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Report on the Activities of the Working Group on Climate Change Detection and Related Rapporteurs

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Summary Report of the Activities of the WMO CCl/CLIVAR Working Group on Climate Change Detection

Combining the interests of CLIVAR and CCl, the Working Group on Climate Change Detection sits at the intersection of observational data and models, though with more of a foot in the observational camp. Together with many collaborators around the world, we are trying to address questions such as: What observational data are needed for climate change detection and attribution? What analyses of these data can provide information useful for climate change detection and attribution? And what international coordination on data issues would improve climate change detection and attribution? We are putting particular emphasis on indices derived from daily data for the analysis of climate extremes. Extremes often have the most impact on society and creating these indices is difficult as the data is less readily available. We have also put an emphasis on delivering a range of other indices to IPCC.

Towards that end, our activities started with a workshop in Bracknell in 1998. This workshop particularly sought to identify and refine appropriate climate change indices which could be derived from daily data and provide insights into changes in extremes. However, it also sought to identify indices of mean quantities, as these are important for IPCC. Out of this meeting grew a Task Group on Priority Indices that created a multinational assessment of changes in extremes and also created a draft Data Dictionary of a vast range of possible Indices, some of which are now incorporated in the IPCC Third Assessment (TAR). As a result, the TAR contains a markedly wider range of indices than did the Second Assessment. The work on changing extremes has been accepted for publication by *Climate Research* and contributed new kinds of results to the IPCC TAR. In this process, we have found that those countries which are very reluctant to release daily data are often willing to share climate change indices derived from these data. Accordingly, key tasks for the Working Group have been to plan and start to execute a series of regional international meetings that can deliver such indices. These have broadly followed a pattern developed by the Asia-Pacific Network in 1998 and 1999. The 1998 Bracknell meeting recognized this and contributed to the subsequent Asia Pacific Network extremes meetings along with our own regional extremes meetings later.

Planning for the new extremes initiative took place at a full meeting of the Working Group in Geneva in late 1999. By this time, it was clear that nearly half of the global land surface was not going to be represented in the *Climate Research* article. Locations not analyzed include southwest Asia, Africa, and the Americas south of the United States. At the 1999 Working Group meeting, we decided that the most beneficial thing this small working group could do to enhance climate change detection work was to try to extend the analyses to the blank areas on the map. To achieve this, we have created a regional climate change workshop “recipe” modeled on the successful Asia-Pacific Network meetings, which have already delivered results to the TAR. The workshops are “hands-on” with internationally recognized climate change experts assisting participants in quality controlling and analyzing their data in standard ways. The results have been to create new insights about changing extremes in previously unanalyzed areas and to build the capacity for further analysis in these regions. To date, two regional workshops have been held, one for the Caribbean in January 2001 and one for parts of Africa in February 2001. Representatives from 40 different meteorological services attended these workshops and returned to their institutions with our specially developed but relatively simple climate change indices analysis software. We intend to host additional regional climate change workshops in the next period of Working Group activity.

Report of the WMO CCl/CLIVAR Working Group on Climate Change Detection

1. Introduction

It is difficult to pick up newspaper nowadays without reading something about global warming. It's also hard to pick up a professional climate journal without realizing that some of the best scientific minds in the world are working on climate change detection and its attribution. So what can a small Working Group on Climate Change Detection contribute to this major endeavor? This is the question Tom Peterson (US) asked himself when he accepted, in April 1999, the Chair of the joint WMO Commission for Climatology / CLIVAR Working Group on Climate Change Detection.

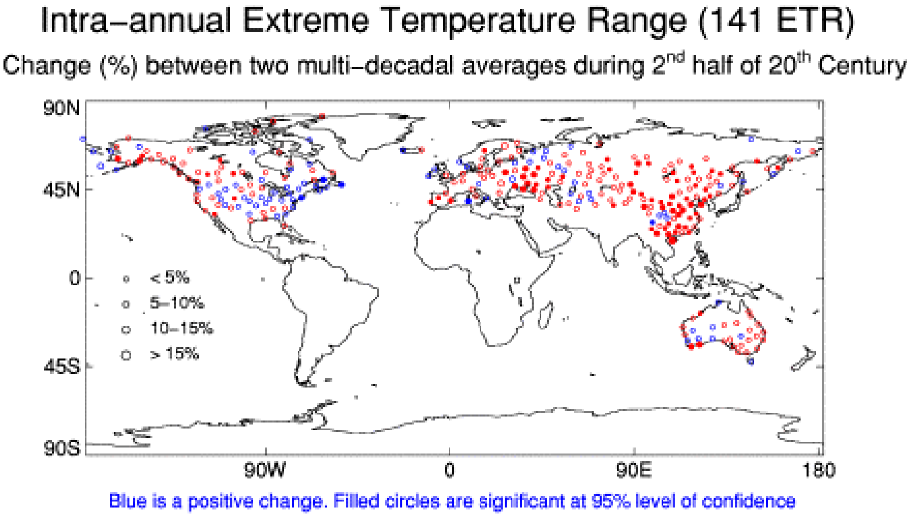
Combining the overlapping interests of CLIVAR and CCl, the Climate Change Detection Working Group sits at the intersection of observational data and models, though with more of a foot in the observational camp. The CLIVAR-nominated members are Gabi Hegerl (US), Phil Jones (UK), David Karoly (Australia), and John Mitchell (UK). From the Commission for Climatology, we have Ms Dolgikh (Kazakstan), Chris Folland (vice-chair, UK), Anjian Sun (China), and Chet Ropelewski (US) who was formerly the Chair but asked to step aside when he started a new job that would not allow him to participate as fully as he thought the chairmanship deserved. Also, Chris, in his capacity as Lead Rapporteur (see Appendix 5 for his report) is working with four nominated Commission for Climatology Rapporteurs on Climate Change Detection Methodologies and Indices: George Gruza (Russia, see Appendix 6), Bill Hogg (Canada, Appendix 7), Abdallah Mokssit (Morocco, Appendix 8) and Neil Plummer (Australia, Appendix 10). In addition, Tom Peterson is the CCl Rapporteur on Statistical Methods with emphasis on analyses of extreme events (Appendix 9). Together with a variety of collaborators around the world, we are trying to address questions such as: What observational data are needed for climate change detection and attribution? What analyses of these data can provide information useful for climate change detection and attribution? And what international coordination on data issues would improve climate change detection and attribution?

2. Development of Climatic Indices, particularly for the IPCC Third Assessment Report

At a meeting of the full Working Group in Geneva in November 1999, we agreed to focus on two main activities. The first was an analysis of indices derived from daily meteorological data. There are several good long-term global data sets of monthly data available to the climate community. But up until now there is no comparable set of daily data. Yet we know that monthly means filter out important information. Long-term daily data allows for analyses of a wide variety of extreme events such as heat waves and flood producing rains that are of great interest to the general public as well as derived parameters that would be of interest to modelers. The indices work started in September 1998 when Chris Folland organized a meeting at Bracknell of a Joint CCl/CLIVAR Task Group On Climate Indices under the banner of the joint Working Group on Climate

Change Detection. This included all the additional CCl Rapporteurs and a report is available from the WMO Secretariat (WMO, 1999; see also Appendix 1). The indices work has continued to build momentum and recently Gabi Hegerl (CLIVAR Rapporteur) has begun a study to determine which indices are relevant to climate models. Chris Folland and his colleagues at the Hadley Centre have also reviewed the accuracy and availability of climate data. Their conclusions were delivered in a lecture delivered to WMO Congress in 1999, and published in the January WMO Bulletin (Folland et al, 2000; see Appendix 5 for more details).

Our task group on indices, chaired by Povl Frich (Denmark) and set up by the task group meeting in Bracknell in 1998, has completed analysis on all parts of the world for which we have data (see Figure 1). A paper describing this analysis with authors from Denmark, UK, Australia, the Netherlands and the US and has been accepted for publication by *Climate Research* (Frich et al., 2001). Key results and diagrams are now in the IPCC Third Assessment Report (TAR), as intended. In view of its importance, the paper is reproduced in Appendix 11. In addition, many other non-extremes indices discussed at the 1998 Bracknell workshop are in the TAR, particularly in the Observed



Intra–annual Extreme Temperature Range (141 ETR)

Change (%) between two multi–decadal averages during 2nd half of 20th Century

Blue is a positive change. Filled circles are significant at 95% level of confidence

Figure 1. To indicate the regions with long-term daily data available for analysis as of 2000, this figure show the results of trend analysis of the Extreme Temperature Range index (the difference between the highest maximum temperature and lowest minimum temperature in a given year) from Frich et al (2001). Red represents a decrease in the range and blue an increase.

Climate Change and Variability chapter. Examples in the IPCC TAR include a number of indices of surface and subsurface temperature change, including proxy indices for up to the last millennium, changes in the cryosphere including glacier length and sea ice extent and thickness, precipitation changes and changes in atmospheric circulation and storms, including hurricanes and tornados. There are a number of others as well.

Key indices are also in the Working Group 1 (Science) Technical Summary and Summary for Policymakers with further indices in the IPCC Synthesis Report, which synthesizes the results of all three Working Groups. A very comprehensive list of possible indices of climatic means and extremes is available in a Data Dictionary. Albert Klein Tank (The Netherlands) has put the list of the indices on the KNMI web site (http://www.knmi.nl/samenw/eca/htmls/index2.html) as well as indices time series from many European stations (http://www.knmi.nl/samenw/eca/index.html). Having the indices task group agree to specific formulae for calculating the different indices has facilitated international collaboration. We have found that many countries, which would not exchange their long-term daily data, are often willing to exchange long-term time series of indices derived from these data. This holds great promise for climate change detection research. Because, for climate change detection purposes, we don't need to know the actual daily temperature at a station, but rather we need to know how the temperature has changed. The information provided by the indices not only includes how the mean values changed over time but how the statistical distribution of the data changed (see Figure 2).

3. Regional Workshops on Changing Climate Extremes

The second major focus of the Working Group's activities builds on this international indices work by trying to fill in the blank areas on the map shown in Figure 1. At the Working Group meeting in November 1999 (see Appendix 2) we decided to pursue this work by fostering regional change workshops modeled after the successful Asia-Pacific Network (APN) meetings that Mike Manton, Neville Nicholls and Neil Plummer (Australia) organized. Both Tom Peterson and Chris Folland attended the first APN meeting, which made major use of the results from the Bracknell indices workshop. The plan for our workshops was to have them be hands-on data analysis workshops, which would both build capacity for climate change analyses in the region and produce results that could be shared with the Climate Change Detection community.

In the process of developing a "recipe" for these workshops, a technical committee was set up consisting of David Easterling (Chair, US), Lisa Alexander (UK), Byron Gleason (US), Malcolm Haylock (Australia), and Albert Klein Tank. The indices formulae described on Albert Klein Tank's web site were converted to Excel since skill in using Excel is widespread. Byron Gleason did this work and created a four part Visual Basic/Excel software packaged he calls ClimDex. The four parts of ClimDex involve:

- Quality control of the data (check precip > 0, Tmin < Tmax, etc.)
- Homogeneity testing (t-tests using user-defined adjacent time periods)
- Calculating derived climate indices (ten from Frich et al. (2001) and a further 5 regionally dependant threshold indicators) and time series
- Visualizing the data spatially

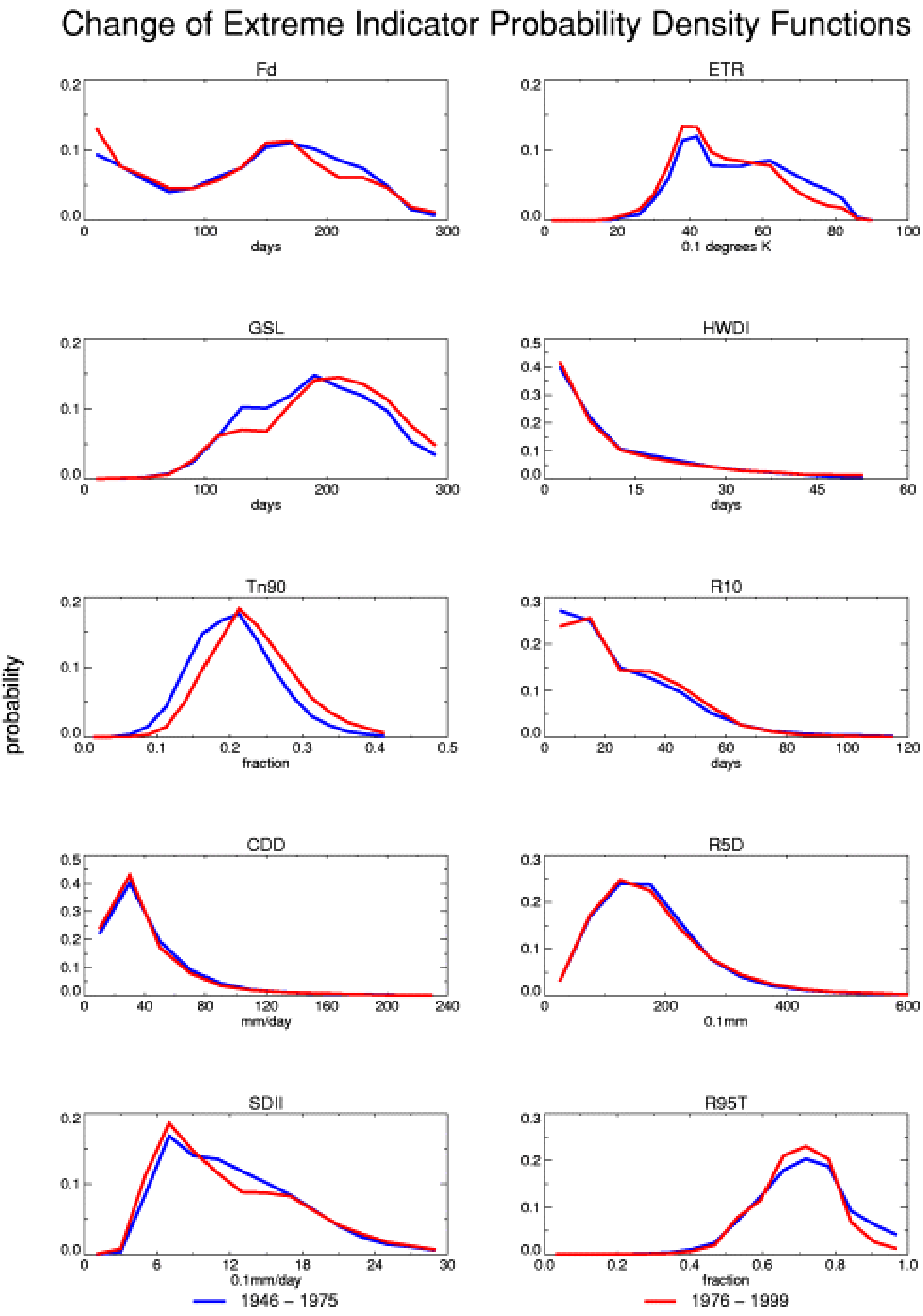


Figure 2. Probability Density Functions showing change in distribution of the 10 extreme indicators (Table 1) over two multi-decadal periods in the second half of the 20th century. From Frich et al. (2001).

INDICATOR		**DEFINITION**	**UNIT**
125	Fd	Total number of frost days (days with absolute minimum temperature below 0 °C)	Days
141	ETR	Intra-annual Extreme Temperature Range (Difference between the highest temperature observation of any given calendar year (Th) and the lowest temperature reading of the same calendar year (Tl)	0.1 K
143	GSL	Growing Season Length (period between when Tday > 5°C for > 5 days and Tday < 5°C for > 5 days)	Days
144	HWDI	Heat Wave Duration Index (maximum period > 5 consecutive days with Tmax > 5 °C above the 1961-90 daily Tmax normal)	Days
194	Tn90	Percent of time Tmin > 90th percentile of daily minimum temperature	%
606	R10	No. of days with precipitation ≥ 10 mm/day	Days
641	CDD	Maximum no. of Consecutive Dry Days (Rday < 1 mm)	Days
644	R5D	Maximum 5 day precipitation total	0.1 mm
646	SDII	Simple Daily Intensity Index (Annual total/ No. of Rdays ≥ 1 mm/day)	0.1 mm/day
695	R95T	Fraction of annual total precipitation due to events exceeding the 1961-90 95th percentile	%

Table 1: Suggested ten key indicators for monitoring change in climatic extremes world-wide. Precise definitions of how to calculate these and many other indicators are available at: *http://www.knmi.nl/samenw/eca/htmls/index2.html*. From Frich et al., 2001.

The quality control tests are fairly simple and are primarily designed to double check the quality of the data prior to using them in the analyses. If problems are found though, the questionable values can be set to missing. Homogeneity adjustments of daily data are so potentially difficult that only a few countries adjust their daily data. The homogeneity testing in ClimDex is designed to detect stations with severe problems so they can be removed from the analysis. The indices calculations are straightforward and produce time series of each of the 15 indices. The final step is visualization of the data both as time series and, using a separate executable, as dots on a map that represents trends. The mapping feature uses freeware so having the participants take the software home causes no copyright problems.

The first of our regional climate change workshops was for the Caribbean and was held in Kingston Jamaica in January 2001. Michael Taylor (Jamaica) and Tom Peterson organized the workshop with excellent assistance from a variety of sources including Lisa Alexander and Albert Klein Tank from the technical committee. Ben Santer (US) described climate change projections for the Caribbean basin, Neville Nicholls reported on the success of the Asia-Pacific Network meetings (see Manton et al, 2001), and Hugh Willoughby (US) discussed the past and future of hurricanes, which is of obvious interest to this region. Participants from 18 of the 22 meteorological services in the region attended along with representatives of 4 regional climate organizations. However, the amount of digital daily data available was less than what we would have hoped, with only about half the countries having any daily data digitized back to before the mid 1970s.

Everyone at the workshop agreed that it was quite valuable. The individual indices provided insights into recent climate change in individual countries and some clearly highlighted dramatic changes in the climate of the region as a whole or parts of the region. For example, since the late 1970s, stations from the southern Caribbean showed strong, nearly linear increases in the number of warm nights (90th percentile of minimum temperature). The additional benefit realised by plotting on the same graph time series of indices from stations from different countries was clear. This demonstrated how cooperative regional analyses can increase confidence in the results. By providing an ability to derive insights into regional climate change from their daily data, the workshop has increased the value that participants place on long-term time series of digital daily data. We expect this will help foster increased data archaeology in the region and thereby improve climate change detection efforts in the future. The results of the workshop analyses will be submitted for publication. The workshop was jointly sponsored by the WMO, the University of the West Indies, NOAA OGP, and NASA through their partnership with NOAA OGP. For more information, see Appendix 3.

The problem of limited digital data was overcome at our next workshop by using a different approach. Rather than focusing on a small region (e.g., North Africa) a call for participants went to all of Africa. Possession of long-term digital daily data was the prerequisite for participation. This second regional climate change workshop was held in Casablanca in Februrary 2001 and hosted by Morocco's Direction de la Météorologie Nationale (DMN). The organizers were David Easterling (US), Abdalah Mokssit, and Valery Detemmerman (WMO). Lisa Alexander again provided technical assistance. Support for the workshop was provided by WMO and DMN.

Participants from 22 African countries brought digital daily data sets with at least 30 years of data. The number of indices addressed by ClimDex was raised from 15 to 18. The workshop went quite well with new insights into recent climate change being gained for this large region, which previously had very limited analysis of long-term daily data. Again a paper is planned describing the results of the workshop analysis. Details, including several diagrams showing results of the analyses, are in Appendix 4.

The plan to develop and refine of a "recipe" for regional climate change workshops appears sound. With the development of ClimDex and experience with past meetings (each meeting had a participant who attended the previous workshop), creating future regional climate change workshops like these should be fairly straightforward. Other major blank areas on the map include southwest Asia and Central and South America. We anticipate the next workshop to be in the South America, though firm plans have yet to be made. If you are interested organizing a regional climate change workshop, particularly in southwest Asia, please let one of the members of the WGCCD know or contact Valery Detemmerman at WMO.

Additional items worth mentioning are that the chair of the WGCCD attended a CCl Advisory Working Group in April 2000 and a CLIVAR Scientific Steering Group meeting in May of 2000. He reported on our activities and plans. Reports of our indices and regional workshop plans were given a warm reception. The main piece of advice we received was to consider incorporating indices derived from ocean data in our analysis. After discussing this with oceanographers, we are not clear how to fit this into our current regional workshop activities as the oceanographic data are already widely available worldwide, and these workshops focus on analysis of previously unavailable daily weather data.

4. Comparison of modelled and observed extremes

A developing focus, foreshadowed at the 1998 Bracknell Task Group meeting, is to compare modelled and observed extremes, initially in atmospheric general circulation models simulating the climate of the twentieth century. Dmitri Kiktev, one of George Gruza's colleagues, is spending a period in 2000-2001 at the Hadley Centre of the UK Met Office working on this. He has created some initial analyses discussed in Appendix 5.

5. Contributions to the Annual WMO Statements on the status of the Global Climate, 1997-2000

The Working Group has a commitment to making significant contributions to the Statement and to guiding its development. The main aim of Working Group contributions has been to place the climatic events in a given year as far as possible in a long-term context. In 1997, the Statement highlighted the unusually persistent negative phase of the Southern Oscillation index in the last few decades (indicating persistent El Nino conditions). In 1998, the contoured seasonal maps of worldwide temperature anomalies were expressed as percentiles for the period 1961-90. This brought out the extreme warmth of 1998 in many areas (the warmest year in the global record) but also highlighted a few areas that were actually substantially colder than normal. As recommended at the meeting of the Working Group in November 1999, the 1999 Statement highlighted the newly published changes in Northern Hemisphere temperature over the last 1000 years derived from proxy and instrumental data. Worldwide precipitation in 1999 was also placed in the longer-term context. In 2000, an innovation was to discuss Arctic and Antarctic sea ice extent in 2000 in the context of the available historical records. The 2000 Statement also highlights the persistent 1998-2001 La Nina; this appears increasingly anomalous in the context of the recent tendency to persistent El Nino conditions.

6. Conclusion

Obviously individual members of the working group have done a great deal of additional work related to climate change detection and to the related phenomenon of large-scale climate variability (e.g., Chelliah and Ropelewski, 2000). Describing everything we've all done would greatly increase the size of this report. The Report of the Lead Rapporteur on Climate Change Detection Methodologies and Indices describes some of these activities and much of the rest can be found described in IPCC TAR chapters. Indeed we did not hold a second working group meeting partly because many of our members were very busy with IPCC work and partly to allow us to focus our resources on holding two regional climate workshops. For this report, we decided to limit the discussion to those activities which would not have been accomplished without the working group. Even with this restrictive definition, we believe the last few years have been an interesting and productive time for the Working Group on Climate Change Detection. We've enjoyed the activities and appreciate the confidence in us you demonstrated by asking us to serve on this working group.

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Appendix 1. Report by Chris Folland (UK), Briony Horton (UK) and Peter Scholefield (WMO) on the Meeting of a Special Task Group on Climate Indices, Hadley Centre, Meteorological Office, Bracknell, U.K., September 2-4, 1998.

1. OPENING OF THE MEETING AND REPORTS OR PREVIEWS OF RELATED MEETINGS

1.0.1 Dr Carson, Director of Climate Research in the Meteorological Office, welcomed the participants to the Hadley Centre (see Annex 1 of WMO, 1999). He encouraged open debate within the group and expressed appreciation for the constructive nature of this joint task group involving both WMO and CLIVAR. He drew the attention of the group to the forthcoming International CLIVAR Conference in Paris (December 1998), attendance at which would be through national delegations. The newly structured European Climate Support Network (ECSN) would be involved to support climate data projects. The Task Group needed to decide on the types of data required and ECSN would then try to provide them for its own area of responsibility.

1.0.2 The Co-Chairman, Mr Folland, outlined the purposes of the meeting as to:

i. contribute to the provision of analyses of indices of climate change, especially for the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2001) but also for subsequent research. For this, access to and use of daily data would be essential;

ii. contribute to wider efforts on extremes being coordinated by Mr Karl, Director of NOAA's National Climatic Data Center (NCDC) in Asheville, NC, USA.

The Agenda for the meeting can be found following this report.

1.0.3 The group noted that Messrs Folland and Karl have been designated Convening Lead Authors for the "Observed Climate Variability and Change" chapter of IPCC 2001. Other members of the Task Group would need to help ensure:

- adequate exchange of daily climate data;
- at least 50% of daily Global Climate Observing System (GCOS) surface data be available for analysis for IPCC 2001 if possible, with data not limited to these stations;
- agreement on who should hold the GCOS surface data;
- agreement on what analyses will be done;
- agreed initial comparisons with model analyses;
- co-ordination of analyses;
- clear responsibility for GCOS;
- consideration of the longer term, e.g. possible IPCC Assessment in about 2005;
- a clear understanding of how this initiative relates to other work on extremes by other groups
- the Commission for Climatology (CCl), CLIVAR and the GCOS Steering Committee are informed of the outcome of this meeting.

1.0.4 The group identified a number of forthcoming meetings relevant to the group's work including WG I (Science) of the IPCC (30 Nov. - 2 Dec.1998), an Asia-Pacific Regional Indices meeting in Melbourne, Australia (December 1998), the CLIVAR conference (Paris, December 1998), and a second extremes workshop in Asheville, NC, USA in March 1999 in tandem with a lead authors' meeting for the "Observed Climate Variability and Change" chapter of IPCC 2001.

1.1 Report of the Chairman of the CCl/CLIVAR Working Group on Climate Change Detection

1.1.1 The Co-Chairman of this meeting and chairman of the Working Group on Climate Change Detection, Mr Ropelewski, outlined some of the challenges facing the Task Group. There was a need for daily data of many types, including gridded satellite data (for analyses of extremes), as well as in situ observations. Even the NCEP reanalysis was not very useful for simple trend analysis, owing to changes in input data. But the group needed to explore how the model-based reanalysis data could be used, e.g. in comparisons of the output from model simulations forced with changing greenhouse gas (GHG) simulations and reanalyses. Use of a fixed model in reanalyses yields more homogeneous simulations of observed changes in climate than from changing weather forecasting models, and therefore better agreement with GHG simulations, though the current generation of reanalyses have significant deficiencies.

1.1.2 This Task Group, Mr Ropelewski thought, was well positioned between the operational and scientific parts of WMO. This provided a good opportunity to identify the scientific needs for data and then to operationalise these needs through the National Meteorological and Hydrological Services. Mr Ropelewski listed the rapporteurs for the CLIVAR and CCl parts of the Working Group, and specific 'projects' relating to climate change. A full Working Group on Climate Change Detection meeting is being planned for early 2000 to present the results of work initiated at this meeting. The group needed to identify a scientifically sound and operationally defensible set of data and indices required for climate change detection (collaboratively with IPCC Working Group 1) with subsequent WMO implementation.

1.1.3 Annex 3 of WMO (1999) contains a brief account of the progress and directions of the CCl/CLIVAR Working Group on Climate Change Detection.

1.2 Report of the WMO Secretariat Representative - Mr P. Scholefield

1.2.1 Mr Scholefield thanked the staff at the Hadley Centre for organising the Task Group meeting. He noted that the best known climate index is the IPCC global surface temperature curve (combined Climatic Research Unit (Univ. of East Anglia) land surface air temperature analyses done with the help of the UK Met Office and sea surface temperature analyses from the UK Met Office). Many others are used by IPCC and others, and the group needed to help assess these and identify more. He reported that WMO issues publications which monitor global climate such as the quasi-biennial Global Climate System Review and the annual WMO Statement on the status of the global climate. This Task Group should consider how to assess and authenticate the various indices used in these publications.

1.2.2 There is also a WMO-sponsored initiative to prepare a book on the Climate of the 20th Century. In particular, the group needed to examine how key parameters of the climate system have evolved and how they can be used in the detection of climate change, bearing in mind research already carried out under CLIVAR.

1.2.3 Mr Scholefield also presented the results of a WMO-CCI Climate Change Indices Task Group meeting held in Melbourne in July 1997, following the June 1997 Asheville meeting, which discussed the following:

- plans for short and long-term work;
- an expansion of the Asheville recommendations for indices;
- further guidance on the detection of climate change and on monitoring climate variability;
- a refined definition of climate change.

1.2.4 Recommendations from the Melbourne Task Group included the need for:

- long-term data sets;
- indices to monitor the evolution of climate over the past 2000 years;
- close coordination with IPCC and CLIVAR on the development of indices;
- to work with GCOS to monitor, archive and develop capabilities of the GCOS Surface Network (GSN) and the GCOS Upper Air Network (GUAN);
- daily GSN data to be exchanged;
- comparisons of indices from observations with those from models.

1.2.5 A summary of the Melbourne meeting can be found in Annex 4 of (WMO, 1999).

1.3 Summary of "Storms" Breakout Group Report from the June 1997 Asheville meeting – Mr C.K. Folland (UK)

1.3.1 Mr Folland summarised Drs Trenberth and Owen's report (see Annex 5 of WMO, 1999). Storms can be classified into three main types: tropical cyclones and hurricanes, extratropical storms, and small scale phenomena (thunderstorms, tornadoes, etc). They are often characterised by extreme winds, temperature and rainfall. It is difficult to create indices of wind speeds from direct measurements as such databases still need building. But there are major inhomogeneities in current wind data. Therefore, wind indices should be derived from mean sea level pressure (MSLP) or surface pressure data. A typical scale of 1,000 km is needed in the extratropics, but higher resolution is required for tropical storms. Large scale pressure patterns should be included, e.g. the North Atlantic Oscillation (NAO). Gridded MSLP data can typically provide geostrophic winds once daily at 10° latitude resolution. These estimates should be selectively calibrated with wind observations. Corroborative data such as wave heights should also be used. A variety of wind statistics are needed, for example winds exceeding particular Beaufort scale values. Monthly statistics are needed as are time series of the indices. Key questions about changes in an index are:

- are the changes statistically significant?
- are there physical reasons for the changes?

1.3.2 Mr Folland noted that MSLP data have significant and sometimes serious problems and substantial work is needed to improve these data. He also noted that most damage was from gusts and therefore a gust index was also required, derived from selected data to calibrate relationships between gusts and averaged wind.

1.3.3 *Tropical Cyclones*. NCDC has a good data set of these, and the Comprehensive Ocean-Atmosphere Data Set (COADS) contains wave heights. These databases need reanalysis, with particularly detailed analysis of land falling tropical cyclones. For example, indices could include:

- strongest cyclone;
- mean intensity;
- track of actual damage;
- normalised cyclones.

1.3.4 *Extratropical cyclones.* Climate applications groups and research communities need to work together in this field. Wind data are very inhomogeneous (see above). Six-hourly changes in pressure require analysis (or 24-hourly changes to avoid aliasing the semidiurnal cycle through changing observation times). Reanalyses have much potential, but need careful exploration owing to inhomogeneities. Upper air winds could be provided by the Comprehensive Aerological Reference Data Set (CARDS). An important feature in some areas is that snowfall distributions change with changes in tracks or intensity of depressions in winter.

1.3.5 *Small-scale phenomena.* These include lightning, hail, wind bursts, local floods, etc. Only high quality stations with good metadata should be used. To fill gaps between stations for these small-scale phenomena, innovative use of remote sensing data may be needed. Station data should be quality controlled against local area mean statistics, as this reduces the severe impact of rapid loss of correlation with distance that militates against good quality control. Trends should be analysed in relation to trends in synoptic patterns as these are likely to be the controlling factors. Insurance statistics are likely to provide useful information. Some high quality stations have been identified and data exchange and analysis has been initiated in Central Europe, e.g. work by Brazdil and colleagues.

1.3.6 Mr Folland stressed that storms are not the central focus of this particular Task Group but some results will be needed for IPCC 2001. It was noted that quality-controlled monthly MSLP analyses now exist back to 1871, but not all the GSN stations may have daily surface pressure data, though this is desirable. The only realistic analysis on a six-hourly time scale will come from reanalyses. Commercial interests in land-based near-surface wind observations are likely to prevent their widespread release, though they are available over the oceans, e.g. from the COADS or UK Met Office marine data bases.

1.4 Summary of "Temperature" Breakout Group Report from the June 1997 Asheville Meeting - Mr C.K. Folland (UK)

1.4.1 Mr Folland stressed that, as with all climate-related indices, temperature indices must:

- be relevant to society;
- reflect the sensitivity of impacts to climate variability and changes;
- give implied warnings of future changes;
- be related to physical changes, e.g. to the NAO or to radiatively forced warming;
- have a good signal to noise ratio where the signal is trend and the noise is interannual variability;
- be definable over large regions in a consistent way;
- be calculable from available, or potentially available, data.

It was also highly desirable to define a subset of key indices for presentation to politicians.

1.4.2 With respect to data, the main need is daily data for which current exchange arrangements are totally inadequate. As a minimum, 50% of GSN data needs to be available for use for IPCC 2001. There is a need to identify who receives and analyses such data so that countries can be satisfied that the use is legitimate. Examples of legitimate users should include contributing authors to the “Observed Climate Variability and Change” chapter of IPCC 2001. To achieve this, a new task group was required to help WMO rapporteurs from each WMO Regional Association or continental area to provide data and indices for IPCC and to report to WMO. To encourage provision of additional data, WMO/GCOS and WMO/CCI should inform and enthuse countries about the work and its application to IPCC reports.

1.4.3 Indices recommended by the Asheville meeting included:

- the frequency with which percentiles of daily maximum and minimum temperatures, calculated from a reference period, are exceeded - the changes at stations should be put onto a common basis and displayed through maps and time series;
- similar analyses for monthly, seasonal and annual temperature;
- maps and time series of changes in diurnal temperature range - these suffer from a lack of spatially complete data - CLIMAT messages should have included monthly mean maximum and minimum temperatures since November 1994, but are often miscoded or missing;
- inter-period temperature differences, between, e.g. consecutive 5 or 10-day periods or consecutive months, seasons or years - interperiod differences often express variability more clearly on a specific time scale than does the standard deviation;
- frost/freeze severity - daily data is essential;
- heat/cold wave duration based on threshold temperatures or exceedance of percentiles - when combined, these give the total duration of seasonal heat waves or cold spells, etc.;
- heat/cold stress using temperature and dewpoint or wind speed.

1.4.4 Mr. Folland recommended that humidity data should be considered as essential exchanged data. An increase in surface vapour pressure or dewpoint is likely to be a hallmark of climatic warming and may have societal consequences. However, many stations do not measure humidity. Mr Hogg pointed out that Canada had found problems with the homogeneity of humidity data and Ms Rosenhagen indicated that the gathering of long time series of humidity data is much more problematic than that for temperature as the daily extremes were not routinely archived. Furthermore, as to the global monthly values, there was a break in the humidity data due to a change in the CLIMAT code in 1968: whereas relative humidity was reported before, vapour pressure has been reported since then. The two cannot be compared exactly. One possible solution is to start with GUAN surface measurements of humidity, which are mandatory.

1.4.5 Especially important key indices were identified as seasonal and annual extremes, the diurnal temperature range and frost severity.

1.4.6 Annex 6 (WMO, 1999) contains the full report of the Breakout Group on Temperature Indices at the Asheville meeting.

1.5 Summary of “Precipitation” Breakout Group Report from the June 1997 Asheville meeting - Dr N. Nicholls (Australia)

1.5.1 Dr Nicholls noted that papers presented at Asheville will be reported in a special issue of ‘Climatic Change’. There will be too much information if all of the indices suggested are used. A small number of indices need to be selected so as not to confuse the intended audience.

1.5.2 The following list of indices should be derived:

<u>from daily data:</u>

- the number of dry days/rain days/hail days/snow days, taking into account the differences in definitions between countries;
- the frequency of exceeding specified thresholds and percentiles, using all days or only days with precipitation;
- the intensity, i.e. mean rainfall for those days having measurable precipitation;
- the maximum length of dry spells based on the number of consecutive days with precipitation below a threshold;
- the frequency distribution of rainfall using a decadally incremented moving 30-year window;

<u>from hourly data:</u>

- The number of hours with precipitation;
- The frequency of exceeding specified thresholds that are based on percentiles;

<u>from monthly, seasonal and annual data:</u>

- the fraction of a country exceeding the 95th percentile value or not exceeding the 5th percentile value.

1.5.3 The following is a minimum set of three indicators:

- the variation in the magnitude of the 95th percentile or 5th percentile of daily values calculated separately for each year;
- the percentage of annual rainfall falling on days wetter than the 95th percentile;
- the fraction of a country exceeding the 95th percentile or not exceeding the 5th percentile on a seasonal and annual time scale.

1.5.4 Analytical methods recommended include:

- calculate percentiles using gamma distribution and maximum likelihood methods;
- aggregate the data from individual stations in appropriate ways.

1.5.5 Dr Nicholls noted that changes or deficiencies in rainfall instrumentation are thought to be less of a problem in the southern hemisphere where fewer stations have snow.

1.5.6 Dr Nicholls then previewed the December 1998 Asia-Pacific Workshop on Indicators and Indices for Monitoring Trends in Climate Extremes to be held in Melbourne. This had been organized because of a lack of representation from S.E. Asia and the South Pacific at the Asheville extremes meeting in 1997. The intention is to enable Asia-Pacific nations to recognise that their data are important, to locate contacts and available data, to identify existing work, to initiate new work and to identify appropriate analyses. Some of the countries are very protective of their data, so an initial approach might be to create regional indices. In this way, the under-represented regions can see a useful output and therefore might wish to participate more fully. There are also substantial variations in ability of the countries to make available the necessary data and in the funding of such activities. To develop such activities with maximum effectiveness, it is felt that South East Asia, the South Pacific, and Africa need to be treated separately. The use of other organisations to help develop or fund such initiatives needs investigation.

1.5.7 Annex 7 (WMO, 1999) contains the full report of the Breakout Group on Precipitation at the Asheville meeting.

2. ONGOING RESEARCH ON CLIMATE CHANGE INDICES AND ASSESSMENT OF CHANGING EXTREMES; RAPPORTEURS' AND OTHER REPORTS ON DATA, INDICES, METHODOLOGY AND RESULTS

2.0.1 Sections 2.1 to 2.12 below constitute brief descriptions of studies and related issues by a number of the participants at the meeting.

2.1 Recent Research Results on Extreme Precipitation in Australia, New Zealand and the Southwest Pacific - Dr K. Hennessy (Australia)

2.1.1 The Australian Bureau of Meteorology (BoM) provided information from 379 high quality stations. Of these, 191 have continuous records, others are composites of 2-3 stations. The data have been tested for their homogeneity. Large-area averages were calculated from the irregularly distributed stations, and maps and indices were produced.

2.1.2 Indices calculated were (a) total rain, and rain days above 1mm; (b) changes in 95th percentile; (c) frequency of days over 25 mm and 50 mm. Data covered the period 1910-1995. Averages were calculated over four Australian climate quadrants as well as political regions and the whole of Australia. Percentiles were calculated over all days, not just rain days. Accumulated data, e.g. over weekends, were evenly distributed during accumulation times.

2.1.3 There were increases in the intensity of 95th percentile rain events. Dr Hennessy noted that the 99th percentile is a truer extreme than the 95th percentile, but the lesser number of more extreme events show larger noise. The frequency of days with >25.4 mm increased in New South Wales through the period. On the southeast coast there has been a statistically significant increase in the number of days with >50.8 mm, though these results are strongly influenced by the very wet La NiŽa years 1973 and 1975. There have been problems with communicating percentiles to government and media, hence thresholds should also be used. In conclusion, rainfall events have increased in intensity over Australia over the period 1910-1995. Trends become statistically significant if smaller areas are analysed. Work is also about to commence on rainfall indices for New Zealand and the South Pacific by Dr Salinger of the New Zealand National Institute of Water and Atmospheric research (NIWA).

2.1.4 Among future work plans are the following:

- analyse trends in the frequency of days over 25 mm, 50 mm, 100 mm using much higher quality stations;
- analyse contribution of daily rainfalls exceeding the 95th percentile to the annual total;

- study trends in two or three day rainfall totals: these have fewer problems relating to accumulated values and do not split the longer rainfall events;
- map spatial changes in intensity;
- calculate return periods;
- identification of synoptic reasons for some of the changes seen.

2.1.5 Annex 8 (WMO, 1999) presents a brief overview of results and plans, together with references, on climate change detection data, methodologies and indices for WMO Region V. This Annex is also relevant to items 2.3, 2.4 and 2.8 below.

2.2 The Incidence of Extremes in Worldwide and Central England Temperatures - Ms B. Horton (UK)

2.2.1 Apparent increases in the incidence of worldwide annual warm extremes since 1900 mainly reflected the overall warming. However, there has been a larger decrease in cold extremes, leading to a tendency to a decreasing total of all extremes worldwide. This might reflect an improved and denser data network rather than a true decrease in variance or other aspects of the analysis. This is being investigated. However, a decrease in the total number of daily extremes in de-trended Central England temperatures may be genuine. This again shows a greater decrease in cold extremes than increase in warm extremes. This may result from changes in regional atmospheric circulation. Mr Folland noted that a possible influence of global warming in genuinely reducing the variance of temperature cannot be ruled out.

2.2.2 Annex 9 (WMO, 1999) provides additional information and references on this matter.

2.3 Recent Research on Extreme Daily Temperature in Australia, New Zealand and the Southwest Pacific - Mr N. Plummer (Australia)

2.3.1 A 48 station network for Australia, homogeneous in 1961-95, was used, plus a new adjusted network covering 1957-96. There are few daily data available before 1957. There are now 600 stations operating, half of which are automatic. A 72 station network was used for New Zealand.

