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Foraminiferal Evidences for 77-Year Cycles of Droughts in India and Its Possible Modulation by the Gleissberg Solar Cycle

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ABSTRACT

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A 1.15 m long core collected from 20 m water depth off Karwar on the western continental shelf of India was studied to reconstruct the paleomonsoonal, precipitational history during the recent past with fine time resolution by exploiting foraminifera as proxy. These established parameters (indicating salinity fluctuations, thus runoff from rivers due to the monsoonal precipitation over catchment area) are an angular-asymmetrical morpho-group, directly proportional to salinity. The mean proloculus size of *Rotalidium annectens* (PARKER and JONES), is inversely proportional to salinity and an abundance of indicator species *R. annectens* (PARKER and JONES) is directly proportional to salinity. These parameters show considerable fluctuations in the core (representing about 450 years) indicating variations in paleomonsoons in a cyclic manner (around 77 years). Attempts to establish correlation between inferred paleomonsoonal precipitation with known climatic cycles affecting the earth's climate suggest a possible link with the Gleissberg solar cycle of around 80 ± 10 years, which is already noted in various other climatic records.

ADDITIONAL INDEX WORDS: *Paleomonsoons, cyclicity, foraminifera, inner shelf, west coast of India, sediment core.*

INTRODUCTION

Due to recurrent floods and droughts occurring over different parts of India, the question of periodicities and trends of rainfall (if any) has assumed great importance (ALVI and KOTESWARAM, 1985). The detailed analyses of rainfall data by several investigators (RAO, 1958; KOTESWARAM and ALVI, 1969; PARATHASARATHY and DHAR, 1974; CHOWDHURY and ABHYANKAR, 1979; PARATHASARATHY and MOOLEY, 1981) identified some periodicities whose period range from quasi-biennial to 15 years. However, these periodicities have limited use for long-term predictions (SARKAR and THAPALIYAL, 1988). Detection of a long-term (decadal to century) trend is beyond the scope of meteorologists due to the shortness (available for the last 100–125 years) of the available record. This problem cannot be tackled without the use of proxy data, *i.e.* indirect evidence of rainfall.

To predict the future behavior of monsoons, understanding of changes with fine time resolution in the recent past is of utmost importance. The proxy records of climatic changes are preserved in the various natural archives such as tree rings, corals, ice cores, lacustrine and terrestrial sediments, etc. Besides these, shallow-water coastal areas with high sedimentation rates appear to have great potential for the understanding of such changes (SMITH and SCHAFER, 1987).

Several factors give tropical sedimentary deposits excellent temporal resolution in their preserved stratigraphic records. High sediment accumulation rate resulting from the large particulate inputs inhibits benthic habitation, reducing destruction of the stratigraphic record by bioturbation. The greater temporal resolution within accumulated strata means that the history of environmental events, both natural and anthropogenic can be well preserved in the coastal sedimentary deposits of the wet tropics (NITTROUER *et al.*, 1994).

Under appropriate circumstances, information concerning paleomonsoonal precipitation can be derived from foraminiferal (foraminifera are highly sensitive marine organisms) records in coastal sediments. Therefore, we have examined a shallow-water sediment core off Karwar on the

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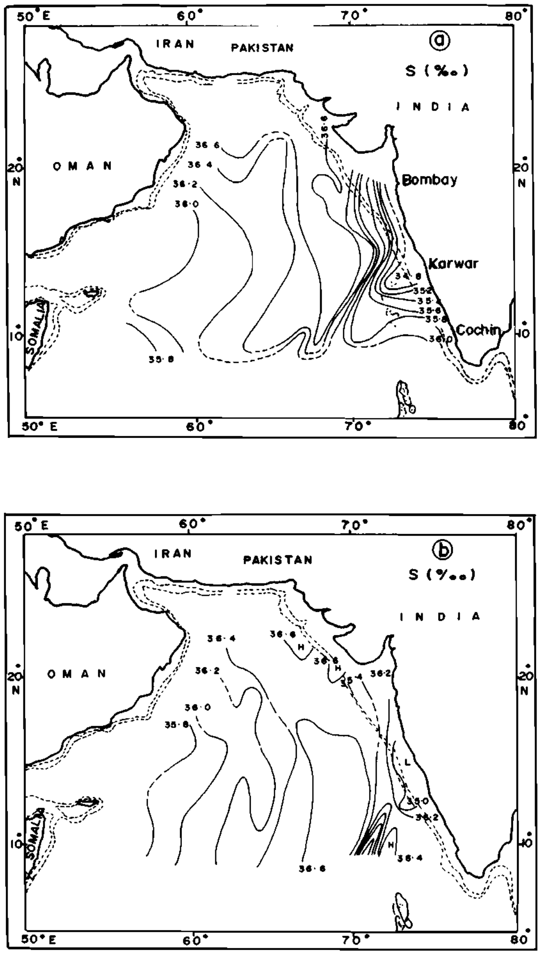

