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CLIMATE ANOMALIES IN EUROPE ASSOCIATED WITH ENSO EXTREMES

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ABSTRACT

Surface pressure, temperature and precipitation anomalies in Europe are composed for the El Niño–Southern Oscillation (ENSO) warm and cold extremes. During warm event winters, negative pressure departures at western and central European stations are associated with positive temperature and precipitation anomalies; the reverse signals are observed in northern Europe. During cold episodes the field of negative pressure deviations is shifted northward with positive temperature and precipitation anomalies, whereas higher pressure is observed over central Europe. This shift of the anomalies corresponds to a shift in the dominating cyclone track (deduced from weather maps), which may be interpreted as the response of the (sensitive tail end of the) cross-Atlantic storm track on the high-pressure anomalies occurring at times in the northern or central part of the North Atlantic/European sector during warm or cold ENSO winters, respectively.

KEY WORDS El Niño–Southern Oscillation Warm and cold events Pressure Temperature Precipitation Anomalies in Europe Cyclone tracks

1. INTRODUCTION

The response of global weather and climate on El Niño–Southern Oscillation (ENSO) warm and cold extremes has been investigated during the past decades, documenting the impact on the circulation patterns even in areas as remote as the north-eastern Atlantic and European sector from the key region of the tropical Pacific.

About 25 years ago, Bjerknes (1966; analysing the 1957–1958 winter) noted a teleconnection between the eastward shift of the equatorial Pacific convection zone (i.e. an ENSO warm event) and the mid-latitude circulation of the Northern Hemisphere affecting the North Pacific and North American area and the North Atlantic and European region. He interpreted this tropical–mid-latitude teleconnection of the winter Northern Hemisphere in terms of a conceptual model: a positive temperature anomaly in the tropical Pacific (extending over about 90° from South America to the mid-Pacific) strengthens the mid-latitude zonal wind system within this sector; the associated negative pressure anomaly (a deeper Aleutian Low) in the extratropical cyclone belt anchors the phases of the prevailing stationary waves (wavenumber 2–3) in the upper westerlies so that a succession of positive and negative stationary wave anomalies appears downwind over North America/Southwestern Greenland and the north-eastern Atlantic/north-western Europe (north-west Russia).

About 10 years ago, van Loon and Madden (1981), and van Loon and Rogers (1981) analysed the global associations of ENSO with a more comprehensive data set, correlating and compositing northern winter pressure and temperature fields with the ENSO signal, including both warm and cold events. In the North Atlantic and European sector they found significant pressure and temperature anomalies. Their mid-latitude response shows an intense Aleutian Low and a low-pressure anomaly over the North Atlantic where the warm–cold difference reveals a north–south see-saw (Iceland Low and Azores High dipole), a pattern similar

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to the North Atlantic oscillation. The temperature anomalies in this area show strong correlations in northern Europe.

More recently, Hamilton (1988) investigated the detailed regional sea-level pressure response in the extratropics on ENSO warm events; Kiladis and Diaz (1989) analysed the temperature and precipitation anomalies associated with the warm versus cold episode. Although these recent results substantiate the regional ENSO responses found in earlier studies, some details are noteworthy. While Hamilton's (1988, figure 7) warm event analysis shows similar intensities of the pressure anomalies in both the Aleutian and Iceland Low areas (emphasizing the relatively strong response of the North Atlantic and European sector), van Loon and Madden (1981, figure 5) find a warm–cold difference at the Iceland Low of half the Aleutian Low magnitude. Kiladis and Diaz (1989) emphasize that warm- and cold-event signals show similar regional patterns of opposite amplitude, as shown by the mid-latitude monopole (Aleutian Low) structure of the warm–cold difference fields in the North Pacific; the meridional dipole in the North Atlantic and European sector (Iceland Low and Azores High), however, appears to indicate a north–south shift of the response patterns, with significant warm–cold differences of the Scandinavian winter temperatures and of the south-west European precipitation.

In this note we supplement a study on 'European Grosswetter' affected by ENSO extremes (Fraedrich, 1990) by detailed maps of the surface temperature, pressure and precipitation responses on both warm and cold ENSO events (section 2) in order to provide some guidance for evaluating the long-range weather forecasting potential in Europe. A synoptic climatology based on cyclone frequencies is added to interpret the observed surface response anomalies (section 3). Finally, in section 4, the results are discussed.

