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Solar and tidal reverberations of deglaciation records from the tropical western Pacific: a clean spectral approach

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The search for the role of solar and tidal cycles in terrestrial climate records is an interesting curiosity. Powerful clean spectroscopy of high resolution carbon and oxygen isotope records from the tropical western Pacific Sulu Sea, over the past 9000–22000 years reveals statistically significant (at >90% confidence interval) spectral lines corresponding to periods of 2980, 690, 322, 250, 174 and 140 years and 1100, 533, 425, 183 and 151 years, respectively. These spectral peaks fall into different solar-climate frequency bands and have beat relationships to each other. The results suggest intricate physical linkages between solar and climate cycles and provide significant information for understanding solar-terrestrial climate variability in the past centuries.

Keywords: clean spectroscopy, solar and tidal cicles, climate changes

Introduction

Proxy climate records preserved in the earth's and oceanic sediments carry significant information about the interactions and evolutionary history of the geosphere-biosphere-cryosphere-hydrosphere and atmosphere. Recently, Linsley and Thunell (1990) studied the high resolution record of deglaciation decoded from the Sulu Sea sediments in the tropical western Pacific. They focused their interest mainly on the study of the nature of oceanographic changes as a possible cause of Younger Dryas events. The data presented by them are a complete record of deglaciation history of the region over the past 27000 years.

Visual inspection of this record indicates significant quasi-periodic variations superimposed on a long term secular trend. The changes seem to be the result of disequilibrium likely triggered from external forcing and/or stemming from within the components of the system dynamics. The long-term apparent trend associated with this variability probably originates from non-linear internal dynamics such as ocean circulation, CO_2 changes, albedo changes, disturbances from internal threshold feedback and collapses of ice sheets (Berger, 1990). However, apparently superimposed short term quasiperiodic fluctuations seem to be related to some external physical forcing which is in contrast to the nature of abrupt catastrophic deglacial changes. Thus, the climate time series (Linsley and Thunell, 1990) seem to contain mixed non-linear responses of terrestrial and extra-terrestrial forcings. In order to understand the physical nature of these various components, it is imperative to perform spectral classification.

Traditional Fourier power spectral analysis is corrupted by the interference of spectral peaks due to convolution of discrete Fourier transform with the so-called spectral window (Vio et al., 1992). This creates difficulties in resolving spectral peaks and makes it difficult to draw any definite conclusions. Hence it is imperative to analyse this deglaciation time series record using a more appropriate clean spectral technique. This particular time series merit special attention due to the fact that there have been several significant changes including the well known Younger Dryas at around 11000–12000 years and catastrophic deglaciation at about 18000 years. Recognition of periodicity in this climate record is helpful in identifying and advancing of endogenic and/or exogenic mechanisms of climatic change.

We present herein: (i) the analysis of a high resolution climate record over the past 27000 years using a clean algorithm of spectral analysis; (ii) a search for periodicities in the range of 120–3000 years; and (iii) a discussion of these results in relation to climate-solar forcing mechanisms.

Data

The unevenly spaced $\delta^{18}O$ and $\delta^{13}C$ data is taken from Linsley and Thunell (1990). These high resolution deglaciation records from the Sulu Sea sediments in the western Pacific exhibit a remarkably cyclic nature. Some portions of the time series, *i.e.* after 7000 years and before 22000 years are not included in the study because of poor data coverage during this period. Data is appropriately detrended prior to spectral analyses (Fig. 1).

The details of various oceanographic aspects of these time series are discussed in detail by Linsley and Thunell (1990). However, the main characteristics of the data relevant to the present study are summarized here. The core was lifted at 3643 m water depth on a bathymetric high on the Cagayan ridge in the center of the Sulu Sea in the tropical western Pacific ocean under ocean drilling program leg 124. Samples were taken at 2.5 cm intervals in the upper 3.5 m of core collected at hole 769A. It is noted that oxygen and carbon isotopic analyses of the Planktonic foraminifer Globigerinoides were used to construct $\delta^{18}O$ and $\delta^{13}C$ transitions. The chronology for the upper 350 cm of hole 769A is based on three AMS ^{14}C ages. Specimens of Globigerinoi-