Figure 1. Salinity changes during monsoon period. (a) at sea surface, (b) at 50 m depth (Ramesh Babu, *personal communication*).

central west coast of India to identify suitable high-resolution records of monsoons in the past.

The main goals of the present study are:

(1) To investigate the short-term (decadal to century) changes in monsoonal pattern during the recent past through foraminiferal proxy evidences, and to delineate the existence of cyclicity (if any) in such records.
(2) To establish a correlation between inferred monsoonal variations with known climatic cycles affecting the earth's climates.
(3) In addition to the above, we develop a line of reasoning to explain the correspondence between extraterrestrial factors on the earth's climate and monsoonal precipitation.

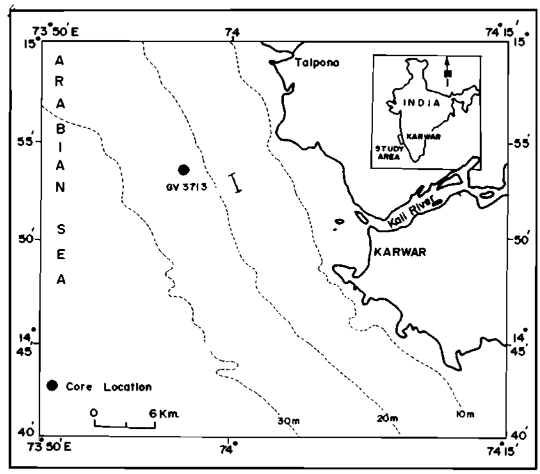

Figure 2. Showing location of the core (*GV 3713*), in the vicinity of the core location line (|—|) indicates position of sub bottom profile shown in Plate 1.

CONCEPTUAL MODEL

Paleo-precipitation can be studied through changes in river discharge as the seasonal heavy precipitation is carried into the Arabian Sea through numerous streams and rivers.

This approach assumes that any variation in the intensity of ancient rains could have affected physico-chemical conditions, such as salinity, nutrient content, and turbulence in nearshore regions, particularly at the mouths of estuaries through varying runoff. The existence of past variations could be ascertained by examining the seaward or landward extent of river-mouth micro-environments. These environments are characterized by different parameters of benthic foraminifera (a dominant fauna in shallow regions). The pulsation of such micro-environments depends upon fresh water (river) influx, as an indirect measure of monsoonal precipitation in the catchment area of the river and is expected to be in phase with changing river discharge.

PHYSIOGRAPHIC SETTING OF THE AREA

The continental shelf, off Karwar, is bordered by the coastal mountain range known as the *Western Ghats*, consisting of Dharwarian metamorphosed rocks of gneisses, schists, phyllites,

