Hydrological response in the Danube lower basin to some internal and external climate forcing factors

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Abstract. The present study aims at investigating the influence of natural forcing factors on Danube river discharge: temperature, precipitation, a drought index, climate indices that characterize internal climate variability, Earth's magnetic field and external solar forcing. We test the validity of hypothesis that discharge variability is influenced both internal and external forcing factors.

Of the internal factors, we tested the predictors from the fields of precipitation, temperature, pressure and geopotential at 500hPa. From the external factors, we considered the indices of solar/geomagnetic activity. Our analysis was achieved separately for each season, for two time periods 1901-2000 and 1948-2000.

We applied developments in empirical orthogonal functions (EOFs), cross correlations, power spectra, filters, composite maps. In analysis of the correlative results, we took into account, the serial correlation of time series.

For the atmospheric variables simultaneously, the most significant results (confidence levels of 95%) are related to the predictors, considering the difference between standardized temperatures and precipitation (TPP), except for winter season, when the best predictors are the first principal component (PC1) of the precipitation field and the Greenland-Balkan-Oscillation index (GBOI). The GBOI is better predictor for precipitation, in comparison with North Atlantic Oscillation index (NAOI) for the middle and lower Danube basin.

The significant results, with the confidence level more than 95%, were obtained for the PC1-precipitation and TPP during winter/spring, which can be considered good predictors for spring/summer discharge in the Danube lower basin.

Simultaneous, the significant signature of geomagnetic index (aa), was obtained for the smoothed data by band pass filter. For the different lags, the atmospheric variables are associated with the solar/geomagnetic variability after about 2-3 years. The possible external signals in the terrestrial variables are revealed also by power spectra and composite maps. The power spectra for the terrestrial variables show statistical significant peaks that can be associated with the interannual variability, Quasi-Biennial Oscillation influence and solar/geomagnetic variability.

The filtering procedures led to improvement of the correlative analyses between solar or geomagnetic activity and terrestrial variables, under the condition of a rigorous test of the statistical significance.

Keywords: NAO, GBOI, serial correlation, low and band pass filter, atmospheric blocking, Danube basin, climate changes

1 Introduction

Climatic system is a closed system, being influenced mainly by external factors, whose action is modulated by the internal mechanisms. Therefore, it is difficult to assess climatic system response to various external factors, the discrimination action of each is sometimes even impossible. The main external factors as is known are: solar activity in its various forms and the greenhouse gases that cause climate variability. Quantifying the impact of each factor on the climate system is subject to various uncertainties. As shown in Cubasch et al. (1997), as well as in Benestad and Schmidt (2009) it is difficult to distinguish between anthropogenic signal and the solar forcing in the climate change, especially if we wanted to assess the respective contributions of the greenhouse or the solar forcing to the recent warming. An explanation of this shortcoming is related to the limitations of simulation climate models and lack of long data on many parts of the Earth, to estimate the impact of solar activity.

In Brugnara et al. (2013) are reviewed recent studies on the impact of solar activity / geomagnetic on the climate. After a statistical reconstruction of the main atmospheric fields for more than 250 years, the authors performed an analysis of the solar signal of 11 years in different reconstructed terrestrial datasets, and they found that there was a robust response of the tropospheric late-wintertime circulation to the sunspot cycle, independently from the data set. This response is particularly significant over Europe.

There were many preoccupations regarding the impact of greenhouse gases, resulting from climate modeling under various scenarios, on the water regime of the Danube. We mention only some of these studies. In Mares et al. (2011, 2012) were processed climate variables obtained from four global models of climate change: CNRM, ECHAM5, EGMAM and IPSL, under A1B scenario. It was found for Danube lower basin, that the probability to have extreme events (hydrological drought and great discharges) increases in the second half of the 21st century comparing to the first half. A more complex methodology for post-processing of outputs of climate models is found in Papadimitriou et al. (2016), where an analysis of the changes in future drought climatology was performed for five major European basins (including Danube) and the impact of global warming was estimated.

Regarding internal factors that influence climate at regional or local scale, best known index is related to the North Atlantic Oscillation (NAO). After Hurrell et al. (2003), NAO is an internal variability mode of the atmosphere, and it is highlighted by a north-south dipole of the pressure, characterized by simultaneous anomalies but with the opposite signs between temperate and high latitudes over the Atlantic sector.

For the south - eastern European zone, only NAO is not a good enough predictor for Danube discharge. Rimbu et al. (2002) showed that there is an out-of-phase relationship between the time series of the Danube river discharge anomalies and the NAO index. Also, Rimbu et al. (2005) was found that spring Danube discharge anomalies are significantly related to winter Sea Surface Temperature (SST) anomalies. In Mares et al. (2002) it was found that NAO signal in climate events in the Danube lower basin is relatively weak, in comparison with other regions.

However, we must note that NAO is a very good predictor for some regions. Thus, for example NAOI is a significant predictor for : Seine river (Massey et al., 2010; El - Janyani et al., 2012), northeastern Algeria (Turki, et al., 2016), southern Sweden (Drobyshev et al., 2011), the northern Italy (Zanchettin et al., 2008).

The recent research (Valty et al., 2015) warns that for the predictor's selection such as NAO, need to consider the dynamics of the total oceanic and hydrological system over wider areas. In fact all climate system needs to be considered. In Hertig et al. (2015) are described the mechanisms underlying the non-linearity and non-stationarity of the climate system components, with a focus on NAO and the consequences of climate non-stationarities are discussed.

In the present study, in comparison with the NAO influence on climate variables in the Danube basin, we analysed the atmospheric index Greenland-Balkan-Oscillation (GBO), which reflect the baric contrast between the Balkan zone and the Greenland zone. The GBO index was introduced first time in Mares et al. (2013b) and in the present study it is shown in detail, the GBOI informativity in comparison with NAOI, for the Danube basin.

It was found that solar activity plays an essential role in modulating the blocking features with the strongest signal in the Atlantic sector (Barriopedro et al., 2008; Rimbu and Lohmann, 2011). Therefore, in the present paper we consider, the indices of blocking type circulation, both on the Atlantic and European sector.

In this paper, except for the highlighting the atmospheric circulation of blocking type taking into account the Quasi-Biennial Oscillation (QBO) phases and solar minimum or maximum (number Wolf), we did not investigate any further interaction between internal and external factors. This interaction was developed in other papers such as Van Loon and Meehl (2014).

The main aim of our work was to select predictors from the terrestrial and solar /geomagnetic variables with a significant informativity for predictand, i.e. discharge in the Danube lower basin. We obtained this informativity by applying robust tests for the statistical significance. The solar and geomagnetic variables, as well as the smoothing procedures through various filters, respectively low pass filter and band pass filters applied in this investigation, shows strong serial correlations. Therefore, all correlative analyzes were performed through rigorous testing of statistical significance. The number of observations was reduced to the effective number of degrees of freedom, corresponding to the independent observations.

This paper is organized as follows: Sect. 2 shows data processed at regional scale (2.1) and large scale (2.2), as well as the indices that define solar and geomagnetic activity (2.3).

In Section 3, we describe the methodology used. There are many investigations related to solar / geomagnetic signal in the Earth's climate, some of them use smoothing of data, both related to solar activity and the terrestrial variables. This smoothing induces a high serial correlation, which produces very high correlations between time series.. Therefore, in Sect. 3 we focused on testing the statistical significance of solar / geomagnetic signal in climate variables, taking into account the high autocorrelation induced by the smoothing processes. We also briefly described the procedure of testing of confidence levels of the peaks of the power spectra.

Section 4 contains the results and their discussion. Concerning the link between atmospheric circulation at the large scale and the climate variables at local or regional scales and described in 4.1, we demonstrated that GBOI is a more significant predictor than NAOI for the climate variables in the Danube middle and lower basin. In 4.2, for the period 1901-2000, we considered several predictors depending on climatic variables in the Danube basin, as well the indices of large-scale atmospheric circulation and we tested predictor's weight for the discharge in the lower basin. In subsection 4.3, are presented the results obtained from the analysis of solar/geomagnetic signal simultaneously with the terrestrial variables (4.3.1) and with some lags (4.3.2) and QBO role in modulating these influences (4.3.3). The conclusions are presented in the Sect.5.

2 Data

2. 1 Regional scale

Since the Danube discharge estimation has great importance for the economic sector of Romania, in the present investigation we focused on predictors for Danube lower basin discharge. The lower basin Danube discharge was evidenced by Orsova station (Q_ORS), located at the entrance of the Danube in Romania and representing an integrator of the upper and middle basin. Our analysis was achieved separately for each season, for the two time series of 100 values (1901-2000) and respectively 53 values (1948-2000). For the period 1901-2000, in the Danube upper and middle basin (DUMB), fields of precipitation (PP), mean temperature (T), diurnal temperature range (DTR), maximum and minimum temperatures (Tmx, Tmn), cloud cover (CLD) were considered at 15 meteorological stations upstream of Orsova. The selection of stations was done according to their position on the Danube or on the tributaries of the river (Fig.1). The values of monthly precipitation and temperature (CRU TS3.10.01) were obtained accessing (http://climexp.knmi.nl). Data-sets are calculated on high-resolution (0.5 x 0.5 degree) grids by Climatic Research Unit (CRU). In order to obtain the grid point nearest to the respective station we selected "half grid points".

The stations position in relation to Orsova is given in Figure 1. For each station a simple drought index (TPPI) was calculated, which is calculated by the difference between standardized temperatures and precipitation. All analyses were achieved using the seasonal averages for all variables considered in this study.

2.2 Large scale

In order to see the influence of large-scale atmospheric circulation on the variables at the regional scale, we considered the seasonal mean values of sea level pressure field (SLP) on the sector (50^0W-40^0E, 30^0–65^0N). We had to extract SLP data from the National Center for Atmospheric Research (NCAR), (http://rda.ucar.edu/datasets/ds010.1). As mentioned in the associated documentation, this dataset contains the longest continuous time series of monthly grided Northern Hemisphere sea-level pressure data in the DSS archive. The 5-degree latitude/longitude grids, computed from the daily grids, begin in 1899 and cover the Northern Hemisphere from 15^0N to the North Pole. The accuracy and quality of this data is discussed in Trenberth and Paolino (1980).

