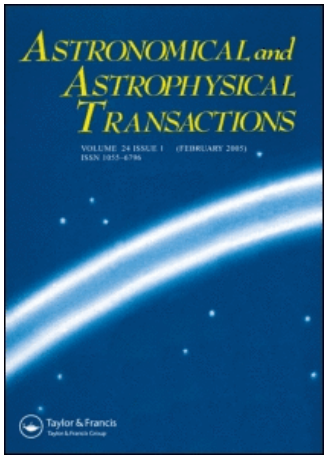

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THE INFLUENCE OF SOLAR ACTIVITY ON THE DANUBE RIVER FLOW, II

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Maximum river flow in the Danube river, at a station, may follow, after a 7 year lag, the maximum total area of complete sunspots, as well as their parts (umbrae and penumbrae), and total areas of faculae. The influence on *minimal river flow* is significant only for total penumbrae areas with a 7 year lag.

KEY WORDS Danube river, faculae total areas, maximal river flow, minimal river flow, penumbrae total areas, sunspot areas, umbrae total areas

1 ORIGINS

Some natural phenomena may be predicted if we suppose that they have an oscillatory character. Sometimes this fact is obvious, at other times this periodicity is hidden and we must keep trying to discover the eventual overlap of vibrations with different amplitudes and periods with displacements in phase. We are familiar with cycles of Solar activity and we know, from experience, that the quantities of water in rivers also fluctuate.

Because of the practical applications it would be of enormous benefit if we could, having a time series of past values of Danube river flow, measured at a station, as well as a time series of Solar activity parameters, and discovering the existing influence of the second on the first series, preview eventual floods or scarcity of water in river beds. In that sense we may use some statistical or probabilistical methods.

So some years ago, I decided to look for existing interactions between the quantities mentioned.

In my first set of papers (Jovanovic, 1986, 1987, 1989, 1990, 1991a) I investigated the influence of total sunspot areas on *river level.* Then, I turned my attention to a better parameter (which shows, in a more realistic way, the abundance or lack of water running in river beds). (Jovanović, 1991b, 1993a, 1993b, 1993c, 1993d, 1994a, 1994b, 1995a, 1995b).

Following suggestive, in Pecker (1987), that the utilization of data, measured at numerous stations, simultaneously, for a solar-terrestrial influence study, may lead to distortion rather than improvement of correlation, I used only the data collected at one station at any one time.

2 DATA AND DATA PROCESSING

The following data notations have been used.

Time series for solar activity (yearly means):

GRCS - TOTAL SUNSPOT AREAS, expressed in millionth parts of the visible solar hemisphere, corrected for sphericity (MPOTVSH.CFS) published in Royal Greenwich Observatory.

GRFS - TOTAL FACULAE AREAS, expressed in MPOTVSH.CFS published in Royal Greenwich Observatory.

GRPS - TOTAL SUNSPOT PENUMBRAE AREAS, expressed in MPOTVSH.CFS published in Royal Greenwich Observatory.

GRUS - TOTAL SUNSPOT UMBRAE AREAS, expressed in MPOTVSH.CFS published in Royal Greenwich Observatory.

Time series for DANUBE RIVER FLOW (yearly means):

BEQN - MINIMUM RIVER FLOW ($m^3\ s^{-1}$).

BEQS - MEAN RIVER FLOW ($m^3\ s^{-1}$).

BEQV - MAXIMUM RIVER FLOW ($m^3\ s^{-1}$).

At my disposal I had all GR series from 1874 to 1982 (daily observations), and river flow series from 1931 to 1990 (monthly means).

Because of the computer processing program I took the GR time series between 1923 and 1982, and the river flow data between 1931 and 1990 (Figure 1).

Following the spectral decomposition theorem, which states that the energy, or variance, of any time series can be broken down into the contribution of statistically independent oscillations of different frequencies (periods), I constructed periodograms for the series mentioned before. Each peak in the spectral periodicity function graph stands for a harmonic. The most outstanding one points to the major frequency (period), and the next to higher harmonics, so-called overtones.

