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

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

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. ~~The~~ quantifying the impact of each factor on the climate system is subject to various [illegible]ainties. As shown in Cubasch et al. (1997) as well as in Benestad and Schmidt (2009) is difficult to distinguish between anthrop[illegible] signal and the solar forcing in the climate [illegible]e, especially if we wanted to assess ~~if~~ the greenhouse or the solar forcing ~~could be r[illegible]ible for~~ the recent warming. An explanation of this shortcoming is related to the limits 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 / geoma[illegible] on the climate. After a statistical reconstruction of the main atmospheric fields for m[illegible] 250 years, the authors performed an analysis of the solar signal of 11 years in different terrestrial datasets, and they found that there was a robust response of the tropospheric late-wintertime circulation to the sunspot cycle, independently from the date 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 model[illegible]ound in Papadimitriou et al. (2016), where an analysis of the changes in future drough[illegible]tology was performed for five major European basins (including Danube) and the impact [illegible] global warming was estimated.

Regarding internal factors that influence climate at regional or local scale, best kno[illegible] index is related to the North Atlantic Oscillation (NAO). After Hurrell et al. (2003), NAO[illegible] an internal variability mode of the atmosphere that depends exclusively on the dipolar pressure distribution.

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[illegible] Also, Rimbu et al. (2005) was found that spring Danube discharge anomalies are [illegible]cantly related to winter Sea Surface Temperature (SST) anomalies. In Mares et al. (2002) 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.

Taking into account that solar activity plays an essential role in modulating the blocking parameters with the strongest signal in the Atlantic sector (Barriopedro et al., 2008; Rimbu and Lohmann, 2011), in the present paper we consider also, the indices of atmospheric circulation of blocking type.

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. 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.

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 ~~analysis~~. ~~Some authors investigating these signals in the terrestrial variables take into account these large serial correlations induced by these smoothing, others do not~~. 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. ~~The confidence level is found by robust method.~~ We also briefly described the procedure of testing of confidence levels of the peaks of the power spctra.

Section 4 contains the results and their discussion. Concerning the link between atmospheric circulation at the large scale and the climate variables at local and regional scales and described in 4.1, we demonstrated that GBOI is a predictor more significant 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 signals (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 periods 1901-2000 and 1948-2000. For the period 1901-2[illegible]n the Danube upper and middle basin (DUMB), were considered fields of precipitation (PP), mean temperature (T), diurnal temperature range (DTR), maximum and minimum temperatures (Tmx, Tmn), clou[illegible] cover (CLD) at 15 meteorological stations upstream of Orsova. The selection of stations wa[illegible] 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) accessing (http://climexp.knmi.nl). Data-sets ar[illegible]lated on high-resolution (0.5 x 0.5 degree) grids by Climatic Research Unit (CRU), a[illegible] selected for each station (with the respective co[illegible]tors) the option "half grid points".

[illegible]he stations position in relation to Orsova is given in Figure 1. For each station was calculated a simple drought index (TPPI), 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 [illegible] the regional scale, we considered the seasonal mean values of sea level pressure field (SL[illegible] 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 girded 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 Hemi[illegible] from 15^0N to the North Pole. The accuracy and quality of this data is discussed in Tr[illegible]n and Paolino (1980).

We found a new index started from tests achieved using correlative analysis between the first principal component (PC1) of the Empirical Orthogonal Functions (EOF[illegible] development of the precipitation field defined at 15 stations from Danube basin and each gr[illegible] point where SLP is defined. By determining the centers of inverse correlation nuclei (positive and negative) 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 d[illegible]d from http://www.ldeo.columbia.edu/res/pi/NAO/

For 1948-200[illegible]d beside of variables taken over 1901-2000, we considered ~~and~~ blocking type indices.

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 W[illegible] number and *aa* index. For the period 1948-2000, solar forcing is quantified by the 10.7 cm solar flux instead of Wolf number. 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 (ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/). The values for the Quasi-Biennial Oscillation

(QBO) 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 filtered by the first principal component (PC1) of empirical orthogonal functions (EOFs) development.

The analyse of the low frequency components of the atmosphere, based on decomposition in multivariate EOF (MEOF), was used by the autho[illegible]e present paper in Mares et al. (2009, 2015, 2016a, b).

The 500 hPa geopotential field was filtered by blocking index (I_B) as is described in 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 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 the periods lower than 8, 10 and 20 [illegible]

Besides the low pass filters specified above, which was applied only to the terrestrial fields, the **band pass filters** were applied both to 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.

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 with different the band frequencies.

As is known in the literature, the response of climate variables to the solar/geomagnetic activity is evidenced not only simultaneously but also certain differences, we performed cross - correlation with a lag of 5 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 ~~applied and the~~ nonparametric Kendall correlation coefficient, which measures ~~of~~ correlation of ~~the~~ 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 ~~on testing~~ the statistical significance of the amplitude of the power spectra in time series. Testing the statistical signific[illegible]f the peaks o[illegible]d from an analysis of a time series by power spectra [illegible]ally[illegible] by building a[illegible]nce spectrum (background) and comparing the amplitu[illegible]trum analyzed time series ~~based spectrum amplitudes~~. This [illegible]m is a series based on [illegible] ~~noise~~ or most often ~~a~~ red noise ~~series~~ (Ghil et al. 2002, To[illegible] and Campo, 1998). ~~A[illegible]~~ all amplitudes above the background noise amplitudes are considered significant. ~~But to test how significant are these peaks are testing their statistical significance compared with different levels of significance desired.~~

[illegible] significance test requires null hypothesis significan[illegible]r spectra[illegible]sis, the null hy[illegible]is is that the time series has no significant peak and spectral ~~estimation differs~~ from the [illegible]oise spectrum ~~(background).~~ 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.

