Multidecadal variability of summer temperature over Romania and its relation with Atlantic Multidecadal Oscillation

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Abstract

We investigate the multidecadal variability of summer temperature over Romania as measured at 14 meteorological stations with long term observational records. The dominant pattern of summer temperature variability has a monopolar structure and shows pronounced multidecadal variations. A correlation analysis reveals that these multidecadal variations are related with multidecadal variations in the frequency of four daily atmospheric circulation patterns from the North Atlantic region. It is found that, on multidecadal time scales, negative summer mean temperature (TT) anomalies are associated with positive sea level pressure (SLP) anomalies centered over the northern part of the Atlantic Ocean and Scandinavia and negative SLP anomalies centered over the northern part of Africa. It is speculated that a possible cause of multidecadal fluctuations in the frequency of these four patterns are the sea surface temperature anomalies associated to the Atlantic Multidecadal Oscillation. These results have implications for predicting the evolution of summer temperature over Romania on multidecadal time scales.

1. Introduction

The variations of surface-air temperature and precipitation are of vital importance for society and economy (Watson et al., 2001). Present-day weather conditions affect the natural, social and economic system all over the globe. Central and southern Europe, including Romania, is considered to be one of the most vulnerable regions affected by changes in the climate system (IPCC, 2007). Regional climate simulations over Europe have revealed that most of the warming in southern part of Europe is related to soil moisture deficit in summer (Goubanova and Li, 2007). Moreover, these simulated changes in high temperatures, in summer, are larger than the corresponding changes in the mean state suggesting also changes in the temperature variability (Rowell, 2005; Fischer and Schär, 2009).

The atmospheric circulation is the principal factor that determines the climate variability in Europe. It can be characterized using circulation patterns or circulation types. The circulation patterns and their corresponding indices are frequently identified using the principal component analysis (e.g. Barnston and Livezey, 1987; Thompson and Wallace, 1998; Compagnucci and Richman, 2008; Philipp, 2009). On the other hand, circulation types can be identified using both subjective as well as objective classification methods (Kyselý and Huth, 2006; Beck et al., 2007; Christiansen, 2007; Fereday et al., 2008; Huth et al., 2008). Subjective manual classification of synoptic circulation patterns have been employed for single countries or limited regions (e.g. Yarnal, 1993), for larger territories like Europe (e.g. Hess and Brezowsky, 1969) and even for the whole hemisphere (Dzerdzeevski, 1968).

Two of the most important phenomena that influence the temperature variability over Europe are the North Atlantic Oscillation (NAO) and the Atlantic Multidecadal Oscillation (AMO). NAO is one of the leading modes of climate variability over the Northern Hemisphere and consists of a north-south dipole of Sea Level Pressure (SLP) anomalies, with one centre located over Iceland and the other one over Azore. Changes in these large-scale modes have a strong influence on the temperature variability (Bárdossy and Caspary, 1990; Xoplaki et al., 2003; Cahynová and Huth, 2009). The climatic effects of NAO have been widely studied, reveling NAO to be the most important source of climate variability in Europe (Hurrell, 1995; Osborn et al., 1999). The interannual to multidecadal climate variations over Europe have been related with variations in both phase and amplitude of NAO. The influence of NAO on the temperature variability over Europe has been intensively studied by different authors (Hurrell, 1995; Slonosky et al., 2001; Dorn et al., 2003; Rauthe and Paeth, 2004; Stephenson et al., 2006).

AMO is defined by the detrended Sea Surface Temperature (SST) anomalies over the North Atlantic from 0^{o}N to 70^{o}N (Enfield et al., 2001) and is characterized by a cycle of about 70 years. Knight et al. (2006) showed that AMO can explain 30 – 40% of the low frequency of the Central England Temperature (CET) variance and that the climate effects of AMO, over Europe, are strongest in summer and autumn.

During the last decade, Romania has experienced the highest summer temperatures in the last 100 years. Just in July 2000, the daily maximum temperature was above 40°C for more than 100 cases at meteorological stations situated over the Romanian territory. These extreme values might be triggered either by anthropogenic factors or by natural occurring changes in the climate system. Considerable attention has been paid lately on the understanding of the natural cycles, so that it may be correctly accounted for in the evolution assessments of greenhouse gases.

Romania is situated in the southeastern part of Europe (Fig. 1) and has a temperate continental climate. Various studies have shown certain changes in surface air temperature and precipitation regimes over Romania. Bojariu and Paliu (2001) found a significant connection between NAO phases and the Romanian temperature variability in winter, while Tomozeiu et al. (2002) showed that the mean maximum temperature over Romania presents a strong seasonal dependence on various large-scale circulation indices and the summer maximum temperature over Romania presents a significant increasing trend, with an upward shift in 1985.

A possible candidate to explain the decadal variability of summer temperature over Romania might be the sea surface temperature (SST) from the Atlantic basin. It has been proposed that SST anomalies govern, at least partly, precipitation and air temperature anomalies in the neighboring continental regions (Hunt and Gordon, 1988; Zorita et al., 1992; Rimbu et al., 2001). In addition, there are strong indications that fluctuations in SST, and hence fluctuations of surface fluxes, are intimately involved in decadal-scale climate variability (Trigo and DaCamara, 2000). Many studies also suggested that the potential predictability of the climate system could be found in the decadal and longer cycles of SSTs (e.g. Rodwell et al., 1999).