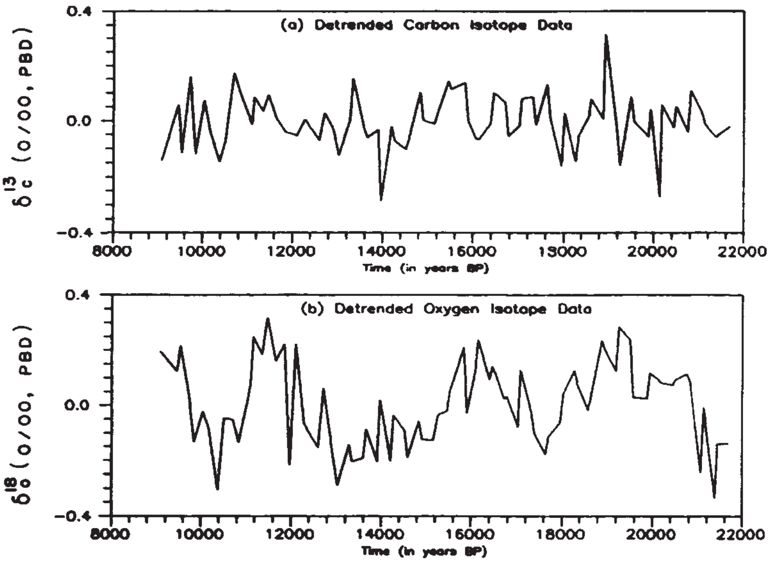

Figure 1. Detrended (a) carbon isotope data, (b) oxygen isotope data (from Linsley and Thunell, 1990).

des ruber from 107 cm, 128 cm and 245 cm yielded corrected ages of 9720 ± 80, 11100 ± 185 or 18320 ± 155 years. Ages for individual samples were estimated assuming constant sedimentary rates between δ^{13}C dates. According to the δ^{13}C ages sedimentation rates in this case vary from 11 cm/1000 years to 16 cm/1000 years during the last glacial (Linsley and Thunell, 1990).

Spectral analysis using the clean algorithm

Robert et al. (1987) have presented an efficient clean algorithm of spectral analysis especially suitable for the analysis of unequally spaced time series. The technique is based on a complex one-dimensional version of the clean deconvolution algorithm widely used in image reconstruction. One of the main advantages of the algorithm is that it removes artifacts introduced by missing data and provides clean stable peaks. Successful application of the clean algorithm has been demonstrated by several workers (Drehar et al., 1986, Duvall and Harvey, 1984; Vio et al., 1992) for analysing astronomical data. The technique has also been applied successfully to long term geophysical and geological records. The equations governing the algorithm and details of the computational procedure have been discussed by Negi et al. (1990, 1996).

Analyses and results

The time intervals between successive data points are quite variable. The minimum sampling interval in the available unevenly spaced data is 62 years. Therefore, the highest period (Nyquist frequency) that can be resolved is ≈120 years. Traditional Fourier analysis of $\delta^{13}C$ provides noisy spectra with dominant peaks clustering near 2900, 700, 472, 322, 250 and 174 years (Fig. 2a). The clean spectral analysis of the same record shown in Fig. 2b reveals six dominant spectral lines corresponding to 2980, 690, 472, 222, 250, 215, 174 and 140 years. In addition to this, the analyses also reveal relatively weaker peaks at 1644, 780, 600, 187, 180, 170, 153 years. It is interesting to note that the clean spectra resolve the spectral peaks more clearly compared to Fourier spectra. Similar analyses of $\delta^{16}O$ oxygen isotope time series also reveal dominant clusters of power near 150–160, 171–183, 200–225, 354–425, 500–550 and 1100–1160 years spectral bands (Figs. 3a and 3b). Both the spectra of oxygen and carbon isotope time series also exhibit some similarity in their spectral structure indicating common link of their physical variability. The statistical reliability of these peaks were tested using Fisher's statistic which indicates a 90% significance level (Shimsoni, 1971).

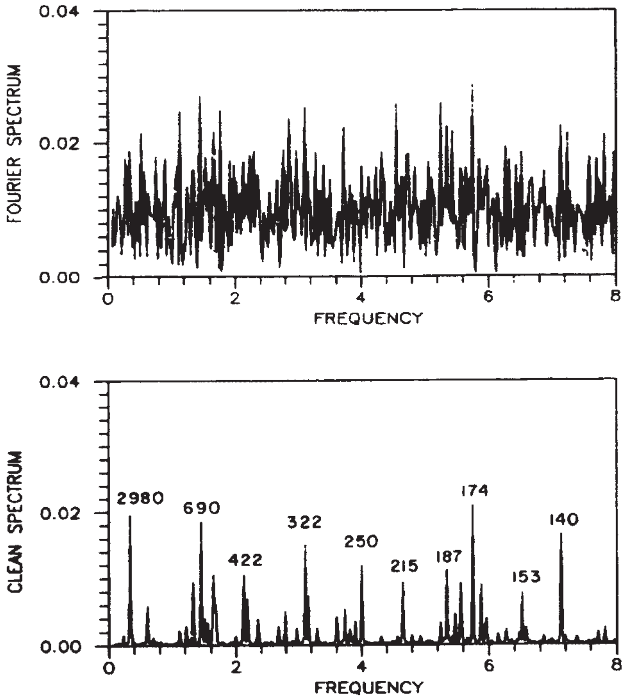

Figure 2. Top: Fourier spectra of carbon isotope data. Bottom: clean spectra of the same data (spectral peaks are in years).