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 harm[illegible]ectral analysis assumes that the data generation process include components purely p[illegible] and white noise which are overlapped (Ghil et al., 2002).

In Mares et al. (2016), more practical details were given on estimating background noise and significance of power spectra peaks, for the applications refering 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 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 [illegible]s that a positive GBO index lead to a low pressure in the Danube basin area and therefo[illegible]gh discharge.

The role of the atmospheric circulation of blocking type on 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 - 0.730 for spring and summer and respectively -0.700 for fall. In winter season, the highest contribution to the discharge in lower Danube basin, it has precipitation field in the upper and middle basin (r = 0.500), followed by 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 th Fig. 7. For spring, the best predictor is clearly drought index (TPPI), taken in winter (r = 0.62), and also for summer discharge, TPPI in spring is a significant predictor (r = -0.55), but quite closely related this is the spring precipitation field quantified by PC1 (r = -0.53).

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

4.3 Solar/geomagnetic signal 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 (M 004, 2008) was applied with three variants that eliminate frequencies corresponding ~~the~~ 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 rela solar or geomagnetic activity.

4.3.1 Simultaneously signal

The Table 2 presents some of the results that have a confidence level higher or least o 95%, which worth to be taken into account 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 Pearson's coefficient. The nonparametric Kendall coefficient is valid for time series that do not have a normal distribution. 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 17-28 yr, but although, highest correlation coefficients were obtained, 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 filtering are necessary much larger sets of data. An example is given in Tab. 2 to test the correlation between the GBOI and Wolf number during fall season.

The results presented in the 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 significantly 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 to mention the aa signal in drought index (TPPI) with the correlation is 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 noting 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 signal 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 annually 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 is applied a smoothing, 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 solar signal, quantified by Wolf number, in the drought index (TPPI), for which in the spring, unfiltered data, filtered by the low pass filter, and those by BPF (4-8 and 9-15) indicate correlations with 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 signals of the geomagnetic and solar activity, we can notice that during spring, TPPI has the best respond 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* signal in Danube discharge at Orsova (Q_ORS), is seen as the most significant, 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 response to *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, was considered this period because some of the atmospheric variables, as indices that define the type blockage 500 hPa, are available only in 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 ~~the~~ Table 3 are presented the correlation coefficients with a high confidence level (>95%), obtained from the simultaneous correlative analyzes between terrestrial variables and gemagnetic (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, especially for highlighting solar signal, where all three blocking indices considered in this paper, respond significantly to the solar impulse.

The solar or geomagnetic signals in the terrestrial variables 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 response to solar activity, quantified by the Wolf number, is statistical 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 ~~the~~ there are solar/ geomagnetic signals 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), significant signals of the solar activity quantified by solar flux 10.7cm were obtained for spring and summer in the Danube discharge at Orsova (Q_ORS), with different lags, especially to a delay of two years, where both unfiltered and filtered time series, indicate statistically significant correlations.

Like in the GBOI case, the discharge is inversely, but well correlated with solar activity. In Fig. 10a, correlation coefficients are shown at the lags 1-5 for three series, unfiltered (UF), smoothed by low pass filter (LPF) and the band pass filter (9-15). It can b[illegible] observed that, if for the unfiltered data, the signal is significant at the lag 1 and 2, for the da[illegible] smoothened by BPF, this signal is at the lags 2, 3 and 4. Taking into account the LPF result, can be considered the [illegible] significant result at the lag 2 years. In the Fig. 10b have been shown the coherent ti[illegible]lutions of the solar flux and discharge, smoothed by BPF (9-1[illegible] with a lag of three years, where, the correlation coefficient is highest (-0. 769) and CL is 99[illegible]

From the above results, we can highlight 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).

A different response to solar activity was found in the time series of the index t[illegible] defines a atmospheric circulation of blocking type over Atlantico-European region, for t[illegible] period 1948-2000, during the winter season. As can be seen in Fig. 11, the response this index to the solar activity is significant with a delay of two years and three years compared 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, winter, atmospheric circulation of blocking type is enhanced (weakened) over the Atlantico-European region.

4.3.3 QBO role

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 these findings, in this paper, the years with east QBO phase, during winter months have been selected, and were mad[illegible] correlations between solar flux and more terrestrial variables. Winter, from the atmospheric indices of blocking type at 500 hPa, best response at the QBO signal, was found in the blocking over the European sector (EBI), with power spectrum shown in Fig. 8a. But the correlation coefficient between the solar flux and the unfiltered EBI during winter, for all those 53 years, is 0.15 and not is 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 a[illegible] 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 2.7ani), 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.