In recent decades Europe has experienced unprecedented rate of summer warming (Klein Tank and Können, 2003; Luterbacher et al., 2004; Klein Tank et al., 2005). Recent studies (Sutton and Hodson, 2005) have looked at the mechanisms that contribute to the formation and prediction of such extreme warm events and they attribute the long-term variability of summer average temperature to a mode of SST called the Atlantic Multidecadal Oscillation (AMO) (Enfield et al., 2001). The AMO is believed to be caused by the North-Atlantic thermohaline circulation (Knight et al., 2005) and it has been linked with the occurrence of Sahel drought (Folland et al., 1986; Rowell et al., 1995), variability in the North Brazilian rainfall (Folland et al., 2001), North American climate (Sutton and Hodson, 2005), U.S. river streamflow variability (Enfield et al., 2001) and the frequency of Atlantic hurricanes (Goldenberg et al., 2001). This pattern has showed marked fluctuations in the 20th century, with intervals between successive peaks and troughs of roughly 70 years (Mann and Park, 1994; Schlesinger and Ramankutty, 1994).

The aim of this study is to search for the physical mechanisms responsible for the multidecadal variability of summer temperature over Romania in connection with sea surface temperature and large-scale atmospheric circulation. It is important to study such connections, because the possibility of predicting temperature anomalies months or years in advance is of great interest to regional economies. Characterization of temperature variability on long time scales and identification of connections to climate forcings provides potential improvement for forecasts when the climate forcings are predictable or slowly evolving (Croley and Luukkonen, 2003).

2. Data and methods

Our study is based on four data sets:

1) Monthly mean air temperature (TT) at 14 stations over Romania, for the summer months (June, July and August[JJA]). The name and coordinates of the stations are presented in Table 1. The temperature data set is quality controlled (Busuioc et al., 2007).

2) The Extended Reconstructed Sea Surface Temperature (ERSST.v3, Smith et al., 2008), with a 2^{o} x 2^{o} resolution.

3) AMO time series index, which was taken from http://www.cdc.noaa.gov/Timeseries/AMO. The AMO index is defined as the SST averaged over 0°-60°N, 0°-80°W minus SST averaged over 60°S-60°N (Enfield et al., 2001).

4) The frequency of daily circulation patterns published by Philipp et al. 2007 (available online at http://www.cru.uea.ac.uk/cru/projects/emulate/). The daily mean sea level pressure (SLP) dataset used to compute the daily patterns was taken from the data reconstructed by Ansell et al. (2006) within the European project EMULATE. Within the EMULATE project a new reconstruction of daily mean sea level pressure, based on instrumental data, has been obtained (Ansell et al., 2006). This data set offers the possibility to extend the view of daily resolved circulation variability back to the year 1850.

All data sets were processed in the same way. First, the summer means (June, July, August [JJA]) were calculated from the monthly means. Then, the summer standardized anomalies with respect to their mean and their standard deviation, estimated for the period 1899 - 2003, were produced. Since our focus is the multidecadal character of the data sets, we applied a 21-year running mean to the standardized time series for all data sets.

The dominant modes of summer temperature variability are based on Empirical Orthogonal Function (EOF) analysis (von Storch and Zwiers, 1999). The aim of the EOF method is to find a new set of variables that capture most of the observed variance from the data through a linear combination of the original variables. The patterns provided by the EOF method show the main spatial features of summer temperature, while their time coefficient describes the dominant temporal variability in the data set. EOF analysis was performed for summer temperature anomalies at 14 stations, using the normalized and detrended time series.

In order to analyze the temporal structure (interannual and decadal variability) of summer temperature variability over Romania we applied a wavelet power spectrum. The wavelet analysis used in this paper follows the methods of Torrence and Compo (1998). Statistical significance is determined against a red noise null hypothesis using a chi-squared test. By decomposing a time series into a time-frequency space, it is possible to determine the dominant modes of variability, as well as, how these modes vary in time. The wavelet transform is designed to analyze time series that contain non-stationary power over many different frequency scales (Daubechies, 1990). The *wavelet transform* breaks up a signal into scaled versions of a *wavelet function*, where the scale of the wavelet (the window) varies with frequency. Thus, the wavelet is narrow in time at high frequencies and the scale of the wavelet increases with decreasing frequency. The wavelet transform, therefore, expresses a time series in a three-dimensional space: time (x), scale/frequency (y), and power (z).

3. Results

3.1 Dominant pattern of summer temperature and its relationship with Atlantic Multidecadal Oscillation

The first EOF (Figure 2.a) captures in-phase variability for all analyzed stations. This monopolar structure (positive values at all stations) emphasizes that mainly the large-scale atmospheric circulation influences the multidecadal variability of the summer temperature over Romania. Although the structure of the first EOF is monopolar, there is a clear difference between the northwestern and southeastern parts of the country. This difference is due to the influence of the Carpathian Mountains, which acts as a barrier between the northwestern and southeastern part of the country. The associated time coefficient (PC1), which gives the temporal evolution of the dominant pattern of temperature over Romania, shows important multidecadal variations for the 1899 – 2003 period (Figure 2.b). A cold interval (1899 – 1920) was followed by a prolonged warm period (1925 - 1965). The last 20 years of the analyzed interval are also characterized by a warm phase. The second EOF (not shown), which explains 6.81% of the total variance, is characterized by a strong dipole between the high altitude stations and low altitude stations.

