On the solar origin of the 200 y Suess wiggles: Evidence from thermoluminescence in sea sediments

G. CINI CASTAGNOLI, G. BONINO, P. DELLA MONICA, S. PROCOPIO and C. TARICCO
Dipartimento di Fisica Generale, Università di Torino
and Istituto di Cosmogeofisica del CNR - C.so Fiume 4, I-10133 Torino, Italy

(ricevuto il 10 Dicembre 1997; approvato il 22 Dicembre 1997)

Summary. — In order to understand the origin of the Suess wiggles, present in the tree ring ^{14}C record, we have studied the thermoluminescence (TL) of a shallow-water Ionian sea core, in an attempt to provide a record of an indicator responding to the solar output more promptly than ^{14}C in tree rings. The spectral content of the TL and radiocarbon records is very similar; neverthless, in addition to the 207 y Suess wave ($A = 3.6\%$), the TL record shows the second harmonic (103.5 y; $A = 2.4\%$), in phase with the envelope of the 11 y solar cycles. This result, obtained by different spectral methods, in particular by Superposition of Epochs (SE) and by Singular Spectrum Analysis (SSA), strongly supports the solar origin of the 200 y Suess wiggles.

PACS 91.50 – Marine geology and geophysics.
PACS 96.40 – Cosmic rays.

1. – Introduction

The solar origin of the 207 y periodicity present in the ^{14}C tree ring record, resulting from repeated Maunder-like maxima, was proposed by Suess, but up to now it remains conjectural; in fact, *a*) it is not possible to find a mechanism to force the Sun at such long periods and *b*) there is no direct evidence for a ~ 200 y signal from the Sun as monitored by sunspots (the record is too short) nor from historical aurorae. Moreover, the solar imprint in the radiocarbon record is very faint [1] because the transport mechanism of ^{14}C (as CO_2) from the atmosphere into the trees acts like a filter for the high frequencies, which could be compared to the observed solar-activity variations.

We consider here the thermoluminescence (TL) profile of a shallow-water core taken from the Ionian Sea (Gallipoli Terrace) in an attempt to provide a record of an indicator responding promptly to the solar output, *i.e.* able to identify centennial and also decadal periodicities, as those which appear in the solar-activity record of the sunspots. We have proposed this possibility in previous papers, using the TL profile measured in two cores (GT14 and GT89-3), at sampling intervals of 2.5 mm and 2 mm, respectively, covering the last 1800 years: the great accuracy reached in the core dating up to two millennia BP allowed us to detect in the TL record an 11 y cycle using both classical methods of time series analysis and Singular Spectrum Analysis (MC-SSA significance level of 95%) [2]. The success in detecting the Schwabe solar cycle in this type of archive gives us the confidence that this indicator may be used to reveal longer periodicities also forced by the solar output.

2. – Analysis of the TL profile

We present here the TL profile of the GT89-3 core (180 m water depth; 39° 45′ 43″ N, 17° 53′55″ E) sampled at consecutive intervals of 2 mm, corresponding to a time step of 3.096 y; in fact we have measured a sedimentation rate $s = (0.0645 \pm 0.0007)$ cm y^{-1}, constant on the average along the core [3, 4]. For this analysis we consider 167 cm (834 samples) of the core covering the last ~ 2600 y (from -605 AD). The experimental procedure to measure the TL signal is the "disk technique" described in [5], where we have discussed the TL measurements of the uppermost part of the core.

The TL time profile, centered (mean value 83 a.u.) and detrended by SSA [6] (from PCs 1-2, $M = 180$), is shown in fig. 1 (red curve). The decadal data of Δ^{14}C (‰) in tree rings, after removal of the long-term trend [7], starting at the same date of the TL record, is also shown in fig. 1 (blue curve).

To search for periodicities in the two time series, we use the method of Superposition of Epochs (SE). In this approach, the time series are partitioned into consecutive segments of fixed length T which are then superposed and averaged on n sub-intervals. By least-square–fitting a sinusoid with period T to the superposed experimental data, we have determined amplitude and phase (with respect to 247 AD)