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 signal, 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 field of temperature, precipitation, cloud cover in the Danube basin, and indices of atmospheric circulation over the European Atlantic region. For climate variables defined in the Danube basin, as predictor we used only the first principal component (PC1) of the EOFs decomposition and a drought index (TPPI) derived from the standardized temperature and precipitation.

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 analyzes 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 signals in 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 signals of solar/geomagnetic activities were obtained in the drought indicator (TPPI). Because the precipitation does not respond just as well as, temperatures to the solar signal, is preferred analysis TPPI variable in stead of temperatures and precipitation separately.
6. From the analysis of correlations with the lags from 0 to five 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. A terrestrial variable that respond to the solar signal, even more significant than to the geomagnetic signal, is atmospheric circulation index GBO, in summer. Therefore, at the 2-3 years after a maximum (minimum) of solar activity, expects a response 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 thi[illegible]tigation, like GBOI, TPPI and atmospheric blocking indices from the outputs of the [illegible]e simulation models. Also we will take into account non-stationarities and non-linearities associated with the major modes of climate variability.

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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 braketes. *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%**

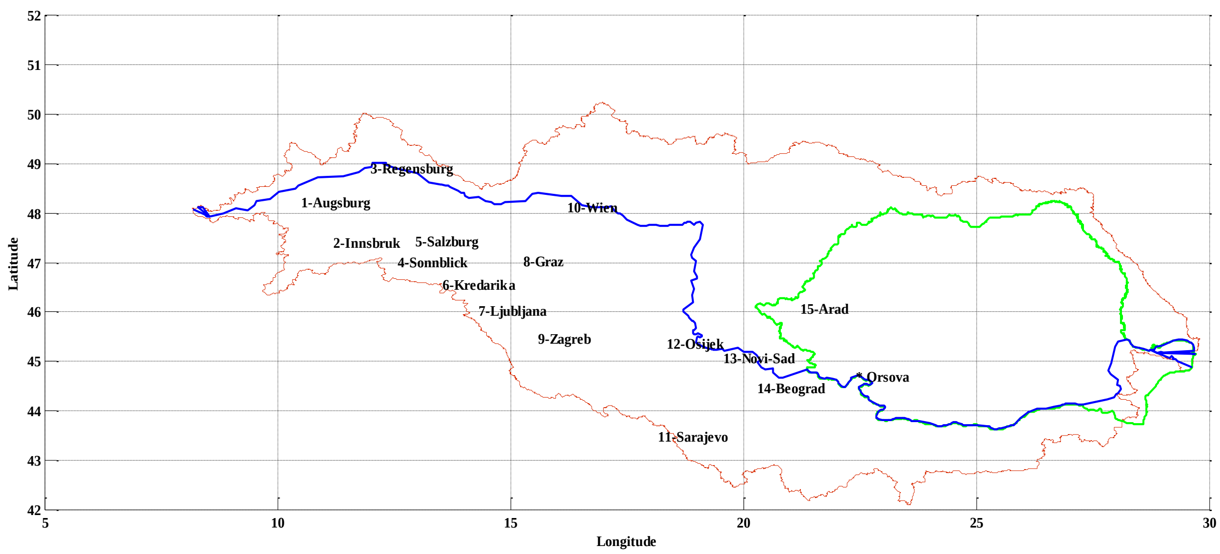


Figure 1. Localization of 15 precipitation stations situated upstream of Orsova station.

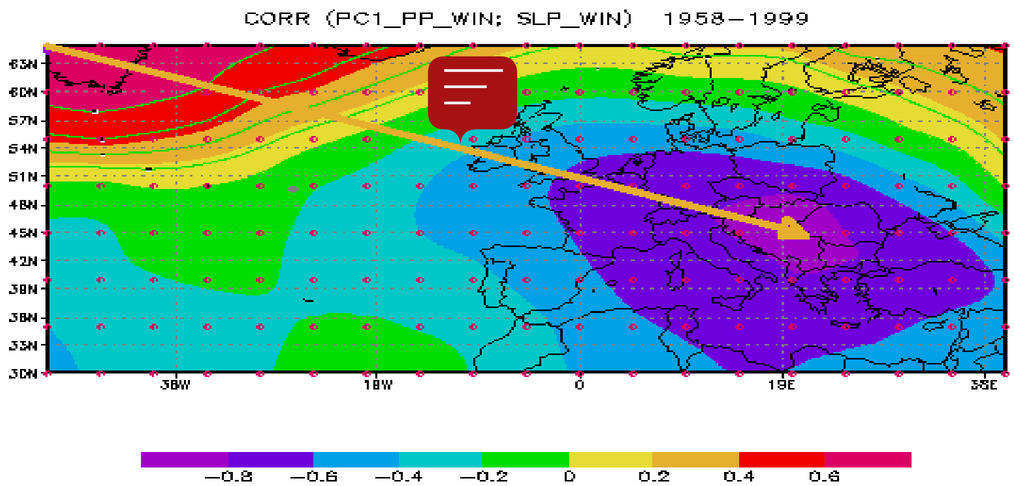


Figure 2. Spatial distribution of correlation coefficients between SLP NCAR and observed PC1- PP during winter for 1958-1999.

