European and North Atlantic daily to MULtidecadal climate variability

EMULATE

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Final management report: November 2004 to February 2006

Section 3: Detailed report organized by Work Packages

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EMULATE home page: http://www.cru.uea.ac.uk/projects/emulate/

SECTION 3: DETAILED REPORT ORGANIZED BY WORK PACKAGES, RELATED TO THE REPORTING PERIOD, NOVEMBER 2004 TO FEBRUARY 2006

Workpackage 1: Create daily gridded MSLP fields from 1850

WP Leader: Phil Jones (UEA)

1.1 Objectives

The objectives of WP1 were:

- Digitize additional daily land station pressure data back to 1850
- Integrate daily land station data with the I-COADS Data Set
- Produce the daily gridded MSLP dataset (1850 to present) using the best method.

1.2 Methodology and scientific achievements related to WP2 including contributions from partners

This WP was completed at the end of year-2. The paper (Ansell *et al*., 2006) documenting the development of the daily gridded sea-level pressure dataset was submitted to a journal and has been accepted. It should appear later in 2006.

1.3 Socio-economic relevance and policy implications

The dataset will begin to be used by others once the paper appears in *J. Climate*. The dataset is the most extensive in terms of length of gridded daily sea-level pressure datasets available for the North Atlantic and Europe.

1.4 Discussion and conclusions

The WP was completed on schedule and all the deliverables are available on the website. A fuller discussion of the outcomes of this WP is included in Part 6 of the EMULATE report.

Workpackage 2: Derive a set of characteristic atmospheric circulation patterns, and study their variations and trends for each season

WP leader: Jucundus Jacobeit (UAUGS)

2.1 Objectives
The objectives of WP2 are:

- Define leading atmospheric circulation patterns for two-month and three-month seasons
- Create a database of quantitative changes in pattern amplitudes since 1850
- Assessments of trends in pattern amplitudes and in the incidence of their extremes
- Characterise within-pattern variability

2.2 Methodology and scientific achievements related to WP2 including contributions from partners

Contributions from the WP leader (UAUGS), the Hadley Centre (MetO), UBERN and from Ian Jolliffe (University of Aberdeen) have focussed on some improvements to the pattern amplitudes already delivered as D6, on comprehensive trend analyses satisfying D10, on studies of within-pattern variability and on some further related dynamical aspects. Figs. 1-16 cited in this summary report are available from the following Website:
http://phygeo7.geo.uni-augsburg.de/emulate/wp2

a) The time coefficients of the MSLP cluster patterns (the pattern amplitudes according to D6) have originally been calculated as correlation coefficients between the cluster centroids and each daily pressure pattern (see also the second annual report). It turned out that these coefficients all tend to be high obscuring differences between the various cluster patterns (due to correlating daily raw MSLP patterns with non-orthogonal sets of cluster centroids derived from error- and latitude-weighted pressure fields). Significant improvements have been achieved at UAUGS by calculating Euclidean distances between each daily pressure pattern and (error- and latitude-) weighted cluster centroids. These distances in terms of inverted and normalised time series will be added as a supplement to D6. Fig. 1 on the Augsburg website comparing original and novel coefficients for a summer example, clearly demonstrates the increased differences between patterns for the Euclidean-based time series.

b) Major parts of work were related to D10: "Assessments of trends in pattern amplitudes and in the incidence of amplitude extremes". Time coefficients of the cluster patterns based on (non-inverted) Euclidean distances were used as pattern amplitudes (increasing values for growing dissimilarities with the corresponding cluster centroids), and their extremes were defined in terms of particular percentiles (2^{nd}, 5^{th}, 10^{th}, 90^{th}, 95^{th}, 98^{th}). Trends within the EMULATE period 1850-2003 have been calculated at UAUGS for the 3-month seasons DJF, MAM, JJA, SON and the overlapping 2-month seasons JF, FM, MA, …, DJ both for pattern amplitudes (based on moving 20-day periods) and for their extreme percentiles (on a seasonal basis). All trends for periods greater or equal than 20 years have been submitted to the non-parametric Mann-Kendall trend test and integrated into triangular trend matrices (with start- and endyear on both axes and the shortest (20-year) periods along the diagonal). Results for all cluster patterns during all 16 seasons and for the 2^{nd} and 98^{th} percentiles will be put on the EMULATE website, some few examples are compiled at the website at Augsburg.

