Project: **1332**

Project title: **The effect of Atlantic Meridional Overturning Circulation on the South Asian monsoon**

Principal investigator: **Chetankumar Jalihal**

Report period: **2022-11-01 to 2023-10-31**

Overview

Migrating from Mistral to Levante took longer than expected. Validation and evaluation of the fully coupled model (MPI-ESM with atm-ocn-land-seaice-icesheet-solid earth) against runs under the same settings in Mistral were required to be carried out. The whole process took the better part of the year, and only now is the model available for production runs. In the meantime, I have been studying monsoons in some of the already existing simulations that were carried out on Mistral. This has thrown new light on our understanding of monsoon processes. Based on these new insights, different experiments have been proposed for the following year. I am currently in the process of communicating these results to a suitable journal. In the time that remains till the end of the current allocation period, I will be carrying out some of the previously planned sensitivity experiments.

Role of cloud and water vapor feedback on monsoons: perspectives from retrograde Earth simulation

Traditionally, monsoons have been attributed to the land-sea thermal contrast. Over the last couple of decades, this theory has been discredited, and the focus has shifted to theories based on meridional movement in the inter-tropical convergence zone (ITCZ) and moist-static energy budgets. Using a simulation of the retrograde Earth, I have assessed the validity of each of these theories. I chose this simulation because a reversal in Earth's rotation while keeping all the other boundary conditions constant, renders a monsoonal Sahara. This substantial transition of the Sahara from a desert to a region of heavy precipitation can elucidate the ingredients essential for a monsoonal climate.In the forward (prograde) simulation, the Sahara is a desert despite having a large thermal contrast with the surrounding ocean. On the other hand, in the reverse rotating world, the Sahara has high precipitation even though the Saharan land is colder than the surrounding ocean. This result aligns with one of the critical arguments proposed against the land-sea thermal contrast theory. In the retrograde simulation, the Atlantic Meridional Overturning Circulation (AMOC) collapses, reducing the interhemispheric temperature contrast in the Atlantic and African sectors. Correspondingly, there is a southward shift in the Atlantic ITCZ.

Interestingly, the ITCZ over Africa moves northward despite the reduced interhemispheric temperature difference. This underscores the role played by local factors, which are accounted for in the moist-static energy budget framework. We find that the cloud and water vapor radiative feedback over the Sahara play a crucial role in the transition from a dry to a wet Sahara and, thus, are potentially one of the key ingredients for the existence of monsoons.

Different evolution of land-Ocean monsoon evolution and role of ice sheets

In the modern climate, the monsoon variability – unforced and forced, across the South Asian monsoon domain is nearly uniform. However, recent studies from models and proxies suggest that on longer timescales, land and ocean monsoons tend to be out of phase. To examine this in a comprehensive earth system model, I considered a long transient simulation (49,000 years ago till present) with realistic forcings from greenhouse gases and changes in Earth's orbit. The ice sheet evolves in an online interactive manner. The model has a decent agreement with various proxies (Fig. 1a). Depicted in Fig. 1b is the evolution of monsoon in this simulation averaged over the South Asian land and ocean regions separately. During the cold glacial period (49ka to ~15ka), land and ocean monsoons evolve in sync. However, land and ocean monsoons are out-of-phase from 15ka to the present. This changing phase between the two monsoons can be explained with the energetics theory. During colder periods, monsoons are driven by the changes in the local moist stability of the atmospheric column called TGMS (total gross moist stability). Since this has a similar variability over land and ocean, monsoons are in phase. During warm periods, net energy flux into the atmosphere is the dominant factor driving monsoons. This parameter lags over the ocean compared to land due to the thermal inertia of the ocean. Thus leading to a phase difference in monsoon evolution over land and ocean.

In the late Holocene (~4ka to present), monsoon strength over South Asian land does not decline, as is expected from proxies. This model has a small "bonus ice sheet" at the end of the deglacial, which persists through the Holocene. Surprisingly, removing the bonus ice sheet resolves this issue (Fig. 1c). This result underscores the sensitivity of monsoons to high-latitude ice sheets and bears important implications for understanding the monsoon response to Heinrich events.