2. SURFACE PRESSURE, TEMPERATURE AND PRECIPITATION ANOMALIES

2.1. Data and analysis

The following ENSO response analysis of the winter circulation in Europe is based on composites of 26 warm (Rasmusson and Carpenter, 1983, their table 2 plus the year 1982) and 22 cold events (van Loon and Shea, 1985, their table 1 plus the years 1975 and 1988). The 26 warm event years since 1880 occur at 1880, 1884, 1887, 1891, 1896, 1899, 1902, 1905, 1911, 1914, 1918, 1923, 1925, 1930, 1932, 1939, 1941, 1951, 1953, 1957, 1965, 1969, 1972, 1976, 1982, and 1986. The 22 cold event years are 1886, 1889, 1892, 1898, 1903, 1906, 1908, 1916, 1920, 1924, 1931, 1938, 1942, 1949, 1954, 1964, 1966, 1970, 1973, 1975, 1978, and 1988. The ENSO signal is analysed for the winter seasons (December to February) at the end of the year of the event when the mid-latitude circulation reveals the strongest response. The warm and cold anomaly composites of the surface pressure, temperature, and precipitation are constructed as the mean deviation from the last 100-year (1888–1987) winter average. The 40 (43, 36) stations observing surface pressure (temperature and rainfall) are chosen to cover more than 80 years for the climate mean and more than 20 (16) warm (cold) extremes. The station data are taken from the World Weather Records (until 1970) and then from the Berliner Wetterkarte (1971–1987).

The mean warm and cold composite anomalies are deduced with the associated standard deviations (left and right value above the station circle). Furthermore, the percentage of consistent signals (value at the bottom) and the significance levels (in the station circle) also are indicated. Percentage of consistent signals is a measure of the stability of the warm or cold responses; it gives the 'percentage correct' signs coinciding with the respective sign of the composite mean anomaly. The significance is estimated by a one-sided t-test; here the null-hypothesis (warm and cold events belong to the same population) is rejected on the 90 per cent (open circle), 95 per cent (full circle) and <90 per cent (dot) levels. The results are displayed in Figure 1 (a and b for warm and cold events) and briefly described in the following.

2.2. Pressure

Warm events show a strong (<-1 mbar) negative anomaly in a zonal belt stretching across western and central Europe (from Ireland to near the Black Sea) and a strong positive anomaly (>1 mbar) over northern