We defined a new index started from tests achieved using correlative analysis between the first principal component (PC1) of the Empirical Orthogonal Functions (EOFs) development of the precipitation field defined at 15 stations from Danube basin and each grid point where SLP is defined. By determining the areas with nuclei of correlations with the opposite signs (positive in Greenland and negative in Balkans) and by considering the normalized differences between SLP at Nuuk and Novi Sad (Fig.2), we obtained this index, which we called *Greenland-Balkan-Oscillation index* (GBOI). This index was introduced by Mares et al. (2013b) and tested in the previous works of the authors (Mares *et al.,* 2014a, 2015a,b, Mares et al., 2016a,b).

The NAOI were download from http://www.ldeo.columbia.edu/res/pi/NAO/

For 1948-2000 period, beside of atmospheric variables taken over 1901-2000, we considered blocking type indices. These indices are calculated in according with the relation (1).

For the geopotential at 500 hPa (1948-2000) provided by *British Atmospheric Data Centre (BADC)* three sectors were taken into account: Atlantic-European (AE) on the domain (50°W- 40°E; 35°N - 65°N), Atlantic (A) defined in (50°W - 0°, 35°N - 65°N) and European (E) in the region (0° - 40°E; 35°N - 65°N).

2.3 Solar / geomagnetic data

For this 100 year period the solar/geomagnetic activities were quantified by Wolf number and *aa* index. For the period 1948-2000, solar forcing is quantified by 10.7cm solar radio flux, which is the solar flux density measured at a wavelength of 10.7cm. Details on **the 10.7 cm solar radio flux and its applications are found in** Tapping (2013).

Since the 10.7cm flux is a more objective measurement, and always measured on the same instruments, this proxy "sunspot number" should have a similar behaviour but smaller intrinsic scatter than the true sunspot number. The solar data were obtained from (ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/).

The Quasi-Biennal Oscillation (QBO) is also used in this study in order to make the link between solar forcing, internal climate variability and discharge variability.

The QBO values were downloaded from Free University of Berlin (http://www.geo.fu-berlin.de/met/ag/strat/produkte/qbo/qbo.dat).

3 Methodology

The time series of the variables considered in the 15 stations were developed in empirical orthogonal functions (EOFs) and only the first principal component (PC1) was kept.

The analysis of the low frequency components of the atmosphere, based on decomposition in multivariate EOF (MEOF), was used by the authors of the present paper in Mares et al. (2009, 2015, 2016a, b).

The blocking index (I_B) at the 500 hPa geopotential field was estimated in according with Lejenas and Okland (1983). Such a blocking event can be identified when the averaged zonal index computed as the 500-hPa height difference between 40° and 60°N, is negative over 30° in longitude. Taking into account the above definition, in the present study, we calculated for each longitude λ, three indices for the regions: Atlantic-European (AEBI), Atlantic (ABI) and Europe (EBI) after the formula:

$$IB(\lambda) = \Phi(\lambda, 57.50\,N) - \Phi(\lambda, 37.50\,N) \qquad (1)$$

where Φ is the 500 hPa geopotential field, and blocking index I_B is a mean for λ longitudes of IB (λ). In our case IB positive reflects a blocking type circulation.

In the preprocessing analyses, low and band pass filters were applied.

Low pass filters were applied to eliminate oscillations due to other factors such as El Niño–Southern Oscillation (ENSO) than the possible influence of solar/ geomagnetic activities. The Mann filter (Mann, 2004, 2008) was applied with three variants that eliminate frequencies corresponding to periods lower than 8, 10 and 20 years.

Besides the low pass filters specified above, which were applied only to the terrestrial fields, **band pass filters** were applied to both the terrestrial and solar or geomagnetic variables. The band pass filters were of the Butterworth type, and the variables have been filtered in the 4-8, 9–15 and 17-28 years bands. We use Butterworth filters, because, in according with Vlasov et al. (2011), and Ault et al. (2012), for these filters their frequency response is nearly flat within the passband, and they are computationally efficient, being recursive filters.

In Lohmann et al. (2004) the solar variations associated with the Schwabe, Hale, and Gleissberg cycles were detected in the spatial patterns in sea-surface temperature and sea-level pressure, using band pass filters with frequencies appropriate to each of the solar cycles. Significant correlations between global surface air temperature and solar activity were obtained by Echer et al. (2009), applying wavelet decomposition.

A possible response of climate variables to the solar/geomagnetic activity is investigated in the literature, not only simultaneously but also with certain delays, we performed cross – correlation between lag -1 and lag 15 years.

Explanation of the physical mechanism of correlations with certain lags between solar activity and climate variables is found in Gray et al. (2013) and Scaife et al. (2013).

In order to find the significance level of the correlation coefficient, we have to take into account the fact that by the smoothing both terrestrial and solar/ geomagnetic variables present a serial correlation. In this case, we have to estimate the equivalent sample size (ESS). There are more methods to find the correlations statistical significance among the series pairs presenting serial correlations. A part of these methods are present in Thiebaux and Zwiers (1984), Zwiers and Storch (1995), Ebisuzaki (1997).

In Mares et al. (2013a), the procedure described by Zwiers and Storch (1995) for ESS estimation was applied in order to estimate the statistical significance of the climatic signal in sea level pressure field (SLP) in 21st century in comparison with 20-th century.

In the present analysis, in order to find the ESS, namely the *number* of *effectively* independent observations (N_{eff}) is applied a simple formula, which is appropriate for the correlations involving smoothed data (Bretherton et al., 1999).

$$N_{eff} = N \frac{(1 - r_1 r_2)}{(1 + r_1 r_2)} \qquad (2)$$

where r_1 and r_2 are the lag-1 autocorrelation coefficients corresponding to the two time series correlated and N number of the observations.

In the next phase, the t-statistic is used to test the statistical significance of the correlation coefficient:

$$t = |r| [(N_{eff} - 2)/(1 - r^2)]^{1/2} \qquad (3)$$

In equation (3), r is the correlation coefficient between the two variables and N_{eff} is effective number used in the testing procedure.

According to von Storch and Zwiers (1999), the null hypothesis $r = 0$, is tested by comparing the t value in equation (3) with the critical values of t distribution with n_e *-2* degrees of freedom.

The correlated time series must have a Gaussian distribution. For this reason in the present study we have also computed nonparametric Kendall correlation coefficient, which measures correlation of ranked data. Applying the algorithm described in Press et al. (1992), correlation values and corresponding significance p-levels are obtained. A comparison between the Pearson and Kendall correlation coefficients is found in Love et al. (2011), where the statistical significance between sunspots, geomagnetic activity and global temperature, is tested.

Among the statistical methods that might be used to test solar or geomagnetic activity signal in the climatic variables, in this study we will take into account also the statistical significance of the amplitude of the power spectra in time series. Testing the statistical significance of the peaks obtained from an analysis of a time series by power spectra is usually done by building a reference spectrum (background) and comparing the amplitude spectrum of the analyzed time series to those of background noise spectrum. This spectrum is a series based on either white or most often red noise (Ghil et al. 2002, Torrence and Campo, 1998). All amplitudes above the background noise amplitudes for a given significance level are considered significant at this level.

A significance test requires null hypothesis significance. For spectral analysis, the null hypothesis is that the time series has no significant peak and its spectral estimate does not differ from the background noise spectrum. Rejection of the null hypothesis means accepting peaks of the spectrum series of observations that exceed a certain level of significance. As shown in Mann and Less (1996) theoretical justifications exist for considering red noise as noise reference (background) for climate and hydrological time series. Also, Allen and Smith (1996), shown that an analysis technique, in order to be useful in the geophysical applications, for the null hypothesis must be considered AR(1). If the white noise is null hypothesis, it may incorrectly indicate a large number of oscillations, which are not significant.

The power spectra achieved in this study were estimated by multitaper method (MTM) (Thomson, 1982, Ghil et al., 2002, Mann and Less (1996)). The MTM procedure is a nonparametric technique that does not require a priori a model for the generation of time series analysis, while harmonic spectral analysis assumes that the data generation process include components purely periodic and white noise which are overlapped (Ghil et al., 2002).

In this study as reference background spectrum was chosen red noise. In Mann and Less (1996) is explained why an AR(1) process is suitable as background noise for the periodicities estimated by MTM procedure. The significance of spectrum peaks relative to the red noise background is based on the elementary sampling theory (Gilman et al., 1963; Perceival and Walden, 1986).

In Mares et al. (2016a), more details were given on the estimate of the background noise and significance of power spectra peaks, for the applications referring to the influence of the Palmer drought indices in the Danube discharge.

4 Results and discussions

4.1 Connection between atmospheric circulation at the large scale and climate events at regional or local scale

The atmospheric circulation at the large scale is quantified in this paragraph by North Atlantic Oscillation index (NAOI), Greenland Balkan Oscillation Index (GBOI) and indices that highlight the blocking type circulation. The direct impact of NAO is less obvious than GBO impact for the surrounding areas of the lower Danube basin as revealed in this study and in previous investigations (Mares et al., 2013b, 2014, 2015a,b 2016a,b).

The high correlations between GBOI and precipitation are stable over time (Table 1). From how GBO and NAO indices are defined, they have opposite signs. Temporal evolution for winter of the first principal component (PC1) for the precipitation in the Danube basin in comparison with GBOI values is given in Fig.3.

The details on the stations are given in Fig.4, where are presented the correlation coefficients between winter precipitation at 15 stations and NAOI and GBOI for two periods 1916-1957 and 1958-1999. From this figure, it is clear that the GBOI signal is stronger than NAO signal, except for the first stations located in the upper basin of the Danube.

