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Variations of Mean Daily Discharge of Danube River at 16 Stations

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Abstract. The river discharge is the main source of freshwater for large surface areas. Its deep minima are connected with drought events, while its maxima – with floods. The time series of river discharge consist of significant seasonal variations, modulated by long-term oscillations. The seasonal, interannual and decadal cycles of Danube river discharge are studied by time series of mean daily data from 16 stations. The data from Orsova station started in 1840. Three stations started in 1900, and the rest – in 20s of the last century. Time series of maximal discharge and seasonal amplitude are created. Their variations in narrow frequency bands are analyzed by the Method of Partial Fourier Approximation (PFA) and compared with the corresponding cycles of the solar activity. The amplitudes of seasonal harmonics from the PFA are compared for all stations. The time delay of the 11-year solar signals to the reaction of river discharge at used stations, are determined from the phase differences. Possible forecast of periods with maximal river discharge on the base of solar cycles is discussed.

Keywords: river discharge, seasonal variations, solar cycles

1. Introduction

The global warming produces significant climate change in last decades, in particular expressed by many floods on territory of European Union. The reason of these floods is the increase of global water circulation, due to warmer oceans and enhanced evaporation, followed by heavy rains and critical values of river level and discharges. The data of Danube river level, measured at 40 main water gauge stations are useful to study and analyze the maximal river discharge variations. The comparison between solar activity and maximal river discharge may discover common solar and river discharge cycles, whose cumulative effects will improve interannual and decadal prediction.

2. Data and Methods

The time series of Danube river daily discharge are prepared in The Global Runoff Data Centre (GRDC), 56068 Koblenz, Germany. The stations with time series longer than 70 years are shown in Table 1 and their location - in Fig.1. The variations of daily discharge of Danube river are presented in Fig.2.

Table 1. Danube stations with long time series of data from The GRDC.

No	Station	Time span	Duration [years]
1	Kirchen-Hausen	1922.8-2009.0	86.2
2	Hundersingen	1929.8-2017.0	87.2
3	Berg	1929.8-2017.0	87.2
4	Dillingen	1923.8-2017.0	93.2
5	Ingolstadt	1922.8-2009.0	86.2
6	Oberndorf	1929.8-2017.0	87.2
7	Pfelling	1925.8-2017.0	91.2
8	Hofkirchen	1900.8-2017.0	116.2
9	Achleiten	1900.8-2016.0	115.2
10	Bratislava	1900.8-2018.0	117.2
11	Nagymaros	1930.8-2000.0	69.2
12	Mohach	1930.8-2000.0	69.2
13	Orsova	1840.0-1991.0	151.0
14	Zimnicea	1931.0-2011.0	80.0
15	Harsova	1931.0-2011.0	80.0
16	Cetal Izmail	1931.0-2011.0	80.0

The daily and annual values of Sun Spot Numbers (SSN) are provided by the Royal Observatory of Belgium, Brussels. The time series spectra are calculated by the Fast Fourier Transform (FFT). The time series of oscillations with a given frequency are calculated by the Method of Partial Fourier Approximation (PFA), whose details are described in (Chapanov et al., 2015).

3. Time series spectra

The FFT spectra of river discharges at Danube stations are shown in Fig.3. The spectra are divided into 4 diferent group, according the amplitude level of interannual oscillations: below 5 m^3/s – stations Kirchen-Hausen, Hundersingen, and Berg; below 100 m^3/s – stations Dillingen, Ingolstadt, Oberndorf, Pfelling, Hofkirchen, and Achleiten; below 200 m^3/s – stations Bratislava, Nagymaros, and Mohach; and below 500 m^3/s – stations Orsova, Zimnicea, Harsova, and Cetal Izmail.

Figure 1. Map of Danube basin and stations location.

