Supplementary Materials for

Precession driven low-latitude hydrological cycle paced by shifting perihelion

The PDF file includes:

Figs. S1 to S5

Other Supplementary Materials for this manuscript include the following:

Movie S1

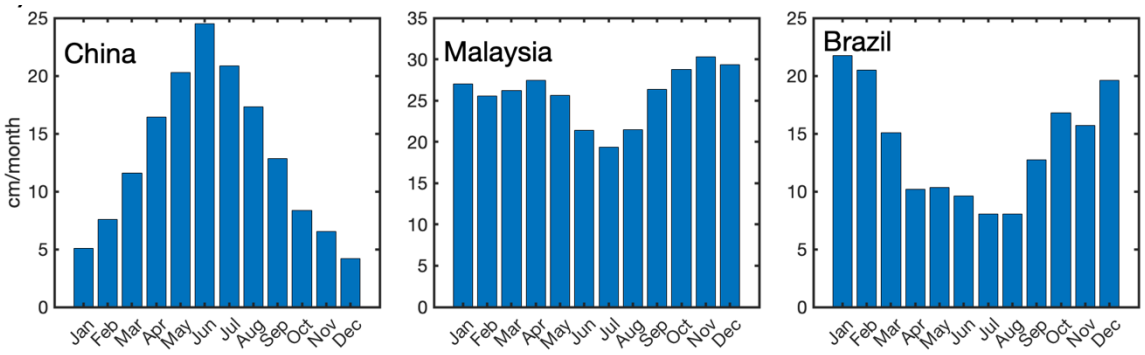

Fig. S1. The seasonal distribution of precipitation near the selected stalagmite oxygen isotope in Fig. 1. Around East China, the dominant rainy season is boreal summer; Around Brazil, it is boreal winter. Near Malaysia, there are two rainy seasons, i.e., boreal spring and autumn. Results based on ECMWF Reanalysis v5 (ERA5) reanalysis dataset covering 1940-2022 (Hersbach et al., 2019).

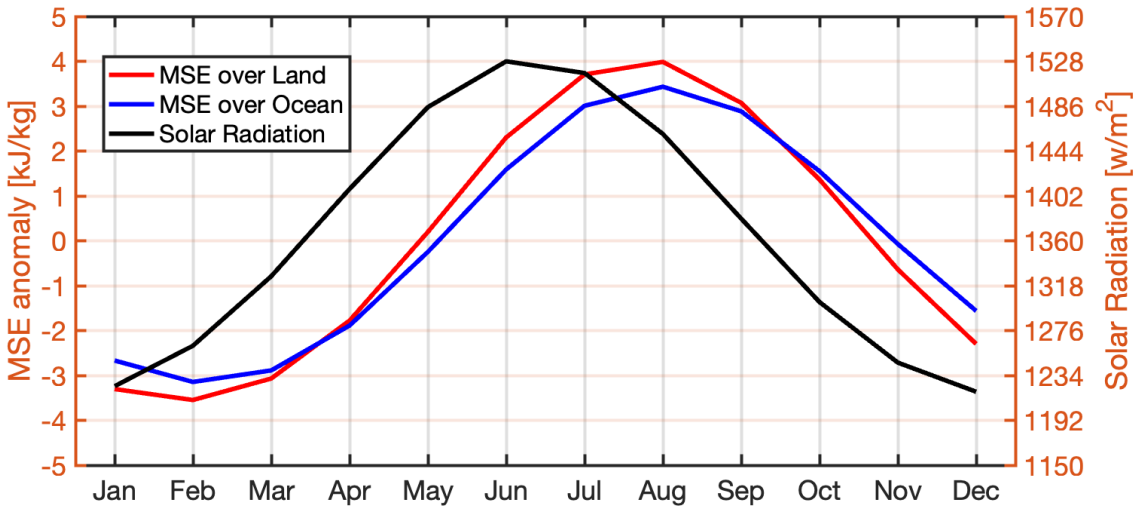

Fig. S2. Seasonal solar radiation (black line) and moist static energy (MSE) anomaly over land (red line) and ocean (blue line). Results are based on the idealized Earth system simulation with obliquity to be 0, and eccentricity to be 0.058. In this setup, the perihelion occurs in June and aphelion takes place in December. Due to different thermal inertia between land surface and ocean, the atmospheric heating over land is much faster than that over the ocean. This leads to stronger increase in moist static energy during perihelion, and vice versa during aphelion.

