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POSSIBLE CONNECTION BETWEEN DANUBE RIVER DISCHARGE VARIABILITY AND SOLAR ACTIVITY

Abstract: Relations between discharge changes and solar activity are very complex and this is the reason why the obtained results are often contradictory. In this paper we tray to explore possible relation between Danube river discharge elements and parameters of solar activity. The best result has been found between flow index and latitude of sunspots. According to literature we propose possible mechanism of solar activity influence on the discharge.

Key words: discharge, Danube River, solar activity.

Садржај: Везе између промена протицаја и сунчеве активности веома су сложене, због чега су добијени резултати често противречни. У раду смо покушали да испитамо могућу везу између елемената протицаја Дунава и параметара сунчеве активности. Најбољи резултат добијен је за везу између индекса водности и асиметрије хелиографске ширине сунчевих пега. На основу литературе предложен је могући механизам утицаја сунчеве активности на протицај.

Кључне речи: протицај, Дунав, сунчева активност.

Introduction

How much of an influence the Sun exerts on earth's climate has long been a topic of heated discussion in the area of global climate change (Franks, 2002). The main reason for the different opinions on this subject derives from the fact that although numerous studies have demonstrated significant correlations among some measures of solar activity and various climatic phenomena (Reid, 1991, 1997, 1999, 2000). The magnitude of the variable solar radiative forcing reported in these studies is generally so small, that it is difficult to see how it could possibly produce climatic effects of the magnitude observed.

Supporters of solar effects theories claim that various positive feedback mechanisms may amplify the initial solar perturbation to the extent that significant climate changes really take place.

Nearby in Europe, a review of the relationship between extreme weather events and the climate during the Holocene also implicates solar forcing as the factor responsible for the above-average rainfall during the Little Ice Age. During this period, according to Starkel (2002), continuous rains and high-intensity downpours coinciding with periods of reduced solar activity were major problems that often led to severe flooding.

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Relations between solar activity, precipitation and river discharge

Perry (1995) has investigated association between Solar-Irradiance Variations and Hydro-climatology of Selected Regions of the USA. He has found that projections of solar-activity cycles for estimating future hydro-climatic events have been suspect because there has been no identified physical mechanism to explain the connection between activity on the Sun and regional hydro-climatic patterns on Earth.

Measurements of the Sun's total energy output (total solar irradiance) by Earth satellites show small changes in total energy that generally follow the solar-activity cycle and are providing new information on the controversial solar/climate relation. These variations have been shown to correlate significantly with regional precipitation in various locations in the USA (Perry, 1994).

The possible mechanism proposed for the coupling of solar-irradiance variations with regional hydro-climate consists of three main components. These are: (1) absorption of solar energy by the tropical oceans in a deep surface layer, (2) transport of that energy by major ocean currents of the Pacific Gyre, and (3) transfer of that energy by evaporation into atmospheric moisture and atmospheric pressure systems that can be advantageous for precipitation formation (Perry, 1994).

Perry has also investigated connection between annual solar-irradiance and annual average flow of the Mississippi River at St. Louis. The best correlation is obtained with a 5-year lag time. The correlation coefficient for these data is R=0.52, significant at the 1% level. An approximate 5-year lag is apparent for other basins and sub-basins between the Rocky Mountains and the Appalachian Mountains, as opposed to the 4-year lag time observed in the Pacific Northwest. Possible explanation for the greater lag time, by Perry, may be in the more eastward location of the ocean temperature anomalies in the Pacific Ocean that affect atmospheric dynamics over the midsection of the United States than over the Pacific Northwest. An additional year may be needed to move the ocean temperature anomalies farther to this location (Perry, 1995). An intriguing observation of individual graphical correlations of annual solar-irradiance variations with annual precipitation and discharge in the United States is an apparent change in effective lag times for a specific location. Prior to the mid- 1970's, lag times were slightly less than lag times after the mid-1970's. This point in time coincides with an apparent shift in atmospheric pressure patterns and with an increase in global surface air temperatures recorded at land-based stations (Graham, 1995).

Investigating the solar activity and discharge of the Parana River, Mauas and Flamenco found that there is a very strong direct correlation between solar activity, as expressed by the yearly Sunspot Number, and the discharge, in intermediate, interdecadal scales. This correlation implies that wetter conditions in this region coincide with periods of higher solar activity (Mauas, Flamenco, 2005).

