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DO WE LIVE IN THE GRAND MINIMUM OF THE SOLAR ACTIVITY?

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Introduction

The solar minimum between Cycles 23/24 is unusual in many ways. It is distinguished by the long declining phase (see data of the Solar Influences Data Analysis Center – SIDC – *http://www.sidc.be/silso/home*), a small value of the polar field (*Svalgaard, Cliver, Kamide, 2005; Svalgaard, 2013*), atypical form of the corona for a minimum (*de Toma et al., 2010*), low-speed, density and temperature of the solar wind (*McComas, 2008; Manoharan, 2012*), small absolute values of the interplanetary magnetic field (*Smith and Balogh 2008; Lee et al. 2009*), abnormally strong galactic cosmic ray flux (*McDonald et al., 2010; Mewaldt et al. 2010*), reduced solar irradiance (*Fröhlich, 2009, 2011*), low geomagnetic activity (*Feynman and Ruzmaikin, 2011*) and others. These changes of solar parameters are probably not unique for the Sun, but the first observed since instrumental recording.

They probably demonstrate the onset of a global minimum of the solar activity. The observed weak magnetic field in active regions (*Livingston and Penn, 2009*) and a reduction of their total number likely affect the mentioned changes of the solar parameters.

It is currently stated (*Schatten et al., 1978; Jiang et al., 2007; Makarov and Makarova, 1996; Muñoz-Jaramillo et al., 2013*) that the polar flux at the solar minima after cycle *n* is a good precursor of amplitude of the next cycle *n+1*. On the contrary, *Benevolenskaya (1982)* concluded that the surface polar field during a minimum of solar activity is not a physically meaningful parameter to predict of a maximum of the following cycles, as the polar proxies at the solar minima correlate better with the activity of the preceding sunspot cycle.

Recently, *Muñoz-Jaramillo et al. (2012)* calibrated 100 years of polar faculae measurements. The resulted signed polar flux consists of data of the Mount Wilson Observatory (1906–1975), the Wilcox Solar Observatory (1975–1996), and Michelson Doppler Imager (MDI) intensitygrams (1996–2010).

In this paper, we discuss a relation between the polar flux and sunspot number that is usually claimed on the basis of correlation.

Correlation analysis for short time-series

Here, a simple test is performed to demonstrate how correlation coefficient depends on trend in short time series. We consider two identical sinusoidal functions – f (Fig. 1) with increasing linear trend ($f_{increase}$) and decreasing one ($f_{decrease}$). The trend at the upper panel (Fig. 1a) is 25% steeper than that at the lower one (Fig. 1b). The length of both series is only 21 values and thus the steepness of the trend influences the correlation coefficient (*Corr* = 0.39 in Fig. 1a; *Corr* = 0.60 in Fig. 1b).

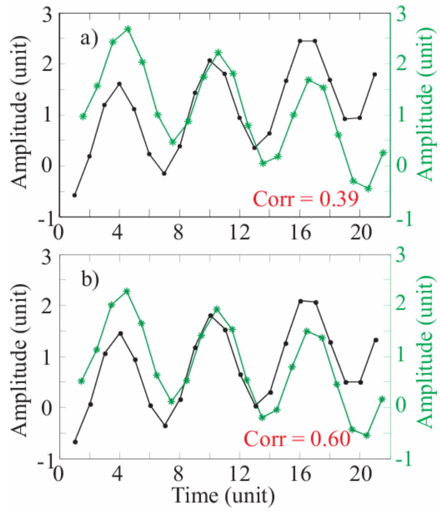

Figure 1. Two sinusoidal functions with trends: $f_{decrease}$ and $f_{increase}$. The trend on the left panel **(a)** is 25% steeper than that on the right panel **(b)**.

If we consider a longer time series (210 points), then the correlation coefficient only slightly depends on the trend (*Corr* = 0.96 instead of 0.39 and *Corr* = 0.94 instead of 0.60). Thus, this simple test illustrates that in lack of statistics the correlation coefficient may not be a measure of similarity between time-series, because trends dramatically influence a correlation.

In the case of real data (sunspot number and polar flux), the length of time series is a twice shorter than the length of the test functions – f. Therefore, a correlation analysis is not appropriate due to very poor statistics.

We use the monthly sunspot number from SIDC and the polar faculae database by Muñoz-Jaramillo et al. (2012). Fig. 2(a) compares the sum of the unsigned polar fluxes in the hemispheres at minima of solar activity (in green color) and the amplitude of sunspot number (in black color). Years of the solar activity minima are 1913, 1923, 1933, 1944, 1954, 1964, 1976, 1986, 1996, and 2008 (according to the NOAA's National Geophysical Data Center –NGDC). The patterns of behavior of the sunspot activity and the polar flux are qualitatively similar. Increase/decrease in the sunspot activity is reflected in the polar flux variations.