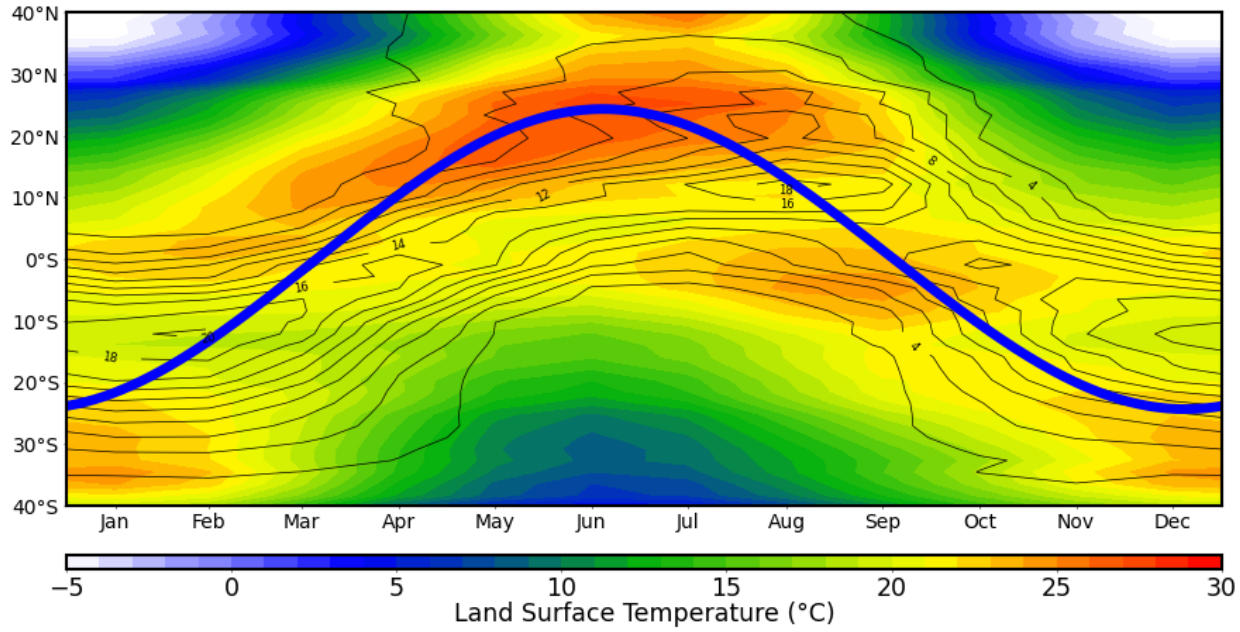

Fig. S3. Seasonal migration of the Sun's zenith point (thick blue line), land thermal equator (shading color) and precipitation over land (black contours). Shading colors represent zonal mean land surface temperature. Contours show the zonal mean precipitation on land (unit: mm/day). The seasonal movement of the Sun's zenith point fundamentally determines the position of the Earth's thermal equator, where deep convection and low-latitude precipitation takes place. Due to the thermal inertia of Earth, the thermal equator and land precipitation do not precisely coincide with the timing of maximal solar radiation, i.e., the Sun's zenith point, but rather experience a delay of approximately 1-2 months. Results are based on the ensemble mean of the 24 simulations with different precessional phases (see Methodology).

