POSSIBLE CORRELATION BETWEEN SOLAR AND VOLCANIC ACTIVITY IN A LONG-TERM SCALE

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ABSTRACT

Volcanic activity on the Earth is described by special annual indices available since 1500. These indices have been compared with annual sunspot numbers. Volcanic activity displays no 11-yr periodicity. Using 21-yr running averages a striking similarity between these two time series is clearly seen. Volcanic activity is generally lower in periods of prolonged maxima of solar activity and higher in periods of prolonged solar minima. There is also a similarity between the spectra of these two series in the long-period range. Main peaks are located in the same periods in both series (200–215 yr, 100–105 yr, 80–90 yr). The influence of volcanic activity on the climate is indubitable. Annual means of surface air temperature display similar long-term periodicity as the volcanic activity.

1. INTRODUCTION

There are many attempts to find and explain influences of the Sun on the climate on the Earth. In the long-term scale the correlations are relatively good. Different parameters have been used for these comparisons: solar activity in general with its long-term periodicity, solar irradiance [1–4], or the length of solar cycles [5–7], but not confirmed by [8]. In the short-term scale the correlation is poor because solar activity displays pronounced 11-yr variation, which has no response in climatic changes. The unresolved problem is why long-term variations in solar activity have a response in climatic variations and the 11-yr variation has not. Therefore some doubts concerning the existence of solar forcing may exist.

Solar forcing is not the only external factor, which can influence the climate on the Earth. There is an indubitable connection between the content of different gasses and dust in the Earth's atmosphere and climatic change [9, 10]. A part of this content has an anthropogenic origin, increasing in the recent time, and another part comes from natural sources. Volcanic eruptions are the most important natural source. They bring big amount of dust and gas into the atmosphere (especially into the higher atmosphere) and it affects the climate on the Earth for a time. After large volcanic eruptions a decrease of the average surface temperature should follow and it is really observed, lasting usually 1–3 years. In the long-term scale, in the period when volcanic eruptions occur more often, a prolonged minimum of the air temperature is being observed. Some authors tried to combine solar and volcanic influences and green-house warming in the recent times [11, 12] and arrived to relatively good agreement with long-term climatic changes.

However, solar activity and volcanic activity seem not to be quite independent quantities, as pointed out by [13, 14]. There are some long-term periodicities similar in both time series. This brings difficulties to distinguish between solar and volcanic influences. The correlation of climatic change with one of these activities brings automatically non-zero correlation with the other activity. In the short-term scale the similarity between solar and volcanic activity is not good. In this paper we shall restrict ourselves on looking for correlations in the long-term scale.

2. DATA AND PROCESSING

Sunspot numbers have been introduced by Wolf and calculated by him since 1849 for each day. Later to the past, only monthly means have been calculated since 1749, and annual means have been guessed since 1610 and later since 1500 [15]. Letfus [16] suggested a revision of given annual values for 1500–1700 using more accurate methods of interpolation. The accuracy of the determined sunspot numbers generally decreases when going to the past. The inaccuracy is important in short-term scale: positions of maxima and minima may differ by ±1 year, the value in the maximum is given with a considerable error etc. But in the long-term scale the accuracy can be taken as satisfactory. Sunspot numbers are available for 1500–2002.

Volcanic activity can be described by different annual indices [17]. These indices have been calculated from indirect observations. In this paper only AI (acidity indices) will be used. Their values depend on acidity of layers in glaciers in Greenland, i.e., on the content of acid aerosols in these layers. These aerosols rise from the SO_2, which is ejected during volcanic eruptions, and they fall down together with atmospheric precipitation in the time when the appropriate layer of glacier is being created. There are also modifications of AI indices – AI1 and AI2 – which take into account

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only aerosols from eruptions located in selected geographic latitudes. But their long-term changes do not differ from those of the AI indices and therefore they will not be processed here. Other indices given also in [17], as e. g. DVI (dust veil index), seem not to be suitable because they differ from zero only in years after big volcanic explosions. All these volcanic indices are available for 1500–1972.

