

European Climate Variability and Extremes Research 2001-2004

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Climate Variability

North Atlantic climate variability has received much attention since the IPCC third assessment report. A selection of what has been published is presented here.

North Atlantic Oscillation (NAO)

Marshall *et al.* (2001) present a comprehensive review of the state of knowledge of Atlantic variability, including the NAO, tropical variability and meridional overturning circulation. Another review of the NAO is given by Wanner *et al.* (2001).

Cassou *et al.* (2004) examined the stationarity of the NAO and highlight the differences between its two phases. Eastward displacement of the centres of action during the NAO+ phase (Jung *et al.* (2003) raises questions about the relevance of a station-based index. The role of SSTs is examined. Both tropical and extra tropical SST anomalies alter the frequency distribution of the North Atlantic regimes.

Evidence for a northeast shift in the Icelandic low and Azores high centres under enhanced greenhouse conditions is presented by Hu and Wu (2004) who examined the NAO in a climate change GCM experiment. They propose an alternative index that accounts for this shift. Still, recent work has been done by Vinther *et al.* (2003) to update the Gibraltar/Reykjavik NAO index using recently digitised Spanish pressure data.

The eastward shift of the NAO is examined further by Peterson *et al.* (2003). Their results reveal the nonlinear dependence of the spatial pattern of the NAO on the NAO index, the pattern being shifted to the east (west) for high (low) NAO index. They suggest that the eastward shift is a consequence of the trend towards higher NAO index during the last several decades of the 20th century.

A new NAO index based on zonally averaged MSLP is proposed by Li and Wang (2003).

Bojariu and Gimeno (2003) review recent work on predictability and methods of numerical modelling of the North Atlantic Oscillation.

The SST forcing of the NAO is examined by Paeth *et al.* (2003). They conclude that while the observed year-to-year NAO fluctuations are barely influenced by the SST, decadal scale changes can be modelled by SST-driven AGCM experiments. The non-stationarity of the NAO-SST relationship is further discussed by Walter and Graf (2002). A MSLP-SST canonical correlation analysis of the North Atlantic is carried out by da Costa and de Verdiere (2002).

A seasonal forecasting model for the NAO has been constructed by Saunders and Qian (2002) using North Atlantic SSTs.

Rogers and McHugh (2002) present an analysis of the degree of independence of the Arctic Oscillation (AO) and NAO. See also Ambaum *et al.* (2001).

North Atlantic Oscillation teleconnections

Trigo *et al.* (2002) present an analysis of European temperature and precipitation and its relationship with the NAO using NCEP reanalyses. It is shown that NAO-related temperature patterns are mainly controlled by the advection of heat by the anomalous mean flow. Precipitable water is shown to be strongly related to the corresponding anomaly fields of temperature, while precipitation rate appears to be controlled by the surface vorticity field and associated strength of the tropospheric synoptic activity.

The relationship between the NAO and North Atlantic and Baltic sea level was examined by Yan *et al.* (2004) (see also Volkov and van Aken (2003) and Johansson *et al.* (2001)). Most of northern Europe shows a positive relationship with higher sea levels under stronger NAO conditions, which is clearer for the winter season. In contrast, a negative relationship exists to the south, covering southwest England. Both the relationships are variable in time and were enhanced during recent decades, possibly due to movements of the NAO- related pressure centres.

The relationship between the AO, NAO and Eurasian snow cover is examined by Saito *et al.* (2004) (see also Hori and Yasunari (2003)) for 1971-2001. On the seasonal time scale, the winter AO is found to be significantly correlated with the preceding autumn Eurasian snow cover (SNCEUR) throughout the period observed. Consistent with this finding, SNCEUR variability led the AO variability on the sub-decadal time scale in the early half of the record. However, starting in the mid 1980s, the AO and SNCEUR vary in phase.

Turkes and Erlat (2003) examined the relationship between the NAO and Turkish rainfall, finding strong winter correlations.