2.3.2 In Australia, there was an increasing trend in the number of days above 90th percentile and a reducing trend in days below the 10th percentile. Strongest trends were for decreases in the frequencies of cool nights. The trends for one-day events were stronger than for three-day events. The greatest changes were in the northern half of the continent. In general, the more extreme events (changes in the 95th and 5th percentiles as well as three-day events) had weaker trends. Daily temperature range (DTR) in Australia decreased in the 1950s and in 1973-5. Inter-diurnal temperature variability has shown little change overall, although there have been some significant regional trends. Mr Plummer related changes in interdiurnal temperature variability over the southwest of the continent to changes in atmospheric circulation over the Australian/Southwest Pacific region. Lower pressure dominated at the start of the period and higher pressure towards the end. There is a strong correlation between the rising inter-period variability and this rise of MSLP: extreme temperatures appear to be more likely under high pressure conditions in this region. Frost frequency has declined over the eastern interior of Australia.

2.3.3 Preliminary work by New Zealand's NIWA examining changes in temperature extremes over New Zealand has revealed further important links with changes in atmospheric circulation over the New Zealand/Southwest Pacific region. A strong reduction in the occurrence of "air" frosts occurred in many areas between 1930-50 and 1951-75, with the shift to a warmer east to northeasterly regime. Although cooler westerly anomalies dominated in the last two decades, the 1976-94 period still experienced a general shift towards fewer days with minimum temperatures below 0°C. Increases in days above 25°C and 30°C occurred with the shift to warmer east to northeasterlies in most areas. However, the shift to a more westerly regime in the more recent period has led to slight decreases over much of New Zealand, except for the eastern fringe where there have been a few more warm days.

2.4 Trends in Winds, Tropical Cyclones and Cyclonicity Over and Near Australia - Dr N. Nicholls (Australia)

2.4.1 For tropical cyclones, inhomogeneities are introduced by changes in definition. But moderate tropical cyclones, unaffected by these changes, decreased from six to two per year while strong tropical cyclones showed a very slight increase. Fluctuations in tropical cyclones are strongly linked to the Southern Oscillation Index (SOI) and the Aug-Sep-Oct SOI can be used to predict the number of the next season's tropical cyclones in the Australian region. Trends in winds were studied for the Bass Strait using surface pressure data. However, introduction of a new barometer introduced inhomogeneities and conclusions are difficult to draw. To study trends in cyclonicity, the number of hours with a cyclone in a gridbox was studied and time series and trends found for 1965-1993. There was decreased cyclonicity in SW coastal Australia and the nearby ocean, matching well with trends in pressure data.

2.5 Climate Change Detection Data, Methodologies and Indices in WMO Region II (Asia) - Dr G. Gruza (Russian Federation)

2.5.1 Station temperature data for the belt 50-55N were used. Variability is high in this belt, and not well correlated with average northern hemisphere or global temperatures. Changes over two recent 30-year periods were compared with the output of a Hadley Centre model with CO2 + aerosols, simulating the same periods. A strong warming in spring in observations in the second period was much less in the model. The model temperature changes also showed markedly less spatial correlation than the observed changes.

2.5.2 Dr Gruza then described a Climate Anomaly Index for 10-year periods from which a Climate Change Index could be created and significance levels of the index calculated. He showed how phase trajectory diagrams could be calculated to see how climate change and climate anomaly indices relate to one another.

2.5.3 Dr Gruza pointed out that there was a need to develop indices that can be used for both models and observations on regional space scales. This would require a dialogue with modellers who need to save the data to create these indices. Modellers are increasingly analysing the output of regional climate models, often embedded within global models, and this also needs to be taken into consideration.

2.5.4 Further information on this subject can be found in Annex 10 (WMO, 1999).

2.6 Climate Change Detection Data, Methodologies and Indices in WMO Region IV (North and Central America and the Caribbean) - Mr W. Hogg (Canada)

2.6.1 Mr Hogg began by raising a number of questions: data must be homogeneous, but over what important time period: 1900-1998?, 1950-1998? Do we fill gaps in time series? He continued that time resolution should include annual, seasonal, daily, plus hourly extremes for precipitation. Canada has problems with inhomogeneous hourly data. Wind has inhomogeneity problems: so we should consider here using a combination of NCEP reanalyses (since 1958) and good observations. But homogeneous daily temperature data, and homogeneous daily rain and snow data exist from about 500 stations.

2.6.2 Variables to be considered are maximum, minimum and mean temperature; precipitation amount and frequency, treating rain and snow separately, and wind. Quantities to be monitored are annual/seasonal extreme values, though these are noisy; yearly estimates of percentiles; coefficient of variation (standard deviation/mean); fraction of annual precipitation (mainly rain) falling in extreme events; fraction of total precipitation falling as rain/snow; return periods, exceedance of (geographically varying) thresholds, e.g. chosen to pass about three events per year. Trends can be regionalised by a cluster analysis of station values. He noted that Canadian rainfall shows interdecadal variability, but no uniform trend.

2.6.3 What should the Rapporteurs concentrate on? Key activities can be seen as:

a) gathering data;
b) encouraging others to gather data;
c) identifying and encouraging analyses, or providing software to countries to help them to do an analysis.

2.6.4 Mr Hogg's report to the meeting can be found in Annex 11 (WMO, 1999).

2.7 Climate Change Detection Data, Methodologies and Indices in WMO Region I (Africa) - Mr A. Mokssit (Morocco)

2.7.1 Mr Mokssit reported that by 2001 it was planned to:

- complete a stage 1 study of detection/attribution over Africa;
- set up a continental database (possibly within ACMAD) containing averages, standard deviations and rainfall indices, but very few extremes have been collated;
- carry out verification/validation of existing results;
- compile information on existing climate studies.

2.7.2 During the period 2001 and 2005 activities foreseen include:

- participating in studies of detection techniques; perform regional model experiments in Africa, but some technology transfer would be required to make this possible;
- involving as many countries as possible in projects as this is the best way to get a wide coverage of data;
- contributing to writing a detection study focusing on Africa;
- creating an inventory of climate data in Africa.

2.7.3 The African activities need to be combined with global programmes. Data from African data sets can then be used to improve global data sets. Some developments moving in this direction have already occurred. Currently there are 18 climatic zones in Africa each with its own set of climatic indices which are used for monthly forecasts by ACMAD. ACMAD provides training and technical support for African NMCs in return for data. ACMAD could collect daily data for African countries. Initially an inventory of existing regional programmes will need to be conducted which may already have usable data.

2.7.4 Mr Mokssit showed examples of climate change indices. Winter minimum temperatures in five Moroccan cities have increased. Thunderstorms in Morocco have increased since 1971, but there has been a recent decrease in rainfall.

2.7.5 Mr Mokssit saw his role as rapporteur as being a focal point for gathering and disseminating information on African climate; evaluating needs - data, etc.; and evaluating how useful global models are for studying African climate and its change.

2.7.6 Mr Mokssit's report to the meeting can be found in Annex 12 (WMO, 1999).

2.8 Climate Change Detection Data, Methodologies and Indices in WMO Region V (Australia and SW Pacific) - Dr N. Plummer (Australia)

2.8.1 A new homogenised Australian maximum and minimum temperature data set has now been created by Blair Trewin of the Australian Bureau of Meteorology, so previous analyses will be extended. These have adjusted daily values for 99 stations from 1957-96. The methodology uses the Easterling and Peterson homogeneity detection method and applies corrections using neighbouring temperature differences for a range of percentiles.

2.8.2 Changes in frost frequency and other extreme indices can be recalculated using these data. It will be necessary to carefully choose thresholds, stations and criteria for data-completeness. He noted that regional averages would be biased by very cold stations. A useful comparison would be to compare the results from daily data with those derived from one-minute data from automatic weather stations. Digitisation of daily and hourly climate data for 50 Australian stations is expected to start in early 1999. A recent development is that more Australian stations should send CLIMAT messages as a new system is being developed in the Bureau of Meteorology that allows this.

2.9 Statistical Methods, Changing Extremes and Climate Change Detection - Dr T. Peterson (USA)

2.9.1 It was noted that a small change in the mean can have a big effect on the extremes, but the extremes consist of only a small number of data. Extremes have a high impact and affect people much more than more normal conditions. There are three types of analysis: parametric (extreme value distributions), non-parametric (percentiles), and threshold.

2.9.2 *Parametric analyses.* Examples of these are the Fisher-Tippett and Gumbel fits to extreme value data. The calculation of return periods should be restricted to twice the data length. These techniques are concerned with fitting the tail of a distribution rather than fitting all the data, as they only apply to data that are already extremes (such as the largest value in a month or a year). If the physical causes of an extreme vary between events, then estimates of return periods will be unreliable. For example, in northeast Florida in 1998, a ridge of high pressure prevented the usual sea breeze from occurring and so there were many days with extremely high temperatures. These would have constituted a once in 1000 year event if the physics had been the same as the more usual cause of extreme temperatures, but this would have been an erroneous conclusion. Distributions may also change with climate change: thus if the distributions are fit to a period with a trend then the results of the analysis may be affected.

2.9.3 *Non-parametric analyses*. Examples are percentiles. All the data are used, rather than just the tail. Percentiles are easily expressed in publicly understandable terms such as much below average, below average, near average, above average, much above average. The threshold changes according to the local characteristics of the data, so such an analysis can be done consistently over a large region. The results are less sensitive to the underlying distribution than are methods that use a specific distribution to fit all the data. But there are problems with precipitation in areas that are always dry.

2.9.4 *Threshold.* These should be physically meaningful, e.g. 0°C or the SST threshold for hurricane formation. A complication is that relevant thresholds are regionally dependent, though possibly the most meaningful to the public and the easiest for the regional media and politicians to grasp.

2.9.5 The choice of approach is data dependent. If the record is short, return periods are unreliable. Fewest assumptions are needed for percentile analyses, but non-parametric analyses are less robust for very high or low percentiles. Thresholds are the easiest to understand but are the most limited in scope. See Annex 13 (WMO, 1999) for further information.

2.9.6 Prof. Anderson noted recent work to develop inference techniques for extreme values. It is now possible to fit generalised extreme value distributions using information from the physics. Parameters in the distributions are functions of the physics. In climate research a changed situation from hindsight can be assessed, even if not in advance. Scientists can look at a mix of two distributions or separate them altogether, e.g. rain from snow can be separated as can high Southern Oscillation (SOI) days from low SOI days. Prof. Anderson noted that there is a well accepted set of estimates of precision for 100-year events, etc. The gamma distribution could be used for extreme percentiles, but there is a danger because the parameters are influenced by the entire distribution and the fit may not be optimal in the tail of the distribution.

2.9.7 The Task Group noted that Extreme Value Analysis (EVA) is important for IPCC 2001 and requires answers soon, so simpler analyses must be employed now. However, extreme value analyses need to be carefully looked at and used beyond this time frame as one of the prominent tools. There is, of course, extensive experience of some of these methods in hydrology and hydrometeorology.

2.10 Climate Change Detection Data, Methodologies and Indices in China - Mr Zhai Panmao (China)

2.10.1 Data available in China include monthly climatic data from the provinces (400 stations, 272 currently used), daily reports from the provinces, a daily precipitation data set, and a 500 year reconstructed record of major floods. The 272 stations have good quality temperature and precipitation data for 1951-1996, but are hard to maintain in near-real-time. A further 197 stations have multiple variables, but these data are not yet available centrally, even within China. The daily precipitation data covers many stations, but many data are missing, so only about 200 stations have been used.

2.10.2 Indices used include mean daily maximum and minimum temperatures, extreme maximum and minimum temperatures, number of hot and cold days (according to a threshold value), cold waves (defined according to regionally-varying temperature reductions), annual precipitation amounts over different thresholds, one-day and three-day maximum precipitation, numbers of rain days, mean intensity of precipitation. There are also indices of historical summer precipitation in the severe flood, flood, drought and severe drought categories. A wetness and dryness index is available from a few stations. Summer and winter monsoon indices are derived from surface pressures at different longitudes. Finally, there is a typhoon index.

2.10.3 Annual temperatures in China show a peak soon after 1930. There are problems with changes in coverage, but the peak persists even when using a reduced number of 37 consistent stations. But there are many gaps during World War II and the station distribution is irregular, with more in eastern China. Since 1959, there has been an increase in China's mean temperature and a reduction in the number of cold days. The winter monsoon has become weaker. Dryness in China has increased since 1900 but over the last 40 years there has been no trend in precipitation overall. However, in western China and along the Yangtze River, precipitation has been increasing, with more floods while northern and southern China are seeing an increased frequency of drought.

2.10.4 Minimum temperatures have increased over all China especially in winter in northern China. Maximum temperatures show a slight increase in northern China. But in the Yangtze River valley, the maximum temperatures have decreased, possibly owing to increased cloud and precipitation. The Daily Temperature Range is decreasing widely. Extreme minima have also risen, especially in autumn and winter. There are no trends in all-China extreme precipitation thresholds, but there has been a decrease in rain day counts at all thresholds, consistent with an increase in the mean intensity of rainfall.

2.10.5 Problems with securing climate data include funding and preservation of manuscript data. China needs to work closer with the international community, derive high quality precipitation data sets, do further studies on precipitation including changes in rain days, etc. and to introduce the results into climate and annual bulletins. Such activities may increase support for climate data.

2.10.6 Mr Zhai's report to the meeting can be found in Annex 14 (WMO, 1999).

2.11 Presentation of the Nordic "REWARD" Project (Relating Extreme Weather to Atmospheric Circulation using a Regionalised Data set) - Mr P. Frich (UK)

2.11.1 REWARD includes a data dictionary containing 100 elements in nine groups. An atlas of extremes exceeding various thresholds is also available (see Annex 15, WMO, 1999).

2.11.2 In the work done so far, no link has been found between annual and extreme daily precipitation over the Nordic countries. No significant trends have yet been found in extreme daily precipitation, but increases in mean winter (Oct-March) precipitation of up to 20% occurred along the west coasts of Fenoscandia between 1931-60 and 1961-90. For single stations, the numbers of days with precipitation greater than 10 mm/day has increased even more, but with no trend in the extremes.

2.11.3 Changes in the temperature range sometimes reflect instrumental exposure changes. In other cases, changes in cloudiness have a real effect on temperature range. Annual extreme maximum or minimum temperatures can be assumed to occur in cloudless almost calm conditions so the complicating factor of cloud and wind can be assumed to be absent. However, it is noteworthy that in Greenland the differences between highest annual maximum temperature and the lowest annual minimum temperature show a decreasing trend through the twentieth century. For a selection of 30 high-quality stations from the Nordic countries, the trend in Extreme Temperature Range (ETR) has been negative over the period 1940-1995.

2.11.4 The Task Group pointed out that local changes to the sites may have caused a reduction of outgoing nocturnal longwave radiation due to interception of radiation by increasing buildings and trees, etc. This is not a problem in Greenland because there are no trees and few buildings. It is a bigger problem in Australia, where all rural stations are by farms with trees. It was also pointed out that, in very maritime climates, the coldest nights sometimes occur with strong cold winter advection associated with strong winds.

2.12 European Climate Support Network (ECSN)

2.12.1 Discussions on the ECSN were led by Mr Klein Tank (Netherlands), Mr Rosner (Germany), Ms Rosenhagen (Germany) and Dr Callander (UK). The new ECSN is placed within EUMETNET. Under the new structure, ECSN is potentially valuable for exchange of climate data. ECSN is divided into sub-groups: data, exchange of information, climate applications and research.

2.12.2 *European Climate Assessment*. The ECSN's biggest current project is the European Climate Assessment for the year 2000, a sequel to its 1995 Assessment (see Annex 16, WMO, 1999). The 2000 Assessment overlaps with other monitoring projects, e.g. various WMO climate status reports, national assessments and IPCC 2001, and coordination is needed. The 2000 Assessment will include analyses of variability and extremes, controlling mechanisms (NAO, etc.) and predictability. Percentile indices are being used because they are more suitable than fixed thresholds for Europe as a whole. Initial work has been done on the De Bilt temperature series. Cold (<10th percentile) days, defined using a gamma distribution, became rarer after the start of the series; warm (>90th percentile) days increased towards the end. Minima <10th percentile generally decreased, maxima >90th percentile generally increased. A longer data set exists for central Netherlands but is not yet quality controlled.

2.12.3 *Collaboration with other European groups*. ECSN may co-operate with the European Environment Agency, but they are more interested in GHG emissions. Prof. Jones suggested that universities should be involved with ECSN because it may make funding easier.

2.12.4 *Data exchange and availability.* In Europe it is difficult to exchange daily data. Although the North European countries have managed to exchange daily pressure data, it will be a complicated process to move one step further and exchange daily data throughout the whole region. The data used for the 2000 Assessment should be made available to researchers. In addition, ECSN could encourage its members to give their GCOS station data to ECSN who would make them available for research. Furthermore, software and analyses could be exchanged. ECSN is committed to be responsive to the research community.

2.12.5 Data sets for the last 100-1000 years are needed for research into long-term variability. Homogenised daily data for several stations back to the 18th century will come from the IMPROVE project. But large amounts of data require digitisation, and greater ease of access to European climate data by the research community needs to be forthcoming. A consolidated daily data set going back 100 years is needed. Variables required are:

- essential: temperature, precipitation (rain/snow);
- very desirable: vapour pressure;
- desirable: radiation or a proxy;
- optional: wind.

2.12.6 Storage on CD-ROM is useful but does not give up-to-date information. Receipt of data via the Global Telecommunications System (GTS) is often incomplete. Monthly CLIMAT messages should contain useful statistics based on daily information but these are also often incomplete.

2.12.7 *Climate monitoring.* An ECSN Applications Workshop was held in June 1998 at Offenbach. Projects included the generation of climate monitoring projects, climate and human health, drought investigations, Geographical Information Systems (GIS) in climate applications, and a Climate Atlas of Europe. All projects are subject to approval by the EUMETNET council. For climate monitoring, Japan and Germany will host monitoring centres for the temperature and precipitation data in CLIMAT messages sent by GSN stations. Monitoring reports will be published on the Internet. Only about 50% of GSN stations report at the moment and only 25% of GSN stations report all parameters. The monitoring centres will follow up on missing messages. Analyses will consider timeliness, availability, reliability, coding errors, errors in data, and quality flags will be applied. The monitoring centres will also retain CLIMAT messages from other stations, while concentrating on the GSN. An implementation workshop will take place in Germany in early 1999. Thirty-seven out of 48 European countries provided information for the last two Annual Bulletins on the Climate in WMO Region VI. As only 18 of the 48 countries are in ECSN, all of them situated in Western Europe, it is essential to involve the other countries (see Annex 17, WMO 1999).

2.12.8 *Research.* Ms Rosenhagen presented some results on indices for the detection of changes in intensity and frequency of extratropical storms. She stressed that trends in the estimation of extratropical storms were best assessed by indices, based on the analysis of MSLP measurements or fields, as observational records of wind measurements were highly biased. Some results of the Waves and Storms in the North Atlantic (WASA) project were presented, which used daily MSLP pressure readings for 20 stations in northern Europe back to the beginning of the century. For these stations, daily geostrophic winds were derived. They revealed that, during the analysing period, there was a weakening of strong winds from the end of the 19th and beginning of the 20th century up to around 1950-1970. After this, the frequency of storms increased, and is now at a level typical of that of the first few decades. Storminess was found to be correlated to the NAO index, as expected, especially in recent years. A stormy period in the late 19th century was not associated with a high NAO index, and may have resulted from low pressure over Scandinavia with predominant strong northwesterlies. Mr Folland noted that this may have been the signal of a vigorous “East Atlantic Oscillation”. Some results were presented of special investigations at the Deutscher Wetterdienst in Hamburg on the influence of possible inhomogeneities and the amelioration of the method by using more than three stations and six-hourly values for the calculation of the geostrophic wind. It was also noted that offshore winds are much more ageostrophic than onshore winds, which has to be taken into account for the interpretation of the geostrophic wind results (see Annex 18, WMO 1999).

3 DEVELOPMENT OF INDICES OF EXTREMES WITH EMPHASIS ON MATHEMATICAL

3.1 A Presentation on Techniques for Analysing Extremes and Creating Indices - Dr T. Peterson (USA)

3.1.1 Dr Peterson gave a presentation on techniques for analysing extremes and creating indices. The basic reason for creating indices is to obtain a simple, clear but not misleading summary of complex information. Indices need to be clear, of long duration, homogeneous and able to be continued into the future. They should not smooth out important changes.

3.1.2 As an example, Dr Peterson showed a standardised precipitation index, based on monthly data, depending on the application, 3, 6, 12, 24 or 48 month moving averages are applied. A distribution is fitted to the resulting time series and each observed value is converted to an anomaly on the scale –3 to +3 standard deviations. The index is clear enough for farmers to understand, and is widely applicable. The probability of a "–2" drought is the same everywhere, though the impact of a –2 drought varies. The index is flexible and it can be adapted to whatever distribution fits best to each station. Area averaging is possible.

3.1.3 Another example shown was a Climate Extreme Index. This is an aggregate of measures of temperature and precipitation or drought that have societal impacts. Its components include the percentage area of the USA with temperatures much above or much below normal, the percentage area with extreme drought or wetness according to the Palmer Index, and the numbers of days with precipitation exceeding 50.8 mm. It showed little trend.

3.1.4 The USA Greenhouse Index has been designed to reflect observed changes which match projected change in climate. Its components are weighted according to the confidence which they are associated with GHG warming, guided by output from models. It showed a slight increasing trend. The discussion highlighted the need for indices to be physically meaningful. Their level of sophistication can be keyed to the audience. Indices can be affected by noise in one component which can be tracked to its source using partial correlations.

3.1.5 Dr Peterson's background report on this matter to the Task Group is included as Annex 19 of the meeting report.

3.2 Use of the Gamma Distribution in the Analysis of Extremes - Ms B. Horton (UK)

3.2.1 Ms Horton gave a presentation on the use of the gamma distribution in the analysis of extremes. Gamma distributions have been fitted to annual and seasonal gridbox temperature anomalies worldwide, and to annual Central England temperature anomalies, as summarised above. The rationale for using gamma, rather than Gaussian, distributions, is that they are better fits to skewed data. But if the data is not skewed, the gamma distribution tends to the normal distribution. Some annual data, and many more seasonal and especially monthly and daily data are skewed. Because gamma distributions are always positive, and are positively skewed, the temperature anomalies were transformed so as to comply with these conditions before fitting. Percentiles were derived from the fitted distributions and transformed back to values in °C. In this way positive and negative skewness can be accommodated. Chi-square tests were used to assess the goodness of fit of the gamma distributions. Prof. Anderson suggested that goodness of fit, especially in the tails, is better tested by plots of the quantiles of the fitted curves against those of the observations. If the fit is good, this plot should be a straight line at 45° to the axes. Another technique is to fit the distribution above a certain threshold as in extreme value analysis.

3.2.2 The paper on gamma distribution and analysis can be found as Annex 20 (WMO, 1999).

3.3 What Can We Produce for IPCC and What is the Job of the WMO Rapporteurs?

3.3.1 The Task Group took up this issue with the discussion led by Mr Folland. There are only about 20 months to produce what is needed for IPCC 2001. IPCC will wish to assess regional information as well as global quantities. About 20-30 key indices will be required for temperature and precipitation. Data can be aggregated over a year when looking at long-term trends, but seasonal data should be included where relevant. Documents describing these indices must be accessible for review, but do not need to have been published, though this is desirable. The IPCC 2001 reviewing procedure will be more rigorous than previously. The most important indices need to be calculated centrally and the major stumbling block foreseen is lack of daily data. Even if half of the daily GSN data were available, large gaps will remain. It was recommended, therefore, that WMO write to Members to request daily GSN data. The letter, to be coordinated by Mr P. Scholefield, should offer the entire available GSN database in exchange for a digital copy of Members' data, as a motivation. Failing this, some countries, unwilling to provide their data, might provide the results of national analyses.

3.3.2 After much discussion, the Task Group identified a preliminary list of indices for IPCC 2001 though it was recognised that IPCC authors may modify this provisional list. The list is contained in Annex 21 (WMO, 1999).

4. COMPARISON OF OBSERVED AND MODEL SIMULATED EXTREMES

4.1 Causes of Twentieth Century Climate Change - Dr S. Tett (UK)

4.1.1 Dr Tett gave a presentation on causes of twentieth century climate change. There was warming in the early part of this century, a slight cooling in the middle, then strong warming from 1970s onwards. The causes could include natural internal variability, natural forcings, and human-induced forcings. Dr Tett performed simulations using the HadCM2 coupled model, with flux adjustments. This model slightly over-estimates the standard deviation of annual mean temperatures, but its geographical pattern is realistic. The simulations were forced with GHG, GHG + sulphates, GHG + sulphates + solar changes, and GHG + sulphates + solar changes + volcanic aerosols. In each, an ensemble of four simulations was run starting from different conditions. Using optimum detection methods, Dr Tett concluded, cautiously, that temperature changes over this century cannot be explained by natural variability, but the later warming can be explained by GHG and sulphates. The early century warming can also be explained by anthropogenic changes, but solar irradiance changes could have made a significant contribution.

4.1.2 The paper by Tett et al. on the subject of climate change this century is included as Annex 22 (WMO, 1999).

4.2 Use of Atmosphere-Only Models in Climate Change Detection - Mr D. Sexton (UK)

4.2.1 Mr Sexton spoke on the use of atmosphere-only models in climate change detection. The HadAM2a atmospheric model was forced with observed historical sea surface temperatures (SST) and sea-ice. Ensembles (in which each member had different initial atmospheric conditions) were run with: GHG fixed at 320ppm equivalent GHG, equivalent GHG + sulphates, equivalent GHG + sulphates + decreasing stratospheric ozone, and equivalent GHG + sulphates + decreasing stratospheric ozone + increasing tropospheric ozone. It was found that human-induced forcing underestimated the observed warming in annual and especially winter half-year Northern Hemisphere (NH) land surface air temperatures. This was because the model's dynamics did not reproduce the recent increase in the strength of NH winter westerlies and the resulting mild winters in Eurasia. In the summer half year, which is dominated by thermodynamics rather than by dynamics, the simulated temperature trends were quite close to the observed. An index of MSL pressure difference between 35^{o} N and 75^{o} N was defined and used to remove the dynamical influence from the observed temperature record. The fit with the model was then better. So it is imperative to model the variation in the NH mid-latitude westerlies correctly to replicate the observed temperature changes though it is not known to what extent these changes are unforced. The model did not replicate the observed decrease in diurnal temperature range. To the extent that this may be due to an aerosol influence on clouds, this mechanism was not present in HadAM2a, now an old model.

4.2.2 Multivariate regression using the "general linear model" was used to show that increasing GHGs have a significant effect on global land surface air temperature trends in the model. The increase in skill in simulating zonally averaged tropospheric and stratospheric temperatures with the addition of the forcings was assessed. To do this, the internal atmospheric variability was estimated from the difference between ensemble members and estimates were made of the uncertainties in observed temperature analyses from radiosondes. It was also noted that the model has insufficient variability in parts of the stratosphere, but overall it has realistic variability.

Changes in simulated zonally averaged modelled temperatures throughout the troposphere and lower stratosphere are significantly more skilful when compared to observed changes when anthropogenic effects are included, demonstrating a probable anthropogenic forcing.

4.2.3 New experiments are underway, using a better model (HadAM3) with improved SSTs. The new experiments include volcanic and solar forcing as well as more realistic anthropogenic forcings. Thus the different GHGs are treated separately rather than as equivalent CO_2. Daily variables are being archived to allow extremes to be examined. The number of combinations of forcings used, and the number of ensemble members in each, has been limited to save computer time while providing sufficient information to determine the effect of each individual forcing. This requires a special analysis to provide an optimal analysis of each forcing. Mr Sexton's paper on this matter can be found in Annex 23 (WMO, 1999).

4.2.4 In the discussion that followed Mr Sexton’s presentation, the Task Group agreed that contrails were important because they add water vapour to the high troposphere and low stratosphere. The group also noted that estimates of uncertainties in the forcings will not include the effects of forcings still excluded from the model. The possibility of comparing, for IPCC 2001, model simulations of extremes with observations was discussed. The Hadley Centre was already finding that models can shed light on the veracity of observations. For example, they support the corrections applied to SST measured using buckets and have been used to identify errors in other data sets. Many of the indices listed in Annex 21 (WMO, 1999) could be produced from model data; others are implicit in data used to force the models. For temperature, co-located data could be used to give as close a comparison as possible, though spatial biases in models could cause difficulty. For rainfall, there will be difficulties related to area averaging of extremes over coarse global model grids. Therefore, it was recommended that temperature should be highest priority, beginning with annual, seasonal and monthly extremes then progressing to daily extremes.

4.2.5 The Task Group was requested to seek a scientist who could visit the Hadley Centre to work on observed and modelled extremes in the period about 2000-2001, for about nine months. The Australian Commonwealth Scientific and Industrial Research Organization may also be able to work on model indices.

5 FUTURE REQUIREMENTS

5.1 Requirements for Daily Data from the GSN

5.1.1 Mr. P Scholefield (WMO) led the discussion on requirements for daily historical and near-real-time data from the GSN. When the GSN was established, there would be a commitment required from all WMO Members to provide daily historical and real-time data, and metadata for their GSN stations. This will be difficult owing to commercialisation, and to the lack of digitised data in some countries. A firm justification of the need for these data is therefore required. The letter to Members (see Section 3.3) would include this justification, as well as the offer of the entire available GSN data base on CD-ROM in exchange for a digital copy of Members’ data. The letter, to be sent in 1999, should also summarise the best practices for operation of the stations and provision of the data required. WMO should maintain the list of GSN stations on a Web site. There should be ongoing efforts to maintain the GSN and replace closed stations.

5.1.2 Monthly GSN data should be processed in real-time. Daily GSN data should be stored and released later for research purposes. Feedback will be given to countries by the Chair of the GCOS Steering Committee and the GCOS Secretariat. Mr Folland suggested that a pilot data set of GSN data be made available for IPCC 2001 to include at least one station from each Member country. This would be worked upon for IPCC, and results, problems, etc. returned to the countries concerned. The policy for exchange of data is under discussion at WMO and a mechanism should be determined so that daily data can be distributed to researchers in a licensed form. It was very desirable that Members release data from as many stations as possible. The Task Group recognised that a complete set of historical records may not be available, nevertheless the group would like as much as possible. The request for GSN data should seek IPCC endorsement to ensure a better response. As a back up, countries could be asked to produce, from their historical data, equivalent information on extremes to that contained in groups 333 and 444 of the new CLIMAT messages. Dissemination of daily data will always be in arrears, so that the information on extremes (in the 333 and 444 groups) from the ongoing CLIMAT messages will be useful.

5.1.3 The group determined that some of the indices listed in Annex 21 (WMO, 1999) could be calculated from complete CLIMAT messages (CODE FM 71-X). These indices could then be kept up to date, even though the daily data will arrive up to several years later.

5.2 Rapporteur's Reports

5.2.1 The designated Rapporteurs on Climate Change Detection Methodologies and Indices should prepare annual reports for CCl. The report of this meeting, including the supporting papers, would constitute the first annual report. It was noted that results used in IPCC need to be documented in detail to satisfy reviewers. Reports should communicate information in an understandable way to countries that lack access to relevant literature. Drafts of the emerging "Observed Climate Variability and Change" chapter of IPCC 2001 should be made available to Rapporteurs, subject to the approval of the other convening lead authors and IPCC. Results will be required by about July 1999 if they are to be included in the first draft of the chapter. At the March 1999 Asheville meeting, consideration should also be given to work on extremes after IPCC 2001.

5.3 Future Activities

5.3.1 The participants at this Task Group meeting agreed to continue to promote the development of, and make recommendations on, the use of indices and indicators for climate change detection on regional and global scales. They also agreed to liase with GCOS on its surface and upper air networks. The terms of reference for regional Rapporteurs are documented in the Report of CCl-XII (August 1997).

5.3.2 A new CCl/CLIVAR Task Group on Priority Climate Indices, to be chaired by Dr Peterson, was proposed to follow directly from this meeting. Its aim would be to gather daily and other data in order to carry out station / regional / global analyses using the indices defined earlier. These analyses would be a prototype of what will be done when the GSN data are more fully available. The group should not rely on GSN data, except from their own countries, where possible. Recommendations from the breakout groups from the 1997 Asheville meeting should be taken into consideration. The new group would include the WMO Regional CCl Rapporteurs on Climate Change Detection Methodologies and Indices (G. Gruza, W. Hogg, A. Mokssit, N. Plummer) and as many of the other attendees at this Task Group meeting as possible.

5.3.3 A much smaller and less formal group on the modelling of extremes was also proposed, to be created later.

5.4 Recommendations

5.4.1 Based on its discussions, the Task Group agreed on the following recommendations to the CCI/CLIVAR Working Group on Climate Change Detection:

5.4.2 The meeting strongly recommended to AOPC and CBS that a baseline data set of daily data, and associated metadata, from GSN stations be made available in time for the Third IPCC Assessment Review due to report in 2001. These data are urgently needed to create indices of changes in the daily extremes of climate that particularly affect society. Of greatest interest are data of daily maximum, minimum and mean temperature and daily rainfall. Examples of such indices include changes in the extreme temperature range in each year and changes in the frequency of heavy daily rainfall events.

1. It was also recommended that selected indices should be updated annually, and be selectively published in the annual WMO statement on the status of the global climate. IPCC would access the data from the designated World Data Centres and the results would mainly appear in the Observed Climate Variability and Change Chapter of the Working Group 1 Report. In this way, nations will be able to have their own changing extremes of climate faithfully reflected and placed within regional and global contexts.

2. Recognising that it may take some time for all countries to provide a full set of GSN data to designated data centres, it was further recommended that a copy of the data from at least one GSN station per relevant country should be made available with at least 40 years of daily data updated to end 1998 (if possible). It would be desirable if, by the end of 1999, historical daily data from 50% of GSN stations should be archived in the World Data Centres A and B for Meteorology. It would also be very desirable, however, for as many stations as possible to be made available with emphasis on the last 40 years. Earlier data are also very desirable. A CD-ROM of all GSN data supplied for use in the IPCC Third Scientific Assessment would be made available to National Meteorological Services by the World Data Centres.

3. To be ready for inclusion in the Third IPCC Scientific Assessment, the daily data would need to be sent to the World Data Centres by the autumn of 1999. The experience gained in this pilot analysis of GSN data would be communicated back to all participating nations by IPCC through WMO. It is hoped that this will catalyse the creation of a full set of GSN data and metadata in time for a more extensive analysis of changing climate extremes for the Fourth IPCC Assessment Review expected to be completed around 2005.

4. It was recommended that the proposed list of standarized indices (see Annex 21 of WMO, 1999) be made widely available to the research community and WMO

Member countries, and that the development and use of these indices be encouraged, especially in the preparation of the IPCC Third Assessment Report and the European Climate Assessment 2000.

5. It is preferable that indices based on winds should be determined from surface and sea level pressure data. Also, humidity is an important parameter for climate indices; therefore an effort should be made to build, maintain and exchange data sets that contain appropriate observational parameters.

6. An effort should be made to involve nations and the climate modelling community in the development of climate indices with subsequent feedback of results.

7. One of the objectives of the next climate extremes indices meeting in Asheville should be to rationalize, as much as possible, the different approaches and strategies for developing indices that were articulated by the three break-out groups from the 1997 meeting

8. Recognizing the need to use a variety of approaches in developing indices, it was recommended that developers be made aware of the advantages and disadvantages (e.g. composite indices) of each example, parametric versus non parametric. Furthermore, the group endorsed a listing of desirable characteristics of indices and particularly that there be set of critical indices that can be understood by policy makers.

9. Following up the proposal from the Asheville 97 meeting, it was recommended that software packages with related guidance material be developed for specific indices and be made available to relevant nations and climate centres.

10. It was recommended that consideration be given to the concept of developing a guidance document on the development and use of indices for monitoring and analysing climate variability, including the occurrence of extreme events and that such a concept, including a data dictionary, be brought to the attention of the planned meeting on indices for extremes in Asheville in March1999.

11. Arrangements should be made for the IPCC Data Distribution Centre to make available simulated model output data for use in developing countries.

12. It was recommended that the CCI Rapporteurs on Climate Change Detection and Climate Change Detection Methodologies develop work plans, taking into consideration the discussions and recommendations of this meeting and that, if possible, the work plans be ready in time for the planned March 1999 meeting in Asheville.

13. In addition to publishing and distributing the report of this meeting in the WCDMP document series, the results and recommendations of the Task Group should be particularly brought to the attention of the Advisory WG of CCI, the chairman of the Joint CCI/CLIVAR Working Group on Climate Change Detection, the chairmen of the CCI Working Groups on Data and on CLIPS, CBS, the IPCC Secretariat, the Scientific Steering Group of CLIVAR, the Joint Scientific and Technical Committee for GCOS and the GCOS Atmopheric Observation Panel for Climate.

15. To ensure that the proposed initiatives will be vigorously pursued, it was agreed that a further research-oriented Task Group should be struck that would continue until the end of the current mandate of the parent joint CCl/CLIVAR WG (2001). It was proposed that its membership include the CCl Rapporteurs on Climate Climate Change Indices and Detection Methodologies and other selected scientists at the September 1998 Task Group meeting. Dr Tom Peterson of the National Climate Data Center, Asheville (World Data Center A) was proposed as chairman of the new Task Group. The Group should be charged with implementing many of the above recommendations which pertain to developing priority global Climate Change Indices. Its key task will be to obtain as many daily climate data as possible, with emphasis on those from GSN stations and from selected nations, in order to provide publishable analyses of the changes and variability with time of some key indices and that could be considered for the Third IPCC Scientific Assessment. Its initial task would be to present a report and plans to the March 1999 Asheville meeting and to the joint CCl/CLIVAR Working Group.

6. CLOSURE OF THE MEETING

6.1 The meeting closed at 16h30 on 4 September 1998.

The complete meeting report, including extended abstracts of the talks, is available from WMO.

REFERENCES:

WMO, 1999a: Report of WMO Working Group on Climate Change Detection Task Group on Climate Change Indices, Bracknell, Berks, UK, 1-3 Sept 1998. Eds: Folland, C.K., Horton B. and P. Scholefield, *WCDMP 37*, *WMO TD 930.* pp20 + 23 Annexes.

Appendix 2. Report by Tom Peterson and Peter Scholefield on the Meeting of the Working Group on Climate Change Detection, Geneva, November 10-12, 1999.

Mr. Jarraud, Deputy Secretary-General of WMO opened the meeting by stating that "as you are no doubt aware, this is the first meeting of this CCl/CLIVAR Working Group on Climate Change Detection since it was first reconstituted by the 12th session of the WMO Commission for Climatology, held here in Geneva in August 1997. Following the evolving close collaboration between CCl and CLIVAR experts, the WMO Commission for Climatology considered the need to broaden the mandate of the previous CCl Working Group to encompass and respond to those requirements of CLIVAR community that are closely related to the detection of climate change. At its 12th session, the Commission designated four rapporteurs in the areas of capacity building, gridded data sets, indices and networks. Four additional positions on the working group were subsequently designated by with the Scientific Steering Group of CLIVAR, focusing on aerosol forcing, forcing data sets and proxy data. In addition to the appointed CCl rapporteurs and CLVAR experts, I am pleased to welcome the experts who were invited to the meeting to provide a broader regional balance into the deliberations. I hope that not only will they beneit from the discussion but that they will offer a unique perspective on climate change which could affect some regions of the world differently. Those living in small island states are very concerned about a projected rise in sea level, so I am glad to see two representatives from these threatened areas among the participants."

The participants included half the Working Group members. In addition to the new Chair (Tom Peterson, US), two of the four CLIVAR nominated members were able to attend, Phil Jones (UK) and David Karoly (Australia), and two of the four CCl nominated members attended as well, Chris Folland (vice-Chair, UK) and Anjian Sun (China). To help broaden our base, additional invited participants included Luc Maîtrepierre (New Caledonia), George Gruza (Russia), Abdallah Mokssit (Morocco), Louis Molion (Brazil), and Michael Taylor (Jamaica), which ensured that all WMO Regions were represented at the meeting. Valery Detemmerman and Peter Scholefield from WMO assisted throughout the meeting and additional WMO participation included visits from Michael Coughlan, Alan Thomas, John Miller and others.

In additional introductory remarks, the Chair read e-mail messages that he had received from a variety of CLIVAR experts just prior to the meeting. Kevin Trenberth, chairman of CLIVAR Scientific Steering Group, urged the Group to actively pursue its mandate and look for ways to involve the broader CLIVAR community and keep them informed. He emphasized the importance of outreach initiatives and suggested organizing workshops and contributing to the CLIVAR newsletter. John Mitchell, from the Hadley Centre, urged efforts to maintain the climate observing networks for the detection of climate change. Neville Nicholls, from the Australian Bureau of Meteorology Research Center, suggested that innovative ways be found to communicate the results of climate change detection studies. He also urged WMO to seek funding to improve historical databases. Tim Palmer, from the ECMWF, suggested that research into synoptic circulation regions could help detect and explain regional temperature trends. What we would decide to pursue at the end of the meeting was quite uncertain at the start.

While the number of participants was relatively small, fortunately, there was considerable discussion and active participation from nearly all attendees. Much of the discussion focused on how to obtain historic climate change information from regions of the globe that don't exchange very much data. In addition to generally encouraging the digitization and exchange of data, we decided to actively pursue regional workshops similar to the Asia-Pacific Network (APN) meeting. Three of us attended the APN meeting: Chris Folland, Luc Maîtrepierre, and Tom Peterson. The climate change indices presentation Mr. Maîtrepierre gave to the Working Group could not have occurred without the APN meeting.