Since the Danube discharge estimation in spring season with some anticipation has great importance for the economic sector of Romania, the best predictors at the large scale for Orsova discharge in spring, with one season anticipation (winter) were revealed, with high confidence level (> 99%): GBOI as well as the atmospheric circulation of blocking type, quantified by European blocking index (EBI). The Figure 5 shows spring Orsova discharge (standardized) in comparison with European blocking index (R= - 0.54) and GBOI (R = 0.53) for winter in the period 1948-2000. The opposite signs of the Orsova discharge correlations with EBI and GBOI are due to the definitions of the two indices. The negative correlations between discharge and EBI can be explained as follows. As shown in Davini et al. (2012), the midlatitude traditional blocking localized over Europe, uniformly present in a band ranging from the Azores up to Scandinavia, leads to a relatively high pressure field in most of Europe. This field of high pressure, which defines a positive blocking index, and that is not favorable for precipitation, leads to in low discharge of the Danube at Orsova. A positive correlation coefficient between the Danube discharge at Orsova and GBOI, means that a positive GBO index lead to a low pressure in the Danube basin area and therefore a high discharge.

The role of the atmospheric circulation of blocking type on hydrological events in the Danube Basin is described in many papers, including Mares et al. (2006), Blöschl et al. (2013).

4.2 Testing predictor variables for estimating the discharge in the Danube lower basin (1901-2000)

To underline the contribution of the nine predictors, defined at the 15 stations in the Danube basin, described in Section 2, we represented in Figure 6 the correlation coefficients between Danube discharge at Orsova (lower basin) and these predictors for each of the four seasons. PC1 in Fig. 6 represents the first principal component of EOFs development of the respective fields. If we take into account the confidence level at 99%, of correlation coefficients for 100 values, it should exceed 0.254. There are many predictors that are statistically significant at this level of confidence, but we take into consideration only those having the highest correlation coefficients. As can be seen from Figure 6, the greatest contribution to the Danube discharge in seasons of spring, summer and fall, brings the drought index (depending on precipitation and average temperature), with the correlation coefficients (r) of -0.450 and - 0.730 for spring and summer and respectively -0.700 for fall. In winter season, the precipitation field in the upper and middle basin has most important contribution (predictor) to the discharge in lower Danube basin (r = 0.500). As the second contribution is GBOI (r = 0.430).

Also, it is revealed that for the spring season, where contribution drought index TPPI is lower than in summer and autumn season, the GBOI and DTR can be considered good predictors with r = 0.420 and respectively -0.417.

Regarding consideration of the predictors with some anticipation to the Danube discharge, the significant results obtained with an anticipation of a season, are presented in the Fig. 7. For spring discharge, the best predictor is clearly drought index (TPPI), taken in winter (r = - 0.62). Also, TPPI in spring is a significant predictor (r = -0.55) for summer discharge. Besides spring TPPI for summer discharge, the spring precipitation field quantified by PC1, also is a important predictor (r = -0.53).

The results obtained in this study are consistent with those of Mares et al. (2016a), where the Palmer drought indices were found good predictors for the discharge in lower basin.

4.3 Solar/geomagnetic signature in the climate fields in Danube basin

Solar activity was represented by Wolf numbers for the period 1901-2000 and by 10.7-cm solar flux for the period 1948-2000. Although the solar flux is closely correlated with Wolf numbers, these values are not identical, the correlation coefficient varying with the season (0.98-0.99). The geomagnetic activity was quantified by *aa* index for the two periods analyzed (1901-2000 and 1948-2000). Regarding the link between solar activity and geomagnetic, details are found in Demetrescu and Dobrica (2008).

Solar/geomagnetic signal was tested by: correlative analyses (simultaneous and cross correlation), composite maps and spectral analyses. Before correlative analysis, data were filtered using low and band pass filters for the terrestrial variables and only band pass filters for the solar / geomagnetic indices.

Related to the low pass filter, the Mann filter (Mann, 2004, 2008) was applied with three variants that eliminate frequencies corresponding to periods lower than 8, 10 and 20 years. The analysis revealed that from the three variants, time series cutoff 8, responded best to variations in solar / geomagnetic activities.

In many investigations, significant solar signal in the terrestrial variables, have been obtained applying band pass filters, for isolating the frequency bands of interest (Lohmann et al., 2004, Dima et al, 2005, Prestes et al. 2011, Echer et al. 2012, Wang and Zhao, 2012).

In the present study we apply a band pass filter with the three frequency bands: (4-8yr), (9-15yr) and (17-28 yr). Because after the filtering process, the time series show a strong autocorrelation, to test the statistical significance of the link between the terrestrial and solar variables, we use the *t-test*, which takes into account the effective number of independent variables and the correlation coefficient between two series. The effective number is determined in function of the serial correlations of the two series analyzed. Details are given in Section 2. The most significant results were obtained for the filtered terrestrial variables, taken with some lags related to solar or geomagnetic activity.

4.3.1 Simultaneous correlative analysis

The Table 2 presents some of the results that have a confidence level, higher or at least of 95%, for the analysis period of 100 years (1901-2000). Here are presented only the results simultaneously for three categories of data: non-filtered (UF), smoothed by low pass filter (LPF), eliminating, the periods less than or equal to 8 years, only for terrestrial variables, and band pass filter (BPF) applied for both time series (terrestrial and solar / geomagnetic indices).

Since not all variables have a normal distribution, the Kendall's coefficient was associated to Pearson's coefficient. There are cases when the difference between the two correlation coefficients is relatively high and this difference may be due to statistical distribution that deviates from normal.

As can be seen from Table 2, smoothing time series lead to improved correlation coefficients, the most significant results were obtained by band-pass filter with frequency corresponding to 9-15 yr. Also, tests were achieved and for band-pass filter with 17-28 yr, for which highest correlation coefficients were obtained. But, it is difficult to take a decision, because the effective number is very small (about 5 years), due to serial correlation very high, caused by such filters. For such band-pass filters (such as 17-28 yr), much larger sets of data are necessary.

An example is given in Table 2 to test the correlation between the GBOI and Wolf number during fall season. The results presented in Table 2, related to the significant correlations indicated by Pearson coefficients (r), are supported by Kendall correlation coefficients (τ), and their levels of significance (p). Bold lines means there are at least two situations for the same season (filtered or unfiltered data) having a significant CL.

As can be seen from Table 2, highest correlations with aa, were obtained during the summer season with r = 0.796 for temperature and with r = - 0.721 for precipitation, for a smoothing by a BPF with the band (9-15yr). Also, in summer, it is worth mentioning the aa influence on drought index (TPPI) with correlation 0.787, corresponding filtering with 9-15 yr. From the definition of this index, it reflects the behavior of both temperature and precipitation, but the sign is given by temperature. It can be noted that drought index TPPI, which is a combination of temperature and precipitation, responds better to signal *aa*, compared to PC1_PP. Therefore, a geomagnetic activity maximum (minimum) determines a situation of drought (wet) in the Danube basin during spring and summer.

Regarding solar activity signature in temperatures and precipitation, the highest correlation coefficients were found for the fall season (0.699) and respectively for spring (-0.538) in the band filter (9-15 yr). From the Table 2, are observed correlations with the number Wolf, with a particularly high confidence level (> 99%) in the case of considering time series smoothed by the band (4-8 yr), as atmospheric circulation index GBOI (summer and winter).

The results obtained in the present investigation, referring to the temperature and precipitation variables are in accordance with the ones from Dobrica et al. (2009, 2012), where have been analysed the annual mean of long time series (100–150 years) for the temperature and precipitation records from 14 meteorological stations in Romania. There are some differences, because in this investigation, fields of temperature and precipitation are taken on another area, smoothing procedures are different and the analysis is done on each season separately. However, the correlations with the geomagnetic *aa* index and Wolf numbers have the same sign, ie positive for temperatures and, negative for precipitation respectively.

Reducing the number of effective observations, when smoothing is applied, is discussed in Palamara and Bryant (2004), where they test the statistical significance of the relationship between geomagnetic activity and the Northern Annular Mode.

Although the results obtained here by the BPF shows the largest correlation coefficients, however those obtained by BPF (9-15) must be analyzed together with results obtained by other filters. An example is the significance of the correlation coefficients between Wolf number and drought index (TPPI), which for spring, for unfiltered data, filtered by the low pass filter, and those by BPF (4-8 and 9-15 yr) indicate a confidence level higher than 90%. It means that significance of the correlation in this case, does not depend on the time series size.

Taking into account both possible signals of the geomagnetic and solar activity, we can notice that during spring, TPPI has the best response for unfiltered or filtered time series.

Considering the importance of the Danube discharge in our study, we analyze solar / geomagnetic signals in this variable. Thus, the *aa* is associated with Danube discharge at Orsova (Q_ORS), with the most significance, during the summer season with correlation coefficient r = - 0.656. But considering our criteria above enumerated, ie significant correlations in at least two cases, it is clear that we must focus on the discharge behavior in fall (Table 2), for which the smoothing by LPF and BPF (9-15) lead to the significant association with *aa* impulse.

In the following, we present results obtained by analyzing the terrestrial and solar or geomagnetic data for the period 1948-2000. Although the time series are relatively short, this period was considered, because some of the atmospheric variables, as indices that define the blocking type circulation at 500 hPa, are available only since 1948. Also 10.7 cm solar flux that defines more clearly solar activity is just beginning in this period. In addition, we wanted to see if it improves the relationship between the terrestrial and solar indices, taking separately the years with positive or negative phase of Quasi-Biennial Oscillation (QBO).

In Table 3 are presented the correlation coefficients, with a high confidence level (>95%), obtained from the simultaneous correlative analyses between terrestrial variables and geomagnetic (aa), and solar activity (flux 10.7cm) indices on the other hand. It is observed that due to short time series, the smoothing by the band pass filter (9-15), although leads to the correlation coefficients with high confidence level, the number of degrees of freedom is quite small.

For this period of 53 years (1948-2000), the smoothing by BPF with the band (4-8 yr) appears most appropriate, for highlighting a possible solar signal, in the three blocking indices.