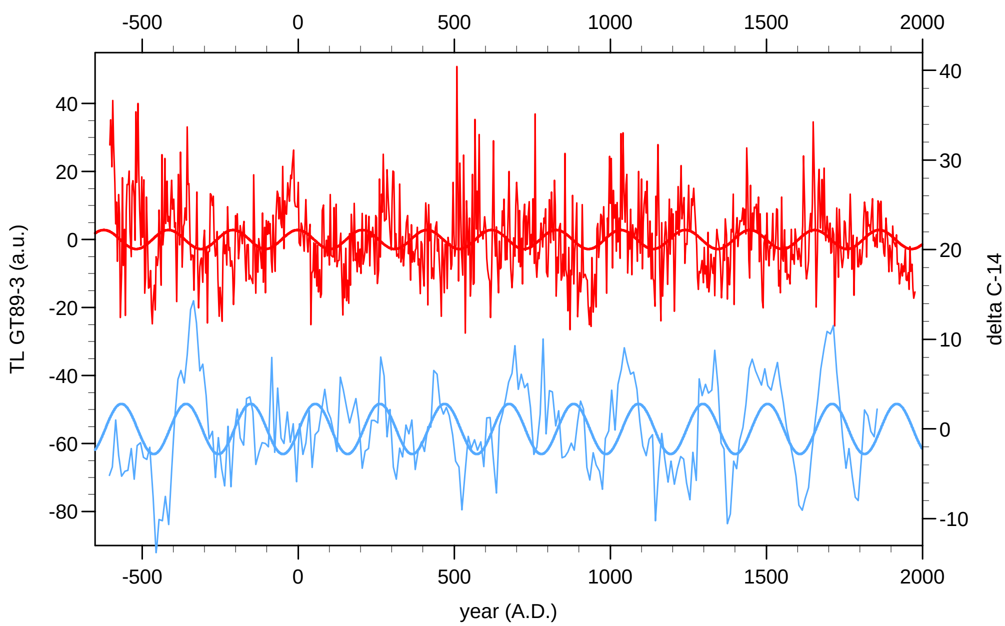

Fig. 1. – The red curve shows the TL time series of the GT89-3 core, detrended by SSA (PCs 1-2) and the blue curve the Δ^{14}C decadal tree ring record [7]. Superposed to the data are shown the 207 y waves, estimated by the method of SE.

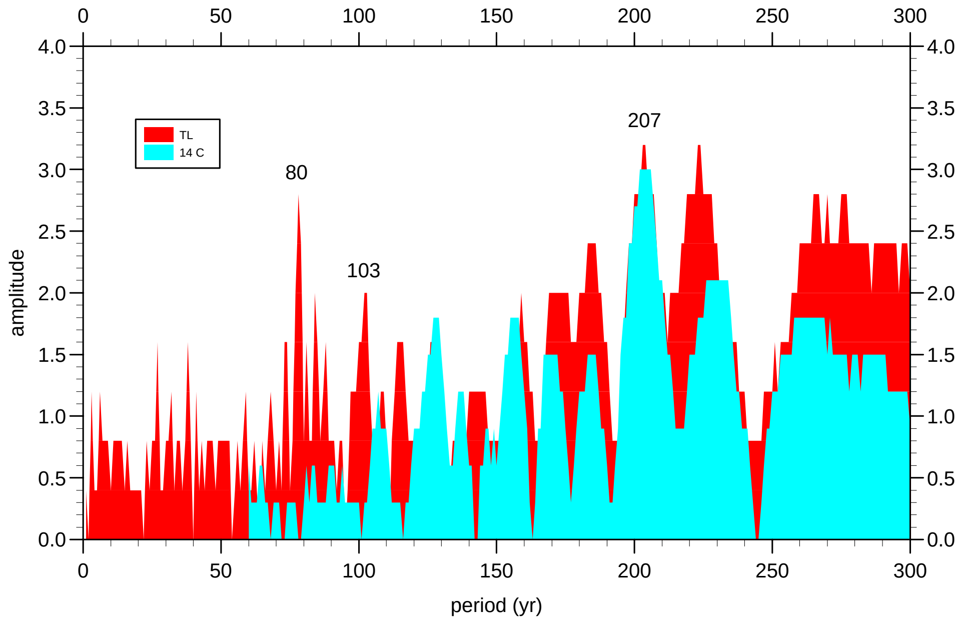

Fig. 2. – Amplitude of the least-square–fit sinusoids to the superposed data as obtained by the method of SE (“stacking”) for the radiocarbon record (blue curve) and for the TL series (red curve) as a function of period T.

of the waves, for T varying up to 300 y, in steps of 1 y. In fig. 2 we show the amplitude of the best-fit sinusoid as a function of T for TL (in red) and for Δ^{14}C (in blue). The close similarity in the behaviour of the two records is evident. In particular, we note that the strongest amplitude in the radiocarbon record is around $T = 207$ y ($A \sim 3$‰, $\phi = 1.13$ rad). This result is in agreement with the presence of the well-known Suess wiggles. The 207 y periodicity is present also in the TL record with an amplitude of 3.6% ($A \sim 3$ a.u., $\phi = 2.82$ rad). We note that the phase difference between the radiocarbon and the TL 207 y waves is $\pi/2$ with TL leading radiocarbon.

In addition, in the same fig. 2 we note that the TL record shows the second harmonic $T = 103$ y with an amplitude of 2.4% ($A = 2$ a.u., $\phi = 4.27$ rad). It appears in the region were the Δ^{14}C power is damped by the effect of the CO_2 reservoir. We note also the presence of the Gleissberg solar cycle at ~ 80 y.

