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Earth's rotation and solar activity

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SUMMARY

The 11-yr signal in the variation of length of day has been successfully identified and significantly linked to solar activity. A physical mechanism involving meteorological and oceanic variation is proposed.

Key words: day length, sea-level, solar activity

INTRODUCTION

With the exception of Currie (1980; 1981a) who 'by accident' discovered the 11-yr variation in the Earth's rate of rotation, no other detailed investigations have been made on this topic. This signal cannot be ascribed directly to a solar energy source because the amount of energy required is too large. Mazzarella & Palumbo (1988b) presented evidence for a solar-induced variation in mean sea-level according to the following scheme: solar activity→ozone→ air temperature→mean sea-level. A change in sea-level, if due to melting of continental ice, will cause a direct variation in the length of day to conserve the change in momentum induced by the net mass redistribution. It would thus not be unreasonable to expect a solar-related signal in the Earth's rotation rate. The present results suggest the mean sea-level to be a source of the 11-yr Earth's rotation variation.

COLLECTION OF DATA

We have examined (i) the yearly historical series of mean sea-level 'MSL' recorded in Genoa (44°24′N, 8°54′E; interval: 1884–1980) as published by Lusetti (1977) and updated (Fig. 1). This series, continuously managed by the Scientific Section of the National Hydrographic Service, is one of the longest European series of mean sea-level (Mazzarella & Palumbo 1988b). We have also examined simultaneous yearly values of (ii) change in the length of day 'ΔLOD' taken from Barnett (1983) (Fig. 1) and of (iii) Zürich sunspot number 'N' taken from Waldmeier (1961) and updated (Fig. 1). N and ΔLOD are planetary indices different from the Genoa MSL. It may seem unreasonable to equate ΔLOD to a local MSL because the latter is largely affected both by land movement and by local meteorology. Both Currie (1976; 1981b) and Woodworth (1985) have proved the European MSL to respond to solar activity. They have found the 11-yr signal in MSL to be strongest in North Europe while it is smallest and sub-significant in South Europe, possibly connected with the local meteorology. In order to solve this contradiction, we have analysed the Genoa data. The tide-gauge of Genoa has never been subjected to changes of location; there is no river-discharge in the Bay of Genoa; geodetic observations performed by the National Geographic Institute have proved the Genoa region to be geologically stable; the Genoa MSL data have been pre-filtered from the internal and external sources of variation (Palumbo & Mazzarella 1980; 1985). The cross-analysis between the Genoa and Trieste MSL (located in Adriatic Sea at about the same latitude of Genoa and beginning from 1890) shows a correlation coefficient equal to 0.9, significant at more than the 0.001 per cent level, while the 11-yr term of Trieste mimics that of Genoa both in amplitude and in phase. All these circumstances indicate that the Genoa MSL is representative of the 11-yr MSL wave in the entire Mediterranean Basin. Hence, we assume that the 11-yr variation in Genoa MSL may reflect the global variability at this frequency.

ANALYSIS

A Box & Cox (1964) analysis has been applied to all the examined series in order to produce a more constant variance in the data. The results obtained show that a square-root transformation is needed only for N. The yearly increases of Genoa MSL and ΔLOD were found to be equal to 1.2 mm yr^{-1} and to 0.03 ms yr^{-1}, respectively. Both are significant at more than the 0.001 level. A detailed explanation of the observed secular trends, together with a stability trend analysis, will be reported elsewhere. We have normalized the MSL and ΔLOD data with respect to their mean linear relation. The advantage of this procedure is that minor variations in the residuals can be subjected to more accurate spectral analysis around the 11-yr period than when they are hidden by simultaneous large mean trends. It must be noted that the sunspot rhythm was very irregular in the interval used for the investigation, that is, the spectral analysis of $\sqrt{N}$ shows an energy peak not located in a narrow band but smeared around an 11-yr period.

Spectral analysis of time series requires prior identification of the normality and stationarity of the signals, properties which are often implicitly and mistakenly

