MECHANISMS CONTROLLING CLIMATE VARIABILITY AT ATLANTIC-EUROPEAN SCALE

Nicoleta Ionac[1], Monica Matei[2], Vlad Năftănăilă[3],

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Abstract. The purpose of the present paper is to analyze the main patterns of Atlantic-European climate variability in the context of observed climate change conditions. In this respect, we have chosen multiple variables in grid points, as they were provided by the *National Centre of Atmospheric Research* (NCAR, USA). The variables taken into consideration are: sea level pressure (SLP), geopotential height, air temperature and specific humidity at different pressure levels (500, 700, 850 mb), over a 60 years' time period (1950-2010). The Empirical Orthogonal Functions (EOF) analysis was applied to identify the anomalies of the chosen variables, both for summer (June to August) and winter (December to February) seasons. The time coefficient series reveal both spatial and temporal variability modes. By using Man-Kendall and Pettitt non-parametric tests, we could also detect the general trends and change points of time coefficient series resulted. One of the most important circulation pattern that was identified is the *North Atlantic Circulation*, which becomes the main pattern of atmospheric circulation variability, at least in winter.

Introduction

The complexity of the climate system and the interaction between its components make it very difficult to understand the mechanism that controls the regional or local climate variability. In the last years, many global and regional models were developed and adapted, in order to include more complex physical mechanisms of the climate system, such us the ENSO (*El Nino-Southern Oscillation)* phenomenon. This type of large scale atmospheric process affects many regions on the globe, causing extreme weather events (e.g. floods, droughts).

[1] Prof. PhD., University of Bucharest, rinmozel@yahoo.com
[2] Ph.D. student, University of Bucharest, monicamatei06@gmail.com
[3] Ph. D. student, University of Bucharest, naftanaila.vlad@yahoo.com

Nevertheless, the weakness of the regional climate models is that these fail to solve some regionalization issues, although a very fine resolution is used. More than this, during the last decades, the anthropogenic emissions of greenhouse gases (GHG) into the atmosphere represents an important factor that must further be added to the simulations performed. Also, as Houghton et al. (2001) point out, the simulations made with climate models show that the most of the observed trend can only be explained when the anthropogenic influence (primarily greenhouse gas emissions) is taken into account.

The most often used approaches to study the climate system are the physically based climate models or statistical analysis techniques. For the analysis of large data sets, in climate research is being used the term of "*climatic signal*" (Busuioc et. al., 2010), which represents the dynamic of the process considered. In other words, depending on the analysis conducted, the climatic signal must be separated from the so-called "*noise*", which contains items of information that are not relevant for the research area. Hence, various methods were developed, taking into account the exclusion of noise from the large data sets. Statistical and dynamical techniques used in climate's projections, seek to maximize the signal and minimize the noise in order to extract the most valuable information. All these techniques try to simulate the natural climate variability and the mechanism that controls it. Moreover, the human influences on climate and the increase of greenhouse gasses concentrations are factors that contribute to climate perturbation.

The main goal of the present study is to detect the potential mechanisms that control the Atlantic-European large scale atmospheric circulation in the climate change context. The European climate variability is strongly influenced by the presence of the North-Atlantic Ocean and the characteristics of atmospheric dynamics in the mid-latitudes (Park and Latif, 2005). As many studies reveals (Hurell 1995, 1996; Hurell and von Loon, 1997), large changes in the wintertime atmospheric circulation have occurred in the past two decades over the Northern Hemisphere, and these changes have had a profound effect on regional distributions of surface temperature and precipitation. The variations over the North Atlantic are related to changes in the North Atlantic Oscillation (NAO). The NAO, which was first identified in the 1920's by Sir Gilbert Walker (Walker and Bliss, 1932), is associated with changes in the surface westerlies across the Atlantic, into Europe and refers to a meridional oscillation in atmospheric mass with centers of action near the Icelandic low and the Azores high (van Loon and Rogers, 1978). Although it is evident throughout the year, it is most pronounced during winter and accounts for more than one-third of the total variance of the sea level pressure (SLP) field over the North Atlantic (Wallace and Gutzler 1981, Barnston and Livezey, 1987). The NAO phenomenon was identified in many studies (Hurrell and Dickson, 2004, Thompson et al. 2000, Wallace, 2000, Wanner et al., 2001) and is most of all defined as one of the most important source of inter-annual variability in the atmospheric circulation (Busuioc et al., 2001).

