, and concentrate on the possible cooling from volcanic effects in 1783-1785. However, valuable data can be extracted to arrive at the outline of the prevalent flow by following the cooling signal, or lack of it, in these proxy studies. Additionally, numerous analyses exist focusing around the year 1816, following the eruption of Tambora, some of which do extend back to 1785. The dust veil index (DVI) for the 1816 time period is very high, as is that in 1785 (3000 and 1000 respectively vs. 1680-1974 average of 475, Lamb, 1972). Some additional inferences may be drawn from and comparisons made to the 1816 data. Both 1785 and 1816 followed moderate (M^+) ENSO events, and the differences between the resultant effects also suggest the presence of a general cold cross-polar flow in 1785.

Most of the cooling effect from Tambora in 1815 occurred in the year immediately following the eruption. Mid-latitude effects from the eruptions in 1783 appear to have lingered for two years (Kington, 1992). Generally, although the decade of the 1780's was already colder than normal in many areas, the cold cross-polar flow appears to be amplified by the effects of the 1783-1785 high-latitude volcanic events in both Iceland and Japan. This amplification is also supported by the findings of Quinn and Neal, outlining the possible combination of effects from the El Chichon eruption and the El Niño of 1982-1983 (Quinn and Neal, 1983b). It would appear, then, that the cross-polar flow might be triggered by additional forced cooling from reduced insolation when occurring in a generally cooler period.

It would also appear that this cross-polar flow short-circuits the normal general atmospheric circulation, particularly at polar latitudes above 60° north. This flow develops brief, yet strong polar outbreaks at the southern end of the cross-polar route in Canada and the eastern United States. This further supports the finding of split-flow in the jet

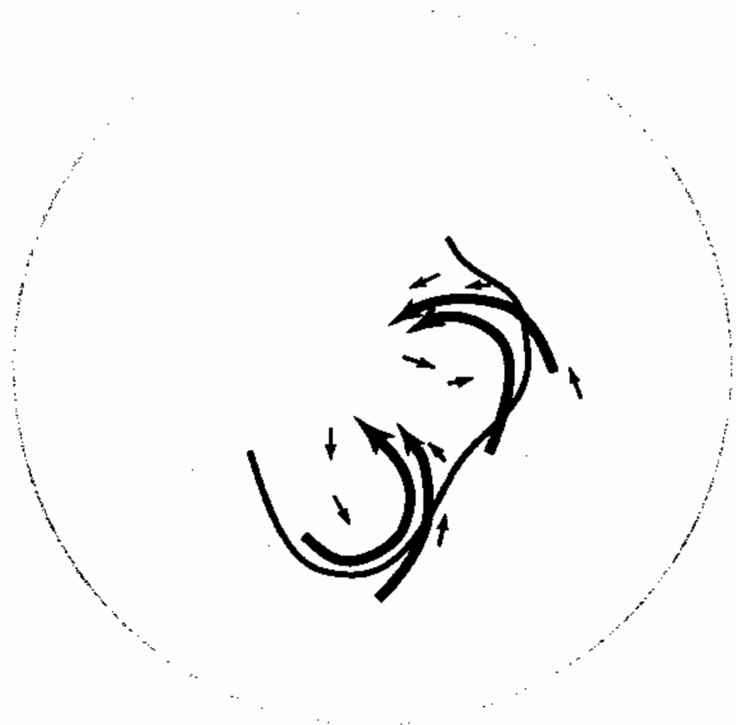


Figure 5.1: Short-Circuit Flow, from Lamb, for the onset of the Würm/Wisconsin glaciation. Thin line denotes average 5300 geopotential meter surface to 500 mb thickness for January. Short arrows denote prevailing surface wind. Broad arrows indicate storm tracks.

stream that may, in fact, sometimes have three branches (see results in Chapter 4). An expanded or displaced polar cell, evidenced by a polar front further south than normal in North America, may take on very different circulation characteristics from the usual, or normal, polar cell of today. These differences are most pronounced in North America, the North Atlantic Ocean, western Europe, and central Asia. I begin the reconstruction, then, with the assumed northwest cold flow in Canada, west of Hudson Bay.

5.2 North America

In addition to my results (see Chapter 4), Content analysis by Baron (Baron and Gordon, 1985) shows that the early 1780's in eastern Massachusetts, in general, exhibit shorter

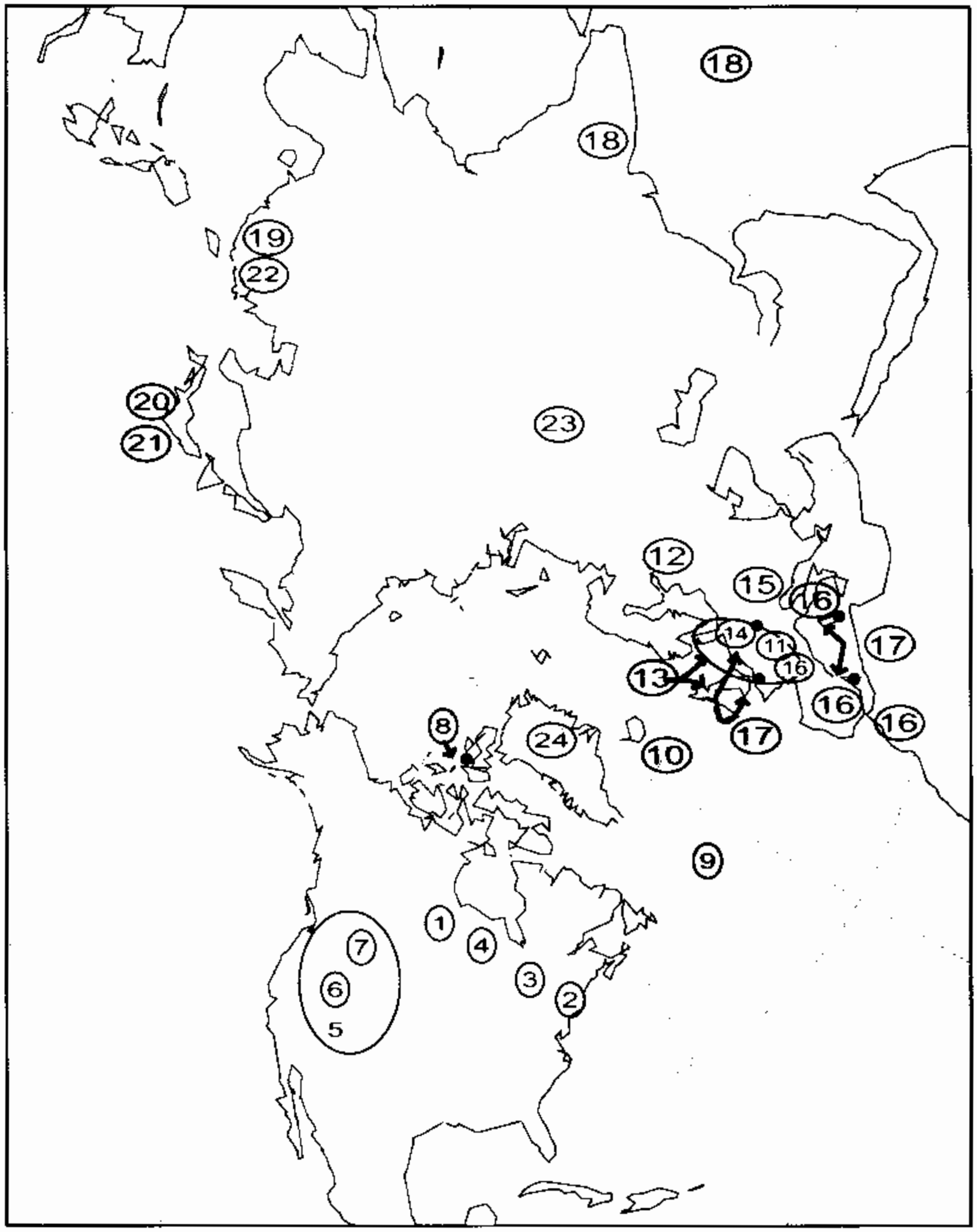


Figure 5.2: Data Points for Reconstruction of Prevalent Flow in 1785. See Table 5.1 for data types used at each point.

Table 5.1: Research types for Data Points

#	Source	Data Type
1.	McNally	Documentary & observational data forensic synoptics
2.	Baron	Documentary & observational data content analysis
3.	Crowe	Documentary evidence triangulation & extrapolation
4.	Fayle	Radial & height increment tree growth analysis
5.	Lough	Tree ring chronologies, regression analysis
6.	Luckman & Colenutt	Latewood marker tree ring chronologies
7.	Fritts & Shao	Standardized tree ring widths, spatial arrays
8.	Alt, et al.	Isotope & melt percent values, synoptic analogues
9.	Lamb	Monthly mean MSL from observations
10.	Ogilvie	Documentary evidence
11.	N.H. Gazette & Pfister	Documentary evidence, newspaper, diaries
12.	Schove	Tree ring analysis
13.	Moberg	Historical observations
14.	Wood	Historical observations
15.	Bednarz & Trepinska	Width & maximum density tree ring studies
16.	Serre Bachet, et al.	Tree ring width
17.	Serre Bachet, et al.	Dendroclimatological & documentary reconstruction
18.	Roy	Documentary evidence, Delhi wheat prices
19.	Wang & Zhang	Documentary evidence, Qing Yu Lu
20.	Tsukamura	Synoptic analogues
21.	Mikami & Tsukamura	Documentary evidence, freeze dates, diaries
22.	Huang Jiyaou	Documentary evidence, dryness/wetness grades
23.	Borisenkov	Documentary evidence, religious chronicles
24.	Meeker & Mayewski	Ice core evidence, ion series

growing seasons, more winter days with fair-sky conditions, more summer days with thunderstorms, and more winter snowfall days than the remainder of the decade. Both shorter growing seasons and more winter days with fair-sky conditions indicate a prevalence of clearer Arctic or polar air masses in both summer and winter. The variablilty and vigor of the atmospheric circulation at other times of the year can be deduced from the more frequent summer thunderstorms, indicating an active summer Alberta storm track. More winter snowfall days would indicate more frequent and slower-moving winter storms. Generally, when not under the direct influence of polar air masses, the northeast could be construed to be near the polar front, its southern edge determined by the storm tracks in eastern North America. These results concur with mine.

Crowe (1992), in his reconstruction of temperatures for Toronto, Ontario, Canada, finds significant effects from the volcanic activity in the summer of 1816, but very little variation during the 1783-1785 time period. Mean July temperature in 1816 (16.1°C) is more than 3° below the 50-year running mean, while 1783-1785 are all within 1° of the 50-year running mean. The similarities in the July mean temperatures of 1783-1785 would indicate a persistent pattern, consistent with the interior of a cold air mass as opposed to the dramatic effects in 1816. Again, assuming that the polar front is generally south of the area in 1785, the effects of the weaker volcanic activity would not be expected to appear in data from so far inland, inside a continental air mass. Further north and west, and deeper into the continent, at Churchill, Manitoba, some cumulative effect on tree growth after Tambora is noted with white spruce (Picea glauca) and tamarack (Larix laricina) studies (Fayle, et al., 1992), but no major effect is found, further supporting the presence of a continental air mass, which is assumed to be present in 1785.

Tree ring chronologies for the western part of North America developed by Lough (1992) show no large deviation from a long-term (1602-1960) mean. As the chronologies are reconstructed from sites at middle latitudes in the western third of the continent, this result is not surprising. In fact, the continentality expected from these interior sites in the southwestern part of Canada and the western USA, within and east of the Rocky Mountains, would prevent or at least dampen the detection of any signal from the east or north. These areas are under the effects of semi-permanent continental pressure patterns and away from the assumed cold northwest flow east of the Rocky Mountains. They would not necessarily exhibit the sensitivity which would be expected in locations more proximate to the cross-polar flow, such as the area further north in central Canada or in northeastern North America.