Concerning the pattern amplitudes Fig. 2 shows the trend matrices for two patterns during winter (DJF). Cluster 1 (an NAO-like pattern, see EMULATE website) has negative distance-trends (i.e. an increase in patterns similar to the centroid) mainly during the last decades; during earlier periods (e.g. ~1910-1970 or from 1860 onwards) less importance is indicated. Cluster 6 (with a strong Russian high and an Atlantic low) has a long-term positive trend in Euclidean coefficients throughout the EMULATE period associated with its negative trend in seasonal cluster frequencies (Philipp *et al*., 2006) indicating a gradual decline for this Russian high pattern since 1850. During summer (JJA, Fig. 3), different cluster trends can be observed: Clusters 2 and 4 with high pressure ridges from the Azores towards northeastern regions depict long-term increases in importance (declining distances), Clusters 5 and 6 with a more retreated subtropical high rather lost some importance (growing distances) except during most recent times.

Concerning the amplitude extremes only a few significant trends can be observed. The above-mentioned decline in the Russian high pattern during winter (Cluster 6) is also reflected in its percentile trends (Fig. 4): increasing ones for the 2nd percentile around 1860-1960 (indicating less distinct realisations of this pattern) as well as for the 98th percentile around 1860-1910 (indicating further growing distances to this pattern). Similar conditions are also evident for autumn (Cluster 4, 2nd percentile, not shown on the UAUGS website).

c) In order to characterize within-pattern variability, several parameters (cp. Jacobeit *et al.*, 2003) have been calculated on a daily basis: a correlation-based approximation for the relative vorticity within the area 40-60°N, 10°W-30°E; an intensity index measuring the pressure gradients between the corresponding centres of action; a temperature index based on 14 Central European stations, and a precipitation index based on 25 stations from this area. All these indices have been calculated as normalized 31-year moving averages for all the seasonal cluster patterns and will be put on the EMULATE website. Fig. 5 from the UAUGS website shows the seasonal vorticity parameter (independently from actual cluster patterns) indicating a recent accumulation of below-average values during winter, spring and summer after an opposite development especially during winter and summer since the late 19th century.

Concerning within-pattern temperatures, Fig. 6 with 3 cluster examples from winter (DJF) shows a distinct impact of global warming with different degrees of intermediate cooling between ~1930 and 1960: for the NAO-like cluster 1 (see EMULATE website) it remains rather moderate, for cluster 2 with a strong Russian high extending up to the British Isles it goes down to well below-average values, and for cluster 6 with the Russian high extending only up to Central Europe it develops even stronger before the recent warming which reaches peak values for the southwesterly cluster 1. During summer (JJA, Fig. 7), two patterns with low pressure around Iceland (cluster 1) or near Scotland (cluster 6) and only moderate ridging towards Central Europe depict a distinct warm period at the beginning of the EMULATE period turning into a striking cool period during the first decades of the 20th century and starting rather late with recent warming. During the transitional seasons, within-pattern temperatures developed quite differently. An example from spring (MAM, Fig. 8) even includes an opposite evolution with a long-term warming throughout the whole period for cluster 2 (low southwest of the British Isles) and a 20th century cooling for cluster 9 (extended high around this region). Detailed studies on regional radiation budgets and boundary conditions would be required to solve such phenomena.

Concerning within-pattern vorticity and precipitation (not always in complete accordance due to different domains, subgrid-scale effects and data restrictions during the earlier periods) the NAO-like cluster 1 for winter shows increases to higher levels since the 1920s with subsequently larger amplitudes for vorticity than for precipitation (Fig. 9). Cluster 7 with a low near Genoa has dropped considerably in vorticity since the 1940s, but within-pattern precipitation turned again already two decades later reaching highest values at the end of the time series (note its calculation as 31-year mean values). During summer (JJA, Fig. 10) two patterns with marginal high pressure influence in Central Europe (clusters 1 and 5) being rather wet during the 1950s are drying out since then in connection with increasing anticyclonicity. These few examples already demonstrate that climate variability is linked not only to frequency changes but also to within-pattern changes of major circulation types (see also Beck *et al*. 2006).

d) Finally, additional analyses beyond the scope of defined deliverables were carried out:

- In order to derive SLP patterns having by definition particular climatic characteristics (e.g. warm, cold, wet or dry in a selected region), simulated annealing clustering of daily MSLP fields has been performed at UAUGS with temperature or precipitation covariates, respectively. For this purpose station-based indices for Central Europe as already used for within-pattern analyses (section c) have been included, and the (seasonally varying) numbers of clusters (see Philipp *et al.*, 2006) have been adopted from the pure MSLP clustering. Figs. 11 and 12 give two examples for the winter season (DJF) sorting the pressure clusters according to successive anomalies in climate [note that this happens intrinsically for precipitation, i.e. clusters with higher (lower) frequencies are always drier (wetter) due to the limited duration of most rainfall events]. The thermal MSLP patterns (Fig. 11) with a temperature range of more than 20°C mainly depict a gradual sequence with a retreating Russian high and an increasing NAO. The precipitation-related patterns (Fig. 12) only include three anticyclonic ones with less precipitation (originating from Russian or Azores high pressure influence), the other ones with increasing precipitation are marked by gradually southward penetrating and deepening cyclonic waves.