Possible relationship between River Po discharge and Cycles of Solar activity is analyzed by Tomasino and Dalla Valle (2000). They found that the strongest peak in the analysis of River Po discharges appears at 8.7 years, a wave length that most astrophysicists and climatologists do not associate with solar activity. So an explanation is in order, especially as the time series of River Po discharges is used by the authors to forecast periods of droughts and floods as well as instances of slime bloom in the Adriatic Sea.

Ocokoljic (1994) distinguished 4 cycles of discharge fluctuations that lasted 29, 45, 16 and 40 years (average 32.5), for the station Orsova in the instrumental period. He claims that “there is no regular chronology in the appearance of very low flow and very high flow years, so it can be said that they are accidental phenomena”. Comparing the cyclicity of low flow and high flow periods with Wolf’s number, same author concludes that “there is almost no relation between them because both wet and dry periods appear in the periods of minimal and maximal sunspots, and no conclusions can be obtained based on this".

However, Ocokoljic cites that each cycle is characterized by transitional years. In addition, he cites the study of Gavrilovic (1981) and concludes that "during these years, or around them, the minimum of sunspots was noticed, or each period of transition from one to another discharge is preceded by maximum of the solar activity".

Relation between Wolf's number, climate elements and river runoff has been investigated by Генев (2004). The author shows that in Bulgaria climate feedback of solar activity is presented by extremely low values for precipitation total and river discharge. The drought in Bulgaria is clearly determined in 2000 when the maximum of Wolf's number has been observed.

Secular sunspot cycle of 80-90 years which modulates the intensity of the 11-year cycle, valid cycles have been derived from the Sun's irregular oscillations about the centre of mass of the solar system. Landscheidt (1998, 1999) has shown that these solar motion cycles are so closely connected with climate phenomena that dependable forecasts of droughts and floods, strong negative and positive anomalies in global temperature, and even El Niños and La Niñas can be based on this relationship.

Similar results were obtained by Ducic (2005) as well. He has found periodicity of 20 years in reconstructed Danube River discharge, which might be connected to above mentioned solar motion influence.

Jovanovic has investigated relationship between solar activity, presented as Total faculae areas, and River Danube discharge in yearly, maximal and minimal values for the period 1931-1990. Results are showing that "the solar activity, in statistical sense may influence the maximal river flow, with seven years lag, and the minimal stream flow after a lag of nine years" (Jovanovic, 1995).

Data and Methodology

The Danube is the river with relatively high number of hydrological gauges with observation for more than 50 years. However, the longest observation period was on the Romanian hydrological gauge Orsova, which was in operation from 1840 up to 1972, when a lake was created by Water –power station Djerdap. After 1972 time-series is charged by data gained by using of electricity generation as well as by measuring overflow waters on Kladovo dam. In this way time-series of 150 years is formed by discharged data during the period 1840-1989[1]. Hydrological gauge Orsova is one of the most reliable gauges on Danube River, because it is locates in Iron Gate which is consisted of rocks, riverbed is steadily and there is no outflow of high waters (Ocokoljic, 1994).

Because of the period length this time-series is representative for the river regime study as well as for the hydro-power utilization of waters. This is also a kind of parameter for proving of representativeness of short series on the other great rivers with similar regime.

Considering the length of the series as well as data reliability, we decided to include them into analyses in relation to the solar activity. According to Jean-Claude Pecker the use of many stations together may lead to distortion of the results instead of amelioration the eventually existing correlation between Sun activity and the discharge of Danube river, for example (Jovanovic, 1995). These are the reasons why we use the data from only one station in analyses.

As a criterion for rating years according to its flow it is adopted that all years with average flow should be between 25 and 75% of total discharge, low flow from 75.1 to 95%,

[1] Period up to 2000 year is charged on the base of data from exchange with Romanian Hydro-meteorological institute.

very low flow 95.1-99% and catastrophic low flow 99.1-99.9%. Grading of wet years would be with similar rates; actually wet year would be in the range from 25 to 5.1%, very wet 5.0-1.1% and catastrophic wet from 1.0 up to 0.01% (Ocokoljic, 1994).