Jevrejeva *et al.* (2003) used wavelet analyses to relate ENSO, NAO and AO indices to ice conditions in the Baltic Sea.

Uvo (2003) detailed the relationship between northern European winter precipitation and the NAO.

Munoz-Diaz and Rodrigo (2003) examined the effect of the NAO on the probability of monthly rainfall terciles in southern Spain. They found that changes in the probability of occurrence of climate categories of rainfall are more complex than only an increase of rainfall amount during the negative NAO phase and a decrease during the positive NAO phase.

The summertime Palmer Drought Severity Index is examined for six European regions by Mares *et al.* (2002) who emphasised the NAO signal in interannual variability.

Goodess and Jones (2002) examined daily Iberian rainfall and its relationship to circulation types, highlighting the relationship to the NAO.

Yoo and D'Odorico (2002) examined the date of termination of the ice season in Northern Europe. The NAO seems to affect mostly the late-winter temperature (January-March) with a significant impact also on the mid-spring (April-May) period, when the air temperature is strongly correlated to the ice dates. They argue that other climatic forcing, related to CO₂-induced regional and global warming, acting at the end of the ice season, are able to induce pronounced trends in the regime of spring temperature and have an important impact on the cryosphere, leading to the earlier occurrence of ice break-up observed in the last several decades.

The relationship between the NAO and winter temperatures across southern Europe was examined by Castro-Diez *et al.* (2002). The results show that temperatures in southern

Europe are sensitive not only to the phase of the NAO, but also to the exact location of the NAO centres of action. This differs to further north.

Cullen *et al.* (2002) examined the relationship between the NAO and Middle Eastern streamflow. They show that the first principal component of December through March streamflow variability reflects changes in the NAO.

Eastern Mediterranean precipitation is examined in relation to the NAO and East Atlantic oscillation by Krichak *et al.* (2002). The results allow explanation of the observed reduction of the north Israeli precipitation by the East Atlantic positive trend during the period.

Teleconnections associated with changing patterns of temperature and pressure anomalies over Israel during the second half of the 20th century were investigated by Ben-Gai *et al.* (2001). Relatively high, statistically significant, correlation coefficients of - 0.8 and +0.9 were found between the NAO Index anomalies and smoothed (5 year running mean) cool season temperature and surface pressure anomalies in Israel, respectively.

Tomozeiu *et al.* (2002) examined winter mean precipitation over Emilia-Romagna, Italy. Strong correlation is detected between PC1 (Emilia Romagna and at the scale of all Italy) and the NAO index. Thus, the changes detected in the winter precipitation around 1985 could be due to an intensification of the positive phase of the NAO, especially after 1980.

Schmidli *et al.* (2002) construct and evaluate a new gridded analysis of precipitation that covers the entire region of the European Alps. A linear trend analysis (1901-90) reveals an increase of winter precipitation by 20-30% per 100 years in the western part of the Alps, and a decrease of autumn precipitation by 20-40% to the south of the main ridge. Correlations with the NAO index are weak and highly intermittent to the north, and weak and more robust to the south of the main Alpine crest.

Fowler and Kilsby (2002) examined variations in precipitation in Yorkshire, UK, and linked these to large-scale atmospheric circulation using the NAO index, objective Lamb weather types, and long-term seasonal and annual precipitation indices at seven sites.

Wibig and Glowicki (2002) examined the variability of minimum and maximum temperature and the daily temperature range (DTR) in Poland. The increase in the minimum temperature was accompanied by a smaller increase in the maximum temperature and a decrease in the DTR. It was found that the DTR changes correlate well with cloudiness, and the extreme temperature changes are related to the NAO.

Beniston and Junco (2002) assessed the manner in which the NAO influences average climatic conditions and extremes of dynamic and thermodynamic variables over the Swiss Alps. As a result of the highly-positive nature of the NAO index in the latter part of the 20th Century it is speculated that a significant part of the observed warming in the Alps results from the shifts in temperature extremes induced by the behaviour of the NAO.

