Decadal precipitation variability over Europe and its relation with surface atmospheric circulation and sea surface temperature

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SUMMARY

The relationships between decadal (>5-year period) observed winter precipitation (PP) variability over Europe and atmospheric circulation and sea surface temperature (SST) during the period 1950–1995 are investigated. More than 48% of the decadal precipitation variability is described by two modes: a meridional dipolar pattern (high PP over northern Europe and low over southern Europe, the Mediterranean and most of central Europe) explaining about 32% of the variance, and an alternating pattern in latitude over Europe (high in central Europe and low in far north-western Europe and the Mediterranean) explaining about 16% of the variance. The first mode is strongly related to the North Atlantic Oscillation.

A canonical correlation analysis between regional precipitation and sea-level pressure fields shows that a PP pattern similar to the first decadal PP mode is associated with a north-westerly circulation anomaly pattern while a PP pattern similar to the second decadal PP mode is associated with a monopolar circulation anomaly pattern over most parts of Europe.

The correlation map between the time series of expansion coefficients of the first PP mode and sea surface temperature emphasizes a global pattern which resembles the linear trend coefficients pattern of SST for the analysed period. The second PP mode is associated with an SST anomaly pattern similar to that of the SST anomalies characterizing ‘decadal El Niño Southern Oscillation’ SST pattern.

Composite maps of global 500 mb geopotential height based on the time series of expansion coefficients of PP modes emphasize global patterns compatible with SST patterns. After removing the linear trend from the data, the first PP pattern remains almost unchanged but it emphasizes mainly regional connections. The second spatial pattern of the second PP mode and its connections are not affected significantly by removing the trend.

KEYWORDS: CCA Decadal ENSO Decadal variability EOF NAO Precipitation

1. INTRODUCTION

The variability of precipitation field at interannual to decadal time-scales has received increasing attention in recent years (e.g. Hulme 1994; Dai et al. 1997; Wibig 1999). The study of precipitation variability is important for life because decadal fluctuations of precipitation affect water resources for human consumption, for agriculture and for other purposes. Also, low-frequency precipitation variability is an important factor in global-change issues as it may obscure human influences on hydrologic variations. In this study we focus on the decadal fluctuations of winter (December, January and February) surface precipitation over Europe (PP) and their relation with atmospheric circulation and global sea surface temperature (SST) anomalies.

Although the precipitation is dominantly episodic, there are low-frequency large-scale climate processes that modulate it on multi-year time-scales. In the European sector, precipitation variations are often related to the North Atlantic Oscillation (NAO). The influence of the NAO on various climatic elements in the Atlantic region has been widely discussed (e.g. van Loon and Rogers 1978; Hurrell and van Loon 1997). During the positive phase of the NAO (deep Icelandic Low and strong Azores High), positive precipitation anomalies prevail over north-western Europe while negative precipitation anomalies dominate much of central and southern Europe and Mediterranean regions (Hurrell 1995). During the last decades, for example, increasing precipitation over north-western Europe associated with decreasing precipitation over southern Europe has been

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observed. These variations in the precipitation field over Europe were related to the persistence of the NAO in its positive phase during that period (Hurrell, 1995).

The low-frequency variability of precipitation over Europe has also been related to other large-scale atmospheric circulation patterns such as Scandinavian, east Atlantic, Central European and east European patterns (Barnston and Livezey 1987; Rogers 1990; Wibig 1999).

Spectral analyses of precipitation over Europe indicate concentrations of power and periodicity at numerous frequencies, but these variations are not sufficiently distinct or reliable to support robust interpretations. However, it is generally accepted (Bjerknes 1964; Kushnir 1994) that different physical mechanisms control distinct climatic anomaly patterns that occur at decadal and subdecadal (interannual) time-scales in the Atlantic European region.

Our analysis is focused on the decadal variability (>5-year period) of precipitation over Europe, aiming at better understanding the connection between precipitation, atmospheric circulation and global SST at this time-scale. The major objective of our study is to search for the spatial and temporal structure of the leading modes of decadal precipitation variability over the region (25°W–70°E; 30°N–75°N) and to relate these modes to atmospheric circulation and SST.