In a nutshell, the APN paradigm is a gathering of representatives from a region to perform hands on analyses of their data under the guidance and tutelage of outside experts. Rather than release the data, a report describing the region's climate change is released. Along with producing this valuable information for climate change detection, the workshops would build capacity in under reported regions and probably encourage future activities. Commitments to pursue regional workshops were made by Dr. Taylor of the University of the West Indies (with Tom Peterson's assistance) for the Carribean, Dr. Molion from Brazil for southern South America, and Mr. Mokssit from Morocco for northern or the Sahel region of Africa. Working together, we produced a "recipe" for these APN-like meetings. A few tweaks in the recipe are expected from the Task Group on Indices. Valery Detemmerman was tasked to help write up the recipe along with a sample proposal, which could be used by the workshop organizer when seeking funding.

Many other topics were discussed at this meeting of the Working Group on Climate Change Detection. For example, we agreed to draft a paragraph appropriate for addition to COP-6 that encourages preservation and digitization of historical instrumental data. The Working Group also helped plan WMO's *Climate of 1999* publication. The agenda and list of recommendations, below, provide a fairly complete indication of the broad range of topics discussed at the meeting. Our Working Group was asked by the CLIVAR Scientific Steering Group to be more active and told that funds would be available for a meeting the following year. We set a tentative date for November 2000 and hoped to hold the meeting in conjunction with a regional climate change workshop in either Jamaica or Morocco. However, the Working Group did not meet again primarily because (a) members were to busy largely because of heavy involvement in IPCC and (b) we thought it was more important to put our efforts into holding regional climate change workshops. The Caribbean workshop could not be held during hurricane season or when classes were in session at the University of the West Indies, so it was postponed until January 2001 (see Appendix 3). The Moroccan workshop followed shortly afterwards in February 2001 (Appendix 4). These two regional climate change workshops are concrete results of efforts set in motion at the November 1999 meeting of the Working Group on Climate Change Detection.

Meeting Agenda

1. Opening of the meeting

    1.1 Opening remarks
    1.2 Adoption of the Agenda

2. Reports by rapporteurs and experts

3. Discussion/actions arising from reports

4. Status report on the GCOS Surface Network (GSN)

5. Proposed experiments using data from GUAN and GSN

6. Raising the visibility of the historical databases in the UNFCCC process

7. Water vapor measurements

8. Forcing data sets

9. Proposed scientific workshop on statistical methodologies

10. The WMO Statement on the status of the Global Climate in 1999

11. Future workshop plans of the Working Group

12. Other business

13. Recommendations

Recommendations

Capacity Building

1. Recognizing the difficulty in obtaining sufficient time-series data from national sources to build a more detailed global picture of climate trends, the Group decided to coordinate a series of regional capacity building workshops designed to facilitate the development and exchange of climate indices, primarily for the purpose of assisting in the detection of changes in climate extremes, as well as to provide a more detailed picture of climate variations. In addition to a limited set of prescribed indices for global analyses, the workshops will have the opportunity to select and develop a subset of specific indices tailored to regional characteristics of the climate. It was further

recommended that the evolving structure of the workshops be based on the APN workshop of 1998 and that the planned follow-up APN workshop in December 1999 meeting be used as an occasion to further develop this concept. Included in this process should be a refinement of the draft action plan, adopted by this meeting (see Annex 3, WMO 1999). Candidate regions for initial workshops in the year 2000 are Africa, the Caribbean and South America. Finally, it was recommended that the IHDP/IGBP/WCRP global change SysTem for Analysis Research and Training (START) and the Inter American Institute (IAI) be approached for co-sponsorship.

2. Related to the workshops was the recommendation to specify a minimum set of about 10 simple feasible indices from the list developed at the September 1998 Bracknell meeting and subsequently elaborated in Povl Frich's Indices Dictionary. This priority list of indices should be accompanied by the methodologies and guidance to develop them with a view to having this "recipe" available for planned regional capacity building workshops in the year 2000. When this "recipe" becomes more refined, it should be made widely available.

3. Another related recommendation was to invite statistical experts for a specific period of the workshops to provide training in statistical methodologies for the analysis of trends and variations that are relevant to the development and analysis of climate indices. It was suggested that this could be an adequate and effective response to the urging of the recent 13th session of WMO Congress for continued efforts to develop standardized methods for homogenization, quality control and detection of trends and/or periodicities in data time series. Furthermore, in noting two recent WMO publications. WCDMP-No. 41[1] and GAW-No.144[2], the Group recommended that useful techniques and methodologies be extracted from them for use at the workshops. It was agreed that this would be an appropriate task for one of the CCl Rapporteur on Statistical Methods.

4. It was additionally recommended to invite some paleo/proxy climate experts to give awareness presentations on their areas of expertise to the regional capacity building workshops. Furthermore, it would be desirable to involve a climate modelling expert in a similar fashion.

5. In addition to and, in some cases rather than, distributing capacity building material directly to WMO Permanent Representatives, the Group recommended that material such as CD-ROMs containing pertinent global data

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[1] WMO 1999: Proceedings of the Second Seminar for Homogenization of Surface Climatological Data, Budapest, Hungary, 9-13 November 1998, Sandor Szalai, Tamas Szentimrey, Csaba Szinell, (Eds) World Climate Data and Monitoring Programme, WCDMP-No.37, WMO-TD No. 930

[2] WMO 1999: WMO/EMEP Workshop on Advanced Statistical Methods and their Application to Air Quality Data Sets, Helsinki, Finland, 14-18 September 1998, Global Atmospheric Watch, No. 133, WMO-TD No. 956

sets be sent to national experts. In this regard, it was recommended to establish an extensive (500 or so) list of national climate change detection focal points, taking into consideration a similar list of CLIVAR experts. Furthermore it was recommended to distribute the relevant CD-ROMs produced by the Japan Meteorological Agency[3], Jet Propulsion Laboratory[4] and the IPCC Data Distribution Centre[5] to the group of focal points, along with appropriate guidance material.

6. In view of the ongoing development work in preparing and evaluating reanalyes data sets and other gridded data sets, the Working Group recommended that a report on the relevance of these recent activities to climate change detection be prepared by the Rapporteur on the Application of Reanalyses and other Global Gridded Data Sets for Climate Change Detection. The report should be distributed to WMO Members, national climate change detection and CLIVAR focal points as well as CCl rapporteurs and members.

UNFCCC Process and the GCOS Networks

7. The Working Group noted with satisfaction the recognition being given to the health of climate observation networks through recent decisions 14 and 5 of the Fourth and Fifth sessions respectively of the of the Conference of the Parties (COP) to the UN Framework Convention on Climate Change. In further noting the absence of any explicit reference in these decisions to the historical records and databases which are essential for studies of climate variability, the detection of climate change, and the development of climate information and prediction services, the Working Group recommended that this shortcoming be addressed as soon as possible. More specifically, over the short term, it was decided to provide the GCOS secretariat with an approximately one-page document containing proposed additions to the existing text in UNFCCC formal documentation related to ***research and systematic observation***. Included should be accompanying rationale that could be provided by the GCOS Secretariat to the next meeting of the Subsidiary Body for Scientific and Technical Advice (SBSTA). Over the longer term, the Group recommended that the recently adopted UNFCCC Reporting Guidelines on Global Climate Observing Systems should be suitably modified so that the identification, preservation, management and exchange of significant historical data sets and associated metadata are incorporated into national plans, capacity building activities and reporting procedures of the Parties. It was agreed that there

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[3] Japan Meteorological Agency, CD-ROM containing 1,045,682 newly digitized and quality-checked Kobe Collection data covering the period 1890 to 1932 and related documents and figures

[4] Jet Propulsion Laboratory 1998, Global Ocean Surface Temperature Atlas Plus, co-publishers Massachussetts Institute of Technology and the UK Meteorological Office

[5] IPCC Data Distribution Centre (DDC), CD-ROM (Version 1.0, April 1999) containing all the information and most of the data sets available on the DDC Green Pages. A copy of the CD can be requested by e-mailing: ipcc.ddc@uea.ac.uk.

should be collaboration with the chairman of the CCl Working Group on Climate Data in the preparation of the document for SBSTA.

8. Noting that COP5, in paragraph 6 of Decision 5, urged Parties, in consultation with the GCOS secretariat, to address deficiencies in climate observing networks, the Working Group recommended that deficiencies in the management of and access to historical databases should be included. The Group expressed its concern upon being informed that 10 of the identified 150 GCOS Upper air Network (GUAN) stations have been silent this year and that results from the June 1999 monitoring of CLIMAT TEMP messages from GUAN stations were poor. Preliminary monitoring of the more recently established GCOS Surface Network (GSN) indicates similar problems. The Group therefore recommended that remedial action be taken through the WMO and GCOS secretariats to rectify the GUAN deficiencies and likewise any GSN problems that are identified in the first report from the GSN monitoring centres, expected in mid 2000. It was expected that GCOS network deficiencies would also be addressed through the UNFCCC process. The Group emphasized the urgency of addressing these deficiencies and hoped that bringing these issues to the attention of policy makers through the UNFCCC process would result in funding support needed to maintain climate observation networks, improve historical databases and make climate data more accessible.

9. The Working Group reiterated the need for global scale data for the detection of global temperature change but also emphasized the importance and need for data at regional space scales and for daily data as well as monthly data for regional studies and developing indices, especially indices of extremes. It recommended that any reference to the GSN or GUAN in UNFCCC documentation should be accompanied by a statement that reflects the intent of the 13th Congress of WMO, which urged: "WMO Members to regard the GSN stations as a standard for developing and improving the denser national reference climatological networks that are needed for climate change studies at the regional to national scale and to facilitate the implementation of the WMO Climate Information and Prediction Services (CLIPS) project."

10. During the discussions, the Working Group agreed that synoptic observations transmitted routinely over the Global Telecommunication System are not up to the standards required for climate variability and climate change detection studies. Noting the work that was already under way to revise the Guide to Climatological Practices, the Manual on the Global Observing System and the concurrent need to update the climatology section in the WMO Technical Regulations, the Group recommended that the CCl Working Group on Climate Data attempt to clarify what constitutes climate standard data. Appropriate regulations and guidance should be promulgated to ensure standards are met, including siting and parameters needed for developing extreme event indices. For its part, the Working Group agreed that, it could provide appropriate input for the Guide to Climatological Practices and, in preparing documentation for

SBSTA, an attempt will be made to elaborate on the "standards" for historical data that are needed.

11. The Working Group decided that there needs to be a scientific evaluation of stations designated as a part of the GSN and GUAN networks, assessing their suitability and priority for climate change detection and attribution studies (see Annex 5, WMO 1999). Such an evaluation would evaluate the impact of these stations on the leading methodologies for climate change detection and attribution, which mostly involve the use of coupled ocean-atmosphere models. In addition to geographical distribution, consideration should be given to the length and quality of the historical data record. It was recommended that the JSC/CLIVAR Working Group on Coupled Modelling be asked to take the lead in conducting suitable experiments.

Exchange of Data

12. The Working Group strongly supported the implementation of WMO Resolution 40 (Cg-XII) - WMO policy and practice for the exchange of meteorological and related data and products including guidelines on relationships in commercial meteorological activities, and wished to emphasize the importance of the following sections:

    - ADOPTS (2*): Members should also provide the additional data and products which are required to sustain WMO Programmes at the global, regional, and national levels*, specifying precisely that data needed for climate change detection and climate variability studies;
    - ADOPTS (3*): Members should provide to the research and education communities, for their non-commercial activities, free and unrestricted access to all data and* products exchanged under the auspices of WMO.

    The Working Group further noted that: Annex 1 to Resolution 40 (Cg-12) specifies a listing of meteorological and related data and products that have been identified as*: "a minimum set of data and products which are essential to support WMO Programmes and which Members shall exchange without charge and with no conditions on use"*. Included in this list are: *"all reports from the network of stations recommended by the regional associations as necessary to provide a good representation of climate, e.g. data in CLIMAT/CLIMAT TEMP and CLIMAT SHIP/CLIMAT TEMP SHIP codes, etc."*. The Working Group recommended that the "etc." should be elaborated to include the historical monthly and daily data and metadata from all CLIMAT and CLIMAT/TEMP stations, including those designated as part of the GSN and GUAN networks.

Automatic Weather Stations

13. In view of the proliferation of automatic weather stations (AWSs), the Working Group expressed its concern about adequate attention being given to the archiving and future use of such data for climate change detection and climate variability studies on global and regional scales. In cases where an AWS replaces a manual observing systems that has been in operation for a long time, the Working Group fully supported the pleas of CCl, CBS and CIMO for a sufficient overlap in observation systems to facilitate maintaining the homogeneity of the historical record. The importance of maintaining accurate metadata was also emphasized.

14. The Group was informed that the recent 2nd International Conference on Experiences with Automatic Weather Stations (27 to 29 September 1999, Vienna, Austria) identified four challenges faced by the users of data from automatic weather stations as follows: maintaining the homogeneity of data sets that include AWS data; standardization of procedures for quality assurance and processing of data from AWSs; defining more precisely the existing and future requirements of users; and training users in the most effective use of AWSs and engaging them in future developments. As users of data from AWSs, climatologists were urged to be more proactive in future AWS developments, including incorporation of AWSs into composite observing systems. In response to this news, the Working Group recommended the development of specifications for a standardized climate AWS, which would record a basic set of climate parameters such as temperature, precipitation, pressure and wind. Particular attention should be paid to ensure extreme values are accurately and consistently recorded in a way that can be accurately related to older, manually-observed data. Also, automated and standardized water vapour measurements should be included due to the significance of this parameter in climate change. There should be close collaboration with the CCl Working Group on Climate Data, CIMO and GCOS in the development of climate specifications for AWSs.

WMO Statement on the Status of the Global Climate in 1999

15. The Working Group recommended that more emphasis in this year's statement be given to the monitoring of climate variability and change. As this will be the last issue of the millennium, it was also recommended that where possible a century perspective be given. A number or pertinent suggestions were made (see Annex 6, WMO 1999) including putting a temperature time series graph covering the last 1000 years on the cover.

Ongoing and Future Research and Development

16. During the course of the meeting, a number of relevant research and development initiatives were discussed and the following recommendations were made:

a. High priority should be given to continued research into the annual cycle of regional climate, including indices to monitor changes through the annual cycle, as well as similar studies of the annual cycle of changes in synoptic atmospheric circulation patterns;
b. The WG should provide the CLIVAR/JSC WG on coupled models with a list of indices to encourage the comparison of modelled with with observed indices. The WG should develop recommendations concerning the data that should be archived by modellers to create such indices, and also to request them to consider providing selected interpolated station data from models as well as grid point data e.g. for GSN and GUAN stations;
c. Representatives of modelling groups who are using climate models to help detect climate change, including climate extremes, should be asked to report to the next meeting;
d. Noting that an assessment of trends in water vapour in the upper troposphere is to be completed early in 2000, suggest to those involved to extend the assessment to the rest of the troposphere and pay particular attention to radiosonde data from GUAN stations;
e. Development of multi-proxy data sets should be encouraged through effective exchange of data and collaborative projects;
f. The Task Group on Priority Climate Indices should emphasize development of indices, which are not highly correlated, but rather contain independent information. Such as those pertaining to the annual cycle, meridional temperature gradient, mean land vs. sea surface temperatures (also maritime vs. continental parameters);
g. The Task Group on Priority Climate Indices should also consider the development of indices that can be considered on a regional basis and compared within and between regions in addition to those for global analyses. Further consideration should also be given to developing indices to indicate the degree of climate variability on a variety of space and time scales.

Outreach Initiatives

17. Regular reports on activities of the WG should be submitted for publication in the CLIVAR newsletter including special reports on relevant meetings such as this one.

18. Prepare a brochure on the climate change detection project, focussing on the development of indices and the related importance of historical data for climate variability and climate change detection studies.

19. Develop and maintain CCl/CLIVAR WG Web site on the WMO server.

20. Arrange for some of the participants of the meeting and possibly the other indices rapporteurs to be nominated as reviewers of chapter 2 and 12 of the IPCC Third Assessment Report at the Government Review stage in spring 2000.

Future Activities of the Working Group

21. Upon being informed of the mutually agreeable discussions between Dr Tom Peterson and Povl Frich from the Hadley Centre, UK meteorological Office concerning the chairmanship of the CCl/CLIVAR Task Group on Priority Indices, it was agreed that Mr. Frich would be a suitable replacement for Dr Peterson as chairman of the Task Group.

22. The Working Group should meet in approximately one year's time to review the results of actions that have been initiated at this meeting and plan future actions to ensure continued progress in studying climate variability and detecting climate change and to prepare a report in time the 13th session of CCl. Ideally such a meeting would take place immediately before or after one of the planned regional capacity building workshops.

23. It was agreed that the reports of the Bracknell 1998 meeting and of this meeting, and the lecture given to 13th WMO Congress by the Deputy Chairman, could serve to respond to the request of CCl-XII for annual progress reports from the chairman and designated rapporteurs. It therefore recommended that the chairman should submit these reports to the president of the Commission and elaborate, as required, on future work plans.

24. Upon completion of the report of this meeting, it was recommended that the chairman consult with each of the rapporteurs and experts on the Working Group concerning their individual work plans leading up to the 13th session of CCl planned for 2001.

Appendix 3. Report by Michael Taylor, University of the West Indies, Jamaica, on the Workshop on Enhancing Caribbean Climate Data Collection and Processing Capability and the Dissemination of Derived Global Climate Change Information for the Region, January 8-12, 2001, Kingston, Jamaica

The view has long been held that within the Caribbean region substantial datasets of daily climate parameters exist, which could shed light on climate change trends within the region. However a number of factors prevented their being made available, even to researchers within the region, which include: (i) the less than convenient (non- electronic) format in which data are currently stored, (ii) the need for quality checking and homogenization of the data, (iii) a genuine fear that the data once exchanged will be used without benefit to the region (i.e., without the accompanying capacity building through the development of regional experts in data analysis and treatment), and (iv) the view that data is an income generator which must not be easily dispensed without discretion. To address these issues, and to initiate the examination of Caribbean climate data for evidence of change in climatic extremes, the Caribbean Climate Data workshop was held in Kingston, Jamaica from January 8-12, 2001.

The workshop was hosted by the Department of Physics of the University of the West Indies (Mona) and organized by Michael Taylor, researcher in the Climate Studies Group Mona and Thomas Peterson, of the National Climatic Data Center (U.S.A.). The workshop brought together data managers from 18 meteorological services across the Caribbean region, representatives of four regional entities with interest in Caribbean climate, and experts in Caribbean climate data quality assessment, and climate change. Given the perceived needs, the workshop had overall aims of enhancing climate data collection and processing capability within the Caribbean, and eliciting climate change information relevant to the region. Specifically the workshop was an attempt to 1) assess daily station climate data stores within the region, 2) promote dialogue between Caribbean data managers and data users, 3) train Caribbean data managers in appropriate techniques for data quality management and homogenization, 4) disseminate software to facilitate data management in individual Caribbean territories, 5) adopt and examine a list of easily calculable and meaningful indices for evidence of climate change in the region, and 6) create an electronic dataset of Caribbean precipitation and temperature records for use within the workshop and for subsequent dissemination to workshop participants and/or their sponsoring institutions.

The week began by putting in perspective for the region the issue of climate change. Plenary talks covered Caribbean climate variability with an examination of observed global influences such as ENSO and NAO (Alessandra Giannini, NCAR); an overview of Atlantic hurricanes of the 21st century (Hugh Willoughby, AOML/NOAA); projections of climate change in the Caribbean basin from global models and the extent to which the results are believable (Ben Santer, Lawrence Livermore National Laboratory); and a review of a similar workshop held in the Asia-Pacific region (Neville Nicholls, Australian Bureau of Meteorology Research Centre).

Armed with a contextual overview of the climate of the region and the importance of data for research, participants were then introduced to science on the data, i.e. quality control and homogeneity (Tom Peterson and Albert Klein Tank, KNMI), as well as to climate indices as a mechanism for extracting climate change information. The necessity of and common techniques for carrying out these procedures were discussed and a common set of 15 indices which might prove indicative of climate change in the region decided upon. The set of indices used was coordinated with other research through the joint WMO CCl/CLIVAR Working Group on Climate Change Detection.

The following three days of the workshop saw participants engaged in hands-on exercises related to the data issues discussed. Participants had previously been asked to carry daily temperature and precipitation data of appreciable length (40 or more years) from their respective territories. Utilizing computers provided by the host institution and ClimDex software developed and provided by Byron Gleason of NCDC, participants initially logged many hours processing the data which they had brought to determine their suitability for the climate change analysis which was to be subsequently performed. The ClimDex software comprises of four steps:

- Quality control of the data (check precip > 0, Tmin < Tmax, etc.)
- Homogeneity testing (t-tests using 5-year adjacent time periods)
- Calculating derived climate indices (ten from Frich et al. (2001) and a further 5 regionally dependant threshold indicators) and time series
- Visualizing the data spatially.

Once the reliability of the data was ascertained, the 15 climate change indices were calculated, again via the easy to use and multi-purposed software provided by the NCDC. These latter activities were under the direction and guidance of Tom Peterson, Albert Klein Tank and Lisa Alexander (Hadley Centre). The latter stages of the hands-on portion of the workshop involved the visualization of the results on suitable plots for use in the discussions of climate change in the region (as revealed by the data) that ensued.

Whereas all of the calculated indices revealed valuable information about climate trends in individual countries, some clearly highlighted dramatic changes in the climate of the region as a whole or parts of the region. For example, since the late 1970s, stations from the southern Caribbean showed strong, nearly linear increases in the number of warm nights (90th percentile of minimum temperature). The additional benefit realised by plotting on the same graph time series of indices from stations from different countries, was the clear understanding of how cooperative regional analyses can increase confidence in the results.

The final day of the workshop was devoted to discussion of the issues surrounding data availability. It became clear to all participants that there was urgent need for data to be digitized as only half of the countries had daily data time series digitized back before the mid-1970's. Additionally, through often impassioned discussion, the need for such quality checked data by end users (e.g., researchers in agriculture, health, and disaster mitigation) was presented. Indeed one of the problems in the region has been getting access to the climate data in whatever form it existed.

By the end of the workshop there was renewed determination on the part of the participants to digitize additional data which existed in their respective countries and to use the digitized data in conjunction with the software (which was made freely available to all participants) to ascertain how the climate of their country was changing. By so doing the capacity for future research would be increased. There was also agreement to make the data and the indices available for the purpose of further analysis on a regional basis and the authoring of a journal article on changes in climate extremes in the Caribbean region. The University of the West Indies (through Michael Taylor) agreed to undertake the collation of the data and indices into a database freely accessible to all the participating institutions, whilst Tom Peterson undertook the coordination of the article with assistance from Michael Taylor and Lisa Alexander. As the workshop was also the first of a series of regional workshops coordinated by the WMO CCl/CLIVAR Working Group on Climate Change Detection, recommendations were also offered on ways to improve future workshops, including ways to improve the software.

The workshop was jointly sponsored by the WMO, the University of the West Indies, NOAA OGP, and NASA through their partnership with NOAA OGP.

References:

Frich, P., L. V. Alexander, P. Della-Marta, B. Gleason, M. Haylock, A Klein Tank and T. Peterson, 2001: Global changes in climatic extremes during the 2nd half of the 20th century, *Climate Research*, accepted.

Appendix 4. Report by Abdallah Mokssit, Direction de la Météorologie Nationale, and Lisa Alexander, Hadley Centre, Met. Office, U.K., on the CCl/CLIVAR Workshop to Develop Priority Climate Indices for Africa , February 18-23, 2001, Casablanca, Morocco

Preamble

In the framework of the Regional Rapporteur on Climate Change Detection and Attribution Studies (CCDAS), African countries were asked to report on their CCDAS activities. However, difficulties were met for a number of reasons:

- absence of such CCDAS;
- lack of the necessary daily data to perform such kind of CCDAS;
- difficultiesin exchanging raw data between countries.

In this situation it was necessary to establish an alternative for countries to produce climate indices by themselves and exchange these indices "rather than raw data" through a capacity building process; So the role of Rapporteur became capacity building implementation.

This idea was introduced and endorsed at the CCl/CLIVAR working group on climate change detection meeting, during November 1999 in Geneva. Hence the working group recommended the organization of a number of workshops on regional climate indices. This workshop was intended to help African countries make good progress in this area. Many climate indices were developed using the longest available and reliable station data. These indices will be shared with the international research community interested in studying the African climate such as the IPCC.

This capacity building process involved 28 participants from 23 African countries (including Morocco) along with 2 representatives from Spain and was conducted by a resource team composed by Lisa Alexander (Hadley Centre, UK), David R. Easterling (NCDC/NOAA, USA), Abdalah Mokssit & Rachid Sebbari (National Met. Research Centre/ DMN, Morocco) and managed by Valery Detemermann from WMO which sponsored the workshop.

Introduction

Interest in the climate system of Africa has been increasing in recent years. Scientific interest and studies have yielded many discoveries such as teleconnections between the African climate and other centers of tropical variability. Both statistical techniques applied to raw data and the use of General Circulation Models (GCM) have allowed important progress in studying the African climate. The social and economic characteristics of most African countries depend on the seasonal and interannual variability of temperature and rainfall patterns. While anomalous variations in these shorter time scale patterns can have serious effects on society, our vulnerability to longer-term climate change, occurring over periods of decades to centuries, will depend on our ability to understand and respond to this change.

The rising interest in Climate Change and its impacts is a consequence of human activities mainly through the release of greenhouse gases. Many studies in Europe and North America show an increasing trend in regional air and surface temperatures. In Africa, it has been difficult for scientists to carry out studies in climate change detection due to lack of data.

Through the initiative of the regional Rapporteur on climate change detection and attribution studies in Africa, a CCl/CLIVAR workshop to develop climate indices for Africa was held in Morocco from 18 to 23 February, 2001. The aim of this workshop was to bring together scientists from a number of African countries to enable them make inventories of their data banks, quality control their existing data and produce climate change related indices for each station using daily rainfall and temperature data. The derived indices will be used for climate change assessment at a regional level. The workshop agenda was divided into three parts: 1) Tele-forum: an intensive exchange of e-mails, faxes and letters explaining the work to be done during the workshop with examples; 2) Pre-forum: training the participants (capacity building action); 3) Forum: each participant demonstrates their ability to perform a national and local study bywriting a country report and making a presentation.

At the end of the workshop, the participants were provided with the statistical software (ClimDex) used to produce climate indices during the workshop. They were also encouraged to update the indices regularly and compute a full set for all the daily records back at their institutions.

African Climate overview

Africa is a vast continent and consequently experiences a wide variety of climate regimes. It has the largest tropical land mass, its east-west extent in the northern Hemisphere being particularly large. While the poleward extremes of the continent experience winter rainfall associated with the passage of midlatitude airmasses, the majority of the continent is strongly influenced by circulations which also extend across large parts of the Atlantic and Indian Oceans. These direct circulations have a pronounced annual cycle and associated variations in rainfall, often described in terms of the movement of the Inter-Tropical-Convergence-Zone (ITCZ).

Data and Indices

To monitor changes in climate and climate extremes, a set of key indices has been computed (e.g. Frich et al., 2001). A good index is expected to have a clear meaning, be highly relevant to people, provide insights into climate change, be homogeneous, easy to understand, be relevant to the practical concerns of policy makers and should not smooth out potentially important changes. Other desirable characteristics of an index for monitoring climate extremes include: a good signal-to-noise ratio for the detection of a trend from one period to another, relevance to economic activity and other aspects of human society, sensitivity to anthropogenically-induced or natural variations in climate and it should be calculable from available observational and model data.

Many types of indices can be drawn up from daily data. Appendix A gives a list of the climate indices that ClimDex computes. Some indices are based on thresholds, some on varying extremes while others are just normalized or combined indices. . The indices are expressed in various ways to facilitate spatial and temporal trend detection and impact analysis.

Daily rainfall and temperature data are needed to compute the above indices. A selection of stations from the Region I GSN station list has been compiled. Most participants brought daily data for selected existing stations in their countries. The period covered by the daily data depended from one country to another and from station to station.

Software and Analysis

Quality control and checking for inhomogeneities are essential when dealing with daily data.. An inhomogeneity in a time series is defined as any change that is not due to change in weather or climate. Among the causes that may lead to such inhomogeneities are changes in: instrumentation, processing, the shelter environs, observing practices or the station location. Abrupt or sometimes gradual changes can be traced to both natural and artifical (human induced) changes. User's are generally more interested in trying to dececct and/or expalin the former and in eliminating or mitigating the effects of the latter.

The ClimDex software, which uses a Microsoft Excel graphical user interface, was developed by Byron Gleason at NCDC, USA to quality control and analyse daily precipitation and temperature data. It also provides users with a way to detect temperature (TMAX and TMIN) inhomogeneities through both visual inspection of the time series and statistical testing of two adjacent periods using a t-test. The current version of the software (v1.1) made use of suggestions from the Caribbean regional workshop. ClimDex_v1.1 now calculates 18 climate indicators (see Appendix A) along with improved homogeneity checks such as allowing user-defined t-test "window" sizes to test for inhomogeneities. Although ClimDex does not provide a solution to inhomogeneity problems, it does highlight potential discontinuities which can be checked against existing metadata. Once satisfied, users can then calculate the derived climate indicators and analyse their results through both graphical and tabulated mediums. When all participating countries have calculated their results, ClimDex uses freely available mapping software to spatially visualise the results for the whole region. Another advantage of the software is that a user familiar with the Visual Basic programming language can tailor each step to their needs e.g. add more indices.

Results

Each participants report on the climate indicesfor their country will be made available to the scientific community. An example of the time series for indicator Tn90 (Fig. 1) is shown for one station. Maps of the results for all stations analysed (Fig.2 - Fig. 7) are shown for six selected indicators:- Tn10, Tn90, Tx10, Tx90, R5d and R95T (see Appendix A).

Fig. 2 shows a negative trend in the number of very cold minimum temperatures and Fig. 3 shows a positive trend in warm night-time temperatures over most countries, including Madagascar and the Seychelles. Exceptions were northern Eritrea and the extreme eastern coast of Tanzania. These coherent patterns of change were also found for maximum temperature (Fig. 4-Fig. 5). The evidence of warming in almost all the countries wasstatistically significant in many cases.

The precipitation indicators R5d (Fig. 6) and R95T (Fig. 7) show a much more mixed pattern of change than the temperature indicators. Neighbouring stations can sometimes show opposite signs of change e.g. Tunisia, making regional analysis difficult. For this reason it is important to consider other kinds of indices which characterize regional precipitation features instead of the local precipitation climate.

Conclusion

This workshop was an opportunity to reach all the initial objectives:

- An inventory of 23 national daily data in Africa.
- 23 national homogenized and quality controlled daily data.
- 23 national detection studies reports based on the set of indices listed in appendix A were produced and presented.
- A set of cumulative indices for the Africa region.
- Validated software ready to be circulated to the remaining African countries

Even with the short (5-day) timescale, this three stage workshop succesfully achieved all its objectives.

Most of the selected indices seem to be very relevant for temperature and give a regional overview of climate change. However the precipitation indices seem to be highly dependent on location and regional studies may therefore need to consider other regionally dependant indices..

The workshop also introduced the new concept of exchanging “derived data” rather than “raw data”. Indeed, given the constraints (e.g. commercial) associated with exchanging raw data, all participants instead agreed to exchange derived indices. It was also a good opportunity to strengthen the collaboration between the African national meteorological services. All participants agreed that such workshops are useful and we therefore recommend that the ClimDex software, and associated manual be sent to the other African countries that were unable to attend the workshop.

References

Frich, P., L. V. Alexander, P. Della-Marta, B. Gleason, M. Haylock, A Klein Tank and T. Peterson, 2001: Global changes in climatic extremes during the 2nd half of the 20th century, *Climate Research*, accepted.

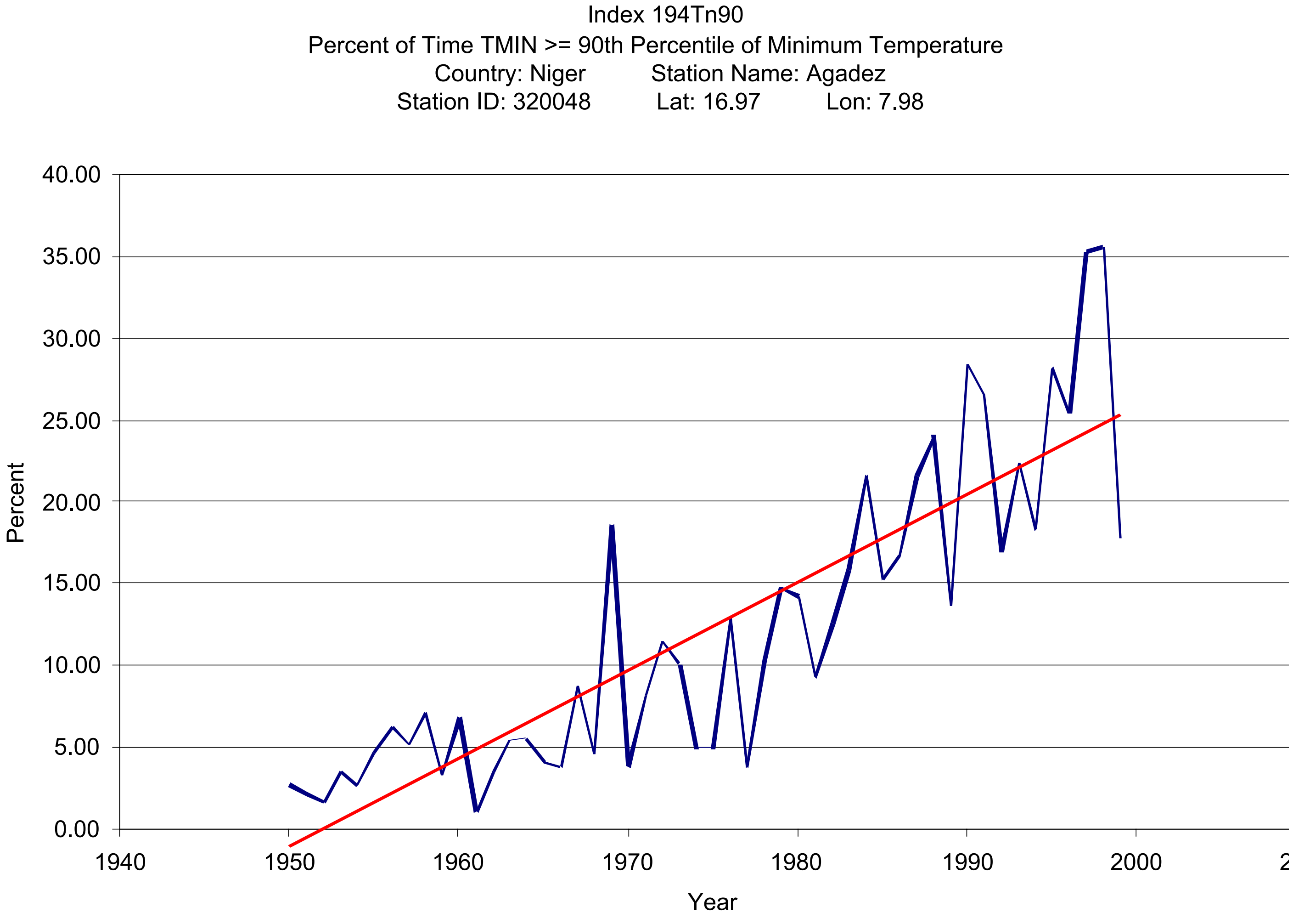

Figure 1: This time series for Tn90 (see Appendix A) is fitted with a least squares trend line. The increase is significant at the 95% level of significance.

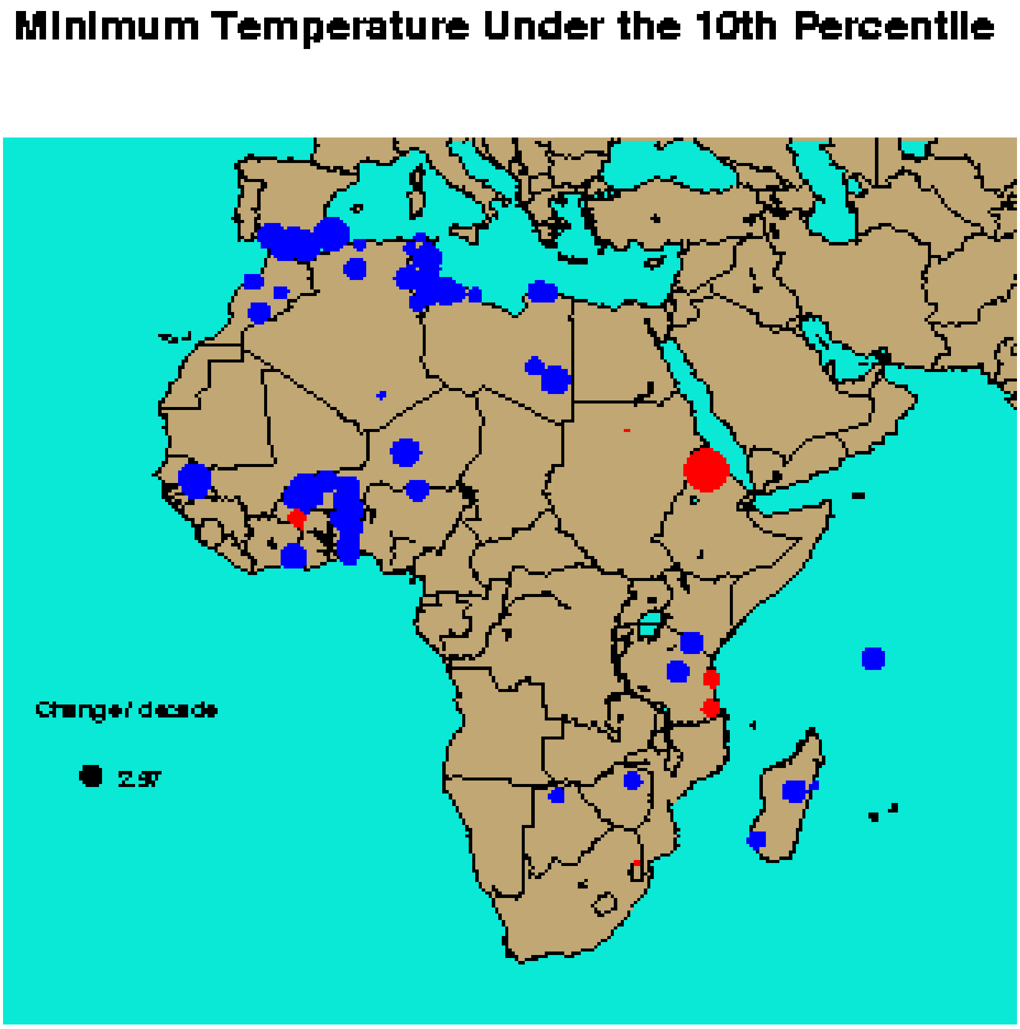

Figure 2: The sizes of the circles represent the change per decade of indicator Tn10 (Appendix A). the circles are normalized to the size indicated in the legend. Red indicates an increase in the indicator; blue a decrease.

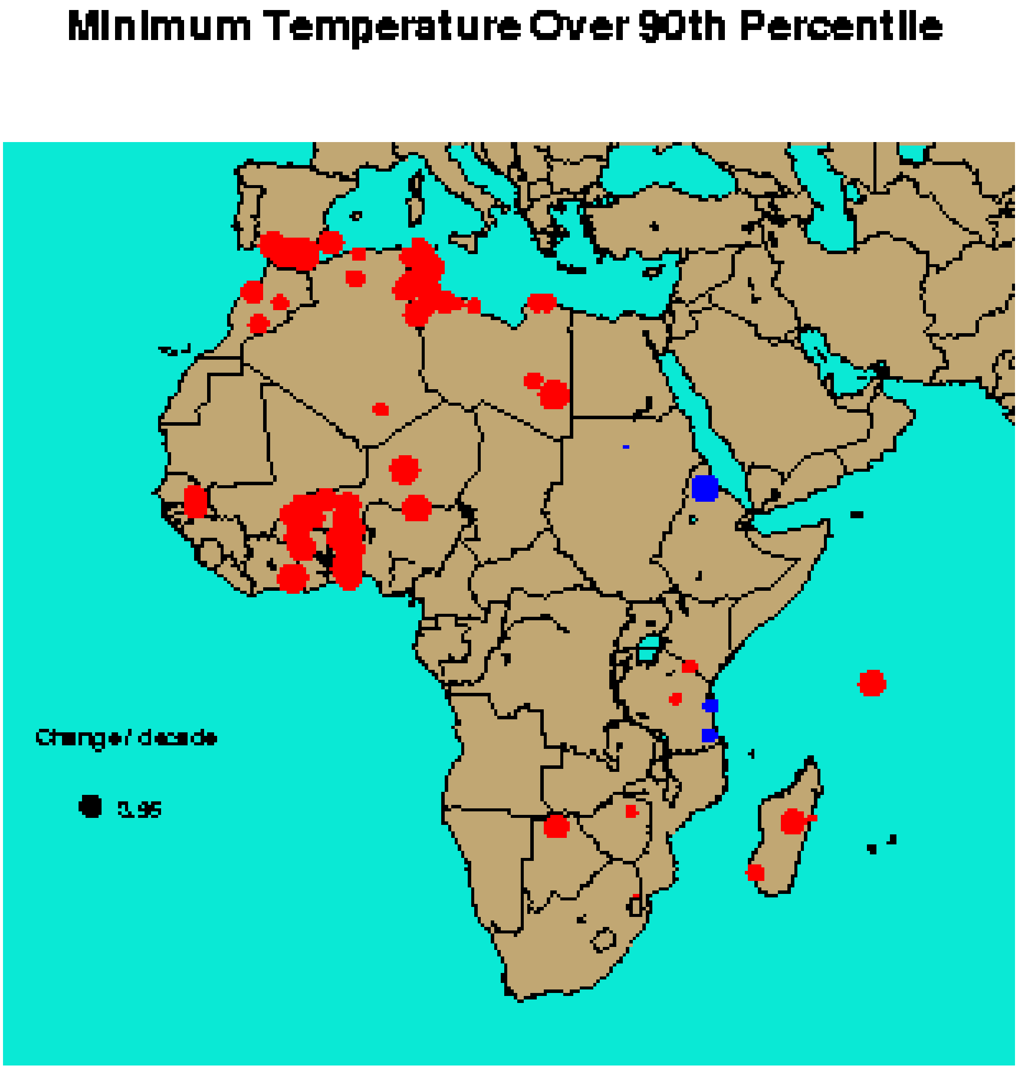

Figure 3: As Figure 2 except for indicator Tn90.