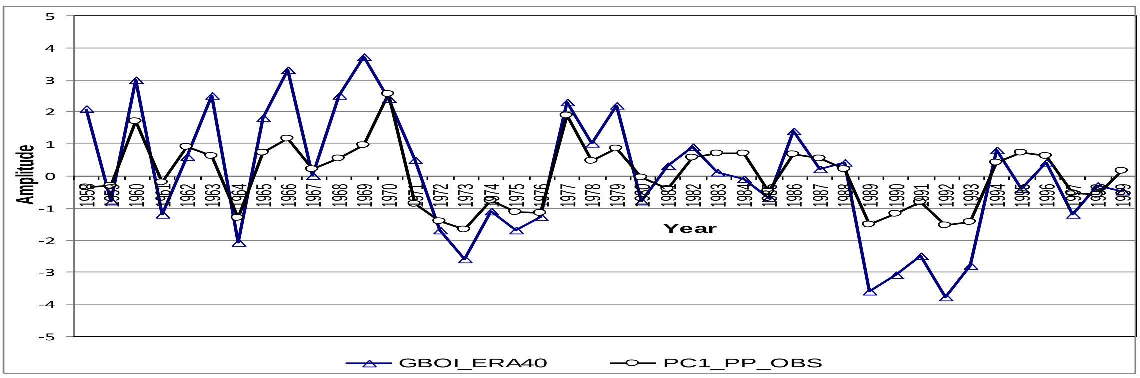


Figure 3. Winter precipitation PC1 versus winter GBOI for 1958-1999 **(R=0.84).**

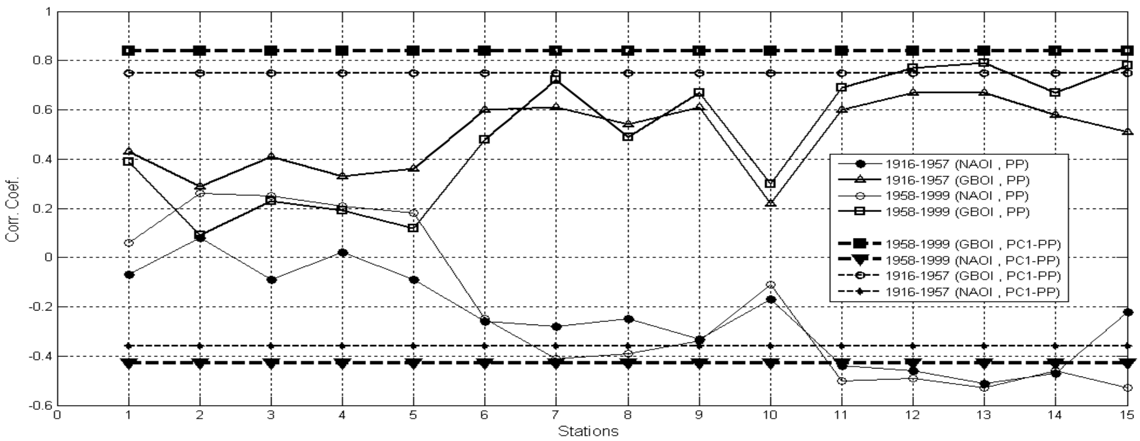


Figure 4. Correlation coefficients between winter precipitation at 15 stations and NAOI and GBOI for two periods: a) 1916-1957; b) 1958-1999. The correlations between PC1-PP and two indices are marked by horizontal lines.

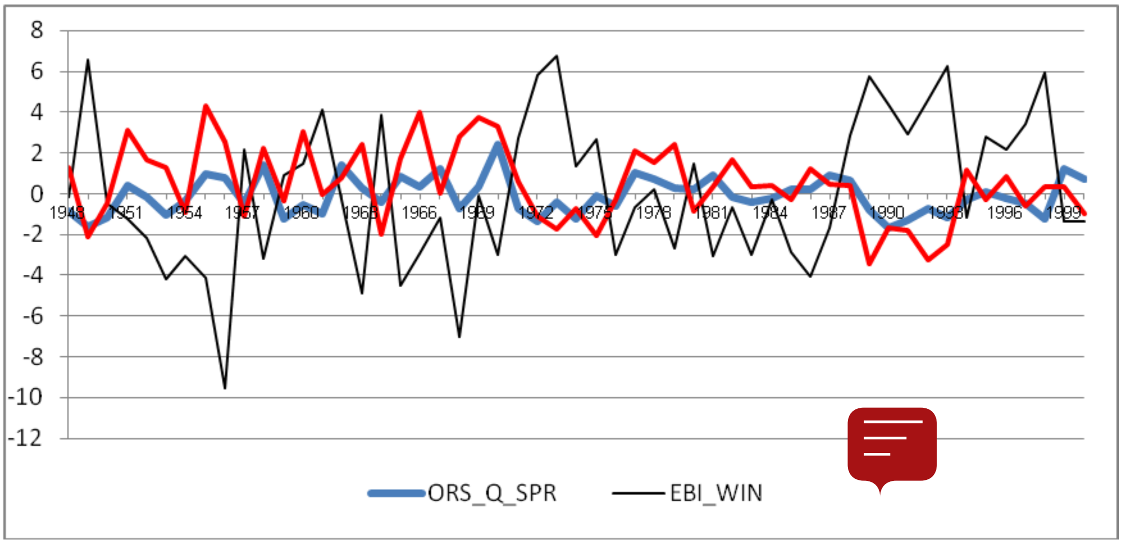


Figure 5. Spring Orsova discharge versus winter European blocking index (R= - 0.54) and winter GBOI (R=0.53) for the period 1948-2000.