The presence of the 103 y periodicity in the TL record is very important, because it represents a possible way to link the Suess wiggles to the solar-sunspot record. Therefore, we were induced to confirm its presence using different spectral methods; here in particular we show the result obtained by SSA. Adopting a window width $\tau_M = M\tau_s \cong 295$ y, where $M = 95$ and $\tau_s = 3.096$ y is the sampling interval, we found that PCs 8-9 carry the centennial periodicity. The robustness of this result was confirmed using a large interval of M-values ($80 < M < 180$). The reconstructed time series from PCs 8-9 (green curve) is shown in fig. 3, together with the wave obtained by the SE method (red curve); we notice the agreement between the results obtained by the two different methods. In order to test the connection of the 103 y signal and the solar activity, we show in the same figure the sunspot number series (yellow curve). We note the overall

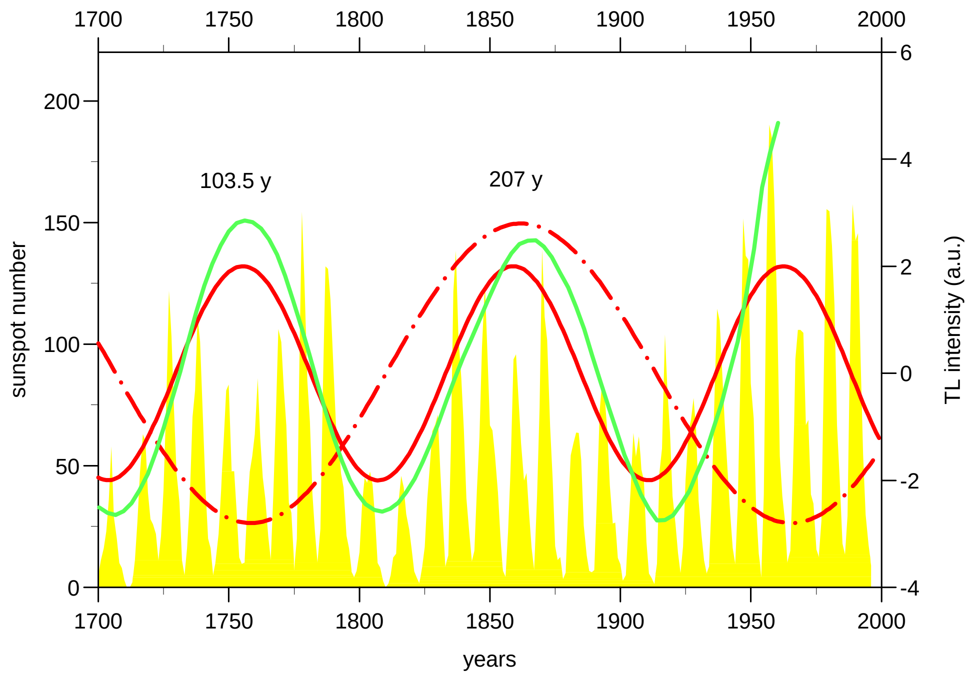

Fig. 3. – 103.5 y and 207 y sinusoidal TL waves (red curves by SE and green curve by SSA) with the sunspot number series (yellow area).

similarity of the two TL signals to the amplitude modulation of the 11 y solar cycle. In the same figure, the TL wave with period 207 y is also shown (red dash-dotted curve). We notice that the 207 y and 103 y waves are in phase, suggesting that the TL index records the ~ 100 y modulation envelope of the 11 y solar cycles with higher and lower amplitude alternatively.

3. – Discussion and conclusion

When crystalline minerals are exposed to ionizing radiation in their natural environment, free electrons and holes are produced. A small fraction of the former becomes trapped at defects in the crystals and these trapped charges are released and are able to recombine giving rise to the TL signal in a radiative process during the heating of the samples. The recombination comes also as a consequence of the exposure of the material to light. There is an equilibrium level of TL in the crystals at the time of settling which is preserved after deposition. The balance between formation and recombination will vary in time. Under the hypothesis that the material does not change, we may be able to trace the level of illumination-irradiation of the mud for the last millennia.

The competition of the two mechanisms determines the TL level stored in the samples. In particular, the sum of the 207 y and 103.5 y waves, which are in phase, suggests that the TL index records the envelope of the Schwabe cycles, with higher and lower amplitude alternatively.

The 11 y and the 103.5 y periodicities found in the TL record suggest a strong connection between the TL signal and the solar output. Moreover, the presence in the TL time series of the ∼ 207 y cycle and of its second harmonic (enveloping the sunspot number record) gives a convincing argument in favour of the solar origin of the ∼ 200 y ubiquitous signal observed in terrestrial archives, in particular in the tree ring radiocarbon.

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We are grateful to Prof. C. CASTAGNOLI for helpful discussions and support and to Mr. A. ROMERO for careful technical assistance.

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