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Solar activity cycles and grand minima occurrence

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Summary. — Sunspot number reconstructions (SNRs) based on dendrochronologically dated radiocarbon concentrations are analyzed through the Empirical Mode Decomposition (EMD) to provide a deeper characterization of the solar activity long-term periodicities and to investigate the role of the Gleissberg and Suess cycles in the grand minima occurrence. The Gleissberg and Suess cycles, with timescales of 60–120 yr and 200–300 yr respectively, represent the most energetic contribution in SNR records. The EMD approach reveals that these cycles are characterized by multiple scales of variation and that the grand minima sequence is produced by the coupling between Gleissberg and Suess cycles, the latter being responsible for the most intense and longest Spörer-like minima, with typical duration longer than 80 yr.

1. – Introduction

The cyclic behavior of solar magnetic activity, characterized by the well known ~ 11 yr periodicity (Schwabe cycle), is often studied by means of the relative sunspot number, also known as Wolf number, and the group sunspot number [1, 2]. Variability on timescales longer than 11 yr has also been found in various studies. By lowpass filtering sunspot number records, Gleissberg [3] detected an ~ 80 yr cycle, thereafter named Gleissberg cycle, confirmed in several more recent studies (see *e.g.* [4, 5]), showing that the periodicity of this cycle varies in the range 60–120 yr. A remarkable feature in solar activity variability is the presence of extended decreases and increases in sunspot numbers. The most known events are the Maunder mimimum (1645–1715) [6], the Dalton minimum (1790–1845), and the period of increased solar activity 1940–1980 [7]. Investigations on centennial and multi-centennial cycles in solar activity have taken significant advantage from the availability of records of cosmogenic isotopes covering the past ~ 10000 yr.

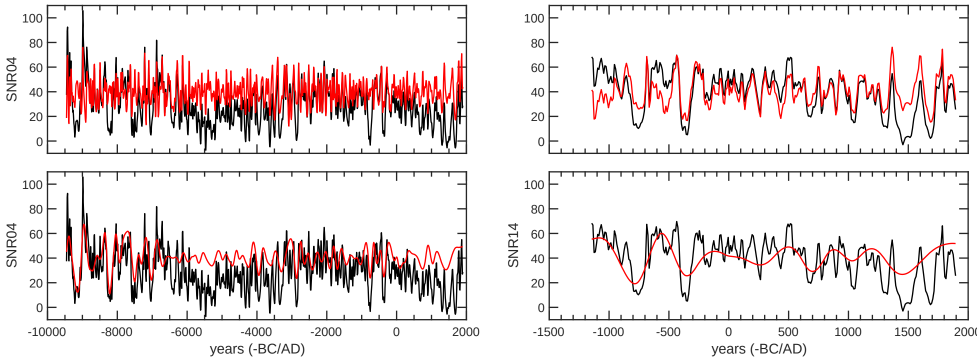

Fig. 1. – EMD reconstructions (red lines) of the Gleissberg (upper plots) and Suess (lower plots) cycles superimposed to the SNR04 (left panel) and SNR14 (right panel) datasets (black lines). An offset of 40 was added to the reconstructions for a better comparison.

Sunspot number reconstructions (SNRs) from these records [8,7,9,11] show that low and high activity states, called "grand minima" and "grand maxima", represent a frequent feature of the last 10000 yr. Analyses of this data have also confirmed the existence of the Gleissberg cycle (see *e.g.* [12,13]) and have revealed other long-term cycles in solar activity (see *e.g.* [14,13]): the ~ 200 yr Suess cycle and the Halstatt cycle at $\sim 2200-2400$ yr. In this work we perform an analysis of the Gleissberg and Suess cycles and investigate their role in the grand minima occurrence. To this aim we apply the Empirical Mode Decomposition (EMD) to two different SNR datasets.

2. – Data analysis and results

Two SNR datasets, with 10 yr cadence and obtained from dendrochronologically dated radiocarbon concentrations, are used in this work. The first one [8] (denoted hereafter by SNR04) is the longest available records and covers the past 11400 yr. The second one (denoted hereafter by SNR14), which spans the time interval from 1150 BC to 1950 AD, is a more recent dataset obtained through updated models for ^{14}C production and geomagnetic dipole moment [10]. The time variability of these data is investigated by applying the EMD [15], a technique developed to process nonlinear and nonstationary data. Through this technique, a time series is decomposed into empirical basis functions named intrinsic mode functions (IMFs), which are zero mean oscillations with amplitude and phase modulations. When applying EMD to SNR04 and SNR14 datasets, 11 and 8 IMFs are obtained, respectively. The energy content of the Gleissberg and Suess cycles, defined as the ratio between the mean square amplitude of their signal and that of the whole time series, is 40% and 29% for SNR04, 63% and 29% for SNR14. The EMD reconstructions of the Gleissberg and Suess oscillations are shown, for both the datasets, in Fig. 1, superimposed to the original signals. The sum of the two cycles (see Fig. 2) reproduces the sequence of maxima and minima observed in the raw data, indicating that the grand minima occurrence can be associated with the coupling of Gleissberg and Suess oscillations. Therefore, we propose a novel criterion to identify grand minima using the signal obtained by summing the Gleissberg and Suess cycles extracted from the EMD of SNRs: a relative minimum of this time series is considered a grand minimum if it is beyond the 90th percentile of the signal distribution function [16]. Through this approach, 27 grand minima are identified in the SNR04 dataset (red dots in Fig. 2),