The association between solar or geomagnetic variability with the terrestrial climate variability can be emphasized also by the periodicities estimation by means of the power spectra. In the present study the power spectra were estimated by means of multitaper method

(MTM). For the time series of unfiltered European blocking index (EBI) during winter, the power spectra given in the Fig.8a reveals that the most significant periodicity is related to QBO (2.4 years), and with an approximately 90% confidence level are the peaks at 10.7 and 14.2 years, which may be linked to 11-year solar/geomagnetic cycle. In Fig. 8b, which represents the power spectrum for EBI in the spring, the only significant peak with a confidence level of 95% is situated at 10 years. This is consistent with the results shown in Table 3, where during spring, the time series of blocking index EBI, both unfiltered and filtered by the band pass filter (4-8) have significant correlations with the aa geomagnetic index. Also, in winter (Fig. 8a), the EBI's possible response to solar activity, quantified by the Wolf number, is statistically significant with CL almost 99%. If we take only spring season, the best significant peak related to QBO (Fig. 8c) is found in blocking index over Atlantic European region (AEBI).

Graphical representation of unfiltered time series was given to see whether there is solar/ geomagnetic signature in the original series. The power spectra of the filtered series were not shown, because these series show peaks corresponding to the frequencies remaining after filtering procedure.

Regarding the period of 53 years (1948-2000), the significant links between the solar activity quantified by solar flux 10.7cm and the Danube discharge at Orsova (Q_ORS), were obtained for spring and summer, with different lags. With a delay of of two years, both unfiltered and filtered time series of the Danube discharge, indicate statistically significant correlations with solar flux.

Like in the GBOI case, the discharge is inversely, but well correlated with solar activity at some lags. In Fig. 10a, correlation coefficients are shown at the lags between -1 and 15 yr, for three series, unfiltered (UF), smoothed by low pass filter (LPF) and the band pass filter (9-15). It can be observed that, if for the unfiltered data, the correlation is significant (95%) at the lag 1, 2 and 3, for the data smoothened by BPF, the significance is situated between 95-99% at the lags 2, 3 and 4. Taking into account the discharge smoothed by LPF, the most significant correlation (90%) is obtained between discharge taken with two and three years delay from solar flux.

In the Fig. 10b have been shown the coherent time evolutions of the solar flux and discharge, smoothed by BPF (9-15) with a lag of three years, where, the correlation coefficient is highest (-0. 769) and CL is 99%.

From the above results, where the correlation between Danube discharge and solar flux, has a opposite sign, we can expect that at 2 or 3 years after a maximum (minimum) solar, the spring discharge to be lower (higher). In the Fig. 10c, the power spectra for the Danube discharge during spring, indicates significant peaks at 4yr (CL close to 95%) and at 10.7yr, with a CL near 90%. These peaks might be associated with the internal atmospheric variability and respectively with the solar variability.

A different possible signature of the solar activity was found in the time series of the index that defines atmospheric circulation of blocking type over Atlantic-European region, for the period 1948-2000, during the winter season. As can be seen in Fig. 11, a possible response of blocking circulation to the solar activity is given by the significant correlations with a delay of two years and three years to the solar flux. It is worth noting that in this case, the filtering process does not lead to an improvement of the significance of the correlation, even if its value increases. Thus it is necessary a rigorous test for correlation's significance, especially for data smoothed.

Therefore, we might conclude that about 2-3 years after producing a maximum (minimum) solar, during winter, atmospheric circulation of blocking type is enhanced (weakened) over the Atlantic-European region.

4.3.3 QBO role in modulation of the influence of solar forcing

Regarding QBO influence on the relationship between solar activity and terrestrial parameters, there are several investigations (Van Loon and Labitzke, 1988; Bochníček et al.1999, Huth et al., 2009), which demonstrated that QBO phase is very important for emphasizing these links. We see in QBO mainly an important modulator of the impact of solar activity on the phenomena of the lower troposphere. To test this hypothesis, in this paper, the years with east QBO phase, during winter months have been selected, and correlations between solar flux and more terrestrial variables were achieved. The correlation coefficient between the solar flux and the unfiltered EBI during winter, for all those 53 years, is 0.15 and it is not statistically significant. By selecting only the years with QBO in the east phase in the winter months (34 cases), the correlation coefficient is 0.32 at the confidence level around 95%. It is interesting that although the power spectrum (Fig. 8a) highlights significant peaks related to the QBO (2.4 and 2.7 years), the correlation coefficient between EBI and QBO is insignificant. This suggests that the spectral representation is very useful in time series analysis and the QBO phases modulate the connection between solar activity and blocking circulation. These findings related with the QBO role are in accordance with the results obtained in Barriopedro et al. (2008), Huth et al., (2009), Sfîcă et al. (2015). In Cnossen and Lu (2011) are presented some of the mechanisms which explain the QBO role in the solar signature in the climate variables. These mechanisms have been supported by both observational and modeling studies, but some of them are yet unclear.

It is enlightening solar impact (by flux) on atmospheric circulation in the lower troposphere, during the east phase of QBO, when the solar maximum is associated with blocking event over the Northern Atlantic and north-western Europe (Fig. 12a), and a geopotential with a opposite distribution that occurs during the solar minimum. (Fig.12b).

The advantage of the composite maps, used to outline the response to the solar variability, is shown in Sfîca et al. (2015), which specifies that through these composite maps, nonlinearities are taken into account, compared to using linear methods.

Our findings, presented in the Fig. 12, are in concordance with Barriopedro et al. (2008), namely, QBO is a modulator of the of the atmospheric circulation transformation from a blocking type circulation to a zonal one and vice versa, under the solar impact.

We mention that in the period 1948-2000 were recorded 34 months of winter (DJF) in which occurred east QBO phase and the solar flux has produced in the lower troposphere an atmospheric blocking events, or a zonal atmospheric circulation, at middle and higher latitudes, depending on the state of maximum or minimum solar activity, respectively.

5 Conclusions

In the present investigation, we focused on finding predictors for the discharge in the Danube lower basin, which present a high level of statistical significance.

In the first part of the paper we tested the predictors for the discharge, from the fields of temperature, precipitation, cloud cover in the Danube basin, and indices of atmospheric circulation over the European Atlantic region.

Each of the temperature, precipitation and cloud cover fields in the Danube basin was decomposed in EOFs, and as predictors were considered only the first principal component (PC1). Also a drought index (TPPI) derived from the standardized temperature and precipitation was taken as predictor for the discharge in the Danube lower basin.

The atmospheric circulation has been quantified by Greenland Balkan Oscillation (GBO) and North Atlantic Oscillation (NAO) indices and the blocking type indices. The analysis was performed separately for each season and on the two period (1901-2000) and (1948-2000).

Main statistically significant results for this part of our research are the following:

1. The correlative analyses simultaneously for each season revealed that, except for the winter season, drought index (TPPI) has the highest weight to the discharge variability in the lower basin of the Danube.
2. Testing the predictors, in order to see their predictive capacity, with a lag of several months in advance of discharge, concluded that TPPI in winter and spring is a good indicator for the Danube discharge in spring and summer respectively.
3. We demonstrated that for the winter, GBOI has an influence on the climate variables in the Danube middle and lower basin more significant than NAOI.
4. Analysis for the period 1948-2000, reveals that in winter, the GBOI weight for the Danube discharge is similar to those of the blocking index over the European sector.

In the second part of the paper, we focused on solar/geomagnetic impact on the terrestrial variables. Because the solar and geomagnetic variables as well as the smoothing procedures through various filters, respectively low pass filter and band pass filters applied in this investigation, shows strong serial correlations, all correlative analyzes were performed through rigorous testing of statistical significance. The number of observations was reduced to the effective number of degrees of freedom, corresponding to the independent observations. The filtering procedures led to improvement of the correlative analyses between solar or geomagnetic activity and terrestrial variables, under the condition of a rigorous test of the statistical significance.

The main findings of our research for this topic are the following:

5. The most significant signatures of solar/geomagnetic variability were obtained in the drought indicator (TPPI). Because the precipitation does not respond just as well as, temperatures to the solar variability, it is preferably analysis the TPPI variable instead of temperatures and precipitation separately.
6. From the analysis of correlations with the lags from -1 to 15 years, delay of the terrestrial variables in comparison with the solar/geomagnetic activity, we obtained very different results, depending on the season and on the considered variables, as well as on the filtering procedure. Such, we might conclude that in winter, about 2-3 years after producing a maximum (minimum) solar, winter, atmospheric circulation of blocking type is enhanced (weakened) over the Atlantic-European region. Also, it was found that the Danube discharge in the lower basin, at the 2 or 3 years during spring and summer, after a maximum (minimum) solar, will be lower (higher).
7. An atmospheric index that is associated with the solar variability, even more significant than to the geomagnetic index *aa*, is atmospheric circulation index GBO, in summer. Therefore, at the 2-3 years after a maximum (minimum) of solar activity, expects a change of atmospheric circulation in the Atlantic-European region, quantified by GBOI, by a diminution of this index, i.e. decrease (increase) of pressure in Greenland area and an increase (decrease) in atmospheric pressure in the Balkans.
8. By multitaper method (MTM) procedure, the power spectra have highlighted both quasi-periodicities related to solar activity and the other oscillations such as QBO. In the time series of AEBI (spring), and EBI (winter) the most significant periodicity is related to QBO (2.2-2.7 years) and with an approximately 90% confidence level there are peaks at 10-14 years, which may be linked to 11-year solar cycle.
9. The composite maps revealed that solar impact (by flux) on atmospheric circulation in the middle troposphere, during the east phase of QBO, is associated with blocking

event over the Northen Atlantic and north-western Europe, and a geopotential with a opposite distribution that occurs during the solar minimum.

In this study, we focused only on observational data, so that in next our investigations, we will take into account significant predictors for the Danube basin found in this investigation, like GBOI, TPPI and atmospheric blocking indices from the outputs of the climate simulation models.

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Table 1. Correlation coefficient between first principal component (PC1) for the precipitation and atmospheric indices NAO and GBO, during winter

Period	NAOI	GBOI
1916-1957	-0.36	**0.75**
1958-1999	**-0.43**	**0.84**

Table 2. Simultaneous correlation (1901-2000) with confidence level (CL) at least 95%, for unfiltered (UF) data, terrestrial variables filtered by low pass filter (LPF) and both time series correlated, smoothed by band pass filtered and the band is specified in the brackets. *r*- Pearson correlation coefficient, *t*- the values of test *t*, τ - Kendall correlation coefficient, p - significance p-level, N_{eff} is the effective number.