Notice that the polar flux demonstrates a decreasing trend, while the sunspots, increasing one, similarly to the test functions – f. The correlation coefficient for the polar flux at the solar minima and the previous sunspot cycle is about zero (Fig. 2b, *Corr* = –0.02), and with the next one, 0.57 (Fig. 2c). Adding or removing even a single point leads to crucial changes of correlation coefficient. For instance, if we remove from the scatter plot (Fig. 2c) point 19, then the correlation coefficient reduces to 0.25.

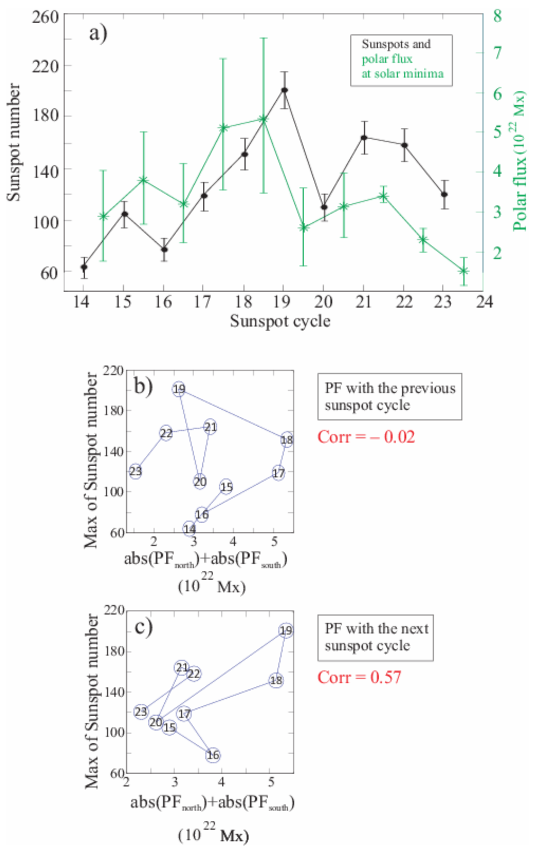

Figure 2. **(a)** The maxima of smoothed sunspot number (black). The sum of the unsigned polar fluxes in the hemispheres (green) at the minima of solar activity. Scatter plot compares the sum of the unsigned northern and southern polar fluxes at the minima of solar activity with the amplitude of the previous sunspot cycle — **(b)**; with the amplitude of the next sunspot cycle — **(c)**.

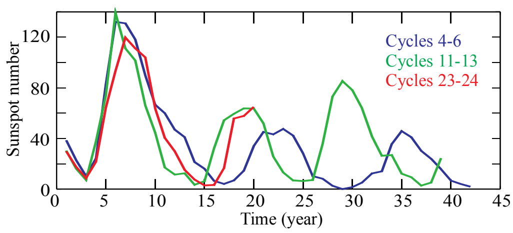

Figure 3. Annual sunspot numbers. The pairs of the cycles are aligned by the minima before Cycles 4, 11, and 23. The cycle numbers refer to the Zürich numbering.

Fig. 3 shows the monthly sunspot number for three onsets of the secular cycle minima. The sunspot number values were taken from the SIDC. We consider Cycles 5–7 as the Dalton minimum, Cycles 12–16 as the Gleissberg-Gnevyshev minimum. Cycles 4–5 are shown in blue, Cycles –13, in green, and 23 and 24, in red. Fig. 3 illustrates that the current situation is something in between the Dalton and Gleissberg-Gnevyshev minima. This suggests to us that the pronounced prolongation of Cycle 23 should be accompanied by a notable suppression of Cycle 24, similar to the Dalton and Gleissberg–Gnevyshev minima. Accordingly, Cycle 24 is about to belong to the new Grand Minimum. If behavior of the sunspot activity is reflected in the polar field, then the Sun may be entering an era of global quiet conditions (*Zolotova and Ponyavin, 2014*).

Conclusions

In our work, we discuss a validity of the correlation analysis for short time series. We demonstrate that trends significantly influence the correlation coefficient. In case of poor statistics, each point crucially changes relationship of time-series. We discuss interdependence between sunspots and polar fields, and argue that correlation analysis is not appropriate, due to lack of statistics.

Similarity between the current sunspot activity and those during the Dalton and Gleissberg-Gnevyshev minima suggest to us the new Grand Minimum.

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