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Milankovitch Theory and Global Monsoon

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The Milankovitch Theory of orbital climate change postulates that changes in the caloric summer half-year insolation (or Northern Hemisphere summer insolation (NHSI) at ~65°N latitude) drive changes in the ice-sheets extent (i.e., global ice-volume) at Earth's orbital periods (i.e., the *sensu-stricto* theory). These insolation-driven changes in turn, incite ancillary changes in other parts of the global climate systems via various forcing and feedback mechanisms (the *sensu-lato* hypothesis). In this theoretical framework the high-latitude glaciation processes took the center stage while the low-latitude global monsoon was essentially excluded. In the last two decades, large numbers of cave $d^{18}O$ records with precise radiometric chronologies have propelled speleothems to the forefront of paleoclimatology. Of particular interest are the speleothem records from North America that reveal a persistent orbital pacing of the North American climate at the precession band, which is nearly in phase with changes in the global ice-volume and atmospheric CO_2 but lags June insolation at 65°N by ~5000 years, in accordance with the *sensu-stricto* Milankovitch theory. Contrastingly, the low-latitude tropical speleothem records manifest an orbital-scale pattern of global monsoon, which is dominated by precession cycles with a nearly anti-phased relation between the two hemispheres. Importantly, the monsoon variations track summer (July/January) insolation without significant lags at the precession band. We thus suggest that precession-induced changes in summer insolation produce distinct climate variability in the ice-sheet proximal and tropical regions predominantly via the (delayed) ice-volume/CO_2 forcing/feedbacks and nearly-in-phase monsoon/CH_4 responses/feedbacks.

As for global-scale millennial events that were superimposed on orbital-scale climate variations, the essence of these events—i.e., conventional ice age terminations and other smaller events (the so-called 'low-amplitude versions of terminations'), is virtually similar. The time-series of millennial-scale variations after removing orbital insolation signals from the speleothem monsoon record and long-term trend in the Antarctic ice core temperature (δD) record characterize the millennial climate variances of both ice age termination and low-amplitude versions of termination events. Remarkably, the millennial-scale variations show significant obliquity and precession cycles that are in-phase with North Hemisphere June insolation, implying a critical role of changes in orbital insolation in triggering the ice age terminations. These observations, in turn, provide new insights into the classic '100 ka problem'.

Indeed, a more comprehensive picture of orbital theory of climate is steadily emerging with the growth of new geological proxy data, particularly the low-latitude speleothem data from the vast global monsoon regime, providing critical complements to marine and ice-core data.