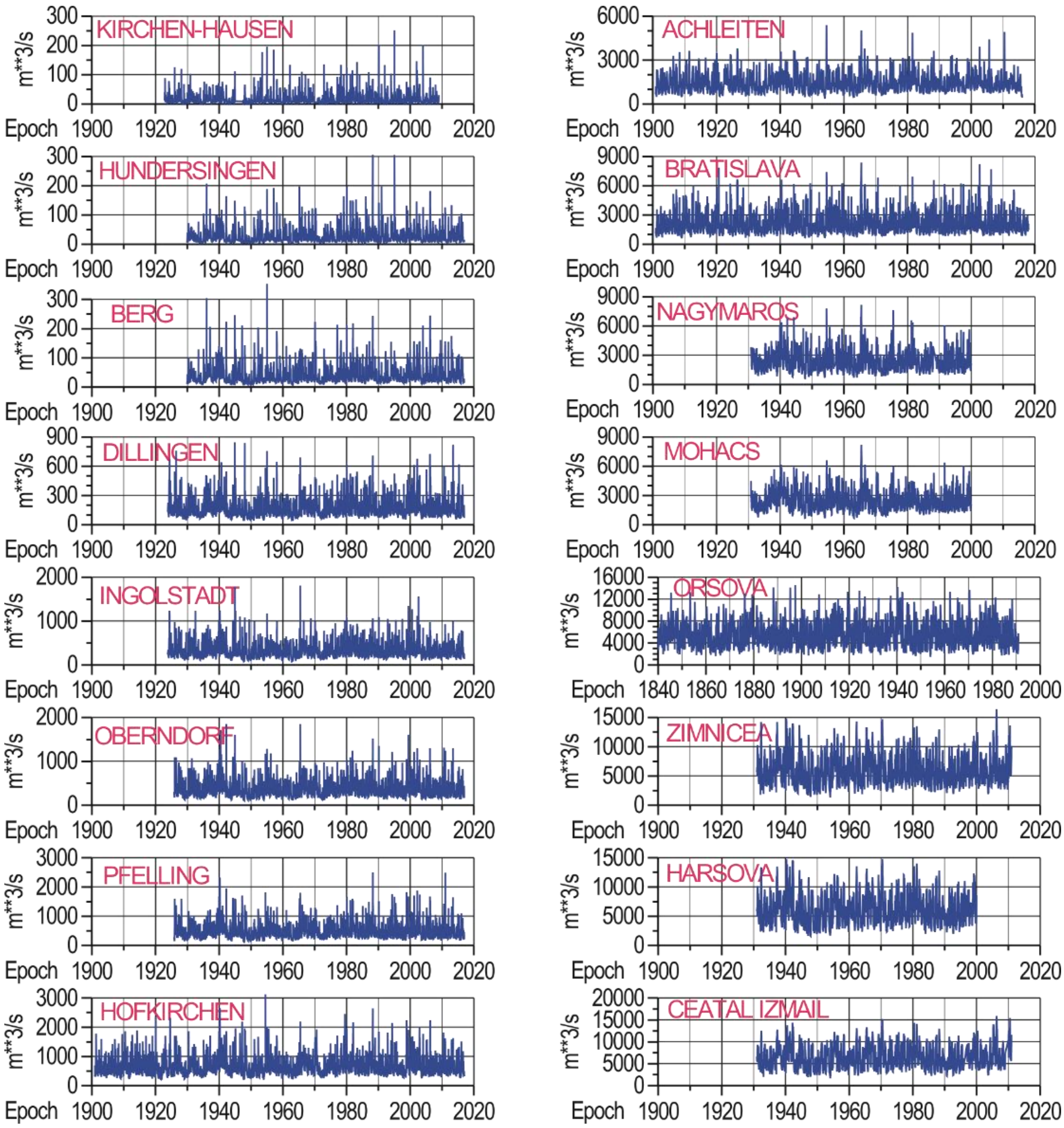

Figure 2. Time series of daily discharge of Danube stations.