To find out how much of precipitation variability remains at decadal time-scale, we have calculated the standard deviation both for unfiltered winter precipitation data (Fig. 1(a)) and for smoothed data with a five-year running-mean filter (Fig. 1(b)). The map of standard deviation of the unfiltered PP field emphasizes two regions of high variability during winter: the Mediterranean region and the western part of the Scandinavian Peninsula. The same regions of high precipitation variability can be identified also at decadal time-scale. Due to the low resolution of the PP data set (5° latitude × 5° longitude), the values of PP standard deviation have to be interpreted cautiously for the regions with complex orography such as Scandinavia. The standard deviation calculated for a certain box represents the variability of averaged PP on that box (Hulme 1992) which may include areas with very different precipitation regimes. It is evident from Figs. 1(a) and (b) that an important part of winter precipitation variability in these regions is determined by processes with time-scales longer than five years. In the same way, the decadal sea-level pressure (SLP) standard deviation (Fig. 1(d)) explains an important part of winter-to-winter SLP variability. A similar result has been obtained by Cayan et al. (1998) who showed that a significant part of PP variability over western North America is contained in the decadal component.

In a modelling study, Rodwell et al. (1999) show that much of the multi-annual to multi-decadal variability of winter NAO can be reconstructed from a knowledge of North Atlantic sea surface temperature. Their results have been confirmed by Latif et al. (2000) who used an atmospheric model forced with observed SST that was able to reproduce well the decadal SLP variability over the North Atlantic and less well the interannual variations. As a conclusion, these modelling studies suggest that the North Atlantic decadal SLP variations (i.e. NAO), which are related to the decadal PP variations over Europe, are predictable to the extent that SSTs themselves are predictable.

The aim of our study is to search for physical mechanisms responsible for decadal precipitation variability over Europe in connection with atmospheric circulation and SSTs in the North Atlantic region and at global scale.

The paper is organized as follows. A brief description of data sets and methods is given in section 2. Results of the empirical orthogonal function (EOF) and canonical correlation analysis (CCA) of the PP and SLP fields are given in section 3. The relation
between PP and global SST and global 500 mb geopotential height is discussed in section 4. The summary of the results and discussion are presented in section 5.

2. DATA AND METHODS

(a) Data

The primary quantity analysed in this study is land surface precipitation over the region (25°W–70°E; 30°N–70°N). Monthly totals of PP were taken from the Hulme gridded land-surface dataset (hereafter, the H dataset). Details about the station data and averaging method used for construction of the H dataset can be found in Hulme (1992,1994). The resolution of the H dataset used in this study is 5° latitude × 5° longitude.

Monthly means of SLP were taken from the updated version of the dataset described by Trenberth and Paolino (1980). The resolution of this dataset is 5° latitude × 5° longitude. The 500 mb geopotential heights were taken from the NCEP/NCAR* reanalysis dataset (Kalnay et al. 1996). The SST data were taken from the Global Ice Sea Surface Temperature, version 2.3(b) (GISST2) dataset (resolution: 1° latitude × 1° longitude), a development from the Met Office (UKMO) dataset (Bottomley et al. 1990). The selected period for our analysis is 1950–1995.

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All fields were processed in the same way. First, grid points with missing observations for 30% or more of the total analysed period were discarded. With the remaining points, normalized anomalies were formed by individual months using local mean and standard deviation. The normalized anomalies for December, January and February (DJF) were averaged to obtain winter anomalies and then the winter anomalies were smoothed with a five-year running-mean filter to obtain decadal component of the fields.

(b) Methods

EOFs and CCA were used to describe both the independent and the 'coupled' variability of PP and SLP and to establish their relation with the SST field. Detailed discussions of EOF and CCA can be found in von Storch (1995) and Bretherton et al. (1992). A brief description of both methods follows here.

The EOF analysis is a statistical technique used for identifying the principal (spatially uncorrelated) modes of variability of a space- and time-dependent field with zero temporal mean. The covariance matrix of the field is constructed and diagonalized, the result being a set of eigenvalues and corresponding eigenvectors. Each eigenvector (EOF) can be regarded as a spatial pattern. The projection of eigenvectors on the original fields gives the time series of expansion coefficients (or principal components (PCs)) which are measures of the 'strength' of each eigenvector at a certain time. The fraction of the total field variance explained by a certain EOF is proportional to its associated eigenvalue. Together, an eigenvalue and its corresponding EOF and PC define a mode of variability.