3. RESULTS

The most pronounced variation in sunspot numbers is the 11-yr periodicity creating a series of 11-yr cycles. The length and especially the height of the individual cycles vary considerably so that some regular long-term changes can be seen (Fig. 1). This long-term change is more distinct when running averages instead of the original values have been used. For calculation of these averages the interval of 21 yr has been used because this choice ensures that the 11-yr variation fully disappears.

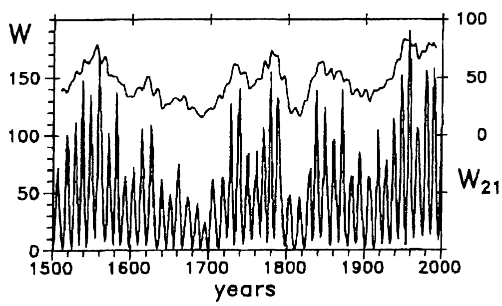

Fig. 1. The course of annual sunspot numbers during five centuries (bottom, left-hand scale) and running averages in the 21-yr interval of the same series (top, right-hand scale).

There is no (or very weak) 11-yr periodicity in the volcanic activity indices. They display only some non-periodical short-term variations. Sometimes, after big volcanic eruptions, they reach much higher values for 1-2 years. Therefore a smoothing is necessary for these data too. Running averages have been applied with the same interval as in the case of sunspot numbers. After this procedure long-term variations and periodicities are clearly seen. These variations for both solar and volcanic activity are shown in Fig. 2. A striking similarity between these curves is clear. Prolonged maxima of solar activity correspond to prolonged minima of volcanic activity, and *vice versa.* This regularity is more pronounced in the last three centuries, probably due to some uncertainty in determining accurate values of the indices in 16th and 17th centuries. The correlation coefficient between these two quantities is –0.38, for data without smoothing it would be only –0.07 due to the lack of the 11-yr periodicity in volcanic data.

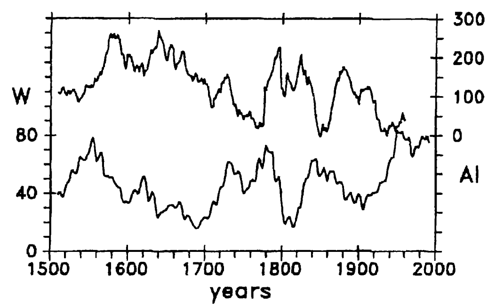

Fig. 2. The smoothed course of annual sunspot numbers (bottom, left-hand scale) and volcanic AI indices (top, right-hand scale).

Another method for suppressing all short-period variations is the filtration within an appropriate band-pass filter. We restricted ourselves on periods between 40 and 600 years. The lower limit is sufficiently far from periods connected with solar cycles and the upper limit is a little behind periods, which can be determined reliably. After this procedure additive constants are removed and filtered values are distributed symmetrically around zero. Filtered curves in Fig. 3 render nearly the same information as those in Fig 2, they are only more smooth. The correlation coefficient between these two curves is –0.50. Solar activity was high and volcanic activity was low in second half of the 20th century. In future decades a long-term decrease of solar activity is being expected and volcanic activity will probably increase in the same time.

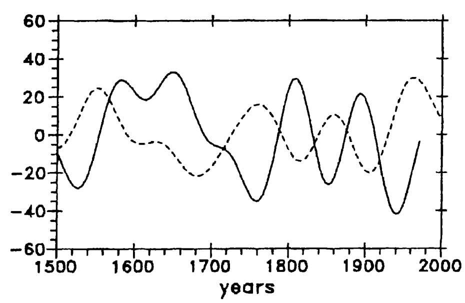

Fig. 3. The course of volcanic AI indices (solid) and annual sunspot numbers (dashed), both series filtered using band-pass filter within periods of 40 – 600 years.

The similarity of periodicity in both data series reflects itself also in spectra (Fig. 4). Peaks in longer periods lie nearly exactly in the same position in both spectra, only their relative height may differ a little. The most significant peaks exceed the 95% confidence level in both spectra. For periods shorter than 100 yr the similarity is not so precise. In general, peaks in periods

200 yr and less are higher in spectra of sunspot numbers than in spectra of volcanic indices.