- In order to present a more comprehensive overview of MSLP patterns included in each cluster, UAUGS followed an idea by Ian Jolliffe to select (besides the nearest pattern to the centroid) additional patterns being distinctly different from it (in terms of Euclidean distances). This may be achieved by iteratively selecting that pattern whose minimum distance to either the centroid or the earlier selected patterns is the highest of all remaining patterns. This growing set of 'fringe patterns' is defined to be complete if the distance to any of the predecessors is lower than the half of the maximum diameter of the corresponding cluster. Fig. 13 presents these fringe patterns for the first 3 MSLP clusters during winter (DJF) clearly pointing to significant differences between patterns within the same cluster. For example, the second pattern within cluster 1 does not reproduce a positive mode of the NAO which constitutes the centroid pattern. Thus, considerable within-cluster variability has to be taken into account during each kind of dynamical analysis.

- The time constrained clustering developed at UWUERZ/UAUGS according to suggestions of Ian Jolliffe aiming at an increased persistence in cluster sequences, was further investigated with respect to appropriate rules for adjusting the degree of constraining, but no definite rules could yet be determined. Instead another extended approach in clustering techniques called COSA (Clustering Objects on Subsets of Attributes) has been elaborated at UAUGS according to suggestions of Ian Jolliffe. First attempts have been made with regional subsets (Central Europe and the Mediterranean area), but interpretation of results is still quite difficult.

- UBERN investigated North Atlantic and European winter cyclone changes from 1881-2003 by applying a Lagrangian cyclone tracking algorithm (Murray and Simmonds, 1991) on the EMSLP dataset (referring to large-scale systems according to the gridded data resolution). Cyclone system density (Fig. 14) has also been computed at grid points north and south of the line connecting 45ºN, 60ºW with 55ºN, 30ºW (Bhend, 2005) providing a North-Atlantic storm track index (Fig. 15 with positive values for a northern position). There has been a significant decrease in the number of cyclones in the central North Atlantic and the Mediterranean region from 1881-2003 linked with a northward shift of the North Atlantic storm track. However, there are considerable uncertainties remaining in the dataset (increasing number of observations) especially for the Atlantic region (high RSOI errors).

- In order to achieve a closer correspondence of circulation patterns to regional extremes in temperature and precipitation, an objective classification into Central European Grosswettertypes (GWT) that has been derived on a monthly scale (Beck et al. 2006) has been adopted to the daily scale within UAUGS-WP2 analyses. This classification (Fig. 16) includes ten major types according to the main flow directions (W, SW, …) and to regional pressure centres (HC: High above Central Europe; LC: Low above Central Europe) and was applied to some of the WP4 analyses.

2.3 Socio-economic relevance and policy implications

The classification of daily SLP fields into atmospheric circulation types has been used for studying circulation dynamics of climatic extreme events (link to WP4), and this will be of major importance for society including risk assessments and mitigation strategies.

2.4 Discussion and conclusions

All contributions from the above-mentioned partners have been presented and discussed during the fourth EMULATE meeting in Gif near Paris (October 2005). The consortium has succeeded in improving the circulation pattern amplitudes (D6), in achieving a complete overview of trends in pattern amplitudes and their extremes (D10), in assessing within-pattern variability by means of several dynamic and climatic parameters, and in making progress with respect to further extended efforts in circulation classification and variability analyses. WP2 has developed a highly sophisticated clustering technique being most appropriate for daily MSLP fields and has been going into the analysis of large-scale circulation variability back to 1850 on a daily scale. Results have been used for first studies on temperature and precipitation extremes (WP4), and these approaches will be further intensified in the future.

Workpackage 3: Relate variations and trends in atmospheric circulation patterns to prominent extremes in temperature and precipitation

WP Leader: Chris Folland (MetO)

3.1 The objectives of WP1 for the reporting period were:

- Document the spatial and temporal relationships between SST and pressure patterns measured on sub-monthly time scales and associated seasonal European temperature/precipitation patterns.
- Assess the influence on the relationship of other external forcings, both natural and anthropogenic, with particular reference to similarities/differences between the seasons.
- Quantify the fraction of the total spatial/temporal variability that can be explained by internal stochastic variability and all available external forcings respectively.
- Develop a gridded drought index data base, and investigate the existence of any links between North Atlantic SST patterns and European drought patterns.
- Make estimates of potential predictability, where feasible, on interannual to decadal time scales.Digitize additional daily land station pressure data back to 1850

3.2 Methodology and scientific achievements related to WP3 including contributions from partners

Deliverables D7 (relating observed North Atlantic-European circulation to SST) and D8 (Gridded database of drought index for Europe) completed. D7 includes a discussion of the summer North Atlantic Oscillation (SNAO) pattern found in EMULATE cluster analyses and empirical orthogonal function analyses. These indicate substantial interannual to interdecadal variability of the SNAO since 1850, a significant fraction of which can be related to SST patterns that differ strongly between interannual and interdecadal time scales. This work was also done in collaboration with the National Center for Atmospheric Research, Boulder, Colorado, USA.