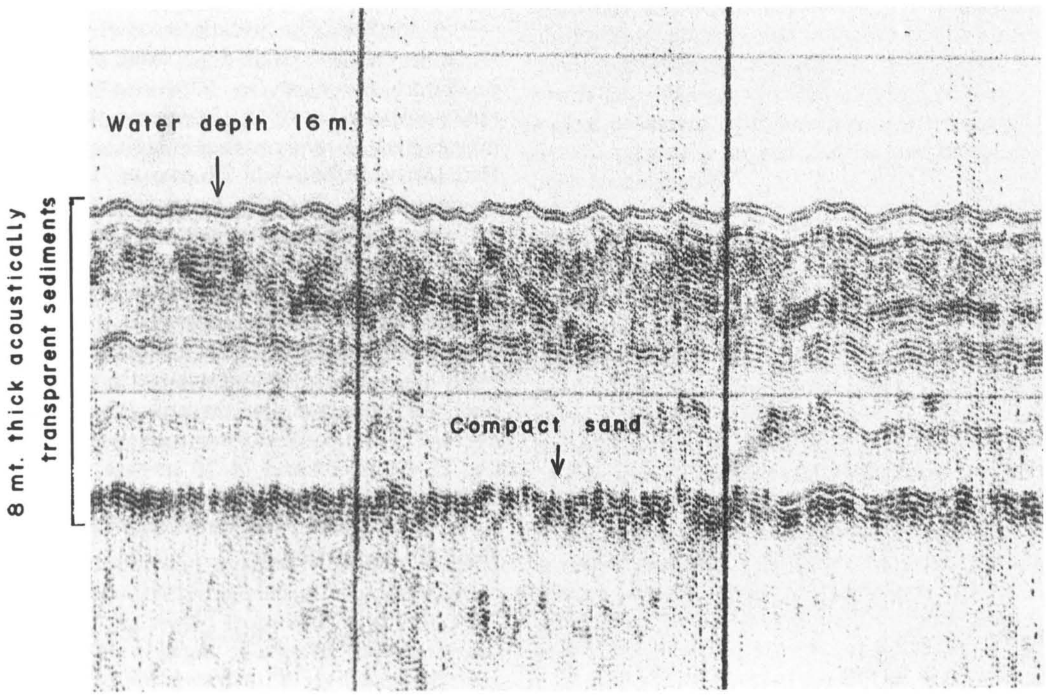

Plate 1. O.R.E. sub bottom profile (location given in Figure 2) in the vicinity of the study area.

quartzite and chlorite schists (KRISHNAN, 1968). This area receives seasonal heavy rainfall during the south-west monsoon (June to September) which is discharged through the two main rivers, the Kali and the Gangavali. The approximate lengths of these rivers are 68 and 40 km, and the annual average discharges are 207 and 156 m^3/sec, respectively (RAO, 1979). Previous studies carried out in this area reveal that salinity decreases and turbulence increases drastically during monsoon periods (ANNIGERI, 1968, 1972; RIVONKAR and REDDY, 1990). Figure 1 clearly indicates that decreases in salinity are not only confined to nearshore regions, but effects are seen up to 25 to 30 km away from the river mouth (RAMESH BABU, *personal communication*).

The seismic survey off the Kali River mouth, in the vicinity of the core (*GV 3713*) location, showed well-stratified, undisturbed, 8-m thick, acoustically transparent sediments (Plate 1). Similarly a down-core study of grain size in another core taken from the same location showed that the sediments are generally clayey silt (ranges of sand 3–5.4%; silt 52–60.5% and clay 35–48%) (HASHIMI, *unpublished data*).

METHODOLOGY

A 1.15 metre long core (*GV 3713*) was collected on board the *R.V. Gaveshani* during her 156th cruise, at lat. 14°53.1′N and long. 73°57.9′E near the mouth of the estuary of the Kali River (Figure 2) at 20 m water depth, using a steel box corer with a cross section of 10″ × 10″. This core was sampled at 5 cm intervals and a total of 23 samples were obtained. The sediment in the inner continental shelf at the presently studied core location is clayey silt.

The samples were washed through a 63 μm sieve and oven-dried. On the basis of external test morphologies, the percentage variation of all angular-asymmetrical forms of benthic foraminifera in the total fauna was calculated; it has been established that they are an excellent indicator of paleo-precipitation (NIGAM *et al.*, 1992). Because of the relative abundance (in percentage) of the species, *Rotalidium annectens* (PARKER and JONES), an