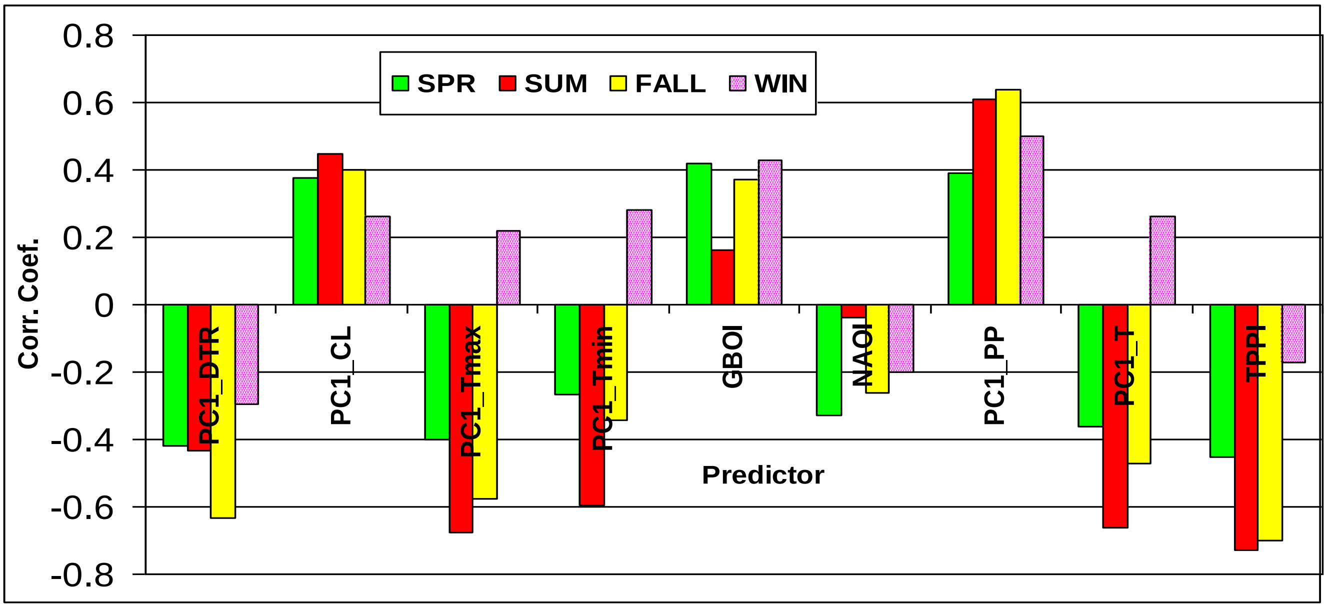


Figure 6. Simultaneous correlations between Danube discharge at Orsova and nine predictors (1901-2000)