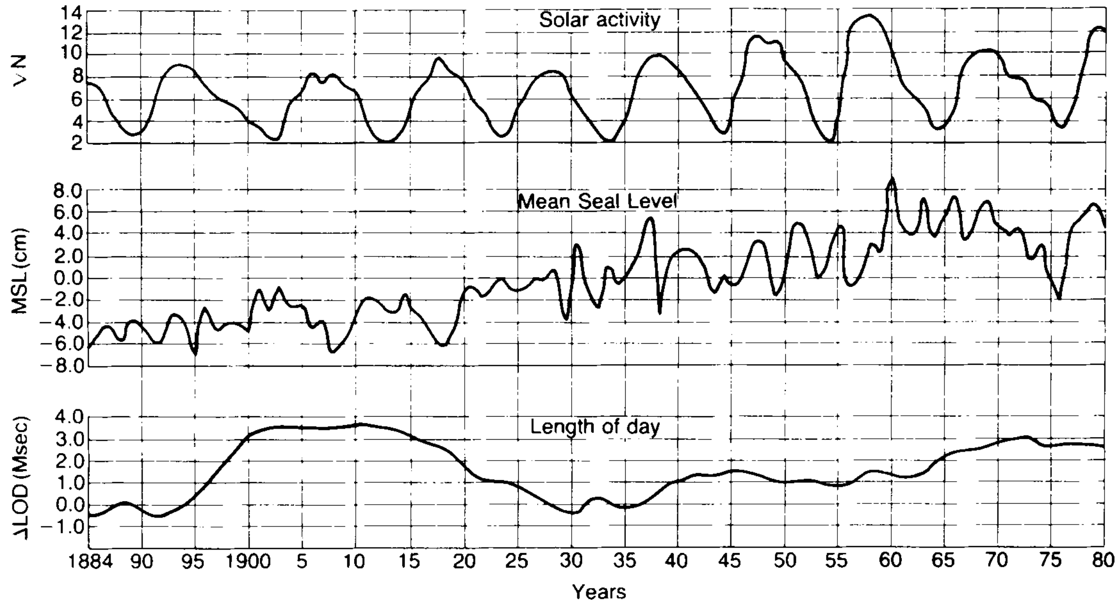

Figure 1. Yearly values of sunspot number ($\sqrt{N}$), yearly variations of mean sea-level (MSL) and length of day (ΔLOD).

assumed to exist. Such properties are relevant because the method of analysis required for non-normal and non-stationary data is generally more complicated than that appropriate for normal and stationary data. We have used a non-parametric approach, utilizing the χ^2 test and Run tests (Bendat & Piersol 1971; Mazzarella & Palumbo 1988a) which do not assume a specific distribution function for the random variable of interest. The normalized power spectra are smoothed according to Hanning coefficients to eliminate the side-lobe effects introduced by rectangular window. The 95 per cent confidence limits have also been computed assuming a χ^2 distribution of the smoothed spectral estimates. In order to discern the contribution of the groups of waves located around the 11-yr period to the total covariance between two different time series, the shift of amplitude (gain factor) and of phase (phase factor) for the 11-yr wave necessary to transform the first series into the second series, have been computed according to a number of degrees of freedom approximately equal to $\mu \simeq 2/11$ (Bendat & Piersol 1971), derived from a compromise of statistical stability between the n yearly values of the series and the 11-yr period. Physically μ is proportional to the square of the signal-to-noise ratio; thus, spectral estimates become more reliable as μ increases. The statistical significance of the 11-yr coherence coefficient between each pair of series has been examined on the null hypothesis of zero population coherence as a function of μ (Panofsky & Brier 1958; Bendat & Piersol 1971; Julian 1975; Mazzarella & Palumbo 1988a). Since the solar climate literature is already too confused by poorly based statistical claims, and in order to test this rather unconventional method of data analysis, the technique has been applied to sets of synthetic random data. The cross-spectrum of $\sqrt{N}$ and white noise does not give an 11-yr signal.

RESULTS

After significant effects of the secular trend have been filtered out, the yearly series of $\sqrt{N}$, MSL and ΔLOD are found to be normal and stationary at the 0.05 level of significance (Table 1) according to 10 and 5 degrees of freedom, respectively, that is, utilizing 13 class-intervals for the χ^2 test and a sub-interval size equal to 10 yr from the Run test. Accordingly, it is possible to compute the power spectra of $\sqrt{N}$, MSL and ΔLOD (Fig. 2) according to 18 degrees of freedom with the 11-yr peaks above the 95 per cent significance level. Table 2 shows that the coefficients of coherence between each pair of $\sqrt{N}$, MSL and ΔLOD are statistically significant at a level not less than 95 per cent. Woodworth (1985) has listed several probable driving sources of 11-yr MSL variations without proposing any of them. Mazzarella & Palumbo (1987b) have explained the linkage between $\sqrt{N}$ and MSL through a physical mechanism involving total ozone and air temperature. They found the gain and phase factors from $\sqrt{N}$ to ozone, from ozone to air temperature and from air temperature to MSL to be equal to 0.01 mm/$\sqrt{N}$, 2.80 °C mm^{-1}, 3.40 cm °C^{-1} and 2.4 yr, 1.4 yr, respectively. Table 2 shows that these factors from MSL to ΔLOD are equal to 0.09 ms · cm^{-1} and −0.5 yr, so that the shift of amplitude and phase from $\sqrt{N}$ to ΔLOD can be obtained respectively by:

$$0.01\ \mathrm{mm}/\sqrt{N} \times 2.80\ \mathrm{°C\ mm^{-1}} \times 3.40\ \mathrm{cm\ °C^{-1}} \times 0.09\ \mathrm{ms\ cm^{-1}} = 0.01\ \mathrm{ms}/\sqrt{N}$$

Table 1. Mean value $\bar{x}$, standard deviation σ, χ^2 value computed using the χ^2 test and number of runs NR computed using the Run test for Zürich sunspot number $\sqrt{N}$, Genoa mean sea-level MSL and change in length of day ΔLOD. The region of acceptance of normality hypothesis according to 10 degrees of freedom and stationarity according to 5 degrees of freedom at the 0.05 level of significance is: $\chi^2 < 18.3$ and $2 < NR < 9$.