To understand the climate change signal is vitally important to human existence, especially in regions sensitive to shifts in water resources and precipitation (Türkeş and Erlat, 2003). Human-induced climate change is expected to critically affect the frequency of extreme climate events such as floods or droughts, as well as coastal storms.

The paper is structured as follows: section 2 describes the data and methods used to identify the anomalies of the chosen variables, while the section 3 outlines the results. Section 4 summarizes the conclusions.

1. Data and methods

This study is mainly based on the re-analysis data provided from the *National Centre of Atmospheric Research* (NCAR, USA), (Kalnay et al, 1996). The variables considered here are: sea level pressure (SLP), geopotential height at 500 mb pressure level (H500), air temperature at 850 mb (T850) and specific humidity at 700 mb (SH700), with a resolution of 2.5º x 2.5º global grids. The area between 45W to 50E and 30N to 60N was selected, for the winter (December to February-DJF) and summer (June to August-JJA) seasons, during the 1950-2010 time interval. We must point out that these data do not represent direct measurements, but have been obtained through a complex algorithm of data assimilation, where the observed data and simulations were used in the construction of dynamical models. In other words, these data represent an approximation of the climate system state. For all the parameters selected, the anomalies have also been computed in order to extract the long-term seasonal mean from the original values.

Many different methods, such as the *Empirical Orthogonal Function* (EOF) analysis also known as the principal component analysis (PCA), as well as the principal oscillation pattern (POP) analysis, cluster analysis (CA) or neural networks have been developed to identify large-scale patterns of climate variability (von Storch and Zwiers, 1999). The EOF analysis (Lorenz, 1956) is one of the most widely-used method and it is applied to represent the climate signal by specific configurations. It refers to the decomposition of the climate signal from a data set by detecting the orthogonal basis functions. In other words, this techniques simplify the dataset, reducing the multidimensional data to lower dimensions that can be properly alayzed. The EOF analysis is used to obtain the main spatial and temporal variability pattern (von Storch, 1995), by decomposing a data set into a set of orthogonal basis functions. More information about the theory of this method can be found in Dommenget and Latif (2002) and Overland and Preisendorfer

(1992). The EOFs can be interpreted as characteristic patterns of variability for the area of interest, which explains the main pattern of circulation types.

In the present study, the seasonal EOF configurations were computed for the above-mentioned parameters, focusing on the first two configurations that explain most of the system variation. These configurations create a noise filter, explaining more that 50% of the total variance and representing meaningful physical processes associated with spatial and temporal patterns. In conclusion, these patterns may be linked to possible dynamical mechanisms. By decomposing the input data, it is expected that the physical process responsible for the generation of the corresponding signal to be identified. The signal detection in the climate field is important to recognize the natural climate variability and separate its driving forces from the anthropogenic ones. By detecting the specific signal from large data sets by EOF configurations, dominant spatial and temporal structures may be detected. In other words, for a given time series, a covariance matrix of the data set is being composed, the former being after decomposed into *eigenvalues* and *eingenvectors*. Each *eigenvalue* represents the percentage of the variance explained, while the amplitude of each EOF series in time is called principal component series (PC).

The EOF time coefficient series are analyzed in order to detect trends and shifts of the corresponding mean values. This analysis has been done by using the non-parametric Mann-Kendall (Sneyers, 1975) and Pettitt (Pettitt, 1979) tests. The Mann-Kendall test can be used to determine whether the observed collection of time series for a variable, exhibits a number of trends that is greater than the number that is expected to occur by chance. The change points have been detected by means of the Pettitt's test, which allows, besides the general trend, the identification of "change points" in the mean of the time series, this also being an important aspect (Busuioc et al., 2001).

2. Results

2.1 EOF configurations. The analysis of the EOF configurations provides a useful tool to detect the main patterns of Atlantic/European climate variability. The input data for the EOF analysis were the anomalies of the re-analysis data taken into consideration, instead of their multiannual average, just to make the physical interpretation easier.