All 36 EMULATE historical model simulations completed. These include 18 with natural forcing and a further 18 with natural and anthropogenic forcing. All the model data has been loaded onto new Hadley Centre externally accessible web site, for access to the partners in EMULATE. These are now available to all outside the project.

Additional sets of calculations were performed or analysed as suggested by the results of the historical ensembles. These include a long coupled ocean-atmosphere control simulation to examine the links between ocean circulation, SSTs and climate. A parallel atmospheric model ensemble with observed long-term stratospheric circulation trends was also performed to examine the effect of the stratosphere on the winter NAO. A large set of one-year atmospheric simulations using composites of observed El Niño sea-surface temperatures was performed to examine the difference in the response of North Atlantic and European climate to strong and weak El Niño events. Finally coupled model integrations were done for conditions of twice the level of pre-industrial carbon dioxide and four times that level to determine if any significant changes in the strength of the SNAO can be seen. An increase in the phase of the SNAO atmospheric circulation pattern favouring increased high summer drought over the UK and Scandinavia clearly emerged.

Further supported by some of the results emerging from the WP3 modelling studies, a forecast for the European winter 2005-6 was made based on the May 2005 North Atlantic sea-surface temperature pattern, issued in July 2005. This technique is partly based on a paper published by the Hadley Centre in 2002 and was assisted by work undertaken during the EU Framework 4 SINTEX project completed in 2003. The technique relies on the re-emergence of the May North Atlantic “tripole” SST anomaly pattern in the following autumn after the summer seasonal thermocline has disappeared, as well as an extension of the SST pattern below the surface. The forecast was for a 2 in 3 chance of a cold winter. The forecast was borne out by events, with Europe experiencing its coldest winter for a decade (see further details in Part 6 of this report). The existence of the new ARGO float array allowed continual monitoring of the pattern of North Atlantic sub-surface ocean temperature anomalies in addition to those at the surface. Work done by EMULATE partners also confirmed the influence of the same “tripole” SST pattern in the winter on the winter NAO.

A paper was published (Scaife *et al.*, 2005) showing that the increase in the winter NAO between 1965 and 1995, which can explain most of the observed mean surface temperature and precipitation changes over that time, can be fully simulated in a climate model by imposing the observed changes in lower stratospheric winds as well as the observed SST changes. This indicates that the stratosphere may play a crucial role in NAO and European winter climate variations on decadal time scales.

A paper has been published (Knight *et al.*, 2005) showing that North Atlantic interdecadal SST variations are influenced by a mode of variability based on natural variations in the thermohaline circulation. The paper includes a prediction of changes in this natural mode in the early 21st century, additional to any anthropogenically-forced changes in the thermohaline circulation:

The model data have been used by the partners within WP3 to examine the role of sea-surface temperatures and climate forcings on European climate, particularly circulation. In addition, the results have also been used in WP4 to examine changes and attribution of extreme events. Andreas Philipp of the University of Augsburg (partner 3) visited the Hadley Centre (partner 2). Discussions focussed on the interpretation of the circulation classification results and the extension of the WP2 mean sea-level pressure data set to do semi-operational monitoring.

Deliverables D11 (influence of SST and circulation on land surface temperature and precipitation), D12 (examination of relationships in D7 and D11 in the model simulations) and D13 (assessment of influence of external forcings and internal variability) have all been completed and posted on the EMULATE website. Some additional new results on possible interannual influences of SST related to the El Niño phenomenon on the summer North Atlantic Oscillation are included in D7 and D11.

A paper (van der Schrier *et al.*, 2006) on the European drought index has been accepted by the *Journal of Climate*: A first draft of a paper on circulation regimes, their relationship to SST, and climate forcings has been completed. It will be submitted to the *Journal of Climate*, but after this final report is finished. A first draft of a paper on simulated changes in extreme events associated with decadal increases in the NAO between 1965 and 1995, is in preparation in collaboration with scientists working on WP4. It will also be submitted to the *Journal of Climate*.