Table 1 Danube river discharge elements and solar activity parameters

Decades	Discharge m^3/s	Low flow	High flow	Flow Index	Extreme Index	Wolf's number	AA Index	Sunspot's areas	Lat of sunspots	Polar faculaes no.
1841-1850	5723	1	4	0,8	0,5	57,4	19,3	0,23		
1851-1860	5474	4	4	0,5	0,8	45,6	17,4	-0,09		
1861-1870	4758	5	1	0,2	0,6	53,2	19,9	0,01	-0,02	0,09
1871-1880	5645	2	4	0,7	0,6	40,6	13,6	-0,01	0,04	0,01
1881-1890	5246	3	1	0,3	0,4	35,2	15,9	-0,31	-0,06	0,04
1891-1900	5287	3	3	0,5	0,6	45,2	16,4	-0,17	-0,06	0,03
1901-1910	5244	3	1	0,3	0,4	36,4	13,2	0,05	-0,08	0,02
1911-1920	6019	2	5	0,7	0,7	41,1	16,0	-0,04	0,04	-0,05
1921-1930	5305	3	2	0,4	0,5	41,8	17,1	0,16	0,00	-0,16
1931-1940	5696	1	2	0,7	0,3	54,3	18,7	0,11	-0,01	-0,15
1941-1950	5151	4	3	0,4	0,7	73,6	22,6	0,07	0,00	-0,03
1951-1960	5458	0	1	1,0	0,1	94,5	25,9	0,12	0,06	-0,05
1961-1970	5855	1	4	0,8	0,5	60,1	19,6	0,46	0,10	0,04
1971-1980	5680	2	5	0,7	0,7	66,6	23,0	0,04	-0,02	0,00
1981-1990	5318	3	1	0,3	0,4	83,0	25,8	-0,13		0,11
1991-2000	5314	3	1	0,3	0,4	64,9	24,1			

Starting with the data provided by Ocokoljic, we created new data base in which we put together catastrophic low flow, very low flow and low flow years, on the one hand as well as very high flow, catastrophic high flow and high flow years on the other hand. This was done because the number of extreme years was very low (17). In this way, using the described methodology, all years are included according to the statistical criteria into the lower and higher quartiles.

This data base includes 38 low flow and 42 high flow years. The average flow (80) years are also included in these analyses.

Flow Index is presented, as a parameter of high flow domination in relation to low flow. While low flow and high flow clearly presented domination of anticyclone and cyclone types of weather thus average years are mixture of synoptic situation impacts. In our opinion flow index clearly shows a relative domination of high flow years, excluding average flow years from the calculation and thereby clearly underlines the synoptic causes of flow variability.

Moreover we take into the analyses the extreme index, as well. It presents total number of low flow and high flow years per decade. This parameter is opposite to the number of average flow years divided by 10. Using the extreme index we try to find out if there are some changes of frequencies of extreme discharge in the Danube flow variability.

In this paper we use extended time series of solar activity indices, which in fact is a database including some traditional indices of solar activity: sunspot areas[2], Wolf number[3],

[2] http://www.gao.spb.ru/database/esai/yr_aro.txt
[3] ftp://ftp.ngdc.noaa.gov/STP/SOLAR_DATA/SUNSPOT_NUMBERS/YEARLY

polar faculae numbers[4] (polar component), latitudes of sunspot[5] (as a parameter of north-south solar asymmetry) and AA Index[6] (as a proxy of the solar wind energy imparted to the magnetosphere).

Described data base with new discharge parameters is given in Table 1.

Results and discussion

Calculation of Pearson's correlation coefficient (R) between parameters of discharge and parameters of solar activity give the best results with Latitudes of sunspots in 4 of 5 discharge parameters (discharge, low flow, high flow, and flow index). The values of R are between 0.4 and 0.73. Only extreme index shows weak relation to solar activity (Table 2).