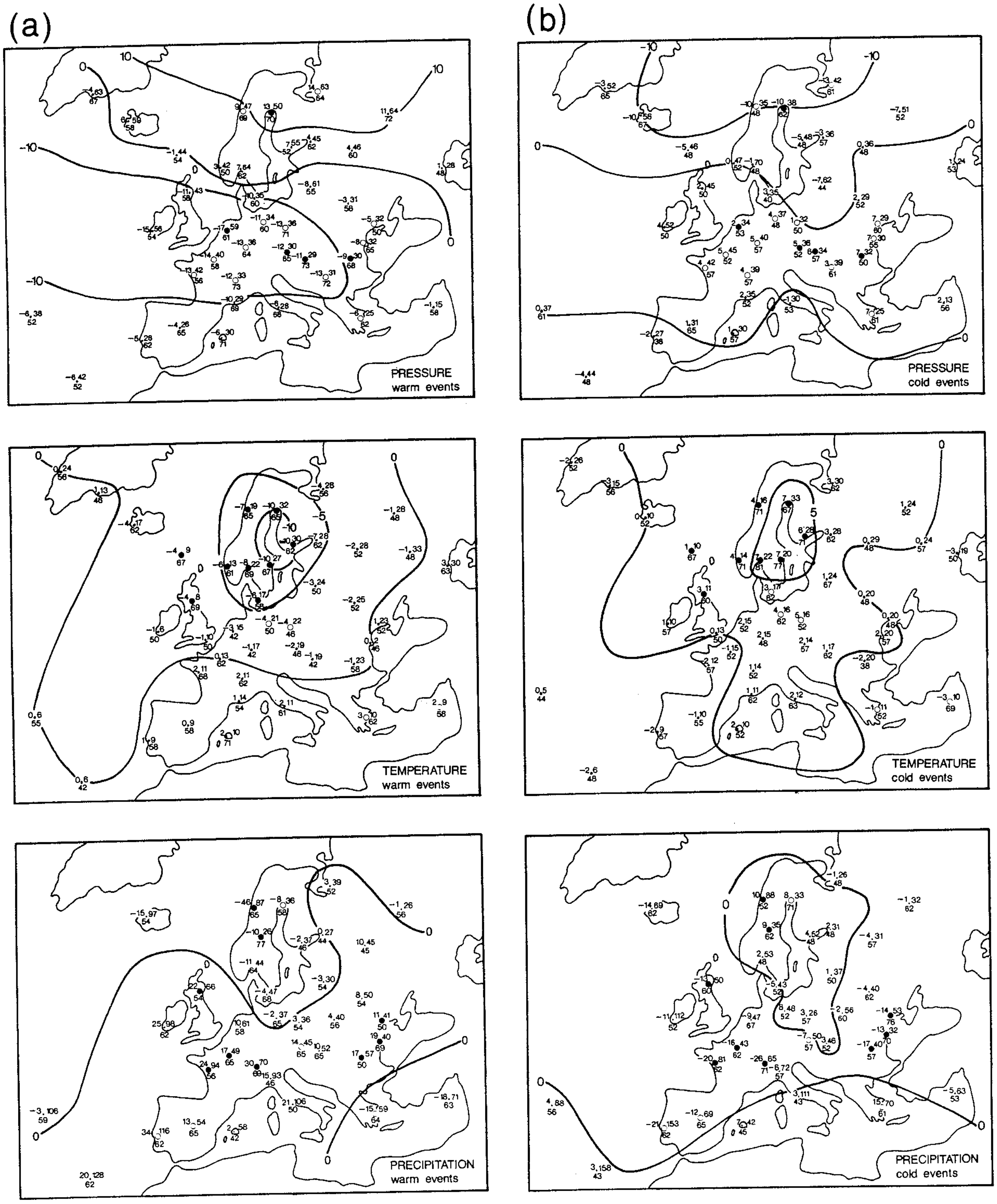

Figure 1. Regional response in Europe on El Niño–Southern Oscillation warm (a) and cold (b) extremes in winter. From top to bottom: surface pressure, surface temperature and precipitation anomalies. The numbers written at the stations are in tenths of millibars (tenths of degrees and millimetres, respectively) deviation from the long-term station mean (left) and the respective standard deviations (right) of the warm (cold) event ensembles. Below, the relative frequency (in per cent) indicates the percentage number of cold or warm-event winters that realize the same positive or negative sign as given by the mean anomaly

Europe (Scandinavia and the adjacent Soviet Union). During cold events the anomaly composites reveal sign reversal. The strongest negative pressure anomalies (< -1 mbar) are observed over Scandinavia, whereas the positive ones across the central and more southern parts of Europe are less intense. Stations located at the core of the anomaly regions pass the 95 per cent significance level (one in Scandinavia, four in central Europe; that is five of 40 stations). These mean-pressure anomalies are in agreement with the European Grosswetter response showing enhanced cyclonic (anticyclonic) circulation patterns over Europe during warm (cold) event winters (Fraedrich, 1990). Furthermore they are not confined to the lower troposphere (see also Hamilton (1988) for warm events), as shown by the equivalent barotropic atmospheric response of GCM (general circulation model) experiments on boundary forcing in the equatorial Pacific region (e.g. Palmer, 1985).

2.3. Temperature

The mean surface temperature anomaly fields show negative (positive) temperature deviations over northern and north-western Europe with extrema up to $\pm 0{\cdot}5$ or 1 K as a response to warm (cold) ENSO events. Nine (of the 43) stations show a warm–cold event temperature contrast passing the 95 per cent level of signifcance. In the areas of the maximum response the sign of the temperature anomalies is relatively consistent. For example, at some Scandinavian stations as many as 70–80 per cent of all cold-episode winters show positive temperature anomalies and almost 70 per cent of all warm-event winters are associated with negative temperature deviations from the long-term mean. Note that the 'percentage correct' number of consistent signs of the pressure anomalies is smaller.

2.4. Precipitation

The winter precipitation response shows a similar structure as the temperature anomaly composites. The warm-event response reveals a precipitation deficit in Scandinavia and a surplus belt over western/south-western and central Europe; the cold-event anomalies lead to a comparable regional pattern but it is characterized by an amplitude reversal. Scandinavia is wetter, whereas the area from the western and south-western parts of Europe to the Black Sea is drier, lacking the rain-bearing frontal systems. There are two (or seven) of the total of 36 stations in each of the areas passing the 95 per cent (or 90 per cent) significance level; the percentage of a consistent response signal can reach the 70 per cent level and higher.

3. CYCLONE TRACKS: A SYNOPTIC CLIMATOLOGY OF ENSO EVENTS

The observed winter anomaly fields (pressure, temperature, and precipitation) in Europe are supplemented by a synoptic climatology. The geographical number distributions of warm and cold-event cyclones (associated with fronts) lead to an identification of the dominating storm tracks and their variability. This phenomenological statistic is complemented by the warm–cold ensemble-averaged mean 500-mbar geopotential height difference field.