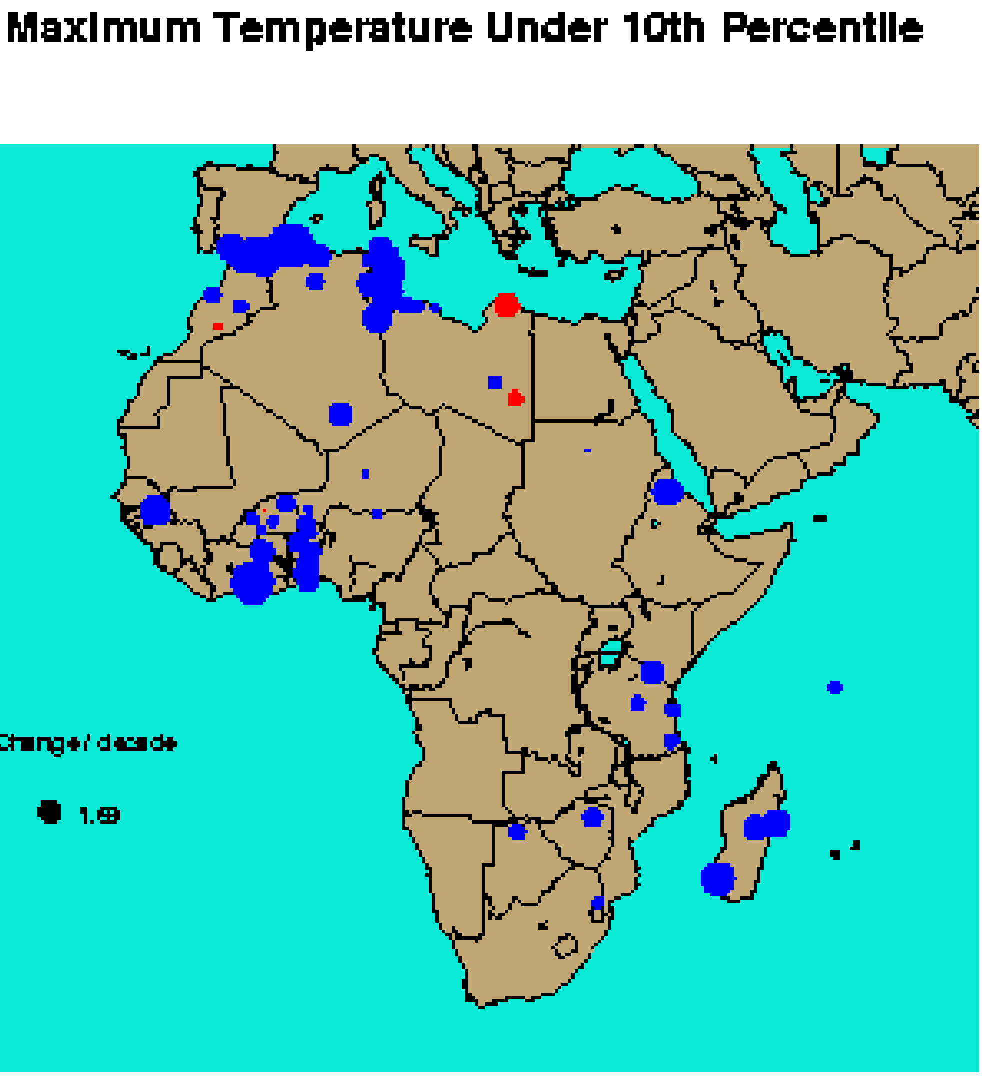

Figure 4: As Figure 2 except for indicator Tx10.

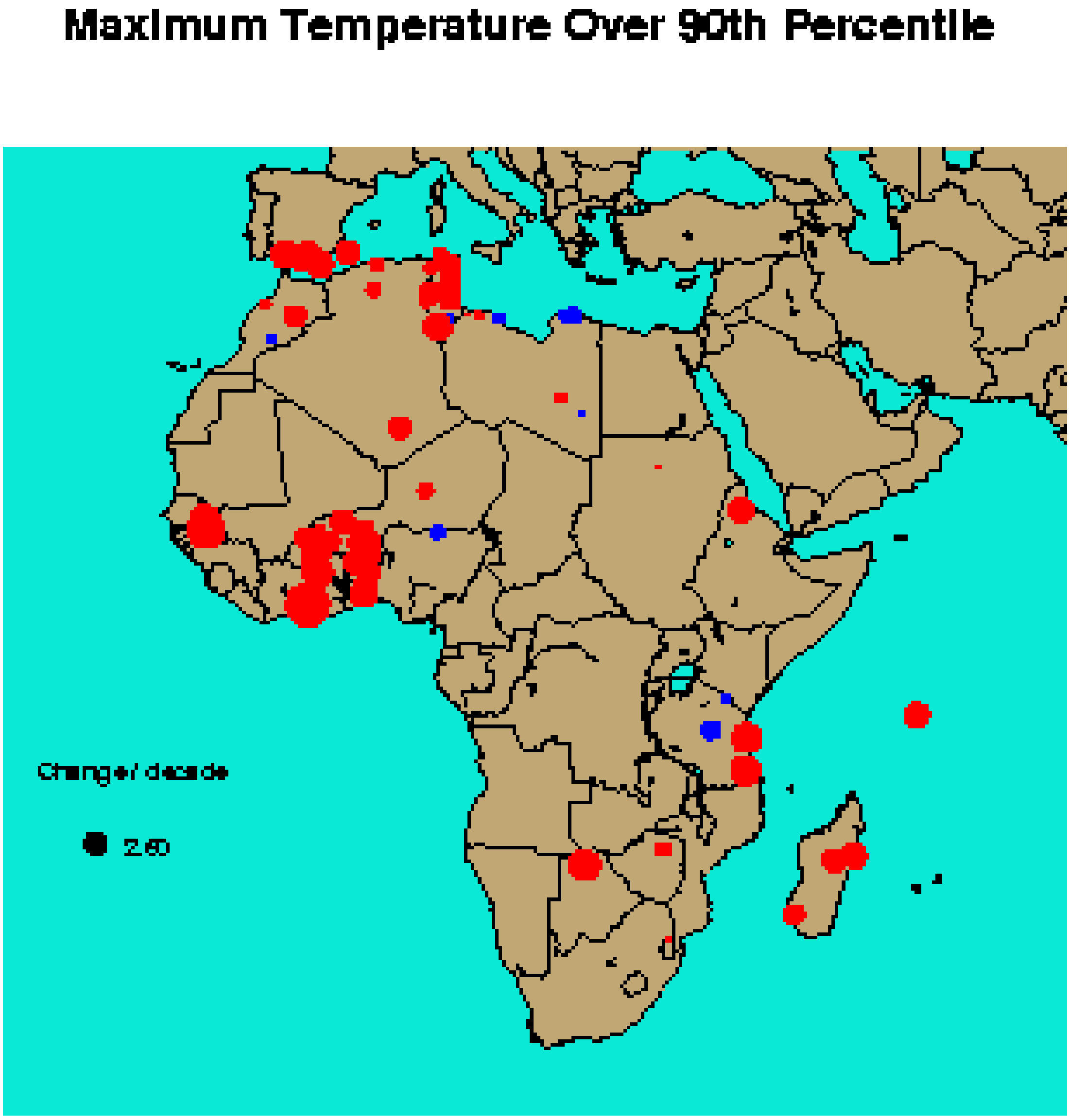

Figure 5: As Figure 2 except for indicator Tx90.

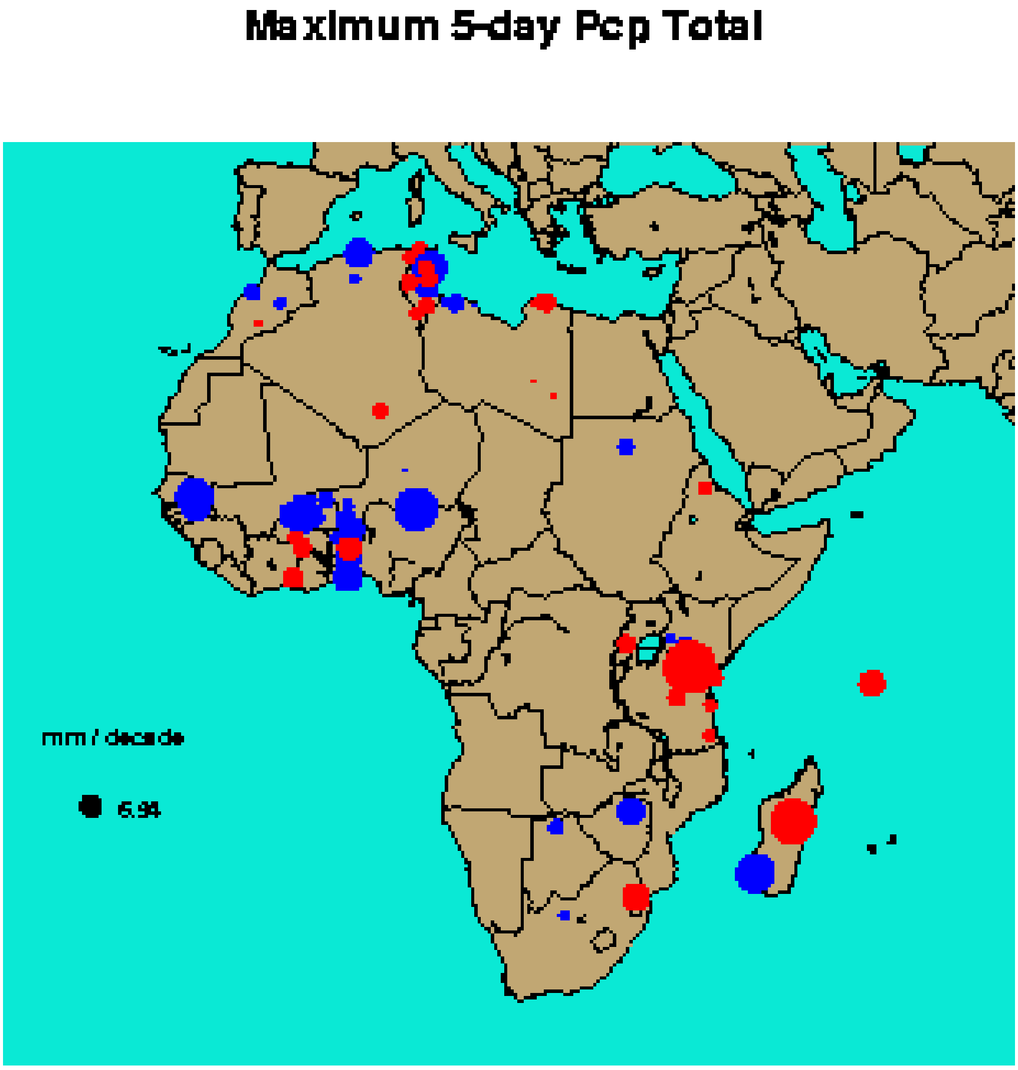

Figure 6: As Figure 2 except for indicator R5d.

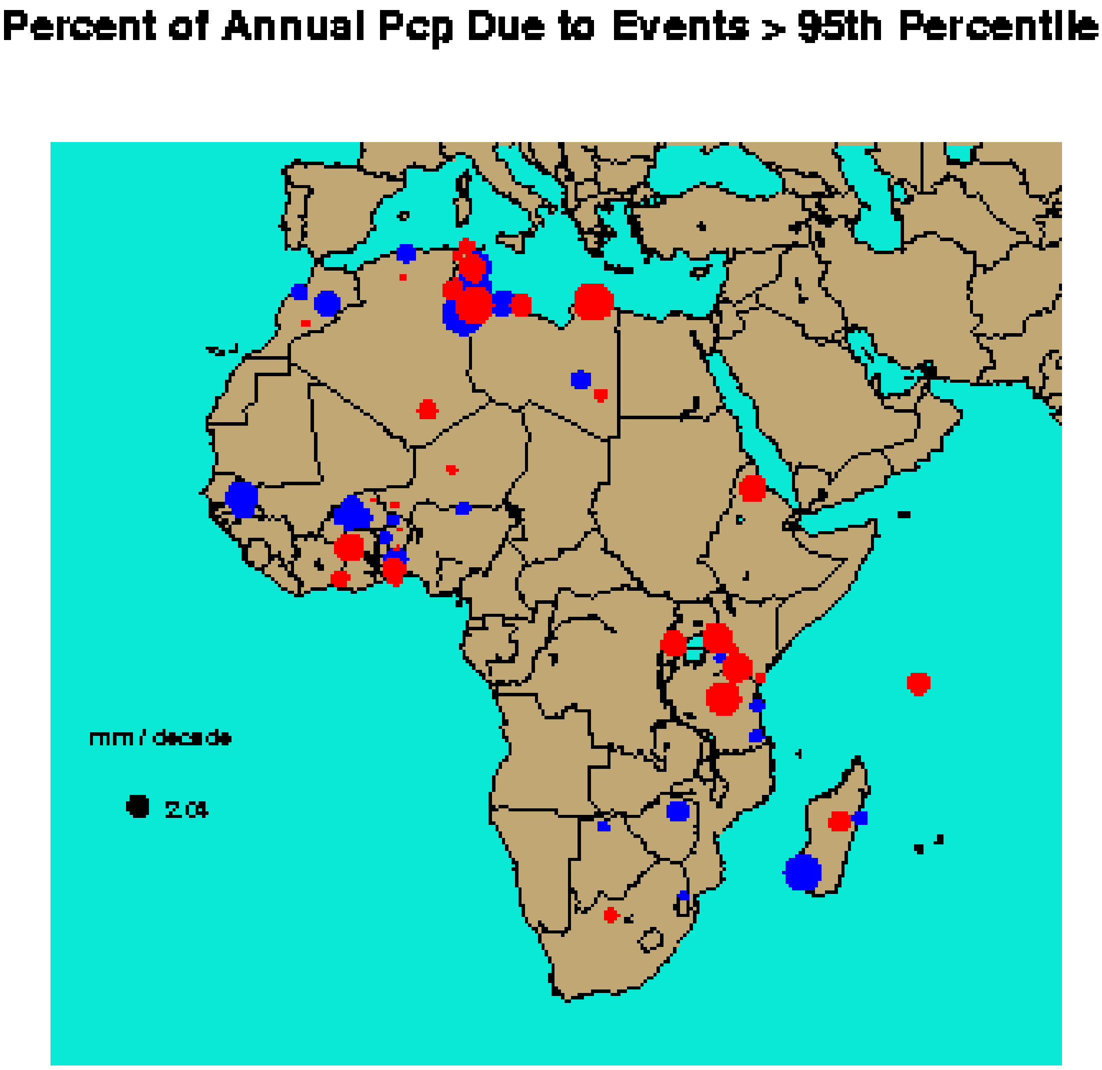

Figure 7: As Figure 2 except for indicator R95T.

APPENDIX A: List of Climate Indices

INDEX NO.	ABBREV.	TITLE	UNITS
125	**FD**	**Number of Days with Frost (Tmin < 0 deg C)**	**days**
141	**ETR**	**Intra-Annual Extreme Temperature Range (Th-Tl)**	**days**
143	**GSL**	**Growing Season Length (when T>5 deg C for >5 days and: T<5 deg C for >5 days)**	**days**
144	**HWDI**	**Heat Wave Duration Index**	**days**
191*	**Tx10**	**Percent of Time Tmax < 10th Percentile of Daily Maximum Temperature**	**% of time**
192 *	**Tx90**	**Percent of Time Tmax > 90th Percentile of Daily Maximum Temperature**	**% of time**
193 *	**Tn10**	**Percent of Time Tmin < 10th Percentile of Daily Minimum Temperature**	**% of time**
194	**Tn90**	**Percent of Time Tmin > 90th Percentile of Daily Minimum Temperature**	**% of time**
606	**R10**	**No. of days with Precipitation >= 10.0 mm/day**	**days**
641	**CDD**	**Maximum Number of Consecutive Dry Days (Rday < 1 mm)**	**days**
644	**R5d**	**The Greatest 5-day Rainfall Total**	**mm**
646	**SDII**	**Simple Daily Intensity Index**	**mm / day**
695	**R95T**	**Fraction of Annual Total Rainfall due to Events Above the 95th Percentile**	**%**
001	**TxGE**	**Number of Days Tmax >= user defined threshold**	**days**
002	**TxLE**	**Number of Days Tmax <= user defined threshold**	**days**
003	**TnGE**	**Number of Days Tmin >= user defined threshold**	**days**
004	**TnLE**	**Number of Days Tmin <= user defined threshold**	**days**
005	**Prcp**	**Number of Days Prcp >= user defined threshold**	**days**

* Indicators introduced with ClimDex_v1.1

Appendix 5: Report from Chris Folland, Hadley Centre, Meteorological Office, UK, WMO CCl Lead Rapporteur on Climate Change Detection Methodologies and Indices and Vice-Chair of the Working Group on Climate Change Detection

My Report is divided into 5 sections:

1. Lead Rapporteur's Report.
2. A Report on the methods of climate change detection and attribution using coupled models with Dr David Sexton.
3. A report on new work comparing modelled and observed extremes by Dmitry Kiktev, a visiting Scientist at the Hadley Centre.
4. Reproduction of my joint paper in the WMO Bulletin (2000) "Uncertainties in climate data sets - a challenge for WMO".
5. Monitoring the Global Upper Air Data Network (GUAN) as part of the Joint Upper Air Data Centre with the NOAA National Climate Data Centre, and new studies of upper tropospheric humidity (Mark McCarthy in my group).

1. Final Report from Chris Folland, Lead Rapporteur on Climate Change Detection Methodologies and Indices, 1997-2001.

The Terms of Reference of the Rapporteurs on Climate Change Detection Methodologies are (Resolution 17, CCl-XII):

a) To collaborate with the Working Group on Climate Change Detection in the development of climate change detection indices and in reviewing relevant parts of WMO programmes and activities, including the Technical Regulations.

b) To keep abreast of scientific developments involving the monitoring, detection and modelling of climate change. In general, the characterisation of evolution of the past climate, and especially to study the underlying principles for compiling reference climate data sets and the development of indices and indicators for use in detecting climate change.

c) To contribute to the study of the homogeneity and the statistical properties of the long-term data series of climate related parameters and to advise on procedures for ensuring homogeneity of climate data.

d) To collaborate closely with experts working on the development of indices and indicators of climate extremes.

My main aim has been to create, through other Rapporteurs and scientists, a comprehensive set of climate change indices for the "Observed Climate Variability and Change" Chapter (Chapter 2) of the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (Folland et al, 2001a). Chapter 2 (about 100 pages) contains the widest range of indices so far created for the Observed Climate

Variability and Change IPCC chapter, with new maps showing changes in climate extremes. The work was helped by my position as Co-Convening Lead Author of chapter 2 with Mr Tom Karl (USA). Key climate change indices are also being published in the Technical Summary and Policymakers Summaries of the TAR, and in the Synthesis Report of the three TAR Working Groups. (Terms of Reference a,b,d).

A key activity as Lead Rapporteur was to hold a focussed meeting of the Working Group on Climate Change Detection in the form of a Task Group on Climate Indices in 1998 at Bracknell. The Bracknell meeting followed on directly from the CLIVAR/GCOS/WMO Workshop on indices and indicators for climate extremes held in Asheville, USA in 1997 (Karl et al, 1999) for which I contributed to two papers (Folland et al, 1999; Jones et al, 1999) with a follow-up article (Horton et al, 2001b). The proceedings of the Bracknell meeting, including more than 20 papers presented there, are recorded in WMO 1999a, effectively my first annual report to WMO. This meeting attracted several leading observational climatologists, statistical experts and some climate modellers. The main aim was to identify and plan to deliver to IPCC a comprehensive set of climate change indices. Further aims were to consider how the international community could improve the analysis of extremes beyond the TAR and to develop practical proposals for comparing the expected new extremes data and models of recent climate change, around 2000-2001.

To help achieve the aims, a Task Group on Priority Indices was set up led by Mr Povl Frich, then in the Met Office. Its first remit was to help identify a comprehensive range of possible indices and document these in a Data Dictionary (see main Working Group Report). This was achieved. A subset of indices was chosen for the TAR, and a special effort was made to write and submit for publication a paper on changing climate extremes. This paper has been accepted (Frich et al, 2001) and the most important extremes indices have been included as figures in Chapter 2. Other related work on indices has been done by the Rapporteurs; this is also in Chapter 2 and listed in accompanying Rapporteurs Reports. (Terms of Reference a).

The second aim was to set up Workshops on Changing Extremes, broadly following a model created by the Asia-Pacific Network (APN) in workshops held in Australia in 1998 and 1999. I attended the first APN Workshop in December 1998 and led a breakout group on analysis methods. The final form of the Extremes Workshops was agreed at a meeting of the full Working Group in Geneva in November 1999. Workshops, involving my colleague Ms Lisa Alexander, were held in Jamaica (January 2001) and Casablanca (February 2001), the latter led by Mr A. Mokssit, one of the Rapporteurs (see also Chairman's and Vice Chairman's combined Report). In the meantime, the results of the APN workshops have been incorporated into Chapter 2 (Manton et al, 2001, reference at end of main Working Group report and Appendix 10). Mr P. Frich and, now Ms Lisa Alexander, are also collaborating in the European Climate Assessment 2000 being led by Dr Albert Klein Tank (Netherlands). This was discussed at the Bracknell Task Group meeting and will also contain new results on changing climate extremes (See Main Report). (Terms of Reference a, d).

Over the last three years I have presented lectures on climate monitoring involving many of the indices in Chapter 2 to UK Government Ministers from four different government departments. This has been useful for more effectively developing and presenting such information to policy-makers and their advisers.

A third aim was to develop methods for comparing modelled changes in extremes with observed changes using indices derived from the Data Dictionary. This work has so far been confined to atmospheric models. A visiting scientist position was set up in the Hadley Centre through Indices Rapporteur, Dr G. Gruza. Dr Dmitry Kiktev started work in September 2000. His preliminary report is at Part 3 of this report. My colleague, Dr David Sexton, has been working with Dr Kiktev in helping to design the experiments and providing model data. David attended the 1998 Bracknell meeting where the general approach was developed. (Terms of Reference b).

Other activities have included an invited Lecture to Thirteenth WMO Congress in May 1999 on "Representativeness, Data Gaps and Uncertainties in Climate Observations". The talk documented these problems in a variety of climate data sets over land and the oceans and described new methods for reducing the problems and, particularly, for quantifying their impact on analyses of climate change. This has led to the first objective quantification of uncertainties in global warming, being published in Chapter 2 and a paper in press (Folland et al, 2001b). A preliminary analysis of the impact on global temperature changes can be found in the written version of the lecture (WMO, 1999b). I also emphasised the urgent need for nations to exchange much more daily climate data to allow global studies of changing climate extremes to be made e.g. from the GCOS surface network. The new extremes Workshops provide a practical way of moving this forward, though much more is needed. An abridged form of the lecture was published in the WMO Bulletin (Folland et al, 2000). These papers represent my second annual report as Lead Rapporteur. (All terms of Reference).

The year 2001 is the culmination of much planning and activity to enhance historical marine data sets though data archaeology and the careful combination of existing digitised data sets at the individual ship observation level. This involves the Met Office, the NOAA Comprehensive Ocean-Atmosphere Data set group, and a number of newly digitised data sets, one back to 1784, including data from USA, Japan and Norway. A Historical Marine Data Workshop is planned for September 2001. The work is being done hand in hand with observational and modelling studies of the modes of climate variability and change. Further digitisation of historic data is in hand. (Terms of Reference b, c)

The better homogeneity of gridded land surface and sea surface temperature data for analysing extremes is a long-standing issue. This mainly arises from local inhomogeneities in the variance due to substantially varying densities of the input data. I have helped develop new methods of achieving better homogeneity with Dr Philip Jones (a CLIVAR Rapporteur of this Working Group). A new global data set has been created, the methods published (Jones et al, 2001) and applied to a new analysis of worldwide monthly and seasonal temperature extremes (Horton et al, 2001a). The new data set is used in Chapter 2. (Terms of Reference c).

The Hadley Centre is part of the GCOS Joint Upper Air Data Centre with the NOAA National Climate Data Centre. Part 5 of this report reviews the current state of the GCOS Global Upper Air Network which we monitor monthly and for which we mainain a web site for WMO. It also mentions new studies of upper tropospheric humidity. (Terms of Reference b).

I am involved with research into methods of climate change detection and attribution. A paper was published on the application of atmospheric models in detection (Folland et al, 1998) and another is in press (Sexton et al, 2001). Atmospheric models are particularly useful for regional detection because the signal to noise ratio is lower than for coupled models. This is because of the use of historically observed sea surface temperature and sea-ice extent, though only partial attribution is possible. The methods are being applied to study the impact of anthropogenic forcing on Central England Temperature (Parker et al, 2001). More advanced mathematical methods of detecting the signals in AGCM experiments are under development (D. Sexton and H. Grubb, personal communication) resulting from collaboration with Reading University Applied Statistics Department.

I am also involved in modelling and observational studies of climate variability and regional change. Much of this is indirectly relevant to Working Group activities but not a direct part of Working Group work at present. Worth mentioning is a new CLIVAR initiative called the Climate of the Twentieth Century (C20C), jointly led by myself and Professor J Shukla at the Centre for Ocean-Land-Atmosphere interaction (COLA) in Maryland. C20C is currently centred around the use of atmospheric models forced with the Hadley Centre’s latest Sea Ice and Sea Surface Temperature Data Set (HadISST1.1) to study climate variability and predictability, including detection of the impacts of various forcing factors. Also included are a variety of forcing data sets representing natural and anthropogenic factors ranging from volcanic forcing to tropospheric ozone. These have been put together in the Hadley Centre in collaboration with the CLIVAR Rapporteur on forcing data sets, Dr John Mitchell. A C20C Workshop is planned later in 2001.

I am a contributing author of the Climate Change Detection and Attribution chapter (Chapter 12) of the IPCC TAR. (Terms of Reference b). Part 2 of this report reviews detection methods, including "optimum detection", being used with coupled models and is my third annual report. This may help further understand Chapter 12.

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2. A review of climate change detection methods using coupled models

David M.H. Sexton and Chris K. Folland, Hadley Centre, Met Office.

Anthropogenically induced climate changes occur in the presence of the background natural climate variability. Detection of such a climate change occurs if an observed climate change is statistically significantly different to any changes due to natural climate variability alone. Attribution of the climate change to anthropogenic causes is the process of demonstrating that the response to anthropogenic forcing in climate models is consistent with the observed change and that any other mechanisms can be eliminated as possible causes. This is difficult at present.

Most detection studies since IPCC Second Assessment Review (IPCC 1996) have used either pattern correlation or (optimal) fingerprint detection techniques to quantify the similarity between observed and modelled climate change. An excellent review of the use of climate change detection methods using coupled models can be found in Barnett et al (1999).

Pattern correlations

Centred and uncentred pattern correlations have been used to quantify the similarity between observed and modelled surface (e.g. Santer et al. 1995) and upper air temperature changes (e.g. Santer et al. 1996; Tett et al. 1996). Studies typically calculate the pattern correlations between observed temperature trends and those generated by coupled model integrations that include various combinations of anthropogenic forcings. These correlations are then compared against the distribution of pattern correlations between the observed temperature trends and trends sampled from a long control integration. Studies with both variables have found that runs that include anthropogenic effects are in better agreement with the observations than would be expected from natural climate variability alone.

Legates and Davis (1997) criticised the use of centred pattern correlations for several reasons, although Wigley et al (1998) used a series of idealised model experiments to show that the statistics were well behaved for climate change detection studies. Detection using pattern correlations has been used in AGCM studies (Folland et al. 1998). They used a suite of AGCM integrations to show that runs which include anthropogenic effects reproduce recent upper air temperature changes significantly better than when the AGCM is forced by changing SSTs only. This approach has less climatic noise, and therefore the influence of anthropogenic effects on upper air temperature changes has also been detected on interannual time scales with centred pattern correlations (Sexton et al, 2001). We do not discuss AGCM methods further here.

Optimal fingerprint detection

A disadvantage of pattern correlation techniques is that they do not provide any information about the amplitude of the anthropogenic signals in the observations. Fingerprint methods solve this by estimating the magnitude of a model-predicted signal (a fingerprint) in the observations, and the associated confidence intervals. First, we discuss the ideas behind this approach, and then show how the optimal fingerprint method can be regarded as a multiple linear regression problem. This makes it easier to discuss the various extensions of the optimum detection methodology in terms of a linear framework.

Optimal fingerprint detection aims to make it easier to distinguish a forced (anthropogenic) climate change signal from the background internal climate variability by increasing the signal (fingerprint) to noise (internal model natural variability) ratio. To explain this, Hasselmann (1976) used a simple example where most of the natural variability could be represented by two orthogonal internal modes. Fig 1 plots the amplitudes of these two modes against each other as they change through time. When there is no climate change present, the amplitudes of the two modes lie within the ellipse for a given percentage (typically 90%) of the time. The shape of the ellipse implies that there is more variance in the mode plotted along the OX axis than the OY axis. B represents a fingerprint that we are trying to detect, which can be made up of a linear combination of the two internal modes. As the signal lies close to the main mode of internal variability along OX, the signal to noise ratio represented by the ratio OB/OBn is small. The optimal approach to fingerprint detection weights down components of the signal that resemble the main modes of internal variability and weights up those parts of the signal that do not. The effect of this weighting is to rotate the signal from B to C, so that OC lies in a direction that maximises the signal to noise ratio OC/Ocn even though the modified signal OC may be smaller than the original signal OB. Although the figure does not show this directly, it is also clearly possible to rotate a signal which lies between O and Bn, which is submerged in noise, to a modified signal that lies between Cn and C, so that the modified fingerprint emerges from the noise.

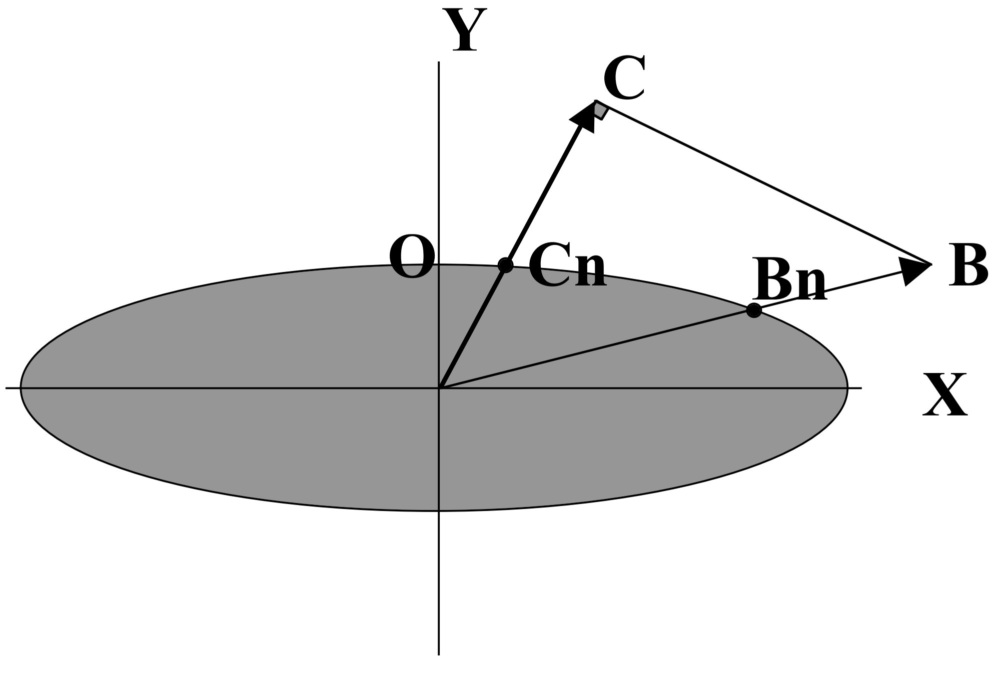

Fig 1. Sketch to demonstrate the principles behind optimal detection (from Hasselmann (1976)).

Recent CGCM studies have re-expressed Hasselmann's strategy as a weighted least squares multiple linear regression problem (Allen and Tett 1999). Here, the observations are assumed to be a linear combination of one or more modelled signals plus noise. The regression analysis estimates amplitudes of the signals with associated confidence regions (or intervals for single signal fingerprints), giving less weight to parts of the signal that resembles the main modes of internal coupled variability as estimated from a long coupled model control run, thus increasing the signal-to-noise ratio. The long control run that is usually available is often split into two parts to provide two noise covariance matrices. One is used for the optimisation step and the second is used for the confidence interval estimation. This is done because use of the same covariance matrix for both steps underestimates the confidence intervals, giving too many significant results. A signal has been detected if its confidence interval does not include zero amplitude and is consistent with observations if the confidence interval contains one. Allen and Tett (1999) show that non-optimised detection produces similar amplitudes to the optimal version, but the confidence intervals are larger and so detection is harder.

Early optimal detection studies used fixed signals (e.g. 30-year annual mean temperature trends in Hegerl et al (1996)). However, attribution of climate change requires several signals to be considered together when all combinations of forcings are tested for consistency with observations (i.e. whether the confidence regions include same magnitudes of the observed as the model signals, i.e. the vector (1,…,1)) (e.g. Hegerl et al. 1997). A practical issue is that the responses to different external forcings can have very similar patterns, which cause degeneracy in the regression analysis, and only one or two forcings can be considered at once. To help alleviate this problem, Tett et al (1999) use spatial-temporal signals. These are signals that consist of an evolving spatial pattern and are less degenerate due to the differing time profile of the anthropogenic forcings. The annual cycle of the response to these forcings may also be different and so use of seasonal data can reduce this degeneracy further (Stott et al, in preparation). Another practical issue is that a truncated set of empirical orthogonal functions (EOFs) must be used to represent the noise covariance matrix. This is required so that the fingerprint is not rotated in the direction of unrealistic high order EOFs. Allen and Tett (1999) developed a test that checks that the variations in the observations not explained by the model signals are consistent with variability from the control coupled run for a given noise covariance matrix. The test not only fails when unrealistic EOFs are included in the analysis, but also checks that there are no large systematic biases in the fingerprints.

The optimal detection strategy at present does not encompass all aspects of the detection problem, although these problems are gradually being addressed. For instance, only a few studies incorporate the error in the observations into the analysis (e.g. Hegerl et al. 1996). There is likely to be an issue here concerning how this is calculated because the existence of uncertainties in corrected, and maybe some so far uncorrected, biases may need to be included in due course. The new observational work of Folland et al (2001) may lead to progress (see Report of Lead Rapporteur on Climate Change Detection Methodologies and Indices). Furthermore, the fingerprint method assumes the model signals are exact, whereas they are actually ensemble mean patterns that are contaminated by some internal climate variability. As a consequence, fingerprint amplitude estimates are biased towards zero. Techniques that estimate the amplitudes when the fingerprints include noise have been used and extend the analysis of Tett et al (1999) (Allen, Stott, pers. comm.). A further issue is that the analysis can estimate fingerprint amplitudes that are significantly larger than unity, relative to observations, implying that that the radiative forcings are too small. Amplitudes of up to five or six times a model signal are plausible and may indicate an error in the magnitude of the forcing included in the model, but anything bigger seems unlikely. A further problem is that detection methods do not yet uncertainties in the radiative forcing.

Some studies have used Bayesian methods (e.g. Leroy 1998), which are discussed in Barnett et al (1999), where probability distributions of the signal amplitudes are specified prior to the analysis. These prior probability distributions may be subjective (the prior belief of the scientist) or based on evidence from other studies such as the plausible ranges for the climate sensitivity to CO2 doubling, but are often simple functions that specify a range of plausible amplitudes. Bayesian analysis produces a modified (posterior) probability distribution for the signal amplitudes, based on the observed data. Therefore, the Bayesian approach estimates the relative likelihood of signal amplitudes based on the observations, whereas the traditional approach only detects a signal when the likelihood of the null hypothesis that the amplitude is zero is small.

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3. Trends in annual climate extremes evaluated from observed and simulated data in an atmospheric general circulation model

Dmitry Kiktev, February 2001
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Temporal trends in climate extremes since 1950 are considered in terms of the following derived indices:

FD [days] - total annual number of Frost Days (Tmin<0°C);

HWDI [days] – Heat Wave Duration Index (maximum period > 5 consecutive days with Tmax>5°C above the 1961-90 Tmax normal);

R10 [days] – Number of days with precipitation ≥ 10mm.

SDII [0.1mm/day] - Simple Daily Precipitation Intensity Index (Annual total number of days with precipitation ≥ 1mm/day);

R95T [%] – Fraction of annual total precipitation due to daily events exceeding the 1961-90 95th percentile;

CDD [days] – Maximum number of Consecutive Dry Days (with precipitation less then 0.1mm/day).

Data

Time series were calculated from station records and the Met Office HADAM3 atmospheric general ciculation model (AGCM). This has a horizontal resolution of 2.5^o latitude x 3.75^o longitude and 19 levels in the vertical. All the AGCM experiments were forced with observed time-varying SST from the Hadley Centre Global Sea Ice and Sea Surface Temperature (GISST) data set. At least 35 constituent years since 1950 were required for station time series. Results of two numerical experiments (NAT and GSTOI) for period from 1950 to 1998 are presented below. Experiment NAT was forced by GISST, and also forcing data sets that represent volcanic eruptions and solar variability. Therefore NAT explicitly contained no increasing greenhouse gases but some warming effects can be expected from the SST data. In addition to the data sets used in NAT, forcing data sets representing the anthropogenic greenhouse gas effect, the direct sulphate aerosol effect, the indirect aerosol effect and the effects of stratospheric ozone depletion and increasing in tropospheric ozone concentrations were used in experiment GSTOI. So this is the more realistic set of experiments. An ensemble of six runs was made for experiment NAT giving six time series of derived climate indicators. An ensemble of only two runs for GSTOI was available (six runs will become available soon), giving two series. For both experiments, time series at all grid points were obtained by averaging over the ensemble of individual constituent series of annual extremes.

Methods

Linear trends in time series of climate extremes since 1950 were estimated using least squares linear regression. An AR(1) model was used to account for temporal autocorrelation. Two methods were employed to determine whether a trend was statistically significant. The first is based on computing the ratio between the estimated slope and its standard error under the assumption that this ratio follows the Students distribution. The second approach is the nonparametric Mann-Kendall test that can be used without knowing the exact distribution of the time series. Two-sided tests at a significance level of 0.05 were employed in both cases. Generally both methods were found to produce a very similar spatial patterns of significance. Results produced by Mann-Kendall test are shown below.

Results

The following analysis considers observed and simulated trends rather in kind (mostly in sign) than in degree and is more a preliminary overview of these results rather than a rigorous analysis.

Temperature indices

Index FD: Total Annual Number of Frost days (Fig.1)

Europe

Station data: A decrease in the annual number of frost days dominates over Europe. Warming tendencies over western and central Europe are mostly statistically significant. The opposite tendency to increase in frost days number can be traced over Balkans, along northern coast of the Black Sea and over the northern part of European territory of Russia. But almost none of these trends are statistically different from zero.

Model data: Generally either NAT or GSTOI experiments reveal a warming tendency over the most of Europe. However, for both this signal was not significant. On the other hand both experiments reproduced a statistically significant increase in frost days number along the coast of the Barents Sea that can be traced in the station data. This was more pronounced in experiment GSTOI.

North America

Station data: A decrease in frost day number prevails over western half of the continent with high percentage of statistically significant trends. There is much regional variation over the central US. Cooling takes place in the southeast of the US and along southern Labrador coast. Mostly these trends are not significant.

Model data: For both experiments, the annual number of days with freezing temperatures declines over the most part of North America (especially along Pacific coast of Canada and the US). In large degree, this warming tendency is statistically significant.

Asia

Station data: A decrease in number of frost days dominates over Asian part of Russia and China with high percentage of statistically significant tendencies.

Model data: For both experiments, trends are less uniform in sign than station tendencies and generally statistically nonsignificant. Instead of warming, experiment NAT shows statistically significant cooling over Central Asia and southwest Siberia.

Australia

Station data: A decline in number of frost days prevails. It is statistically significant at some locations in the south and east of the continent.

Model data: Both experiments indicate a statistically significant decrease of frost day numbers over southern half of Australia.

Index HWDI: Heat Wave Duration Index

Europe

Station data: General increase in heat wave duration occurs. It is statistically significant over central Europe.

There is a regional-scale decrease near the Black Sea (in particular Crimea, Caucasus). At some locations it is significant.

Model data: Reproduced trends are mostly not significant.

North America

Station data: Generally heat wave duration increases over Alaska and western and central Canada. This tendency is statistically significant in many instances. A significant decrease takes place over Labrador and the central United States.