In Figure 1, the first two EOF configurations of the SLP parameters are shown, both for summer and winter seasons. In the summer season, for the EOF 1, which explains 39% of the total variance, an increase of the anti-cyclone configurations centered in the northwestern part of Europe may be noticed. The EOF 2, which explains 15% of the total variance, a bipolar structure, with one component centered in the northern part of the Atlantic Ocean, is shown. This configuration shows an increase of the anti-cyclonic structures in Europe, with pronounced positive anomalies in the southern part of the Black Sea.

In the winter season, for the EOF 1 (40% of the explained variance), an extended cyclonic/ anti-cyclonic structure on the whole Atlantic/European area is shown. The increase in the cyclonic configurations (negative anomalies), is equivalent to the increase of the anticyclone configurations (positive anomalies). This type of structure brings, over the European territory (including Romania), a southwest/northwest circulation. The EOF 2 pattern (24% of the explained variance) shows a northwest/southeast bipolar structure, represented by the anti-cyclonic/cyclonic component centered in the northern part of the Atlantic Ocean and the anti-cyclonic/cyclonic component centered in the northwestern part of Europe. This points to the intensification of the western circulation over Europe, the structure being very close to that of NAO, but not identical. However, from this structure, we can identify the intensification of the NAO phenomenon in winter. Being known as the major pattern of large scale circulation variability over Europe, the NAO has an important impact on the European climate, by influencing the weather regime. The intensification of the western circulation is associated to the intensification of the NAO phenomenon in the winter season (Busuioc et al., 2010).

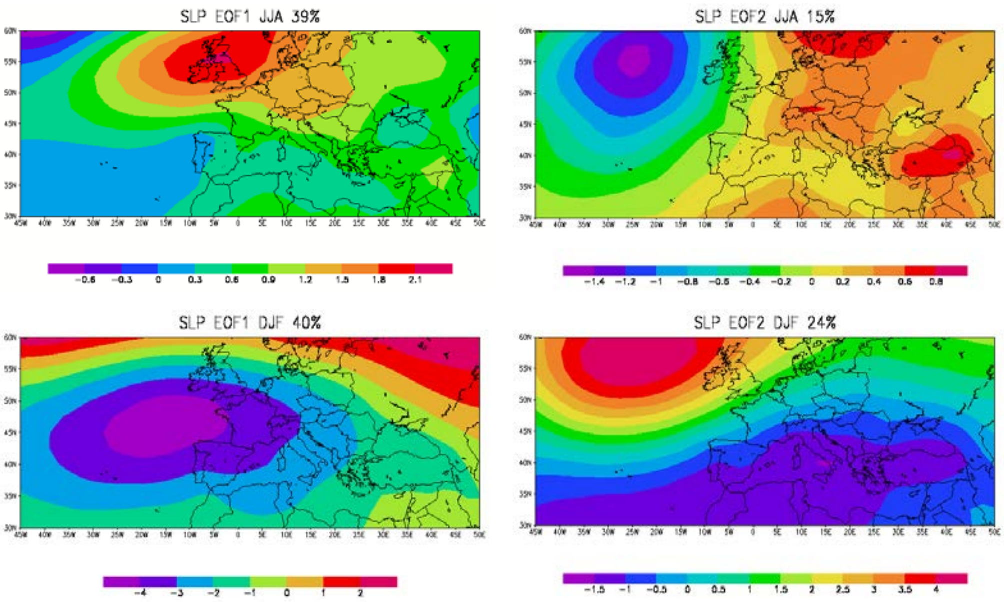

Fig. 1 - The first two configurations of the EOF s based on SLP
(sea-level pressure) parameter for the summer and winter seasons

For the H500 parameter (Figure 2), the configuration of EOF 1, in the summer season, explains 32% of the total variance. This structure shows an anti-cyclonic structure centered in the northwestern part of Europe. This structure is similar to that of the SLP parameter, for the summer season. The EOF 2 configuration (18% of the explained variance), also reveals a bipolar structure with the corresponding centers located in the northwestern part of Europe and northeastern part respectively. The increase of positive anomalies is obvious in winter, when the configuration of the EOF 1 (32% of the explained variance) points, in the western part of Europe, to a pronounced positive trend of the representative anomalies. The EOF 2 representation, which reveals 30% of the explained variance, exhibits a very similar configuration with that of the SLP parameter, which we may interpret as being an important pattern influencing Europe (NAO phenomenon).