PC1 time series, smoothed with a 21-year running mean filter, resembles the evolution of the summer AMO index (Figure 3.a). AMO was identified as the first rotated EOF of the Atlantic SST and has a periodicity of around 60-80 years (Enfield et al., 2001). The correlation coefficient between PC1 and summer AMO index is 0.8 (99% significance level). High (low) summer temperatures occur during the warm (cold) phase of the AMO index. This supports the analysis of Sutton and Hodson (2005) which showed that the occurrence of extreme temperatures over Europe is related to long-term changes in the AMO phase.

The wavelet power spectra of summer PC1 (Figure 3.b) and summer AMO index (Figure 3.c) reveals that the power of the two time series is broadly distributed, the most significant peak being in the 60 years band. The cross wavelet transform (XVT) between PC1 and summer AMO index is shown in Figure 3.d. The cross wavelet analysis between the two time series provides a measure of coherence at each frequency (Torrence and Compo, 1998). Both time series show high coherency in the 60 years band, which is known to be a periodicity characteristic to AMO (Schlesinger and Ramankutty, 1994).

3.2 Relationship with global SST

Several studies have established that large-scale SST anomalies are linked to decadal climate variability (Dai et al., 1997; Cayan et al., 1998; Latif et al., 2000). Rajagopalan et al. (1998) found evidence of significant coherence at decadal time scale between tropical South Atlantic SST and NAO, with warm SSTs associated with the positive phase of NAO.

To assess the links between the summer temperature over Romania and global SST we have constructed the composite maps of summer SST for the years of ***High*** (> 1 standard deviation) and ***Low*** (< -1 standard deviation) values of summer PC1. This threshold was chosen as a compromise between the strength of the climate anomalies associated to temperature variability and the number of maps which satisfy this criterion. Further analysis has shown that the results are not sensitive to the exact threshold values used for our composite analysis. Here we will show just the map corresponding to the difference between ***High*** – ***Low*** years.

The composite map between summer PC1 and summer SST is shown in Fig 4. The main characteristic of the composite map is the quasi-monopolar structure in the North Atlantic with positive SST anomalies over the entire North Atlantic. The PC1 time series is strongly related with SST anomalies over the whole basin, consistent with the correlation between PC1 and AMO (Fig 2.a). As indicated by other studies (Latif et al., 2004; Knight et al., 2005) such a quasi-monopolar structure is associated with the extreme phases of the AMO (Mesta-Nuñez and Enfield, 1999). High (low) SST anomalies are associated with positive (negative) phase of AMO. Taking into account the structure of the composite map, we can say that during the warm phase of the AMO, Romania experiences relatively high summer temperatures, which is in agreement with the evolution of the summer PC1 time series, presented in Figure 2.a.

3.3. Relationship with the frequency of daily circulation patterns from the North Atlantic

To study the connection with the atmospheric circulation we used the frequency of the daily circulation patterns published by Philipp et al. (2007). These daily patterns were derived using a clustering scheme that combines the concepts of simulated annealing and diversified randomization (SANDRA), which is a more stable statistical scheme compared to the commonly used k-means method (Philipp et al., 2007). Application of the SANDRA algorithm to daily atmospheric circulation in the domain (20◦N-75◦N;70◦W-40◦E) can be optimally represented by 9, 11, 6 and 8 patterns in winter (DJF), spring (MAM), summer (JJA) and autumn (SON), respectively (Philipp et al. 2007). In total, 34 patterns characterize the atmospheric circulation over the whole year. In our study, we have used the frequency of the six summer patterns covering the period 1850 to 2003. A detailed description of the patterns is given in Philipp et al. (2007).

To identify the daily atmospheric circulation patterns related to the summer temperature variability over Romania, we correlate the summer PC1 and the summer AMO index with the time series of the frequency of the summer daily circulation patterns. The correlation coefficients between JJA PC1, the summer AMO index and the frequency of JJA patterns are given in Figure 5.a. The time series of summer PC1 and summer AMO index are significantly positively correlated (99% significance level) with the frequency of clusters 3 and 6 and negatively correlated (99% significance level) with the frequency of clusters 2 and 4, respectively. The time series of summer PC1 and the frequency of patterns 2, 3, 4 and 6 are shown in Figure 5.b. The temporal evolution of the time series is similar, being in agreement with the correlation coefficients. All time series present strong multidecadal variability.

Since the spatial structures of the summer patterns are already published (Philipp et al., 2007) and available online at the EMULATE web page (http://www.metoffice.gov.uk/hadobs/emslp/), we present here only the patterns that are strongly related to the summer PC1, that is: clusters 2, 3, 4 and 6, respectively. To have a clear image of the atmospheric circulation patterns associated with the frequency of the daily circulation patterns 2, 3, 4 and 6, at multidecadal time scales, we have constructed the composite maps of summer SLP for the years when the times series of each pattern was higher than 1 standard deviation (***High***) and lower than -1 standard deviation (***Low***), respectively. In Figure 6 we show just the maps corresponding to the difference between ***High*** – ***Low*** years. Prior to the composite analysis, both the times series of the patterns frequency and SLP data were smoothed with a 21-year running mean filter. The resulting patterns (Figure 6.a, b, c, d) resemble the corresponding daily anomaly patterns presented in the original paper of Philipp et al. (2007).