Model data:

Experiment NAT: Practically none of the trends are significant.

Experiment GSTOI: In large degree produced tendencies are significant and consistent with station trends.

Asia
Station data: Warming trends in heat wave duration prevails over Russia and northern China. In many instances they are statistically significant over Siberia. As the HWDI indicator is not really valid outside mid-latitudes, we don't consider its behaviour further southward.
Model data: Generally areas with no significant trend prevail.

Australia
Station data: Statistically nonsignificant warming trends prevail over Australia.
Model data: The NAT and GSTOI experiments demonstrate mostly positive trends in heat wave duration over the continent. This signal is statistically significant at some areas.

Precipitation indicators

Index R10: Number of days with precipitation >10mm

Europe
Station data: Increase in R10 over eastern Europe, Scandinavia, UK and Ireland; statistically significant in many instances. Regional-scale fluctuations in sign of the trends over the rest of Europe. The latter tendencies are mostly nonsignificant.
Model data: No significant or clearly pronounced trends over Europe for both experiments.

North America
Station data: General increase in R10. Statistically significant in southeast and south of the US and at some locations along the pacific coast of Canada.
Model data: Both experiments display a significant increase in R10 over the central part of the US.
Statistically significant signals at some locations along the Pacific Coast were reproduced in the GSTOI experiment. Generally these trends over the coastal area agree with station data.

Asia
Station data: Virtually no significant trends.
Model data: Practically no significant trends.

Australia
Station data: No clearly pronounced trends.
Model data: Most parts of the continent show no significant trends, at least for those areas with station data.

Index SDII: Annual total number of days with precipitation ≥ 1mm/day).

Europe
Station data: Although in general daily intensity of precipitation is on the rise over Europe, this tendency is mostly nonsignificant.
Model data: No significant trends were reproduced in both experiments.

North America
Station data: General increase in daily precipitation intensity with high percentage of significant trends occurs in the southeast of the US and along the Pacific coast of Canada.

Model data: In general, a statistically nonsignificant increase in SDII prevails over the continent although a positive significant signal was reproduced in both experiments over some areas in the US. In addition, significant positive trends along the Pacific coast of Canada and negative trends over Alaska were reproduced in GSTOI experiment.

Asia
Station data: Virtually no significant trends
Model data: Virtually no significant trends in the areas covered with station data

Australia
Station data: No significant trends
Model data: No significant trends

Index R95T: Fraction of annual total precipitation due to daily events exceeding the 1961-90 95th percentile.

Europe
Station data: Generally the fraction of total annual precipitation due to daily events exceeding the 1961-90 95th percentile tends to grow, but the signal is mostly statistically insignificant. There are some consistent positive changes in R95T over the central and southern parts of the European territory of Russia.
Model data: Areas with no significant signal prevail over Europe in both experiments.

North America
Station data: With the exception of Alaska, generally R95T grows over the US and Canada. However, this signal is consistently statistically significant only in the east of the US and along the Pacific coast of Canada.
Model data:
Experiment NAT: Several spots with a significant increase in the index occur over the central US and Labrador.
Experiment GSTOI: There is a significant decrease over western part of Alaska and a statistically significant increase in the northeast of Alaska. Spots with a significant increasing signal were reproduced in the west of the US.

Asia
Station data: Virtually no significant trends
Model data: Virtually no significant trends in the areas covered with station data.

Australia
Station data: Practically no significant trends.
Model data: Practically no significant trends.

Index CDD: Maximum number of Consecutive Dry Days (with precipitation less then 0.1mm/day).

Europe
Station data: A statistically insignificant slight increase dominates over western and central Europe. A decline in dry season duration prevails over eastern Europe. At some locations it is statistically significant.
Model data: Practically no significant changes.

North America
Station data: Slight decrease prevails over the eastern half of the US. At some locations this is statistically significant.
Model data:
Experiment NAT: Several spots with significant decline in dry period duration were reproduced in the west and central part of the US.
Experiment GSTOI: Significant decrease in CDD values in the south and west of the continent and Alaska.

Asia
Station data: Decline in dry period duration prevails over Russia and Central Asia. In some instances it is statistically significant. Slight statistically nonsignificant increase dominates over eastern China.
Model data: Practically no consistent trends over the areas covered with station data. A spot with a statistically significant increase in CDD to the south of Aral Sea, instead of observed decrease, was simulated in experiment NAT.

Australia
Station data: No significant trends over the most parts of the continent. A statistically significant decrease in dry season duration at some locations in the southwest of the continent.
Model data: A statistically significant decrease was simulated in the southwest Australia in both experiments. Several spots with significant signal in the central part of the continent were reproduced in experiment NAT.

Conclusions

In some instances, spatial patterns in simulated trends in experiment GSTOI turned out to be closer to observed trends than in experiment NAT as might be hoped (see, for example, HWDI, R10, SDII over North America or FD and CDD over Central Asia). However, more formal tests need to be employed and the set of GSTOI experiments extended to six members. A more rigorous quantitative comparison of the results will be performed soon.

4. UNCERTAINTIES IN CLIMATE DATA SETS - A CHALLENGE FOR WMO

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ABSTRACT

To set the scene, we present some newly published evidence for climate change over the last one hundred to one thousand years. Then we discuss some of the data that we need to study climate change and to detect it. These needs are placed in the context of statements made in climate conventions and international programmes about the requirements for climate data. We

concentrate on the problems of selected data sets important for studying climate change in the context of gaps in data coverage, how representative the data are of regions being studied, and the uncertainties that are believed to exist in the measurements including their biases. Particular stress is placed on the new interest in climate extremes and why they are crucial for planning and sustainability. We emphasise the fact that extremes are currently difficult to study because the data availability problems are severe. We then briefly describe so-called optimal methods of analysing climate data. These allow the effects of data gaps and data errors on uncertainties in the analysis to be integrated and quantified. Finally, we draw some conclusions.

INTRODUCTION

A hundred years ago a wonderfully produced Atlas of Meteorology was published to celebrate the state of meteorology at the close of the 19th century (Bartholemew and Herbertson, 1899). In its Introduction, the great Scottish climatologist Alexander Buchan said 'it is evident that meteorology will confer greater benefits than is now possible when the network of stations is spread over regions where there are none, or so few as to give no adequate representation of the meteorology of those regions'. We wish to demonstrate that, despite much progress, many climate networks still suffer from similar problems in the closing year of the 20th century. The problems are compounded by serious limitations in the digital access to and exchange of those climate data that do get measured. Unlike 1899, there is a new urgency in 1999: the imminent likelihood of substantial climate change, e.g. as described in IPCC (1996).

RECENT WORK ON TEMPERATURE CHANGES

Figure 1 illustrates a recently published reconstruction of Northern Hemisphere temperature changes and its uncertainties using palaeoclimate data (Mann et al, 1999). The palaeoclimatic data were calibrated using instrumental data since the late 19th century which are added at the end of the series. Mann et al (1888) give further details on reconstructing the climate of the last millennium. A remarkable picture is emerging of a slow long term cooling over most of the last 1000 years, though with fluctuations, that ended suddenly in the mid nineteenth century, followed by an unprecedented rate of warming in the 20th century. This warming has occurred mainly in two periods: in the early part of the 20th century and in the past 25 years. It appears that 1998 may have been the warmest year in the Northern Hemisphere since AD 1000 and the 1990s have been the warmest decade. (The latest data for 1999 at the time of writing seems set to confirm both statements). As far as we can tell, the picture for the globe is similar, where the 10 warmest years in the instrumental record since 1860 have occurred since 1983, seven of them in the 1990s.

DATA PROBLEMS IN THE CONTEXT OF CLIMATE CHANGE

Important questions - requiring adequate data - that are being studied by the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) due to report in 2001 include:
Is the climate warming?
Is the intensity of the hydrological cycle changing?
Is the atmospheric or oceanic circulation changing?
Is the climate becoming more variable or extreme particularly with respect to heatwaves, storms, floods and droughts?
Can we detect more confidently anthropogenic influences in the climate records, tentatively identified in the 1995 IPCC report?

Although climate data networks for monitoring climate variability and detecting climate change must work together with those for weather forecasting, we will demonstrate that data availability is far from sufficient for climate networks to support the above needs. An overview of the problems is given in Karl et al (1995).

Figure 2 gives an overall view of changes in data coverage of some key climate networks over the last century. The overall impression is of a steady increase in the spatial coverage of available data, as shown on the left-hand axis, until the last 20 years or so, when most networks sadly show a decline. This is particularly evident for the radiosonde network. The recent decline in data coverage evident in Figure 2 is at variance with articles 4 and 5 of the 1992 UN Framework Convention on Climate Change (UNEP, 1998). The extent to which we succeed in meeting internationally agreed requirements will directly affect the capability of the IPCC to provide advice to governments, particularly for monitoring, detecting and attributing climate change and evaluating models that predict future climate. It also affects the capability of the World Climate Research Programme (WCRP) to increase our understanding of climate change.

Satellite data should be mentioned at this stage. Although many types of satellite data are potentially valuable for climate studies, they usually cannot yet replace most of the traditional ground-based data for climate change assessment. They do have the potential to fill data gaps, often by blending with in situ data, but they must be calibrated against in situ data to obtain homogeneity with the past data. Unfortunately, many satellite data have time-varying biases that are at least as serious as those of ground-based data. So they have proved quite difficult to use in climate change studies, despite major efforts by climatologists.

We now illustrate both some problems, and prospects, for climate change analyses particularly using radiosonde and surface temperature networks. Figure 3 shows the spatial coverage of radiosonde temperature data at 50 hPa and 700 hPa for two chosen decades using the Hadley Centre radiosonde data set (Parker et al, 1997). Serious data gaps can be seen in the Southern Hemisphere and over the oceans. This makes the assessment and detection of climate change in the troposphere and lower stratosphere particularly difficult. The data gaps are just as large in the most recent decade illustrated as they were in the first decade shown. Recently WMO has designated a GCOS Upper Air Network or GUAN. If fully implemented, GUAN will allow adequate measurements of climate change and variability on larger space scales using radiosondes. The ability of the GUAN to represent the atmosphere over say seasonal or yearly averages would be somewhat greater, as the areas which stations represent would be larger. However we do need to retain additional stations if we are going to have a detailed picture of atmospheric temperature and humidity on the regional space scale.

Figure 4 shows monthly radiosonde temperature stations reporting over the Global Telecommunication System in February 1999. It highlights currently designated (mid 1999) GUAN stations which did not report that month, though some stations may not yet exist, while others simply did not report or were not received at the Hadley Centre. Concentrations of missing GUAN stations can be seen in the tropics. If all GUAN stations reported regularly, we would have a good picture of changes in tropical atmospheric climate and a reasonable picture in other areas. So it is very important for nations to concentrate on making the GCOS Upper Air Network operate successfully as radiosondes can provide crucial data for climate change detection, as shown in the 1995 IPCC Assessment.

We now move to land surface air and sea surface temperatures (SSTs). Even for decadal climate averages, where we can allow substantial amounts of missing data, parts of Africa and surrounding ocean areas still have insufficient data to estimate climate change at all. Even with the data available, there is still significant uncertainty in the observations, as these have been made over the past one and a half centuries by a variety of methods.

Using SST data is quite difficult. This is illustrated in Figure 5 (adapted from Folland and Parker, 1995) by a few of the varying methods of collecting sea-water which have been used over the last 100 years in order to take its temperature. Picture (a) shows an insulated bucket used by the United Kingdom in recent decades, a semi-insulated bucket used in Europe and an uninsulated canvas bucket used by the United Kingdom. Picture (b) shows a wooden bucket of the kind often used to collect sea water in the nineteenth century The chief problem in the past was the loss of heat from the sea water due to evaporation from the walls of uninsulated buckets while a measurement was being made. This problem was minimal for the insulated bucket, greatest for the canvas bucket and intermediate for the wooden. This has led to time and geographically varying biases in the original sea temperature data. Modern measurements are also somewhat heterogeneous and their problems yet to be fully resolved. Figure 6a shows typical corrections (mostly positive) applied to early SST data by IPCC (Folland and Parker, 1995), based mainly on physical models of the heat exchanges of buckets with the environment. The spatially varying corrections for December 1940 reach nearly 1°C in a few places east of Northern Hemisphere continents. Corrections vary with season and through time until 1942, after which corrections are currently not applied. These large corrections were the result of a monitoring system that was not, and still is not, properly designed to monitor climate change. The need for further, smaller, corrections to modern SST data has still to be thoroughly investigated but is indicated by results in Folland et al (1993).

Figure 6b shows biases in the 1980s and 1990s in polar orbiting satellite SST data (e.g. Reynolds et al, 1989, Reynolds, 1993). Here we compare globally-averaged ship and buoy data with the satellite data; in this period we consider that in situ data were reasonably homogeneous compared with the satellite data. The latter were severely affected by stratospheric aerosols from the eruptions of Mt El Chichon in the early 1980s and Mt Pinatubo in the early 1990s that biased the SSTs much too cold, and there were other biases too. These satellite measurements, like the surface measurements, have not been designed properly for climate change monitoring or detection. Even now it is proving hard to adequately correct the satellite sea temperature data, despite much effort. Quite serious problems of homogeneity also exist in the available mixture of in situ and satellite sea-ice data that are currently under investigation by one of the authors.

Similar, slightly less serious problems of inhomogeneity permeate the land temperature data (e.g. Parker, 1994). Past biases due to different types of thermometer screen remain insufficiently researched.

Recently, WMO members have agreed which of their surface stations shall be part of the GCOS Surface Network (GSN). The initial design of the GSN was done carefully and is described in Peterson et al (1997). Figure 7 shows the distribution of all surface CLIMAT stations reporting monthly; outlined triangles show GSN stations which were not yet operational or from which a reasonably complete set of messages were not received over the period 1991-1998. There is a strong concentration of these stations in the tropics. When the GSN network was designed, data gaps in the tropics were particularly noted. If all GSN stations regularly reported from the tropics (and some of these stations may now be reporting), we would have a good representation of surface temperature almost everywhere over land on large regional space scales. So it is very important to fully implement the GSN network. In establishing the GSN, WMO Members are being urged to regard the GSN stations as a standard for developing and improving the denser national reference climatological networks that are needed for climate change studies at the regional to national scale. Importantly, GSN stations will also facilitate the implementation of the WMO Climate Information and Prediction Services (CLIPS) project.

THE NEED FOR DAILY DATA TO MONITOR CHANGING EXTREMES

A main reason why an expected climate warming of a few degrees centigrade over land in the 21st century is important involves the extremes. Figure 8 shows why a seemingly small change in the mean is important. We concentrate on daily distributions as these are often the most sensitive ecologically, but the conclusions about return periods are even stronger for monthly mean values. In figure 8, curve B, we have artificially added 2°C to the 1961-90 frequency distribution for daily maximum Central England temperature in August (Parker et al, 1992), keeping the shape of the distribution the same. The implied changes for the return periods of the warmer daily temperatures are listed in table 1. The return periods for warm extremes are reduced to one third giving more frequent extremes by today's standards. In fig 8, curve C, we illustrate the potential implications of a plausible change of in the shape of this frequency distribution, retaining a 2°C mean warming. We note that the 25% of coldest Augusts over the period 1878 to 1998, when daily data is available, have a narrower frequency distribution of daily temperature than the 25% of warmest Augusts (not shown). This arises because cold Augusts have air mostly derived from the Atlantic but warm Augusts, while retaining some of these cool flows, have a greatly increased frequency of flow from the warm continent. In a future warmer climate, a broadly similar mean change to a wider daily distribution in summer is plausible: air derived from Europe is expected to warm appreciably faster in the next century than air derived from the Atlantic even if the frequency of airflow directions changes little. Figure 8, curve C, shows the effect of adding 2°C to the 1961-90 average but increasing the standard deviation of the daily maximum August temperature. As seen in table 1, this leads to a further dramatic reduction in return period estimates for very warm days.

Table 1 Return periods (years) of daily maximum August temperatures in Central England, 1961-90 and 2°C warmer climates. For explanation see text.

Daily max. August temperature (°C)	A) Normal August (1961-90)	B) 2 degrees added to A	C) As B, but variability increased
26 °C exceeded	0.8	0.3	0.2
28°C exceeded	2.1	0.8	0.3
30°C exceeded	6.0	2.1	0.6
32 °C exceeded	17.6	6.0	1.3
34 °C exceeded	54.1	17.6	2.7
36 °C exceeded	171.5	54.1	5.8

Karl and Knight, (1998) have recently shown for the United States that the fraction of total precipitation contributed by the uppermost ten percentile of daily precipitation events, i.e. heavy rainfall, shows a statistically significant increase over this century. This has accompanied a mean increase in rainfall. This implies that the shape of the rainfall distribution has changed in a way we expect more widely in a future warmer climate. This would have major consequences in hydrological design. Is this happening globally?

Horton et al, (submitted) shows that for daily Central England temperature over the year as a whole, extreme cold days have decreased in frequency very substantially over the past century as the climate has warmed, whereas the extreme warm days have increased in frequency by markedly less. Jones et al (1999) show that the total number of daily extremes tends to reduce. This again implies a change in the shape of the frequency distribution. There is tantalising evidence that this kind of behaviour -cold extremes decreasing faster than warm extremes have increased, at least up to now- may have occurred elsewhere, and even over the oceans (Horton et al, submitted). If so, it would have substantial consequences for our understanding of the character and impact of climate change. But we need daily historical data to find out, and to put individual countries' experience into the global context.

Many other questions can be asked about changing extremes that IPCC would like to investigate. Some examples:

What changes are occurring in the length and severity of droughts?
What changes are occurring in frost frequency, or in growing season length?
Is the frequency or intensity of extreme winds or pressure gradients changing?
Are extreme apparent temperatures, a function of both humidity and temperature, becoming more frequent?

This could cause increased severity or frequency of heatwaves and become critical to human sustainability in tropical cities. Preliminary analysis (not published) of limited datasets have shown, that the 90th percentile of the daily minimum temperatures has gone up, sometimes dramatically, at most stations analysed, indicating that the warmest night time temperatures are increasing, especially in the tropics and subtropics. Much more and much better daily data is needed to verify these interesting new results before answering one of the big remaining questions: Is the combination of changing extremes consistent with expectations from models that predict global warming? Given historical and operational worldwide daily data to answer these questions, a consistently analysed and internationally agreed set of Environmental Extremes Indicators could be distributed regularly to all nations by WMO.

In 1998, a Task Group of the Commission for Climatology/CLIVAR Working Group on Climate Change Detection strongly recommended to the Commission for Basic Systems that a baseline data set of daily data and associated metadata from the GSN stations should be made available for the Third IPCC Assessment. In response, CBS has made a statement encouraging members to provide historical daily data at GSN and GUAN sites for the analyses of climate indicators for the IPCC Third Assessment. Urgent action regarding the availability and exchange of data is needed if IPCC is to report effectively on changing climate extremes in 2001 as has been demanded.

RECONSTRUCTING CLIMATE FIELDS FROM DATA WITH GAPS

Reanalysis using fixed atmospheric models is one of the major achievements of the 1990s (WMO, 1998b). It will greatly help research in interannual climate variability and make a substantial contribution to understanding climate mechanisms. However, Reanalyses have recently been shown to be unreliable for estimating trends. Some of the reasons relate to model biases, but also significant are inhomogeneities in the input data, particularly from radiosondes and satellites. So apart from model improvements, it is essential for future accurate Reanalyses of climate trends that the input data be homogeneous over the last few decades, and into the future.

Finally, we discuss how we can best analyse spatial patterns of climate data with temporal and spatial data gaps. Figure 9a shows the distribution of SST data in January 1878. Figure 9b shows a full reconstruction of SST for that month, showing a classical warm pattern of the great El Nino of January 1878 in the central and eastern equatorial Pacific that is hardly evident in the original data. We used a mathematical method called "eigenvector projection" (Rayner et al, 1996), which has also been used in another form by Smith et al (1996). Eigenvectors are merely orthogonal spatial patterns. Here we use linear combinations of pre-defined spatial patterns of SST anomalies, including one describing global warming. A recent version of the Hadley Centre atmospheric climate model forced with these reconstructed patterns of SST, including the corrections for sea temperature biases described before, has reproduced the Southern Oscillation index observed at that time very well. The extreme warmth of global land surface air temperatures due to the 1877-78 El Nino was well simulated too. This El Nino reconstruction is used in a recent paper analysing the character of El Nino variations since the late nineteenth century (Kestin et al, 1998).

Linear combinations of similar spatial patterns are the basis of new techniques of analysing historical climate data that more optimally allow for the effects of data gaps and data errors. One technique is called reduced space optimal interpolation (Kaplan et al, 1997, 1998) and the other, even newer and still being perfected (Shen et al, 1998), is called reduced space optimal averaging. They are versions of optimal interpolation and averaging that use the orthogonal spatial patterns in place of the more usual correlation functions. This turns out to be much more satisfactory with very large time-varying data gaps. One of these patterns looks quite like the El Nino pattern we have just shown. Figure 10 shows the result of applying optimum averaging to the IPCC global temperature data up to 1998. An estimate of uncertainties in the average due to random errors and data gaps is created, together with additional uncertainties due to the corrections for sea temperature biases. Other biases need including and some refinements of the details of the method are expected. Nevertheless, this shows the potential of optimum averaging for quantifying uncertainties in many climate time series. However, it must be emphasised that optimum interpolation methods are much better at reconstructing large spatial scales (like the simpler eigenvector projection method). There is no reliable substitute on small space scales for measured data, so these estimation methods do have serious limitations on most national scales.

CONCLUSIONS

Our first conclusion is that the current data network was not designed adequately, or at all, to measure, detect or attribute climate change. Tremendous efforts are still needed to adjust data for time-varying biases, and reanalyses are very sensitive to data biases. Large time-varying data gaps in the historical record cause many uncertainties that we can now start to quantify, but they may still prevent us from monitoring some regional climate changes at all. Unfortunately the decline in observational networks is having a detrimental impact on key climate data sets. Optimum analysis methods can improve our estimates of climate change and help quantify uncertainties, but they are no substitute for homogeneous data of adequate density and high quality. So we need both to improve existing networks and to preserve, digitise, and quality control the large amount of data and metadata that we know already exist in paper archives.

Very importantly, daily data are particularly difficult to access and need especially rigorous quality control. These data are urgently needed to monitor changes in climate extremes for the reasons explained above. So we require access to digitised, historical data and metadata, and a Global Climate Observing System that is purpose-built and maintained, with its quality continuously monitored, to help guide governments to make appropriate policy responses to the challenge of global warming.

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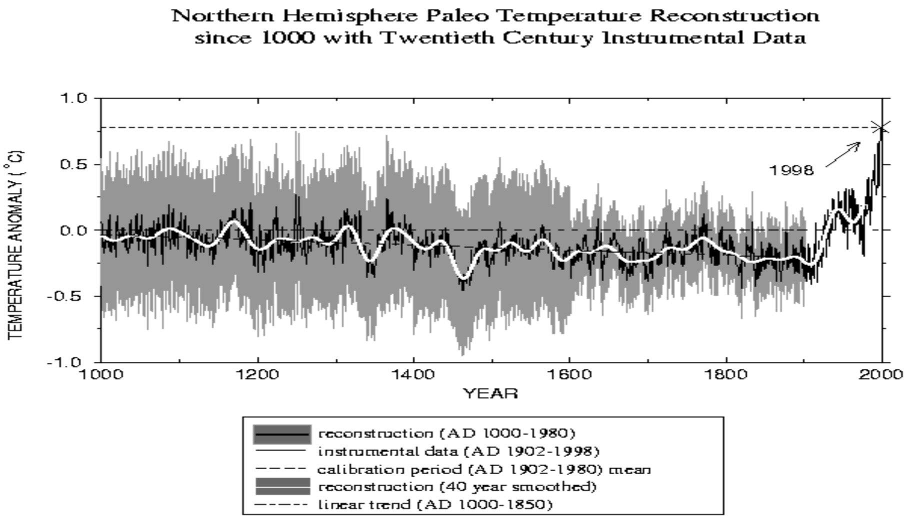


From M. Mann et al. (Geophysical Research Letters, March 1999, and Nature, May 1998)

Figure 1 Reconstruction of Northern Hemisphere temperature by Mann and coworkers. Shaded region represents the twice standard error limits in annual reconstructed values before the instrumental era (ending in 1901) using several types of proxy data.

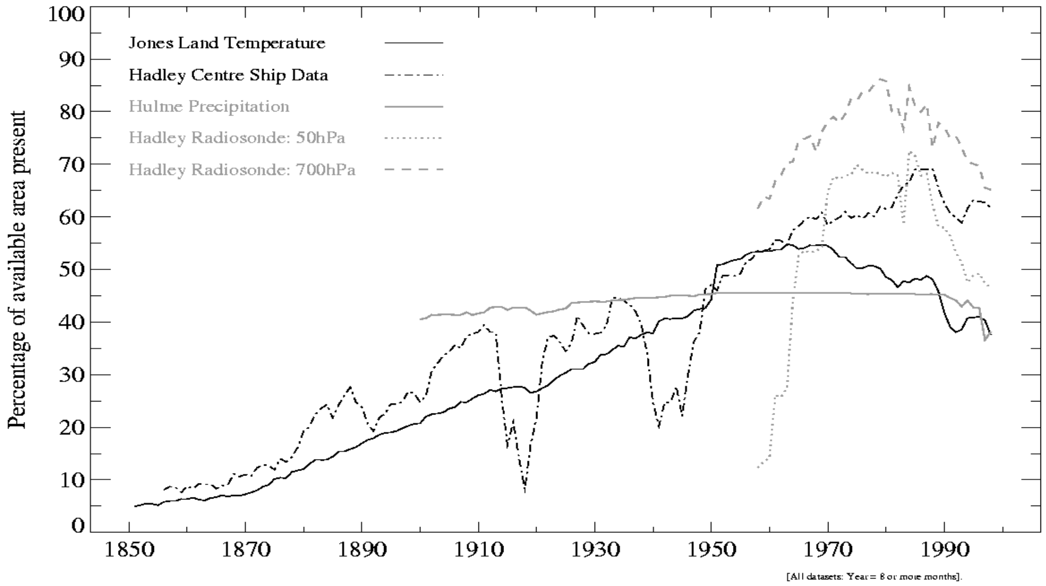


Figure 2 Changes in spatial coverage for selected data types important in climate change studies. The available area is e.g. global land for rainfall, global ocean for ship sea surface temperature data or global atmosphere for radiosonde data.

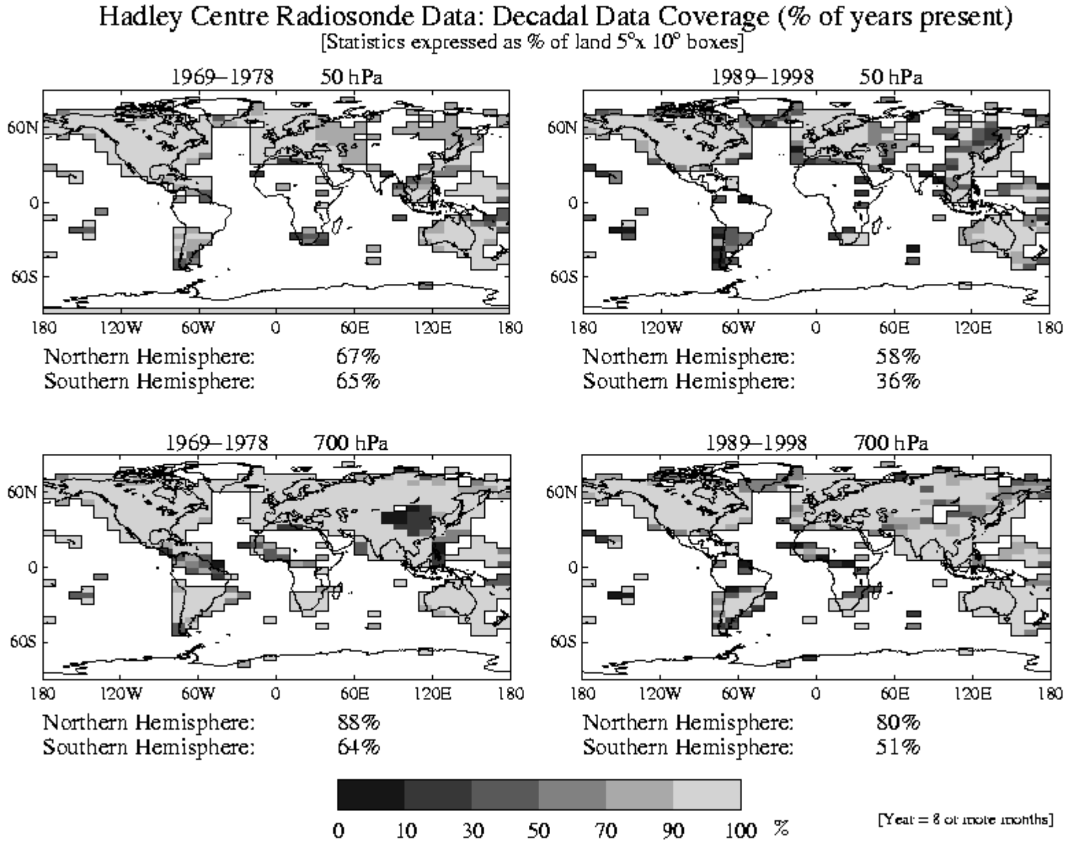


Figure 3 Percentage spatial coverage of radiosonde temperature data in the decades 1969-1978 and 1989-1998 for annual average values. For a year to be present, eight or more months had to be available. The maps show the percentage of years available in each decade.

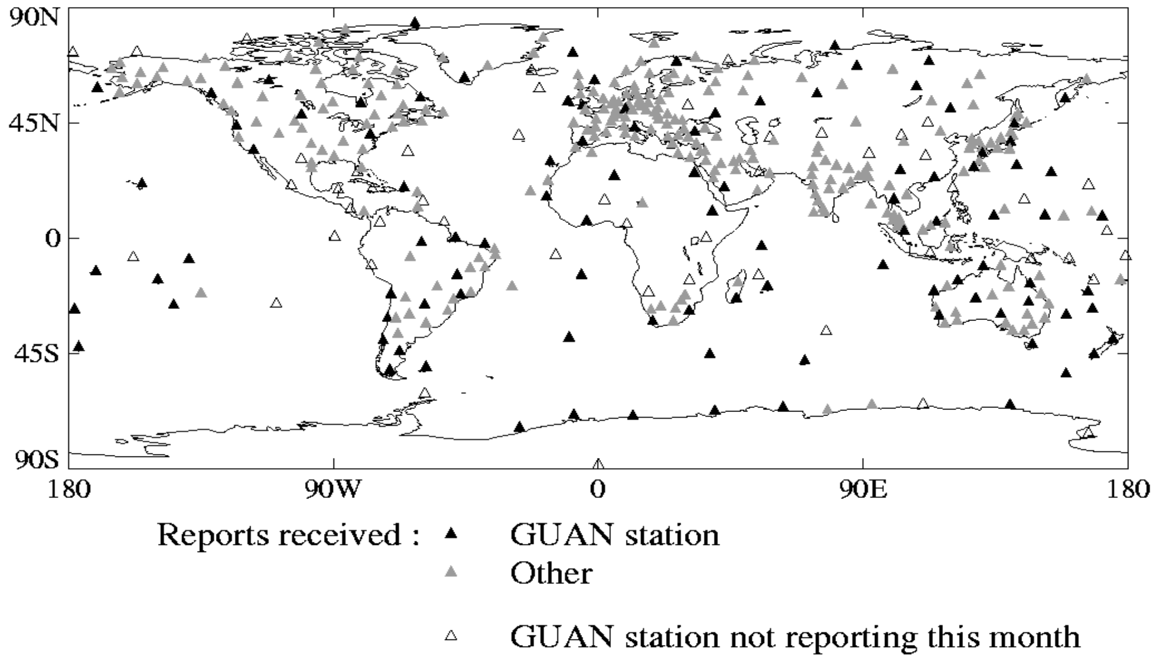


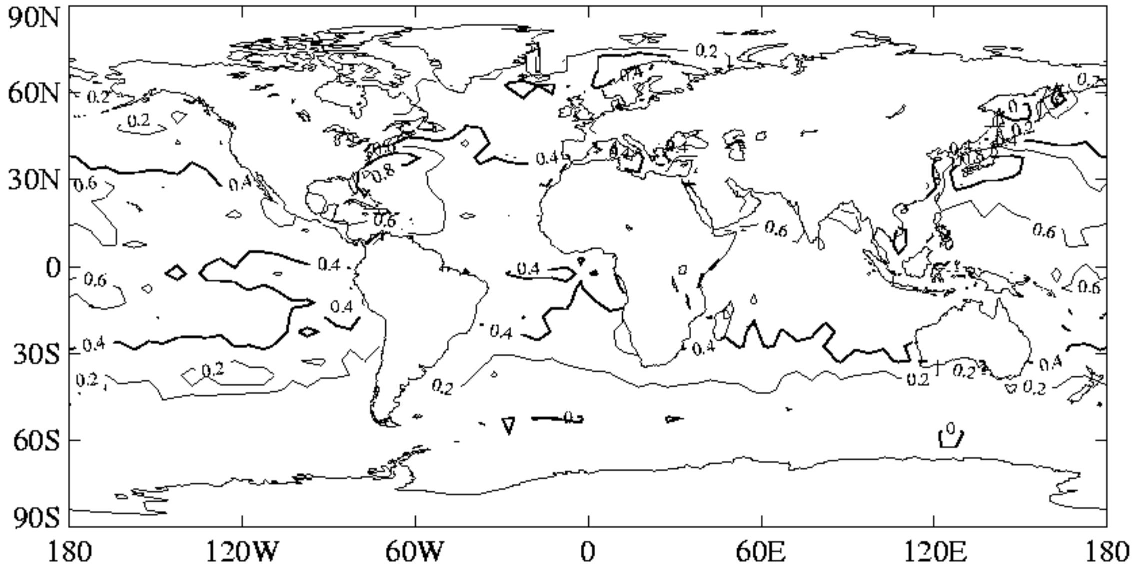
Figure 4 Radiosonde temperature stations reporting over the global telecommunication system via CLIMAT TEMP messages in February 1999 compared to the designated distribution of GCOS GUAN stations.

Figure 5 Four types of buckets used to collect sea water whose temperature was measured on the decks of ships. (a) (left) the UK Met Office REF 1800 black insulated bucket; (centre) German

metal and leather bucket (right) the UK Met Office MKIII canvas sea temperature bucket. (b) ship’s wooden bucket, 1891 (courtesy of Scottish Maritime Museum).

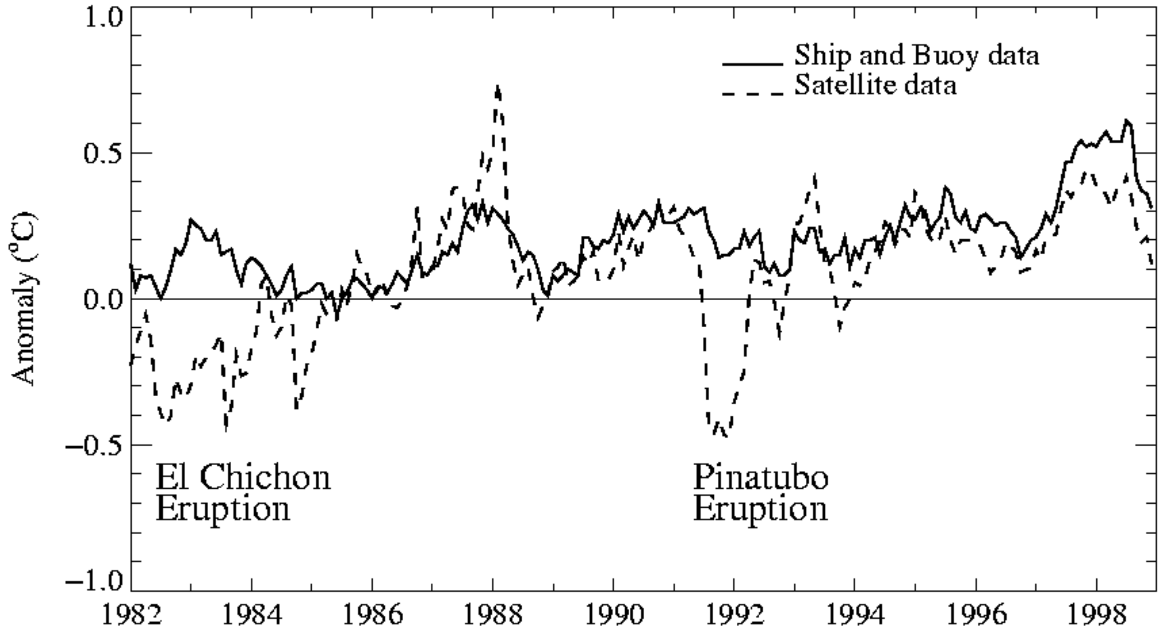
Sea Surface Temperature Corrections, December 1940

[Isopleths every 0.2°C. Alternate isopleths heavier]



From Folland and Parker, Quart. J. Roy. Met. Soc., 1995

Problems with Polar Orbiter Satellite Sea Surface Temperature Data – Volcanic Eruptions and other Causes



world for December 1940 (b) Globally-averaged satellite sea surface temperature data compared to in situ data over the period 1982-99. The differences are largely time-varying biases in the satellite data.

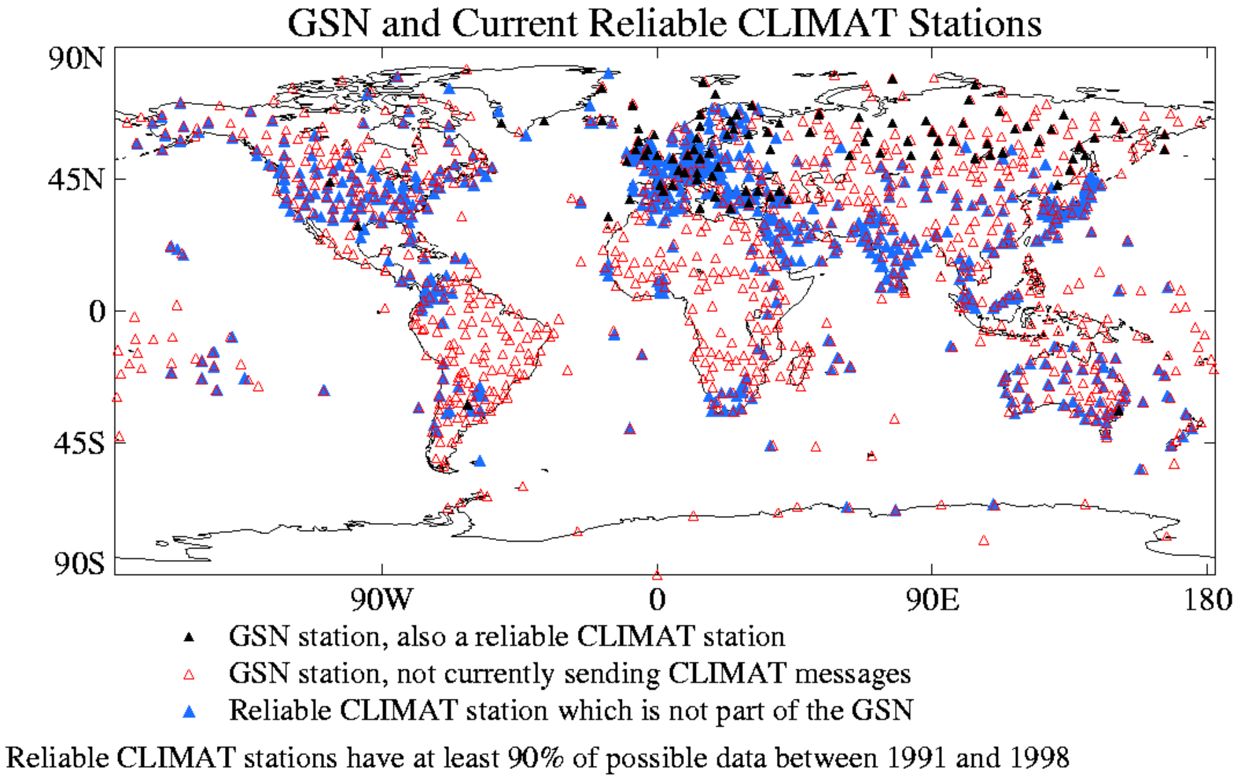
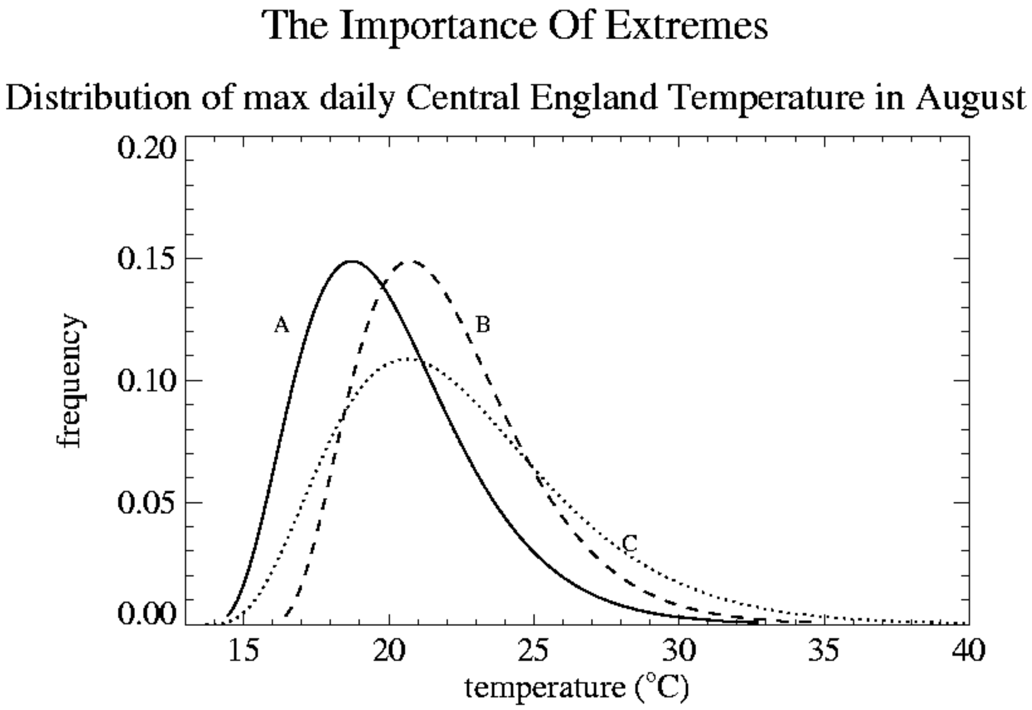


Figure 7 Receipt of data from CLIMAT and the new GSN stations.

