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Study of the solar signal in mean Central Europe temperature series from 1760 to 1998(*)

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Summary. — We used a new series, highly reliable and representing the mean surface temperature of Central Europe for the period 1760-1998, to study Sun-Climate relationships. The results indicate that the influence of solar activity is evident only on a long time scale, in particular for the period 1860-present. On a short time scale it is not directly evident. From the spectral analysis we deduced that the strength of solar signal in the temperature series has an intermittent behaviour. We proposed a mechanism of resonance between the two non-linear systems, the Sun and Earth climate, to explain our results.

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1. – Introduction

The main task of climatologists is to understand if the global warming observed during the last century can be related to anthropogenic effects or to natural variability. Estimation of natural climate changes is therefore important for a credible assessment of the man-made signal. Natural changes can be due to internal factors like the coupling between different climate components (ocean and atmosphere) or to external forcing like variation in the solar constant and volcanic activity.

The possible connection between solar variability and global change has long been the most controversial area of solar-terrestrial relations (a good review can be found in [1,2]). The possible mechanisms of interaction are: the direct effect of the varying total solar irradiance with solar activity [3-5], the variations in the ultraviolet spectral band of solar irradiance [6-9], and the solar wind variations that affect the flux of cosmic rays in the earth's atmosphere [10-13].

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TABLE I. – *Correlation coefficients between NAO and MAT and between R_z and MAT series, both for the original and the filtered series and for the residuals (differences between the original series and their 22y Gaussian low-pass filter).*

MAT	R_z			NAO		
	Original series	22y Gaussian filter	Residual	Original series	22y Gaussian filter	Residual
W	–	0.42	–	0.42	–	0.45
Sp	–	0.26	–	0.38	0.39	0.38
S	–	0.28	–	–	–	–
A	–	0.48	–	–	–	–
Y	–	0.48	–	0.26	–	0.35

Great help in understanding the mechanisms of climate change can come from the analysis of long climatic records of proxy data from all over the world. They provide long series that allow us to determine how climate has changed over the last few climatic cycles. Instrumental series are available only for the last 150 years, on a global scale, but they have the advantage of being more precise than the proxy. For longer periods we can refer only to single series (the central England temperature is the longest one) that can be affected by inhomogeneity or local climatic effects.

Till now, the studies performed on instrumental temperature data have highlighted a good agreement between solar activity and climate variations, but only on a secular time scale [14-18].

In this paper we intend to look for Sun signature by analysing a new highly reliable series (it is the mean of about 100 homogenized series from stations covering a large region around the Alps) starting from 1760: the European Alps Temperature series [19].

2. – Data

In the frame of an EU Project (Alpclim), more than 100 temperature series —some of them starting in the 1760s— were collected for the Alpine region (from 43 to 49 latitude degrees and from 3 to 19 longitude degrees) and a strict work of homogenisation was performed (the details of the procedures are well described in Böhm *et al.*, [19]). Then, we obtained a homogeneous 240 year-long series, with a good signal-to-noise ratio due to the great number of available stations. We used this mean Alpine temperature series (MAT) to extend the study of Solar-Climate relationship far back into the past.

From monthly MAT data yearly anomalies series were calculated. Yearly values were conventionally made to correspond to the period December 1st-November 30th and dated by the year in which January occurred. Sunspot number (R_z) and North Atlantic Oscillations (NAO) were used as proxies for Solar activity and internal forcing factor respectively.

In fig. 1 the annual anomalies of the MAT, R_z and NAO series filtered with a 22y Gaussian low-pass filter are displayed.

The correlation coefficients between R_z and MAT and between NAO and MAT series are indicated in table I, for the original and the filtered series and for the residuals (differences between the original series and their 22y Gaussian low-pass filter).

The influence of solar activity is evident only on a long time scale. In fact, we observe