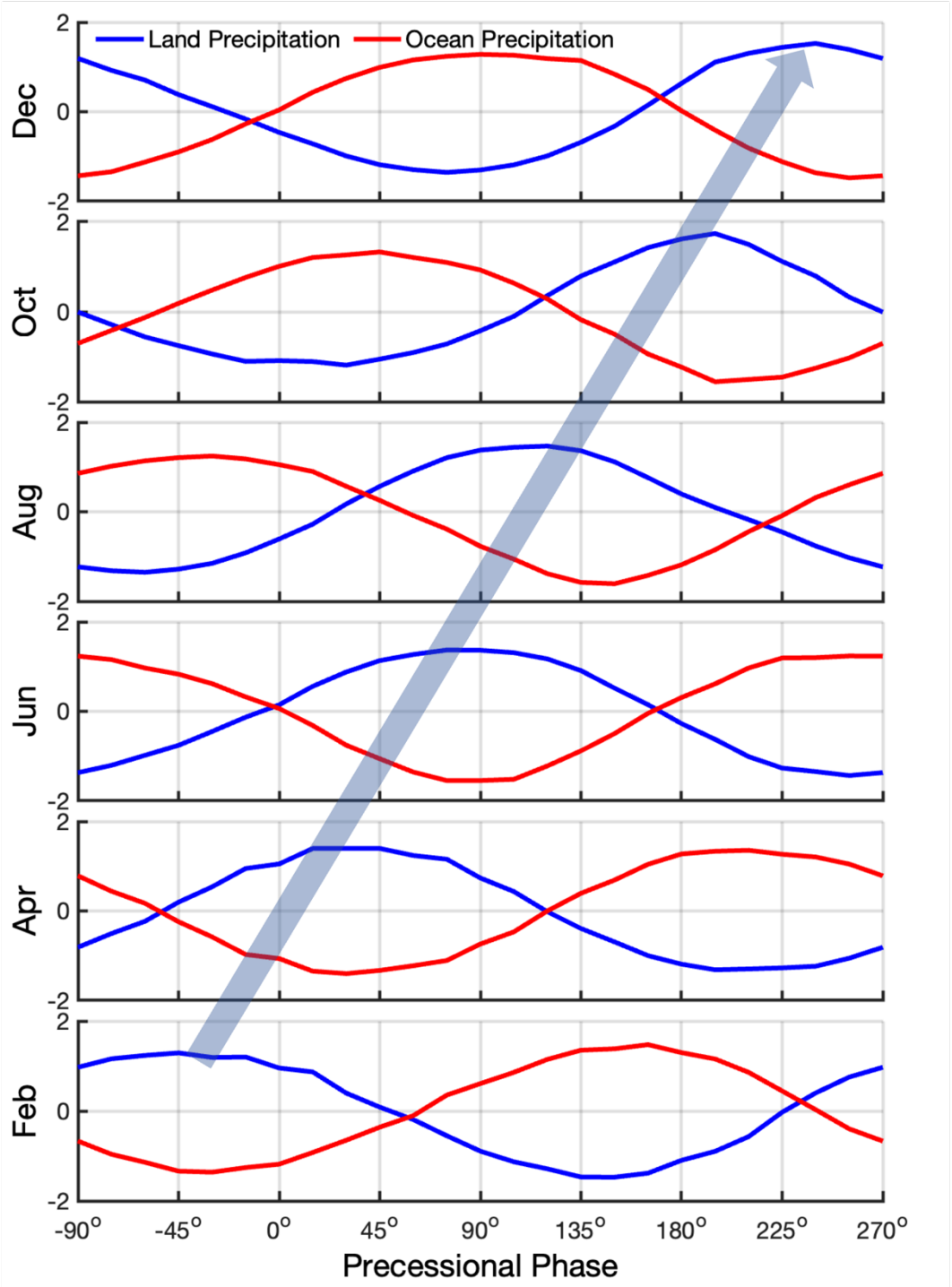

Fig. S4. Tropical convective precipitation over land (blue lines) and ocean (red lines), respectively. These precipitations are shown as standardized total amount of convective precipitation over tropical area (30°S-30°N). Enhances land precipitation around perihelion correspond to decrease ocean precipitation. Due to seasonal shifting perihelion (blue arrow), the seasonal land precipitation maxima are achieved at different precessional phases. Results based on 24 AWI-ESM time-slice simulations recovering a precessional cycle (see Materials and Methods).

