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Evidence for Solar Forcing of the Indian Ocean Monsoon in a High-Resolution Speleothem Record from Oman

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Although, a number of climate records appear to show correlations between centurial and decadal scale cycles of solar activity and climate, the absolute changes in solar intensity on these timescales are generally small and solar influence on climate, direct or indirect, is not well established. We present a high-resolution study of variation in the Indian Ocean monsoon during the period from 10.3 to 6.2ka derived from oxygen isotope variation in a Th/U dated speleothem from Oman. The speleothem $\delta^{18}O$ values serve as a proxy for estimating variation in monsoon intensity by measuring past changes in $\delta^{18}O$ of monsoon rainfall as recorded in speleothem calcite $\delta^{18}O$. At present, information on monsoon variation on decadal to centurial timescales is limited to identification of 'centurial-scale' changes in sedimentary records, but these studies lack the resolution to determine specific periodicities or forcing mechanisms. Our results suggest that one of the primary forcing functions on the monsoon over this time period is solar activity.

The speleothem studied is taken from Hoti Cave, located in northern Oman on the southwestern side of the Oman mountains (57º21'E, 23º05'N, 800meters above sea level). The modern climate of the area is arid to semi arid, and the area is not presently affected by the Indian Ocean monsoon system. During the early to mid-Holocene, however, the northern limit of monsoon rainfall belt was shifted far north of its modern location, including covering the area of Hoti Cave, which resulted in deposition of a set of large stalagmites in the cave.

To produce a high-resolution record of climate variation during this pluvial period in northern Oman we took very closely spaced samples from a 43cm core from stalagmite H5 for stable isotope analyses, and more widely spaced samples for Th/U age determinations by thermal ionization mass spectrometry. The Th/U ages show that the cored material was deposited between 10.2ka and 6.2ka. Growth rates vary considerably during this period, ranging from 0.03mm/y to 0.57mm/y. A total of 1020 samples for isotopic measurements were drilled from the core by hand with an average sampling interval of 0.4mm, yielding an average time resolution for the core of 4.1 years. For the fastest growth interval, however, between 7.9 and 8.3ka, the resolution increases to 1.4 years between samples. Spectral analyses of the $\delta^{18}O$ results show statistically significant periodicities centered on 354, 205, 134 and 87 years. Two broader sets of cycles centered on 32a and 21a also exist in the spectral analysis of the entire data set. Over the time period from 7.9 to 8.3ka, more rapid speleothem growth results in a much higher resolution ^{18}O record. Within this growth interval, spectral analysis reveals further cycles with periodicities of 24a, 7.5a, and 3a.

Most of the periodicities present in the H5 records also appear in the Holocene $\Delta^{14}C$ record measured on tree rings. The number of common cycles observed in spectral analyses led us to make a direct comparison of the H5 $\delta^{18}O$ curve and the $\Delta^{14}C$ curve for the period of deposition of the H5 record. By adjusting the ages of the $\delta^{18}O$ curve within the errors of the Th/U age determinations at each measurement point, we were able to match the two curves to a remarkable degree. In both overall character and the shape and amplitude of individual peaks, the two curves are strikingly similar. The strong similarity between the smoothed secular variation curves and spectral analyses of the H5 $\delta^{18}O$ isotopic record and the $\Delta^{14}C$ record suggests that both are responding to the same climate forcing. Much of the variation in $\Delta^{14}C$ at these timescales is attributed to solar forcing through variations in solar activity and intensity. Maxima of ^{10}Be concentrations in polar ice cores that are synchronous to maxima in $\Delta^{14}C$ further reinforce this interpretation. Thus, to the extent that centurial and decadal variation in the $\Delta^{14}C$ record is controlled by changes in global solar radiation, so must be changes in the intensity of the Indian Ocean monsoon.