The composite maps of pattern 2 and 4 (negatively correlated with summer PC1) and SLP are shown in Figure 6.a and Figure 6.c, respectively. According to these patterns, negative temperature (TT) anomalies are associated with positive SLP anomalies centered over the northern part of the Atlantic Ocean and Scandinavia and negative SLP anomalies centered over the northern part of Africa. This pattern favors the advection of cold air from the high latitudes throughout the southeastern part of Europe, including Romania. The composite maps of patterns 3 and 6 (positive correlated with PC1) and SLP are presented in figure 6.c and Figure 6.d, respectively. The low-pressure system over the British Isle and the high-pressure system over the south-central part of Europe induce negative temperature anomalies over the western part of Europe and positive temperature anomalies over the eastern part of Europe, including Romania. According to Sutton and Hodson (2005) the positive phase of AMO is associated with a low SLP center situated west of the United Kingdom, a pattern which is similar to the ones identified for patterns 4 and 6, respectively.

These results are also in agreement with the recent results of Della-Marta et al. (2007) who showed that extreme high temperatures over Europe have a multidecadal oscillation. One possible mechanism for the patterns identified is that AMO modulates the frequency of these daily patterns during its extreme phases, and in this way modulates the variability of summer temperature. These tendencies are clearly reflected in the correlations between summer PC1, the summer AMO index and the patterns frequencies.

4. Discussion

In this study, we have investigated the decadal variability of summer temperature over Romania and its connection with global SST and large-scale atmospheric circulation. We have found evidences supporting the analysis of Sutton and Hodson (2005) and Della-Marta et al. (2007) which stated that the occurrence of warmer than average summer temperatures over Europe are related to long-term changes in the AMO.

The first principal component of summer temperature over Romania presents a strong multidecadal variation. A cold interval starting 1899 up to 1920 was followed by a very warm period from 1925 until 1965. Since around 1990, the time series shows the indication of a new warm period. These extreme phases are significantly correlated with the phases of the summer AMO index. High values of PC1 of the summer temperature over Romania are significantly correlated with anomalously high SST over the entire North Atlantic basin. This monopolar structure of the SST anomalies is associated with AMO and confirms the findings presented before. There is also a strong evidence that the frequency of U.S. droughts (McCabe et al., 2004) and the frequency of European heat waves (Della-Marta et al., 2007) are both sensitive to Atlantic SSTs.

The alternance of these warm and cold phases might be related to the frequency of different weather patterns. The correlation coefficients between summer PC1, summer AMO index and the frequency of the summer circulation patterns (Philipp et al., 2007) shows that both PC1 and AMO index are significantly related with four summer patterns (pattern 2, 3, 4 and 6, respectively). According to Philipp et al. (2007) the frequency of pattern 2 has increased and the associated pattern, in the SLP field, was associated with the strong cooling around 1900, a cooling which is also present in our summer PC1 time series.

One of the main aspects of our study is that we proved that not only on global or continental scale, but also at regional scale, the influence of AMO has a strong impact, especially during summer. Taking into account that AMO index has increased since around 1990, we may experience a period similar to 1925-1965 and the summer temperatures may be greater than the average in the next decade. These results have implications for predicting the evolution of summer temperature on decadal time scales.

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Figure 1. The topographic map of Romania and the location of the stations used in this study

Figure 2. a) First EOF of summer (June/July/August - JJA) temperature (TT) and b) the corresponding time series (PC1)

Figure 3. a) The time series of PC1 (blue line) and time series of summer AMO index (red line), after a 21 years running mean has been applied

b) The continuous wavelet power spectrum of the time series of PC1;

c) The continuous wavelet power spectrum of the time series of summer AMO index;

d) Squared wavelet coherence between the time series of PC1 and summer AMO index.

The thick *black line contour* is the 5% significance level against red noise.

Arrows indicate the phase of the coherence, where right is in phase and left is in out-of-phase.

Colors show the power (or variance).

More details of the method are found in Torrence and Compo (1998)

Figure 4. The composite map between JJA PC1 and SST (the contour lines indicate the SST normalized anomalies significant at 95% significance level on a standard t-test)