Variable	*Season*	*r*	*t*	τ	*p*	N_{eff}	*CL*
Correlation with aa							
PC1_TT(UF)	**Spring**	**0.224**	**2.184**	**0.137**	**0.043**	**92**	**95%**
PC1_TT(4-8)	**Spring**	**0.606**	**6.457**	**0.401**	**0.000**	**74**	**99.5%**
PC1_TT(UF)	**Summer**	**0.310**	**2.663**	**0,206**	**0.002**	**69**	**99%**
PC1_TT(LPF)	**Summer**	**0.345**	**2.037**	**0.210**	**0.002**	**33**	**95%**
PC1_TT(9-15)	**Summer**	**0.796**	**5.130**	**0.570**	**0.000**	**17**	**99.5%**
PC1_TT(LPF)	Fall	0.453	2.865	0.304	0.000	34	99%
PC1_PP(LPF)	**Spring**	**-0.371**	**2.201**	**-0.315**	**0.000**	**32**	**95%**
PC1_PP(9-15)	**Spring**	**-0.669**	**3.437**	**-0.501**	**0.000**	**17**	**99.5%**
PC1_PP(9-15)	Summer	-0.721	3.910	-0.523	0.000	16	99.5%
TPPI(LPF)	Fall	0.452	2.869	0.310	0.000	34	99%
TPPI(UF)	**Spring**	**0.275**	**2.676**	**0.186**	**0.006**	**90**	**99%**
TPPI(LPF)	**Spring**	**0.299**	**1.736**	**0.261**	**0.000**	**33**	**90%**
TPPI(4-8)	**Spring**	**0.525**	**5.313**	**0.338**	**0.000**	**76**	**99.5%**
TPPI(9-15)	**Spring**	**0.402**	**1.660**	**0.325**	**0.000**	**16**	**85-90%**
TPPI(UF)	**Summer**	**0.224**	**2.121**	**0.153**	**0.025**	**87**	**95%**
TPPI(LPF)	**Summer**	**0.318**	**1.921**	**0.187**	**0.006**	**35**	**~95%**
TPPI(9-15)	**Summer**	**0.787**	**4.856**	**0.572**	**0.000**	**16**	**99.5%**
Q_ORS(LPF)	**Fall**	**-0.324**	**1.946**	**-0.210**	**0.002**	**34**	**~95%**
Q_ORS(9-15)	**Fall**	**-0.562**	**2.454**	**-0.419**	**0.000**	**15**	**95-98%**
Q_ORS(9-15)	Summer	-0.656	3.210	-0.470	0.000	16	99%

Correlation with Wolf number							
PC1_TT(4-8)	Summer	0.288	2.453	0.157	0.021	68	98%
PC1_TT(9-15)	Fall	0.699	3.770	0.550	0.000	17	99.5%
PC1_PP(4-8)	**Spring**	**-0.242**	**2.133**	**-0.190**	**0.005**	**75**	**95-98%**
PC1_PP(9-15)	**Spring**	**-0.538**	**2.417**	**-0.363**	**0.000**	**16**	**95-98%**
PC1_PP(4-8)	Winter	-0.370	3.298	-0.265	0.000	70	>99%
TPPI(UF)	**Spring**	**0.211**	**1.973**	**0.148**	**0.029**	**85**	**95%**
TPPI(LPF)	**Spring**	**0.299**	**1.736**	**0.261**	**0.000**	**33**	**90%**
TPPI(4-8)	**Spring**	**0.245**	**2.154**	**0.159**	**0.019**	**74**	**95-98%**
TPPI(9-15)	**Spring**	**0.585**	**2.708**	**0.395**	**0.000**	**16**	**98%**
TPPI(9-15)	Fall	0.673	3.796	0.553	0.000	19	99%
GBOI (4-8)	Summer	-0.346	2.982	-0.230	0.001	67	99.5%
GBOI (4-8)	Winter	-0.343	3.169	-0.218	0.001	77	>99%
GBOI (17-28)	Fall	-0.899	3.485	-0.707	0.000	5	95-98%
Q_ORS (4-8)	Winter	-0.263	2.329	-0.163	0.016	75	98%

Table 3. Same as Table 2 but for 53 years (1948-2000).

Variable	*Season*	*r*	*t*	*τ*	*p*	N_{eff}	*CL*
Correlation with aa							
EBI (UF)	**Spring**	**0.259**	**1.836**	**0.151**	**0.110**	**49**	**~95%**
EBI (4-8)	**Spring**	**0.528**	**3.864**	**0.382**	**0.000**	**41**	**>99%**
ABI (UF)	Fall	-0.257	1.848	-0.118	0.210	51	~95%
ABI (9-15)	Spring	0.605	2.157	0.426	0.000	10	>95%
AEBI (9-15)	Winter	0.749	3.134	0.589	0.000	10	98.5%
Correlation with flux 10.7 cm							
TPPI(LPF)	Spring	0.444	1.502	0.322	0.001	11	85-90%
ABI(4-8)	Fall	0.578	4.124	0.312	0.001	36	99.9%
AEBI(4-8)	Fall	0.530	3.697	0.360	0.000	37	99.9%
EBI (4-8)	**Winter**	**0.419**	**2.678**	**0.272**	**0.004**	**37**	**98.5%**
Q_ORS(4-8)	**Winter**	**-0.603**	**4.390**	**-0.351**	**0.000**	**36**	**99.9%**
GBOI (4-8)	**Winter**	**-0.695**	**6.034**	**-0.428**	**0.000**	**41**	**99.9%**

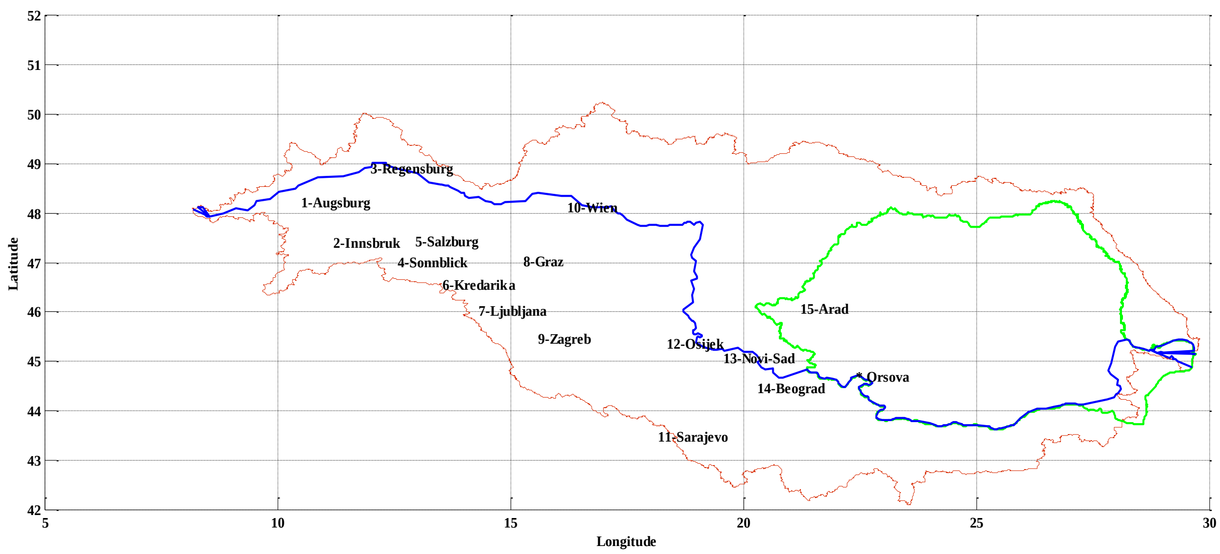


Figure 1. Localization of 15 precipitation stations situated upstream of Orsova station.

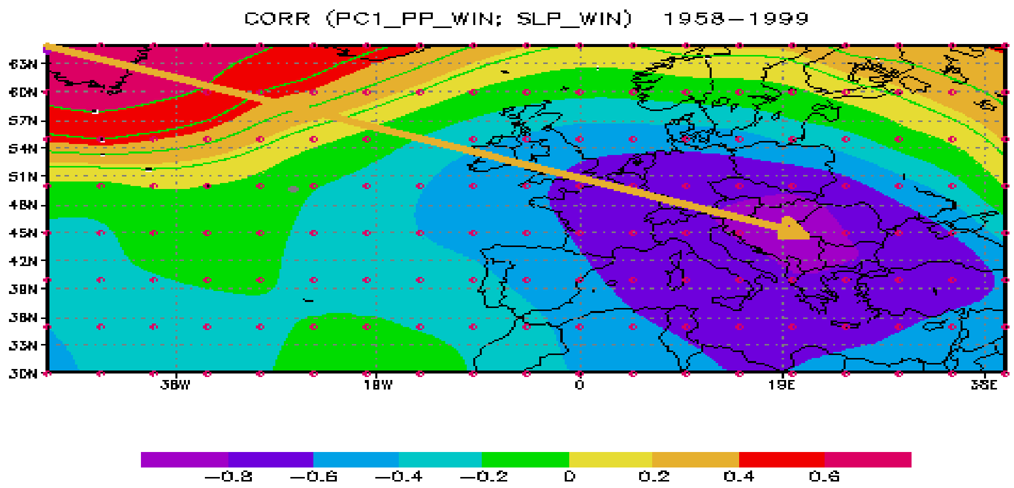


Figure 2. Spatial distribution of correlation coefficients between SLP NCAR and observed PC1- PP during winter for 1958-1999.