3.1. Cyclone tracks

The position and frequency distributions of cyclones lead to a synoptic climatology of the storm tracks and their variability. This statistic is deduced from daily surface weather maps (Berliner Wetterkarte, 1952–1989) on grid-cells of 5° latitude by 5° longitude covering the eastern North Atlantic and European sector from 40° west to 40° east and between 35° north and 80° north. The data set covers the ensembles of the last eight warm and eight cold events since 1952 (section 2). The total numbers of cyclone days (per warm or cold winter season) in this sector remain almost the same (that is 320 ± 48 for the warm-event and 316 ± 21 for the cold-event ensemble). The geographical number distributions of both warm and cold events show major frequency maxima, which characterize the (tail end of the) cross-Atlantic storm track in the north-eastern Atlantic and European sector (Figure 2): (i) a northern branch extending from the cyclogenic area off the south-east coast of Greenland via Iceland through the Norwegian Sea north of Scandinavia towards Novaya Zemlya; (ii) a

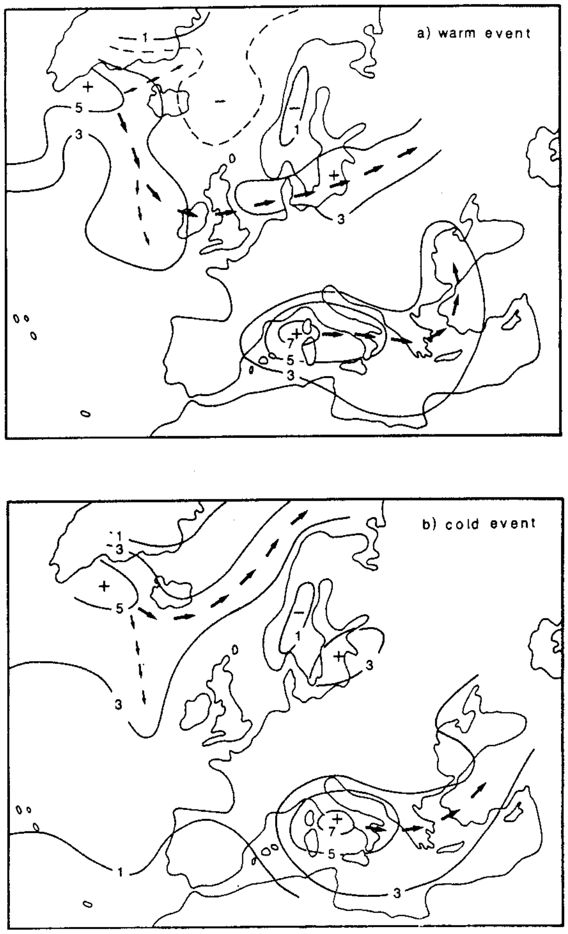

Figure 2. Number of the daily occurrence of cyclones (associated with fronts) in 5° latitude by 5° longitude grid cells during an ensemble-averaged warm (a) and cold (b) event winter, each composed of eight episodes (1952–1989)

southern branch across Scotland to central Europe and the southern Baltic into the Soviet Union; note also an enhanced cyclone frequency induced by (cut-off) lows moving southward from Greenland before they dissipate. Furthermore, (iii) there is a cyclone frequency maximum induced by the major cyclogenic area over the Gulf of Genoa and extending eastward through Greece and Turkey. Whittaker and Horn (1982; analysing the 20-year mean annual cycle of extratropical cyclone activity in the Northern Hemisphere, 1958–1977) identify both the primary (north of Scandinavia) and secondary (across central Europe) storm paths as part of the tail end of the cross-Atlantic cyclone track, and the Mediterranean cyclone activity in winter. While the latter remains basically unchanged in the warm and cold ENSO episodes, the primary (northern) track dominates in the cold-event ensemble whereas the secondary (central) branch prevails in the warm-event averages. This shift of the tail end of the cross-Atlantic storm track leads to the observed warm/cold event surface response (section 2). Lower pressure, higher temperature, and precipitation fields over the northern part of Europe (observed in the cold ensemble) and over the central and southern part of continental Europe (in warm ensemble) are a direct consequence of the shift of the cyclone track.