Supposing that we have two stationary time series, x_t, and y_t, and that we wish to assess the extent to which we can use past x_t to predict y_t, cross-correlations are used as a criterion of evaluation. If the processes are zero mean, we define then, by means of cross-correlations the expected value of y_t.

The next step was the construction of corresponding periodograms for the GR series, as well as for the BE series. Search for paired independent oscillations with the same frequencies (periods) has been carried out.

For practical reasons I took a 42 year-long time series section and looked for the highest cross-correlation values, for maximum and minimum river flow due to solar influence.

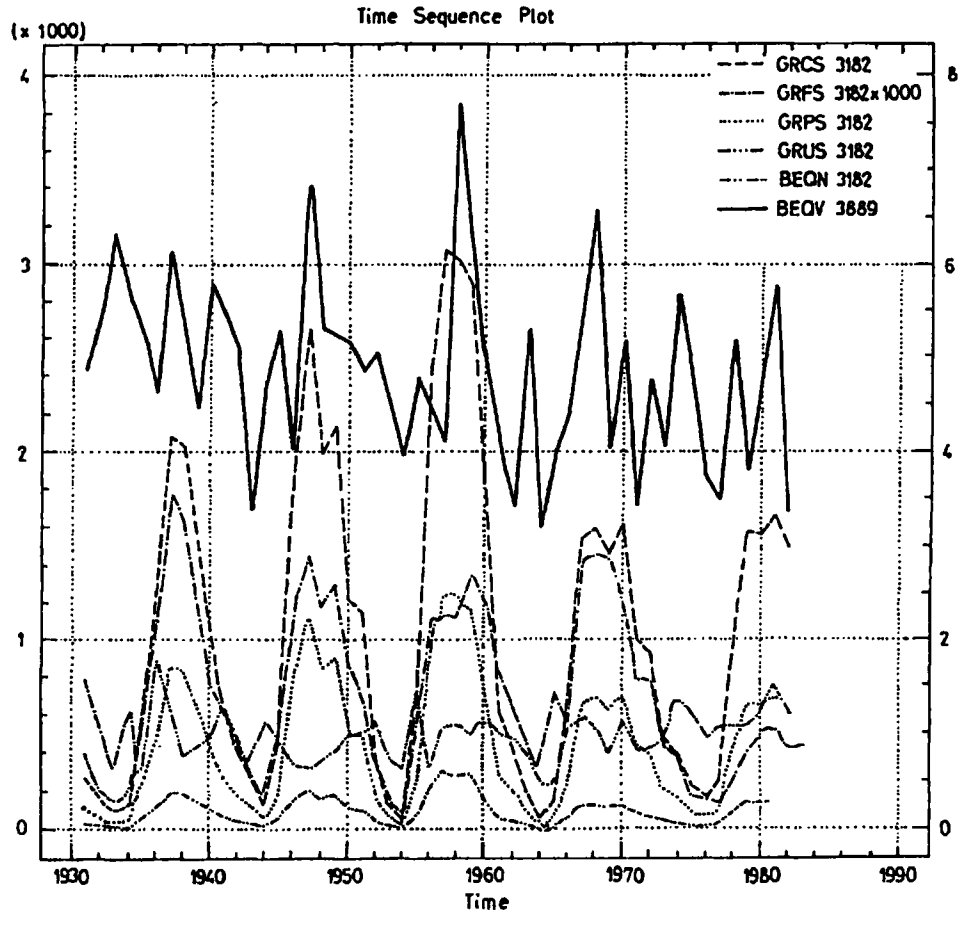

Figure 1

In conclusion, Fourier series residuals have been calculated. A comparison of frequency histograms with normal distribution function has been made. Finally, the Chi-square test has been applied to all cases.

3 RESULTS

The periodogram for GRCS2382, TOTAL SUNSPOT AREAS, shows that there are 10 independent fundamental oscillations. Six of them have their responses in six of 12 independent frequencies for *maximum river flow*, BEQV3190. The first overtone of the BEQV series corresponds to the sixth overtone of the GRCS series, the second to the first, the third to the major frequency, the fourth to the fifth, the

fifth to the second, and the eleventh overtone of BEQV is response to the seventh overtone of the GRCS series (Jovanović, 1993a).