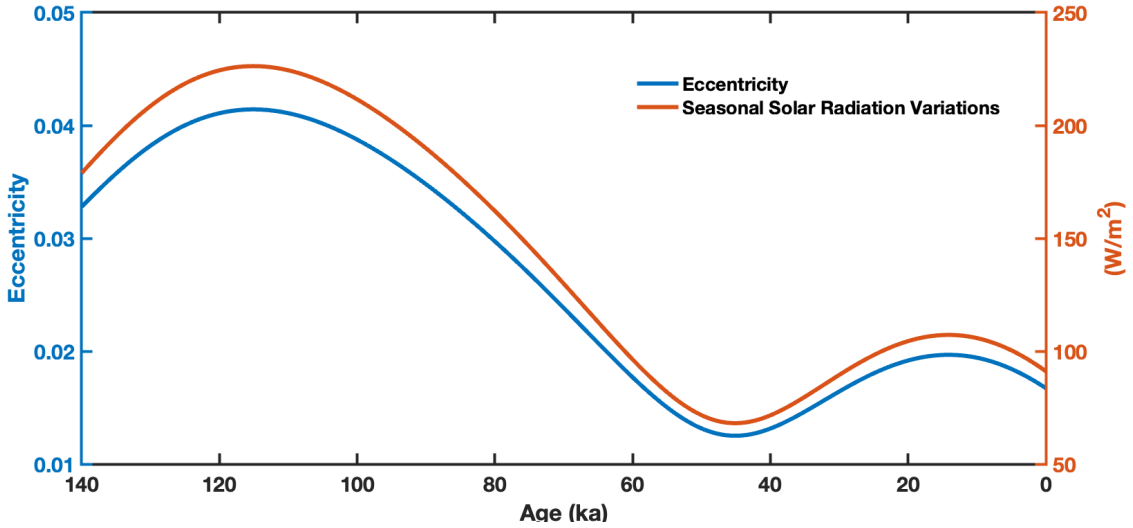

Fig. S5. Eccentricity and magnitude of seasonal variations of solar radiation strength in the past 140 ka. The eccentricity is calculated based on Berger (1978), and the amplitude of seasonal incoming solar radiation intensity is calculated as the difference between the solar radiation at perihelion and aphelion.

Movie S1 can be access from this link https://zenodo.org/doi/10.5281/zenodo.11395458

Movie S1: Shifting season and latitude of perihelion due to precession of the Earth's rotation axis. (A) Schematic view of perihelion. (B). Geometric perspective showing how precession of the Earth's rotation axis alters the latitude of perihelion. The yellow arrows illustrate the solar radiation. The black lines represent the Tropic of Cancer and Tropic of Capricorn, respectively. The pink line gives the latitude of perihelion which is the latitude of the Sun's zenith point when perihelion occurs. (C). Evolution of seasonal solar radiation pattern within a precessional cycle. The color circle depicts the seasonal distribution of solar radiation, which is determined by the distance between the Sun and the Earth. The changing number at the top of subpanel give the precessional phase. The pink dot represents the position of perihelion. Wherever the perihelion takes places, the insolation at that latitude and season reaches its maximal value within a precessional cycle. (D). Changing latitude of perihelion in a precessional cycle. Within a precessional cycle, the latitude of perihelion moves from the Tropic of Capricorn to the Tropic of Cancer and back again, like the movement of Sun's zenith point within a year. In this movie, the eccentricity is set to 0.058 and the obliquity is fixed at 24.5^{o}.

References:

Hersbach, H., Bell, B., Berrisford, P., Horányi, A., Sabater, J. M., Nicolas, J., Radu, R., Schepers, D., Simmons, A., Soci, C., & Dee, D. (2019). Global reanalysis: goodbye ERA-Interim, hello ERA5. ECMWF Newsl, 159, 17–24.