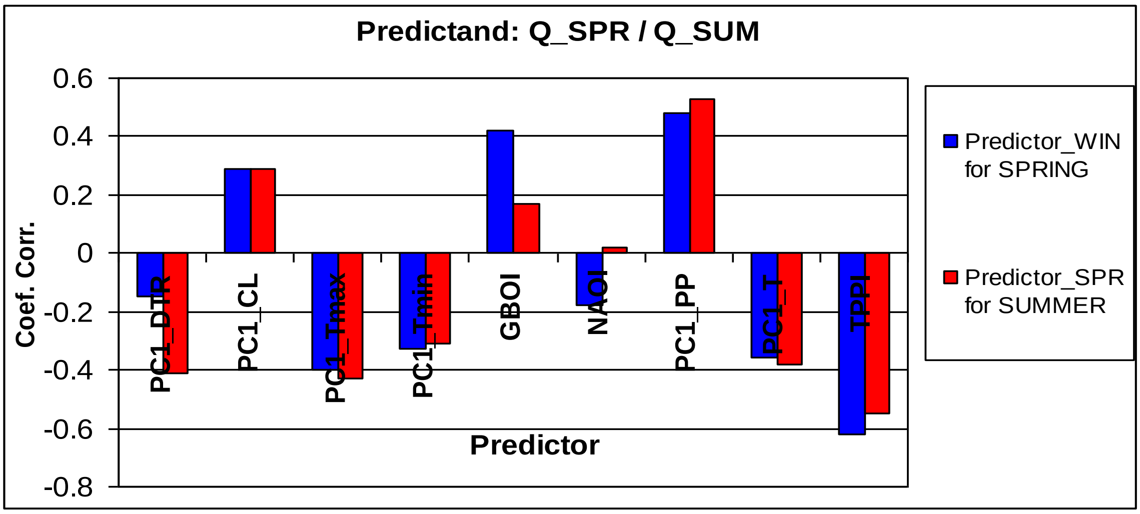
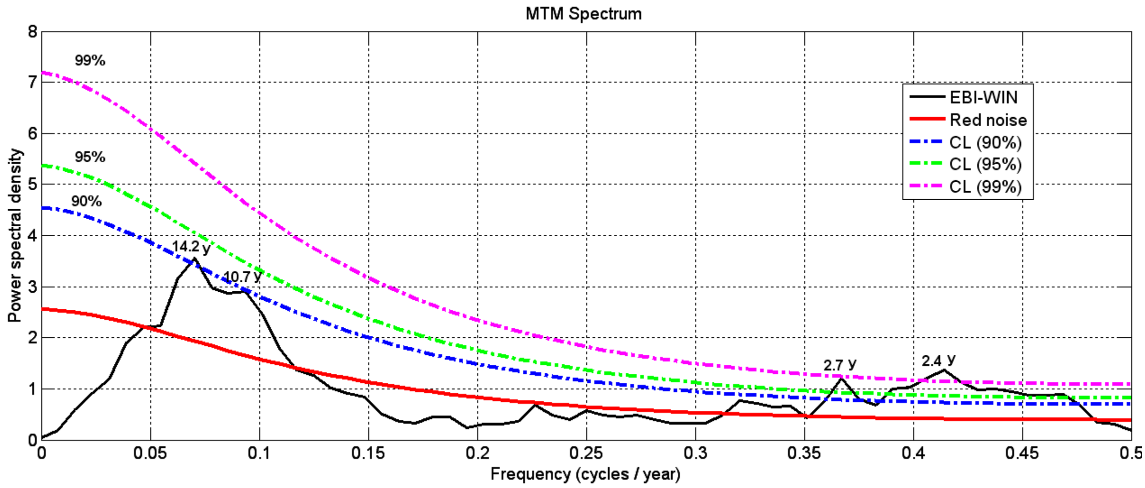
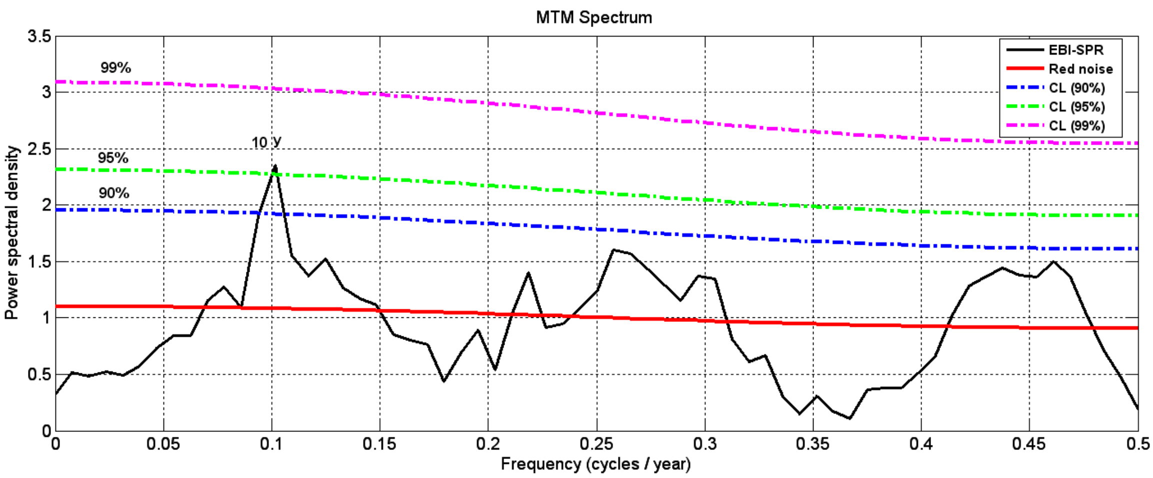


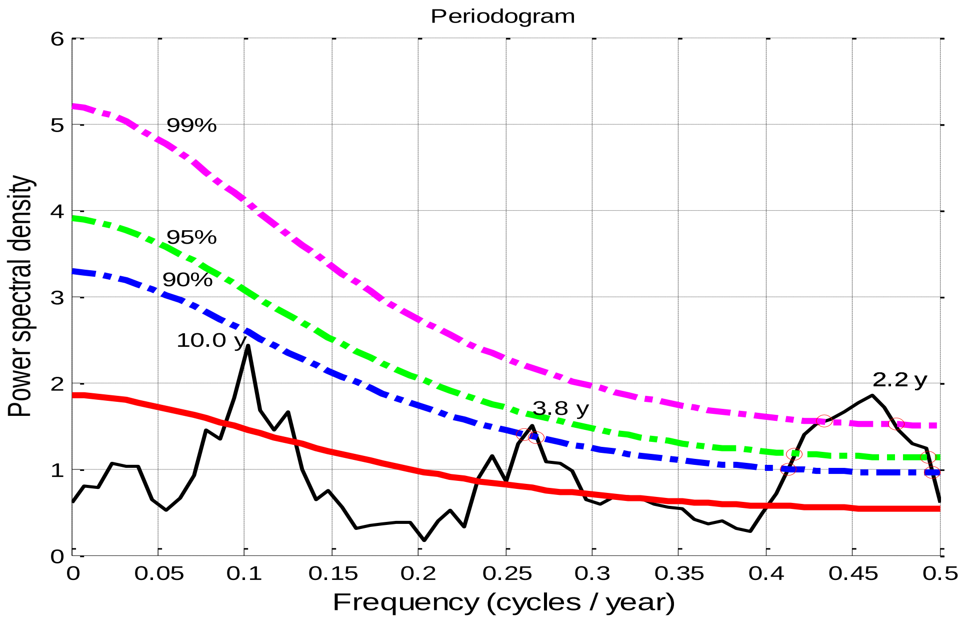
Figure 7. The correlation between Orsova discharge (Q) in the spring / summer and the nine predictors in the winter/spring.