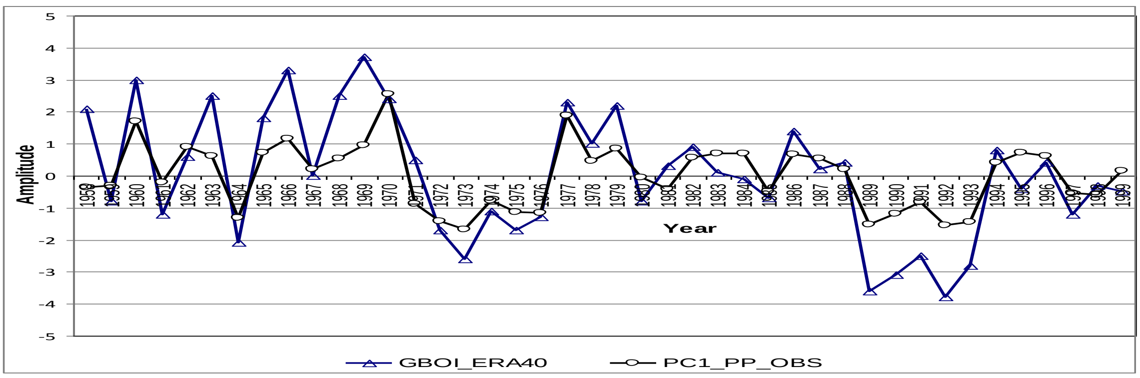


Figure 3. Winter precipitation PC1 versus winter GBOI for 1958-1999 **(R=0.84).**

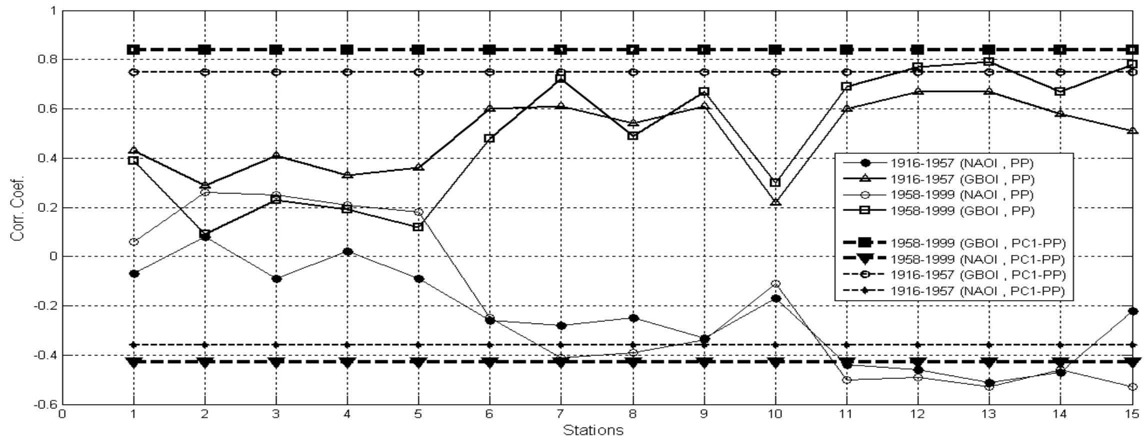


Figure 4. Correlation coefficients between winter precipitation at 15 stations and NAOI and GBOI for two periods: a) 1916-1957; b) 1958-1999. The correlations between PC1-PP and two indices are marked by horizontal lines.

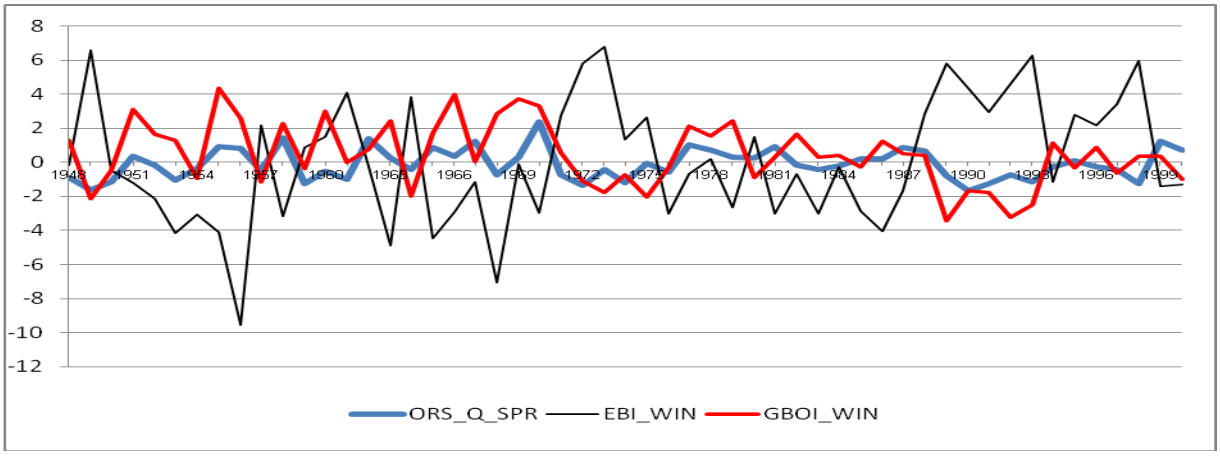


Figure 5. Spring Orsova discharge versus winter European blocking index (R= - 0.54) and winter GBOI (R=0.53) for the period 1948-2000.

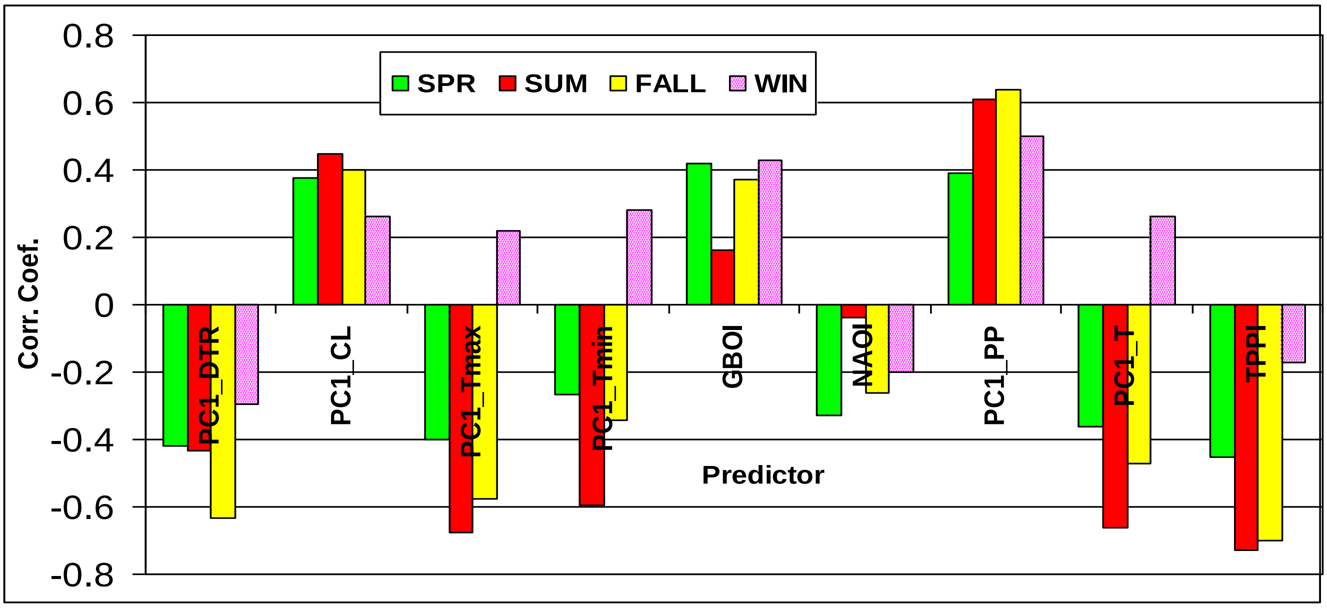


Figure 6. Simultaneous correlations between Danube discharge at Orsova and nine predictors (1901-2000)