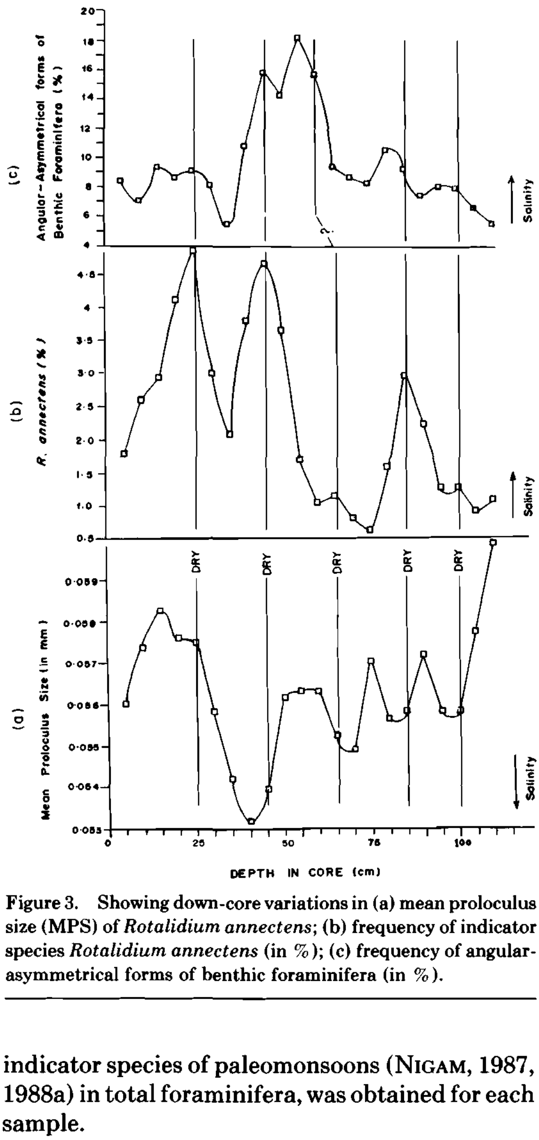

Figure 3. Showing down-core variations in (a) mean proloculus size (MPS) of *Rotalidium annectens*; (b) frequency of indicator species *Rotalidium annectens* (in %); (c) frequency of angular-asymmetrical forms of benthic foraminifera (in %).

indicator species of paleomonsoons (NIGAM, 1987, 1988a) in total foraminifera, was obtained for each sample.

About 75 specimens of the same species from each level of the core were separated. The diameter of the proloculus (initial chamber) of each specimen was measured with 25 μ precision. The average (in 3 decimal digits) of all measurements (in mm) was computed in order to obtain mean proloculus size (MPS) at each level. This MPS has been found to be inversely proportional to the salinity, and thus indicates the effects of fresh water in the coastal regions especially near river mouths (NIGAM, 1988b). All the above parameters were plotted against depth in core (Figure 3). In order to establish the chronology of the climatic events, accumulation rate was estimated by ^{210}Pb method.

^{210}Pb Method. The measurement of ^{210}Pb activity in the core was carried out using the standard procedure described by KRISHNASWAMY *et al.* (1971). About 5 g of the powdered samples was digested successively with HF, HNO_3, $HClO_4$ and HCl in the presence of Pb carrier. The Pb was precipitated as $PbCrO_4$. From this, the Pb was radiochemically purified using the ion-exchange technique, and Pb was precipitated as $PbSO_4$. The $PbSO_4$ of the samples was counted in a low background gas-flow beta counter (LAL and SCHINK, 1960) over a period of 20–30 days. The activity of ^{210}Pb was determined by the growth of its daughter ^{210}Bi. ^{226}Ra was also measured; however, the average of the bottom three sections in the core, *i.e.*, 22–24, 50–52 and 74–76 cm was assumed to be in equilibrium with parent ^{226}Ra, and their value of (0.96 + 0.08) was substracted to calculate the ^{210}Pb excess activity.

$$\underset{(dpm/g)}{^{210}Pb_{excess}} = \underset{(dpm/g)}{^{210}Pb_{total}} - \underset{(dpm/g)}{^{226}Ra}$$

Parent supported ^{210}Pb values (0.96 ± 0.08) dpm/g was substracted from the total concentration. The average computed sedimentation rate is 2.6 mm/year. This average uniform rate has been used to assign the apparent ages to the different intervals of the core.