a)



b)



c)

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

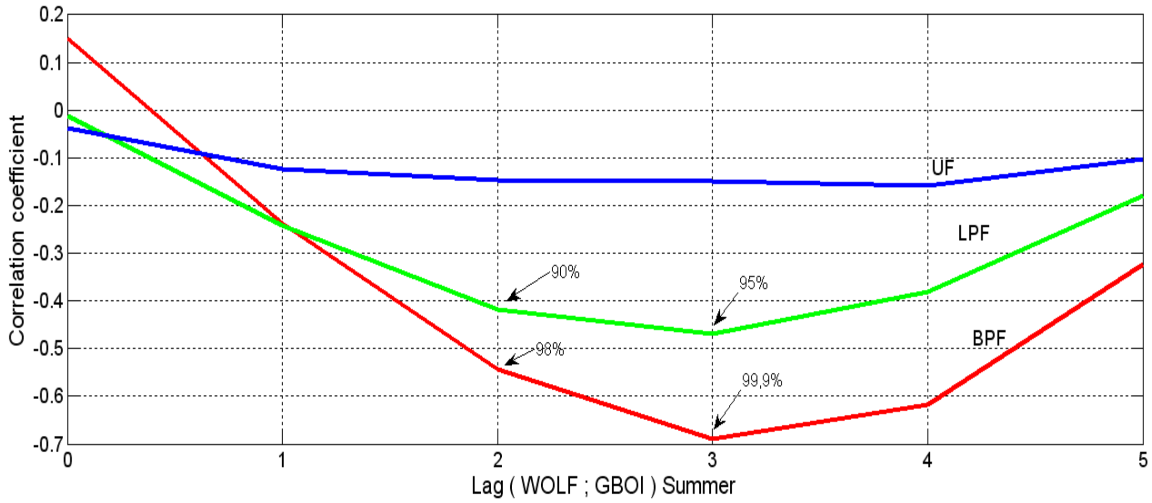
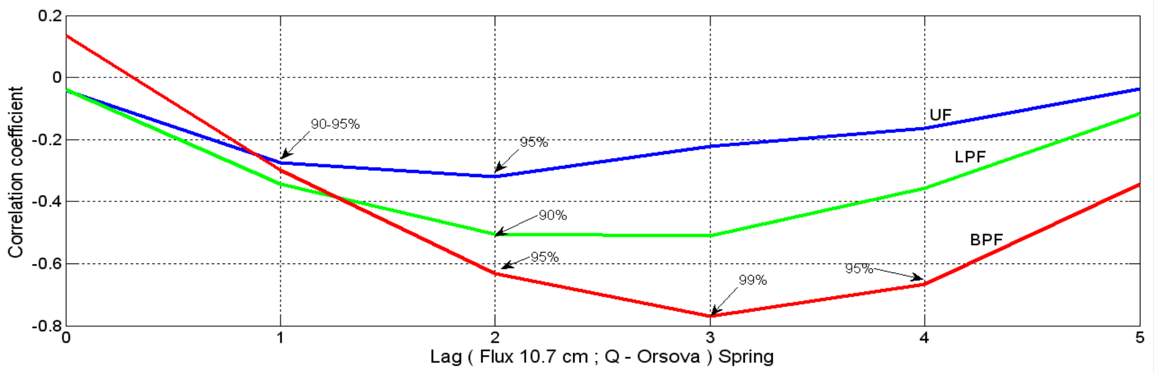
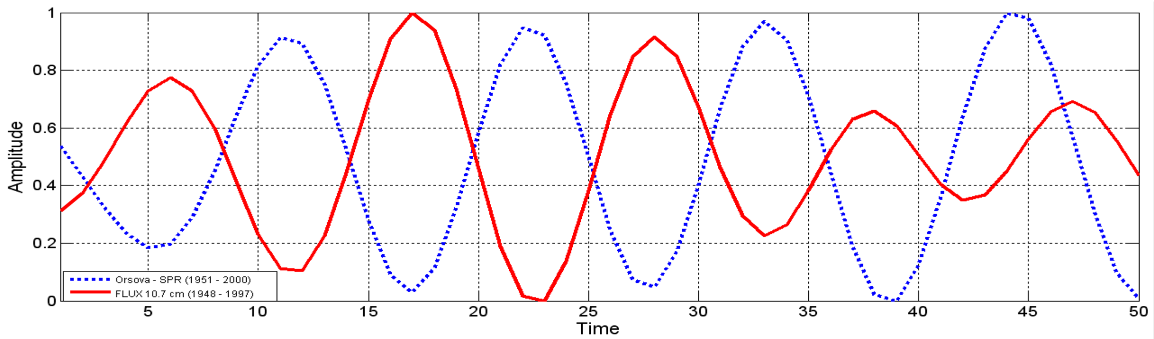


Figure 9. Correlation coefficients, between Wolf number and GBOI index in summer with the lags 0-5, for three time series: unfiltered (UF), smoothing by low pass filter (LPF) and by band pass filter (9-15)



a)



b)

Figure 10. Solar (Flux 10.7cm) signal in the Orsova dischage (Q_ORS), during spring (1948-2000).

a) Correlation coefficients, between solar flux and Orsova discharge with the lags 0-5, 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.