The CCA is an appropriate tool to search for a linear relationship between two space/time-dependent variables (Barnett and Preisendorfer 1987; von Storch and Navarra 1995). The CCA selects a pair of spatial patterns of two space/time-dependent variables such that their time coefficients are optimally correlated. The time coefficients, or canonical time series, describe the strength and the sign of the corresponding pattern for each realization in time. Usually, prior to the CCA, the original data are projected onto their EOFs and only a limited number of them are retained, explaining most of the total variance. This also serves as a data-filtering procedure to eliminate noise.

3. Variability of PP and SLP fields

In this section we present the results of the analysis of decadal variability of PP and SLP fields and discuss their connections at regional scale. First, PP and SLP fields are separately analysed using the EOF method so as to identify the prominent modes of variability of individual fields. Then these two fields are related to each other using the CCA.

(a) Precipitation

The first two leading EOF modes of decadal PP variability together account for about 48% of the total decadal PP variance. According to North’s rule (North et al. 1982) these modes are well separated so that they represent distinct modes of precipitation variability. Although the next few modes are well separated according to North’s rule, we do not analyse them in our study because their spatial structures are quite complex and their physical significance is difficult to explain.

The first mode (Fig. 2(a)), which has a considerable power at a time-scale of about seven years, looks very much like the spatial structure of PP anomalies induced by the NAO in winter (Hurrell 1995; see also ‘white paper’ on Atlantic climate variability
by Marshall and Kushnir*). When the precipitation anomalies over the Mediterranean, southern Europe and most of central Europe are negative, northern Europe is dominated by positive anomalies of PP (hereafter, the positive phase of the first PP mode).

The time series of the expansion coefficients of this mode (Fig. 2(c), solid line) shows strong decadal variations. From 1950 until the early 1970s, the first principal component, PC1, exhibits a downward trend so that a continuous decreasing of winter PP over northern Europe together with an increasing of PP over central and southern Europe occurred during this period. A sharp reversal has occurred in the early 1970s when a strong positive trend started and lasted the next two decades.

PC1 correlates significantly (correlation coefficient = 0.8) with the NAO index (Fig. 2(c), dashed line) defined as the difference in normalized pressures between Lisbon, Portugal and Stykkisholmur, Iceland (Hurrell 1995). Hence, the most important mode of PP winter decadal variability over Europe seems to be related to the NAO.

The second mode (Fig. 2(b)), which has enhanced power at time-scales of about 11 years and accounts for 15.9% of the total variance, exhibits an alternating pattern in latitude over Europe (positive PP anomalies in central Europe and negative anomalies in far north-western Europe, the Mediterranean, northern Africa and the Middle East). This mode contains some elements of the first mode identified by Dai et al. (1997) in an

EOF analysis of PP variability over the North Atlantic sector using unfiltered PP data from their gridded data set.

At most of the grid points of the analysed area, the time series of PP emphasize strong linear trends during the considered period. The spatial pattern of linear trend coefficients of PP for the period 1950–1995 (not shown) matches the spatial pattern of EOF1. In order to see to what extent linear trend influences the PP patterns, as well as their relation with the NAO, we performed an EOF analysis of linear detrended PP data. The first PP pattern (Fig. 3(a)), which explains 24.6% of the total variance, looks very much like the EOF1 obtained from the undetrended data. The correlation between its expansion coefficients (Fig. 3(c), solid line) and the detrended NAO index time series (Fig. 3(c), dashed line) is 0.75. Also, the spatial (Fig. 3(b)) and temporal (Fig. 3(d)) patterns of the second mode of PP variability are similar to those obtained from undetrended PP data. We may conclude that the linear trend of the fields does not significantly alter the spatial PP patterns and their relation to the NAO.

(b) Sea-level pressure

The first two leading EOFs of SLP field account for about 77% of the total decadal SLP variance, while individually they explain 64.5% and 11.4% respectively, of the total variance.

The first mode (Fig. 4(a)) presents an out-of-phase relationship between SLP anomalies in such a way that negative SLP anomalies prevail over northern Europe and Iceland in association with positive SLP anomalies over southern Europe, the Mediterranean, northern Africa and the Azores. When this mode prevails, the north-westerly circulation
over Europe is enhanced. The time series of its expansion coefficients (Fig. 4(c)) emphasizes a continuous decreasing of the strength of the north-westerly circulation over Europe from 1950 to the early 1970s. From the early 1970s to the 1990s an increasing strength of the north-westerly circulation can be observed.