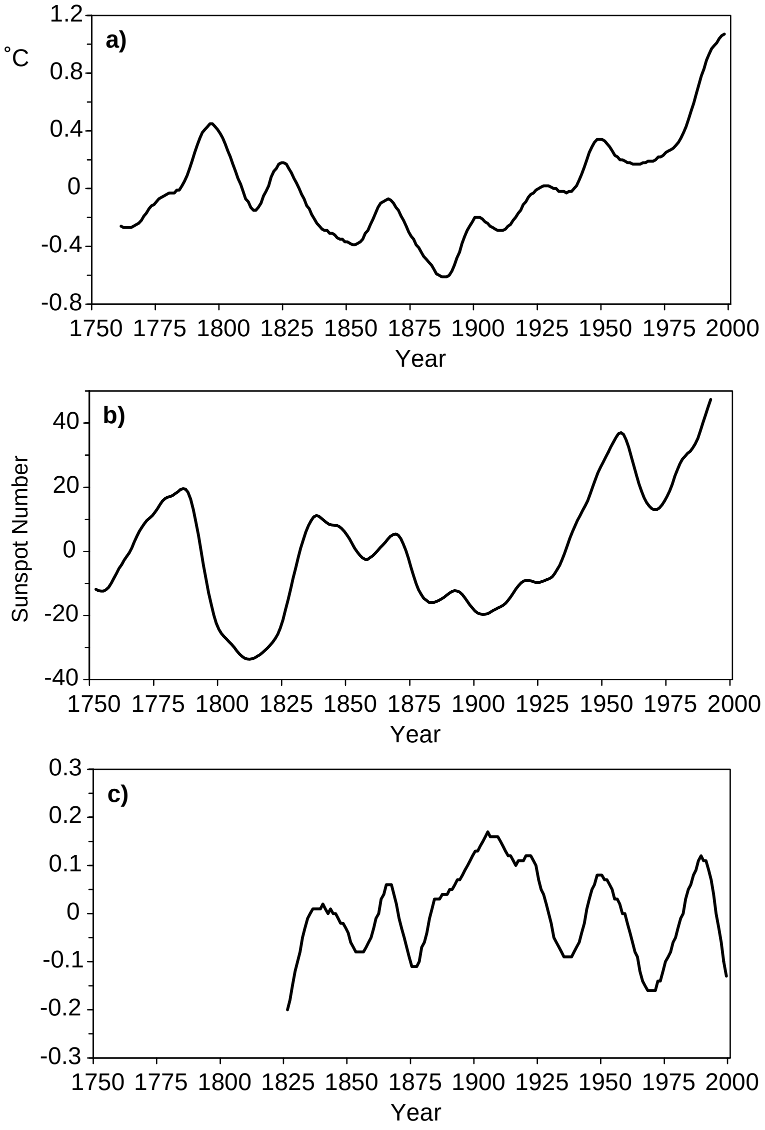

Fig. 1. – Annual anomalies of the MAT (a), R_z (b) and NAO (c) series filtered with a 22y Gaussian low-pass filter.

quite a good correlation only considering the 22y Gaussian low-pass filter of MAT and R_z, mainly due to winter and autumn, the season with the strongest temperature trend for the period 1860-present, as observed by Böhm *et al.* [19].

Moreover, it is evident that the good correlation between MAT and NAO series (significant in winter and spring but not for summer and autumn, both for the original series and for the residuals) is mainly due to short-term variations: the correlation coefficient for the filtered series is very close to zero in winter and for the year.

Than, the high-frequency variability of Alpine temperatures seems to be mostly related to the NAO, while the solar signal could be found in long-term behaviour.

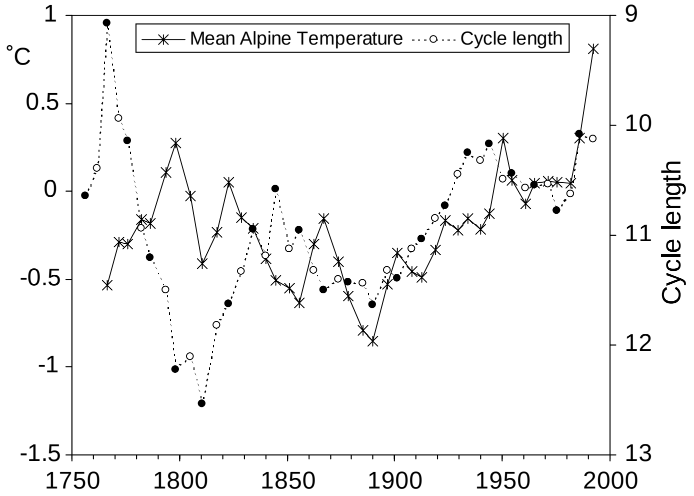

Fig. 2. – Variation of the sunspot cycle length (left-hand scale) determined as the difference between the actual smoothed sunspot extremum and the previous one (black dots = minimum, white dots = maximum). The cycle length is plotted at the central time of the actual cycle. The unsmoothed last values of the MAT series have been indicated with (*).