3.2. 500-mbar geopotential

The ensemble-averaged 500-mbar geopotential height fields support these results. In the European and North Atlantic sector the warm–cold difference (Figure 3) shows a dipole of enhanced (reduced) heights in the central

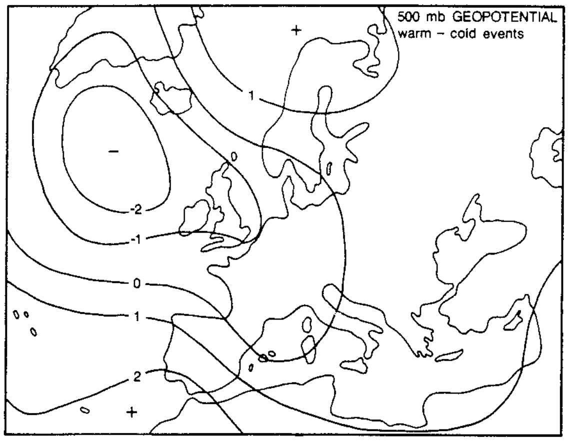

Figure 3. The mean 500-mbar geopotential height difference (in gpdam) between warm–cold ENSO event ensembles (1952–1988)

part of the eastern North Atlantic and European sector during the cold (warm) event ensemble and the opposing pattern, but of lesser intensity, in the northern part of the sector. This corresponds with the main features of the observed surface pressure fields (Figure 1) and with the dominance of the anticyclonic (cyclonic) Grosswetter mode. Therefore, the *positive* geopotential height or surface pressure anomalies (over northern Europe in the warm-event and over the central part in the cold-event ensemble) may be interpreted as a stationary eddy forcing, which shifts the sensitive tail end of the cross-Atlantic cyclone track to the primary northern (or secondary central) route during cold (warm) events.

4. SUMMARY AND DISCUSSION

The following qualitative interpretation relates the mean composite anomalies of temperature and precipitation to the pressure anomaly, which, in turn, can be associated with the position of the mean cyclone tracks.

(i) In the ENSO warm-event ensemble the negative pressure anomaly (or cyclonic Grosswetter) covers a zonal belt extending from Ireland to the Black Sea. This surface pressure anomaly appears to indicate an area of enhanced cyclonic activity with more frequent or more intense storms moving across central Europe (i.e. the cyclonic European Grosswetter). This southward shift (relative to the cold event) of the European part of the cross-Atlantic cyclone track may be interpreted as its response to high-pressure anomalies over Scandinavia, because the storm-track tail is more sensitive to external forcing than its initial phase in the jet entrance region. The polar air masses in the area of the high-pressure anomalies over Scandinavia are responsible for the negative surface temperature and precipitation departures in northern Europe, while wet conditions are observed in the western, central and southern parts owing to the frontal systems associated with the cyclones.

(ii) In the ENSO cold-event ensemble the cyclones occur further north, leading to the observed negative pressure anomalies over northern Europe. High-pressure anomalies and enhanced anticyclonic Grosswetter over the eastern North Atlantic and the western and central parts of the European continent are associated with the observed northward shift of the cyclone track. Again, not unlike the warm event, it may be the positive pressure anomaly in western and central Europe (or the anticyclonic North Atlantic and European Grosswetter) on which the sensitive tail end of the cross-Atlantic storm track responds by moving northward (and not the opposite), with its positive temperature and precipitation anomalies owing to an increase in the frequency of the rain-bearing frontal systems. Consequently, the western and south-western parts of Europe (in particular the area of winter rain) realize a precipitation deficit. In this sense isopleths of warm–cold-event differences (or correlations between ENSO and the surface pressure field in Europe (van Loon and Madden, 1981) can be interpreted by an externally forced shift of the mean steering flow of cyclones, with the associated temperature and precipitation anomalies.

(iii) These regional pressure, temperature, and precipitation field structures remain basically unchanged for the subsequent spring and summer seasons (not shown). Although the amplitudes or mean anomalies decrease the number of significant stations passing the 95 per cent level is still sufficiently large to satisfy the overall field significance required; the only exception is the summer temperature-anomaly field, which appears to be less affected by horizontal advection than, possibly, owing to enhanced rainfall, by convective overturning.

Finally, it should be mentioned that this ENSO response analysis of the Atlantic and European sector serves primarily as an a posteriori interpretation after the effect. The prognostic value and dynamic interpretation needs further investigation; Europe 'is farthest away from the key regions of ENSO', so that 'it is not surprising if at times the influence of the oscillation is superceded by other effects' (van Loon and Madden, 1981). For example, the extratropical wintertime atmospheric circulation also is sensitive to certain extratropical sea-surface temperature anomalies and not only to anomalies associated with El Niño (Wallace and Jiang, 1987).

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