The EOF2 of SLP (Fig. 4(b)) emphasizes an alternating pattern of SLP anomalies from the south-eastern to the north-eastern part of the considered region (positive anomalies over Iceland, north-western and central Europe and negative SLP anomalies over much of the Iberian Peninsula, the Azores and north-east of the Caspian Sea). The time series of its expansion coefficients (Fig. 4(d)) shows that the positive phase of this mode dominates periods of the 1960s and 1990s while the negative phase dominates the 1950s and 1970s.

The spatial structure of EOF1 calculated from detrended SLP data (not shown) is almost identical to the EOF1 represented in Fig. 4(a). The EOF2 of detrended SLP (not shown) does not emphasize a spatial pattern similar to that represented in Fig. 4(b) but an out-of-phase relationship between SLP anomalies over the North Atlantic and Europe. The explained variance of EOF1 (EOF2) of the detrended SLP fields decreases (increases) in comparison with that of the corresponding EOFs obtained from undetrended fields.

(c) Connection between precipitation and sea-level pressure

A simple visual inspection of the time series of expansion coefficients represented in Figs. 2(c) and 4(c) shows that the leading mode of decadal PP variability seems to be related to the leading mode of decadal SLP variability. The correlation coefficient
between their expansion coefficient time series is 0.85. Also, the second modes of PP and SLP (Figs. 2(d) and 4(d)) seem to be related, although the correlation coefficient is smaller than in the case of the first modes.

To better assess and confirm the relationship between PP and SLP variations, a CCA between the two fields was performed. In contrast to the individual EOF analysis described above, the CCA of the two fields identifies only those modes of behaviour in which the PP and SLP are optimally correlated. Prior to CCA, the two fields were filtered with the EOF technique, and only the first four modes of SLP and the first five modes of PP, explaining more than 85% of the decadal variance of each field, were considered in the analysis.

The first CCA pair exhibits a correlation between PP and SLP coefficient time series of 0.95, explaining 32.5% of the total decadal PP variance and 58.6% of the total SLP variance, respectively. The patterns (Figs. 5(a) and (b)) look very much like the first EOFs of both variables (Figs. 2(a) and 4(a)) and represent a link that can be explained based on physical processes related to the NAO (van Loon and Rogers 1978; Hurrell 1995). During the positive phase of the first CCA modes (enhanced PP over northern Europe and enhanced north-westerly circulation over Europe) the Icelandic Low and Azores High are stronger than normal and shifted polewards, enhancing the south-westerlies over north-western Europe. This shift in the main circulation patterns over the North Atlantic is associated with a pronounced shift in the storm tracks and the related synoptic eddy activity, so that the moisture transport from the North Atlantic
extends much further to the north and east over Europe than in the normal case. At the same time, the moisture transport over southern Europe, the Mediterranean, and much of central Europe is less intensive than in the normal conditions. This anomalous moisture transport could be at the origin of the NAO-like pattern of PP over the European region.

The second pair of CCA (0.8 correlation) explains 9.7% of the total PP variance and 10.2% of the total SLP variance, respectively. The patterns (Figs. 6(a) and (b)) resemble the second EOF of both variables (Figs. 2(b) and 4(b)). These patterns can be related to changes in characteristics of precipitating weather systems (i.e. storm tracks and cyclone frequencies) owing to the large-scale circulation anomalies. The CCA2 pattern of SLP (Fig. 6(b)) over the North Atlantic resembles the pattern identified by Deser and Blackmon (1993), who have reported an EOF pattern in the North Atlantic SLP and surface zonal wind that has considerable power at 9–12 year time-scales, and depicts anomalous westerlies at 45°N–60°N.

The connection between precipitation processes and the surface circulation is much more complex and only purely qualitative explanations have been presented here.

4. GLOBAL CONNECTIONS OF PP

(a) PP–SST

In this section we present the results of the analysis of the connection between decadal precipitation modes of variability and sea surface temperature anomalies. Several studies have established that there is a strong connection between large-scale SST
anomalies and decadal climate variability (Latif et al. 1997; Cayan et al. 1998). Large-
scale SST fluctuations can be linked to atmospheric circulations that produce precip-
itation fluctuations. Although our analysis was focused on the region (25°W–70°E; 30°N–75°N), we looked at the associations between the decadal precipitation modes of variability over Europe and the global SST. Possible links between SST anomaly patterns and decadal precipitation fluctuations have been examined using correlation between winter SST anomalies and time series of expansion coefficients of the first two decadal precipitation modes described in section 3.