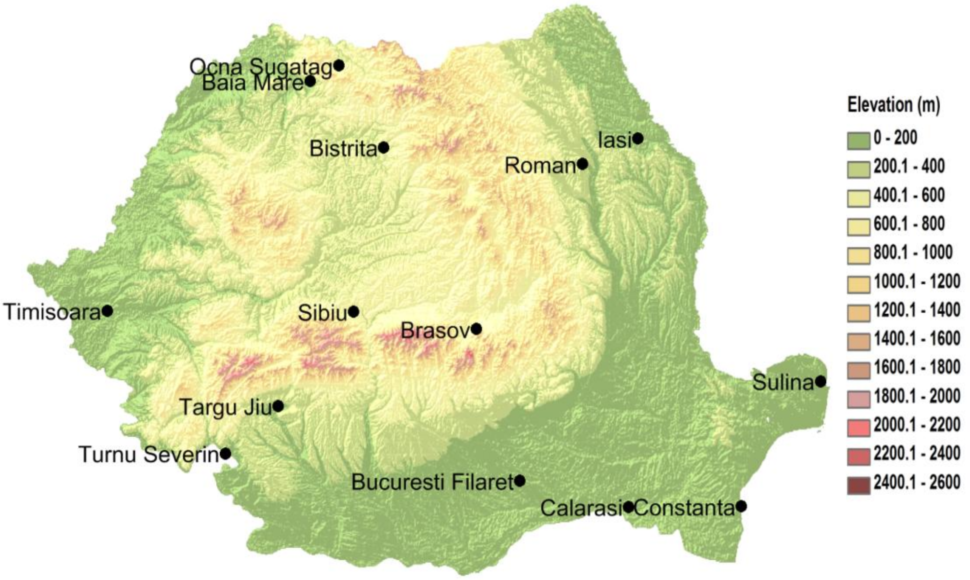
Figure 5. a) Correlation coefficients between summer PC1 (black bar) and summer AMO index (red bar) and the summer patterns frequency and

b) time series of PC1 (black line) and time series of pattern 2 (red line), pattern 3 (blue line), pattern 4 (green line) and pattern 6 (magenta line)

Figure 6. SLP pattern associated with the multidecadal variations in the frequency of

a) pattern 2, b) pattern 3, c) pattern 4 and d) pattern 6

Units: hPa



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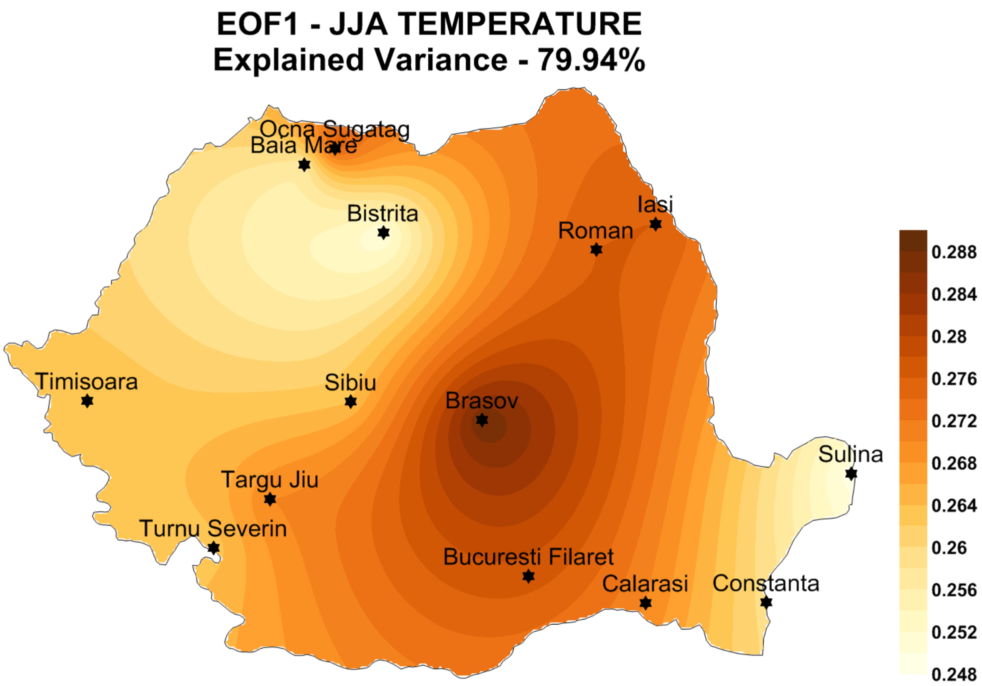

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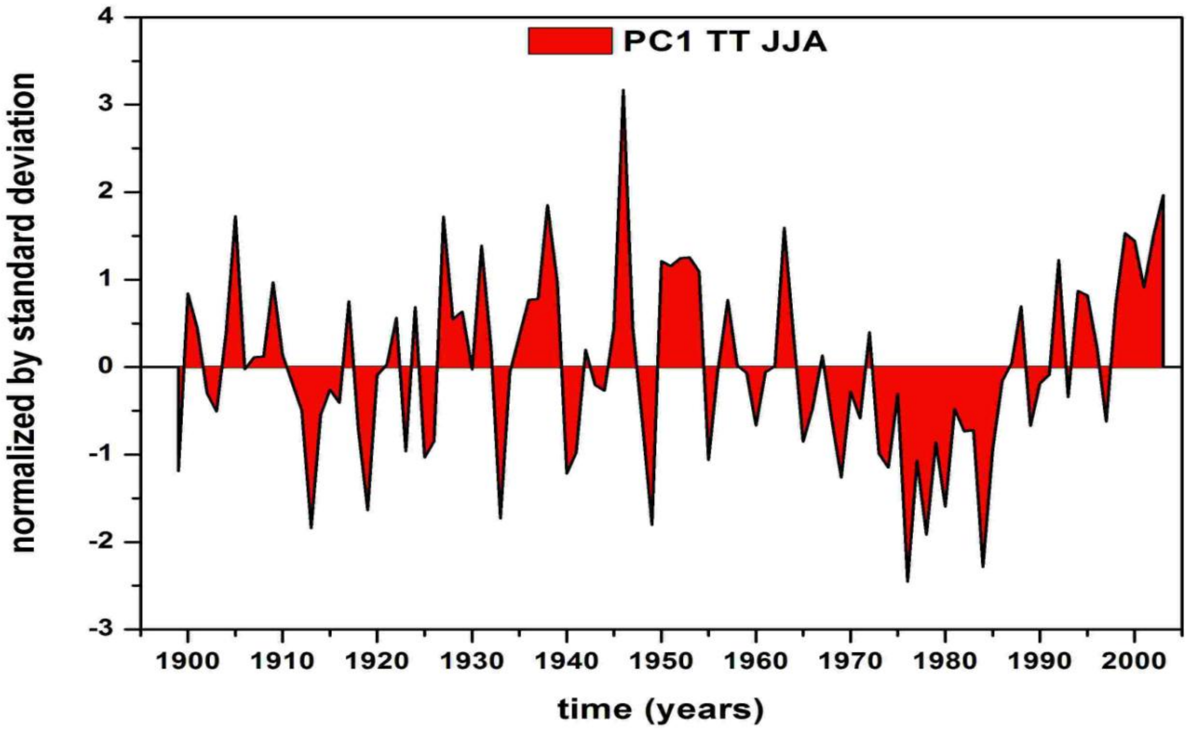