The major frequency of MAXIMUM RIVER FLOW, BEQV3190 series has a period of 3.75 years, the first overtone of 2.31 years, the second of 59.99 years, the third of 10 years, the fourth of 4.29 years, the fifth of 5.46 years, the sixth of 2.61 years, the seventh of 3.33 years, the eighth of 20 years, the ninth of 6.67 years, the tenth of 2.86 years, and the eleventh of 2.07 years.

The greatest value for cross-correlations, GRCS3182 → BEQV3182, corresponds to the lag of 7 years, meaning that, in the case of GRCS versus BEQV *maximum river flow may follow, after 7 years lag, the maximum total area of sunspots.*

A Chi-square test for BEQV's six of 12 independent frequencies gives the value of 1.83183 with 2 degrees of freedom and a significance level of 0.40015 (Jovanović, 1994a).

The major frequency of the BEQN, MINIMUM RIVER FLOW series has a period of 7.50 years, the first overtone of 2.61 years, the second of 3.70 years, the third of 5 years, the fourth of 59.99 years, the fifth of 3.33 years, the sixth of 3.75 years, the seventh of 4.29 years, the eighth of 20 years, the ninth of 2.07 years, the tenth of 12.00 years, and the eleventh overtone of the BEQN has a period of 5.99 years (Jovanović, 1993a).

Three of 12 independent fundamental oscillations of the BEQN3190 series for *minimum river flow*, are responses to three of 10 fundamental independent oscillations which constitute the GRCS series. The fourth overtone of the BEQN series corresponds to the first overtone of GRCS series, the seventh to the fifth, and the ninth overtone of the BEQN series responds to the seventh overtone of the GRCS series.

The maximal value for cross-correlations, GRCS3182 → BEQN3182, stands for a lag of 18 years, so that we may conclude that, in the case of GRCS versus BEQN, *minimum river flow may follow, after 18 years lag, the maximum total area of sunspots.*

A Chi-square test for BEQN's three of 12 independent frequencies gives the value of 3.91618 with 2 degrees of freedom and a significance level of 0.141128. Therefore, it is not worth discussing.

A periodogram for TOTAL PENUMBRAE AREAS, GRPS2382, shows that there are 10 independent fundamental oscillations. Five of them have their responses in five of 12 independent frequencies for *maximum river flow*, BEQV3190. The major frequency of the first has its response in the third overtone of the second series, the first overtone in the second overtone, the fifth in the fourth, the sixth in the first, and the seventh overtone of the GRPS series in the eleventh overtone of the BEQV series.

The greatest value for cross-correlations, GRPS3182 → BEQV3182, corresponds to the lag of 7 years, that is, in the case of GRPS versus BEQV, *maximum river flow may follow, after 7 years lag, the maximum total area of sunspot penumbrae.*

A Chi-square test for BEQV's five of 12 independent frequencies gives the value of 0.350805 with 1 degree of freedom and a significance level of 0.553658.

The series for *minimum river flow*, BEQN3190, incorporates four independent fundamental oscillations corresponding to four fundamental independent oscillations of the series GRPS2382. The third overtone of the BEQN series is the response to the second overtone of the GRPS series, the fourth to the first, the seventh to the fifth, and the ninth overtone of the BEQN series is the reponse to the seventh overtone of the GRPS series.

According to cross-correlations, GRPS3182 → BEQN3182, the maximum positive value stands for a lag of 7 years, and the most negative value for a lag of 5 years. So we may say that *minimum river flow may follow, after 7 years lag, the maximum total area of sunspot penumbrae.*

It is remarkable that the Chi-square test, GRPS versus BEQN, gives for four independent frequencies the value of 1.07463 with 2 degrees of freedom and a significance level of 0.585315!