The correlation map between the time series of expansion coefficients of the first PP mode and global SST (Fig. 7(a)) shows a nearly global-scale pattern. When the positive phase of the first PP mode dominates the PP variability over Europe, a tripole-
like SST pattern extends over the North Atlantic (positive SST anomalies around 30°N and associated neighbouring negative SST anomalies to the north and south). The South Atlantic and the Indian Ocean are dominated by positive SST anomalies. At the same time, in the Pacific positive SST anomalies prevail except for a large area around 20°N where SST anomalies are negative.

The correlation map represented in Fig. 7(a) resembles the map of linear trend coefficients of SST for the period 1949–1991 presented by Latif et al. (1997). This similarity suggests that the global connection of the first PP mode is a consequence of the linear trend identified both in PP and SST fields for the analysed period. The correlation map between PC1 of detrended PP and detrended SST (Fig. 7(b)) confirms our supposition that the global structure of SST anomalies shown in Fig. 7(a) is due mainly to the linear trend of PP and SST fields. The correlation map of detrended data (Fig. 7(b)) shows distinct spatial patterns of high correlations but not a global-scale pattern as in the case of undetrended data (Fig. 7(a)), so that we expect that the associated circulation patterns present well-defined regional characteristics. It is apparent that the removing of linear trend does not significantly affect the ‘tripole’ pattern over the North Atlantic. This result is in agreement with our finding that linear trend does not significantly affect the relation between the first PP mode and the NAO at decadal time-
scale (Fig. 3(c)). Therefore, the atmosphere–ocean interactions from the North Atlantic seem to be the source of decadal variability of the NAO (Rodwell et al. 1999) and the main cause of the first decadal PP mode. It is also apparent that after removing the linear trend the correlation still remains significantly high in the North Pacific and some regions from the southern hemisphere. A physical explanation for these teleconnections is difficult to find.
The correlation map between the expansion coefficients of the second PP mode and the SST also presents a global-scale pattern (Fig. 8(a)). When Europe is dominated by the positive phase of the second PP mode a 'decadal ENSO**'-like pattern (Knutson and Manabe 1998) dominates the Pacific SST anomalies. In this case a tongue of anomalous warm water appears in the eastern tropical Pacific and extends polewards along the coasts of North and South America while cold water dominates parts of the sub-tropics and the mid-latitudes of both hemispheres. Positive SST anomalies dominate the Indian and Atlantic Oceans apart from a region located east of the coast of North America where negative SST anomalies prevail. A similar pattern is obtained for the case of detrended PP and SST data (Fig. 8(b)). It is worth noting that the SST anomalies are relatively high over the central, north-eastern and south-eastern Pacific which is not the key region of SST anomalies that characterizes ENSO events at interannual time-scale. A similar SST anomaly pattern dominated the Pacific during the period 1990–1994 and was interpreted as a manifestation of a decadal SST mode of variability which is different to the ENSO mode (Latif et al. 1997).

\[(b) \quad PP-G500\]

As Figs. 7 and 8 suggest, the SST anomaly patterns associated with the first two leading modes of undetrended PP variability over Europe are nearly global. Therefore, we expect atmospheric circulation anomaly patterns to be compatible with the PP and SLP patterns and also to be extended at global scale. To verify this supposition we have selected the field of geopotential height at 500 mb (G500) where the large-scale anomalies of atmospheric circulation can be properly identified. Composite maps of G500 based on the time series of expansion coefficients of the first two PP modes have been constructed both for undetrended and linear detrended data. The composites were constructed by averaging those G500 maps for which the corresponding expansion coefficient of PP mode was greater (less) than $+1(-1)$ standard deviation of its time series. These thresholds were chosen as a compromise between the strength of the atmospheric circulation patterns and the number of cases in each composite. To emphasize the characteristics of the patterns of atmospheric circulation anomalies, we have represented also, on the same map, the field of difference between the positive and the negative composite map.