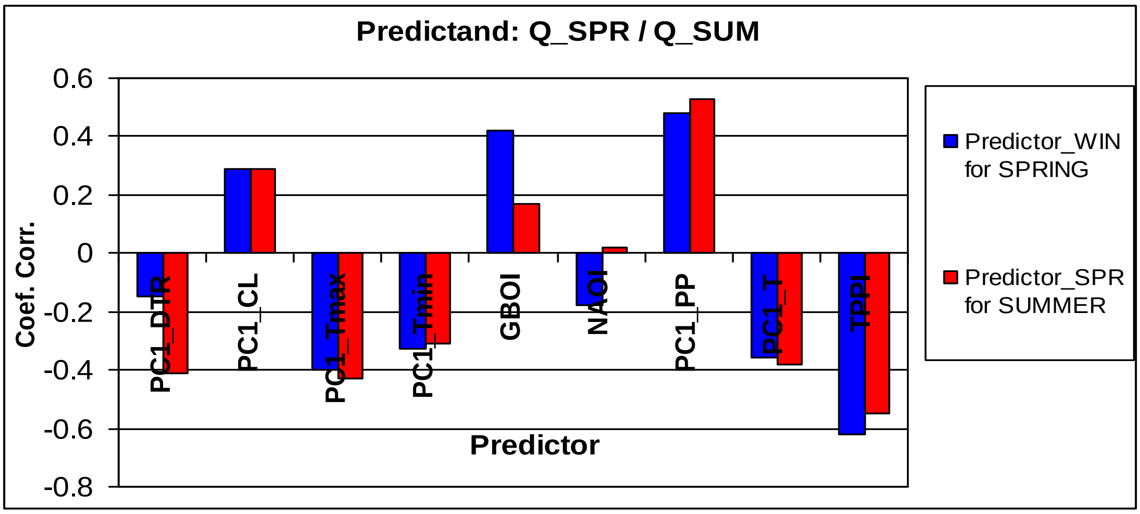
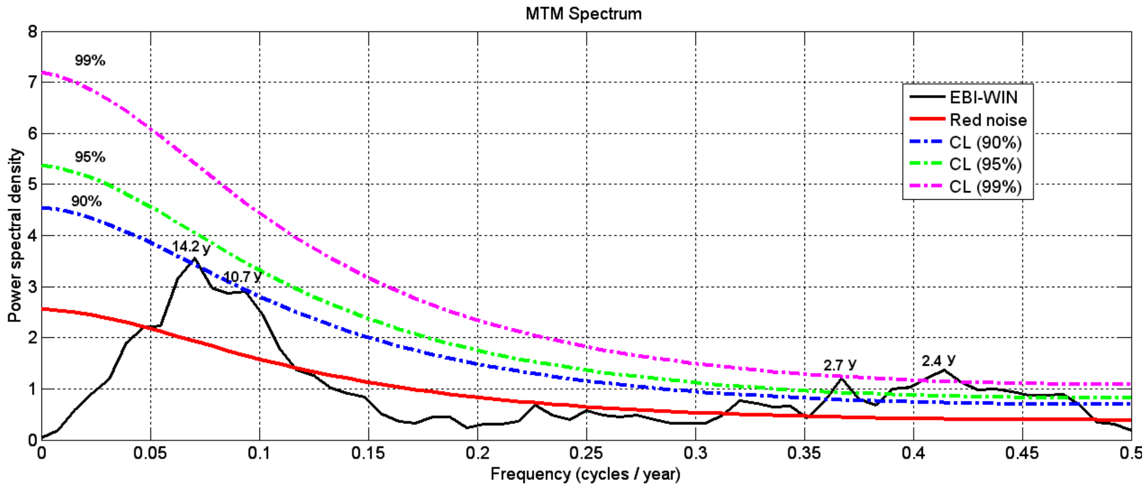
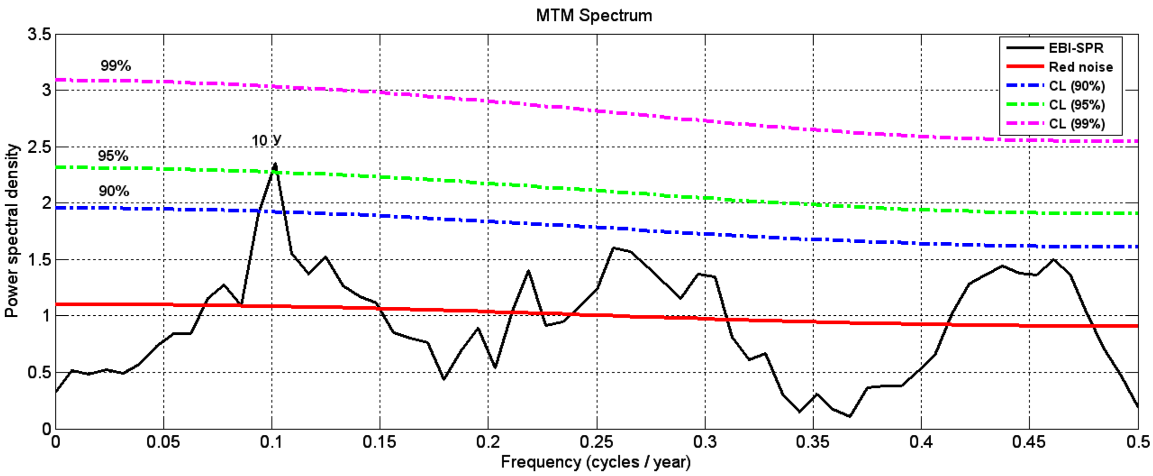


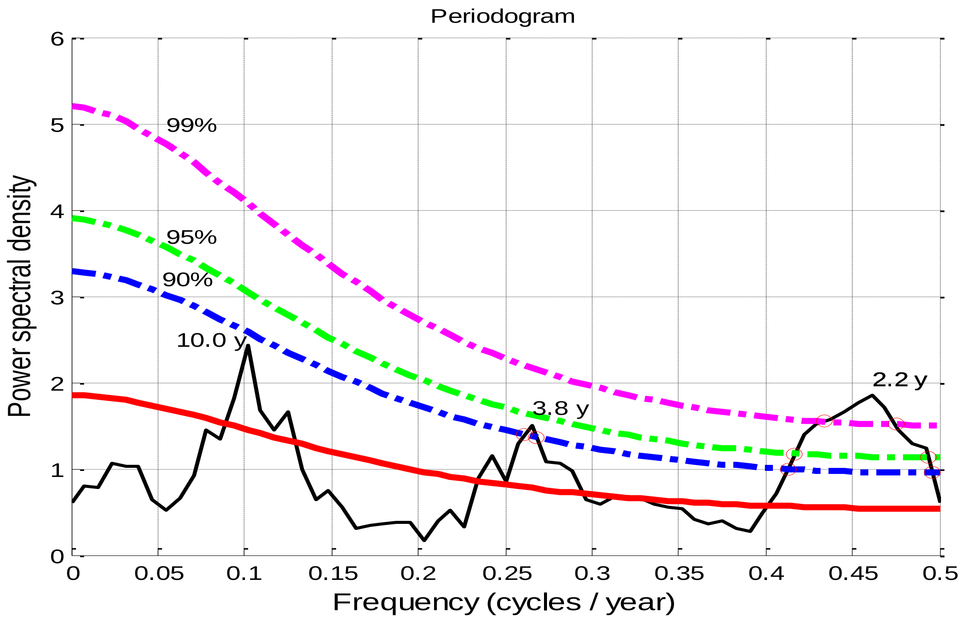
Figure 7. The correlation between Orsova discharge (Q) in the spring / summer and the nine predictors in the winter/spring.



a)



b)



c)

Figure 8. Power spectra for the blocking indices: winter EBI (a), spring EBI (b) and spring AEBI (c).

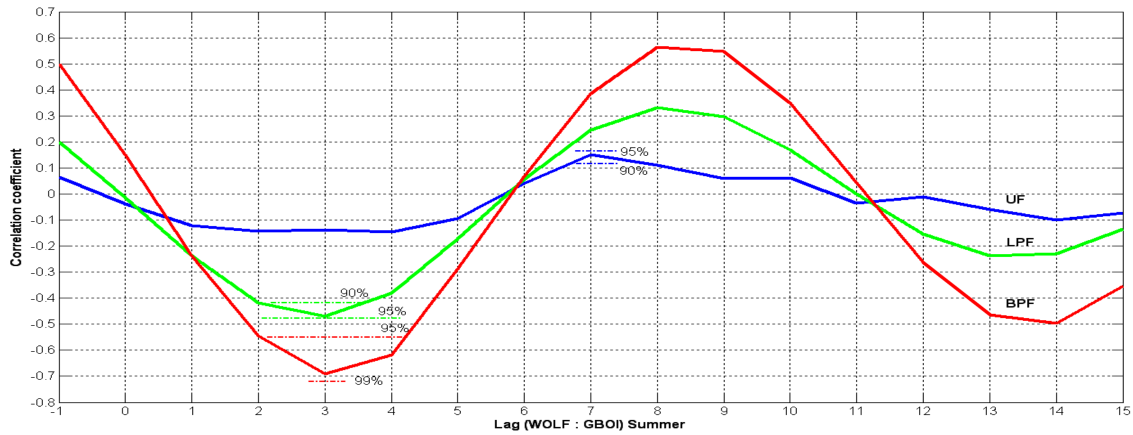
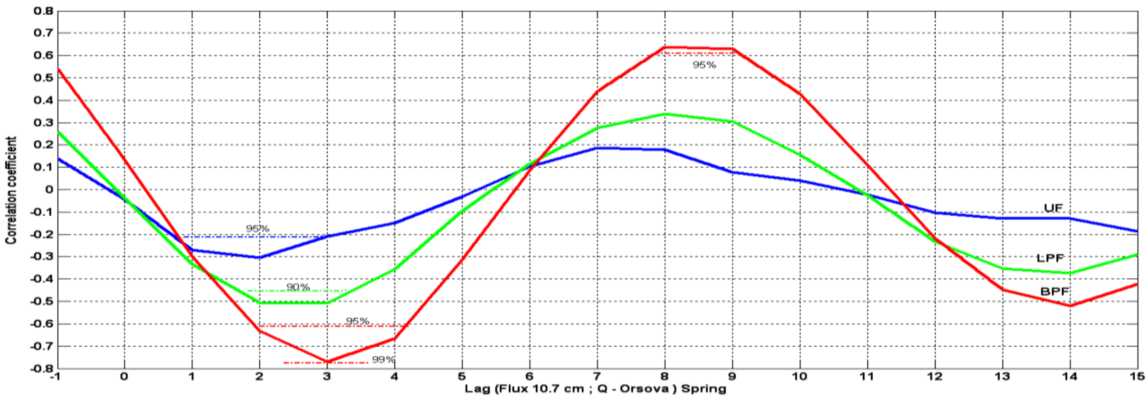
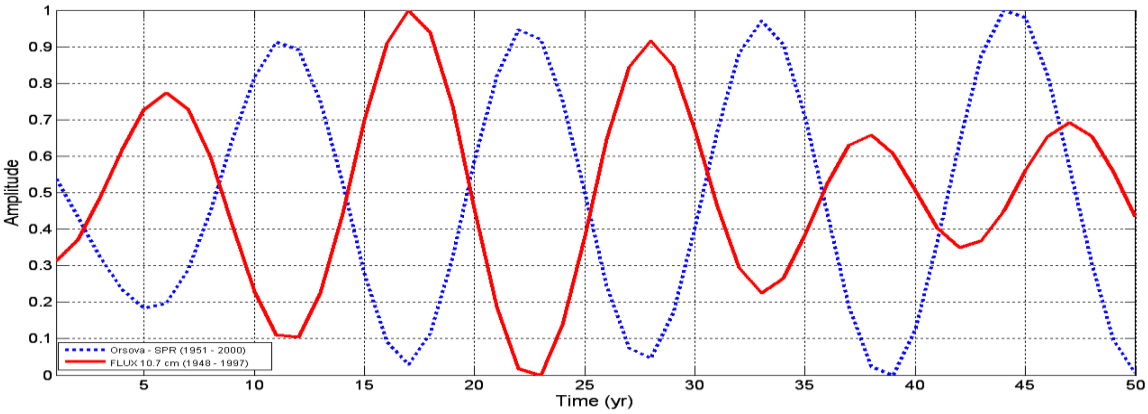