	$\bar{x} \pm \sigma$	Computed χ^2	Number of runs
$\sqrt{N}$	6.8 ± 2.8	16.0	6
MSL	−326.1 ± 2.4 cm	16.5	7
ΔLOD	1.0 ± 1.5 ms	16.0	4

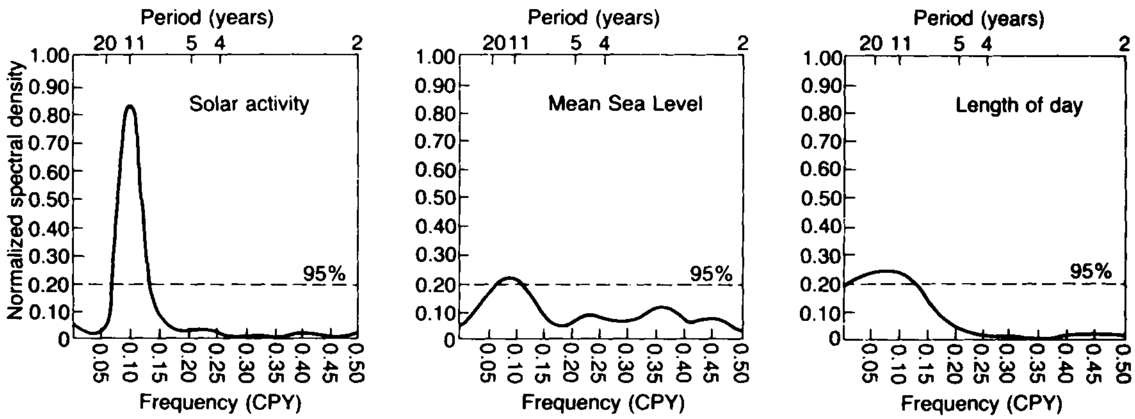

Figure 2. Normalized spectral density of solar activity, mean sea-level and length of day. The dashed line indicates the 95 per cent significance level of the equivalent white noise process based on 18 degrees of freedom.

Table 2. 11-yr wave amplitude derived from a spectrum smoothed by a Hanning function together with 95 per cent confidence limits for Zürich sunspot number $\sqrt{N}$, Genoa mean sea-level MSL and change in length of day ΔLOD. Gain and phase factors, coherence coefficient γ_{12} and confidence level computed on the null hypothesis of zero population coherence according to 18 degrees of freedom.

	11-yr Amplitude		
$\sqrt{N}$	*MSL*	*ΔLOD*	
3.65(2.73; 5.41)	1.30(0.98; 1.93) cm	0.08(0.06; 0.12) ms	
Gain factor	*Phase factor*	γ_{12}	*Confidence level*
0.01 ms/$\sqrt{N}$	(from $\sqrt{N}$ to ΔLOD) 0.9 yr	0.6	99%
0.09 ms cm^{-1}	(from MSL to ΔLOD) −0.5 yr	0.5	95%

and by

$$(2.4 + 8.9 + 1.4 - 0.5)\ \text{yr} = 1.2\ \text{yr}$$

Munk & Revelle (1952) found that a rise in MSL of 1 cm, if due to the melting of continental ice, causes an in-phase increase of 0.06 ms in ΔLOD, to conserve the change in momentum induced by the net mass redistribution.

DISCUSSION

The above results can be summarized as tabulated below.

The first two rows suggest that the 11-yr signal in MSL is the source of the related signal ΔLOD. On the other hand, the last two rows show that our experimental results are in good agreement with those obtained from the Munk & Revelle model. In conclusion, subject to our initial assumption that the 11-yr signal in the Genoa MSL data is representative of global variability at this frequency, the ascertained 11-yr signal in Earth's rate of rotation can be reasonably ascribed to solar activity through coherent variations in meteorological and oceanic data.

	Method of analysis	*Gain factor*	*Phase factor* (yr)
From $\sqrt{N}$ to ΔLOD	computed directly	0.01 ms/$\sqrt{N}$	0.9
From $\sqrt{N}$ to ΔLOD	computed through ozone, air temperature and MSL	0.01 ms/$\sqrt{N}$	1.2
From MSL to ΔLOD	computed directly	0.09 cm cm^{-1}	−0.5
From MSL to ΔLOD	computed through Munk & Revelle model	0.06 ms cm^{-1}	0.0

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