Monsoon response to global climate change

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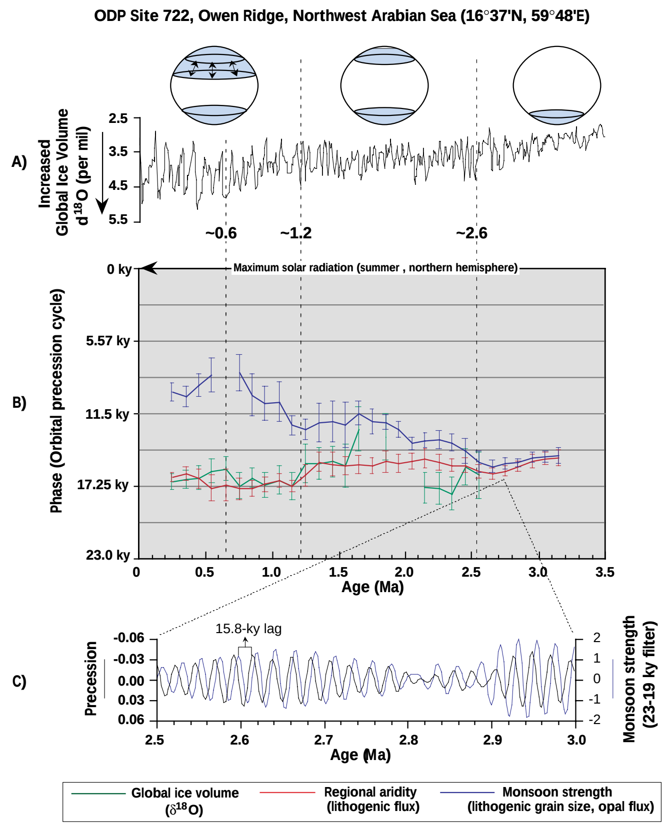
From seasonal to tectonic time scales, the Earth's climate responds to changes in external forcing (solar energy) and internal dynamics (the redistribution of energy among the hydrosphere, cryosphere, atmosphere, and lithosphere). Orbital-scale (23,000 year) climate cycles are driven largely by variations in solar-radiation associated with precession of the Earth's orbit.

Over the last ~600,000 years, a portion of global climate change is linked directly to cyclical changes in global ice-volume (the ice-ages) which in turn, is linked directly to changes in orbital precession. Thus, climate change at this scale, including variations in the strength of the Asian monsoon, appear locked in step (phase-locked) with cyclical insolation forcing.

However, the three-million year long climate records from Site 722 (Arabian Sea) indicate that the timing of strong monsoons changed systematically relative to changes in ice-volume and precession forcing as the northern hemisphere developed high-latitude ice sheets [*Clemens, et al.,* 1996]. Prior to 2.6 million years ago (Ma), ice sheets were largely restricted to the south pole (A). At this time the strongest monsoons occurred 16,000 years into each 23,000-year precession cycle and were coincident with times of increased ice-volume and global aridity (B,C). With the initiation and growth of northern hemisphere ice sheets after 2.6 Ma, the strongest monsoons occurred progressively earlier within each precession cycle. In addition, well-documented increases in ice volume at 2.6, 1.2, and 0.6 Ma, correspond to changes in the timing (phase) of the monsoon response to precessional forcing (B). Together, these data indicate that increases in high-latitude ice sheets weaken the low-latitude Asian Monsoon, driving the observed phase shifts.

Mechanisms for weakening low-latitude monsoon circulation are currently being explored using coupled ocean-atmosphere general circulation models. Potential mechanisms include increased albedo associated with snow cover or vegetation change, downstream effects of decreased sea surface temperatures in the North Atlantic, and decreased export of latent heat from the southern Indian ocean.



Part A. Changes in global ice volume over the past 3.5 Ma [*Tiedemann et al.,* 1994] and schematic evolution of global ice sheets. Part B. Phase plot showing the relative timing of maximum ice volume, aridity, and monsoon strength within each 23,000 year precession cycle. Part C. An example of the actual time-series data used to define a single point on the phase plot (in this case, for the monsoon data point centered at 2.75 Ma).

References:

Clemens, S. C., D. W. Murray, and W. L. Prell, Nonstationary Phase of the Plio-Pleistocene Asian Monsoon, *Science, 274,* 943-948, 1996.

Tiedemann, R., M. Sarnthein, and N. J. Shackleton, Astronomical timescale for the Pliocene Atlantic d^{18}O and dust flux records of ODP Site 659, *Paleoceanography, 9,* 619-638, 1994.