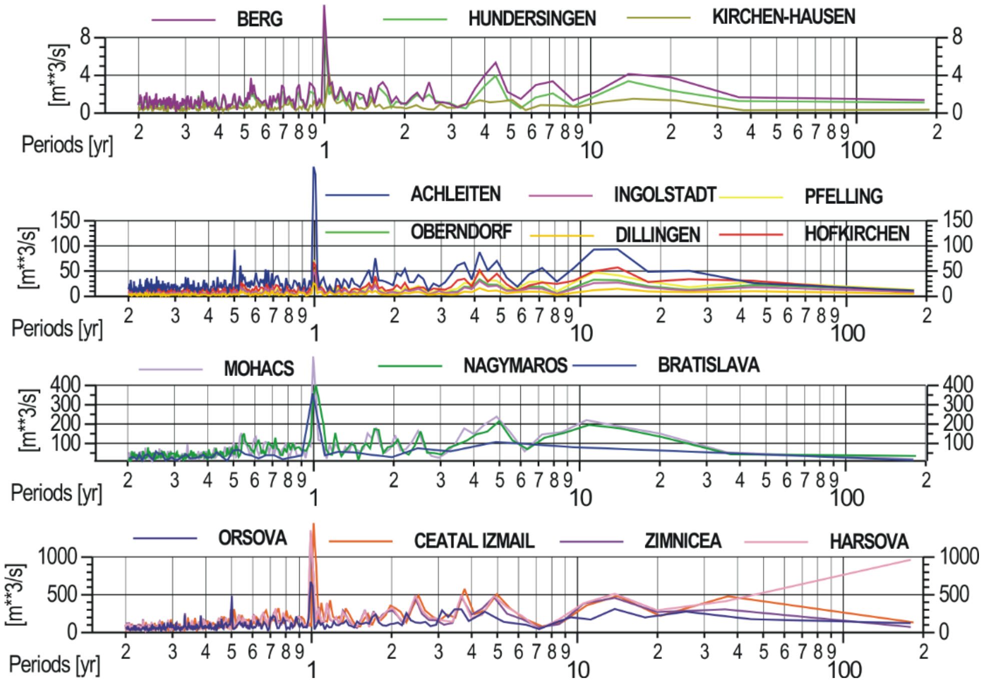

Figure 3. FFT spectra of daily discharge of Danube stations.

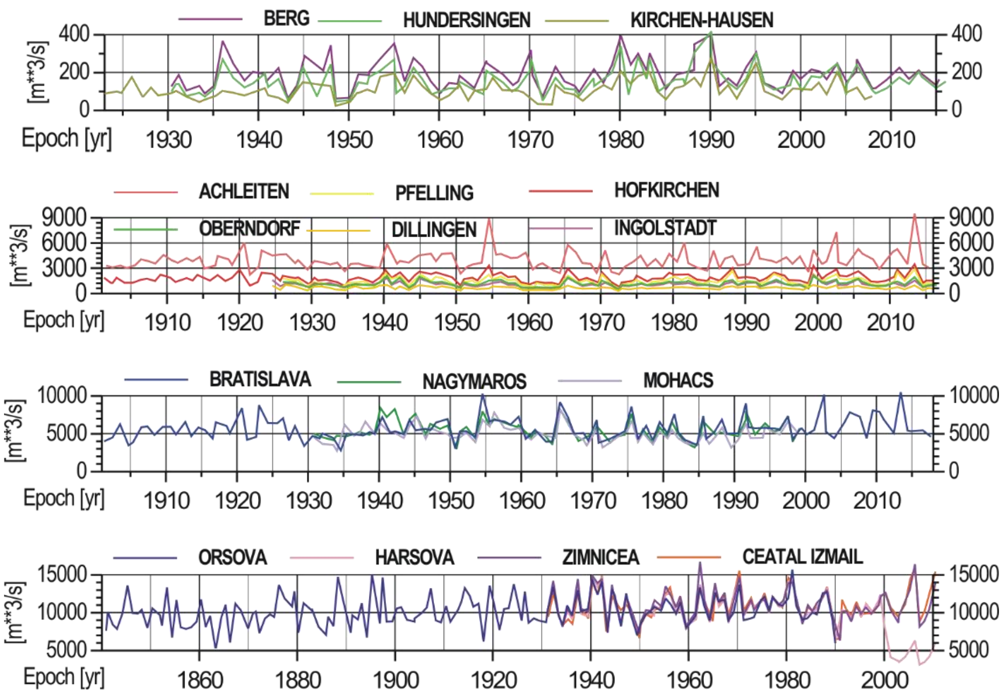

Figure 4. Seasonal variations of Danube discharge.

4. Seasonal variations and floods

The seasonal variations of Danube discharge at 16 gauge stations are determined as difference between the maximal and minimal value of river discharge during a calendar year (Fig.4). Their values are divided into 4 grouped, similar to time series spectra. Most of these time series are highly correlated in the frame of their groups. It is remarkable that the first 3 stations stations (Kirchen-Hausen, Hundersingen, and Berg) have very low level of mean discharge between 13 and 38 m^3/s, while their level of maximal daily discharge is 250-350 m^3/s, which is enough to cause floods. Other stations periodically have discharges, whose level is many times larger than their mean values. A major part of these maxima are connected with floods, so the model of their oscllations may predict flood probability in next decades.

5. Solar signals in maximal discharge

The variations of SSN are compared with the 11-year cycles of Danube stations discharge in Fig.5. The most of river discharge data is collected in last century. For the period 1902 – 2008 we have 10 solar cycles, whose mean duration is approximately 10.6 years. The 10.6-year oscillations of Danube discharge are presented in Fig.5, where all discharge maxima synchronously point out to the solar minima. This synchronization is achieved by proper shifts of x-axes to the left from the initial epoch of SSN variations. These shifts mark the delay of river reaction to the solar signals in the frame of 0-3 years with an exception of station Zimnicea.