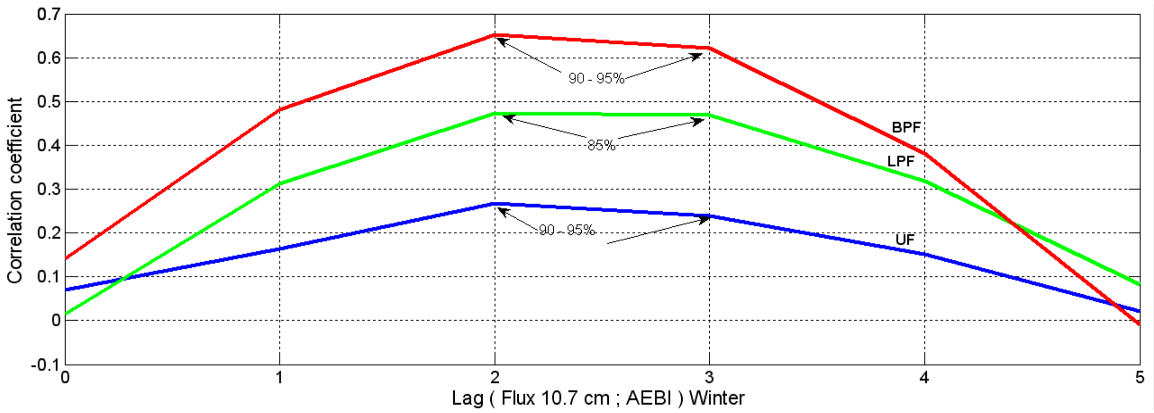
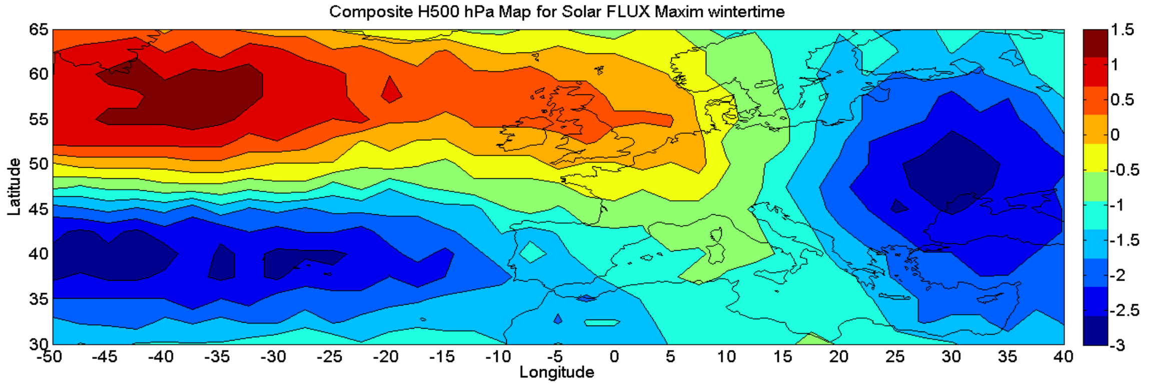
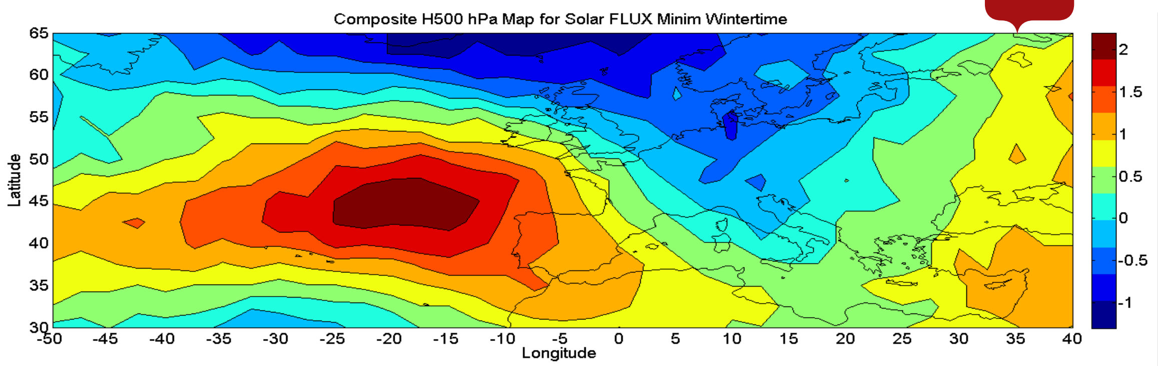


Figure 11. Correlation coefficients, between solar flux and AEBI with the lags 0-5, during winter (1948-2000), for three time series: unfiltered (UF), smoothing by low pass filter (LPF) and by band pass filter (9-15).



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