Solar control of southwest monsoon on centennial timescales

M. Tiwari[1,*], R. Ramesh[1], B. L. K. Somayajulu[1], A. J. T. Jull[2] and G. S. Burr[2]

[1]Physical Research Laboratory, Ahmedabad 380 009, India
[2]NSF Arizona AMS Facility, University of Arizona, Tucson, AZ85721, USA

Solar forcing is proposed to be a major governing factor for the southwest monsoon (SWM) strength during the Holocene. The southeastern Arabian Sea is significantly affected by monsoon run-off and is an ideal testing ground. We analysed stable oxygen isotopic composition ($d^{18}O$) of three species of planktonic foraminifera (*Globigerinoides ruber*, *Gs. sacculifer* and *Globarotalia menardii*) with high time-resolution (~ 50 yrs) in a sediment core raised from the region, and documented past variations in SWM precipitation. High-resolution isotopic and spectral analyses show that solar forcing indeed played a major role in governing the past variations in SWM precipitation on centennial timescales.

Keywords: Arabian Sea, foraminifera, monsoon, stable isotopes, solar forcing.

IT has been proposed that earth's climate is sensitive to mild changes in solar output at decadal to millennial timescales[1]. Currently, there has been renewed interest in climate forcing by Total Solar Irradiance (TSI), which shows remarkable agreement with the smoothened global temperature of the 20th century[2]. Precise measurement of TSI has been made using space-borne radiometers; it varies with an rms amplitude of about 0.1% in response to the changing area covered by sunspots on the solar disk. But this variation seems to be too low to cause widespread climatic change. It could be that there is a large amplitude, slowly varying component of TSI, overlooked by the space-borne measurements. It is believed that TSI might have been lower by as much as 0.25% during the Maunder Minimum (AD ~ 1700) than at present[3] and even a minor variation in TSI (0.1–0.3%) could bring about major changes in monsoonal precipitation via various positive feedback processes, such as moisture availability and changes in atmospheric circulation[1,4,5]. Neff *et al.*[4] measured stable oxygen isotope ratios ($d^{18}O$, monsoon proxy) in Oman speleothems for the period 9 to 6 ka and compared them with $\Delta^{14}C$ values from tree rings, which are dependent on cosmic ray fluxes modulated by solar activity. They found excellent correlation between the monsoon and solar activity proxies and proposed that variation in solar radiation has a prominent control over the monsoon on centennial to decadal timescales. Fleitmann *et al.*[6] analysed Holocene stalagmites from Oman and compared $d^{18}O$ data with GRIP ice core $d^{18}O$ and $\Delta^{14}C$ records from tree rings. They proposed that early Holocene monsoon circulation was controlled by glacial boundary conditions such as northward heat transport in the Atlantic and thermohaline circulation. Subsequently, after 8 ka, as the thermohaline circulation stabilized, the monsoon circulation responded more directly to solar forcing[6]. Agnihotri *et al.*[7] obtained a core from the northeastern Arabian Sea, off the Gujarat coast and analysed it for three palaeoclimatic proxies (organic carbon, nitrogen and aluminum content of marine sediments) for the past 1200 years and compared them with TSI data. They found nearly similar trends for these proxies and TSI variation within the radiocarbon dating errors; lower TSI was accompanied by lower productivity and reduced run-off, indicating weakened SWM. Spectral analyses of the TSI, palaeoclimatic proxies and SWM rainfall yielded similar periodicities, which led them to infer that solar forcing controlled the monsoonal precipitation on multi-decadal timescales[7,8], similar to the results obtained on varve sediments off Karachi[9]. They[7] reported weight % and not the burial fluxes; these proxies reflect the strength of the SWM wind and not precipitation. The southeastern Arabian Sea offers an opportunity to determine the past fluctuations in precipitation, as it receives freshwater run-off during the SW monsoon[10]. We carried out high-resolution oxygen isotope analysis of planktonic foraminifera from a sediment core in the region, which documents past variations in SW monsoon precipitation.

The core is from the eastern continental margin of the Arabian Sea (12.6°N, 74.3°E; water depth = 400 m; dated length = 252 cm) off Mangalore coast (Figure 1). This core (SK145-9) has eleven dates covering ~ 13,000 calendar years (spanning 252 cm length) providing an average sedimentation rate of 19 cm/10^3 years (Table 1). It has an average resolution of ~ 50 years per cm. The top 50 cm has been sampled at every centimere and below 50 cm sampling was done at every 2 cm. The top 50 cm of this core (sampled closely), covering a time span of approximately 2800 years (Figure 2), has been taken for further studies. Thus it offers a high time-resolution and therefore will aid in under-

Table 1. Uncalibrated and calibrated AMS radiocarbon ages of planktonic foraminifera for core SK145-9. Errors quoted are 1 *s*

Depth (cm)	Radiocarbon age (yrs BP)	Calibrated age (yrs BP)
0–2	844 ± 36	410 ± 80
23–25	1899 ± 56	1330 ± 80
40–41	2506 ± 39	2030 ± 70
50–52	3210 ± 41	2860 ± 70
78–80	3952 ± 53	3820 ± 80
124–126	6308 ± 48	6650 ± 60
160–162	8124 ± 66	8450 ± 90
174–176	8891 ± 64	9210 ± 270
210–212	9359 ± 57	9840 ± 230
228–230	9922 ± 58	10430 ± 380
250–252	11913 ± 73	13180 ± 350

*For correspondence. (e-mail: tmanish@prl.res.in)