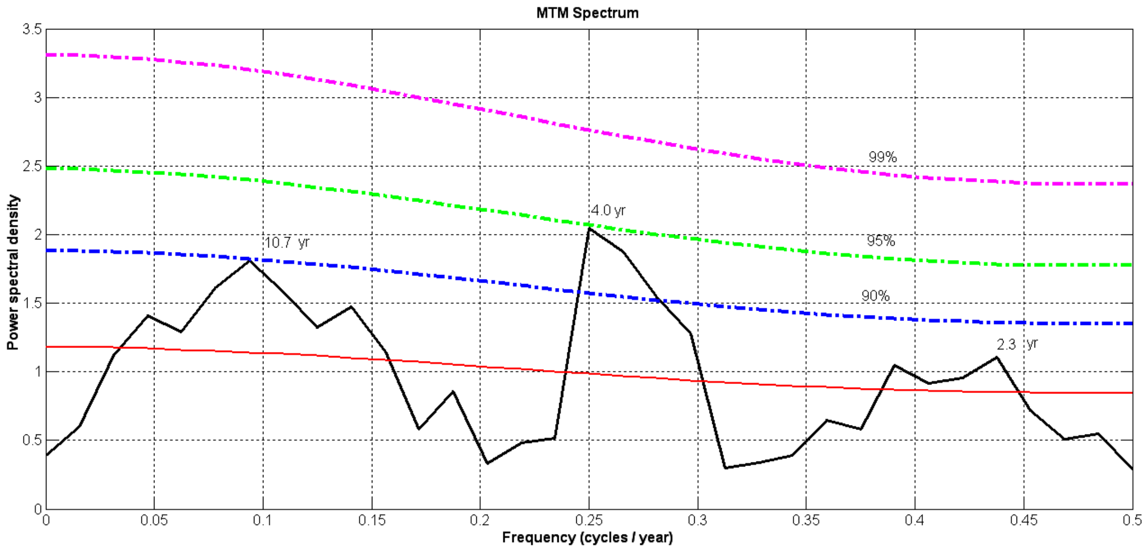
Figure 9. Correlation coefficients, between Wolf number and GBOI in summer with the lags between -1 and 15 yr, for three time series: unfiltered (UF), smoothing by low pass filter (LPF) and by band pass filter (9-15). The Wolf number is considered before GBOI, from 1 to 15yr.



a)



b)



c)

Figure 10. The test of a possible association between solar (Flux 10.7cm) and the Orsova dischage (Q_ORS), during spring (1948-2000).

a) Correlation coefficients, between solar flux and Orsova discharge with the lags from -1 to 15 yr, for three time series: unfiltered (UF), smoothing by low pass filter (LPF) and by band pass filter (9-15);
b) Temporal behavior of the solar flux and Q_ORS, filtered (9-15) with a delay of 3 years to flux. The time series are normalized.
c) Power spectra for spring discharge at Orsova. The time series is unfiltered.

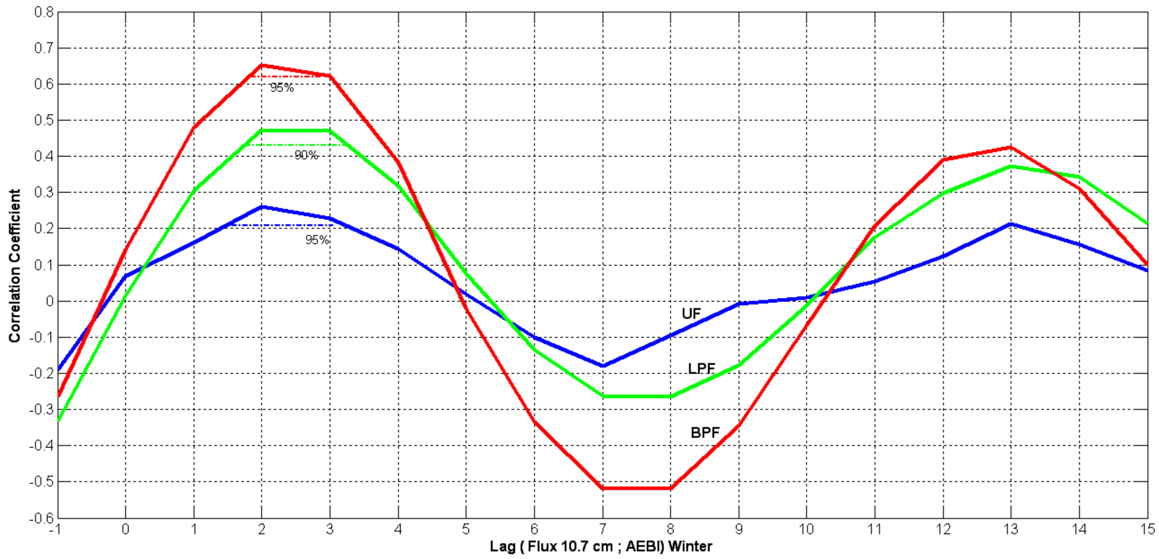
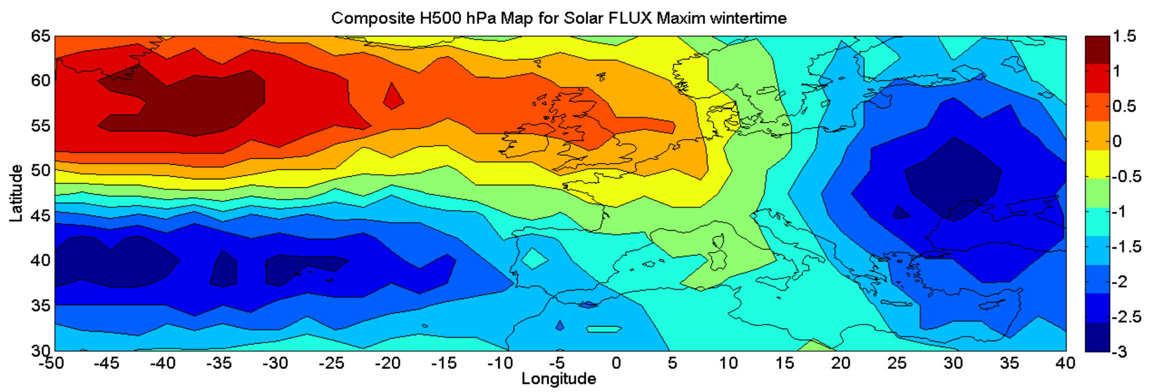
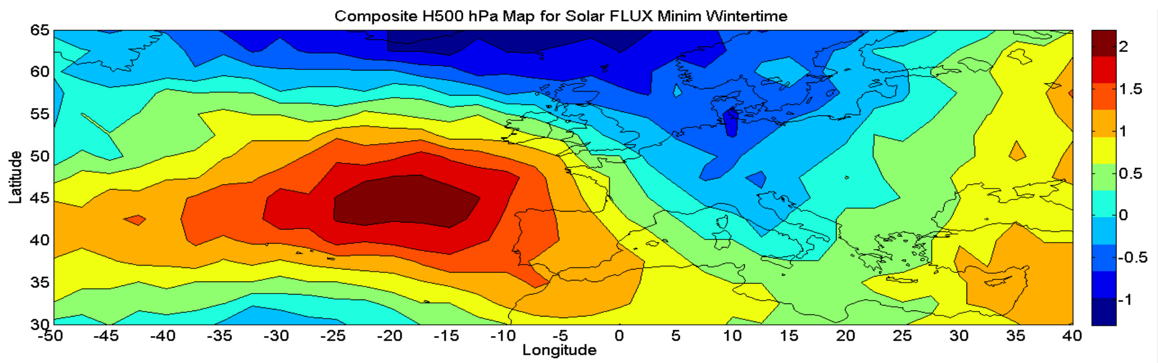


Figure 11. Correlation coefficients, between solar flux and AEBI with the lags between -1 and to 15yr, during winter (1948-2000), for three time series: unfiltered (UF), smoothing by low pass filter (LPF) and by band pass filter (9-15).



a)



b)

Figure 12. Composite maps for the winter H500 hPa anomalies, corresponding to solar flux associated with the east phase of QBO (1948-2000) and: a) maximum flux b) minimum flux

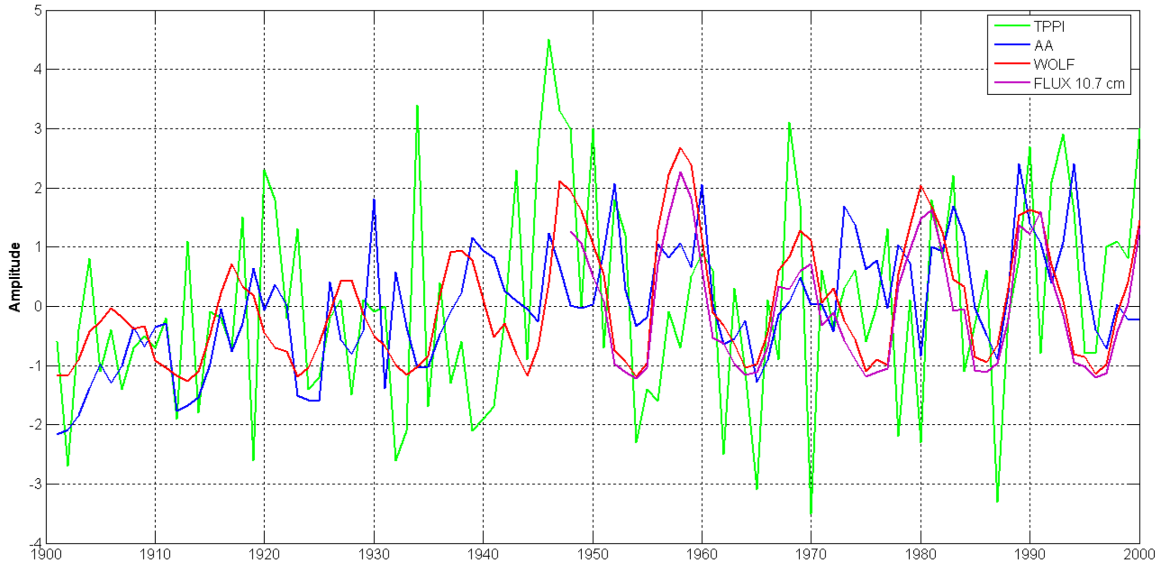


Figure 13. Time series of Wolf number, aa, and TPPI for the period 1901-2000 and solar flux since 1948. All time series are standardized.