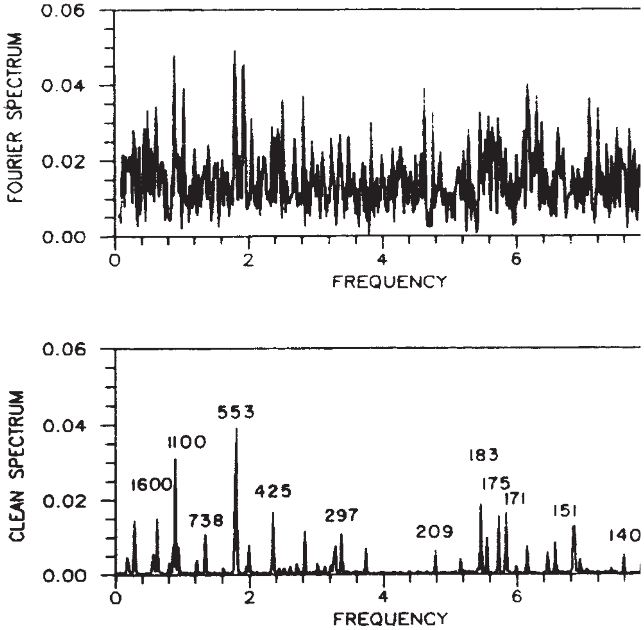

Figure 3. Top: Fourier spectra of oxygen isotope data. Bottom: clean spectra of the same data (spectral peaks are in years).

In a related power spectral study of solar activity as reflected by radiocarbon variation based on absolute chronology from tree ring counts (Sonett and Finney, 1990; Suess and Linick, 1990; Libby et al., 1976) spectral lines at a number of periods, specifically 2300, 964, 753, 717, 493, 413, 357, 229 and 208 years were found. Comparison of climate periodicities obtained in our analysis with radiocarbon cycles exhibit close correlation. This might indicate that the Sun's activity is directly or indirectly implicated in global climate variability. Our present result is also consistent with a model of solar-atmosphere-ocean-resonances (Sonett and Finney, 1990). Interestingly, higher order cycles of 1100–1160 and 500–550 years also coincide closely with planetary conjunction cycles, *i.e.* time of conjunction of major planets leading to catastrophic terrestrial upheaval including climate (Fairbridge and Hillaire, 1977).

Physics of interactions

Solar-climate beat cycles

The complete spectrum of solar cycles present in climate records (Figs. 2 and 3) consists of 5 distinct groups with splitting of spectral peaks. The first group, the carbon spectra, exhibit highest power corresponding to bifurcated cycles of 187, 174 and 170 years with a main peak at 174 years. This gives an average period of 176.3 years which corresponds to 178.8 year periodicity in the Sun's motion (Jose, 1965; Charvatora and Strestik, 1990) (also called the King Hale cycle) as suggested by the planetary theory of sunspots and lunar tides.

The other clustered solar cycles (for details refer to Table 1) seem to have beat frequency relationship to each other which may have originated from non-linearity in the system. In such situations, there is a possibility that the interaction of two frequencies may provide strong signals at their beat periods. The relationship can be easily found by comparing pairs of split periods. The interactions of the two frequencies, for instance, f_1 and f_2 will give beat periods at frequencies $(f_1 - f_2)$ and $(f_1 + f_2)$. The beat periods calculated for the 170-174-187 years couplet give evidence of 85-90 years cycle for $(f_1 + f_2)$ which is well known as Gleisberg cycle, and has been invariably reported in various climate records (Burroughs, 1992). The beat cycles corresponding to $f_1 - f_2$ provides a cycle of 2200–2600 years which is interpreted as basic cycle in radio carbon spectra (Sonett and Finney, 1990). A 2200 year cycle indicate rotational motion of Trefoil through a full circle *i.e.* by 30^o in 180 years (Charvatova and Strestik, 1991). The analysis of dendochronologically dated tree rings with the parameter ^{14}C indicate 2250 and 88 year cycles corresponding to these beat cycles in temperature record (Damon, 1989). In addition, Bray (1980) proposed a cyclicity of the order of 2600 years in climate/glacial record and a similar cycle of 2600 years in solar variability which is close to the 2900 years cycle in our present analysis. Another dominant peak around 322 years with smaller peaks near 400 years may correspond to the »super solar cycle« as proposed by Landscheidt (1987) which is derived by observing the characteristic features of the Maunder Minimum and the Medieval Maximum.