3. – Results

3˙1. *Long-term behaviour.* – From fig. 1 we observe that the long-term behaviour of the R_z series agrees with temperatures for the period 1860-1998, while for the first part of the series the relationship is not as clear as the last one, even if some characteristics of solar activity are evident in the MAT: for example, we can well identify the Dalton minimum around 1810. It is worth noticing that the quality of the Wolf sunspot data is good after 1818 and questionable, 1749-1817, to poor, 1700-1748, in the first period [20]. It is also true that sunspots do not account for the whole solar activity.

Many researchers have suggested that solar irradiance has varied in phase with the Gleissberg cycle (80 to 90 year periodicity) and that the envelope of the 11-year sunspot cycle is causing a significant part of the changes in the global temperature. Friis-Christensen and Lassen [21] observed that the smoothed sunspot number cannot be a usable index of solar forcing and that a better set of data that support the suggestion of a solar activity forcing on climate is the variation of the solar cycle length. They revealed a good agreement between this solar activity proxy and the Northern Hemisphere Temperature.

We performed the same analysis extending the calculation of the solar cycle length back to the 18th century and applying the same 1-2-2-2-1 filter they used [22]. We considered both the minimum to minimum and the maximum to maximum cycle length to improve the statistic. Relating this series to the MAT we observed once again that the relationship between temperature and solar activity worsens before the 1850s (fig. 2).

Then, considering sunspot number and Schwabe cycle length as a proxy for the solar activity, we did not find a persistent signal of solar forcing along all the MAT series. This is clear also observing fig. 3, where the correlation between filtered R_z and MAT series, for a 50 years running window, is plotted *vs.* the years (each correlation value is associated to the year in the middle of the 50y window). A non-constant correlation

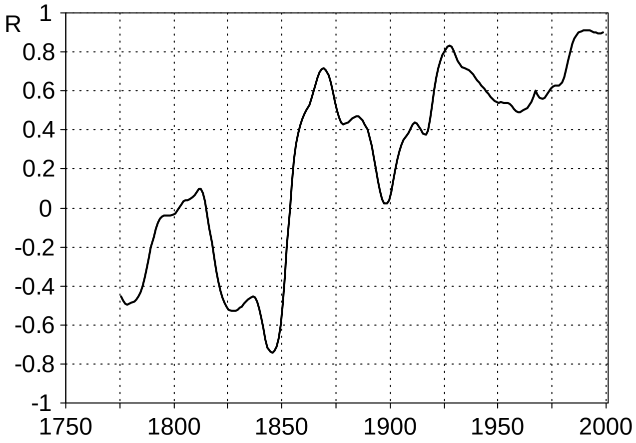

Fig. 3. – 50y running box correlation between 22y Gaussian low-pass filtered MAT and R_z series. Correlation values are associated to the year in the middle of the 50y window.

between the two series is evident, with low correlation values before 1850s followed by a strong increase and an oscillating behaviour.

Some authors have claimed that a lag of about 5 years could exist between climate change and solar signal [23]. We found the best correlation between R_z and MAT for a delay of six years, as emphasized in fig. 4, where the correlation coefficient between filtered R_z and lagged MAT series *vs.* time delay is plotted. This could be explained with the inertia of the climate system, that does not provide an immediate answer to the solar forcing.

3˙2. *Oscillations.* – We also performed a spectral analysis to look for a signature of forcing factors in MAT.

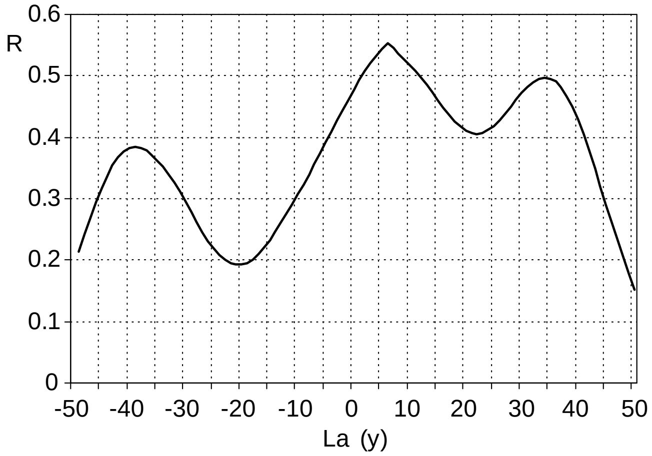

Fig. 4. – Correlation coefficient between 22y Gaussian low-pass filtered R_z and lagged MAT as a function of the lag between the two series.