3.3 Socio-economic relevance and policy implications

The forecasting for the winter season over Europe, developed within WP3, has enormous potential benefits for national economies and utility companies across Europe. One successful forecast for the 2005/06 winter is encouraging, but considerable effort will be needed to further understand the mechanisms that lay behind the approach and ensure that coupled climate models reflect these processes correctly. Additionally, better understanding of the processes should lead to improvements in success rates, which currently stand at 2 out of 3. The climate model integrations will be particularly useful in this regard. The influence of the current climate warming also needs to be accounted for more explicitly.

Related to the successful forecast, the new work undertaken in EMULATE explaining the long-term increase in the NAO between the 1960s and 1990s also augurs well for additional improvements in the predictability of European winters. The various databases developed within the project will provide an excellent sample of historic and modelled variability with which to test additional ideas.

3.4 Discussion and conclusions

WP3 has yielded substantial advances in analysis and interpretation of temperature and precipitation over Europe in relation to regional atmospheric circulation and to sea surface temperature in the Atlantic and further afield, especially in winter and summer. Typical patterns of drought and moisture are now better understood in the light of characteristic patterns of mean sea level pressure and their connected oceanic temperature signals. WP3 has enabled improvements in seasonal prediction, and the potential for such predictions is now clearer. However, model simulations have demonstrated the need for a much improved representation of the stratosphere for winter seasonal climate prediction and for simulation of long term trends in winter climate over Europe. The simulations have begun to unravel the anthropogenic influences on European climate, especially in summer, and suggest a tendency to substantrially more frequent drought in future under increasing greenhouse forcing, especially for regions affected by the SNAO. Some predictability of the SNAO in current climate conditions seems likely from SST, and will be a strong focus of research to follow up the EMULATE work.

Workpackage 4: Relate variations and trends in atmospheric circulation patterns to prominent extremes in temperature and precipitation

WP leader: Anders Moberg (SU)

4.1 Objectives

The objectives of WP4, relating to the reporting period, are:

- Determination of a selection of extreme climate indices for Europe and assessment of changes in these indices since 1850.
- Determine the significance of atmospheric circulation for the extreme indices.
- Ascertain whether extremes of climate had different characteristics in the late 20th century from those evident in the late 19th and early 20th centuries and determine the likely magnitude of human influences.

4.2 Methodology and scientific achievements related to WP4 including contributions from partners

Much work in months 24-40 has been based on analyses of the indices for temperature and precipitation extremes that were developed as D9 in year-2. Some errors and inhomogeneities in the original station data obtained from external data providers were discovered. Therefore, part of the work has consisted of replacing data for a number of stations with improved versions of daily data, in particular the precipitation series from Russian stations. When the first version of D9 was developed, we had only access to Russian data that had not been subject to homogenization. During 2005, however, scientists outside EMULATE released a new homogenized version of the Russian precipitation series. To improve the quality of the EMULATE database of precipitation indices, we updated our station database with these series. Additionally, we had to delete daily minimum temperature data for Romanian stations, which were found to be erroneous. The work with updating the station database has primarily involved partners 1, 7 and 8. Corrected extremes index series have been made available on the EMULATE public domain website.

Based on the corrected data base, several studies have been made of trends in indices for temperature and precipitation extremes over various periods, e.g. 1850-2003, 1880-2003, 1901-2000. Results from these studies contribute to deliverable D14. Further analyses, contributing to D15, have dealt with determining statistical relationships between the leading atmospheric circulation patterns over the North Atlantic and Europe (based on results from D3, D5 and D6) and various indices for temperature and precipitation extremes in Europe during the entire 20th century or back into the late 19th century. For D16, output from simulations with an atmospheric model (data produced in WP3) have been analysed with the purpose of identifying the likely anthropogenic influence on the occurrence of temperature extremes. All eight partners have contributed to varying extent to deliverables in WP4. Major parts of the work are briefly described below. All analyses have been reported in either scientific manuscripts submitted to journals, or department reports or as reports specifically written for the project.

D14: Assessments of changes in temperature and precipitation extremes since the late nineteenth century

Indices for daily temperature and precipitation extremes analysed for the period 1901-2000. Under leadership of partner 7, with contributions from all other partners, a selection of 19 of the 64 indices in D9 has been analysed. Linear trends have been calculated at all stations west of 60°E over the period 1901-2000. The size of trends at indices based on different percentiles (2^{nd}, 5^{th}, 10^{th}, 90^{th}, 95^{th}, 98^{th}) have been compared with indices for mean conditions, to see if trends in extremes have behaved differently compared to those in the mean. Analyses were also made for six selected European sub-regions. Results were presented both as maps showing trends at individual stations and as time series for selected stations and regions, as well as graphs that compare trends in different percentiles. A paper has been submitted and is in review (Moberg *et al*., 2006).