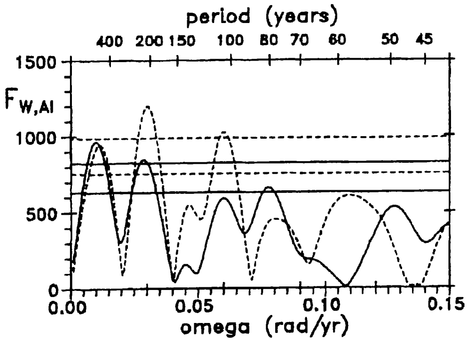

Fig. 4. The spectra of volcanic AI indices (solid) and annual sunspot numbers (dashed). Horizontal lines show the 95% and 99% confidence levels for the appropriate spectra.

Spectra in Fig. 4 were computed from the whole interval for which the original data are available though a little different for both series used. Unfortunately, spectrum of observed surface air temperature cannot be added because the data are available only for much shorter interval. The air temperature has been observed in Prague-Klementinum since 1771 [18] and the observation continues till now. Therefore all spectra were computed once more for the interval 1773–1972, i. e., 200 years, which is the period for which all data are available. The correlation between the course of solar and volcanic activity is better in the selected interval than in the whole interval where the data are available: the coefficient is –0.41 for smoothed data using 21-yr running averages and –0.67 for filtered data. All spectra are plotted together in Fig. 5. Using this shorter interval the peak in the period of 400 yr cannot be determined and peaks only in periods around 200 and 100 years take place. Both peaks lie nearly in the same position in all three spectra. Some of them, however, do not reach the 99% confidence level. The similarity between spectra of solar and volcanic activities is better than between the spectrum of air temperature and any other spectrum.

As to the phase, prolonged maxima of surface air temperature correspond to prolonged maxima of solar activity and minima of volcanic activity. This agrees with the explanation that volcanic dust and gasses cause a decrease of the observed surface air temperature. Due to lower content of this dust during prolonged minima of volcanic activity the temperature is higher. Because the increase of volcanic activity is being expected in the next decades, a small decrease in the air temperature should follow. This would partly compensate the rapid temperature increase which is done by anthropogenic factors.

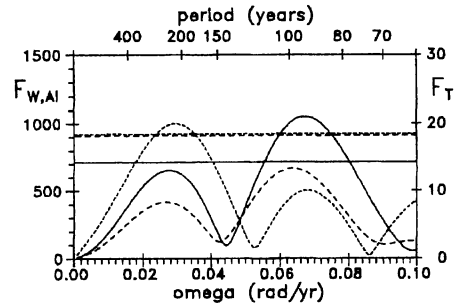

Fig. 5. The spectra of volcanic AI indices (solid, left-hand scale), annual sunspot numbers (long dashed, left-hand scale) and surface air temperature in Prague (short dashed, right-hand scale) for 1773–1972 (200 years). Horizontal lines show the 99% confidence level for the appropriate spectra.

4. CONCLUSIONS

The narrow similarity between solar and volcanic activity in the long-term scale suggests two quite different possible consequences:

a. Solar activity governs the volcanic activity on the Earth in long-term scale. Volcanic activity is usually higher in periods of prolonged minima of solar activity and *vice versa.* However, the mechanism of this forcing is not known. Perhaps geomagnetic activity mediates solar influences (unfortunately, series of these data are too short). If it will be confirmed in the future, then solar influences on the climate could be considered as being mediated by the volcanic activity, creating a chain: solar activity – (geomagnetic activity) – volcanic activity – climate changes. Direct solar influence on climatic changes is, of course, not excluded. But it is difficult to distinguish what part of these changes is mediated by volcanic activity and what part is direct solar influence. It would be also necessary to explain why this chain does not work in short-term scale.

b. The similarity of the long-term course of solar and volcanic activity is accidental and is pronounced only in the last few centuries. Then long-term natural climatic changes would be caused only by long-term changes of volcanic activity. The role of solar activity would be in this case only apparent due to the accidentally similar course of both activities during the last five centuries. Nevertheless, some small direct solar influence is not excluded. In this case no similarity in short-term scale can be expected and it is not necessary to look for an explanation why it is not observed.

These two different conclusions mean that the investigation of solar, volcanic and climatic changes together in a considerably longer period (at least one millenium) is very desirable.

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