The area of investigation is rather free from extensive storms which cause large scale erosions. The core also does not show any sign of break or sudden change in sedimentation process.

Foraminiferal Tracers of Paleomonsoons

We examined the records of angular-asymmetrical forms, the indicator species *Rotalidium annectens* (PARKER and JONES), and mean proloculus size (MPS) variations of *R. annectens*. These three well established ecological indicators are linked to a paleomonsoon's intensity in independent ways. For example, NIGAM *et al.* (1992) established that angular-asymmetrical forms of benthic foraminifera could be taken as a proxy indicator of paleomonsoonal precipitation. They (NIGAM *et al.*, 1992:Figure 2) found strong inverse relationship between the down-core percentage variations of these forms and physical meteorological rainfall record for the last 116 years. Similarly, earlier studies carried out along the west coast of India (NIGAM, 1987, 1988a) revealed that the foraminiferal species *R. annectens* was very rare to absent near river mouths, reflecting the dilution by fresh water. NIGAM and RAO (1987) and NIGAM (1988b) reported that mean proloculus size (MPS) could be an effective tool for paleoclimatic reconstructions, and they observed that MPS is inversely proportional to salinity ($r = -0.78$). The values were above the significance value (0.66) at the 99% confidence level, and thus suggest a relationship with freshwater river discharge, which depends on the monsoonal precipitation. This view is further tested by comparing the down-core variations in MPS at close intervals, with the physical rainfall data of the catchment area of the Kali River. The comparison indicates a direct correlation between the two (NIGAM and KHARE, in press).

RESULTS AND DISCUSSION

The minimum and maximum MPS recorded are 0.052 and 0.060 mm respectively, frequency of *R. annectens* varied from 0.55 to 4.88%, and percentage abundance of angular-asymmetrical forms fluctuated between 4.70 and 23.26%. In order to avoid noise in these data, moving averages were plotted in Figure 3a–c (which varied in MPS from 0.053 to 0.060 mm, in frequency of *R. annectens* from 0.63 to 4.87%, and in the case of angular-asymmetrical forms from 5.37 to 18.39%).

Since MPS is inversely proportional to salinity, troughs in curves (Figure 3a) suggest higher salinity conditions and are marked with 'Dry'. Similarly abundance of *R. annectens* is directly proportional to salinity fluctuations; thus, the peaks in the curve (Figure 3b) suggest higher salinity (dry) conditions. As the abundance of angular-asymmetrical forms is found to be an indicator of high salinity, peaks in the curve (Figure 3c) suggest dry conditions.

For the purpose of comparing the events inferred from three different parameters, we have joined the dry phases by lines (Figure 3). There is an overall similarity in the results. The comparison also revealed that dry conditions may be occurring in a cyclic manner at around 20 cm intervals.

On the basis of the ^{210}Pb method, we estimated the average sedimentation rate in this core to have been 2.6 mm per year. Therefore, the 20 cm sediment thickness should correspond to approximately a period of 77 years, and the whole 1.15 m long core may encompass about 450 years.

Cause for Cyclic Climatic Changes

Conventionally, it is believed that climate variability is a common phenomenon due to natural processes (GATES, 1979; HARE, 1979, 1985). The sun is the ultimate source of energy in meteorological processes, and thus a possible association between the solar output and the weather has long been investigated.

The *astronomical theory of climatic changes* was originated by CROLL (1875) and subsequently developed by MILANKOVITCH (1941). They suggested that the periodic changes in the eccentricity of the earth's elliptical orbit around the sun (100,000 years), tilt of the earth's axis (40,000 years) and precession of the earth's axis (23,000 years) were responsible for the glacial/interglacial cycle. Later this view was elaborated and modified by many others (RUDDIMAN and MCINTYRE, 1979; IMBRIE and IMBRIE, 1980; BERGER, 1988). Other studies have shown that major monsoonal fluctuations also occurred at these orbital periods (PRELL, 1984; PRELL and KUTZBACH, 1987; CLEMENS *et al.*, 1991; CROWLEY *et al.*, 1992; HOWARD and PRELL, 1992; LOURENS *et al.*, 1992).