Luckman and Colenutt, (1992) conducted additional studies in the high-elevation Canadian west, above 50° N. Their results support the assumption that this region is out of the cross-polar flow, and influenced more by a flow from the Pacific Ocean. Although there is some reduction in radial tree growth, which could be attributed to a general cooling, wide variation is found in the mid-1780's. This would be consistent with an onshore flow from the Pacific; any stabilizing continental effects would be expected further east and south. At these higher latitudes, the effects of this stronger zonal flow would be exhibited here in the Canadian Rockies as compared to the region near the United States-Canada border. As they are not, thus ruling out a zonal flow extending into the center of the continent, a strong cold northwest flow in central Canada may be additionally supported, while still implying a flow from the Pacific.

In the western United States, Fritts and Shao (1992) reconstructed temperature and precipitation from a variety of spatial arrays of sites. These areas included the Columbia Basin, the California valleys, intermountain basins, southwest deserts, the northern high plains and the southern high plains. Throughout the entire area, temperature and precipitation data for the period from 1750 to 1800 show very little variation from the norm, with the exception of the temperature reconstruction for the high plains data set. There is a colder than normal period which stretches from 1770-1790 and is found only in the high plains data set. In the absence of any other large deviations in the time frame, one may assume that persistent cold affected only the high plains, which is consistent with a steady northwest flow from northern Canada. The southern high plains are apparently unaffected, which supports the cold northwest flow from central Canada curving eastward towards the Great Lakes and the northeastern United States, and south of Toronto. This western edge of the circulation in 1785 is also consistent with Lamb's suggested flow.

5.3 Arctic and Iceland

In a cross-polar flow, Arctic locations in northern Canada would be directly in the path of continental air masses migrating across the North Pole from Asia. In any flow, evidence of volcanic activity would be found in high Arctic ice. Indeed, a marked signal is present in ice cores from the Agassiz and Devon sites in the high Canadian Arctic (Alt, et al, 1992). However, similarities in the effects from both the 1815 and 1783-1785 eruptions show that the period of both was one of general cooling in the Arctic. Brief episodes of further cooling followed both eruptions as well. Circulation patterns following each, however, are different.

Alt et al, (Alt, 1985, 1987, Alt, et al, 1985), using previously developed analogues, further conclude that the general synoptic pattern around the time of the Tambora eruption is similar to that in 1972, as characterized by the presence of a strong 500 millibar (50kPa) vortex centered near northern Greenland (Figure 5.3). No analog is presented for 1785. The western edge of this circulation is in a similar location to that of the 1785 cross-polar flow. The eastern side, however, shows a return flow poleward from the central North Atlantic Ocean. In contrast, my results indicate that the circulation in the 1780's appears to continue eastward as a strong zonal flow across the Atlantic. In the case of 1785, the center of the vortex (Icelandic Low) would most likely be depressed further southward and expanded eastward. This may explain Alt's findings, where the circulation pattern after the Laki eruption was different from that of Tambora. This expansion and eastward shearing of the low pressure vortex will also be identified in the European data discussed below.

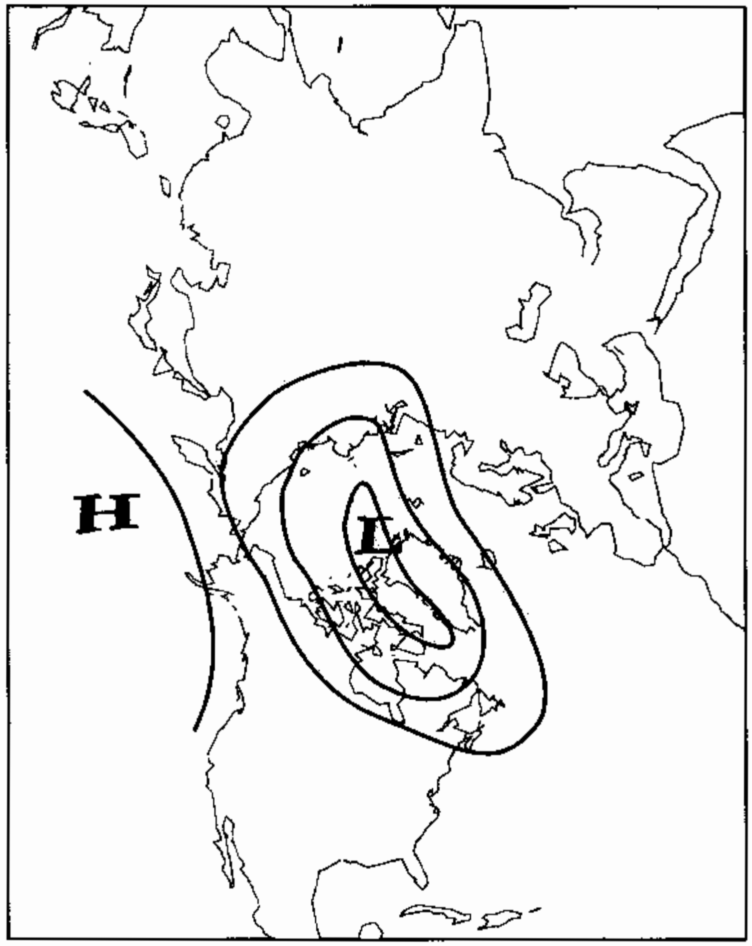


Figure 5.3: Summer Circulation of 1972, analogous to 1816, from Alt.

Ogilvie (1992) studied sea ice records for the area around Iceland and shows that on a decadal scale the 1780's contained the greatest amount of sea ice on record. The series extends back to 1501. There is a positive correlation between sea ice incidence and temperature (Bergthorsson, 1969, Ogilvie, 1981, 1984a), and the cold regime thus inferred could be caused by an increase in the flow around the semi-permanent high over Greenland and an extended low pressure area in the Atlantic Ocean. It is possible that a Rex block may have developed, similar to the one in Figure 5.4, but displaced northward. This circulation pattern agrees with the flow around the high pressure area over Europe as well, and can help explain the mechanism by which northern Europe is both colder and drier than normal.

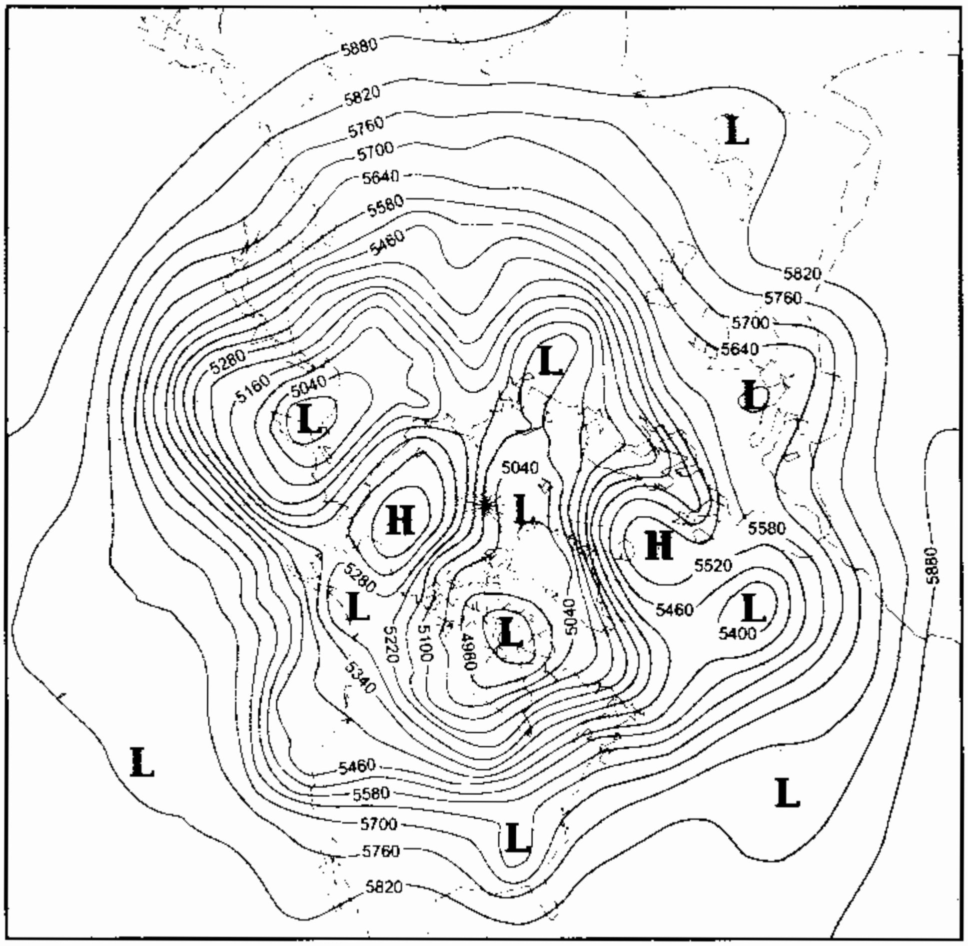


Figure 5.4: 500 mb (50 Kpa) Circulation in mid-March, 2002. Note Rex block (high north of low) in eastern Atlantic, and split flow upstream.

5.4 Atlantic Ocean and Europe

Lamb (1992) refers to a pattern similar to that in 1785 in reconstruction of pressure patterns for the summer of 1816 over the Atlantic Ocean and western Europe. Broad zonal flow north of 40° N to 50° N in the Atlantic Ocean is driven by broad low pressure from 50° N to 60° N. This also agrees with Alt, et al and Ogilvie above. The increased pressure gradient between the (Icelandic) low pressure to the north, which is displaced southward and sheared eastward from the normal position near Greenland and the subtropical (Bermuda) high to the south drives a strong flow from central and eastern North America across the Atlantic over a flattened ridge. This would also force the north side of the subtropical (Bermuda) High in the Atlantic to be sheared eastward, increasing the advection of more moist maritime air into southern Europe (Figure 5.5). The implication for stronger surface winds in the ocean under the core of the flow is borne out by observations from ships of being blown off the coast and unable to make ports in North America before supplies ran out (Bermuda Gazette, 1785).

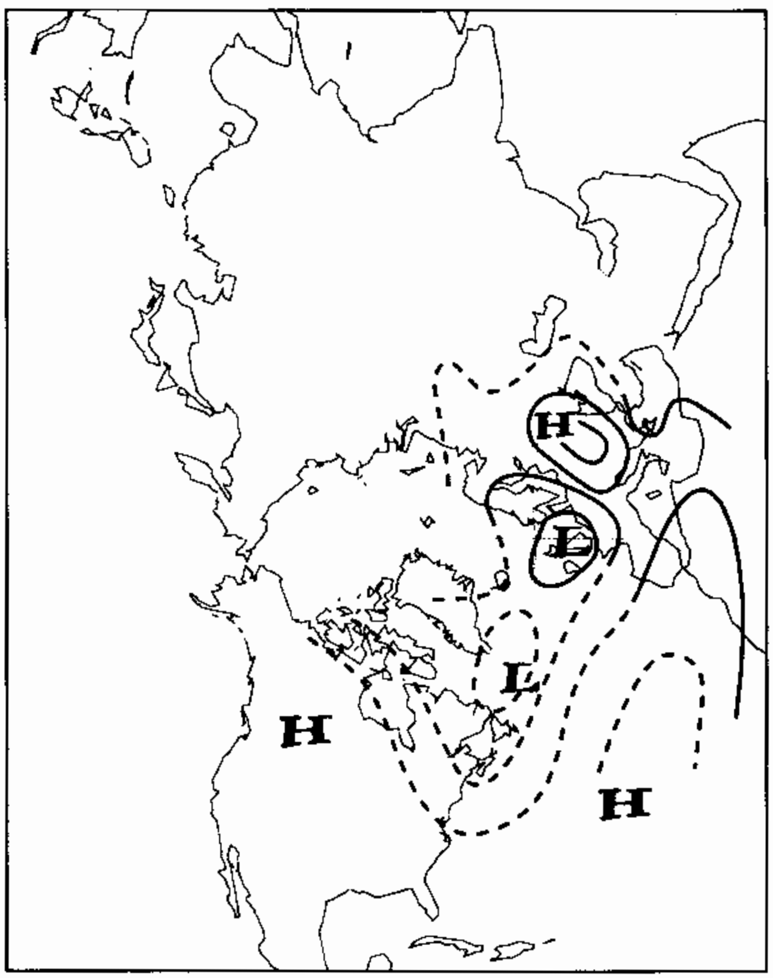


Figure 5.5: Reconstructed flow for July, 1816, after Lamb. Dashed lines inferred by Lamb.