The periodogram for TOTAL UMBRAE AREAS, GRUS2382, has 12 independent fundamental frequencies. To seven of them correspond *seven* independent fundamental frequencies of the BEQV3190 series for *maximum river flow.* The major frequency of the GRUS has its response in the third overtone of the BEQV series, the first overtone in the second overtone, the third in the eighth, the fourth in the fifth, the eighth in the fourth, the tenth in the first, and the eleventh overtone of the GRUS series has its response in the eleventh overtone of the BEQV series (Jovanović, 1994b).

The maximum value for cross-correlations, GRUS3182 → BEQV3182, stands for the lag of 7 years, meaning that, in the case of GRUS versus BEQV, *maximum river flow may follow, after 7 years lag, the maximum total area of sunspot umbrae.*

The confirmation of this conclusion is not very persuasive because the Chi-square test gives the value of 1.11157 with 1 degree of freedom and a significance level of 0.29174.

Five of 12 independent fundamental oscillations of the *minimum river flow*, BEQN3190, match to five fundamental independent oscillations of the GRUS2382 series. To the second overtone of the GRUS series the major frequency of the BEQN series corresponds, to the first overtone corresponds the fourth overtone, to the eighth the seventh, to the third the eighth, and to the eleventh of the GRUS series corresponds the ninth overtone of the BEQN series.

Cross-correlations, GRUS3182 → BEQN3182, show that the greatest positive value is the lag of 22 years, and the most negative value is the lag of 5 years. So we may say that minimum river flow may follow, after 22 years lag, the maximum total area of sunspot umbrae.

However, the Chi-square for five of 12 independent frequencies of the BEQN series gives the value of 1.38387 with 1 degree of freedom and a significance level of 0.239444 (Jovanović, 1994b).

The periodogram for GRFS2382, TOTAL AREA OF FACULAE series, has 10 independent fundamental frequencies. Seven of them have their responses in seven independent fundamental frequencies of *maximum river flow series*, BEQV3190. The major frequency of GRFS has its response in the third overtone of the BEQV series, the third overtone in the fourth, the fifth in the major frequency, the sixth

in the seventh, the seventh in the sixth, the eighth in the eleventh, and the ninth overtone of the GRFS has its response in the first overtone of the BEQV series (Jovanović, 1995a).

The maximum value for cross-correlations, GRFS3182 → BEQV3182, stands for the lag of 7 years, so we may conclude that, in the case of GRFS versus BEQV, *maximum river flow may follow, after 7 years lag, the maximum total area of the faculae.*

The Chi-square for five of BEQV's seven of 12 independent fundamental frequencies gives the value of 0.600969 with 1 degree of freedom and a significance level of 0.438280.

Seven of 10 independent fundamental oscillations of the GRFS2382 series have their responses in seven of 12 independent fundamental frequencies for *minimum river flow*, BEQN3190. The first overtone of the BEQN series corresponds to the seventh overtone of the GRFS series, the third to the fourth, the fifth to the sixth, the sixth to the fifth, the seventh to the third, the ninth to the eighth, and the eleventh overtone of the BEQN series to the second overtone of the GRFS series.

The maximum positive value for cross-correlations, GRFS3182 → BEQN3182, stands for a lag of 19 years, and the most negative value stands for a lag of 2 years, meaning that, in the case GRFS versus BEQN, minimum river flow may occur, after 19 years lag concerning the maximum total area of faculae.

A Chi-square test for seven of 12 independent frequencies of the BEQN series gives the value of 1.62331 with 1 degree of freedom and a significance level of 0.202631. This is a result that can be reglected.

4 CONCLUSION

The spectral decomposition theorem followed by cross-correlation calculations, based on Chi-square tests, enables us to say that the MAXIMUM RIVER FLOW in the Danube river, at a station (expressed in $m^3\ s^{-1}$) may follow, after 7 years lag, the maximum total areas of complete sunspots, as well as their parts (umbrae and penumbrae), and total areas of faculae all expressed in millionth parts of the visible solar hemisphere, corrected for sphericity. The influence on MINIMUM RIVER FLOW is significant only for total penumbrae area with a 7 years lag again.

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