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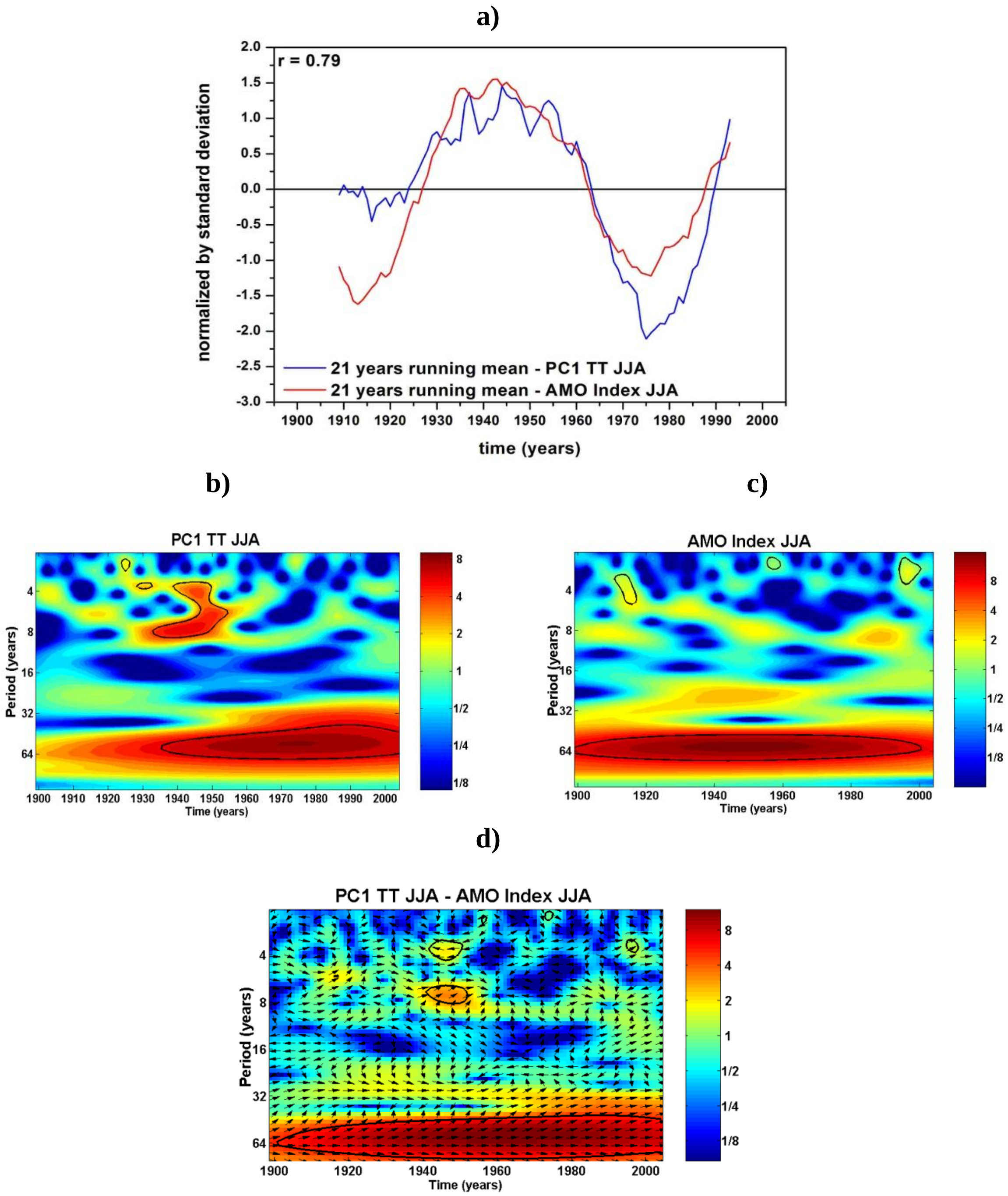

Figure 3. a) The time series of PC1 (blue line) and time series of summer AMO index (red line), after a 21 years running mean has been applied

b) The continuous wavelet power spectrum of the time series of PC1;