High pressure in northern Europe is larger in this flow, which . if present in 1785, may explain the very hot. dry summer in England (Fowle's Gazette, 1785). as well as conditions that are drier and warmer than normal in Switzerland (Pfister, 1981), and drought in Finland (Schove. 1954) . The northern edge of the flow continues across northern Europe, and curves poleward, aided by a strong high pressure ridge in central Asia. Arctic air masses originating in central and eastern Asia then follow the flow eastward and then northward, eventually crossing over the Arctic. and completing the short-circuit cross-polar flow. A split in the flow from its southern edge into west-central Asia is implied, with an eastward displacement of the subtropical high over the Asian subcontinent supplying the moisture for storm tracks to the east.

Northern Europe, under the influence of cooler and moist air transported rapidly across the North Atlantic Ocean could be expected to be cooler, on average, with similar variability as that which is noted in the northeastern part of North America. The average temperatures as reconstructed for three stations in central England, Uppsala, Sweden, and De Bilt, the Netherlands, do indicate that a cooling period began by 1780, reaching a minimum in 1785 (Moberg, 1996). Wood (1992) notes that average January temperatures for six European cities (Stockholm, Copenhagen, Edinburgh, Berlin, Geneva and Vienna) are below the 31-year normal in 1780 and 1781, above normal for 1782 and 1783, well below normal for 1784, and near normal for 1785 and 1786. The dry summer in England and cooler July readings in western and northern Europe can be explained by the presence of a persistent high pressure ridge over Britain and the Baltic, the eastern side of which allows cold advection into Europe proper.

Further south and east in Europe, the general cooling noted above for the decade is seen in tree ring studies from the Alps and Tatra mountains (Bednarz and Trepinska, 1992). The general cooling is evident through the decade of the 1780's, and is most likely the result of summer outbreaks of the cold air on the eastern side of the high pressure ridge over Britain and the Baltic before its return northward in eastern Europe. The sensitivity to increased variation as well as a more pronounced cooling trend is evident more in the Tatra mountains than in the Alps, implying that the Tatras in Poland are closer to the edge of the flow, and thus closer to the edge of the polar front. Switzerland and central Europe remain under the influence of the expanded continental high and implied upper ridge.

Dendroclimatic reconstructions from tree ring widths in southwestern Europe and northwestern Africa for the 1780's (Serre-Bachet et al, 1992) help to define the southern stream of the split flow from the eastern Atlantic Ocean. Reconstructions of the temperature for eastern France and Rome indicate cooling, which would support a cold flow from off the eastern side of the northern European ridge. Precipitation records do not extend from the present back to 1785. Serre-Bachet, et al also analyzed reconstructions of temperature at four grid points on the Jones (Jones et al, 1985) network. For 1785, the English Channel grid point (50°N, 0°W) shows little variation from normal, although colder temperatures are indicated in the ensuing decade. The Mediterranean grid point (40°N, 10°E) shows a 7-year cooling trend is already underway, reaching a minimum in 1785. The grid point in southern Poland (50°N, 20°E), shows rapid cooling over a 6-year period, while the grid point in eastern coastal Spain (40°N, 0°W) is near the maximum of a 12-year rise which peaks in 1783.

It is evident from the tree ring studies in the Tatra Mountains above that the cooler flow in Poland can be supported. The English Channel area, away from both the northern and southern branches of the split flow, is less affected by anomalous conditions, which is consistent with a ridge overhead. Precipitation data from Morocco, which is the lowest (driest) in the record from 1500-1975, and the warmer temperatures in Spain could support either the eastward displacement of the subtropical high or the existence of an African ridge extending northward and westward. In either case, a strong flow across the Atlantic, curving both north and south of Britain, can be inferred.

5.5 India and Asia

In India, regular weather observations do not commence until 1792, but wheat prices in Delhi (Roy, 1972) do show a marked increase in 1782 and 1783. The immediate cause may be tied to ENSO activity and a failed monsoon. This might be affiliated with a northern hemispheric circulation anomaly, in that a reduced flow from the west, part of which has turned poleward, might allow a stronger high and ridge to develop over the Indian subcontinent. A split in the flow would be implied. However, an eastward migration of the monsoon, causing the spike in wheat prices would be consistent with both an El Niño event and the eastward displacement of other pressure systems in eastern Africa. There is no corresponding anomaly in wheat prices in 1810-1820 (Pant, et al, 1992).

A split flow can be inferred from ion-concentration studies of GISP-2 ice cores (Meeker and Mayewski, 2002). They constructed sea level pressure anomalies for winter (December, January and February) and spring (March, April and May) during the Little Ice Age (LIA) (1400's to 1800's in this study) from a proxy series extending back 1400 years BP. Results do show reduced pressure across the north Atlantic and into south central Asia during the LIA. This would support both a southern split from the cross-polar flow and an eastward migration of high pressure systems over the Indian sub-continent.

In a very broad sense, Borisenkov (1992), using documentary evidence, finds that the 30-year seasonal averages in mid-Russia show little difference from normal for the autumn, winter, and spring, but higher than normal readings for the 1780-1800 period. This nearly 1°C anomaly is only slightly lower than that reconstructed for the 1800-1830 period, which is the highest in the entire1501-1900 record. Warmer conditions in the summer would be consistent with the prevalence of continental air masses that may be advected northward in the cross-polar flow, modifying (cooling) over the pole, and then arriving in North America as cold outbreaks in summer.

5.6 China, Japan and the Pacific Ocean

Generally wetter weather in eastern China can be noted at Nanjing and Suzhou in 1785 from the Qing Yu Lu or the Clear and Rain records (Wang and Zhang, 1992). References to the year 1816 indicate severe flooding in eastern China as well, as a result of an eastward retreat of the subtropical high, (Huang Jiayou, 1992). The Yangtze and Yellow river basins would be affected in both cases, and a parallel might be drawn to the 1780's. However, in 1816, the polar front in Japan shows no change from normal, and, in fact, the summer was warmer and longer than normal, implying a more prevalent meridional flow (Tsukamura, 1992). In 1785, increased zonal flow and eastward migration of regular pressure patterns, including the displaced monsoonal flow over India, is already assumed. The increased rain in 1785 may have come from tropical cyclones hitting land further south than normal.

Polar air masses from central Asia would be steered towards the pole in a cross-polar flow, prior to arriving at the east Asian coast. Continuing in the cross-polar flow, these continental air masses would be directed southward from the Arctic, and become the source for the notable cold outbreaks in eastern North America. Any expansion of cold air masses in Asia in the summer, however, might affect Japan, which is on the eastern edge of this flow. This would be expected to be found in cooler summer conditions, without any attendant increase in storminess. In fact, during the 1780's, and from 1783-1785 in particular, Japan did suffer extraordinarily cool and wet summers, leading to famine conditions from poor rice harvests (Mikami and Tsukamura, 1992). Lake Suwa, Japan, froze 22 days earlier than the decadal average, which is earlier than any other year in the series from 1772 to 1794 (Wood, 1992).

The fact that there is evidence for zonal flow in eastern Asia and Japan in 1785 would also point to a more sensitive response somewhere in the western part of North America. A strong zonal flow over the northern Pacific, unlike the meridional flow established for the decade of 1810-1820 above, could be then be responsible for the signal from high Rocky mountain trees in the southwestern Canadian study cited above (Lough, 1992, Luckman and Colenutt, 1992). This does not preclude a quasi-meridional flow over a flattened ridge in the Pacific, similar to that in the Atlantic, but does imply an onshore flow from the west in the Canadian Rockies.

Thus, the circulation pattern of the entire northern hemisphere can be outlined, showing the short-circuit cross-polar flow, excluding those areas which would not be directly affected, such as southeastern Asia westward to the Indian Ocean. The efficiency with which this flow can drive polar outbreaks from the continental source regions of east and central Asia, the Arctic, and northern Canada, eventually arriving in northeastern North America, then appears viable.

5.7 Tropics and Southern Hemisphere

Evidence of a more pronounced zonal flow across the Pacific Ocean at lower tropical latitudes might be found in the increased total particulate deposition and decreased $\delta^{18}O$ values in the Quelccaya ice cap in Peru. This is observed for the first half of the decade, with maxima at 1783-1785 (Thompson and Mosley-Thompson, 1986). In the southern hemisphere, data are sparse, but tree studies of sub-tropical to sub-antarctic species in South America (Villalba and Boninsega, 1992) do show decreased temperature, perhaps in response to the Laki-Asama events, after 1783 at 37-39° south latitude for a one year period, very little, if any response at 41° south latitude, and a pronounced response three to seven years later at 54° south latitude. It would appear that more data and research are required to identify the propagation of a signal through the prevailing westerlies in the stronger global circulation pattern in the southern hemisphere.

5.8 ENSO Effects

Quinn's (1983b) research does indicate an amplification of anomalous patterns when ENSO and volcanic events occur simultaneously. With the results below, combined with the disconnect from the main flow noted above, it is much more reasonable to assume that the cross-polar flow would exist with little direct connection to ENSO activity. The years preceding 1785 did show increased ENSO activity, with which with many weather events worldwide can be associated.

Deficient floods in the Nile River are associated with ENSO activity 80.3% of the time from the mid-1500's to today (Quinn. 1993a), and in strong events, the correlation is higher. Record drought in Chile, which is characteristic of Little Ice Age climate patterns (Quinn and Neal, 1992), is in evidence through the beginning of the 1780's. The drought conditions are broken only by the very strong ENSO event of 1782-1784. Another well-established teleconnection with an El Niño and the northeast is a warmer winter (United States Dept. of Commerce. 2002). As this was certainly not the case in 1785, this can give more weight to the strength and persistence of the cross-polar flow.

Additional teleconnections associated with El Niño activity include drought in eastern and northern Australia, and an east monsoon drought over Indonesia. Drought in northeast Brazil is noted as well. Further work by Quinn has found that southern California also experiences higher rainfall during El Niño years about 87% of the time (Quinn, 1993a). These effects, although expected, could not be proved or disproved with the data cited in this chapter.

There is a general suppression of tropical storm activity in both the Atlantic and Pacific Ocean during El Niño years (Dong, 1988, Gray and Schaeffer, 1991, O'Brien, et al, 1996). This reduction in the number of storms does not preclude hurricane development. In fact, one might expect to find fewer, stronger and faster moving storms due to the more vigorous steering currents at upper levels of the atmosphere, and the larger temperature gradient between the colder-than-normal ocean waters to the north and the warm tropics. Dixon points out that there are fewer hurricanes in an El Niño year, yet the frequency of landfall of those which do occur in an El Niño year is slightly higher (Dixon, 1996).

In summary, observation of the climatic conditions associated with the very strong (VS) El Niño of 1782-1784 and the moderate (M^{+}) event of 1785-1786, can help to develop the broad picture of northern hemispheric circulation in 1785. The tropical region and those areas affected directly by the El Niño appear to behave independently of the higher latitude westerlies and cross-polar flow, which exhibits the hallmarks of a generally cooler climatic regime resembling that of the Little Ice Age. This reconstruction, with the apparent disconnection between the cross-polar flow and tropical southeast Asia raises an interesting question for future research: Did the eastern displacement of the pressure and wind systems from the Indian Ocean to eastern Asia allow the polar cell to drift southward and eastward in to North America and the North Atlantic Ocean, or was the preferential movement of the polar cell to those areas the forcing factor? Figure 5.6 represents the reconstructed complete short-circuit cross-polar flow for 1785.