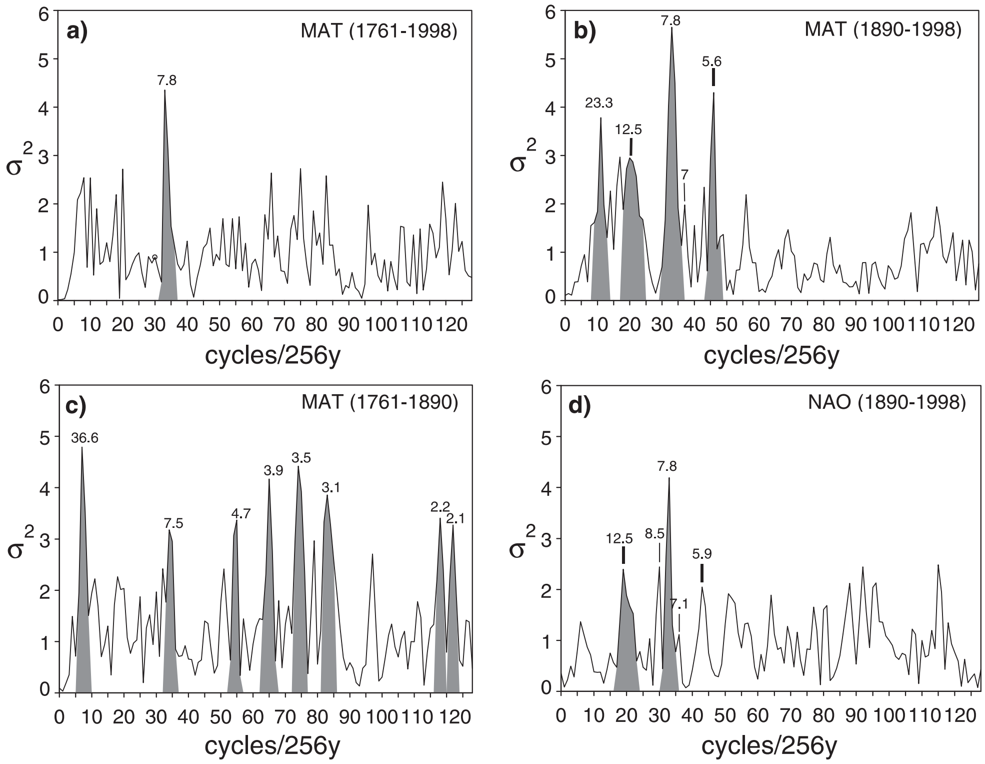

Fig. 5. – Power spectrum of a) MAT from 1761 to 1998, b) MAT from 1890 to 1998, c) MAT from 1761 to 1890, d) NAO from 1890 to 1998. Shadow peaks are significant more than 95% . Bars over some peaks indicate frequency values spaced from the 7.8y periodicity of frequency intervals which are integer multiples of about 1c/88y and 1c/22y.

We used the Fast Fourier transform power spectra analysis [24] to study the behaviour of yearly MAT and NAO series detrended with a high-pass filter. This filtering consists of calculating the residuals of the series from a 60y-running interpolating 3rd-degree polynomial curve.

In the power spectrum of MAT series (fig. 5a) the 7.8y periodicity, typical of the NAO indexes (fig. 5d), appears highly significant; there is no direct evidence of solar periodicity. Considering the first (1761-1890) and the second (1890-1998) part of the series separately we can see in the latter a strong increase in the significance of the 7.8y periodicity. The power spectra of NAO for the period 1890-2000 (fig. 5d) appear very similar to the MAT one: in both spectra the significant periodicities are 7.8y, 12.5y, 5.6y, plus 22y but only for MAT.

For a better understanding of the behaviour along the series of periodicities resulting significant from power spectra, we studied them with cyclogram analysis [25].

Using cyclogram analysis it is possible to determine whether or not a given oscillation persists through the entire time series with the same phase and, if not, when it is strong and when it is weak. We specify here that a cyclogram of a series of N equispaced terms, as better explained elsewhere [26], is the geometric sum of the Fourier vector components of a test period t of any running subseries of length τ. The cyclogram will be a straight