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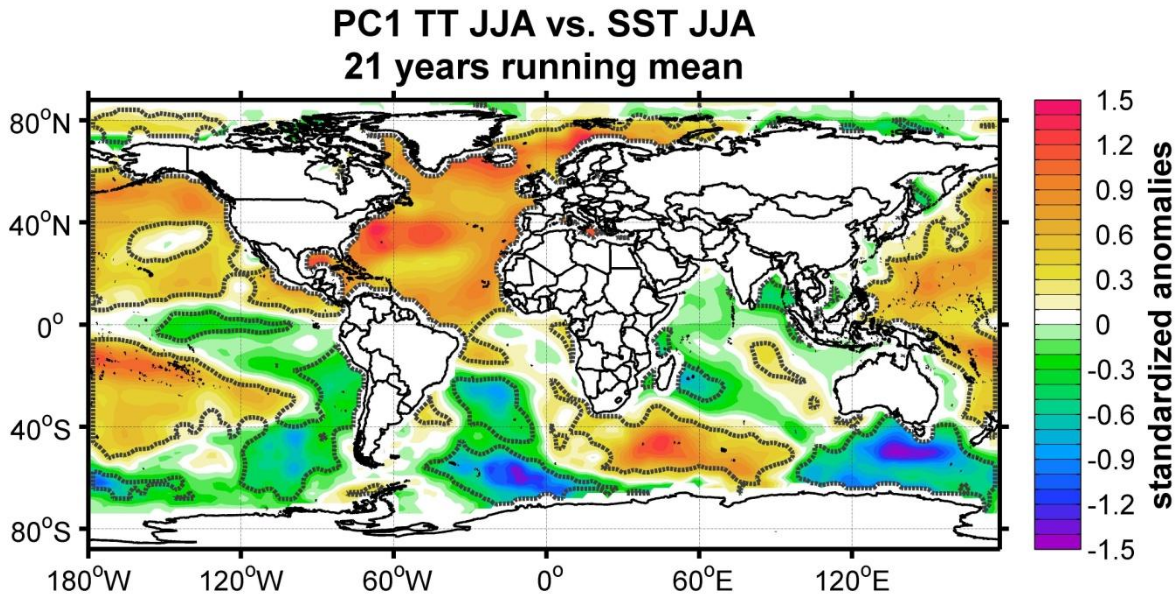
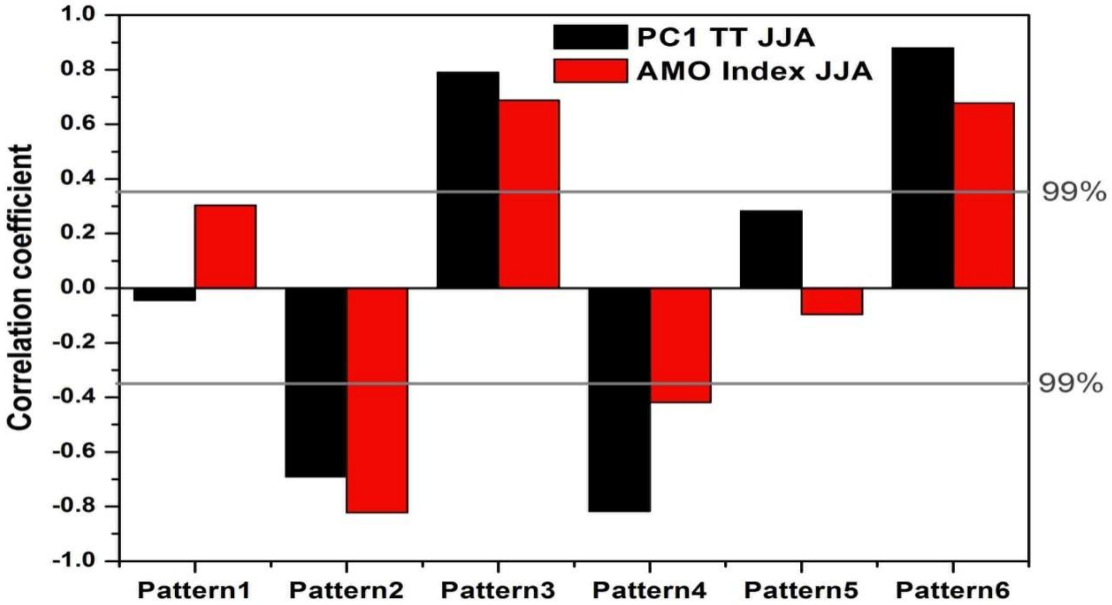


Figure 4. The composite map between JJA PC1 and SST

(the contour lines indicate the SST normalized anomalies significant at 95% significance level on a standard t-test)

a)



b)