In addition to these periodicities, smaller cyclic activities such as the 11 year cycle in numbers of sunspots (SEN GUPTA, 1957; JAGANATHAN and BHALME, 1973; KING, 1973; WARD and RUSSELL, 1981; CHOWDHURY *et al.*, 1981; CHAKRABORTY and BONDYOPADHYA, 1986), the 22 year Hale (double sunspot cycle), characterized by the reversal of the sun's magnetic field and sunspot orientation, and possible variations of the solar diameter (CHERNOSKY, 1966; MITCHELL *et al.*, 1979; LANSFORD, 1979; BHALME and MOOLEY, 1981; SCHUURMANS, 1981; SCHOVE, 1983; STOCKTON *et al.*, 1983; SHALTOUT and TADROS, 1990), and the 45 year double Hale solar magnetic cycle (FAIRBRIDGE and HILLARE-MARCEL, 1977) have also been implicated in climatic change.

An undulation of about 80 years may also be seen in a record of sunspot numbers over 350 years known as Gleissberg solar cycle (EDDY, 1977). SCHOVE (1984) reported that several climate cycles in the 60 to 90 years range have been documented (EDDY and BOORNAZIAN, 1979; DUNHAM *et al.*, 1980; PARKINSON *et al.*, 1980; GILLILAND, 1981; LANDSCHEIDT, 1981; FEYNMAN and FOUGERE, 1984). A cycle of almost the same length has been observed by us in the recurrence of dry conditions during the last few hundred years.

In view of the foregoing, we suggest that the cyclic recurrence of dry conditions (*ca.* 77 years)

Table 1. *Showing record of 80 ± 10 years cycle in solar and climatic events in different regions.*

1. Solar radius		PARKINSON *et al.*, 1980 (80*); GILLILAND, 1981 (76*); LANDSCHIT, 1981 (79*)
2. Auroral record	—	GLEISSBERG, 1965 (88*); SISCOE, 1980 (80*); FEYNMAN and FOUGERE, 1984 (88*)
3. Atmospheric ^{14}C	—	STUIVER, 1980 (70*); STUIVER and QVAY, 1980 (79*)
4. Temperature	Northern Hemisphere	AGEE, 1980 (90*); SCHLESINGER and RAMANKUTTY, 1994 (65–70*)
	Low latitude region especially (S. India)	JOSEPH and AMATYA, 1986 (90*)
	Global average Sea surface temperature	REID, 1987 (80–90*)
5. Rainfall	Beijing (China)	HAMEED *et al.*, 1983 (78–80*); CURRIE and FAIRBRIDGE, 1985 (78–80*)
6. Flood level of river	Nile river Africa	FAIRBRIDGE, 1984 (78*)
7. $^{18}O/^{16}O$ ratio in Ice core	Greenland Ice sheet	JOHNSEN *et al.*, 1970 (78*)