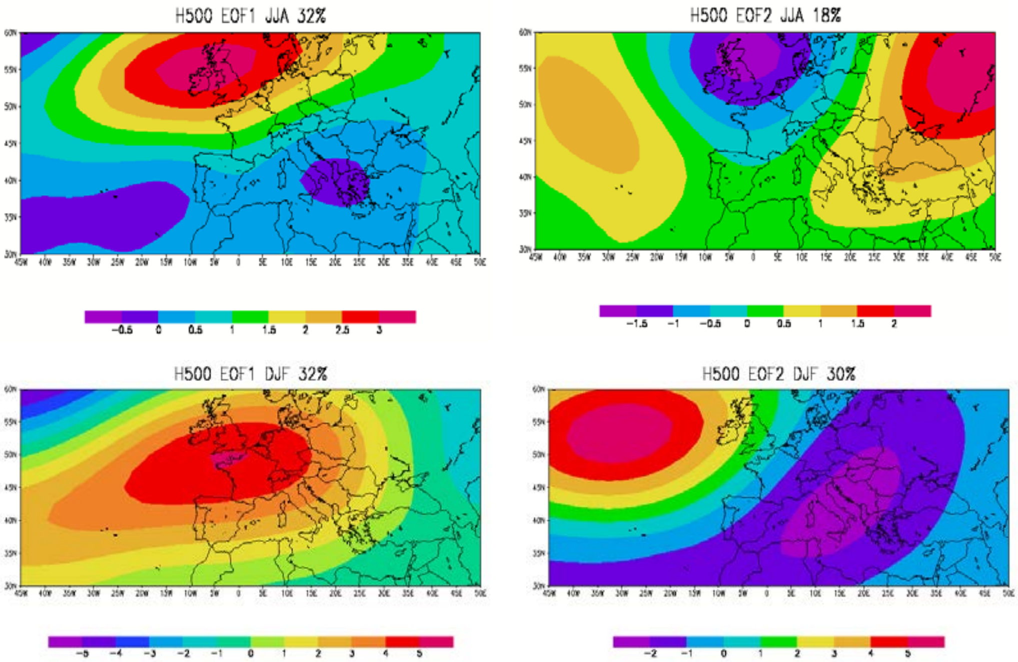

Fig. 2 - The first two configurations of the EOF s of the H500 (geopotential height at 500 mb pressure level) parameter for the summer and winter seasons

From the EOF configurations of the H500 parameter in the winter season, we can infer that both of them have an important influence over European climate's variability (a fact revealed from their corresponding variances). Moreover, their similar patterns with those of the SLP parameter reveal that the patterns explained by the EOF configurations are important for detecting the influence of large scale atmospheric circulation on climate's variability in Europe. Besides, this specific type of configuration, which extends over the whole Europe, shows that its corresponding dominant pattern of the large scale circulation may really control the regional climate variability.

In Figure 3, the EOF s for air-temperature at 850 mb pressure level are presented. The first EOF (1), with 33% of the explained variance, shows an evident increase of the positive anomalies all over the area of interest. The most pronounced positive anomalies may be detected in the northeastern part of Europe. The EOF 2 configuration, which has a lower explained variance (17%), shows a positive variation trend towards West, while the northeastern parts of the continent are dominated by pronounced negative anomalies.