Table 2 Pearson's coefficient correlation

Pearson's correlation	**Wolf's number**	**AA Index**	**Sunspot's areas**	**Latitudes of sunspots**	**Polar faculaes no.**
Discharge	-0,04	-0,13	0,38	0,55	-0,36
Low flow	-0,30	-0,14	-0,49	-0,56	0,41
High flow	-0,19	-0,24	0,25	0,40	-0,15
Flow Index	0,30	0,11	**0,53**	**0,73**	-0,41
Extreme Index	-0,39	-0,31	-0,16	-0,08	0,18

Data for sunspot areas show constantly higher values of R for discharge parameters (excluding extreme index) then usually taking parameters such as Wolf's number and AA index. Connections between polar faculae numbers and discharge parameters are also showing better correlation for discharge, low flow and flow index then Wolf's number and AA index.

Table 3 Spearman coefficient correlation

Spearman correlation	**Wolf's number**	**AA Index**	**Sunspot's areas**	**Latitudes of sunspots**	**Polar faculaes no.**
Discharge	0,13	0,03	0,31	0,57	-0,34
Low flow	-0,20	-0,10	-0,51	-0,57	0,37
High flow	-0,06	-0,20	0,11	0,34	-0,32
Flow Index	0,28	0,12	0,50	**0,68**	-0,44
Extreme Index	-0,14	-0,18	-0,26	-0,01	-0,04

Excluding the extreme index, relations between Wolf's number and AA index with discharge parameters are mostly weaker than with other parameters. The conclusion therefore is that searching relation between Wolf's number and AA index and planet process is not always the best way for studying impact of solar activity. Weak relations might be the reason why some authors denied causal relation between solar activity changes and climate changes. Топлийски (2007) analyzes impact of solar activity on climate in Bulgaria by calculating correlation coefficients between Wolf's indices and main climate elements. It is established that the correlation between solar activity and climate in Bulgaria is not clearly

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[4] http://www.gao.spb.ru/database/esai/yr_pfs.txt
[5] http://www.gao.spb.ru/database/esai/yr_fio.txt
[6] http://www.gao.spb.ru/database/esai/aa_mod.txt

determined. It is obvious that in order to find out the relation between solar activity and climate changes we need more studies as well as great number of solar activity parameters.

The results of non-parametric tests such as Spearman (Table 3), Kendall Tau (Table 4), Gamma (Table 5), are similar to Pearson's coefficient correlation.

Table 4 Kendall Tau coefficient correlation

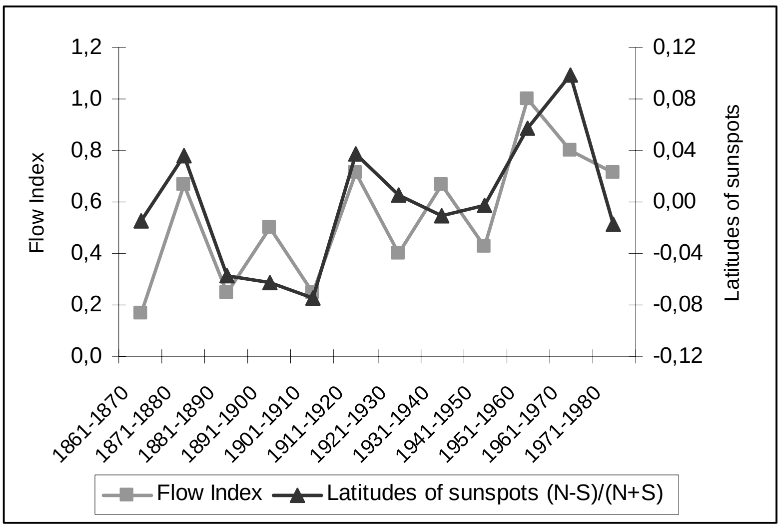
Kendall Tau correlation	**Wolf's number**	**AA Index**	**Sunspot's areas**	**Latitudes of sunspots**	**Polar faculaes no.**
Discharge	0,10	0,08	0,28	0,42	-0,23
Low flow	-0,13	-0,07	-0,37	**-0,46**	0,28
High flow	-0,04	-0,15	0,10	0,30	-0,23
Flow Index	0,23	0,12	0,37	**0,51**	-0,30
Extreme Index	-0,10	-0,12	-0,19	0,00	-0,08

Table 5 Gamma coefficient correlation

Gamma correlation	**Wolf's number**	**AA Index**	**Sunspot's areas**	**Latitudes of sunspots**	**Polar faculaes no.**
Discharge	0,10	0,08	0,28	0,42	-0,23
Low flow	-0,14	-0,08	-0,41	**-0,50**	0,31
High flow	-0,04	-0,17	0,12	0,32	-0,25
Flow Index	0,24	0,13	0,39	**0,52**	-0,32
Extreme Index	-0,10	-0,12	-0,20	0,00	-0,09

According to all calculation we have done in the paper it is obvious that the best correlation are between flow index and latitude of sunspots. It could be seen on the Figure 1.