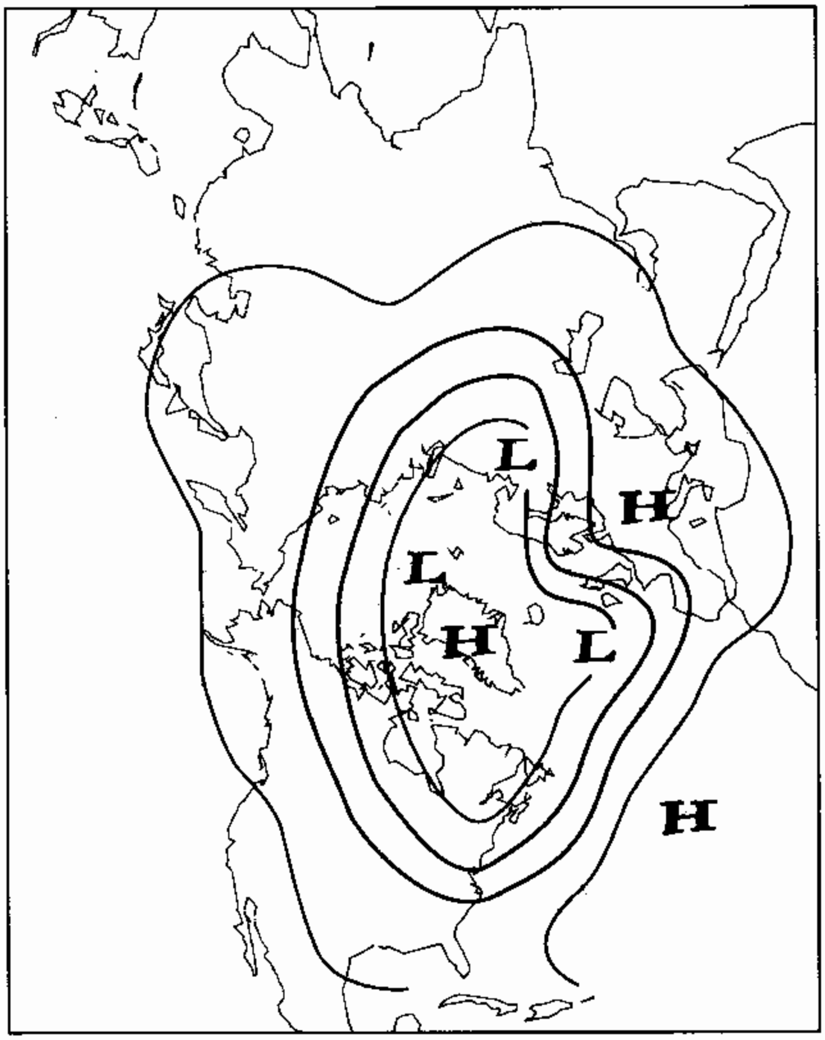


Figure 5.6: Reconstructed short-circuit cross-polar flow for 1785.

CHAPTER 6

SHIPS' PROTESTS AS A DATA SOURCE

Ships' protests have been used for centuries as legal documents to record and detail damages and indemnify Captains from fault. In 1785, an incident of damage sustained by an insured English ship or its cargo would be reported to the nearest crown colony, thus protecting the Captain from insurance claims against him or the ship's owners upon arrival at his destination. Although a Notary Public deals with protests today, the late eighteenth century claimant would have to appear personally before a colonial Governor, and swear out a protest. The document would then be officially recorded with the colonial Secretary.

Protests were filed for any number of reasons. Any damage to a ship or its cargo would have had grave repercussions for the Captain or the ship's owner. Without a reason for the damage, the Captain or owner could be held personally liable. In a time when a single ship's cargo could represent many personal fortunes, it was imperative that any question as to fault be removed. A Captain's reputation and career was also at risk. Thus the protest, in addition to acting as a legal deposition for the insurance syndicates, also cleared the Captain or owner of both blame and liability.

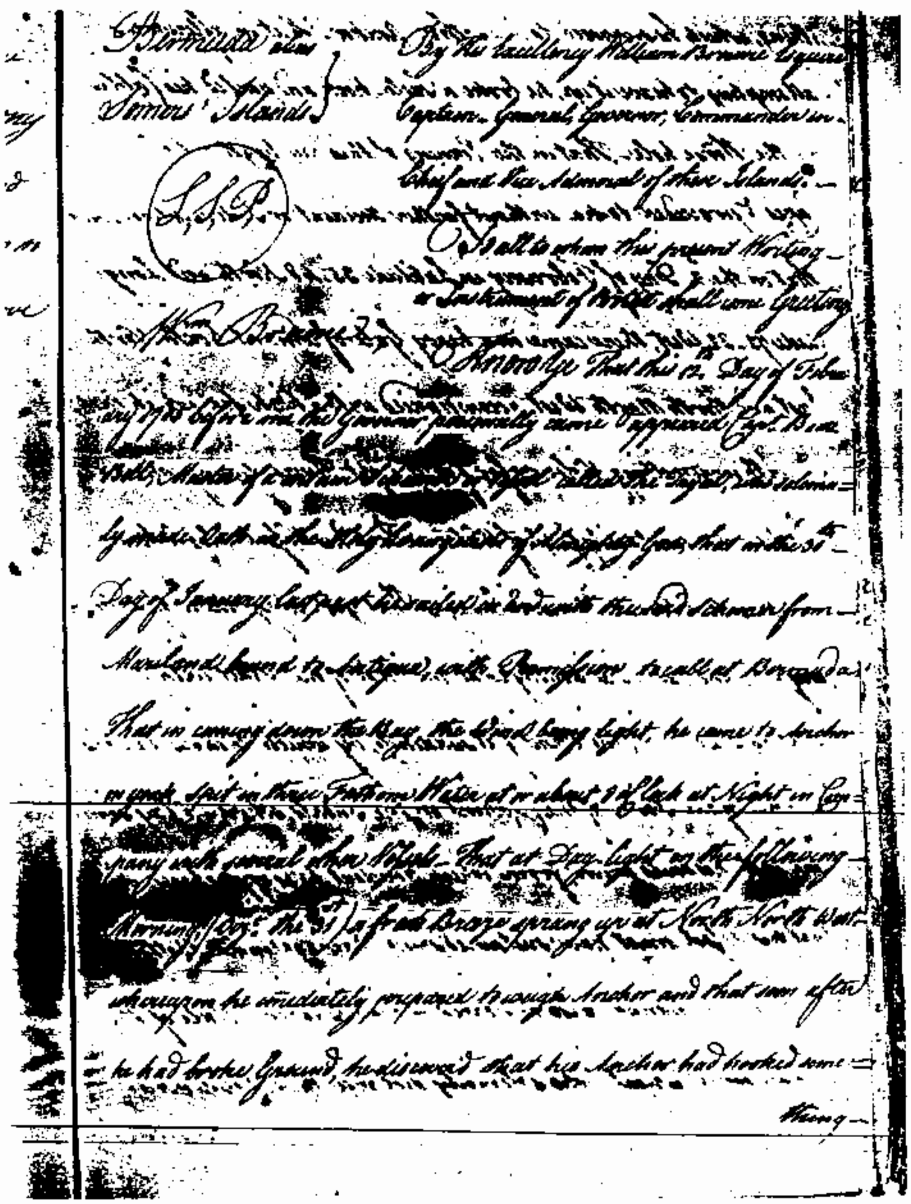
In 1785, a ship's Captain had few options for filing a protest if an accident occurred in the western North Atlantic Ocean. Prior to that time, colonial Governors were available in many locations along the North American seaboard. However, the English insurance syndicates would not recognize a document from the new United States of America yet, and indeed many ports and new States prohibited trade with English ships at all. Ships flagged in England were, at the time, prohibited from engaging in commerce in American ports. In fact, they were not even allowed to call in port to swear out a protest (State of Rhode Island, 1785). Their nearest available port for most was Bermuda.

I found a number of protests in the Bermuda Archives in Hamilton, Bermuda. I estimate that 4800 protests exist there in various compilations and records, from the years 1693 to 1887. For the year 1785, 21 protests were found. Of the 21, 1 dealt with legal matters unrelated to maritime insurance on the Islands. Of the remaining 20, 7 dealt with non-weather related damage events, including mistakes in steering or navigation (3), improper loading, leaks, and poor crew work (2). and weather events in late 1784 (2). The remaining 13 protests detailed specific weather events, and contained valuable information for reconstructing the weather of the time. None from early 1786 referred to weather events in 1785.

The weather observations contained in the protests are quite concise and painstakingly represented. After all, if the weather was the cause of damage to a cargo or a ship, great pains would be taken to record as much as possible about the event. Indeed, the records of these weather events are revealed in far more detail than might be found in an ordinary ship's log. Thus, a reasonable reconstruction of a meteorological scenario can be achieved.

In order to extract the weather information, the same procedure used for a diary or ledger is employed (see Chapter 3). Although translation is not necessary, the penmanship and grammar must be understood. Reverse writing, impressed upon a page from a facing page in the original ledgers, must be ignored (Figure 6.1). In cases where the reverse writing impression completely obscures the original, comparisons can be made with other protests. There are occasions where specific phrases and legal terminologies are repeated from document to document. Familiarity with the recording secretary's penmanship and colloquialisms can also aid in determining words or phrases which may be obscured. Because the actual weather information appears in different places in each protest, the entire document must be accurately transcribed.

Figure 6.2-6.4 show a protest from the Master and Mate of the Vigilant from 1785, and is transcribed as follows:



Bermuda alias Somers' Islands } By his Excellency William Browne Esquire Captain General, Governor, Commander in Chief and Vice Admiral of these Islands.

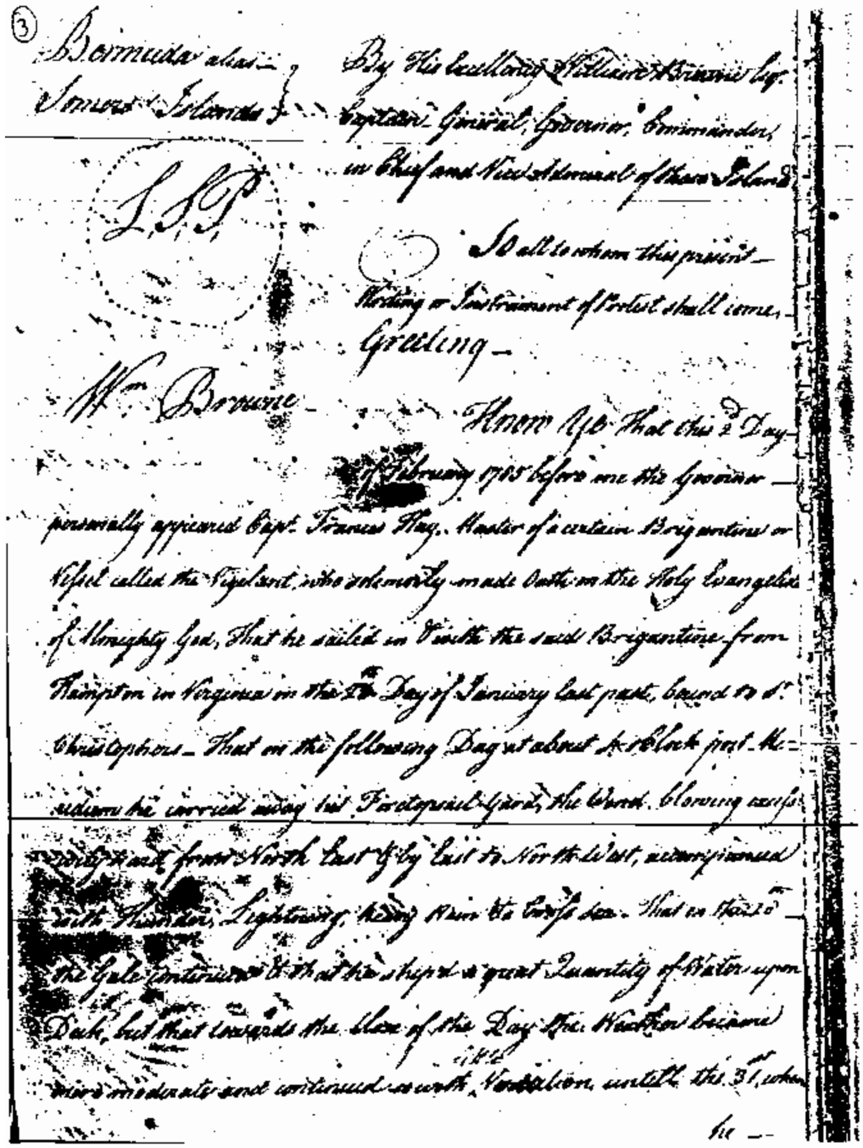
L.S.

To all to whom this present Writing or Instrument of Writing shall come Greeting.