This result means that during solar maxima, the increased local evaporation leads to the minima of 11-year discharges and vice versa. Similar results are obtained in (Chapanov et al., 2015), where the Danube monthly discharge at station Drobeta - Turnu Severin (Orsova) is synchronized with the solar oscillations with 11-, 13-, 22- and 45-year periods. Other solar harmonics with periods 4-6; 7-9; 16 and 23-32 years are potential driver of interannual and decadal oscillations of Danube discharge.

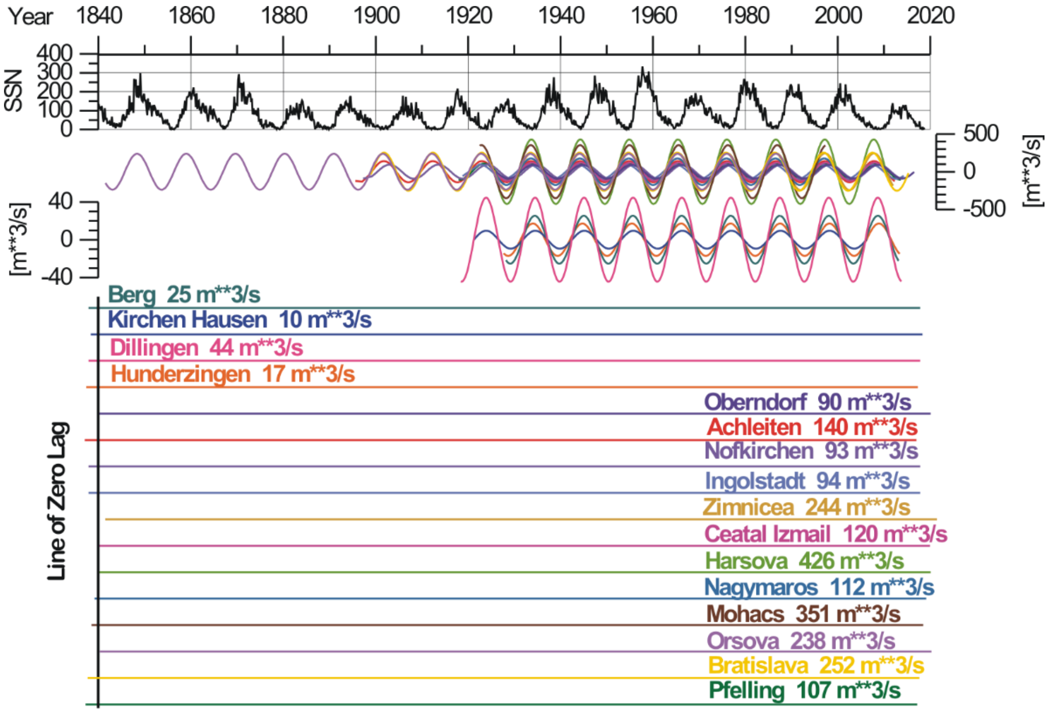

Figure 5. Comparison of Sun Spot Numbers (SSN) and 10.6-year oscillations of Danube station discharge. The left y-axe of discharge covers stations with small amplitude below 50 m^3/s. The right y-axe of discharge represent stations, whose 10.6-year amplitudes are between 90 and 426 m^3/s. The initial points of station x-axes in the left of the Line of Zero Lag determines the time delay of river reaction to the solar signals.

6. Conclusions

The time series of daily discharge of Danube river, measured in various gauge stations since 1840, give good opportunity to study the variations of maximal discharges and their connection with floods. The spectra of river discharge at Danube gauge stations are almost coherent inside 4 groups, separated by the level of their oscillations: stations Kirchen-Hausen, Hundersingen, and Berg – (a); Dillingen, Ingolstadt, Oberndorf, Pfelling, Hofkirchen, and Achleiten – (b); Bratislava, Nagymaros, and Mohach –(c); Orsova, Zimnicea, Harsova, and Cetal Izmail – (d). The seasonal variations of river discharge are highly correlated inside these groups, so a common set of oscillations from each group may predict maximal discharge in next decades and flood probability. The solar influence on maximal Danube daily discharge is manifested by synchronous 10.6-year cycles of station discharge and sunspot numbers, where the river reactions are delayed to the solar signals in the frame of 0-3 years. The models of solar influence on maximal river discharge with all solar harmonics may significantly improve the accuracy of flood forecasts.

Acknowledgments

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