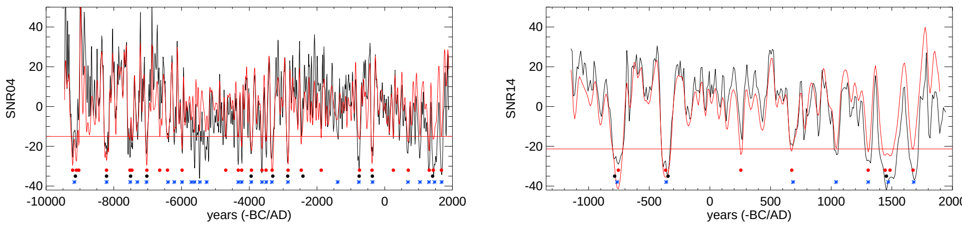

Fig. 2. – SNR04 (left panel) and SNR14 (right panel) time series (black lines) and respective EMD reconstructions including Gleissberg and Suess cycles (red lines). Horizontal red lines correspond to the 90th percentile of the EMD reconstruction distribution functions. Red dots mark times when the EMD reconstructions are beyond the 90th percentile of their distribution function. Black dots correspond to grand minima also occurring in a relative minimum of the EMD reconstructed Suess cycle. Blue asterisks indicate the grand minima identified in [7].

mostly coincident with those identified in previous works [7, 9, 11]. It is also found that the grand minima which also occur in a relative minimum of the EMD reconstructed Suess cycle (black dots in Fig. 2) are longer than the others, with a duration of more than 90 yr.

In conclusion, the EMD represents an effective tool to investigate the periodicities associated to long-term solar activity cycles in SNR records. Our results indicate that the grand minima generation can be attributed to the coupling between the Gleissberg and Suess cycles and that the events occurring around minima of the Suess cycle are the longest and most intense Spörer-like minima.

REFERENCES

[1] Usoskin I. G. and Mursula K., *Solar Phys.*, **218** (2003) 319.
[2] Clette F., Svalgaard L., Vaquero J. M. and Cliver E. W., *Space Sci. Rev.*, **186** (2014) 35.
[3] Gleissberg W., *J. Br. Astron. Assoc.*, **68** (1958) 148.
[4] Frick P., Galyagin D., Hoyt D. V. *et al.*, *Astron. Astrophys.*, **328** (1997) 670.
[5] Kolláth Z. and Oláh K., *Astron. Astrophys.*, **501** (2009) 695.
[6] Eddy J. A., *Science*, **192** (1976) 1189.
[7] Usoskin I. G., Solanki S. K. and Kovaltsov G. A., *Astron. Astrophys.*, **471** (2007) 301.
[8] Solanki S. K., Usoskin I. G., Kromer B., Schüssler M. and Beer J., *Nature*, **431** (2004) 1084.
[9] Inceoglu F., Simoniello R., Knudsen M. F., *et al.*, *Astron. Astrophys.*, **577** (2015) A20.
[10] Usoskin I. G., Hulot G., Gallet Y. *et al.*, *Astron. Astrophys.*, **562** (2014) L10.
[11] Usoskin I. G., Gallet Y., Lopes F., Kovaltsov G. A. and Hulot G., *Astron. Astrophys.*, **587** (2016) A150.
[12] Lin Y. C., Fan C. Y., Damon P. E. and Wallick E. I., *International Cosmic Ray Conference*, **3** (1975) 995.
[13] Peristykh A. N. and Damon P. E., *Jour. Geophys. Res. (Space Phys.)*, **108** (2003) 1003.
[14] Suess H. E., *Radiocarbon*, **22** (1980) 200.
[15] Huang N. E., Shen Z., Long S. R., *et al.*, *P. Roy. Sos. Lond. A Mat.*, **454** (1998) 903.
[16] Vecchio A., Lepreti F., Laurenza M., Alberti T. and Carbone V., *Astron. Astrophys.*, **599** (2017) A59.