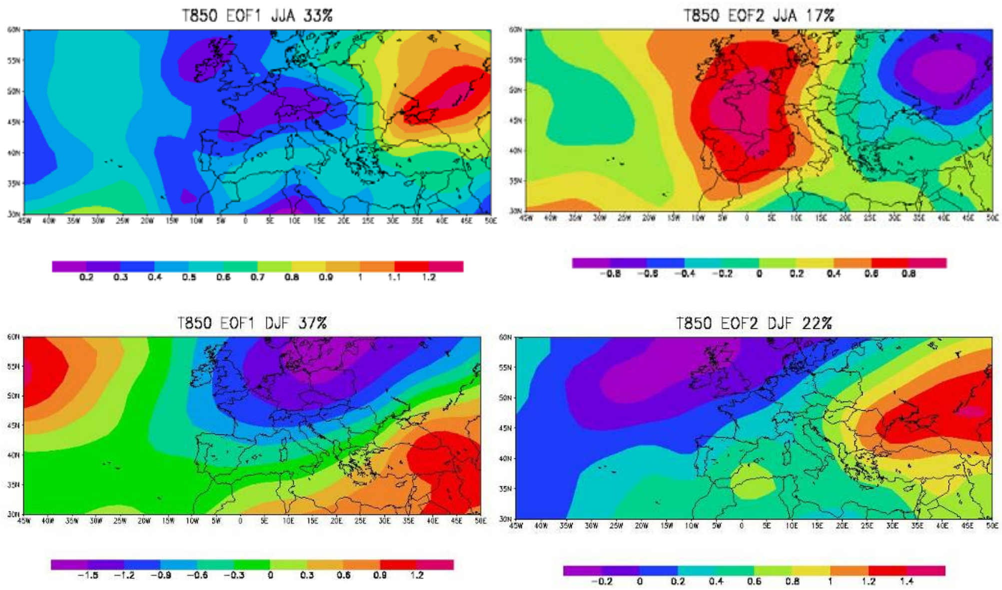

Fig. 3 - The first two configurations of EOF s of the T850 (air-temperature at 850 mb pressure level) parameter for the summer and winter seasons

In winter, the circulation patterns of the EOF 1 configuration are located mostly to the northern parts of Europe (negative anomalies) and on the opposite southeastern parts of the continent (positive anomalies). The first EOF configuration explains 37% of the total variance and the second, 22%. EOF 2 reveals two important circulation centers located in the northern part of the Atlantic Ocean (negative anomalies) and in the eastern part of the European continent. Both EOF s show similar bipolar structures, with two important centers of opposing negative and positive anomalies, respectively.

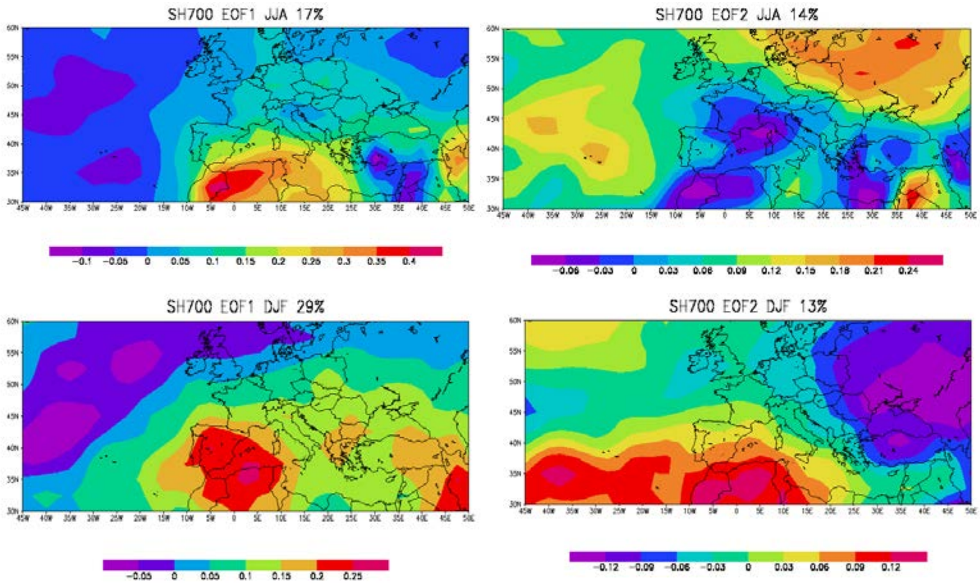

Fig. 4 - The first two configurations of the EOF s of the SH700 (specific humidity at 700 mb pressure level) parameter for the summer and winter seasons

Similar methods of computing the EOF configurations were also applied for the specific humidity parameter at the 700 mb pressure level (SH700) (Figure 4). In summer, the analysis of the resulting chart shows an important downward trend in the frequency and intensity of the EOF configurations, with positive anomalies in Europe. The most pronounced negative anomalies may be detected in the Atlantic Ocean area, while positive anomalies are to be detected in the Mediterranean basin. The two SH EOF s have a much lower explained variance (EOF 1 - 17% and EOF 2 - 14%) than the other parameters, but present similar circulation types over Europe.