Herrera *et al.* (2001) examined the relationship between the NAO and rainfall in the Canary Islands. They identified four main synoptic circulation types that are responsible for about 80% of the precipitation in the region, three of which are sensitive to NAO phase.

Quadrelli *et al.* (2001) examined winter precipitation variability over the Alpine region for 1971-1992. They identified two distinct climate regions, located north and south of the chain, which exhibited an increase and a more significant decrease in precipitation, respectively. The two leading precipitation principal components are characterized by significant relationships with large-scale anomalies: the NAO explains most of the Alpine precipitation variance, and a strong link is found with Euro-Atlantic blocking.

Saenz *et al.* (2001) examined winter temperature variability over southwestern Europe. They found the NAO only influences the meridional gradient of temperature over the area, and this mode explains a significantly lower fraction of variance than the first mode, which is highly correlated with East Atlantic variability.

Cassou and Terray (2001) identified relationships between the low frequency variability of the zonal wind jet at 200hPa (U200) over the North Atlantic-Europe domain and the geographical distribution of the SST anomalies. For winter months over the 1959-1998 period, the U200 signature of the two phases of the NAO is captured from NCEP reanalyses in a cluster pair associated with the North Atlantic SST tripole. The classification also extracts a "La Nina" mode related to a strong ridge off Europe and reduced jet over the Azores.

Murphy and Washington (2001) examined the relationship between UK and Ireland precipitation variability and the North Atlantic sea-level pressure. They identified new patterns of SLP that are more closely linked with precipitation variability than the NAO.

Rebetez (2001) analysed day-to-day variability of two century-long daily minimum and maximum temperature series from Switzerland. Higher NAO index values tend to be associated not only with warmer temperatures but also with lower day-to-day variability. They conclude that the temperature warming during the 20th century has happened mainly through the loss of the coldest part of the series, not only in the 24-hour or yearly cycle, but also through the loss of the coldest episodes in each month.

Pozo-Vazquez *et al.* (2001) studied the relationship between European winter temperature spatial and temporal modes of variability and the NAO during the period 1852-1997. The results indicate that quasi-periodic oscillations in the NAO do not lead to more extreme episodes, but rather that an extreme value of the oscillation is more likely to persist for few years. They found that winter temperatures, in a large part of Europe, do not vary in a linear manner with respect to phase and intensity of the NAO.

Bednorz (2004) examined the variability of snow cover in Eastern Europe. Strong relationships exist with mean temperature. A positive correlation between snow depth and precipitation appeared significant only in some areas. The correlation between the number of days with snow cover and the NAO index is large and statistically significant only in central Europe and it becomes insignificant to the east of 30 degrees E.

Lucero and Rodriguez (2002) identified the spatial patterns of decadal and bi-decadal fluctuations in annual rainfall in Europe. Decadal relationships with the NAO were identified.

Other climate variability studies

Sutton and Hodson (2003) highlighted the importance of Atlantic SST and ENSO on North Atlantic climate by performing an ensemble of GCM experiments forced by observed SST for 1871-1999.

Zveryaev (2004) investigated seasonal differences in interannual and intraseasonal precipitation variability over Europe. They found significant differences in patterns and magnitudes of variability between seasons over most of the region.

Martin *et al.* (2004) examined the relationship between springtime (March-May) precipitation in the western Mediterranean area and several North Atlantic teleconnection patterns of low-frequency variability for the period 1948-89. They conclude that two main North Atlantic large-scale atmospheric patterns, the NAO and the east Atlantic jet, explain about 50% of the total spring precipitation variability in the western Mediterranean area.

Recent warming in the northeastern Atlantic Arctic was studied by Rogers *et al.* (2004). They found that since winter 1972, SLP over the Barents and Norwegian Seas has been unusually low during NAO+ winters. Little pressure field change occurred during NAO- winters or around the Denmark Strait, the normal location of the Icelandic Low. Simultaneously, the NAO+ mode became highly persistent on a month-to-month basis throughout the NAO+ winters.