Wm Browne

Know ye That this 12th Day of February [illegible] before me the Governor personally came & appeared Capt. [illegible] Bell, Master of a certain [illegible] called the [illegible], who solemnly made Oath on the Holy Evangelists of Almighty God, that on the 31st Day of January last past he sailed in and with the said Schooner from Maryland bound to Antigua, with Permission to call at Bermuda; That in coming down the Bay, the Wind being light, he came to Anchor in [illegible] Spot in three Fathoms Water at or about 8 o'Clock at Night in Company with several other Vessels. That at Day light on the following Morning (Sunday the 1st) a fresh Breeze sprung up at North North West whereupon he immediately prepared to weigh Anchor and that soon after he had broke Ground he discovered that his Anchor had hooked some thing

Figure 6.1: Example of obscuration of text by impression of reversed writing from facing page.


(3) Bermuda alias Somers Islands } By His Excellency William Browne Esq. Captain General, Governor, Commander in Chief and Vice Admiral of these Islands

L.S.P.

To all to whom this present Writing or Instrument of Protest shall come, Greeting –

Wm Browne

Know Ye That this 2 Day of February 1785 before me the Governor personally appeared Capt. Francis Hay, Master of a certain Brigantine or Vessel called the Vigilant, who solemnly made Oath on the Holy Evangelists of Almighty God, That he sailed in & with the said Brigantine from Hampton in Virginia on the 2 Day of January last past, bound to St. Christophers – That on the following Day at about 4 o'Clock post Meridiem he carried away his Foretopsail Yard, the Wind blowing excessively hard from North East & by East to North West, accompanied with Thunder, Lightning, heavy Rain & a Cross Sea – That on the 2 the Gale continued & that he shipped a great Quantity of Water upon Deck, but that towards the Close of the Day the Weather became more moderate and continued so with little Variation until the 31, when he –

Figure 6.2: Ship's protest from the *Vigilant*, 1785.

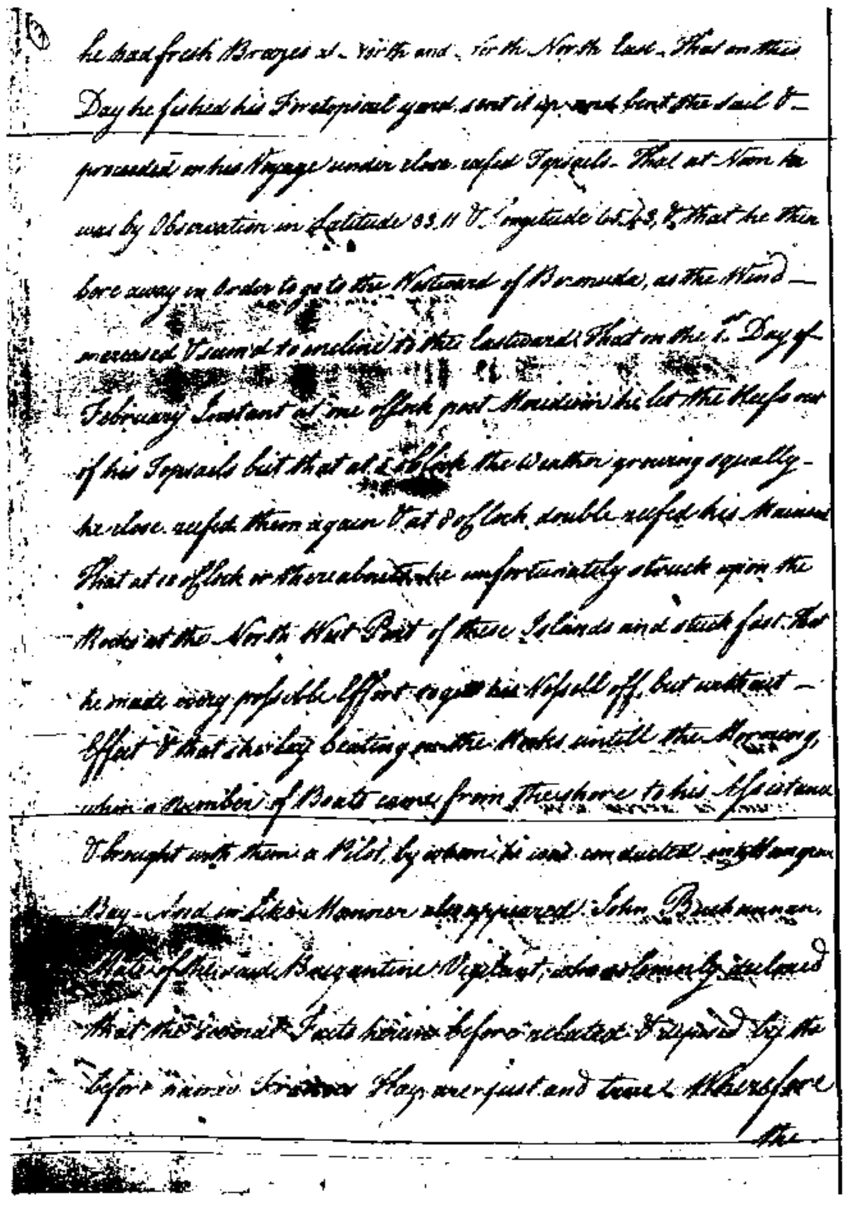
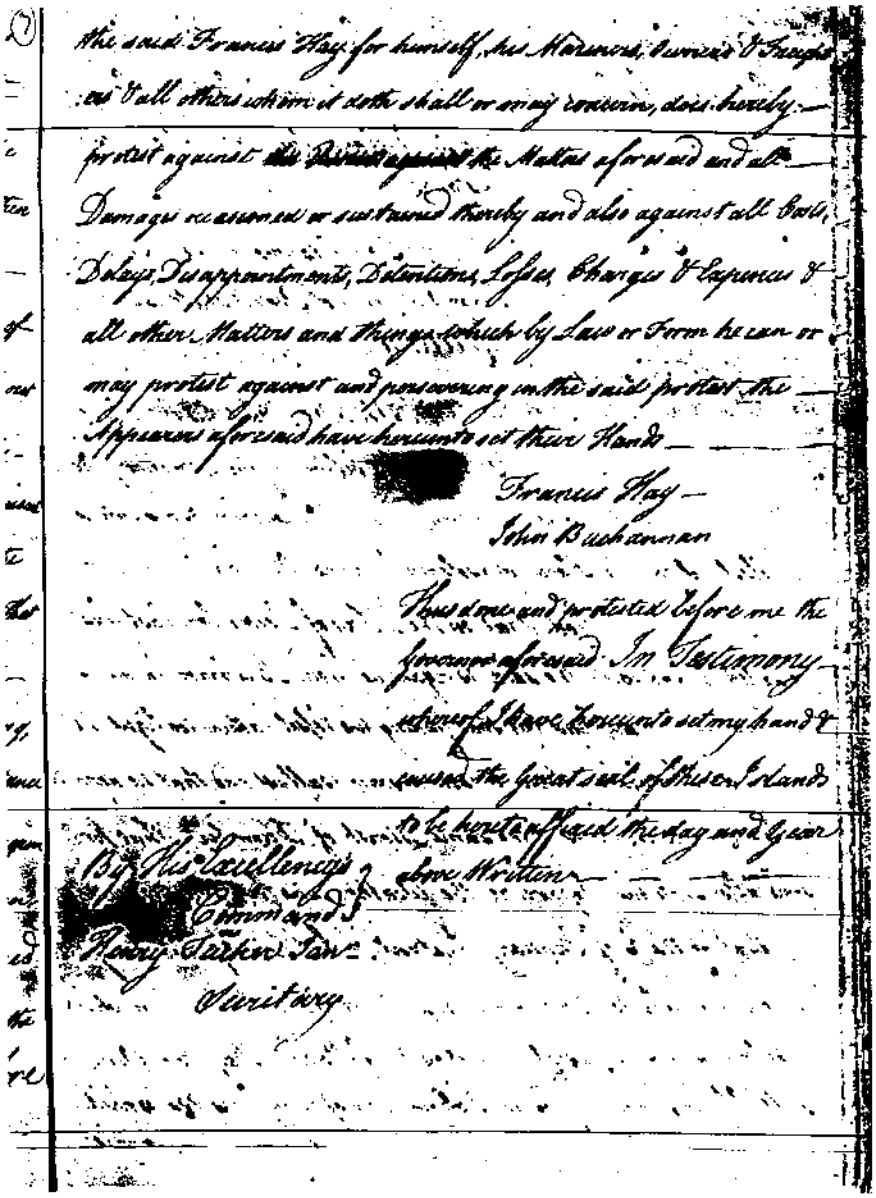

he had fresh Breezes at North and [illegible] North East. That on this Day he fished his Foretopsail yard, sent it up and bent the sail & proceeded on his Voyage under close reefed Topsails. That at Noon he was by Observation in Latitude 33.11 & Longitude 65.48, & that he then bore away in order to go to the Westward of Bermuda, as the Wind increased & seem'd to incline to the Eastward. That on the 1st Day of February Instant at one o'Clock post Meridian he let the Reefs out of his Topsails but that at 2 o'Clock the Weather growing squally he close reefed them again & at 8 o'Clock double reefed his Mainsail. That at 11 o'Clock or thereabouts he unfortunately struck upon the Rocks at the North West Part of these Islands and stuck fast. That he made every possible Effort to get his Vessell off, but without Effect & that she lay beating on the Rocks untill the Morning, when a Number of Boats came from the shore to his Assistance & brought with them a Pilot, by whom he was conducted into Mangrove Bay. And in like Manner also appeared John Buchannan Mate of the said Brigantine Vigilant, who solemnly declared that the several Facts herein before related & deposed to by the before named [illegible] are just and true. Wherefore the

Figure 6.3: Continuation of ship's protest from the *Vigilant*, 1785.



the said Francis Hay for himself, his Mariners, Owners & Freighters & all others whom it doth shall or may concern, doth hereby protest against the Matters aforesaid and all Damages occasioned or sustained thereby and also against all Costs, Delays, Disappointments, Detentions, Losses, Charges & Expences & all other Matters and Things which by Law or Form he can or may protest against and persevering in the said protest the Appearers aforesaid have hereunto set their Hands

Francis Hay
John Buchanan

Thus done and protested before me the Governor aforesaid In Testimony whereof I have hereunto set my hand & caused the great seal of these Islands to be hereto affixed the day and year above Written

By His Excellency's Command
Henry Tarker Jun.
Secretary

Figure 6.4: Conclusion of ship's protest from the *Vigilant*, 1785.

Bermuda alias Somers' Islands" Wm Browne"

By His Excellency William Browne Esq. Captain, General, Governor, Commander in Chief and Vice Admiral of these Islands,

To all whom this present Writing or Instrument of Protest shall come Greeting.

Know ye that this 2nd Day of February 1785 before me the Governor personally appeared Capt. Francis Hay. Master of a certain Brigantine or Vessel called the Vigilant, who solemnly made Oath on the Holy Evangelists of Almighty God. That he sailed in and with the said Brigantine from Hampton in Virginia on the 26th Day of January last past bound to St. Christophers. That on the following Day at about 4 oClock past the meridian he carried away his Foretopsail Yard, the wind blowing excessively hard from the North East by East to North West, accompanied with Thunder, Lightning, heavy Rain and Cross Sea. That on Jan 28th the Gale continued and that he shipped a great Quantity of water upon Deck, but that towards the Close of the Day the Weather became more moderate and continued with little variation until the 31st, when he"

he had fresh Breezes from the North and North North East. That on this day he fished his Foretopsail yard, sent it up and bent the sail, & proceeded on his voyage under close reefed Topsails. That at Noon he was by Observation in Latitude 33.11 & Longitude 65.43, & That he then bore away in Order to go to the Westward of Bermuda, as the wind increased & seem'd to incline to the Eastward. That on the 1st Day of February Instant at one oClock past Meridian he let the Reefs out of his Topsails but that at 5 oClock the weather growing squally he close reefed them again & at 8 oClock, double reefed his Mainsail. That at 10 oClock or thereabouts he infortunately struck upon the Rocks at the North West part of these Islands and stuck fast. That he made every possible effort to get his Vessel off, but without Effect & that he lay beating on the Rocks until the Morning, when a number of Boats came from the shore to his Assistance & brought with them a Pilot by whom he was conducted into Mangrove Bay. And in like Manner also appeared John Buchanan, Mate of the said Brigantine Vigilant, who solemnly declared that the several facts herein before related and defined by the before named Francis Hays were just and true. Wherefore the"

the said Francis Hay for himself. his Mariners. Owners & Freighters & all others who it doth shall or may concern, does hereby protest against (overwritten) the Matters aforesaid and all Damages occasioned or sustained thereby and also against all Costs, Delays, Disappointments, Detentions, Losses, Charges & all other Matters and things by which Law or Form he can or may protest against and persevering in the said protest the Appearers aforesaid have hereunto set their Hands.