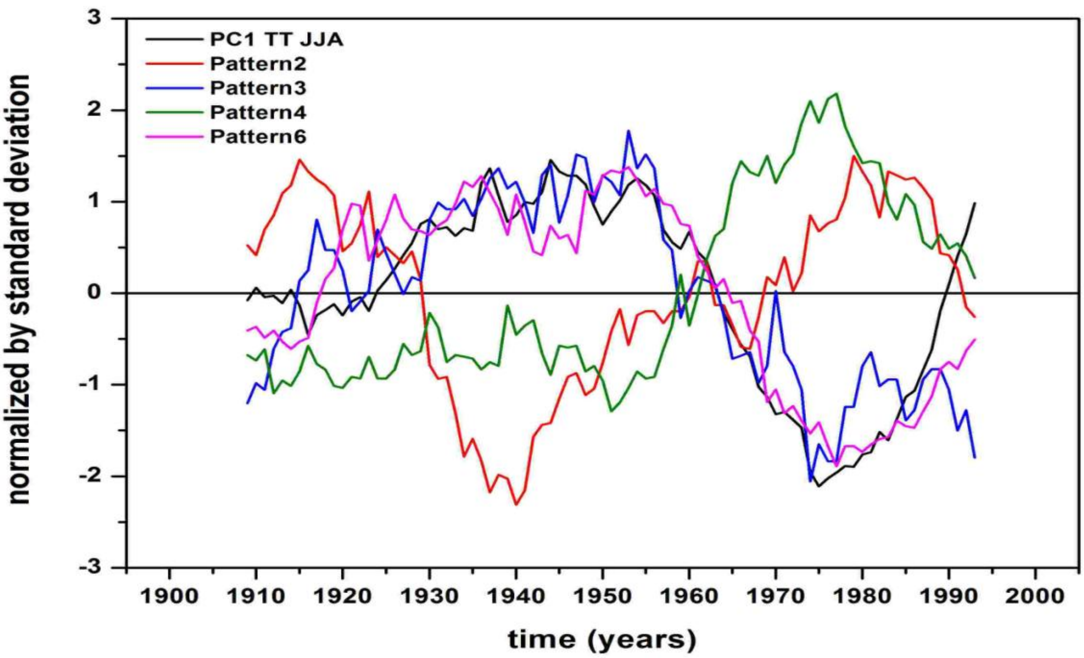


Figure 5. a) Correlation coefficients between PC1 (black bar) and summer AMO index (red bar) and pattern frequency and
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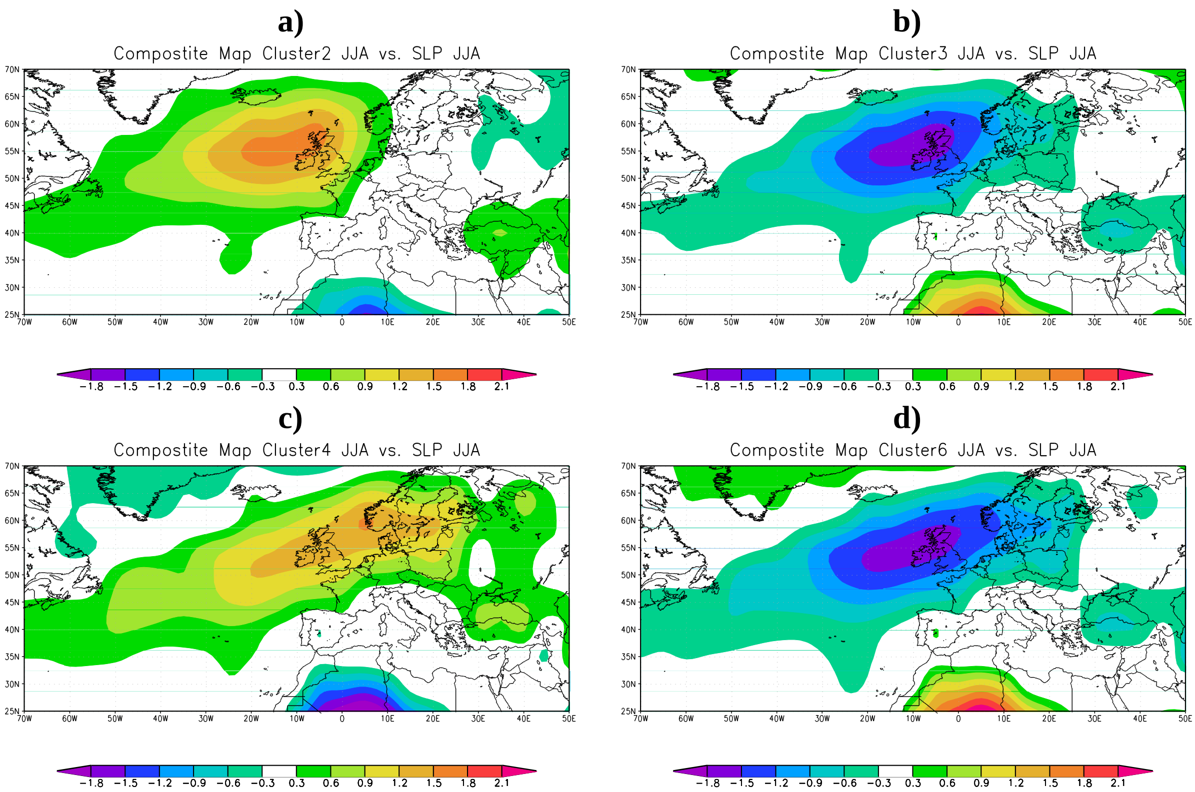

Figure 6. SLP pattern associated with multidecadal variations in the frequency of a) pattern 2, b) pattern 3, c) pattern 4 and d) pattern 6

Units: hPa