Figure 1 Decadal changes of flow index and latitude of sunspots



Georgieva (2002)[7] has observed relation between long-term changes in atmospheric circulation, Earth rotation rate and north-south solar asymmetry. She claims that earlier studies show a relation between long-term changes in the Earth's rotation rate and the prevalence of zonal or meridional types of circulation. The results, however, have been confined to the 20th century and to the Northern hemisphere. In her paper she compares the long-term changes in the length of the day (LOD) and the temperature contrast between the equator and the pole in the Northern and the Southern hemispheres as an indirect measure for the zonality of the atmospheric circulation. She has found during the 20th century in the Northern hemisphere a high negative correlation between the rotation rate and the equator/pole temperature contrast, while during the 19th century the correlation has been positive. For the Southern hemisphere, the situation is opposite. The correlation changes itself when the North–South asymmetry of solar activity also changes its sign. The decadal changes in LOD are shown as having relation to the changes in the North–South asymmetry of solar equatorial rotation rate probably caused induced by planetary-driven changes in the angular momentum of the solar system.

On the other hand, Georgieva et al. (2000)[8] have explored solar activity, presented by North-South solar activity asymmetry and surface air temperature changes. They have found strong correlations between solar activity and surface air temperature for certain locations. The authors concluded that the sign of the correlation seems to be determined by the North-South solar asymmetry. Also they have found out that the phase of the stratospheric winds quasibiennial oscillations does not determine the sign of the correlation, but rather enhances or suppresses this influence.

The relation between parameters of solar activity and Danube River discharge elements is indirect and probably is in function through atmospheric circulation. Prohaska (1979) has investigated correlation dependences of middle and maximal annual discharge with characteristics of atmospheric circulation processes and solar radiation as well as methods of forecasting. His conclusion is that Danube River discharge variability has a more significant connection with Index of atmospheric circulation than the Index of solar radiation.

Conclusion

Investigating relation between solar activity and the discharge we decided to take hydrological gauge Orsova due to its homogenous conditions and its longest data base (from 1840). We have explored several discharge elements (low flow, high flow, extreme flow and flow index) in relation with several solar parameters (sunspot areas, Wolf numbers, polar faculae numbers, AA index and latitudes of sunspots). The most significant results we have come to are for flow index and latitudes of sunspots (R=0.73).

Complex mechanism of these relations is indirect and is in function through prevalence of zonal or meridional types of atmospheric circulation.

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ВЛАДАН ДУЦИЋ
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Р е з и м е

МОГУЋА ВЕЗА ИЗМЕЂУ КОЛЕБАЊА ПРОТИЦАЈА ДУНАВА И СУНЧЕВЕ АКТИВНОСТИ

Проблем веза сунчеве активности и процеса у географском омотачу одувек је привлачио пажњу истраживача. Релативно мале промене Соларне константе су камен спотицања у тим истраживањима. Поједини аутори, ипак, то објашњавају амплификацијом сунчевог сигнала у самој земљиној атмосфери. У прилог реалности тих веза иду и подаци за дуге периоде у којима је утврђена несумњива веза између сунчеве активности и хидрометеоролошких процеса.

У нашем истраживању користили смо податке са хидролошке станице Оршава како због дужине низа података (од 1840), тако и због хомогених услова мерења. Испитивали смо више елемената протицаја (протицај, мале воде, високе воде, индекс водности и индекс екстремности) са параметрима сунчеве активности (Волфов број, АА индекс, површина под сунчевим пегама, соларна хемисферна асиметрија сунчевих пега и број поларних факула).

Најбоље везе су утврђене између индекса водности и соларне хемисферне асиметрије сунчевих пега (R=0.73) што је статистички значајно на нивоу од 0,05. Механизам тих веза је веома сложен и одвија се, вероватно, преко смена меридионалних и зоналних типова циркулације земљине атмосфере.