Further two periods of 140 years and 153 years give beat periods of 73 years and 1644 years. It is interesting to note here that climate oscillation in the global temperature record with period of 65–70 years has recently been suggested by Schlesinger and Ramankutty (1994). Similarly, an astronomical variation of 1650 years is known as the period of Earth-Moon orbital motion. Stacey (1963) notes that maximum perigeal spring tides repeat approximately every 1668 years when the Moon is in perigee and the Earth at perihelion. Towards the higher frequency end of the spectrum two peaks centred around 140 years and 153 years in our analysis correspond to 130 years and 154 years cycle found in the time series of number of tropical cyclones and length of cyclones season respectively (William, 1981). These cycles are also invariably found in various temperature and climate records (Libby et al., 1976 and Libby and Pandolfi, 1977).

Our present analyses indicate that there is perhaps only one basic cycle of about 176–180 years corresponding to »King Hale cycle« in climatic records. Several other periods in the range of 300–400, 600–700, 800–1000, 1600, 2200, and 2900 are simply the result of beating phenomena in solar-climate records (Table 1).

Table 1. Climate cycles obtained from the clean spectral analysis of high resolution deglaciation record as compared with ^{14}C climate periodicities and their beat periods

Split periods f_1, f_2 in years	Beat periods (years)			
	$f_1 + f_2$		$f_1 - f_2$	
140, 153	73	Global climate cycle (Schlesinger and Ramankutti, 1994)	1644	Moon-Earth tidal cycle (Fairbridge, 1984; Fairbridge and Hillaire, 1977)
174, 187	90	Gleisberg cycle	2200	Primary solar cycle Sonett and Finney (1990)
459, 447	233	Primary cycle in radio carbon climate records (Sonett and Finney, 1990; Suess and Linick, 1990)	15898	Precession split cycles
611, 596	302	Radio carbon spectra (Suess and Linick, 1990)	1044	Primary cycle in radio carbon spectra) (Sonett and Finney, 1990; Suess and Linick, 1990)
691, 757	361	Radio carbon spectra »super cycle« (Sonett and Finney, 1990)	7949	Higher order climate cycle (1/3 of precessional period)

Discussion

The possible relationship between the Sun's motion and variability of solar activity has been suggested by Charvatova and Strestik (1991). A plausible mechanism exists whereby the incidence of solar radiation and flare emissions vary directly with the solar cycles (William, 1981). Such corpuscular radiation is normally detected at the lower part of magnetosphere but some radiation may reach the Sun's atmosphere near the magnetic pole. At the time of weak geomagnetic field variations, the shielding effect of magnetosphere would be considerably reduced. This will allow penetration of solar corpuscular radiation into the atmosphere at lower levels with low magnetic latitudes eventually blanketing the Earth completely (William, 1981 and references therein). This may lead to catastrophic upheavals in global climate. There is observational evidence which suggest that geomagnetic field intensity modulates the climate changes by magnifying solar activity and atmospheric circulation (Bucha, 1991). It is interesting to note that the cycles in our analysis *i.e.* 2980, 2200, 1644, 600–700, 400, 250, 190, 153 match with most of the solar cycles and also have been observed in magnetic activity and magnetic excursion (Bonifay, 1987).

Conclusions

Clean spectroscopy of high resolution deglaciation records reveals stable and statistically significant periodicities in solar cycles band. A basic deglaciation cycle with a 176 year periodicity correlates remarkably with the well established 178 year King Hale cycle, while other cycles reveal beating phenomena. Several questions remain yet to be settled regarding the physical linkage of the Sun and climate variability. However, our present analysis clearly indicates the role of exogenic forcing in triggering terrestrial climate variations and may provide significant constraints for understanding the solar-terrestrial climate relationships.

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References

Berger, W. H. (1990): The younger dryas cold spell – a quest for causes. Palaeoceanography, Palaeoclimatology, Palaeoecology (Global and Planetary Change Section), **89**, pp. 219–237.

Bonifay et al. (1987): Study of the Holocene and late Wurmian sediments at Lacdu Bouchet (Heute-Lore, France): First result. In: Climate history periodicity and predictability by M. R. Rampino et al., pp. 88, Van Nostrand Reinhold Company, New York, 1987.

Bray, J. R. (1968): Glaciation and solar activity since the fifth century B. C. and the solar cycle, Nature, **220**, 672–674.