Trend atlas of the EMULATE indices: Extreme temperature and precipitation climates over Europe. We have also developed an atlas which gives a more complete picture of trends in the various indices in D9. This atlas shows the spatial distribution of indices, the temporal trends of selected indices, annual trends, seasonal trends and time series for regional means. The atlas is developed as a department report by partner 8, with contributions from partners 1, 3 and 7.

Spatial and temporal temperature variability and change over Spain during 1850-2003. More detailed analyses of trends in temperature and precipitation indices focussing on Spain have been led by partner 5, with contributions from partners 1, 6, 7 and 8. Rotated Principal Component Analysis has been carried out to identify spatial modes of long-term temperature variability. Relationships between Spanish spatial modes of temperature variability and large scale atmospheric circulation anomalies, the North Atlantic Oscillation and Southern Oscillation, have also been assessed for the period 1894-2003. A journal manuscript is nearly completed for submission.

The development of a new daily adjusted temperature dataset for Spain (1850-2003). The work on digitizing and homogenization of Spanish data carried out during year 2 has now been documented in a journal paper that has been accepted for publication (Brunet *et al*, 2006). This work was led by partner 5, with contributions from partners 1, 3, 7 and 8. An empirically based minimisation of the bias related to the impact of changing exposure of thermometers on the records has been undertaken. The Standard Normal Homogeneity Test was applied to check homogeneity of raw Tmax and Tmin data on a monthly basis. Analyses of the daily precipitation records from Spain have also been carried out during this reporting period.

A method of homogenizing the extremes and mean of daily temperature measurements. Partner 6 has developed a new method of homogenizing daily temperature data that is capable of adjusting not only the mean of a daily temperature series but also the higher order moments. The performance of this method is demonstrated in a paper accepted for publication (Della-Marta and Wanner, 2006). Results show that given a suitably reliable reference station, the method produces reliable adjustments to the mean, variance and skewness of daily temperature data.

Analysis of the length of western European summer heatwaves since 1880. Partner 6 has also undertaken a detailed analysis of the past behaviour of summer heatwaves in co-operation with partner 1. Using 54 high quality homogenized daily maximum temperature series from western Europe (based on a subset of the data in D9, where 26 station series were homogenized with the method mentioned above), the change in frequency, persistence and variance of extreme summer temperatures have been investigated. A main conclusion is that, over the period 1880 to 2003, the length of summer heatwaves over western Europe has doubled and the frequency of hot days has increased by 173%. A journal manuscript has been submitted.

Trend matrices for regional climatic time series. Partner 3 has calculated, for daily mean temperature and daily precipitation at selected stations, trend matrices for the EMULATE period 1850-2003. These show how the size and sign as well as the statistical significance of trends change as a function of start and end years for the trend analyses. Analyses are made for two European regions ("Germany" and the "Greater Alpine Region"). Trends have been calculated for all periods greater or equal than 20 years with statistical significance determined by the non-parametric Mann-Kendall trend test. Results are documented in a project report.

Growing season trends in the greater Baltic area. Partner 8 has, based on the daily temperature series from D9 and daily temperature series from other European stations with shorter records, evaluated different existing and new indices used for calculating the thermal growing season for the Greater Baltic Area. There was little difference in trends depending on the indices used. The general mean trend for the twentieth century has been towards a lengthening of the growing season of about 20 days. A department report is prepared.

D15: Assessments of the influence of atmospheric circulation variations on the incidence of extremes

Summer heat waves over western Europe 1880-2003, their change and relationships to large scale forcings. Partner 6 has, together with Partner 5, analysed reasons for the increased length of summer heat waves, by investigating the teleconnections between atmospheric circulation, sea surface temperatures, precipitation and heat wave events over western Europe. Using Canonical Correlation Analysis, heat waves over western Europe are shown to be related to anomalous high pressure over Scandinavia and central western Europe. We also find statistical evidence that long-term changes in the Azores High, continental European SLP, North Atlantic SSTs and European summer precipitation have driven the increased heat wave occurrence.

Correlations between indices for temperature and precipitation extremes in Europe and the leading atmospheric circulation mode during 1901-2000. The relationships between the first EOF of the daily SLP field (from D3 in WP1) and 25 selected temperature and precipitation indices (from D9) have been analysed over the entire 20th century by Partners 7 and 2. This gives an overview, for the whole of Europe, of how the relationships vary among indices and seasons. The correlations for each station have been plotted as maps. A graphic summary of results is made for two selected regions of particular interest (NW Europe and the Iberian Peninsula). Analyses of the time stability of the correlations are also assed using running 31-year correlations calculated for stations in the two selected regions.