*Period of cycle mentioned in original reference

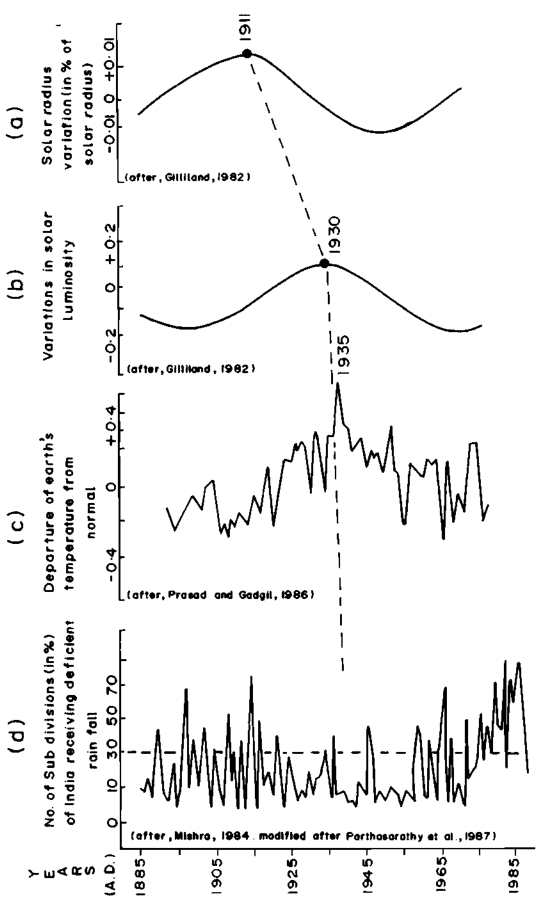

Figure 4. Showing the trends of (a) solar radius, (b) luminosity, (c) earth's temperature, and (d) percentage of meteorological subdivisions of India receiving deficient rainfall.

revealed in our data seems to be very close to the Gleissberg cycle of sun.

Evidence of almost similar cycles are also seen in many solar/climatic records (Table 1). Furthermore, rainfall records of India (summer monsoonal as well as average rainfall) and Western Sahel clearly exhibit the clustering of drought years at a time interval of around 70 years (REPORT—DEPARTMENT OF SCIENCE AND TECHNOLOGY, GOVT. OF INDIA, 1991; HELLDE'N, 1991), which is very close to *ca.* 77 years cycle between dry periods, reveled in the proxy data of paleomonsoons in this study. Occurrences of the similar cycle are also documented in the rainfall record of Beijing, northeastern China (HAMEED *et al.*, 1983; CURRIE and FAIRBRIDGE, 1985) and Nile flood levels in Africa (FAIRBRIDGE, 1984).

A Possible Mechanism

According to EDDY *et al.* (1982), "The equilibrium temperature of the earth's surface and sea is ultimately determined by a balance between solar radiation absorbed by the earth primarily at visible and near infra-red wave lengths, and long-wave radiation that is re-emitted to space. Should the total solar input vary as a persistent trend, the surface temperature of the earth will in time respond in a direct and predictable fashion". A change of only a few tenths of a percent in the total energy radiated from the sun is sufficient to cause profound meteorological changes (HERMAN and GOLDBERG, 1977). The correlation of solar activity variations with climate changes on time scales of centuries led to the suggestion that the solar luminosity may vary by around 1% on these time scales of several decades or longer. Solar (GLEISSBERG, 1965; GILLILAND, 1981) and terrestrial (JOHNSEN *et al.*, 1970; MITHCELL *et al.*, 1979) variations on a 70–80 years time scale are ubiquitous, and may be consistent with variation (76 yr) in luminosity (GILLILAND, 1982). The currently available satellite data are sufficient to rule out a major solar-variation effect on surface temperature in the short term, but longer-term effects are still possible and may even be quite important (HOFFERT, 1991).

GILLILAND (1982) has reported that "the theoretical models of the sun have consistently suggested that large changes of solar luminosity would accompany changes of solar radius; theory also predicts that compared to radius, variations in the solar luminosity are larger" and long-term variations in the solar luminosity lead to corresponding changes in the climate of the earth (HOYT, 1979).

In view of the previous summary, an attempt is made to compare the recent trends of solar radius and variations of solar luminosity (Figure 4a and b respectively) (GILLILAND, 1982) and global temperature (Figure 4c) (PRASAD and GADGIL, 1986). As reported by GILLILAND (1982), "The variation of luminosity trails the radius variation by 18.5 years and the climate response introduces a further lag of around 5 years". Therefore, the solar radius maximum of around 1911 is followed by a luminosity maximum around 1930 and maximum earth's temperature response around 1935. The period around 1935 shows a relatively higher precipitation as revealed by fewer meteorological subdivisions showing deficient rainfall (Figure 4d) (MISHRA, 1984; modified after PARATHASARATHY *et al.*, 1987).

In view of the above discussions and an apparent association between the Gleissberg cycle and clustering of dry periods in our proxy data, we speculate further that cyclic changes in the solar radiations as determined by periodical changes in the sun's radius (Gleissberg cycle) may possibly modulate the earth's climate as well as monsoonal precipitation. A relationship of this type, if confirmed by further measurements, may have significant implications for the study of paleoclimates and their predictions.

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