Dunkeloh and Jacobeit (2003) analysed monthly rainfall in the Mediterranean and related this to 500Z and 1000Z using canonical correlation analysis. Coupled patterns specifically linked to one or two seasons include an east Atlantic jet related pattern for summer and a Mediterranean meridional circulation pattern for winter and spring. The most important pattern recurring with dynamical adjustments throughout the whole year reflects the seasonal cycle of the Mediterranean oscillation, which is linked (with seasonal dependence) to the Northern Hemisphere teleconnection modes of the AO and NAO.

Motivated by an attempt to predict summer (June-August) UK temperatures, the time-lagged correlations between summer UK and European temperatures and prior snow cover, North Atlantic SSTs, and the NAO were examined by Qian and Saunders (2003). Seasonal expansion in the Azores high pressure system may play an important role in the time-lagged relationships, which gives rise to usable but non-stationary predictive skill.

Staeger *et al.* (2003) analysed observed global and European surface air temperature, mean-sea-level pressure and precipitation with respect to their response to external forcing factors such as anthropogenic greenhouse gases, anthropogenic sulfate aerosol, solar variations and explosive volcanism, and known internal climate mechanisms such as ENSO and the NAO. The study attempts to answer the question whether a significant anthropogenic climate change is visible in the observed data.

Moron and Plaut (2003) examined the ENSO influence on European winter weather regimes. They found significant changes in the frequencies of five regimes depending on the month and phase of ENSO.

Monthly MSLP grids reconstructed back to 1659 were examined by Jacobeit *et al.* (2003) who identified variations of dynamical modes of the atmospheric circulation for January and July. Their results indicate the great importance of within-mode variations.

Junge and Stephenson (2003) used a multiple regression model to quantify the importance of wintertime mean North Atlantic SSTs for explaining (simultaneous) variations in wintertime mean temperatures in northwestern Europe.

Otterman *et al.* (2002) attribute a large part of the 1948-1995 observed warming in Europe to more predominant southwesterly winds in winter, originating from the warmer southwestern North Atlantic.

Drevillon *et al.* (2001) examined 41 years of the NCEP reanalyses to investigate the interactions between the SSTs, the storm track activity and the time mean atmospheric circulation in the North Atlantic-Europe region. A lead-lag singular value decomposition analysis between seasonal 500 hPa geopotential height and SST captures a significant covariance between a summer SST anomaly and a strong winter anticyclonic anomaly over Europe.

Spatial and temporal characteristics of winter snow depth variation over northern Eurasia and their connections to SSTs and associated atmospheric circulation anomalies, surface air temperatures, and precipitation were examined by Ye (2001). They identified quasi-biennial and quasi-decadal signals in snow depth and related these to SSTs in the Pacific and Atlantic.

Climate extremes

Since Frich *et al.* (2002) completed a near-global study of trends in indices of extreme temperature and precipitation (referenced in AR3), several studies have looked in more detail at Europe.

Europe-wide studies

Klein Tank and Konnen (2003) examined daily temperature and rainfall series for over 100 European stations for 1946-99. Averaged over all stations, indices of temperature extremes indicate "symmetric" warming of the cold and warm tails of the distributions of daily minimum and maximum temperature in this period. They found a reduction in temperature variability for the earlier part of the period and an increase in variability for the much warmer later part. For precipitation, all Europe-average indices of wet extremes increase in the 1946-99 period, although the spatial coherence of the trends is low.

Wijngaard *et al.* (2003) assessed the homogeneity of the European Climate Assessment dataset (Klein Tank *et al.* (2002)), a subset of which is used in Klein Tank and Konnen (2003). They found that in the sub-period 1946-99, 61% of the temperature series and 13% of the precipitation series are considered 'doubtful' or 'suspect'. About 65% of the statistically detected inhomogeneities in the temperature series labelled 'doubtful' or 'suspect' in the period 1946-99 can be attributed to observational changes that are documented in the metadata. For precipitation, this percentage is 90%.