Francis Hay

John Buchanan

This done and protested before me the Governor aforesaid In Testimony whereof I have hereunto set my hand & caused the Great Seal of these Islands to be hereto affixed the day and Year above written

By His Excellency's Command

Henry Tucker Jun'r

Secretary"

The importance of the protest cannot be understated, in that the Captain appeared before the Governor the very afternoon that his ship was escorted into Mangrove Bay, which is at the western end of the main Island in Bermuda. Whether or not the Governor was nearby is unknown, but the offices of the Governor and Secretary were at the time in St. George's, at the far eastern end, 20 or so kilometers away by land.

The value of the meteorological information becomes clear in that the observations of North East by East to North West winds by the Master of the Vigilant, along with the notation of the thunder and lightning, indicates the passage of a frontal system strong enough to damage the ship's rigging. From the reconstruction of American observations in 1785, there is a trailing frontal system in the Chesapeake area on the 26th, along which a storm could easily have formed, which would have moved out to sea the following day. A secondary cold front is observed moving offshore from New England on 27 January, which could account for the storm's intensification in the Atlantic Ocean. This would be the weather system encountered by the Vigilant on 28 January 1785.

The next storm originates as a weak low moving offshore from the Chesapeake on 29 January and intensifies offshore. Its intensity is noted in America only by the lone observation of stormy weather" at Sandy Hook, New Jersey (*New Hampshire Gazette*, 1785), but is inferred by other observations of offshore winds from Virginia to Massachusetts. It is this second storm that brings the shift in the winds to the already damaged Vigilant, and eventually causes its wreck.

Additional support for these meteorological events is provided by another protest filed by the Master of the schooner Tryal. The schooner was in port in Bermuda on 31 January 1785. This account reads, in part: at daylight sprang up a fresh breeze at NNW", dragging the ship's anchor. However, they successfully put to sea in the evening. This could also be the same event encountered by the Vigilant on 28 January.

On 2 February, the morning after the Vigilant strikes the rocks in Bermuda, and the day the Vigilant finally made port under the control of a pilot is another portion of the protest from the Tryal: but that on the 2nd Day of February in Latitude 35.48 North and Longitude 72.32 West there came on a heavy Gale of Wind at North North East and North North West accompanied with a high Sea which lasted with unremitting violence for forty-eight hours, during which his decks were constantly full of Water." The Tryall eventually made it back to Bermuda only to be damaged on the shoals on approach.

Without the information from the Vigilant, it is only inference from surface winds in America and persistence from previous days' observations that indicates a storm offshore. The Sandy Hook observation, initially a candidate for outlier" status in a reconstruction, becomes valid when the protest from Vigilant is considered. Further verification is provided by the protest filed by the Tryall. Although both ships survived to sail another day, and the value of ships protests as an historical legal document is certain, the additional value to forensic synoptic analysis is now apparent as well.

CHAPTER 7

OCTOBER STORMS AND FLOODS OF 1785 AND 1996

7.1 Introduction

One of the most notable meteorological events in the year 1785 was the storm and flood of 18-22 October. Storm damage was reported across all of eastern New England, with concentrated flooding in the Presumpscot River valley of southern Maine. Contemporary diary and journal entries are quite explicit regarding the intensity of the storm, its length, and its rarity in the memory of the observers. Both the localization and of flooding and the extent of attendant damage is well recorded. There are remarkable similarities between this storm and the notable storm and flood in the same region of New England on 18-22 October, 1996. These similarities include specific comments about the extent of the flooding and the synoptic meteorological situation.

The increased number of reports and comments, versus the remainder of the year, and the wide geographic area included regarding the storm and flood of 18-22 October, 1785 exceed those of any other weather event in the study of that year. In some cases, comments regarding this event culled from almanacs and diaries are the only ones pertaining to weather at all. The comments also speak to the severity of the event. Many comments allude to a prolonged rain and rapid flood or freshet which is the greatest in the memory of both the observers and their elder contemporaries. These observations, in addition to regular contemporary observations and reports, which are quite explicit, provide sufficient data for a reconstruction of the event. To complete the reconstruction, I use both meteorological and commentary evidence.

7.2 1996 Observations

There are numerous sources of information regarding the October, 1996 storm (Hodgkins and Stewart, 1997, Keim, 1998, Cannon, 2000) as well as the actual synoptic and cooperative observer reports from the event. What drew the authors attention to the similarity to the 1785 event was the similarity in anecdotal descriptions used. In both 1785 and 1996, for example, there are reports of bridge washouts on the Presumpscot River in southern Maine, torrential rains, and people being rescued by boat (Portland Press Herald, 1996).

7.3 1996 Synoptics

There are recorded instances of excessive rainfall and flooding in southern Maine driven by either persistent banding and convergence of precipitation, or land-falling tropical systems such as Hurricane Bob (Sardinha, 1998). However, the 1996 event was uncommon, as it was comprised of both a mature, cutoff, extratropical system and a direct connection via an occluded front to an offshore tropical system (Cannon, 2000). In this case, the tropical system was Hurricane Lili, which passed nearby offshore at the same time. Cannon shows the presence of an efficient advective mechanism for precipitation from Lili into an already wet extratropical system, along and north of the occluded front.

The synoptic situation for the primary storm is not uncommon. The original low pressure system originated in Colorado, and moved eastward. Blocking high pressure in Canada moved to southwestern Newfoundland and stalled in a slowing upper-level flow and developing Rex block. As the surface storm matured to occlusion in Pennsylvania, having already entrained significant Gulf of Mexico moisture, the upper level flow became cut off, further slowing the storms progress into northern New England. The attendant occlusion worked northward into Massachusetts, deteriorated into a trough, and lingered over the next few days. This scenario is sufficient for a sustained period of rain, occasionally heavy, but generally not sufficient for either widespread or localized flooding. However, low-level convergence, producing a banded effect and heavier precipitation common in winter storms in the area (Malargus et al, 1995) also played a role in increasing the precipitation, and has been noted in other significant events in the area (Cannon, 1992). Some flooding might be expected from this synoptic situation.

What is not common is the entrainment and advection of the additional tropical moisture from Hurricane Lili offshore. This is the mechanism responsible for the additional excess rainfall into the specific southern Maine area. The fact that the tropical moisture is banded and thus formed a train of radar echoes aimed into a small area, once captured by the synoptic system, is responsible for highly localized excess precipitation. If additional bands were entrained, flooding may have become more widespread. The combined effects of both the primary storm and the tropical moisture from Hurricane Lili provide the basis for comparison with the 1785 event as well as supporting the resultant flooding (Figure 7.1).

7.4 1785 Observations

Reports of sustained heavy rain in 1785 are geographically concentrated in the central New England area, but rain is mentioned in almost all of the sources throughout the northeastern United States. Comments speak to a 48-hour rain event, a hard, unceasing rain, and rapid flood or freshet. See Table 7.1 for a compilation of comments. The extent of the area affected by the storm is also outlined by the widespread locations of the diarists. To the north, heavy rain and attendant damage are reported from Newbury, Vermont to Hallowell, Maine. Towards the south, record crests are reported on rivers in southern New Hampshire and northern Massachusetts. Disruptive rain is reported south to Virginia. Analysis of this spatial coverage indicates, however, that the bulk of the rain fell in southern Maine and New Hampshire.

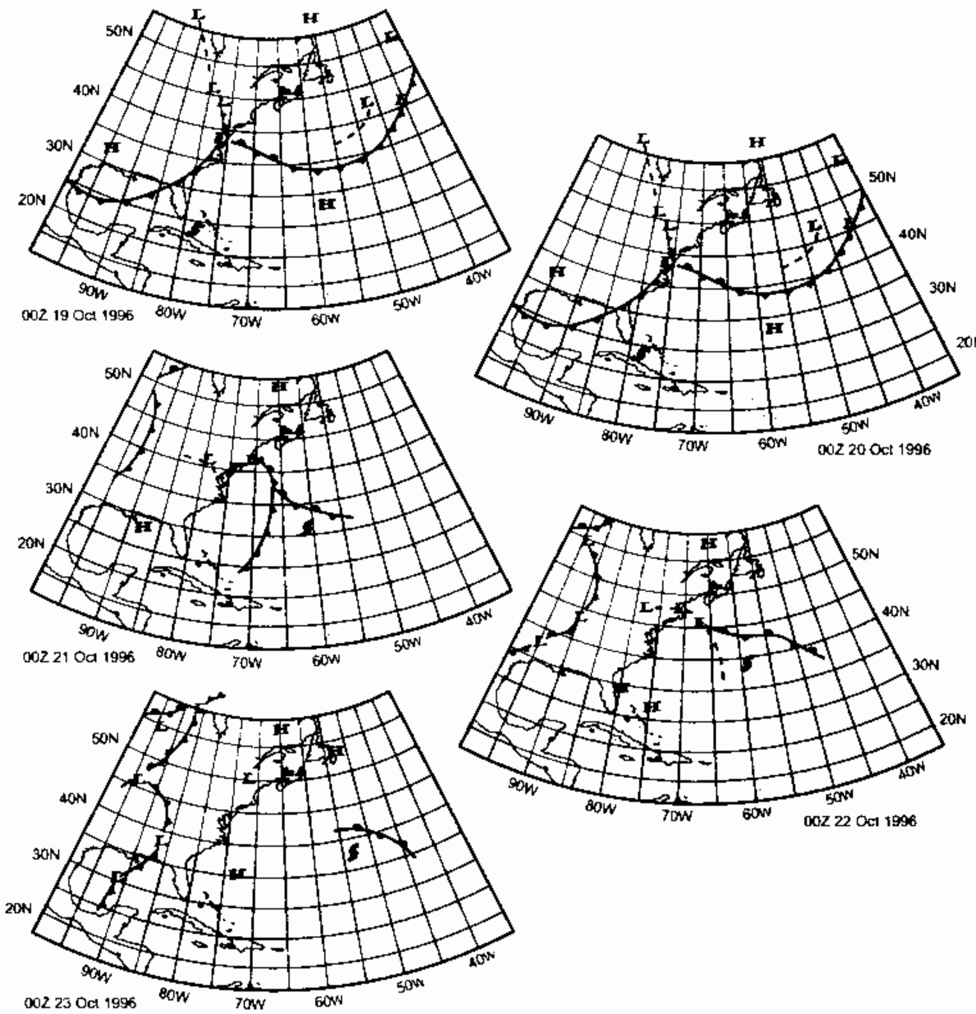


Figure 7.1: 00Z for 19-23 October, 1996.

Many records identify the specific damage sustained in the Presumpscot River Valley of southern Maine. When compared to the damage reported in the same area during the 18-22 October storm of 1996 C.E., the similarities become quite remarkable. Navigation and evacuation by canoe is common to both storms. There are mentions of washed-out bridges on the Presumpscot River in both cases as well. The intensity of the localized flooding and damage may indicate the presence of tropically enhanced rainfall, similar to the 1996 event. Indeed, there are no other events of this scale alluded to in any other sources from

1785. Other heavy or extended rain events do not produce the number or character of the comments from any of the diarists or observers. There are no other cases of such excessive flooding.

7.5 1785 Synoptics

The 1785 event shows a number of similarities to that of October, 1996, coincidentally including the nearly identical dates. A cold-core high-pressure area moves eastward from Hudson Bay, a ridge from which is noted 18-19 October, 1785 (Figure 7.9). Upper level flow begins to form a trough as a warm front passes northward through New Haven on the evening of 19 October. Stormy weather is noted in Dedham, Massachusetts that evening (Ames, 1785). By the morning of 20 October, the front appears to have moved into the southern portion of the northern New England states, while additional developing wet weather is described in the mid-Atlantic states. Horse races are postponed at Alexandria, Virginia (Washington, 1785), and Madison (1785) notes a very rainy morning in Orange County, Virginia as well.