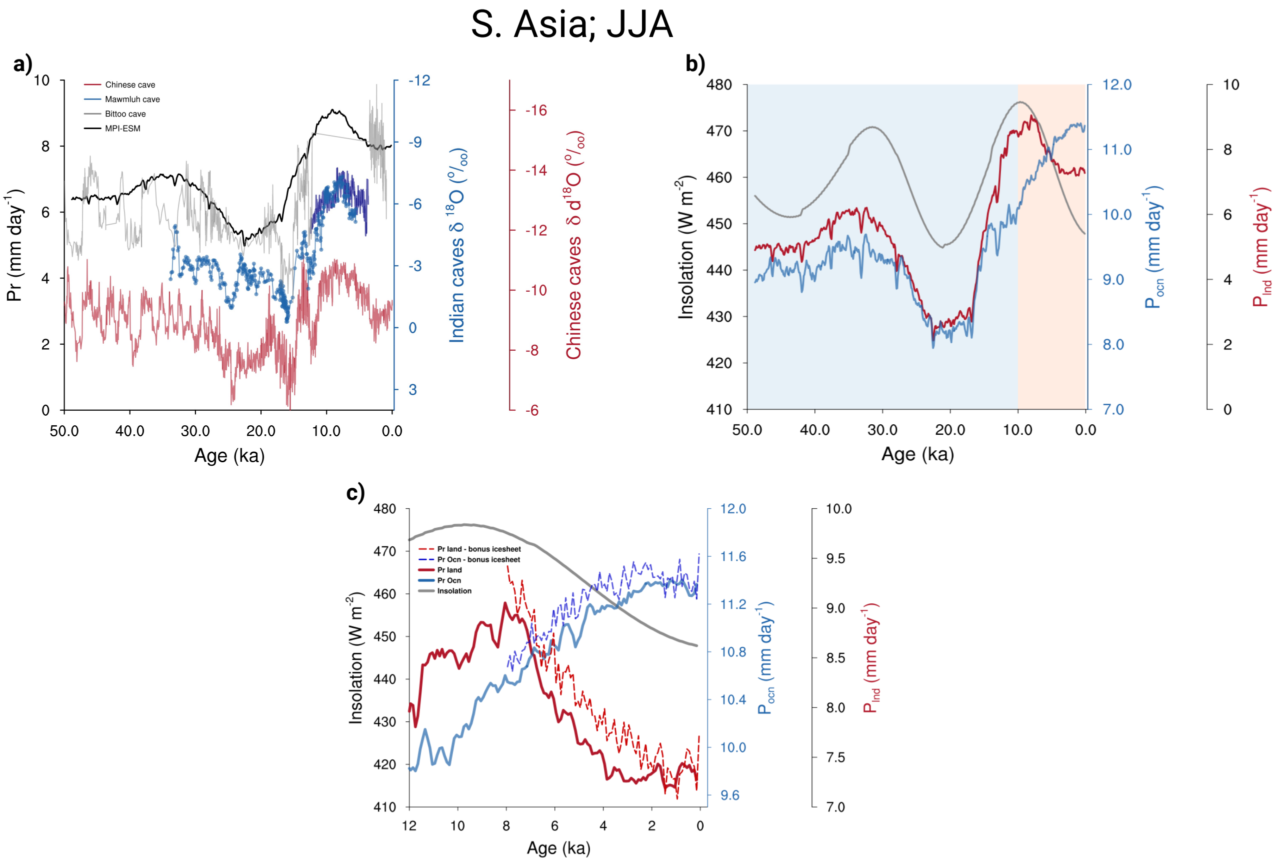

Figure 1: The time series of **(a)** Jun-Jul-Aug (JJA) mean precipitation rate over South Asian land (in black) from the MPI-ESM simulation used in this study. The grey line shows the $\delta^{18}O$ from the Bittoo cave in north India (Kathayat et al., 2016), the red line depicts $\delta^{18}O$ from the Chinese caves (Cheng et al., 2016), and the blue line with markers is $\delta^{18}O$ taken from the Mawmluh cave MWS-1 (Dutt et al., 2015). The thin violet line represents the $\delta^{18}O$ from another speleothem in the Mawmluh cave (Berkelhammer et al., 2012). **(b) & (c)** Shows time series of JJA mean insolation over South Asia in grey, precipitation area averaged over land-only grids (red thick line) and ocean-only grids (blue thick line). **(c)** The thin dashed lines represent precipitation from another simulation with the bonus ice sheet removed. Red and blue lines depict precipitation over land and ocean, respectively. The region considered for this plot spans from 10°N to 29°N and 75°E to 95°E.

References:

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