Daily MSLP classifications and PCA-derived circulation patterns in relation to temperature and precipitation extremes. Partner 3 has analysed relations between the atmospheric circulation and the incidence of temperature and precipitation extremes in Germany. One study deals with the importance for such extremes of circulation patterns derived from daily MSLP classifications, based both on cluster analysis (from D5 and D6) and Grosswetterlagens. Another study specifies major circulation patterns during five-day sequences linked to the extremes by means of extended principal component analyses. An example result reveals that within-type variations of large-scale circulation types play an important role in the relationships between circulation and climate extremes.

Surface temperature anomalies extremes and SLP cluster Association. Partner 4 developed another approach for associating temperature extremes to atmospheric circulation patterns. First, they identified the individual days with extreme temperature conditions at each station with data back before 1900. Then, they associated each of these occurrences with the atmospheric circulation type in each particular day, by using the cluster classification made by Partner 3 (D5 and D6). Finally, they calculated, for each station, the conditional probability that a temperature extreme occurs within a certain atmospheric circulation type, using a five-grade scale (very unlikely, unlikely, normal, likely, very likely). This analysis focussed on Europe south of 60ºN and west of 35ºE.

Climate extremes and the North Atlantic Oscillation. Partner 2 studied the relationships between temperature and precipitation extremes and the North Atlantic Oscillation. This study is largely based on ensemble simulations for the later half of the 20th (from WP3). The “all forcings” simulations were complemented with another ensemble, which additionally uses a perturbation that mimics the observed trends towards stronger stratospheric westerlies. This gives a better reproduction of the observed increase in the surface NAO. The model experiments were then used to examine the impact of changes in NAO on the frequency of extreme events. Comparisons were also made with observational results from Partner 7. This analysis mainly contributes to WP3, but is also relevant in the context of D15.

D16: Assessment of the likelihood of any anthropogenic influence on extremes.

The climate model simulations from WP3 have been further analysed by Partners 8, 1, 2 and 7. Daily near-surface air temperature (Tmin, Tmax, Tmean) and precipitation (prec) from the 36 model integrations were used to calculate a number of indices over the period 1951-2000. Results for the natural-only runs were subtracted from those of all-forcings runs. To minimize the effect of internal variability, ensemble means of all runs in each subset were used. The difference in the means and the difference in trends over the 50 years were analysed for each season (DJF, MAM, JJA, SON). Both the warm and cold tails of temperature distributions were assessed as well as the 95th percentiles of daily precipitation. Results reveal significant differences between the two ensembles of simulations, which are interpreted as the anthropogenic influence on extremes.

4.3 Socio-economic relevance and policy implications

An example of socio-economic relevance of WP4 is the need of the insurance industry to better understand how precipitation and temperature extremes have been changing in the recent past and to which degree an anthropogenic influence can be seen in these occurrences. WP4 provides essential background knowledge for estimating the expected occurrence of weather-related extreme situations in the near future.

4.4 Discussion and conclusions

WP4 has essentially followed the work plan and all items described there have been addressed. All partners have contributed with different kinds of analyses. Much of the work undertaken in months 25-40 was based on deliverables from year 2 (D5 and D6 in WP2, D9 in WP4) as well as on model data from WP3. Among the results from the several studies undertaken, the following can be highlighted:

(a) Linear trends over the period 1901-2000 show a warming for all European temperature indices investigated. There are, however, large regional differences in temperature trend patterns. Winter precipitation totals, north of 40degN, have increased significantly by ~12% per 100yr. Trends in 90^{th}, 95^{th} and 98^{th} percentiles of daily winter precipitation have been similar. There is an overall weak tendency for summer precipitation to have become slightly more intense but less common.

(b) Over the period 1880 to 2003, the length of summer heatwaves over western Europe has doubled and the frequency of hot days has increased by 173%. Western Europe's climate has become more extreme than previously thought and the hypothesized increase in variance of future summer temperature has been a reality over the last 125 years.

(c) Around 46% of the variability in summer heat waves can be explained by a statistical model combining combination of summer SLP anomalies, summer Atlantic and Mediterranean SSTs and summer European precipitation anomalies as predictors. There seems to be some predictability of heat wave events at the decadal scale.

(d) There are significant differences between the mean values and trends over 1951-2000 in the model simulations made with anthropogenic-plus-natural forcings compared to those made with natural-only forcings, both in temperature and precipitation extremes. Seasonal and regional patterns can be identified, but not all differences are statistically significant.

Workpackage 5: Dissemination and Exploitation of Results

WP Leader: Phil Jones (UEA)

5.1 Objectives

The objectives of WP5 were to develop the website, ensure that the project was managed efficiently and to make all the results available from the project to the outside world.