By the afternoon of 20 October, it is clearing in Virginia, and a steady southerly flow with rain is established from Philadelphia to Massachusetts. Rain late is noted in Salem, Massachusetts (Holyoke, 1785). On the morning of 21 October, as high pressure moves to the Quebec/Ontario border, surface low pressure appears to move very close to Massachusetts Bay. As the low continues to move just offshore, there are observations of winds shifting to the north and northwest in a wide area from south-central Maine to Pennsylvania. Madison reports some clearing, but notes atmosphere very thick. During this entire time, heavy rains are reported in many locations, particularly in northern Massachusetts, southern New Hampshire, and southern Maine.

This supports the intensification of an upper-level negatively tilted trough and occlusion. When compared with reports from southern New England, reports from southern Vermont, New Hampshire, and Maine would indicate that those areas were north of a stalled warm or occluded front situated in Massachusetts. Forensic synoptic analysis of the previous few days also supports this assumption. This front may have deteriorated into a lingering trough, similar to the 1996 event, but the advective dynamics would have remained the same in either case.

The front would appear to be still south of Cape Ann, Massachusetts by late on 21 October 1785. Reports of an onshore wind support this assumption. In fact, a Dutch ship is driven onto Plum Island on the night of 21 October, 1785 (Perley, 1891). This onshore flow supports a mechanism for tapping any moisture from the east. Additional evidence of rain off the ocean penetrating inland comes from numerous mentions of high water in the days following the storm. These reports are found in comments Haverhill, Massachusetts, in the Merrimac River valley, which would point to a heavy rain event upriver to the north (e.g. central and southern New Hampshire) a day or two earlier.

At this same time, 22 October 1785, two ships in the Atlantic Ocean, the brigantine Apollo and the schooner Nancy (Ships Protests, 1785) note the rapid approach and passage of a strong gale, forcing the former onto the rocks at Bermuda, and damaging the latter sufficiently for her Captain to change course for Bermuda. Once in port, both Captains swore their protests, in which observations of the winds are consistent with the passage of a tropical storm or hurricane. The rapid passage of the gale from late on the 22nd to the 23rd is also consistent with the course of a hurricane that has been captured by the long wave trough at or near the east coast of North America. In this type of capture and redirection of a tropical system, rapid northward acceleration would be expected. Therefore, bands of precipitation in the northern quadrants of the tropical system could have reached and been captured by the offshore warm front and driven into New England along the occlusion from late on the 21st into the 22nd, providing a source for the additional moisture outlined above (Figure 7-2).

By 22 October, the original primary surface low appears to have retrogressed back onshore in eastern Massachusetts, continuing the rainfall, and implying capture by a cutoff low at 500 millibars. Should that be the case, then very cold air would begin to advect behind the system as it eventually drifts eastward and offshore to the initial long-wave trough position. This occurs as the Rex block begins to break down. In fact, by 23 October, a cool, stiff wind from the west is reported in Connecticut, rain ends in many locations, a secondary cold front is on the 24th, from New Hampshire to New York State. A great frost is noted in Shrewsbury, Massachusetts by the 26th. The trailing front from the retreating storm is pushed south of Virginia and does not return. Cold Canadian air then advects in to the region. Complete working maps for 18-27 October, 1785 may be found in the Appendices.

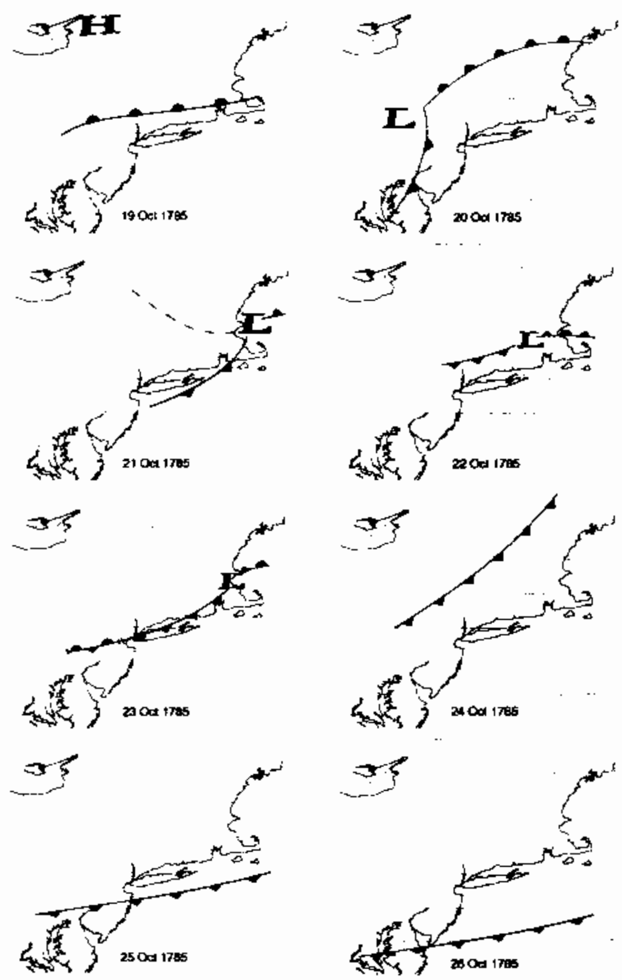


Figure 7.2: Afternoon, 19-26 October, 1785.

7.6 Comparison

Both the 1785 system and the 1996 system developed an occlusion that connected the dying primary low with one on the triple point offshore. The 1785 case seems to have the primary low just offshore, while the 1996 system kept a surface low inland. Therefore, the positions of the now negatively-tilted 500-millibar troughs may be slightly different. However, the advection of continued moisture from offshore and continued heavy rain now necessitates the identification of an additional moisture source, which may, in fact, be a tropical system passing offshore. The precipitation from this system then advects westward along the north side of the occlusion and/or remnant trough into extreme southern Maine, New Hampshire, and in northeastern Massachusetts. It is apparently centered on the Presumpscot River valley in Maine. The pressure at Cambridge continues to fall, indicating continued intensification of the nearby primary low, or the passage of a tropical system nearby, thus enhancing the flow along the occlusion from offshore.

Surface analysis of the 1996 event (Cannon, 2000) indicates that Hurricane Lili ran northward in the Atlantic Ocean outside (east) of Bermuda, yet precipitation still reached New England. The reports from the Apollo and the Nancy indicate that the hurricane or tropical system of 1785 ran northward in the Atlantic inside (west) of Bermuda. This places the storm (and long wave trough position) even closer to the North American continent, offering further evidence that tropical moisture was closer and tapped more efficiently in the 1785 event.

Although the passage of a tropical system so late in the season in 1785 might be initially discounted, thus assessing the 1785 system as a local disturbance, there is ample evidence of an active tropical storm season throughout the Caribbean in that year (Rappaport and Fernandez-Partagas, 1995). Indeed, numerous reports from newspapers of the time refer to hurricanes, one of which rivaled that of 1772 at Christianstaed, St. Croix (Fowles New

Hampshire Gazette and General Advertiser, 1785). Newspaper reports from Jamaica reported severe damage from hurricanes that year. Lives were lost in the Cayman Islands (Williams, 1992). Storms were noted both at the end of August and in September, 1785. Tables 7-2 and 7-3 indicate the vigor of the tropical season in the 1780s. Now with the increased frequency of tropical activity in 1785 established, and assumption that tropical activity could be present so late in the season can be supported. even though sea surface temperature in the Caribbean has been shown to be cooler (Winter, et al, 2000).

7.7 Conclusions

There appear to be many similarities between the 18-22 October storm and flood of 1996, and that of on 18-22 October 1785, 211 years earlier. Forensic synoptic analysis shows that significant comparisons can be made both of surface synoptics, and implied for the upper levels of the atmosphere. Comments and reports from both contemporary diarists and modern journalists are both similar and specific for each event in both spatial and temporal ranges. The similarity is further outlined by specific reports and results from the Presumpscot River valley of Southern Maine and surrounding areas for each event. As excessive rainfall was exacerbated by the advection of offshore tropical moisture in 1996 into the same river valley, I find that a similar situation may have occurred in 1785.

Assumptions have been made by various federal and state agencies regarding the expected reoccurrence of the 1996 storm, estimating it to be in excess of a 400 to 500 year event (Keim, 1998, Hodgkins and Stewart, 1997). A reconstruction of the weather of 1785 and the similarity in the anecdotal comments surrounding both storms shows that they can be directly compared. In both cases, a mature storm reaches occlusion nearby and flooding is exacerbated by the inclusion of moisture from an additional source. Hurricane Lili is the source in 1996, and it appears that a tropical storm or hurricane is involved in 1785 as well. The two systems are 211 years apart, and this result is clear with only the year 1785 having been investigated.

In light of the fact that these two events show such numerous and site-specific similarities, a case can be made to assign the 1996 event to a minimum of a 211-year recurrence. Therefore, flood insurance and reinsurance rates, which may have been calculated on the 400 to 500 year basis of reoccurrence, may need to be refined. The fact that the late 18th century research used herein only covers one year leads to a further conclusion that reoccurrence might, in fact, be even more frequent.

CHAPTER 8

RESULTS AND CONCLUSIONS

The process of forensic synoptic analysis as outlined and applied to the year 1785 has numerous benefits to both historical and climatological research, most importantly indentifying individual weather events. These events are not visible in monthly, seasonal and annual averages, and can only be resolved with analysis at the daily level. The immediate historical and human impact of these events can be more fully realized as well. Analyses of average temperature, for example, do not resolve the maxima and minima, or the anomalous events which can affect daily life.

A summary of the benefits of of the procedures used in this study is outlined below. Each individual process stands on its own as a viable methodology for either historical or meteorological research. It is the juxtaposition and interrelation of these methods which produces the final result, and allows the development of insight into the general circulation of the atmosphere, the position and displacement of the polar cell, and the daily weather of 1785. This interdisciplinary approach also allows insight into the social and political climate of 1785, and the effects that weather may have had on daily life.

Conclusions reached from the analysis are summarized below. Inferences can be made about the regularity of certain weather patterns at the surface, and their effect on commerce, trade, and life in 1785. Additionally, upper atmospheric flow can be reconstructed and compared with other proxy data from around the world. These results provide valuable information about the general circulation in the northern hemisphere and the size and location of the polar cell. Results also show a pattern to which we might look for clues to a general cooling of the atmosphere, and the effects we might expect on the human condition.

Use of the data and techniques in future work and recommendations for further research are included below. Application of the techniques used herein will be valuable to the study of any period in time. Inclusion of additional diaries and sources for 1785 can further refine the resolution of the results. Development of data for the remainder of the 1780's would be a logical next step. Acquisition of additional data should be undertaken as well.

8.1 Historical Data Extraction

The historical insight from the use of material not commonly included in research on the climate is clear. Newspapers, biographies, military and church records, personal diaries and correspondence can be shown to have both intrinsic meteorological value and important historical implications. While analyzing these ephemera for viable weather data, extracting historical information can provide additional understanding into life during the late eighteenth century.

As an example, the Nathaniel Ames diary, while primarily a weather record, also includes occasional references to life in the town of Dedham, Massachusetts in 1785. Inserted in between observations of the sky and weather is one note of particular interest. After returning from a meeting of the Board of Selectmen, he expresses his outrage at the decision to dam the Charles River, precluding him from teaching his son how to fish for salmon the way his grandfather and father had taught him. What marvelous comments can be made to those trying to understand the implications of urban sprawl today.

When analyzing these ephemera together, connections and comparisons can be made between otherwise unrelated locations. For example, frontier life in modern-day Maine and Pennsylvania can be compared with life in larger towns such as Philadelphia, Cambridge and New Haven. One can easily discover what life was like for a landed gentleman of the period by paying attention to the commentary of George Washington. Each mention of drought in England, thunderstorm damage in New England, or tropical storms in the Caribbean enhances our understanding of the relationships between the people in each location.

The record from the most rural of locations, such as that recorded by Ballard, not only outlines the trials of frontier life, but amplifies our respect for the serious manner in which early settlers recorded their existence. With very little comment, Ballard mentioned that famine was imminent until ice-out allowed a ship to arrive. In urban locations, the attention paid to accurate record-keeping is clear as well. Ezra Stiles in New Haven, with little fanfare, and between his regular temperature observations, notes the death of a daughter. Three weeks later, he notes her burial with the same detached manner.