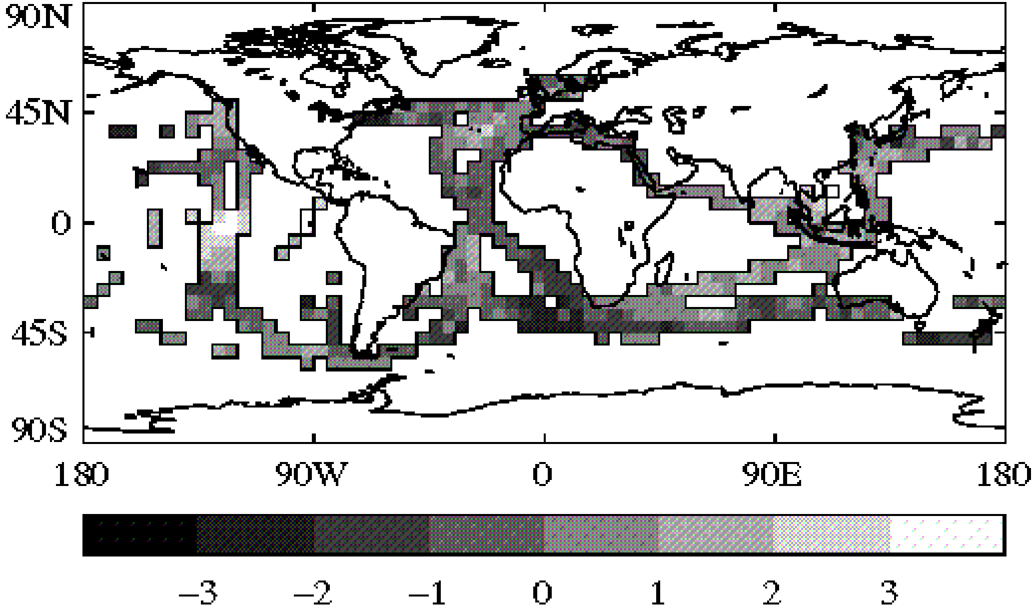


The Importance Of Extremes

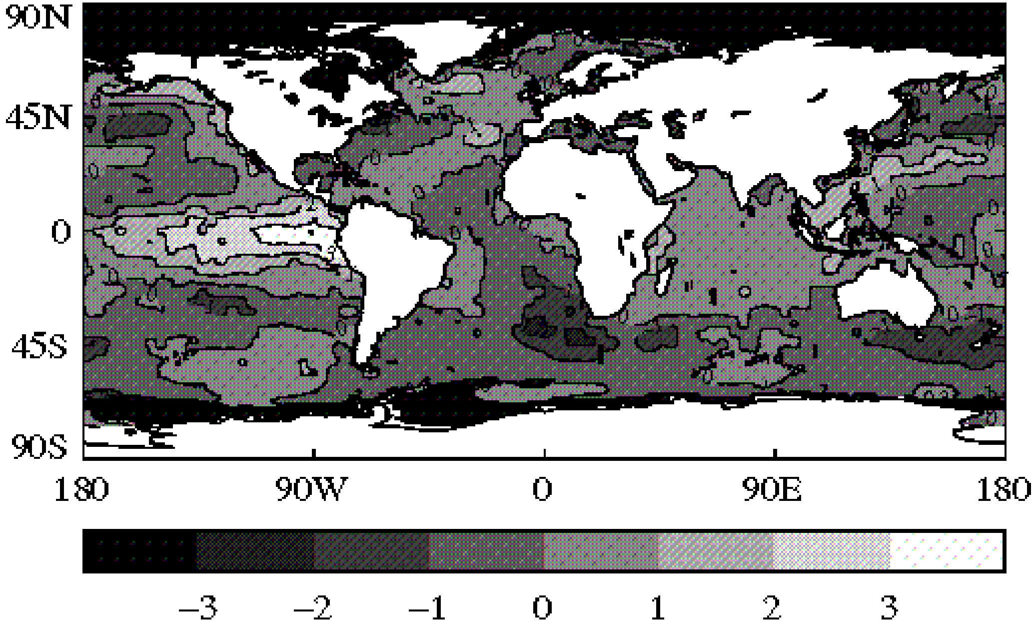
Distribution of max daily Central England Temperature in August

Figure 8 A) Frequency distribution of daily maximum temperature for August from Central England, 1961-90. B) Influence of an increase of 2°C in the mean daily maximum August temperature, relative to the climate of 1961-90. C) Influence of a plausible change in the shape of the distribution of daily maximum Central England temperatures in a warmer August climate. For explanation see text.

Filling Data Gaps



January 1878 Sea Surface Temperature
(°C, deviation from 1961–90)



Reconstructed using orthogonal variability patterns

Figure 9 (a) Available spatial distribution of sea surface temperature data in January 1878 during one of the greatest El Nino events of the nineteenth century. (b) Reconstruction of global sea surface temperature using orthogonal patterns of variability via the method of eigenvector projection. Black areas in the Arctic and near Antarctica are estimates of sea-ice extent.

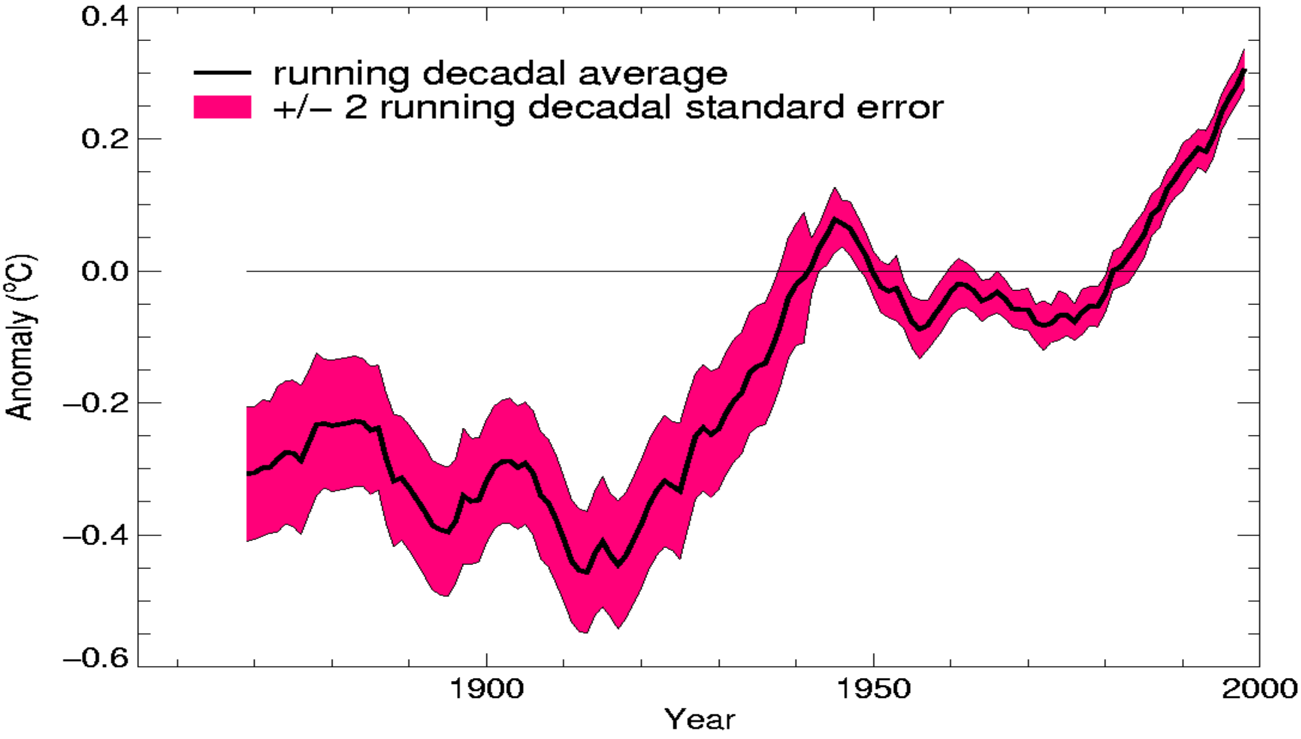


Figure 10 Running 10-year averages, and two standard errors, of global mean surface temperature (expressed as differences from a 1961-90 average) for the period 1860-1998. These result from reduced space optimum averaging of land surface air temperature and sea surface temperature data.

5. Monitoring the GCOS Upper Air Network (GUAN), and studies of upper tropospheric water vapour.

Mark McCarthy, Hadley Centre, Met Office, March 2001.

The aim of the GUAN is to provide a network of upper air radiosonde stations that meet specific record length and homogeneity requirements as set out by the GCOS programme. This is an attempt to address the problem of a decaying global network with poor spatial distribution. 150 stations have been selected as shown in the accompanying diagram.

The Met Office Hadley Centre and National Climate Data Centre (NCDC) in the USA are joint GUAN data analysis centres. As part of our contribution, the Hadley Centre has undertaken a number of initiatives.

- GUAN web site: http://www.metoffice.gov.uk/research/hadleycentre/guan/index.html has been created to act as a central focus for communicating information to or from the GUAN initiative. The site provides direct and easy access around Met Office, NCDC, GCOS, ECMWF web sites. The site has proved to be a useful pool of information for contributors and potential users.
- Near-real time monitoring: Figure 1 samples the monthly monitoring of CLIMAT TEMP messages received over the Global Telecommunications System (GTS) at the Hadley Centre each month. Currently, approximately 70% of potential GUAN data is received. Improvement of this rate of data receipt has been identified as high priority and the GCOS programme are putting in place measures to try and resolve problems at National Met. Service (NMS) level.
- Improvements to historical time series: Initial work has been conducted on radiosonde temperature records. We wish to address problems related to completeness and inhomogeneity of individual records. Data have been obtained from the CLIMAT TEMP archive held at the Hadley Centre, MONADS monthly statistics based on the Comprehensive Aerological Reference DataSet (CARDS) held at NCDC, and other data obtained directly from NMSs. A median selection process has been adopted to select the appropriate source for homogeneous segments of the time series identified with reference to changes in reporting hour. Considerable improvements in temporal data coverage have been achieved. A GUAN database has been established and partially populated.
- Future Hadley Centre plans: Provision of components of the GUAN database through the external web site. Improved humidity series, including an upper tropospheric water vapour study. This will include new and aternative observing platforms like satellites, development of climatologies and where possible, analysis of trends and their radiative consequences for the climate system. This is being done collaboratively with Dr Ralf Tuomi at Imperial College, London.

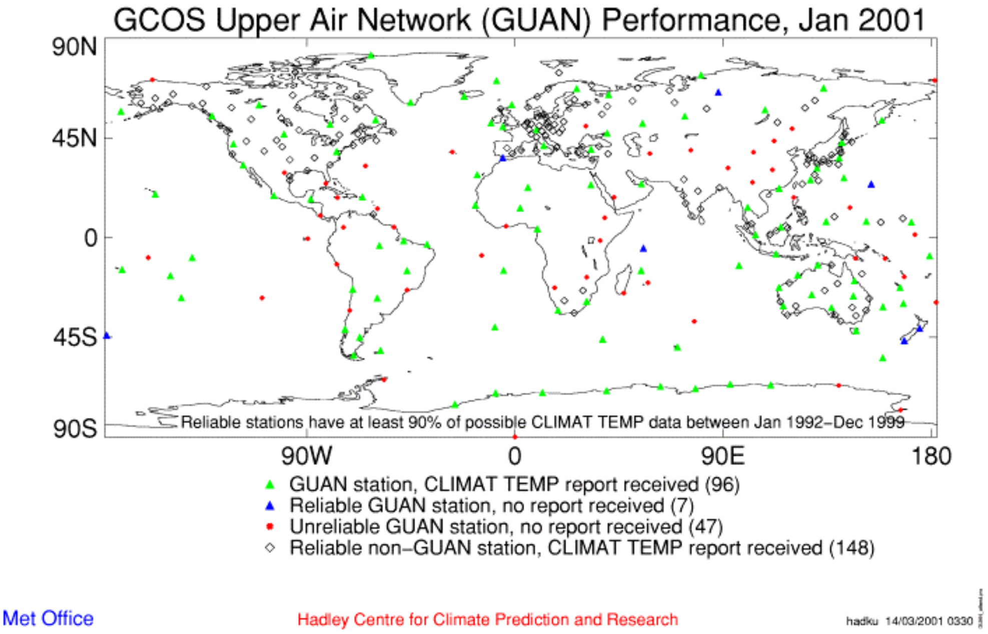


Figure 1. Performance of the GUAN network at January 2001

Appendix 6: Report from George Gruza, Institute for Global Climate and Ecology, Russia, WMO CCl Rapporteur on Climate Change Detection Methodologies and Indices

I have prepared and published several papers on related topics which are described at the end of this report. Immediately below is a summary of the most relevant talk I gave entitled "Climate Change Detection data, methodologies and indices: recent developments and plans in WMO Region II (Asia)" which I gave at the Joint CCl/CLIVAR Task Group on Climate Indices, Hadley Centre, Meteorological Office, Bracknell, UK, Sept 2nd –4th 1998 (see Appendix 1).

To what extent are climate variability and changes similar or dissimilar in different regions of the Globe?

How many and what indicators of climate variability and changes should be developed for each region?

What is a climate signal? Is it possible to estimate a climate signal in the past from observed data as the response to a change in concentration of carbon dioxide and aerosols?

What statistical properties and characteristics of observed and modeled climate are necessary for diagnosis and comparison?

How should observed and modeled climate signals be compared?

The statistical characteristics of climate and of climate change appear to be dissimilar in different regions.

Statistics summarizing climatic variations over geographical regions are found to be useful for the more detailed specification of the state and change of regional climates. It is expedient, in particular, to include the Climate Anomaly Index (CAI) and Climate Change Index (CCI) in the set of indicators of the climate variability and changes.

The Climate Anomaly Index (CAI, Equation 1) is defined as the Euclidean distance between the point describing the current climate state and the point representing the time-mean state (the normal). The larger the CAI, the further removed is the point representing the instantaneous climate state from the centroid of the points.

$$CAI_y = \sqrt{\left[\frac{1}{n} \sum_{i=1}^{n} \left(\frac{z_{yi} - \overline{z_i}}{\sigma_i} \right)^2 \right]}$$

where z_{yi} is the value at grid-point i in year y, the overbar represents the mean, and σ represents standard deviation.

The Climate Change Index (CCI, Equation 2) is defined as the Euclidean distance between two points describing two climate states. The concepts of CAI and CCI are also presented in Table 1, bottom row.

$$CCI = \sqrt{\left[\frac{1}{n} \sum_{i=1}^{n} \left(\frac{\bar{z}_{y_1 i} - \bar{z}_{y_2 i}}{\sigma_i} \right)^2 \right]}$$

Magnitudes of CCI were generally larger than those of CAI in several recent decades; this enables us to conclude that differences between individual decadal mean surface air temperatures became generally larger than differences between each of these decadal means and the climatic normals. Indices of Climate Anomaly and Climate Change are only weakly correlated. CCI definitely increased in recent decades. We should investigate whether this is connected only with the recent warming, or with other causes also.

Variations of the spatial non-uniformity of the mean 10-year temperature anomalies were small in the 20th century.

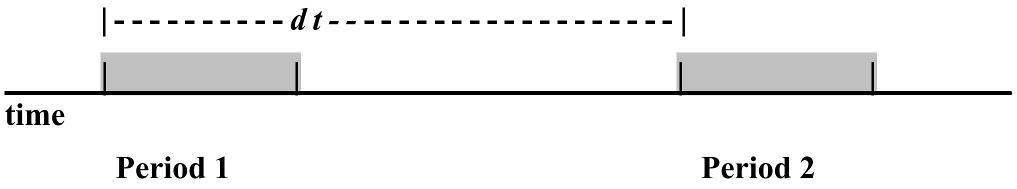
An analysis of climatic change within the latitude belt 50 ° – 55° N in Eurasia demonstrated a geometric similarity between spatial distributions of mean interdecadal changes in 10-year air temperatures for numerous pairs of decades with the same differences of CO2 and CO2 + aerosol concentrations.
The level of this "climate signal" is approximately proportional to the forcing gas concentration change. Nevertheless the scatter of temperature changes is quite large, which hinders signal detection using standard statistical methods.

Comparison between observed and modeled (HadCM2SUL) climate variability and interdecadal changes of surface air temperature within the latitude belt 50 ° – 55° N in Eurasia showed some similarities but also major differences. In the spectrum of modeled time series of annual air temperature the amplitudes of oscillations with periods less than

7 years are underestimated and, apparently, an artificial periodicity at about 30 years is detected.

Table 1 **Climate State & Climate Change Indices**

Spatial statistics (*averaging over space area*)	Time Statistics (*averaging over time area*)		
	CLIMATE STATE		**Climate Change**
	Period-1: **E1**	***Period-2:*** ***E2***	***dE=E1-E2***
E=Mean	**E(*E1*)=EE1**	**E(*E2*)=EE2**	**E(*dE*)=EdE**
S = S T D	**S(*E1*)=SE1**	**S(*E2*)=SE2**	**S(*dE*)=SdE**
Q = R M S	**Q(*E1*)=**$\mathbf{CAI}_1$	**Q(*E2*)=**$\mathbf{CAI}_2$	**Q(*dE*)=CCI**



Advantages of a climatic signal estimated from observed data in comparison with modeled:

- stronger signal,
- greater agreement between signals appropriate to various levels of concentration of carbon dioxide and aerosol,
- smaller scatter between different estimates of signals.

In addition to this talk, I prepared and published several papers on related topics, including:

Rankova, E., and G. Gruza, 1998: Indicators of climate change for the Russian Federation. - Meteorology and Hydrology, No.1, pp. 5-18 (in Russian).

> *Observed climate changes over the Russian Federation (RF) territory are considered. Changes in surface air temperature are investigated, together with changes in precipitation and drought indices, and also the percentage of the Russian territory experiencing climatic anomalies below and/or above certain specified percentiles. Several indicators based on monthly mean temperature and precipitation station data are proposed to be used to quantify regional climate change.*

Gruza G. V., 1998: Indices and indicators of climate variability and changes in extreme events. –Theses of 7th International Meeting on Statistical Climatology. Whistler, BC, Canada. P. 49.

> *The statistical climate structure and variability are investigated using the best available instrumental data and statistical tools. A method is proposed for the estimation of climate change magnitudes, based on an index, used as a probability criterion for the detection of significant climate change. Special indices and indicators appropriate for the assessment of climate variability and change in extreme events, their intensity and frequency are suggested. The improved data on current trends in climate and weather extremes for the Northern Hemisphere and Russia are shown. It is shown that in 20th century average over the RF territory and, in particular, over its western permafrost free part, temperature increased, while precipitation decreased, drought index increased, and extremes weakly increased.*

Gruza, G., and E. Rankova, 1999: Climatic response to changes in greenhouse gases concentration as based on the surface air temperature observations over the Russia territory. – Izvestija RAN. Fisika Atmosfery i Okeana, 1999, v.35 (in Russian) (in press).

> *Assessments and spatial patterns of the climate response to the changes in atmospheric concentration of greenhouse gases are presented. An analysis of climate responses is made by using decadal mean surface air temperature over the Russia territory as a whole and within Russian latititudinal belt 50-55N. The comparison between observed and modelled climate responses was made by using station observations and Jones' grid box data and the Hadley Centre's couple atmosphere-ocean model HadCM2 output.*

Gruza, G.V., E.Ya. Rankova, V. Razuvaev and O. Bulygina, 1999: Indicators of climate change for the Russian Federation. Climatic change. Kluwer Academic Publishers, Dordrecht, Boston, London (in press).

> *Several indicators based on monthly and daily temperature and precipitation station data are used to quantify regional climate changes. Some of these are the components of two aggregated indices of climate change, suggested by Karl et al. (1996): the Climate Extremes Index (CEI) and the Greenhouse Climate Response Index (GCRI). For the RF territory as a whole, and for its western part, the "Russian Permafrost Free (RPF) territory" in particular, changes in surface air temperature are investigated, together with changes in precipitation*

and drought indices, and also the fraction of the Russian territory experiencing climatic anomalies below and/or above certain specified percentiles. Composite indices CEI-3 and GCRI-3 based on three parameters (air temperature, precipitation and drought indices) are examined, as well as the Climate Anomaly Index (CAI), known in Russia as Bagrov's coefficient of "anomality".

Appendix 7: Report from W. D. Hogg, Environment Canada (retired), Canada, WMO CCl Rapporteur on Climate Change Detection Methodologies and Indices

The rapporteur began his work by proposing, at the 1997 Asheville Workshop on Indices and Indicators for Climate Extremes, a series of indices suitable for tracking climate variables and extremes in northern climates. These were later repeated in Easterling et al. (1999). As detailed there, the ideal extremes index will have a number of desirable characteristics. It will improve the signal to noise ratio for trend. It will be associated with significant economic or social impacts of climate. It will be sensitive to changes associated with greenhouse gas warming. It must be easily mapped. It should be logically definable and meaningful everywhere.

There are at least two ways to characterize the degree of exposure to extreme events: either the frequency that a threshold is exceeded in a fixed time period, or the magnitude of a low probability occurrence as calculated using data from a fixed time period. These statistics can be calculated from the original hourly or daily data or by applying extreme value sampling theory and using only the extremes themselves for some limited time, moving window. The indices considered particularly appropriate for monitoring northern climates were described, with examples, in Easterling et al. (1999). In the same paper, two generalized extremes indices for land areas in high latitudes were proposed and defined: a general index, sensitive to all-season and annual impacts and a cold season index emphasizing winter impacts.

To test their utility, time series of several of these indices were generated for locations in Canada but the generalized indices have not yet been comprehensively evaluated. Results of analyses of these time series were summarized and provided for inclusion in Chapter 2 of the IPCC Third Assessment Report. Since 1900 in Canada, there has been a decrease in the occurrence of extreme low temperatures during winter, spring and summer and a decrease in the occurrence of extreme high temperatures during winter and spring. Decadal variability is the dominant feature in both the frequency and intensity of extreme precipitation events in Canada over the century. Heavy snowfall events in northern Canada and spring heavy rainfall events throughout the country have shown an increase but the observed increase in precipitation totals in the 20th century was mainly due to increases in the number of small to moderate events. These results and the indices used have been reported on in detail in Zhang et al. (2000), Bonsal et al. (2001) and Zhang et al. (2001).

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Appendix 8: Report from Abdallah Mokssit, Direction de la Météorologie Nationale, Morocco, WMO CCl Rapporteur on Climate Change Detection Methodologies and Indices

In my activity related to Climate Change the main actions are listed below:

- participation as a focal point of regional (Maghreb:Morocco,Algeria,Tunisia) in the preparation of a paper about Climate Change and Water resource management in the Maghreb) which includes papers referenced here after;
- participation in an Impact study entitled : Climate Change and Water resource in OUERGHA dam (reservoir);
- initiation and supervision of climate change in a precipitation study in Morocco based on a number of CCDAS indices;
- introducing as a member of the Scientific Committee of ACMAD (African Centre of Meteorological Application Development) the necessity to promote participation of African countries in Climate Change studies in Africa:
- introduction of CCDAS in ACMAD strategic plan,
- a regionalization of Africa with the corresponding indices (at a monthly scale) was established;
- initiation and supervision of Statistical Software to calculate 20 indices : this software, based on Systat, was performed and tested on daily Moroccan Data
- initiation of the idea of Regional (Capacity Building) Workshops on CCDAS and participation in the coordination and the organization of the Casablanca Workshop:

In the framework of the Regional Rapporteur on Climate Change Detection and Attribution Studies (CCDAS), African countries were asked to report on their CCDAS activities. However, difficulties were met for a number of reasons:

- absence of such CCDAS;
- lack of the necessary daily data to perform such kind of CCDAS;
- difficulties in exchanging raw data between countries.

In this situation it was necessary to establish an alternative for countries to produce climate indices by themselves and exchange these indices "rather than raw data" through a capacity building process; So the role of Rapporteur became capacity building implementation.

This idea was introduced and endorsed at the CCl/CLIVAR working group on climate change detection meeting, during November 1999 in Geneva. Hence the working group recommended the organization of a number of workshops on regional climate indices. This workshop was intended to help African countries make good progress in this area. Many climate indices were developed using the longest available and reliable station data. These indices will be shared with the international research community interested in studying the African climate such as the IPCC.

This capacity building process involved 28 participants from 23 African countries (including Morocco) along with 2 representatives from Spain and was conducted by a resource team composed by Lisa Alexander (Hadley Centre, UK), David R. Easterling

(NCDC/NOAA, USA), Abdalah Mokssit & Rachid Sebbari (National Met. Research Centre/ DMN, Morocco) and managed by Valery Detemermann from WMO which sponsored the workshop.

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Appendix 9: Report from Thomas C. Peterson, National Climatic Data Center, U.S., WMO CCl Rapporteur on Statistical Methods with emphasis on analyses of extreme events and Chair of the Working Group on Climate Change Detection

The body of the report of the Working Group on Climate Change Detection describes much of my activities as chair and rapporteur. This report is intended to briefly describe activities that were not discussed previously. The terms of reference discuss studying the most appropriate methods for solving statistical problems in the use of climate data including investigating and reporting on statistical aspects of problems of spatial interpolation, network design, time series analysis, extreme events and quality control. Three types of activities are relevant to report: database building efforts, analysis of climate data including development of new analysis techniques, and participation in various meetings.

The basic database building work requires developing statistical tests to solve many of the problems described above. For example, quality control must address extreme values and utilize spatial interpolation and homogeneity adjustments focus on assessments of time series. Database building work started out with a focus on global long-term monthly in situ data, specifically the Global Historical Climatology Network (GHCN). This included developing a suite of quality control tests (Peterson et al., 1998c). Also, our 21-author homogeneity review paper provided a single forum to discuss many different methodologies used to address the homogeneity of climate data (Peterson et al., 1998b). Later database work expanded into blending GHCN with satellite-derived surface temperature (Williams et al., 2000, Peterson et al., 2000, and Basist et al., 2001). We also started building an international (not truly global yet) daily in situ data set described in Frich et al. (2001). Additional related activity included evaluation of homogeneity adjustments in radiosonde data (Free et al., 2001).

The development of a new climate analysis methodology that maximizes the available in situ data is described in Peterson et al. (1998a). This work investigated the statistical aspects of the problems of spatial interpolation of data to make optimal use of the existing networks as well as statistical aspects of the problem of time series analysis, which are two of the terms of reference for the rapporteurs on statistical methods in climatology. We also developed an operational global temperature index as a way to merge land and ocean surface temperature time series (Quayle et al., 1999). Analyses of climate change includes understanding the significance of changes in pan evaporation (Golubev et al., 2001 and Lawrimore et al., 2000), an assessment the impact of urbanization on global temperature time series that indicated that observed changes in global surface temperature don't significantly change when all urban stations are removed from the analysis (Peterson et al., 1999), and an analysis of the impacts of different homogeneity assessments on climate change analysis in the U.S. and globally (Hansen et al., 2001). The most relevant analysis to the extremes part of the terms of reference was one examining changes in climatic extremes during the second half of the 20th century (Frich et al., 2001). In addition to the contribution some of this work made to IPCC, I was also involved in editing part of Chapter 2 of the IPCC TAR.

I participated in a number of meetings relevant to my responsibilities as rapporteur and chair of the working group. These included the meeting of the special Task Group on Climate Indices, Hadley Centre, Bracknell, September, 1998; CLIVAR Scientific Steering Group meetings, May 2000 and probably 2001; Atmospheric Observation Panel for Climate meetings, April 1999, 2000, and probably 2001; the WMO Commission for Climatology Advisory Working Group, Reading England, April 2000; a meeting of the "Detection Group," Livermore, February 2000; the NASA GISS Conference on Climate Change of the Past Fifty Years, New York, November, 1999; and the first Asia-Pacific Network Workshop on Indicators and Indices for Monitoring Trends in Climate Extremes, Melbourne, December, 1998. Also Chris Folland and I wrote a short report for the *CLIVAR Exchanges* entitled: Climate Change Detection: What can a small Working Group do about It? (Peterson and Folland, 2000).

At the September 1998 Bracknell meeting (Appendix 1), I gave two talks. One was a background talk on *Methods for Analyzing Extremes* and the second was on *Techniques for Creating Indices*. Between the two, they gave a background and a starting point for much of our future work with climate change indices. These talks discussed issues, such as the pros and cons of parametric versus non-parmetric analyses techniques for extremes, that are central to the terms of reference as rapporteur for statistical methods in climatology with an emphasis on analyses of extreme events and are available in extended abstract form in the meeting report (WMO, 1999).

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Appendix 10: Report from Neil Plummer, Bureau of Meteorology, Australia, WMO CCl Rapporteur on Climate Change Detection Methodologies and Indices

Summary

As Rapporteur in the WMO CCl Climate Change Detection Methodologies and Indices task group during the past three and a half years, I have contributed to the goals of the group through:

I. Contributing analysis of changes in climate indices over Australia;
II. Collaborating in studies of climate extremes over the Asia – Pacific region;
III. Contributing studies towards the IPCC Third Scientific Assessment of Climate Change and also playing the role of Expert Reviewer;
IV. Promoting the concept of GCOS, particularly within Australia and the South Pacific region; and
V. Helping to ensure that climate data management activities support climate change and climate variability research

Introduction

The Rapporteur's activities will be noted against the most appropriate term in the Terms of Reference (ToR) as provided in the Abridged Final Report of CCl-XII (WMO 1997). These terms of reference are as follows:

*(*a) To collaborate with the Working Group on Climate Change Detection in the development of climate change detection indices and in reviewing relevant parts of WMO programmes and activities, including the Technical Regulations;

*(*b) To keep abreast of scientific developments involving the monitoring, detection and modelling of climate change, in general, the characterization of evolution of past climate, and especially to study the underlying principals for compiling reference climate data sets and the development of indices and indicators for use in detecting climate change;

*(*c) To contribute to the study of the homogeneity and the statistical properties of the long-term data series of climate-related parameters and to advise on procedures for ensuring the homogeneity of climate data; and

*(*d) To collaborate closely with experts working on the development of indices and indicators of climate extremes.

In this report, the Terms of References ToR-a, ToR-b and ToR-c, will be hereafter referred to as: "Collaboration and review", "Developments in indices and datasets", and "Homogeneity analysis", respectively. A discussion of ToR-d will be included in "Collaboration and review". Since the Rapporteur has been the Supervisor of the Climate Data Management sub-section of the National Climate Centre (NCC) throughout the period covered by this report, an additional section titled “Data Management supporting climate change detection” is included.

Collaboration and review

The Rapporteur’s participation in the task group stemmed from involvement at the GCOS/CLIVAR/WMO Workshop on Indices and Indicators for Climate Extremes held in Asheville, USA, in June 1997. I was the lead author in two papers presented to the workshop – one on the Australian climate data (Plummer et al. 1997b) and the other on an analysis of extremes (Plummer et al. 1997a).

In 1998, I participated in a CLIVAR/WMO CCl Task group meeting on Climate Indices at the UK Meteorological Office (UKMO) and presented work on recent changes in Australian climate extremes. An extended abstract "Joint CCl/CLIVAR Task Group on Climate Indices: Climate Change Detection data, methodologies and indices – recent developments and plans in WMO Region V (Australasia and Southwest Pacific)" was prepared in collaboration with other scientists in the region and was submitted to the Hadley Centre (Appendix 1).

Together with some members of the CLIVAR/CCl Working Group on Climate Change Detection and climatologists from about 15 countries within the Asia-Pacific region, I was a co-organiser and participant at the Asia-Pacific Network (APN) Workshop on Indicators and Indices for Monitoring Climate Extremes in the Bureau of Meteorology, 8-10 December 1998. This meeting was organised by the Bureau of Meteorology Research Centre (BMRC) and sponsored by the Asia-Pacific Network for Global Change Research (APN). A major aim of the meeting was to plan the development of climate extremes indices within the region for the IPCC Third Assessment Report.

In October 1999 I visited ZAMG (Austria) and KNMI (The Netherlands) and discussed data homogeneity and analysis of climate extremes with several scientists. In May of the following year, Lisa Alexander and Ian Macadam (Hadley Centre, UKMO) visited the Bureau and held discussions with myself and other NCC staff on recent collaboration on analyses of climate extremes. Paul Della-Marta (NCC) subsequently provided Australian input to a paper on recent changes in extremes over a number of regions of the globe.

I have reviewed several papers on climate change and climate data through requests from editors of international scientific journals (e.g. *Journal of Climate, International Journal of Climatology*). In late 2000, I was an Expert Reviewer for the IPCC Third Assessment Report and a referee for the 2001 State of the Environment Report (Australia), which contained a chapter on climate variability. I am currently an Associate Editor of the *Australian Meteorological Magazine*.

Developments in indices and datasets

A study of changes in climate extremes in Australia and New Zealand followed the 1997 Asheville workshop (Plummer et al. 1999b). This was a result of a collaborative effort from scientists at the Bureau of Meteorology, CSIRO Atmospheric Research, The University of Melbourne, Australian Institute of Marine Science and the New Zealand Institute of Water and Atmospheric Research - NIWA). This paper built on results from earlier studies and showed *inter alia* that heavy rainfall had increased over Australia and, at least in recent decades, that warm days and nights had increased in frequency and cool days and (especially) nights had become less frequent. Changes over New Zealand were influenced by changes in atmospheric circulation. Following the Asheville workshop, I also contributed to the development of a set of temperature indices for climate extremes analysis (Folland et al. 1999).

The second APN Workshop in December 1999 was specifically designed to allow countries to analyze their daily climate data for changes in climate extremes. Participants from 15 countries collaborated. Again, I was a member of the organizing committee for this BMRC/APN workshop and was also co-author on Manton et al. (2001), which presented the results of the workshop. These results included a decrease in the number of rain days throughout Southeast Asia and the western and central South Pacific in recent decades and a decline in the frequency of extreme rainfall events at most locations (Figure 1). The third APN workshop will be held in Melbourne in April 2001. I am on the organizing committee and expect to give two presentations – the first on the activities of the Climate Change Detection Methodologies and Indices task group and the second on the CLIMARC project (discussed below).

Through the work of Collins et al. (2000), I was involved in the recent update of Australian climate extremes. Some interesting new results were found. While this study confirmed the trends described in Plummer et al. (1999b), it used the high quality daily temperature data set of Trewin (1999) to improve spatial coverage. Collins et al. showed that both frost frequency and frost season length has declined since at least 1957, when computerised observations were available. The study also suggested that inter-daily temperature differences had declined in recent decades whereas previous studies (e.g. Plummer 1996), using slightly different analysis methods and fewer stations, had suggested a less clear signal over Australia.

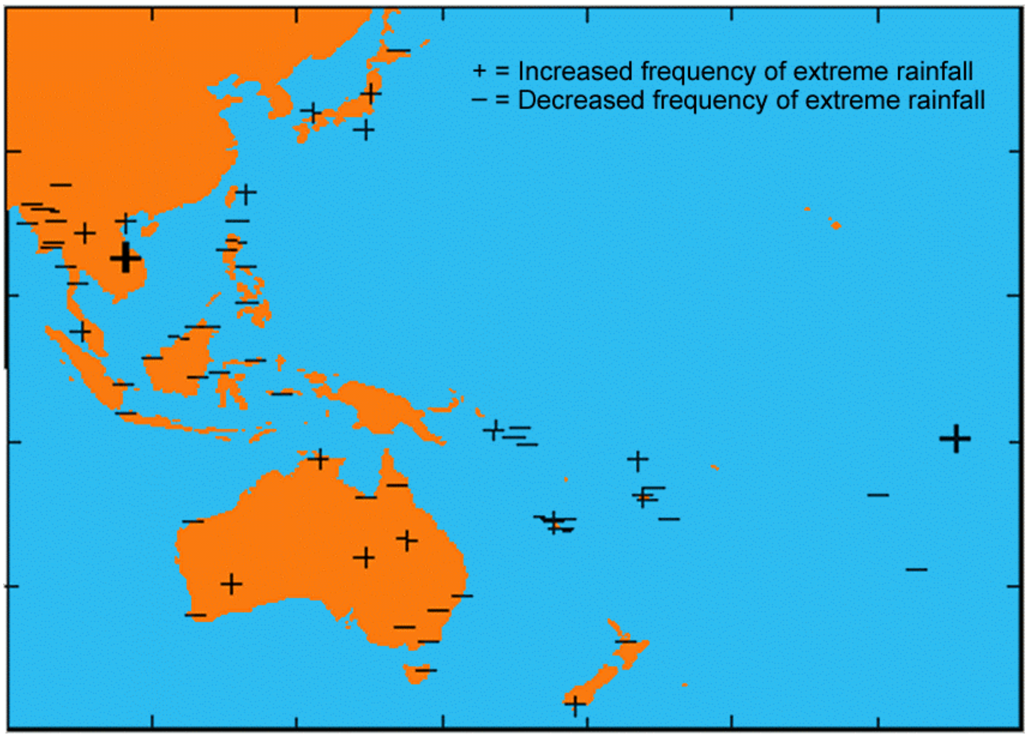


Figure 1. Changes in extreme rainfall events in the Asia Pacific region. Derived from analysis conducted at the BMRC/APN "second" workshop and adapted from Manton et al. (2001).

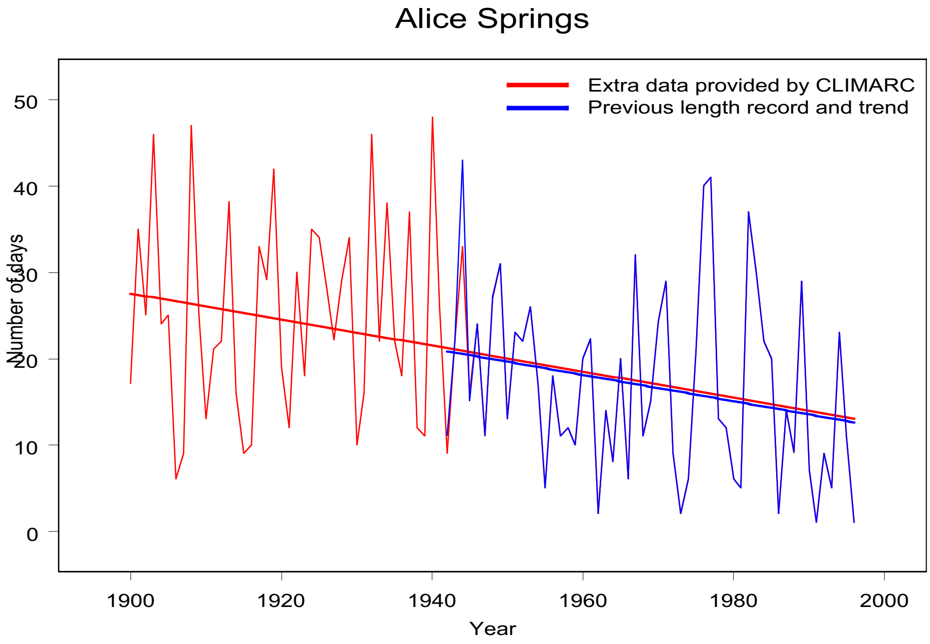
The NCC's CLIMARC project is addressing the need to get historical hourly and daily climate observations computerized and into the climate database. Although monthly means and other statistics have computerized records, most pre-1957 Australian daily and hourly climate observations are only found in manuscript form. External contributors to the project include state agricultural agencies and the Agriculture, Forestry and Fisheries Australia and Australia's rural R&D Corporations under the Climate Variability in Agriculture Program. The NCC is collaborating with the Queensland Department of Primary Industries on managing the project and the work is being done within the NCC. After substantial development of computer systems, the NCC began processing historical records under CLIMARC in early 1999. The goal is to computerize complete records for 50 stations throughout Australia by June 2002 and, as of January 2001, 31 were completed.

In October 2000, a paper was presented at the NCC organized Cli-Manage 2000 conference titled "Climate observations: meeting future needs" (Plummer et al. 2000b). Colleagues within the NCC also illustrated some of the early gains from longer period CLIMARC data at the conference (Figure 2).

The update of high quality temperature, precipitation and cloud data sets for Australia has been undertaken by the Climate Change Unit (Collins and Della-Marta) within the NCC (see http://www.bom.gov.au/climate/change/auscc.shtml). These are used in the production of annual climate assessments and provide the basis for an annual media release.