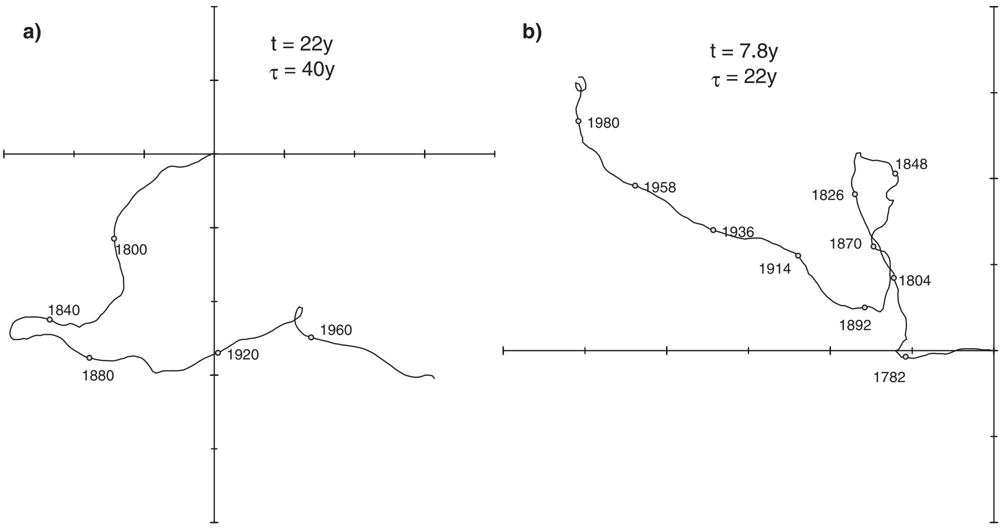

Fig. 6. – The 22y phase cyclograms of MAT from 1760 to 1998 (a). The length of running subseries is $\tau = 40$. Marks indicate vector computed from completely independent subseries. The distance between two marks corresponds to a time interval of τ. b) like a) for period 7.8y and $\tau = 22$.

line if the series represents a sine wave of period t and will be a line turning respectively to the right or to the left according to whether the period is longer or shorter than t. The square of the extension of a cyclogram is equal to the corresponding value of the power spectrum.

Figure 6 shows the phase cyclograms of the 22 (a) and 7.8 (b) years periodicities for the MAT series. The 22y period reaches a significant ($> 95\%$) extension only for the interval 1850-1998. Turning points around 1850 and 1950 indicate strong phase variations. 7.8y period reaches the most significant ($> 95\%$) extension for the interval 1885-1998.

This intermittent behaviour of the periodicities in the MAT series might be due to the non-linear nature both of the terrestrial climate system and its forcing factors.

4. – Conclusions

Looking at the spectra and cyclogram analysis results, we believe that the 22y periodicity in MAT (fig. 5b) could be attributed to the direct influence of Solar activity that, in the period 1890-1998, appears to be in good agreement with Earth temperature also as concerns long-term behaviour [15-17, 21, 27]. The other common periodicities both in MAT and NAO spectra (the most significant 7.8y) support the hypothesis that MAT is mainly affected by NAO.

Observing fig. 5b and 5d we noted that the 12.5y and 5.6y significant periodicities are situated on both sides of the more significant 7.8y peak, at frequency interval of 1c/22y, typical of solar dynamo. Other less significant periodicities, like 7y and 8.5y are situated at a frequency interval of 1c/88y (Gleissberg periodicity). This pattern may indicate that the 22y and 88y periodicity can be modulating waves of the NAO main periodicity 7.8y, that could be seen as the result of a combination of frequencies corresponding to 11y and 22y periodicities. All these considerations might support the hypothesis formulated by

Attolini *et al.* [28] that the Sun behaves as a non-linear system forced by an oscillator having the Hale frequency with 1c/88y and 1c/132y as subharmonics.

Climate and solar dynamo are not linear systems. The climate has a lot of internal variability supporting oscillations with many frequencies. The direct effect of changing solar irradiance in driving climate change is believed to be small, and amplification mechanisms are needed to enhance the role of solar variability. As Tobias and Weiss [29] point out, resonance may play a crucial role in the dynamics of the climate system: when a typical frequency of the non-linear solar forcing factor is similar to that of the chaotic climate system then a dramatic increase in the role of the solar forcing is apparent and complicated intermitted behaviour is observed.

In fact, looking at the behaviour of the Schwabe periodicity in the sunspot series by means of a cyclogram analysis [28], a periodicity longer than 11 years is evident in the first part of the series, while it is shorter than 11 years in the second part, where we found a signal also in the MAT series (fig. 6).

The idea of "stochastic resonance" inducing enhanced coherence of global temperature fluctuations with the solar cycle was already proposed by Lawrence and Ruzmaikin [30]: "a noisy or chaotic non-linear system can amplify a week, periodic input".

This is to demonstrate that the solar signal has not the same strength anytime in the climate and that we have the strongest effect when resonance occurs.

Therefore, the solar forcing on the climate system could be a non-constant signal and this complicates the identification of the real anthropogenic contribution to the global warming.

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