Closer to the larger towns, one can gain an understanding of the difference between life there and more rural locations. Commentary from Reverend Cushing in Waltham, Massachusetts, refers to trading pulpits often with his neighbors in what he called "Little Cambridge" and other locations. He also notes the profound differences between his congregation and those of his contemporaries. Life in the cities was good enough to foster more than religion. Political thought could blossom as well. The inhabitants of York, Cumberland, and Lincoln counties in Maine were exhorted in 1785 to "to meet at the Meeting-house of the Rev. Messrs. Smithy and Deane, in Falmouth, on Wednesday the fifth day of October next, to join in a conference, then and there to be held, on the proposal of having the said counties erected into a separate government..."(The Poughkeepsi Advertiser, 1785)

Coventry's record of his travel from Scotland to America is punctuated by his observations of his shipmates, along with noting stormy weather, and his assessment that more than a few of them night not be capable of a good first impression on debarkation. He and his upper-class friends were not going to allow that to happen. His decision to array himself in full Scottish regalia for his arrival did not go unnoticed. An editorial in the newspaper on that day commented on their arrival in New York by saying: "...Decency, sobriety, and good education stamp their characters, and their behavior does honor to the country whence they have arrived. Such inhabitants are wanted in the United States of America" (The Poughkeepsie Advertiser, 1785).

The ease of travel for people in the Boston area can be compared with the grueling march of General William Buell's men westward from Connecticut to Fort Pitt. Although a military operation, the mentions of whippings and search parties for observers outline the difficulties they faced. The few moments of comfort at roadside inns along the way provide a window into the rare moments of relaxation for soldiers of the time. Travel at sea was no easier. A number of reports mention that ships were at times forced to return to England after being "blown off the coast" or "beat off the continent". Ice prohibited ships from navigating the Delaware River to Philadelphia through much of January and into February, 1785 (The Independent Journal, 1785).

The luxury of Madison living at Montpelier in Virginia or Holyoke in Salem, Massachusetts, when compared with northern Maine, rural New Hampshire, or western Pennsylvania gives us a snapshot of the large differences in social status already present in the infancy of the United States. Nevertheless these souls were true to their tasks in observing the weather. Despite the extraordinarily primitive conditions faced by the pioneers in the Hudson Bay Company posts and factories, records were faithfully kept. Despite being locked in ice for months at a time, logs of the ships supplying the outposts were faithfully recorded as well.

These insights would not be possible without having to research entire documents, in hopes of finding a reference to the weather. As an interdisciplinary tool, it is important to note that the value of the meteorological information is equal to that of the historical information. Researchers of history should be aware that the slightest mention of the environment can be of benefit to reconstruction of the weather and climate. Of equal importance is the fact that weather researchers should be aware of the historical context of their analyses. This interdisciplinary approach will only enhance our understanding of both climate change and its impact on the human condition.

8.2 Meteorological Data Extraction

The value of diaries in meteorological research is well known. Many diarists, even today, will begin their entry with a notation of the weather. The extraction of usable meteorological data from other types of ephemera for use in forensic synoptic analysis is not as common. Application of the extraction process to newspaper articles, travelers' journals, personal correspondence, and military and church records has proved a valuable tool in expanding the database of useful observations. The increase in both spatial and temporal resolution attained by inclusion of data from these otherwise unrelated sources makes possible a much more accurate representation of smaller-scale changes in weather pattern and events.

Some diaries, which may include single or occasional references to the weather are not suitable for time-series or statistical content analysis. Analysis of these sparse data in regard to the reconstructed weather maps can also assist in an increase in spatial and temporal resolution of the weather. Even a diary with a single mention of the weather now can be treated as a valuable source for information. Mentions of weather events as related in newspaper articles are also rich sources for mining weather information, as are mentions of the weather, albeit in passing, in other journals and books. Newspaper reports provide evidence of meteorological events from remote locations, albeit sometimes months later.

Of specific importance is the discovery and use of Ships' Protests in this research. These documents, buried in tropical archives and referenced only on rare occasions in legal research, can now be shown to be excellent sources of meteorological information from the open ocean as well as providing important historical insight as to commerce and trade at the time. Notable storms and weather events are exquisitely detailed, and, at the synoptic level, can provide valuable proof of both the presence or absence of storm tracks and air mass size and location.

8.3 Surface Conclusions

The most important result on a day-to-day basis is the resolution of individual weather events. These are impossible to recover from monthly or annual data. The discovery of the October storm stands out as particularly important. A very similar storm occurred in 1996. All statistical attempts to estimate the probability of a similar storm occurring again range from 350 to 500 years. Insurance and reinsurance rates are calculated on these statistical analyses. The fact that the two storms are only 211 years apart is if great value to the insurance industry. Added to the fact that this similar storm was found in only one year of study (1785), a case can be made to undertake studies of additional years.

The most notable result of surface synoptic analysis on a seasonal basis is the delay in springtime warmth. Although the ranges between summer maxima and winter minima are similar, the absence of a transition pattern in the spring, and to a certain extent in the fall, supports the conclusion of a more variable weather pattern in 1785, when compared to the last decade. The conclusion is supported both by anecdotal and instrumental data. The pattern and flow during this lag in the advance of springtime warmth may indicate a lingering snow pack to the north and west lasting well into the spring months, and perhaps forcing the low and mid-level atmospheric flow around its edges.

Additional results include cold onshore flow which penetrates from the coast as far inland as Albany, New York (strong polar High to the north all year), an active mid-Atlantic storm track through June (indicating a well-established cool-season split flow), the autumn stationary front in New England appearing in mid-August (as opposed to October), lack of an autumnal transition season, Arctic air by September, and mP air (cold Pacific Ocean origin) arriving by early December. These results all point to a year in which winter patterns prevail, spring and fall are exceptionally brief, and summer very short.

8.4 Upper Air Conclusions

The same techniques used to develop surface weather patterns at the synoptic scale can be used to reconstruct upper air patterns and flow. The consistency with which the pattern defaults to a coastal baroclinic zone can be explained by a larger temperature difference between land temperatures similar to today and much colder sea surface temperatures. What is notable is the strength of the zonal flow throughout most of the year. This conclusion is supported with both forensic synoptic analysis and anecdotal data. There are many reports of ships being "blown off the coast" and either unable to make their primary destination, or having to turn back to Europe. This can only be explained by a coupling of lower-level jetstream winds and the surface.

Although this type of pattern is indicative of a negative North Atlantic Oscillation (NAO), the downwind results in 1785 are different. A split flow in the North Atlantic appears to preferentially shift more storms northward instead of directing the majority towards the Mediterranean Sea. Although the western portion of the Atlantic resembles the pattern from a negative NAO episode, the eastern Atlantic does not.

8.5 Global Circulation Conclusions

It is clear from the results above that the polar front never really retreats to a modern-day summer position and is, in fact in evidence throughout the year. This implies that the polar cell was either larger or displaced towards eastern North America and the Atlantic Ocean in 1785. Proxy studies from two dozen locations elsewhere in the northern hemisphere reveal a upper air pattern which, when combined with the results from this study, appear to outline the polar cell itself. It appears that the polar cell was indeed displaced, as data from eastern Asia and the Pacific do not support a global expansion. This produces a "short-circuit cross-polar flow" similar but not identical to that which is theorized for the beginning of the last ice age.

8.6 Comparison of 1785 and 2003

Temperature information is discussed in depth in Chapter 4. The most startling similarities, though, are those which affect the human condition. The fact that economic hardship and death seems to have taken so many in Europe by surprise in the summer of 2003 is understandable, as weather records do not extend far enough back in time to show the frequency of such events. The identification of heat and drought in much of Europe in 1785, along with the similarities in the atmospheric circulation, might have at least provided some warning to those countries, and allowed for some preparation.

An additional feature of the analysis of the similarity between the two years could be the potential for further research as well. For example, we have yet to uncover any evidence from Central America for abnormal conditions in 1785 (although some anecdotal sources apparently do exist in the central Archives, according to preliminary research by the author). Nevertheless, there are numerous reports of record cold in Guatemala in the winter of 2003-2004 (Prensa Libre, 2003), including the freezing of the fountain the the main plaza, an event which eludes the memory of even the oldest inhabitants. Can we then imply that there was drought there in 1785 as well? It is present, along with the cold, in 2003. Finding the southern extent of the subtropical jetstream would go far in determining the forcing mechanisms present at the time, and perhaps determining whether the polar cell forced the displacement of subtropical systems eastward, or whether an eastward displacement of subtropical systems allowed the polar cell to preferentially slide towards eastern North America and the Atlantic Ocean. This general movement of semi-permanent systems might, in fact, be the forcing mechanism which allows the short-circuit cross polar flow to form.

8.7 Use in Future Work

Comparisons of these results to other sets of long-term normal data and modern-day 30-year norms will allow insight into decade-to-century scale climate trends, and may refine our view of climate variability. The semi-diurnal resolution will allow for finer analysis of other parameters such as growing seasons, thunderstorm frequencies and severe weather events. Most importantly, individual weather events, which are not resolved in monthly averages, can be specifically assessed. From this point, it is possible to expand the analysis further into the interdisciplinary study of weather effects on migration, settlement, the spread of religion, disease, the rise and fall of governments. and socio-economic change as well as on specific events such as a military campaign. By factoring the effects of weather into these studies, we can investigate the actual effects, if any on historical events. This interdisciplinary application represents an additional value for these data and the results obtained.

Future comparisons may also be made with other records or data sources, such as church records and account books, both of which would increase the resolution to an even finer scale. The actual weather maps can be used as a template against which these records can be tested, which would both verify their accuracy and provide a positive feedback mechanism for further refinement of the weather map itself. More precise locations of the meteorological features would be the immediate result, while opening up an untapped source of meteorological information.

8.8 Recommendations

It is of critical importance to acquire, process and archive any additional data sets that may be available. This study shows the value of even a single mention of the weather in a diary or other source, especially when compared with concurrent observations. It is also important to make historians and researchers aware that any mention of the weather, from any time or place, however unimportant to their research, is vital to the continued study of the weather and climate. Notification of this importance and an offer to copy or store the information should be considered. A central location for digitization and storage of original ephemera and digitization of data sets that might be available on loan are also a priority.

Further research could center on identification of severe events to assess their frequency. Reinsurance rates might then be more representative of the recurrence of these events. Averages for all locations should be extracted and compiled for comparison with modern-day norms. Annual averages, for use in decadal-scale research should be undertaken, And finally, a transfer function for direct comparison with paleoclimatic studies should be considered.

The results presented here show that this cooler weather regime identified in 1785 is associated with frozen rivers and harbors in Pennsylvania until March, impassable roads and snow cover to three feet deep in Massachusetts until April, heavy frost in Virginia in May. ice in the Kennebec in Maine until June, ice in the Atlantic shipping lanes year round, strong west winds in the Atlantic. and more frequent tropical storm activity. If, in fact, our current climate trend becomes one of cooling, even on a regional or local level, this information becomes important. Our understanding of the weather with which our ancestors contended may, in fact, be more valuable to us in understanding our future than our past.

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Lou McNally was born in Cambridge, Massachusetts on January 24, 1951. He attended schools in Concord, Massachusetts, graduating Concord-Carlisle High School in 1969. He worked as a land surveyor and theatrical producer until entering the Meteorology program at Belknap College, receiving the A.S. Degree in 1973. He continued through the A.A. Degree in Media and Communications from Lyndon State College, and graduated magna cum laude with a triple major B.A. in 1975. He returned to school at the University of Maine and earned the M.S. in Quaternary Sciences in 1994.

Lou has worked for 25 years in the media and communications field, specializing publicly in radio and television broadcast meteorology and privately in consulting and forensic meteorology and has received numerous awards including two Emmy Awards for Outstanding Individual Achievement from the New England Chapter of the National Academy of Television Arts and Sciences.

He hopes to continue and expand his work as a speaker, writer, and program host communicating the wonders of weather and climate change to the public. He is a candidate for the Doctor of Philosophy degree Interdisciplinary in Meteorology from The University of Maine in May, 2004.