Homogeneity analysis

As previously mentioned, the NCC maintains high quality data sets of temperature, precipitation and cloud. The homogeneity analysis work is largely done by the NCC's Climate Change Unit although Climate Data Management have contributed through the efforts of one of its staff in maintaining the high quality daily temperature dataset (Trewin 1999). The Climate Change Unit also assisted with the homogeneity analysis at the second APN Workshop in December 1999. I was involved in the work of Peterson et al. (1998) on summarising homogeneity analysis, although the contribution was provided prior to 1997.



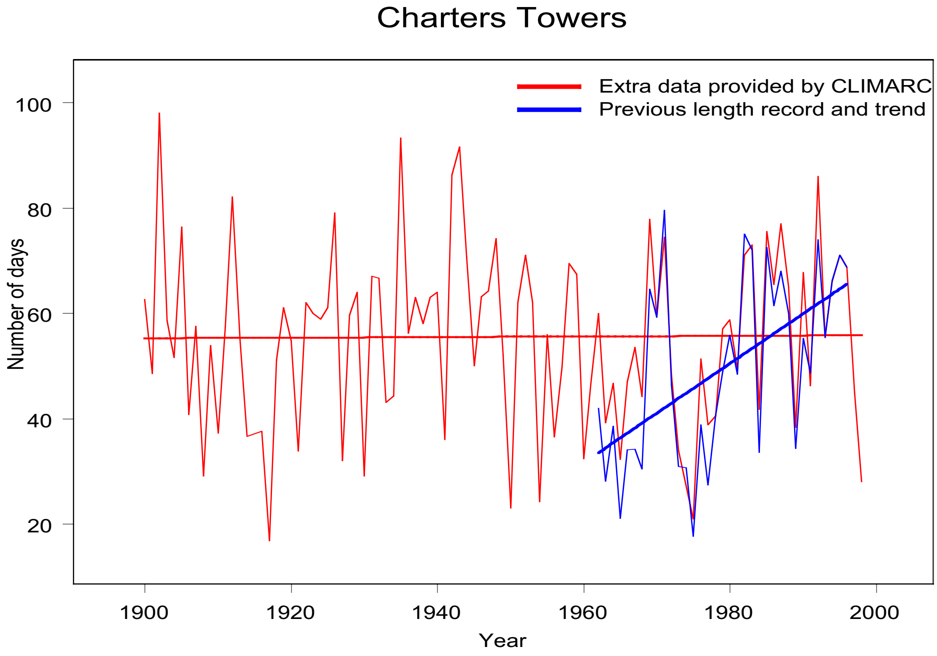


Figure 2. Extending the climate extremes analysis throughout the twentieth century is being made possible through the CLIMARC project. Annual frequency of frost days (top) and hot days (bottom) at Alice Springs (central interior) and Charters Towers (northeast). Analysis from Collins, Della-Marta and Trewin (National Climate Centre).

Data Management supporting climate change detection

I have been Supervisor of the Climate Data Management sub-section of the NCC since mid-1997. As a result, part of my work has involved the management of climate data in support of climate change and climate variability.

Over the reporting period, the work of the NCC's Climate Data Bank program has included:

I. Co-management of the CLIMARC project (i.e. computerising historical climate data)
II. Participating in the WMO Port Meteorological Officer's Training Workshop for RA-V/RA-II (Plummer 1999) and presenting a talk on Metadata and Standards
III. Presenting a talk on "AWSs in Australia: a climate perspective" at the Second International Conference on Experiences with AWSs in Vienna (Plummer et al. 1999a)
IV. Contributing, largely through Kelvin Wong (NCC), to the WMO CCl Task Group on a Future Climate Database Management System (CDMS)
V. Being part of the organising committee for the Global Climate Observing System (GCOS) Regional Implementation Workshop in Samoa in August 2000 (Plummer et al. 2000a). I gave a talk on the status of the GSN and GUAN. I was also a participant in an informal meeting of GCOS national coordinators in Melbourne in August 2000
VI. Development of a new CLIMAT data management system, which has allowed Australia to increase the number of CLIMAT reporting stations by about 30. 82 stations now report internationally
VII. Helping to ensure the climate data needs are communicated to the Bureau's Observation Program (e.g. advising on distribution of funding for Reference Climate Stations)
VIII. Development of new data quality monitoring systems
IX. Development of improved metadata and making it more accessible through, for example, assisting in projects to computerise and/or image station history files

Conclusions

Although my role at the Bureau of Meteorology has allowed me less time for activities directly related to the objectives of the Task group, I have worked with others within and outside of the Bureau of Meteorology to help ensure that Australia, and the broader Asia – South Pacific region, contribute to the global climate change effort.

It is possible that I will be nominated for the CCl contribution to the CBS Rapporteur's on "Observational data requirements and redesign of GOS" or "On requirements of data from automatic weather stations". If that is the case, and if the parties are agreeable, we may consider an alternative rapporteur from the Bureau of Meteorology for the WMO CCl Climate Change Detection Methodologies and Indices task group.

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Appendix 11. Final version of "Global Changes in Climatic Extremes during the 2nd half of the 20th Century" by P. Frich, L.V. Alexander, P. Della-Marta, B. Gleason, M. Haylock, A. Klein Tank and T. Peterson, *Climate Research*, accepted.

Global changes in climatic extremes during 2nd half of the 20th century

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and Peterson T.^

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Abstract

A new global dataset of derived indicators has been compiled to clarify whether frequency and/or severity of climatic extremes changed during the second half of the 20th century. This period provides the best spatial coverage of homogenous daily series, which can be used for calculating the proportion of global land area exhibiting a significant change in extreme or severe weather. The authors chose ten indicators of extreme climatic events, defined from a larger selection, that could be applied to a large variety of climates. It was assumed that data producers were more inclined to release derived data in the form of annual indicator time series than releasing their original daily observations. The indicators are based on daily maximum and minimum temperature series, as well as daily totals of precipitation and represent changes in all seasons of the year. Only time series which had 40 years or more of almost complete records were used. A total of about 3,000 indicator time series have been extracted from national climate archives and collated into the unique dataset described here. Global maps showing significant changes from one multi-decadal period to another during the interval from 1946 to 1999 have been produced. Coherent spatial patterns of statistically significant changes emerge, particularly a near uniform global increase in warm summer nights, a decrease in the number of frost days and a decrease in intra-annual extreme temperature range. All but one of the temperature-based indicators show a significant change. Indicators based on daily precipitation data show more mixed patterns of change but significant increases have been seen in the extreme amount derived from wet spells and numberno. of heavy rainfall events. We can conclude that a significant proportion of the global land area was increasingly affected by a significant change in climatic extremes during the second half of the 20th century. These clear signs of change are very robust, however large areas are still not represented, especially Africa and South America.

Key Words: Observed climatic extremes, derived indicators, temperature, precipitation, climate monitoring, global change

1.0 Introduction

Global change indicators are developed and maintained by many centres throughout the world. The aim of these aggregated indicators is to monitor climate change as and when it happens. The Intergovernmental Panel on Climate Change (IPCC, 1995) concluded that anthropogenic effects have discernibly influenced the global climate, one effect being the rise in global mean temperature of 0.7°C since the second half of the 19th century (Nicholls et al., 1996, Parker et al., 2000). A rise in the mean would not necessarily lead to a rise in extreme temperature events if the spread of the temperature distribution remained the same. If the change in mean, however, was related to a shift in distribution then this could have a major impact on society and ecosystems e.g. fewer frost days and increased heatwave duration. The research agenda whilst being concerned with detection and attribution studies, has now also moved onto monitoring climate change. Nicholls et al. (1996) emphasised that further work on analysing changes in climatic extremes was required. The availability of a global daily dataset was, and still is, less than adequate for this kind of analysis (Folland et al., 2000). Indicators of climatic extremes have been developed through a number of international workshops (Nicholls et al., 1999; Folland et al., 1999 and Manton et al., in press). Increasingly, climate change detection and attribution studies have focussed on changes in extreme events, which require daily observations. Access to a globally complete and readily available full resolution daily dataset is restricted for a number of reasons. Consequently we have defined ten climatic indicators, which can be calculated locally by data-producing centres. Time series of these indicators can subsequently be exchanged between and used by both modelling groups and climate monitoring centres. Global datasets of unambiguously defined indicators could also provide the baseline data and benchmarks for evaluating climate change scenarios in the future. Both traditional climate change indicators and these new extreme indicators have been developed in close collaboration between leading international centres and will be available in near real time as resources allow. These indicators may form the basis for a future web-based and more coherent global information system on climate change monitoring based on Global Climate Observing Systems (GCOS) data. A tentative name for such a system would be: GCOS Extremes Monitoring (GEM) Network.

The aim of this paper is to clarify whether the frequency and/or severity of extreme weather and climate events have changed in recent decades. The problem of separating changes due to sampling, station exposure and real changes in extremes remains a challenge for the scientific community (Nicholls and Murray, 1999; Mohr, 2000). We have chosen to use a fixed network of high quality stations to reduce the effect of varying sampling biases.

This paper will build on existing available evidence for changes in climatic extremes. Section 2 will describe the rationale for developing and selecting the ten indicators used in this study and the quality and availability of data. Section 3 will describe methods used in aggregating data and the methods used for testing whether any one time series displays a significant change over the analysis period. Global maps, time series and summary diagrams will be presented in Section 4, followed by our interpretation and discussion of the results in Section 5. Finally, we summarise our conclusions in Section 6.

2.0 Rationale for analysing indicators of changing extremes

2.1 Planning meetings

Following a meeting of the World Meteorological Organisation (WMO) Commission for Climatology (CCL)/Climate Variability (CLIVAR) Working Group on Climate Change Detection in September 1998 (Folland et al, 1999), a number of meetings were held in Europe (European Climate Assessment Council (ECAC) in Vienna, IPCC in Paris, Commission for Basic Systems Advisory Working Group (CBS AWG) in Reading, and WMO CCL/CLIVAR in Geneva), Australia (Australia-Pacific Network (APN) in Melbourne), and USA (IPCC in Asheville). It was realised at these meetings that insufficient time was available to collate a global daily dataset, analyse it and publish the results for inclusion in the IPCC Third Assessment Report. Subsequently, it was agreed that participants should exchange only derived indicator time series. This process has now resulted in the compilation of data files, each containing data derived from as many daily temperature and precipitation series as possible world-wide.

The WMO CCL/CLIVAR Joint Working Group on Climate Change Detection held another meeting in Geneva in November 1999, and recommended that a list of 10 simple and feasible indices be produced.

This priority list of indices should be accompanied by methodologies and guidance on how to develop them for follow-up regional capacity building workshops in 2001.

It was also emphasised that development of indices should focus on indicators which were not highly correlated, but rather contain independent information. Indices should also be considered on a regional basis and compared within and between regions in addition to those for global analyses. Further consideration should also be given to developing indices to measure changes in climate variability on a variety of space and time scales.

A final requirement appeared from very recent studies of extremes (e.g. Manton et al., in press, Zhang et al., in press). Generally, these linear trend analyses of very rare events did not give significant results on traditional seasonal and regional scales. We realised that time series, which were based on just a few extreme events per year or season, would rarely provide the robustness needed. We thus had to limit our search for indicators accordingly. Robustness turned out to be a key requirement and in the next section we will describe our selection of less extreme, and therefore less noisy, but hopefully more robust indicators.

2.2 Indicators selected

The ten selected indicators are listed in Table 1. The numbering system follows Frich et al. (1996) with later additions (Frich, 1999) and some completely new indicators seen here for the first time (see Appendix A).

These recommended indices potentially cover many aspects of a changing global climate. Frost days (**Fd**) would sample the winter half-year in all extra-tropical regions, particularly the beginning and end of the cold season in many continental and high latitude climates. Intra-annual Extreme Temperature Range (**ETR**) would span the most extreme high temperature event of the summer season and the most extreme low temperature event of the winter season. Heat Wave Duration Index (**HWDI**) would sample the daytime maxima during the summer half year in most climates and **Tn90**, which is the percent of observations exceeding the daily 90th percentile for the 1961-90 base period, would sample primarily the warm nights during late summer and early autumn. Length of the thermal Growing Season (**GSL)** would sample spring and autumn anomalies in the higher latitudes.

Maximum number of Consecutive Dry Days (**CDD**) could potentially become a valuable drought indicator for the dry part of the year, whilst number of days with precipitation $\geq$ 10 mm (**R10**) and the Simple Daily Intensity Index (**SDII**) would similarly summarize the wet part of the year. The greatest 5-day precipitation total of the year (**R5d**) and the fraction of the annual total greater than or equal to the daily 95th percentile (**R95T**) would represent some of the most extreme flood-producing events of the year.

2.3 Data selected

Trewin (1999) has developed a high-quality daily temperature dataset for Australia. These records have been adjusted for inhomogeneities at the daily time-scale, by taking into account the magnitude of discontinuities for different parts of the distribution. Station records mostly extend from 1957, when digitised daily records are generally available in the Australian National Climate Centre’s database, through to 1996. European temperature data have been collated as part of the European Climate Assessment 2000 (Klein Tank et al., in prep.). Time series have been carefully selected by national experts and have been scrutinised through visual inspection. Remaining temperature data have been provided from the National Climate Data Center (NCDC) archives (Peterson et al., 1997a)

Precipitation stations from Australia were selected from the high-quality daily rainfall data set (Lavery et al., 1992). This data set was compiled from an exhaustive investigation of station history documentation to remove stations with bad exposure, instrumentation or observer accuracy. A series of statistical tests was utilised to further check the station integrity. Specific tests were also performed to check the influence of the change from imperial to metric units in 1974 as well as to check for bad observer practice. The 181 stations chosen provide a broad coverage of the country's main climatological regions.

European precipitation data have been collated as described above. To our knowledge, no adjusted daily time series have entered the European dataset. Remaining national data throughout the world have been compiled by NCDC. These data were analysed for inhomogeneity with the most inhomogeneous time series discarded from the analysis (Peterson et al., 1998). The methodology used was that of the Global Climate Historical Network - GCHN (Peterson et al., 1997a).

The criteria for including indicator time series based on daily data have varied from data source to data source. Generally, a year was considered missing in a station record if it contained more than 10% missing daily values or more than three months during the year contained more than 20% missing daily values. Each station record used also needed to have at least 40 years worth of data between 1946 and 1999.

3.0 Methods

Some extreme events are very localised (e.g. flooding in a narrow coastal zone or on one side of a mountain range), although they may still be part of a global pattern. Given the data sparsity and the lack of spatial coherency in some indicators, it was decided that the global maps should contain station data and not gridded data. In some parts of the world (e.g. South Africa, Europe and north-eastern U.S.A.) there were networks of higher density available which would have had an undue influence on any global average calculation. Assuming that the indicator time series were of equal quality, it was decided to thin the network so that it was homogenised to a density of 1-2 stations per 250,000 square kms, as recommended by GCOS (http://www.wmo.ch/web/gcos) and others (Peterson et al., 1997b). We have therefore chosen to calculate a simple global average of all valid stations. The thinning technique uses the underlying assumption that station density reflects population density and is described in more detail in Appendix B.

Two methods were employed to analyse each of the extreme indicator time series (see Appendix B). The first method compares the average of one post-1946 multi-decadal period to another by means of a t-test. The results are presented in Figures 1a-10a and show both the percentage change and significance of the change between these two periods for each station and extreme indicator. The second method aims to spatially average the results of each indicator time series. This was performed by calculating the anomalies in each year of the indicator time series from a base period of 1961-1990. The time series of this analysis can be seen in Figures 1b-10b. The trend of each has been calculated by weighting the anomalies according to the number of stations available from the network each year and has been tested for significance using weighted linear regression analysis (e.g. Draper and Smith, 1966).

Finally, probability density functions (PDF) are calculated for each indicator. These are calculated by giving each indicator a number of ‘bins’ across its range and calculating the corresponding frequency, similar to producing histograms. The result is then normalised to sum to 1 to give estimated probabilities rather than a frequency distribution (Figure 11).

4.0 Results

Each map (Figures 1a through 10a) shows for all stations analysed, whether or not there has been a statistically significant change from one multi-decadal average to the next during the second half of the 20th century. Note that colour coding changes between maps to associate wetter and cooler climate with blue and associate hotter and drier climate with red. For each indicator, we have also illustrated the development through time (see Figures 1b through 10b) of the relative proportions of global stations sampled affected by changes from the 1961 – 1990 base period. To help interpret these diagrams, we have provided an insert (Figures 1b – 10b) showing the number of indicator time series used in the analysis along with Figure 11 that shows the PDF for each indicator time series. The two PDF’s shown in Figure 11 for each extreme indicator correspond to the two multi-decadal periods used in the analysis shown in Figures 1a -10a. The PDF’s show the varied distribution of the climate indicators some being severely skewed in both directions while some are close to normal. We have not applied a stringent test for normality of distributions given that t-tests are robust against non-normal distributions (Ramsey and Schafer, 1997). However, in each case we recommend taking the shape of the PDF in account given that the more normal looking the distribution, the more confidence that we can place in the result.

Finally, Figure 12 summarises the observed changes over the period analysed. The data coverage is sparser at the beginning and end of this time frame, so we have only shown results between 1951 and 1996.

5.0 Discussion

5.1 Circulation changes

Dramatic regional and seasonal changes in UK precipitation have been linked to atmospheric circulation changes (Alexander and Jones, in press); specifically wetter winters (October - March) in north-west Scotland in recent decades and drier high summers (July and August) since the early 1970's in all regions of England and Wales. These changes have very distinct impacts on the occurrence of extremes. It has been suggested that decreases in rainfall in south-west Australia, including extremes, have been caused by a southward shift in rain-producing weather patterns (Allan and Haylock, 1993, Smith et al., 1999). Whether these local or regional circulation changes are indeed local, or they are part of a systematic global change, remains to be seen. The results presented here do indicate that a significant and growing proportion of the global land area analysed has been affected by changes in climatic extremes. Individual El Nino events and exceptionally long and active phases of the North Atlantic Oscillation both seem to correlate to an increase in the global land area affected by changes in extremes.

5.2 Temperature-based results

Generally, all temperature-based indicator maps (Figures 1a-5a) show roughly similar spatial patterns of change. Most of the Northern Hemisphere and Australia show a warming over the 1946 to 1999 period. Notable exceptions are the south-central states of the USA, eastern Canada and Iceland, as well as areas in central and eastern Asia. The temperature-based indicator time series (Figures 1b–5b) are intended to reflect the map-based results over time and show whether there is any significant change over the whole period analysed.

The annual number of frost days (Fd) shows a near uniform global decrease over the second part of the 20th century (Figure 1a). All areas analysed, except the south-central part of the USA, Iceland and a few places in eastern Asia, show significantly fewer frost days per year, when the most recent 20-27 year period is compared with a previous 20-27 year period. Figure 1b shows that there is a statistically significant decreasing trend in the number of stations experiencing frequencies of frost days which is in accord with the PDF for Fd in Figure 11.

In many parts of the world, the intra-annual extreme temperature range (**ETR**) shows a systematic and statistically significant decline over the past 4-5 decades (Figure 2a). Often the reductions from one multi-decadal period to another are as large as several degrees and are mainly associated with increasing night-time temperatures (e.g. Tuomenvirta et al., 2000). Figure 2b shows that there was a significant decline in **ETR** over the period 1951 - 1996. Several previous studies (e.g. Plummer et al., 1995, Torok and Nicholls, 1996) have identified decreasing trends in diurnal temperature range throughout Australia over recent decades, largely due to minimum temperatures having increased more so than maximum temperatures. However, the **ETR** results do not stem from changes in cloud cover, as initial analyses have revealed that the two extreme ends of the temperature distribution often occur during clear sky conditions. The hottest temperature reading of the year is most often observed on a sunny afternoon, at least in the extra-tropics, whereas the coldest temperature reading of the year is most often observed on a clear winter night.

A lengthening of the thermal growing season (**GSL**) has been observed throughout major parts of the Northern Hemisphere mid-latitudes with the notable exception of Iceland (Figure 3a). Growing season indices defined in global analyses are generally not appropriate for the relatively warm Australian climate. The majority of Australian stations would be considered to be in permanent growing conditions using many growing season definitions used elsewhere. In Australia, growing seasons tend to be crop specific and more dependent on rainfall patterns. Consequently there is no easily defined growing season index for this continent. Based only on the Northern Hemisphere stations there does appear to be a significant increase in **GSL** over time (Figure 3b)

Significantly longer heat wave duration (**HWDI**) has been observed in Alaska, the Midwest of the USA, central and eastern Europe, Siberia and central Australia. Shorter heat waves have occurred in south-eastern USA, eastern Canada, Iceland and in southern China (Figure 4a). The mixed results shown in Figure 4a are supported by the fact that although there appears to be a globally upward trend in **HWDI** (Figure 4b), it is not statistically significant. **HWDI** has limited usefulness in warm climates with little day-to-day variability. For example, Kuwait, where temperatures may quite often reach above 40^o C, the climate is so stable and the variability so subdued, that heat waves as defined in **HWDI** have never occurred.

The trend of warming nights is clearly shown in the **Tn90** indicator map (Figure 5a), showing a nearly uniform global increase in most of the land areas examined with the exception of eastern Canada, Iceland and around the Black Sea. Generally, the frequency of warm minimum (**Tn90**) temperature extremes has increased throughout the world over the comparison periods to a significant extent. Figure 5b again reflects this with the past decade showing an increase of about 50% from the 1961-1990 base period. This result should also be compared to its PDF from Figure 11 showing the shift in distribution of **Tn90** over the two periods sampled. The fact that Tn90 appears to be highly correlated with **Fd** may well be because we are seeing a coherent global change signal.

5.3 Precipitation-based results

Generally, all precipitation-based maps (Figures 6a-10a) show a mixed pattern of positive and negative changes. Some of the more robust changes relating to wet extremes can be summarised as follows: southern Africa and south-east Australia, western Russia, parts of Europe and the eastern part of the USA all show a significant increase in most indicators of heavy precipitation events; eastern Asia, Siberia and south-west Australia all show a decrease in the frequency and/or the severity of heavy precipitation events. However, most of the precipitation indicators are showing a significant upward trend in their annual anomalies (Figures 6b-10b).

The number of days with greater than 10mm (**R10**) show that coherent patterns of a positive change (Figure 6a) occur over Russia, U.S.A. and parts of Europe. The same applies for South Africa and most of Australia. Although the pattern is mixed, there is much more significant positive change than significant negative change. This can be compared to Figure 6b which shows this significant increasing trend. **R10** is a simple index yet means very different things in different regions of the world. Some stations, e.g. on the Norwegian West coast have, on average, more than 120 days with rainfall greater than 10mm per year, while one of the inland stations in Australia has an average of only 4 days per year. Nonetheless, **R10** has proved to be a robust indicator, providing spatially homogeneous regions of both positive and negative changes.

The maximum number of consecutive dry days (**CDD**) show in general a reduction (Figure 7a) with notable exceptions in parts of South Africa, Canada and eastern Asia. This general pattern, however, is shown in the time series plot (Figure 7b) which reflects the decreasing trend in **CDD** and its significance at the 95% level of confidence.

The maximum 5-day precipitation total (**R5D**) is the indicator of flood-producing events and shows a general increase throughout large areas of the globe. Notable and coherent areas in western Russia and most of North America show a significant increase in this indicator. Some areas show a significant decline during the second half of the 20th Century e.g. eastern China. Again this pattern is reflected in the statistically significant upward trend of **R5D** (Figure 8b).

The Simple Daily Intensity Index (**SDII**) is defined as the mean daily intensity for events greater than or equal to 1mm per day. This has increased over many parts of Europe, Southern Africa, USA and parts of Australia, although the patterns of change are also variable in these parts of the world showing some relatively nearby stations with opposite signs of change. The decrease in this index over eastern Australia reflects an increase in the number of rain days rather than a decrease in rainfall (Hennessy et al. 1999). As the pattern is mixed, although there does appear to be an increase in this indicator, the trend is not significant (Figure 9b).

The fraction of annual total precipitation from events wetter than the 95th percentile for 1961-1990 (**R95T**) shows that major increases have been observed in Alaska, eastern USA, central Europe and southern Australia (Figure 10a). There are a few coherent areas of decrease and hence we see an upward (but not significant) trend in Figure 10b. The 1961-90 95th percentile is the average of the 95th percentiles calculated for each year using all days (or all days that meet the missing data criteria). Therefore this is the average rank 18 event. Some concerns have been raised about the **R95T** index due to the fact that it is basically the same as the number of events above the threshold. The **R95T** index examines the contribution to total precipitation of a changing number of events. A year with more events above the threshold will almost always show a larger proportion of the total rainfall from these events simply because there are more events. At a later stage **R95T** may be redefined as the number of events above the threshold but for the purposes of this study we have chosen to include the totalling component.

6.0 Summary and Conclusions

6.1 Observed changes in extreme indicators

We have observed a systematic increase in the 90th percentile of daily minimum temperatures (**Tn90**) throughout the analysed area, especially in the mid-latitudes and subtropics where data are available. This increase is accompanied by a similar reduction in the number of frost days (**Fd**) and a significant lengthening of the thermal growing season (**GSL**) in the extra-tropics in the Northern Hemisphere. The intra-annual Extreme Temperature Range (**ETR**) is based on only two observations per year; still it provides a very robust and significant measure of declining extreme temperature variability. This particular indicator is considered a direct measure of anthropogenic impacts on the global atmosphere. Clear sky radiative heat loss during winter appears to have declined as has the amount of incoming solar radiation during the summer. The latter may be explained by increasing amounts of jet contrails (see also Travis and Changnon, 1997). The result is a clear global pattern of reduced intra-annual temperature variability and warrants future analysis on extreme cold and warm temperatures. There are still outstanding problems to resolve before a globally accepted definition of a heatwave duration indicator can be calculated and exchanged between NMS on a routine basis.

Our results show an increase in the frequency of heavy precipitation events (e.g. **R10** and **R5D**) in some regions of the World, accompanied by changes in the drought frequency (**CDD**) in some regions of the world.

6.2 Increasing global collaboration

Global collaboration in developing, selecting and analysing ten extreme indicators has led to a major achievement with respect to understanding patterns of changing extremes. This study builds on solid work in many National Meteorological Services (NMS) and is likely to initiate further regional efforts throughout the world.

Countries participating in the Asia-Pacific Network (APN) have held successful meetings in December 1998 and December 1999. New datasets and analysis have become available and a major paper will be published (Manton et al., in press).

The European Climate Assessment 2000 (ECA2000) have held meetings in November 1998 and another meeting is planned in October 2000. Early results are available at website: http://www.knmi.nl/samenw/eca/index.html. A book will be published in 2001 (Klein Tank et al. (in prep.)). The European NMS will produce a CD-ROM with the global daily dataset in 2001.

Collaboration between the University of the West Indies, NCDC and Caribbean countries has resulted in a scheduled meeting in Jamaica in January 2001. The START Programme is also offering support to hold a workshop in Casablanca in February 2001 to bring together NMS in Africa. Future work will also include analysis of the GCOS Surface Network (GSN) (Peterson et al. 1997b). Extended east African collaboration has resulted in a much-improved database for countries from the Sudan to Mozambique.

A coherent global climate information system will need to be based on a systematic naming convention for a limited number of well-defined climatic indicators. This will help to facilitate access to climate data and metadata as suggested by GCOS, and may help to secure a seamless interface within and between the main data providers. Increasingly, climate change monitoring will focus on changes in extreme events, which require an agreed set of indicators based on homogeneous series of daily observations. While this paper shows reliable results for the countries analysed, to gain a truly global understanding of changes in climatic extremes there is still much work needed to help other countries e.g. Africa and South America to homogenise their data.

Climate monitoring analyses need to be done in near real time in order to enable us to give the best guidance to Governments and other interested parties. We therefore need access to near real time observations with daily resolution, as well as a better global coverage. We need to create a climate information and data acquisition system which will serve a wide range of national and international requirements, such as those formulated by GCOS.

6.3 Summary

Examination of the results of this analysis indicates that, for the global land areas examined, on average during the second half of the 20th Century, the world has become both warmer and wetter. Wet spells produce significantly higher rainfall totals now than they did just a few decades ago. Seven out of ten indicators analysed on a global scale over the past five decades give coherent and significant results. Heavy rainfall events have become more frequent and cold temperature extremes have become less frequent during the 2nd half of the 20th century. These observed changes in climatic extremes are in keeping with expected changes under enhanced greenhouse conditions.

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Table 1

INDICATOR		DEFINITION	UNIT
125	Fd	Total number of frost days (days with absolute minimum temperature below 0 °C)	days
141	ETR	Intra-annual Extreme Temperature Range (Difference between the highest temperature observation of any given calendar year (Th) and the lowest temperature reading of the same calendar year (Tl)	0.1 K
143	GSL	Growing Season Length (period between when Tday > 5°C for > 5 days and Tday < 5°C for > 5 days)	days
144	HWDI	Heat Wave Duration Index (maximum period > 5 consecutive days with Tmax > 5 °C above the 1961-90 daily Tmax normal)	days
194	Tn90	Percent of time Tmin > 90th percentile of daily minimum temperature	%
606	R10	No. of days with precipitation ≥ 10 mm/day	days
641	CDD	Maximum no. of Consecutive Dry Days (Rday < 1 mm)	days
644	R5D	Maximum 5 day precipitation total	0.1 mm
646	SDII	Simple Daily Intensity Index (Annual total/ No. of Rdays ≥ 1 mm/day)	0.1 mm/day
695	R95T	Fraction of annual total precipitation due to events exceeding the 1961-90 95th percentile	%

Table 1: Suggested ten indicators for monitoring change in climatic extremes world-wide. Precise definitions of these and many other indicators are available at http://www.knmi.nl/samenw/eca/indicator_descriptions/)

APPENDIX A

Indicator			Rationale	Expected changes under enhanced greenhouse conditions (based on IPCC, 1995)
125	**Fd**	days	Total number of frost days (days with absolute minimum temperature below 0 °C)	
Source: Frich et al (1996). Limitations: Not valid in the Tropics.			Effects on agriculture, gardening and recreation especially in extra-tropical region. Easily understood by general public	Fd is assumed to decrease as a result of a general increase in local and global mean temperature
141	**ETR**	0.1 K	Intra-annual Extreme Temperature Range (Difference between the highest temperature observation of any given calendar year (Th) and the lowest temperature reading of the same calendar year (Tl))AND EXTREME TEMPERATURE RANGE ON THIS LINE???	
Source: Frich (1999) T Limitations: None			A simple measure of temperature range for each year Generally good quality control applied as the warmest and the coldest day of the year will normally attract some interest	ETR is expected to decrease as a direct result of increased nocturnal warming under clear sky conditions. Additional decrease in ETR may be expected from reduced daytime solar insolation through a thickening cover of cirrus clouds.
143	**GSL**	days	Growing Season Length (period when Tday > 5°C for > 5 days and Tday < 5°C for > 5 days)	
Source: Frich (1999) Limitations: Not valid outside mid-latitudes			Important for agriculture	GSL is expected to increase as a direct result of increasing temperatures and indirectly as a result of reductions in snow cover.

144	**HWDI**	days	Heat Wave Duration Index (maximum period > 5 consecutive days with Tmax > 5 °C above the 1961-90 daily Tmax normal)	
Source: This study Limitations: Not really valid outside mid-latitude climates.			Linked with mortality statistics	Heat waves are expected to get longer and more severe due to a direct greenhouse effect under clear sky conditions and due to an indirect effect of reduced soil moisture in some regions
194	**Tn90**	%	Percent of time Tmin > 90th percentile of daily minimum temperature	
Source: This study. Limitations: None			A direct measure of the number of warm nights. This indicator could reflect potential harmful effects of the absence of nocturnal cooling, a main contributor to heat related stress	NSummer night-time warming is expected in a greenhouse gas forced climate. This will partly come about as a clear sky radiative effect, partly be a result of increased cloud cover from additional humidity being available for nocturnal condensation. Main effect is expected in late summer, when atmosphere holds maximum amount of moisture
606	**R10**	days	No. of days with precipitation ≥ 10 mm/day	
Source: Frich et al (1996). Limitations: very regionally dependent but still valid in all climates analysed			A direct measure of the number of very wet days. This indicator is highly correlated with total annual and seasonal precipitation in most climates	Greenhouse gas forcing wWould lead to a perturbed climate with an enhanced hydrological cycle. More water vapour available for condensation should give rise to a clear increase in the number of days with heavy precipitation
641	**CDD**	days	Maximum no. of Consecutive Dry Days (Rday < 1 mm)	
Source: Frich (1999). Limitations: None			Effects on vegetation and ecosystems Potential drought indicator A decrease would reflect a wetter climate if change was due to more frequent wet days	Under sustained greenhouse gas forcing, the interior of continents may experience a general drying due increased evaporation
644	**R5D**	0.1 mm	Maximum 5 day precipitation total	
Source: et al1996This study Limitations: None			A measure of short-term precipitation intensity Potential flood indicator	See R10Greenhouse gas forcing would lead to a perturbed climate with an enhanced hydrological cycle. More water vapour available for condensation should give rise to a clear increase in the total maximum amount of precipitation for any given time period
646	**SDII**	0.1mm/ day	Simple Daily Intensity Index (Annual total/ No. of Rdays ≥ 1 mm/day)	
Source: This study Limitations: none			A simple measure of precipitation intensity	Greenhouse gas forcing in most climate models lead toindicate higher rainfall intensities
695	**R95T**	%	Fraction of annual total precipitation due to events exceeding the 1961-90 95th percentile	
Source: Frich et al (1996) Limitations: May be highly correlated with number of extreme events			A measure of very extreme precipitation events	Greenhouse gas forcing in most climate models lead to higher rainfall intensities, particularly giving rise to a shift in the distribution.See R10

APPENDIX B Method for finding percentage of global land area sampled showing significant change

Creating a thinned, quasi-homogeneous network of stations

Let equal the interstation distance between all possible combinations of stations and let be the total number of stations received for each extreme indicator. We then sort into ascending order i.e.

where

Consider which is the shortest interstation distance between stations and say. We then remove one of these from the station record. The station that is removed is the station which appears first in the remaining list of e.g. if contains station and , then station would be removed from the station list and hence all which contain station are removed. This process is repeated for etc. until a threshold value is reached. This is determined using the criteria that we should have at least one station every 250,000 square kms. Hence

The stations which appear in the above this threshold are kept. This ensures that more remote stations remain but thins the network where there are higher density clusters.

The following cases use the thinned network for calculation.

Testing the difference between two multi-decadal averages (global maps).

Let _ represent the extreme values for one station such that _ can be divided up into two periods, _ _ which both have at least twenty years worth of data.

If we write

(1)

where $i \geq 1946$ and $n \leq 1999$, then we define

(2)

where and is rounded down to the nearest integer.

To test if there is any significant difference in the means between the two periods, a t-test is implemented as follows:-

Calculate the sums of the squared differences from the mean for each of $\underline{\boldsymbol{A}}_S$ and $\underline{\boldsymbol{B}}_S$ such that:-

(3)

and

(4)

where and are the means of $\underline{\boldsymbol{A}}_s$ and $\underline{\boldsymbol{B}}_S$ respectively.

Define the null hypothesis as

If *nA* and *nB* are the number of elements in $\underline{\boldsymbol{A}}_s$ and $\underline{\boldsymbol{B}}_S$ respectively then the number of degrees of freedom, ν, is given by

$$\nu = (nA + nB) - 2 \tag{5}$$

and hence the common population variance is

(6)

From eqns (5) and (6), we now have enough information to calculate a two-tailed significance test at the 5% level of significance. The t-test statistic is given by

(7)

Eqn (7) now enables us to calculate the significance, $\sigma_{s,}$ that the means of $\underline{\boldsymbol{A}}_s$ and $\underline{\boldsymbol{B}}_S$ are significantly different at a 95% level of confidence. Hence H_0 is rejected if $\sigma_S < 0.05$ (5%).

Calculating the percentage difference between the means of the two periods i.e.

(8)

and given the latitudes and longitudes of each station, we can plot this change and show its significance, as in Figures 1a through 10a.

Creating a time series of anomalies (time series plots).

The time series of anomalies shown in Figs 1b – 10b were calculated as follows. Using the definition of in Eqn (1) we define the climatological average, for station using the 1961 – 1990 base period i.e.

(9)

The average of all stations in the indicator time series is then defined as:-

(10)

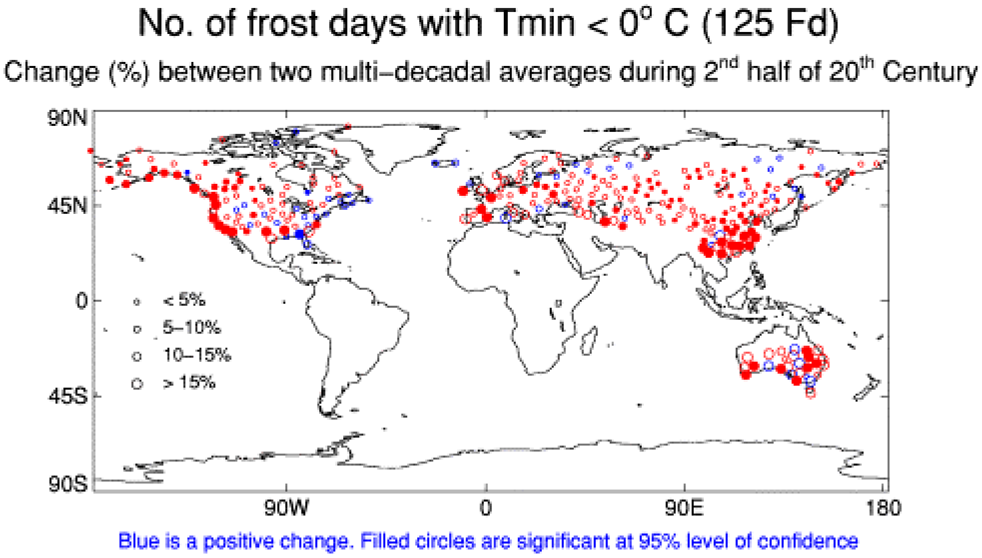
where is the number of stations. Given that there is one extreme indicator value for each station for each year, we simply define the average for each year as the sum of all the extreme indicator values in a year divided by the number of stations available in that year. Thus we can express this as a percentage anomaly for each year as follows:-

(11)

where .

The values of were assigned weights proportional to the number of stations contributing data for that year. The weights were used in a weighted linear regression analysis of which calculated both the weighted least squares trend in and its statistical significance.

The results are shown in Figures 1b through 10b with inserts showing the value of the weighting function.



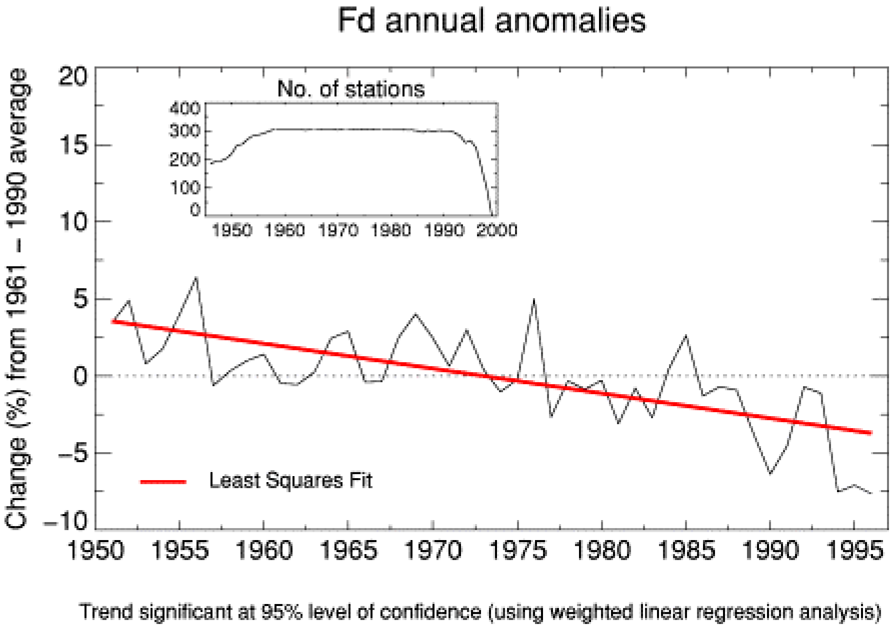
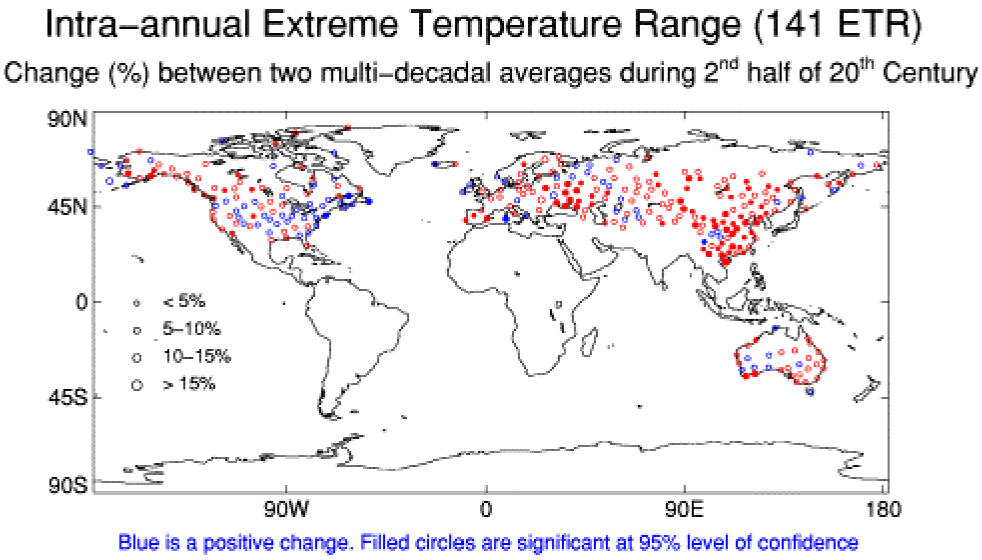


Figure 1a (top) Circle sizes represent the percentage change in the number of frost days **Fd** (Table 1) at each station between two multi-decadal periods during the 2nd half of the 20th Century. The colour coding specifies the sign of the change and the statistical significance of the change is calculated using a t-test (Appendix B).