The composite map corresponding to the first PP mode based on undetrended data (Fig. 9(a)) emphasizes a coherent global G500 anomaly pattern. Figure 9(a) shows that

* El Niño Southern Oscillation.
negative anomalies of geopotential height at 500 mb dominate the polar regions in both hemispheres and positive anomalies dominate the mid-latitudes, determining the enhancement of zonal circulations in both hemispheres. The enhanced north-westerly circulation observed over Europe agrees with the results of the EOF analysis presented in section 3. The composite map of detrended data (Fig. 9(b)) shows that the anomalies of atmospheric circulation at 500 mb are limited in principal to the northern hemisphere. The most well-defined pattern is that associated with the NAO. This fact supports our supposition that the main cause of circulation anomaly related to the first decadal PP mode is the atmosphere–ocean interaction over the North Atlantic. According to Rodwell et al. (1999) the decadal SLP anomalies in the North Atlantic (i.e. NAO) are induced by local SST anomalies that produce local changes in atmospheric heating, surface evaporation and precipitation in such a way that thermal and geopotential structure associated with the NAO is reinforced. However, remote forcings, such as SST anomalies in the Pacific Ocean, can also influence the North Atlantic variability (Latif et al. 2000).

The composite map of winter geopotential height at 500 mb based on expansion-coefficient time series of the second PP mode calculated for undetrended (Fig. 9(c)) and detrended data (Fig. 9(d)) are very similar. In both maps a Pacific North American-like pattern can be identified (Wallace et al. 1996). In the Atlantic European region the anomalous circulation pattern is compatible with that represented in Fig. 6(b). Hence,
the second PP mode is related to a nearly global-scale circulation anomaly pattern which seems to have some links with the Pacific SST anomalies. The anomalous warming in the Tropics and anomalous cooling in the subtropics and mid-latitudes of the Pacific Ocean could cause a shift in the mean position of the subtropical jet streams in such a way that the position of the troughs and ridges of the Rossby waves associated with the jet streams are modified. For such SST patterns the meridional temperature gradient is enhanced and can be associated with higher than normal thermal wind which determines more intense jet streams. Figure 9(d) suggests that there is a northward shift in the jet stream over north-western Europe associated with a southward shift in the jet stream over the Mediterranean and eastern Europe. This circulation pattern can be responsible for the changes in the characteristics (i.e. storm tracks, cyclone frequencies) of precipitating weather systems that cause PP anomaly patterns similar to the EOF2 of PP data (Fig. 2(b)).

5. SUMMARY AND DISCUSSION

In this study, based on observational data, we have investigated the dominant decadal variability modes of winter precipitation over Europe and their connection to atmospheric circulation and sea surface temperature during the period 1950–1995. The analysis was done both for undetrended and detrended data.

The leading mode of PP variability over Europe emphasizes an out-of-phase relationship between PP anomalies over northern Europe and those over southern Europe, the Mediterranean and most of central Europe. Its patterns remain almost unchanged after removing the linear trend. For the undetrended data the correlation pattern between the time series of expansion coefficients of the leading PP mode and the global SST has a global extension. After removing the linear trend from the data the correlation map emphasizes regionally distinct patterns of high correlations. This fact suggests that regional processes could be responsible in determining the circulation anomaly patterns associated with the leading mode. The SST tripole pattern in the North Atlantic, associated with the NAO, is distinctly represented both in the undetrended and detrended correlation maps. There are also some regions from the North Pacific and southern hemisphere which are connected to the first detrended PP mode. The associated circulation pattern of this PP mode is limited mainly to the northern hemisphere with the strongest circulation anomalies over the North Atlantic. We can speculate that the physical processes from the North Atlantic region are at the origin of the leading decadal PP mode.

The second mode of PP emphasizes a meridional alternating pattern of anomalies over Europe. Its associated SST pattern is global. It has a horseshoe-type signature in the tropical Pacific similar to the SST anomaly patterns characterizing ENSO events with connections in the Atlantic and Indian Oceans. However, the most important SST anomalies associated with this mode are not located in the ENSO key region from the eastern Pacific but in the north-eastern and south-eastern Pacific. The associated circulation pattern is global and contains some elements of the Pacific North American pattern (Wallace et al. 1996).

The global circulation anomaly patterns associated with the first leading PP modes contain the corresponding regional patterns of atmospheric circulation that have resulted from the regional analysis. Therefore, we may conclude that the PP modes of decadal variability over Europe are parts of the large-scale PP anomaly patterns.

Most of the results presented here are based on too few degrees of freedom to be strictly statistically significant. However, the compatibility between the corresponding patterns in the analysed fields make our results convincing.
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