Haylock and Goodess (2004) examined daily winter rainfall at 347 European stations for 1958-2000. They found that a large part of the observed trends and interannual variability in the maximum number of consecutive dry days and the number of days above the 1961-90 90th percentile of wet-day amounts could be explained by changes in large-scale mean atmospheric circulation. The NAO was important in explaining large scale observed trends in these indices.

Moberg and Jones (2004) compared mean and extreme temperatures in a recent run of the Hadley Centre regional climate model with observations for 1961-1990. They found good agreement for latitudes 50-55°N, but seasonal biases up to 5K over other regions. Even larger errors (up to 15K) exist in extreme temperatures.

A number of studies have focussed on changes in extremes for smaller regions within Europe.

Regional temperature and precipitation extremes

Brunetti *et al.* (2004) examined trends in temperature and rainfall over Italy during the twentieth century. They found trends towards warmer and drier conditions, but with an increase in rainfall intensity and longer dry spells.

Regional temperature extremes

The 2003 European heat wave was examined by Beniston (2004) and Schar *et al.* (2004) and Luterbacher *et al.* (2004). Luterbacher *et al.* (2004) show that summer 2003 was by far the hottest since 1500. Beniston (2004) shows that the 2003 heat wave bears a close resemblance to what many regional climate models are projecting for summers in the latter part of the 21st century. Schar *et al.* (2004) show that this heat wave is statistically very unlikely given a shift in the mean temperature. An increase in variability is needed to adequately explain the probability of such an event occurring.

Domonkos *et al.* (2003) examined the variability of winter extreme low-temperature events and summer extreme high-temperature events using daily temperature series (1901-98) from 11 sites in central and southern Europe. They found a slight warming tendency, but only a few of the changes, mostly in the northernmost sites, are statistically significant. Strong connections are present between the frequencies of extreme temperature events and the large-scale circulation on various time scales.

Extreme temperatures in central Europe are examined by Kysely (2002a, Kysely (2002b). Kysely (2002a) compared extreme temperatures in GCMs, observations, and results downscaled from GCMs and observations. Kysely (2002b) examined daily temperature at Prague-Klementinum to determine changes in heat waves and their relationship with circulation.

Garcia *et al.* (2002) analysed daily maximum temperature at Madrid and found circulation patterns associated with extremely high temperatures. A circulation index was derived to characterise and forecast a hot day occurrence.

Jungo and Beniston (2001) highlighted the change in the seasonal temperature limits at different latitudes and altitudes in Switzerland. Winter minimum temperatures at high altitude sites and summer maximum temperatures at low altitude sites in the north, in particular, changed considerably during the 1990s.

Brabson and Palutikof (2002) carried out an extreme value analysis of the Central England Temperature record from 1772 to present to show that both cold summer and hot winter extremes have evolved differently from their means. The reasons for the trends in extremes occurrence are related to changes in the underlying atmospheric circulation.

Xoplaki *et al.* (2003b) examined the interannual and decadal variability of summer (June to September) air temperature over the Mediterranean area for the period 1950 to 1999. They show that more than 50% of the total summer temperature variability can be explained by three large-scale predictor fields (300 hPa geopotential height, 700-1000 hPa thickness and SSTs). Xoplaki *et al.* (2003a) find similar results when examining 24 stations in the northeastern Mediterranean.

Regional precipitation extremes

Frei and Schar (2001) present a statistical framework for the assessment of climatological trends in the frequency of rare and extreme weather events based on the stochastic concept of binomial distributed counts. The results demonstrate the difficulty of determining trends of very rare events. The statistical method is applied to examine seasonal trends of heavy daily precipitation at 113 rain gauge stations in the Alpine region of Switzerland (1901-94). For intense events (return period: 30 days), a statistically significant frequency increase was found in winter and autumn for a high number of stations.

Hand *et al.* (2004) carried out a study of extreme rainfall events over the UK during the twentieth century. They identified 50 flood-producing events with durations up to 60 hours. The rainfall events were classified by meteorological situation, location and season, allowing the identification of conditions under which extreme rainfall occurred.