Figure1b (bottom) Differences in the average extreme indicator **Fd** value between 1951 and 1996 from the average 1961-1990 value. The anomalies reflect the pattern of change in Figure 1a through time. The insert represents the weighting factors used in the linear regression analysis but note that the weights are shown for all years between 1946 and 1999.



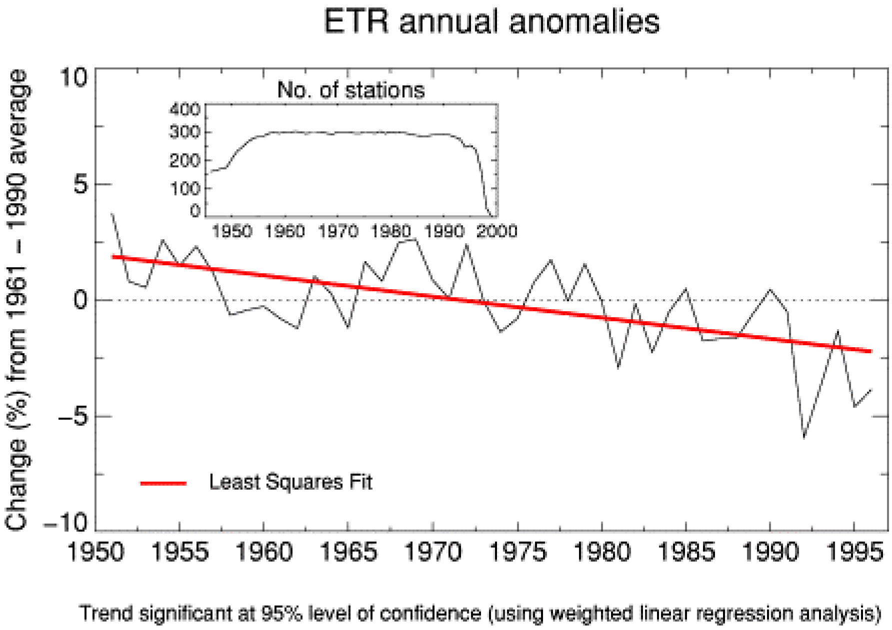
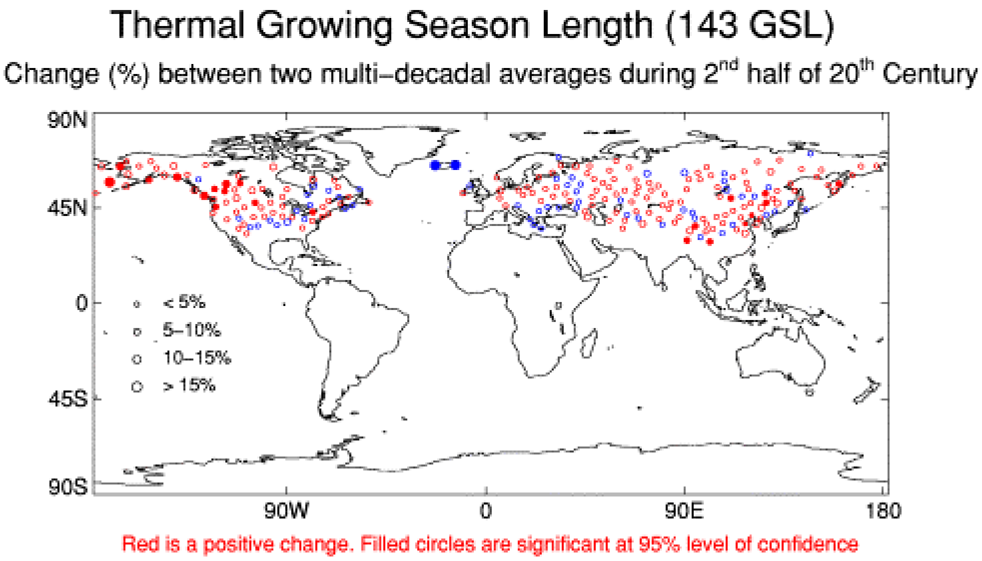


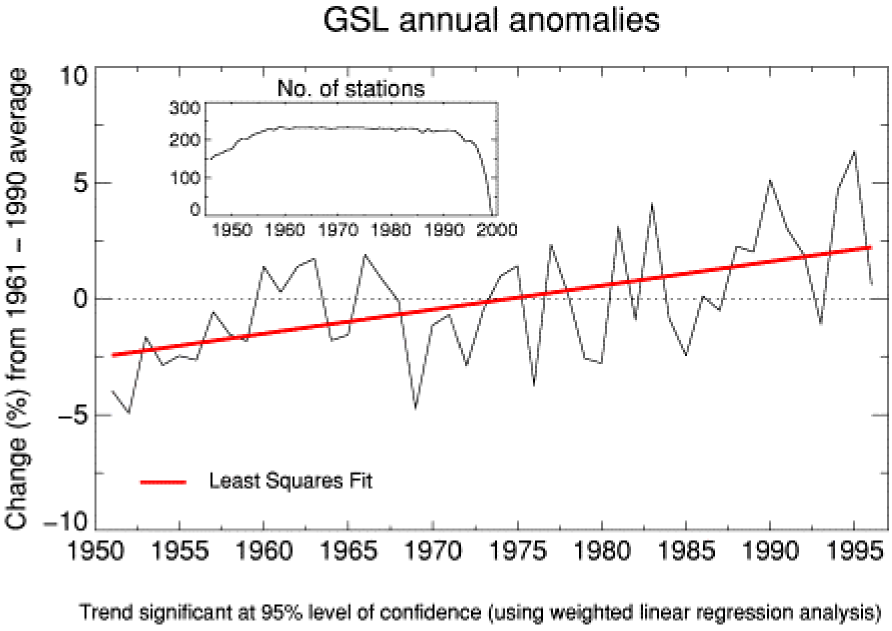
Figure 2a (top) As Figure 1a, but for intra-annual extreme temperature range **ETR** (Table 1).
Figure 2b (bottom) As Figure 1b, but for **ETR**.



Thermal Growing Season Length (143 GSL)

Change (%) between two multi–decadal averages during 2nd half of 20th Century

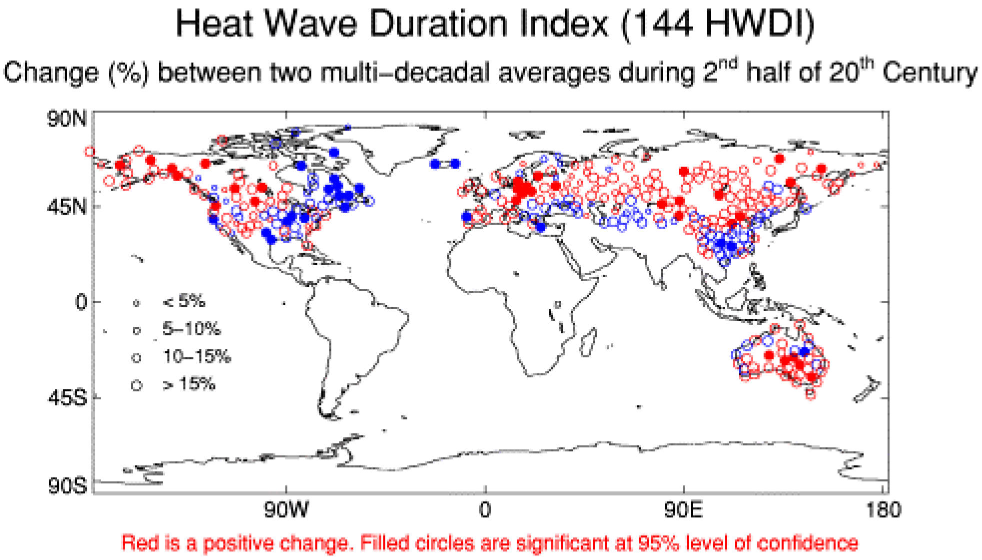
Red is a positive change. Filled circles are significant at 95% level of confidence



GSL annual anomalies

Trend significant at 95% level of confidence (using weighted linear regression analysis)

Figure 3a (top) As Figure 1a, but for growing season length **GSL** (Table 1).
Figure 3b (bottom) As Figure 1b, but for **GSL**.



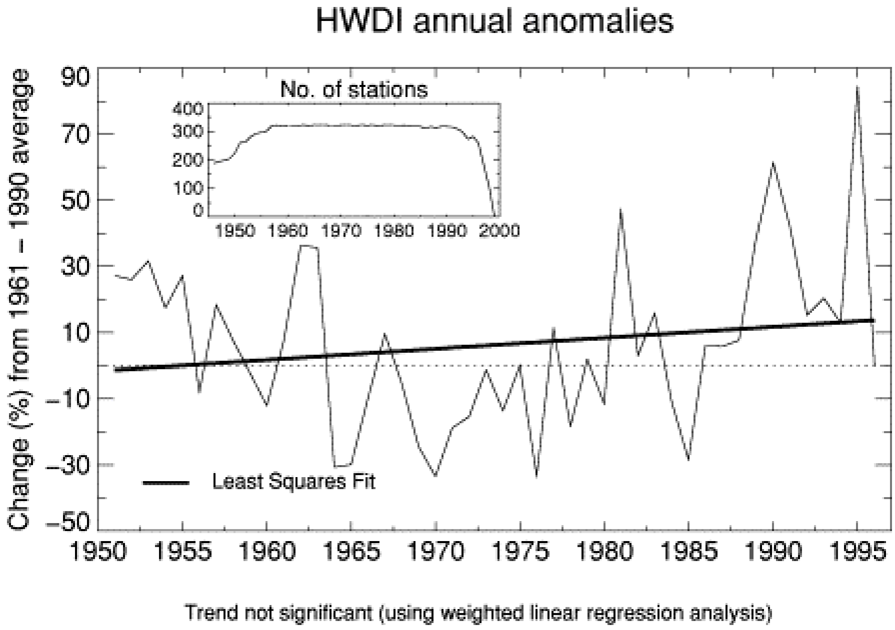
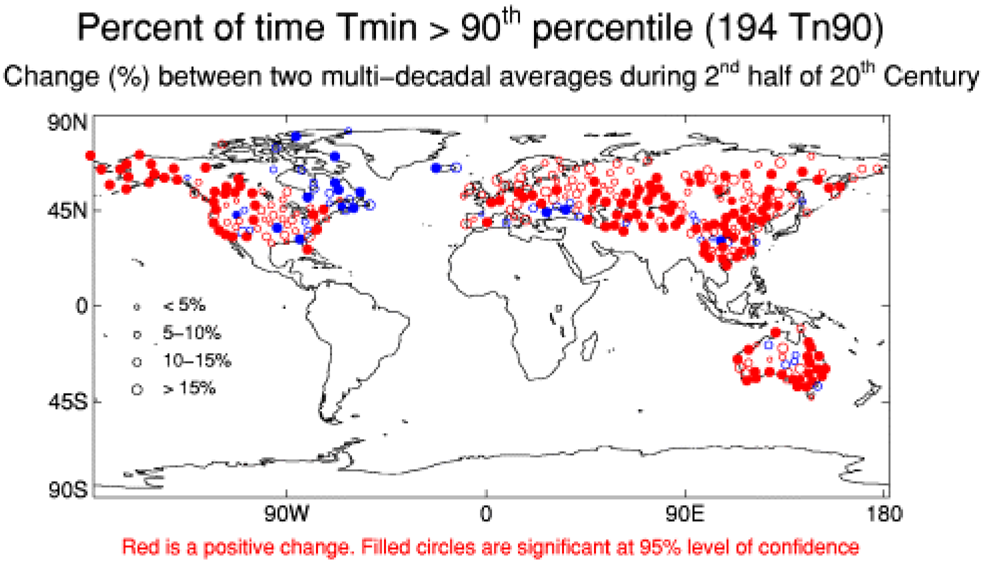


Figure 4a (top) As Figure 1a, but for heatwave duration index **HWDI** (Table 1)
Figure 4b (bottom) As Figure 1b, but for **HWDI**.



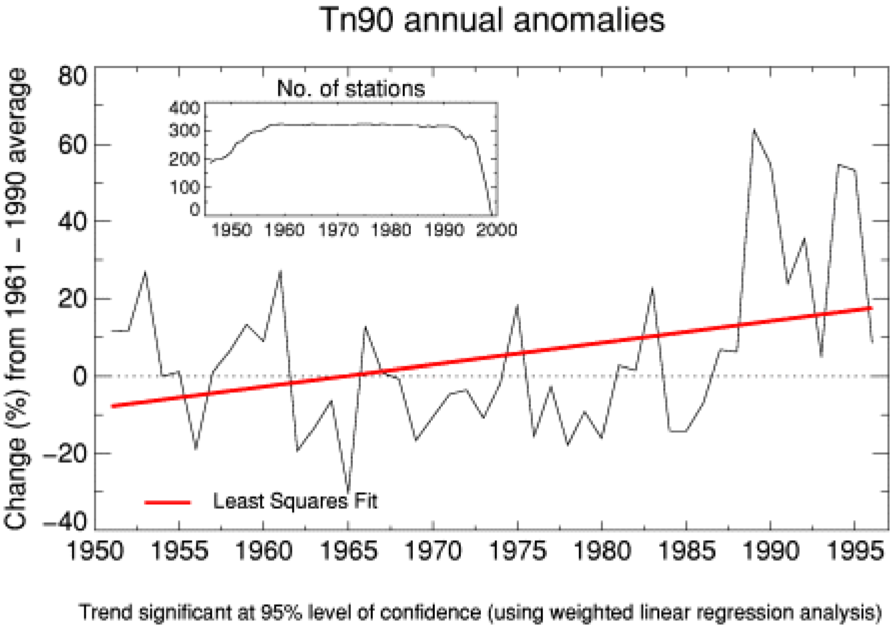
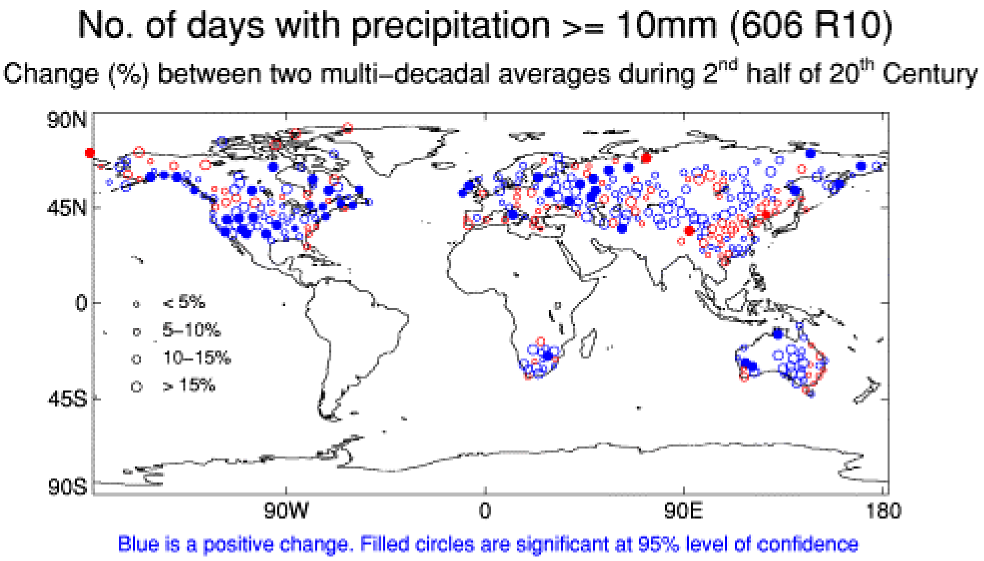


Figure 5a (top) As Figure 1a, but for percent of time when the daily minimum temperature is above the 90th percentile of the daily 1961-1990 value **Tn90** (Table 1).
Figure 5b (bottom) As Figure 1b, but for **Tn90**.



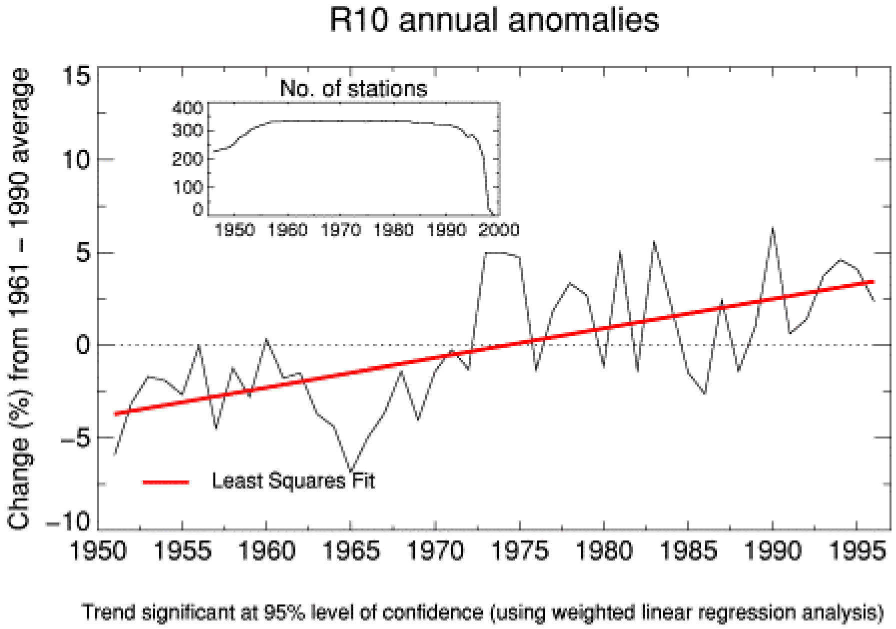
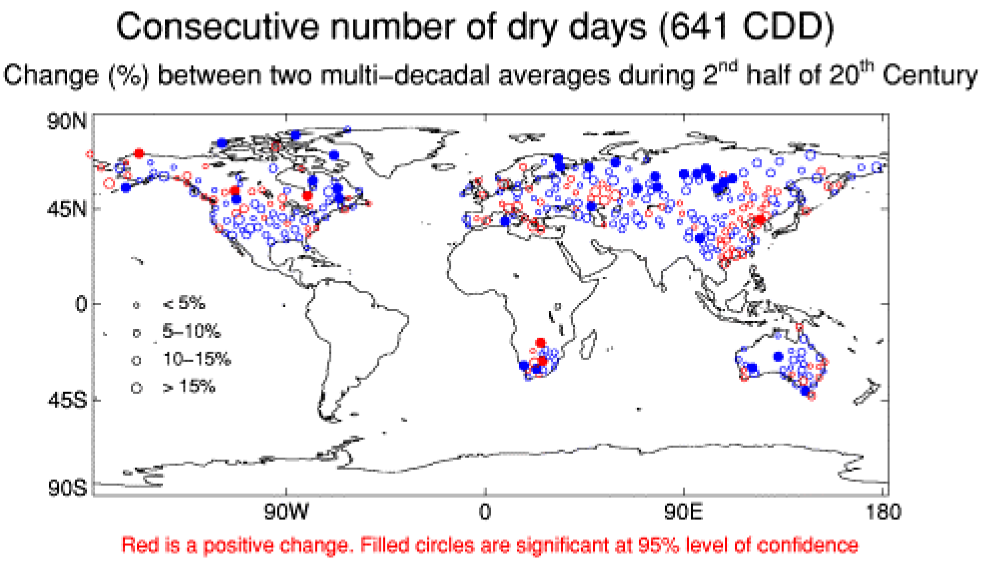


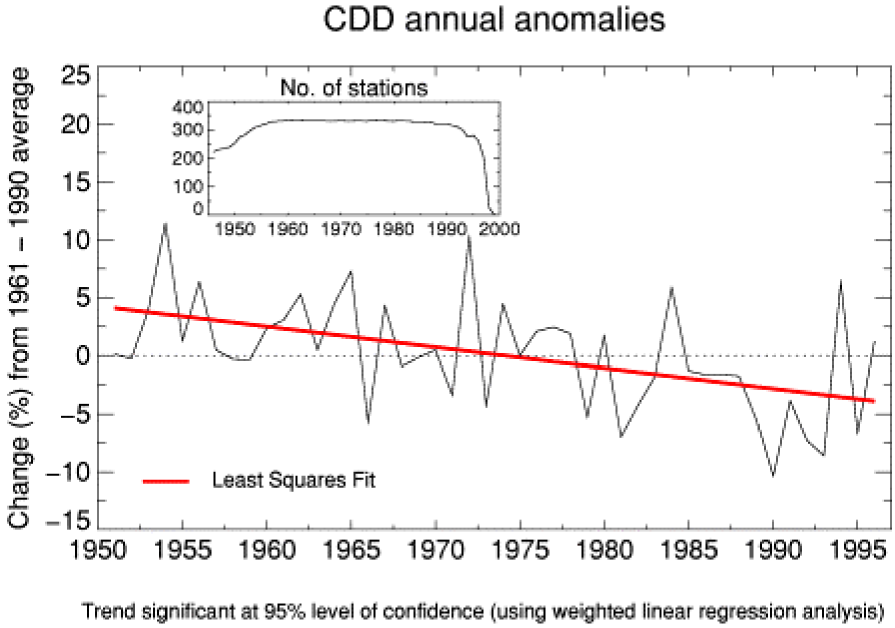
Figure 6a (top) As Figure 1a, but for the annual number of days with greater than or equal to 10mm of precipitation **R10** (Table 1).
Figure 6b (bottom) As Figure 1a, but for **R10**.



Consecutive number of dry days (641 CDD)

Change (%) between two multi–decadal averages during 2nd half of 20th Century

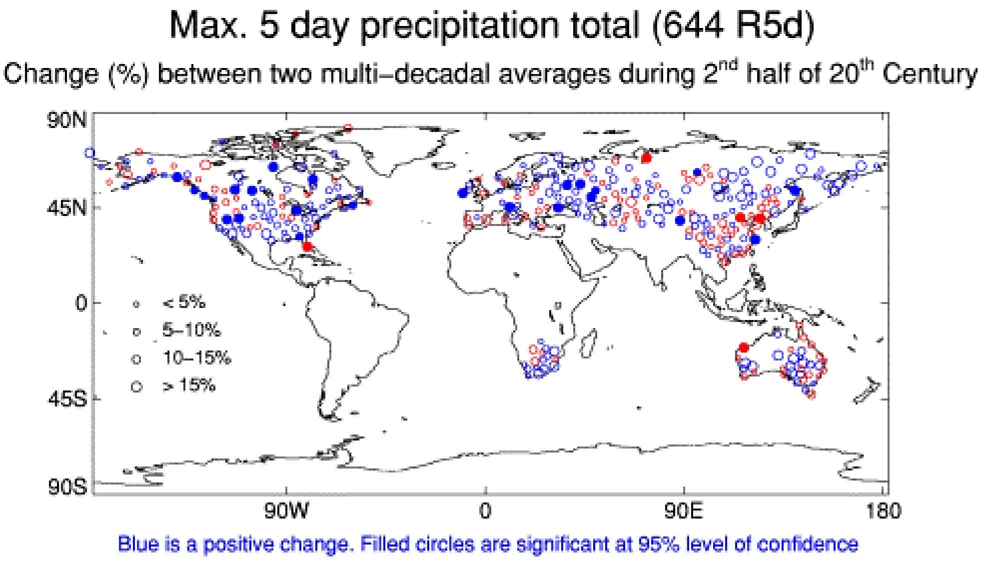
Red is a positive change. Filled circles are significant at 95% level of confidence



CDD annual anomalies

Trend significant at 95% level of confidence (using weighted linear regression analysis)

Figure 7a (top) As Figure1a, but for the consecutive number of days with less than 1mm precipitation **CDD** (Table 1).
Figure 7b (bottom) As Figure 1b, but for **CDD**.



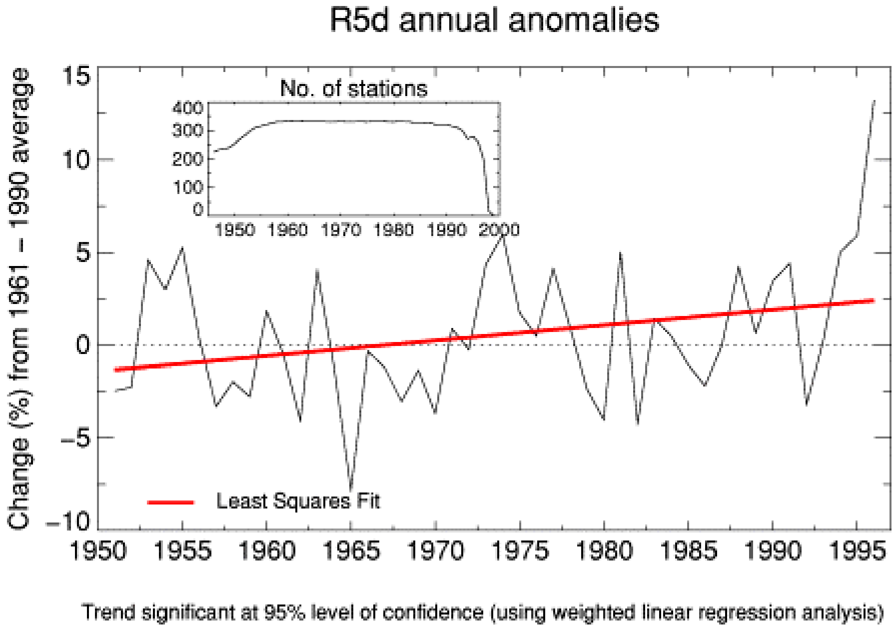
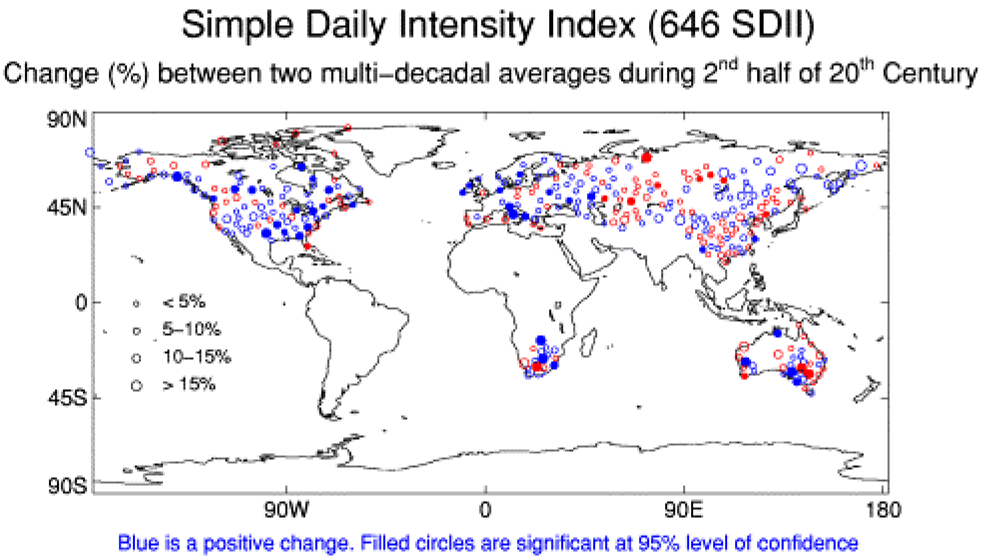


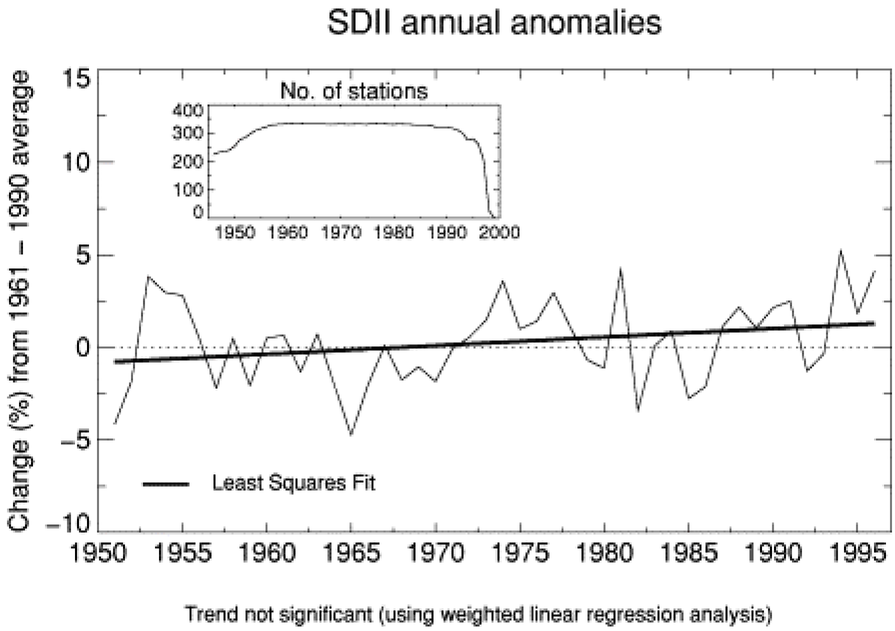
Figure 8a (top) As Figure 1a, but for maximum 5-day precipitation total **R5d** (Table 1).
Figure 8b (bottom) As Figure 1b, but for **R5d**.



Simple Daily Intensity Index (646 SDII)

Change (%) between two multi–decadal averages during 2nd half of 20th Century

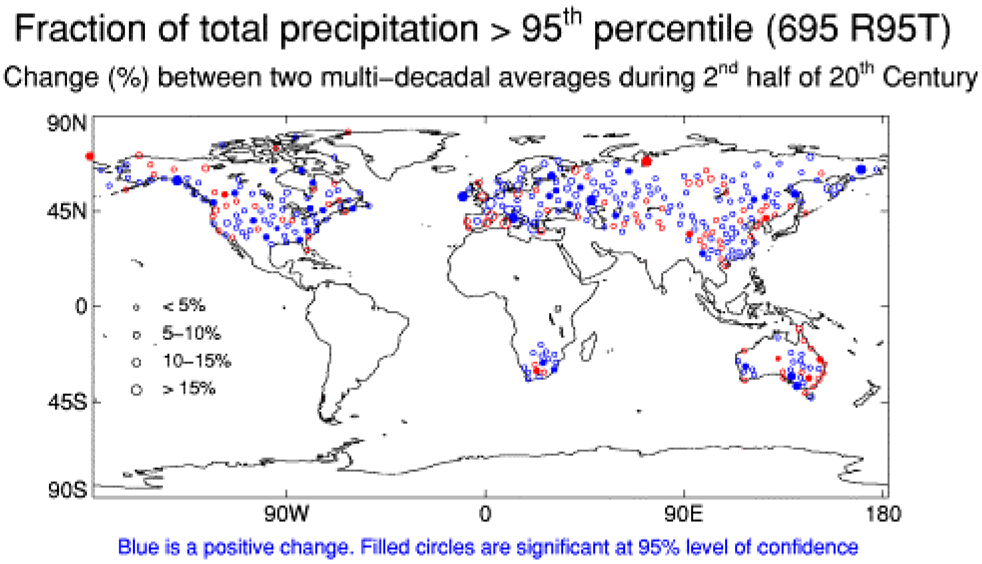
Blue is a positive change. Filled circles are significant at 95% level of confidence



SDII annual anomalies

Trend not significant (using weighted linear regression analysis)

Figure 9a (top) As Figure 1a, but for Simple Daily Intensity Index **SDII** (Table 1).
Figure 9b (bottom) As Figure 1b, but for **SDII**.



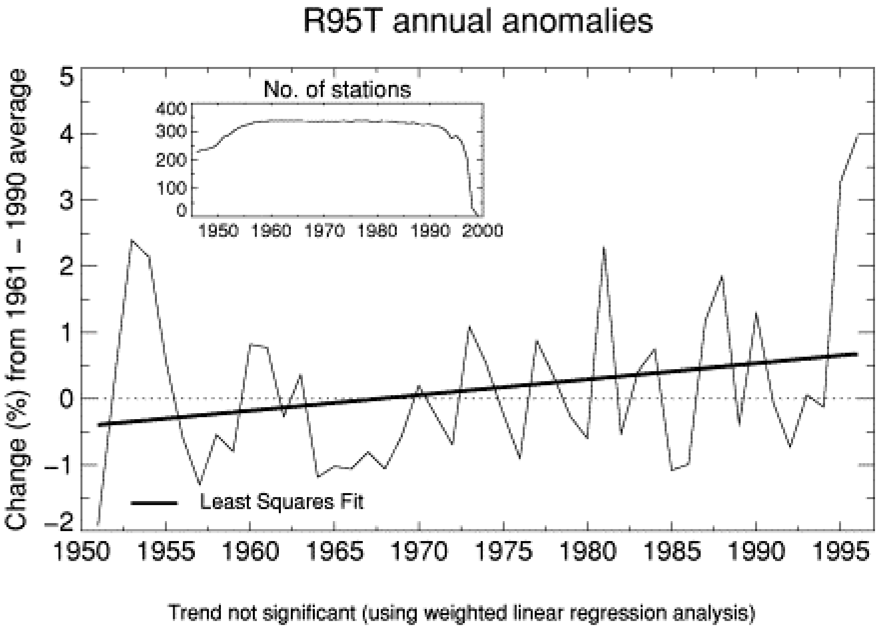


Figure 10a (top) As Figure 1a, but for the fraction of annual total precipitation due to events exceeding the 1961-1990 daily 95th percentile **R95T** (Table 1).
Figure 10b (bottom) As Figure 1b, but for **R95T**.

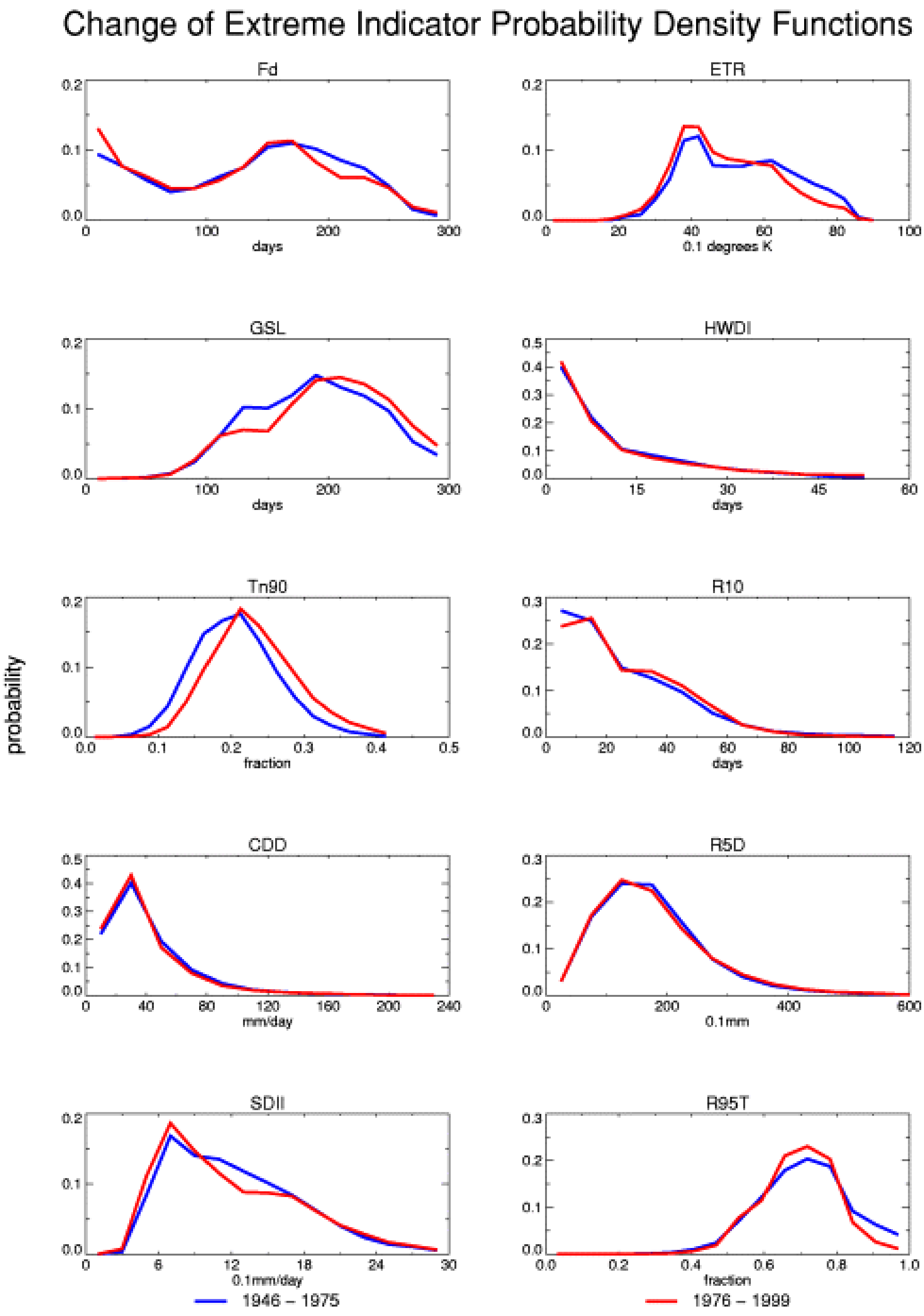


Figure 11. Probability Density Functions showing change in distribution of the 10 extreme indicators (Table 1) over two multi-decadal periods in the second half of the 20th century.

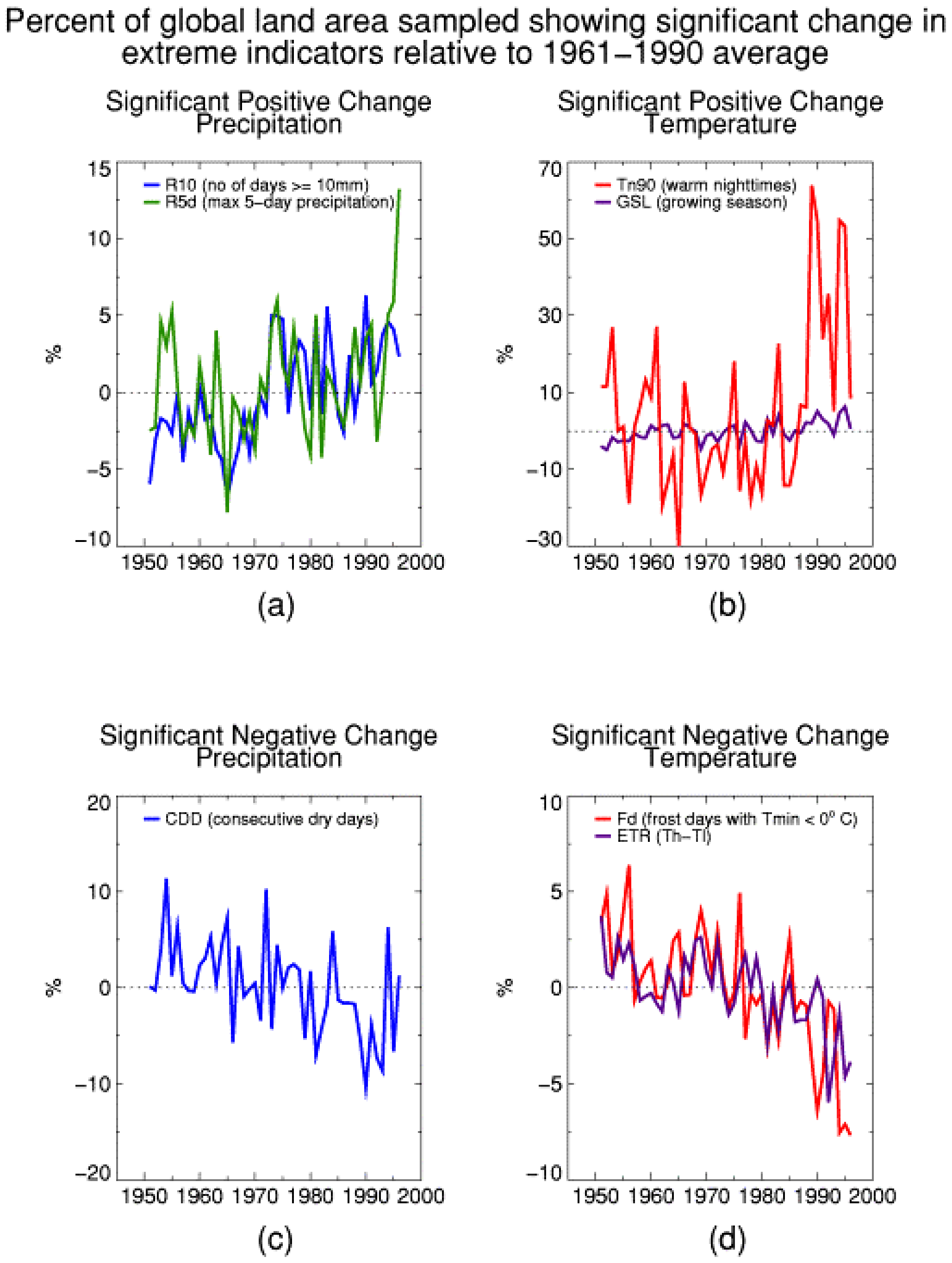


Figure 12. Summary of the results from Figures 1b – 10b which show a significant trend at the 95% level of confidence over the period from 1951-1996.