Bucha, V. (1991): Solar and geomagnetic variability and changes of weather and climate. J. Atmospheric and Terrestrial Physics, **53**, pp. 1161–1172.

Burroughs, W. J., (1992): Weather cycles: Real or imaginary? Cambridge University Press.

Charvatova, I. and Strestik, J. (1991): Solar variability as a manifestation of the Sun's motion. J. Atmospheric and Terrestrial Physics, **53**, pp. 1019–1025.

Damon, E. D. (1989): Radiocarbon, solar activity and climate. Workshop on Mechanism for Tropospheric Effects of Solar variability and the quasibiennial oscillation, NCAR, Boulder, Colorado, pp. 199–200.

Drehar, J. W., Robert, D. H. and Lehar, J. (1986): Very large array observations of rapid non-periodic variations in OJ287, Nature, **320**, 239–242.

Duvall, T. L., Jr. and Harvey, J. W. (1984): Rotational frequency splitting of solar oscillations, Nature, **310**, 19–22.

Fairbridge, R. W. and Hillaire, M. C. (1977): An 8000 years palaeoclimate record of the Double Hale 45 yrs solar cycle, Nature, **268**, 413–416.

Jose, P. D. (1965): Sun's motions and sunspot. Astron. Jour., **70**, 193–204.

Landscheidt, T. (1987): Long range forecasts of solar cycles and climate change. In: Climate history and predictability (Ed. Rampino et al.).

Libby, M. et al., (1976): Isotopic tree thermometer, Nature, **261**, 284–288.

Libby, M. and Pandolf, L. J. (1977): Climate periods in tree, ice and tides, Nature, **266**, 415–417.

Linsley, B. K. and Thunell, R. C. (1990): The record of deglaciation in the Sulu Sea: Evidence for the younger dryas event in the Tropical Western Pacific. Palaeoceanography, **5**, no. 6, pp. 1025–1039.

Negi, J. G., Tiwari, R. K. and Rao, K. N. N. (1990): 'Clean' spectral analysis of long-term sea level changes, Terra Nova, **2**, pp. 138–141.

Negi, J. G., Tiwari, R. K. and Rao, K. N. N. (1996): Clean periodicity in secular variations of dolomite abundance in deep marine sediments, Marine Geology, **133**, 113–121.

Robert, D. H., Lehar, J. and Dreher, J. W. (1987): Time series analysis with clean derivation of spectra, Astron. J., **93**, 968–989.

Schlesinger, M. E. and Ramankutti, N. (1994): An oscillation in the global climate system of period 65–70 years, Nature, **367**, 723–726.

Simshoni, M. (1971): On the Fisher's test of significance, Geophys. J. Roy. Astr. Soc., **23**, 373–376.

Sonett, C. P. and Finney, S. A. (1990): The spectrum of radiocarbon, Phil. Trans. Roy. Soc., London A, **380**, pp. 413–426.

Stacey, C. M. (1963): Cyclic measure. Some tidal measures concerning equinoctal years, Ann. New York Acad. Sciences, No. 6.

Suess, H. E. and Linick, T. W. (1990): The C record in bristlecarie Pine wood of the past 8000 years based on the dendrochronology of the late C. W. Ferguson, Phil. Trans. Roy. Soc., London A, **330**, pp. 403–412.

Vio, R., Christiannis, Lossi O. and Provenzale, A. (1992): Time series analysis in astronomy: An application to quasar variability studies, Astron. J., **391**, 518–530.

William, G. E. (1981): Sunspot period in the late Precambrian glacial climate and solar planetary relationship, Nature, **291**, 624–628.

SAŽETAK

Utjecaj Sunca i plime čvrste Zemlje na podatke o deglacijaciji iz zapadnog tropskog Tihog oceana: »clean« spektralni pristup

R. K. Tiwari i K. N. N. Rao

Razmatra se utjecaj Sunca i plime čvrste Zemlje na podatke o klimi u prošlosti. »Clean« spektroskopija visoke razlučivosti podataka o izotopima ugljika i kisika iz Sulu mora (zapadni tropski Tihi ocean) koji se odnose na razdoblje prije 9000–22000 godina otkriva statistički signifikantne spektralne linije koje odgovaraju periodima od 2980, 690, 322, 250, 174 i 140 godina (ugljik), odnosno 1100, 533, 425, 183 i 151 godina (kisik). Ovi spektralni šiljci odgovaraju različitim solarno-klimatskim frekventnim pojasevima. Rezultati upućuju na tijesnu povezanost solarnih i klimatskih varijacija.

Ključne riječi: »clean« spektroskopija, solarni ciklusi, klimatske promjene

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