In winter, we can also notice a decrease of the positive anomalies structures over Europe (EOF 2 having 13% of the explained variance), which roughly corresponds to an increase of the negative anomalies. Instead, the EOF 1 shows positive anomalies all over Europe, with a center-area located in the

Mediterranean basin. The EOF 1 explains 29% of the total variance and it looks very much like the EOF 1 in summer, the Atlantic Ocean being dominated by large negative anomalies.

2.2. Main components. In order to detect the temporal variability of the EOF configurations, the time coefficient series was computed for both seasons taken into consideration. The resulting PC time series were analyzed in order to detect the trend and shifts of their mean values. The analysis of the linear trend was made on the null hypothesis of "no trend" (Busuioc et al., 2001), by using the Mann-Kendall non-parametric test. The shifts of the time series were also determined by using the Pettitt's test, which works on the principle of applying the concept of "change points".

Parameters	**EOF 1**		**EOF 2**	
	JJA	**DJF**	**JJA**	**DJF**
SLP		**1979 ↓**	**1978 ↓**	1970 ↓
H500	**1982 ↑**	**1986 ↑**	**1985 ↑**	
T850	**1980 ↑**	**1986 ↑**	**1976 ↑**	1975 ↑
SH700	**1989 ↓**	**1979 ↓**		

Tab. 1 - The significant linear trends for the main component series of the first two EOF s for the statistic level of 5 % (bold arrows) and 10 % (simple arrows)

In the table below we presented the most significant trends and shift points that have been detected in the PC series, analyzed at the level of 5% and 10% significance, respectively. For the SLP parameter, in winter, the PC series present a downward trend, significant at the 5% significance level, while the EOF 2 presents the same downward trend, but more significant at the 10% level. In summer, the EOF 2 configuration points to the same trend, correlating with the spatial configuration structure. For the H500 parameter, all the corresponding EOF configurations show an upwards trends, the same trend also resulting for T850 (see Table 1). Instead, for the specific humidity at 700 mb pressure level, the EOF 1 configurations during the summer and winter seasons, present downward trends (5% significance level).

The trends and shift points detected by the two statistical methods we have applied are fully consistent with the EOF configurations shown above and these can explain the main features and modes of the Atlantic/European climate variability.

Conclusions

In the present study, we have tried to identify the most important large -scale atmospheric configurations which have a significant influence on climate's variability in Europe. The results obtained show that the Atlantic/European climate variability is influenced by changes in the regime of different circulation patterns. The results also highlight the important role of the Atlantic Ocean on the weather regime over Europe.

The increase in the anti-cyclonic structure over Europe is shown by the EOF configurations of the sea level pressure parameter (SLP) in summer, which are associated with an upward trend of the air temperature at 850 mb pressure level (T850). This determines the air temperature's increase over Europe. The geopotential height at 500 mb pressure level (H500) also shows positive anomalies which affect the European climate, including the Romanian territory. The most important positive anomalies that have been detected, with large amplitudes, were also revealed by the main component series associated to the corresponding most important EOF configurations.

Another important aspect that must be pointed out is represented by the influence of the North Atlantic Oscillation on weather in Europe. The EOF configuration of the SLP parameter in winter presents a similar NAO structure. More exactly, the shift point detected in 1979 and the general negative trend detected, can be associated to the negative phase of the NAO, recorded in the winter of 1978-1979 (Gimeno et al., 2002). This analysis detects important patterns of the large scale atmospheric circulation in the climate change context revealed by many studies (Nazmiye, 2003, Escalet et al., 2012). The results are also in accordance with those presented by Busuioc et al., 2010, Busuioc and von Storch, 1996, for the Atlantic/European scale.

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