Short term rainfall rates between 5 minutes and 24 hours for Barcelona were examined by Casas *et al.* (2004). Events were clustered to give four main classes of extreme rainfall events in the area.

Skaugen *et al.* (2004) downscaled daily precipitation using the Max Planck Institute GCM to generate scenarios of extreme rainfall under enhanced greenhouse conditions. The analysis of

changes in extreme value patterns shows tendencies towards increased extreme values and seasonal shifts for the scenario period.

Fowler and Kilsby (2003a) and Fowler and Kilsby (2003b) examined 1, 2, 5 and 10-day annual maximum rainfall for 1961 to 2000 from 204 sites across the UK. Little change is observed at 1 and 2 days duration, but significant decadal-level changes are seen in 5 and 10-day events in many regions.

European flood frequency was examined by Mudelsee *et al.* (2003). They presented longer-term records of winter and summer floods in two of the largest rivers in central Europe, the Elbe and Oder rivers. For the past 80 to 150 yr, they found a decrease in winter flood occurrence in both rivers, while summer floods show no trend, consistent with trends in extreme precipitation occurrence.

Frei *et al.* (2003) examined mean and extreme precipitation for five RCMs. They found that, despite considerable biases, the models reproduce prominent mesoscale features of heavy precipitation.

Benestad and Melsom (2002) examined the relationship between Atlantic SST and extreme autumn precipitation in southeast Norway. They found that the SSTs could explain as much of the rainfall during unusually wet November months in 2000 and 1970 as the SLP.

Alpert *et al.* (2002) analysed daily rainfall over the Mediterranean to determine the changes in rainfall intensity categories for 1951-95. They found increases in extreme rainfall in Italy and Spain but no change in Israel and Cyprus.

Brunetti *et al.* (2002) studied daily rainfall over Italy to determine changes in the longest dry period, the proportion of dry days and the greatest 5-day rainfall totals. There has been a large increase in summer droughts over all of Italy but there is no significant trend in the extreme rainfall intensity.

Crisci *et al.* (2002) examined daily rainfall at Tuscany to determine 30-year return period intensities.

Booij (2002) compared extreme precipitation at different spatial scales by comparing results from using stations, reanalysis projects, global climate models and regional climate models.

A 100-year daily rainfall record for Uccle (Belgium) was examined by Vaes *et al.* (2002). They found no significant trend in extreme rainfall.

Fowler *et al.* (2004) used two methods to assess the performance of the HadRM3H model in the simulation of UK extreme rainfall: regional frequency analysis and individual grid box analysis. Both methods use L-moments to derive extreme value distributions of rainfall for 1-, 2-, 5- and 10-day events for both observed data from 204 sites across the UK (1961-1990) and gridded ~50 km by 50 km data from the control climate integration of HadRM3H. Although there are some problems with the representation of extreme rainfall by the HadRM3H model, almost all are related to the orographic enhancement of mean rainfall.

The same methods were used in the companion paper Ekström *et al.* (2004) to examine results from HadRM3H for a future scenario ensemble of enhanced greenhouse conditions. The authors suggested that by the end of the 21st century the return period magnitude for a 1-day event would have increased by approximately 10 % across the UK, with values for 10-day events increasing more in Scotland (up to +30 %) than England (-20 % to +10 %).

Osborn and Hulme (2002) examined daily precipitation in the UK over the period 1961-2000. They showed that it has become generally more intense in winter and less intense in summer. Recent increases in total winter precipitation are shown to be mainly due to an

increase in the amount of precipitation on wet days, with a smaller contribution in the western UK from a trend towards more wet days.

Palmer and Ralsanen (2002) presented a probabilistic analysis of 19 GCM simulations with a generic binary decision model. They estimated that the probability of total boreal winter precipitation exceeding two standard deviations above normal will increase by a factor of five over parts of the UK over the next 100 years.

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