5.2 Methodology

The website was developed early in the project and was used extensively to exchange datasets between the partners. At the end of the project, the website has all the deliverables (or links to the partner website where they can be downloaded from) and will in the future have all the papers that have resulted from the project.

5.3 Socio-economic relevance and policy implications

There are extensive datasets on the EMULATE website, which will be useful to scientists across Europe. These include: the daily gridded sea-level pressure dataset for 1850-2003; daily circulation types for this same period using three different methods; two sets of 18 ensemble members of simulations of HadAM3 (available from Partner 2), one using just natural forcing factors with the other set using natural and anthropogenic forcing; a drought database for Europe and an extensive database of 64 climate extreme indices based on 75 temperature and 121 precipitation series.

5.4 Discussion and conclusions

All the datasets, deliverable reports, the final report and the resulting papers when published will remain on the EMULATE website for at least three years.

References

Ansell,T.J., P.D. Jones, R.J. Allan, D. Lister, D.E. Parker, M. Brunet, A. Moberg, J. Jacobeit, P. Brohan, N.A. Rayner, E. Aguilar, M. Barriendos, T. Brandsma, N.J. Cox, P.M. Della-Marta, A. Drebs, D. Founda, F. Gerstengarbe, K. Hickey, T. Jónsson, J. Luterbacher, Ø. Nordli, H. Oesterle, M. Petrakis, A. Philipp, M.J. Rodwell, O. Saladié, J. Sigro, V. Slonosky, L. Srnec, V., 2006: Daily mean sea level pressure reconstructions for the European-North Atlantic region for the period 1850-2003. *J. Climate* (in press).

Beck, C., J. Jacobeit & P.D. Jones, 2006: Frequency and within-type variations of large-scale circulation types and their effects on low-frequency climatic variability in Central Europe since 1780. *Int. J. Climatol*. (accepted).

Bhend, J., 2005: North Atlantic and European Cyclones: Their Variability and Change from 1881 to 2003. Master Thesis. Institute of Geography, University of Bern, Switzerland.

Brunet, M.., Saladié, O., Jones, P. D., Sigró, J., Moberg, A., Aguilar, E., Walther, A., Lister, D., Y López, D., 2006: The development of a new daily adjusted temperature dataset for Spain (1850-2003, *International Journal of Climatology* (in press).

Della-Marta, P. M., Wanner, H., 2006: A method of homogenizing the extremes and mean of daily temperature measurements. *J Climate* (in press).

Jacobeit, J. *et al*., 2003: Atmospheric circulation variability in the North-Atlantic-European area since the mid-seventeenth century. *Clim Dyn* **20**: 341-352.

Knight, J. R., Allan, R. J., Folland, C. K., Vellinga, M. and Mann, M.E., 2005: A signature of persistent natural thermohaline circulation cycles in observed climate, *Geophysical Research Letters,* **32,** L20708, doi:10.1029/2005GL024233.

Moberg, A., Jones, P.D., Lister, D., Walther, A., Brunet, M., Jacobeit, J., Alexander, L. V., Della-Marta, P. M., Luterbacher, J., Yiou, P., Chen, D., Klein Tank, A. M. G., Saladié, O., Sigró, J., Aguilar, E,, Alexandersson, H., Almarza, C., Auer, I., Barriendos, M., Begert, M., Bergström, H., Böhm, R., Butler, J. C., Caesar, J,, Drebs, A., Founda, D., Gersengarbe, F-W., Micela, G., Maugeri, M., Österle, H., Pandzic, K., Petrakis, M., Srnec, L., Tolasz, R., Tuomenvirta, H., Werner, P. C., Linderholm, H., Philipp, A., Wanner, H. and Xoplaki, E.. 2006: Indices for daily temperature and precipitation extremes analysed for the period 1901-2000. *Journal of Geophysical Research – Atmospheres* (in review).

Murray, R. & Simmonds, I., 1991: A numerical scheme for tracking cyclone centres from digital data, Part I: development and operation of the scheme. *Australian Meteorological Magazine*, **39**, 155-166.

Philipp, A. *et al*., 2006: Long-term variability of daily North-Atlantic–European Pressure Patterns since 1850 classified by Simulated Annealing Clustering (submitted).

Scaife, A., Knight, J. R., Vallis, G. K. and Folland, C.K., 2005: A stratospheric influence on the winter NAO and North Atlantic, *Geophysical Research Letters,* **32,** L18715, doi:10.1029/2005GL023226.

van der Schrier, G., Briffa, K. R., Jones, P. D. and Osborn, T. J., 2005: Summer moisture variability across Europe, *J. Climate* (in press).