Evaluating the Indian Summer Monsoon Variability in the warm climate

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Abstract

Indian Summer Monsoon Rainfall (ISMR) plays a critical role in agriculture and in turn affects the economy of India. Accurate and timely prediction of ISMR and its variability is necessary to mitigate its adverse effects. In the recent period, there is a large debate on ISMR variability in a warming climate. Many Coupled General Circulation Models (CGCM) are also showing a large spread in the Indian Summer Monsoon (ISM) Rainfall variability of the future projections (end of the 21st century). Understanding the variability of ISMR through past periods will help to predict the ISMR under the future warmer scenario with improved skill. To achieve this, we have selected the warm mid-Pliocene (3.0-3.3 Ma) period which has similar external forcing such as, carbon dioxide (CO_2) concentration comparable to the end of the century and orbital parameters were the same as the present period. To evaluate the ISMR variability during the mid-Pliocene, we have used five Coupled Model Intercomparison Project phase 6 (CMIP6) models simulation datasets. All the model's skill in predicting the ISMR is evaluated using available observations and reanalysis datasets during the historical period (1914-2013). During the mid-Pliocene, we find an increase in the seasonal rainfall over most parts of India than the recent period. The enhanced CO_2 forcing in the mid-Pliocene led to increase in both Surface air temperature (SAT) over the Indian landmass and SST over the Indian Ocean which favors more evaporation and increased convective activity over India. In combination, the enhanced Temperature Gradient between the Indian landmass and Arabian Sea (TGIA) during the recent period strengthened the ISM circulation. It is also observed that synoptic scale features like heat low, monsoon trough and the wind circulation at lower (850 hPa, cross equatorial jet observed along the Somalia coast and over the Arabian Sea) and upper levels (at 200 hPa, tropical easterly jet over the southern peninsula) are intensified and found to be consistent with the higher precipitation observed over the Indian subcontinent.

Data and Methodology

- In this study five models from the Coupled Model Intercomparison Project 6 (CMIP6) are used selected on the availability of these datasets for the warm mid-Pliocene period which are Community Earth System Model (CESM), Earth Consortium (EC), Goddard Institute for Space Studies (GISS), Hadley Centre Global Environment Model (HadGEM), Norwegian Earth System Model (NorESM).
- Reanalysis and observational datasets is used for the recent Historical Period (1914-2013); GPCC for precipitation, COBE SST for SST, NOAA-CIRES Reanalysis V2 for wind (u,v) and NOAA/CIRES/DOE 20th Century Reanalysis V3 for Mean Sea Level Pressure (MSLP).

Models' Validation

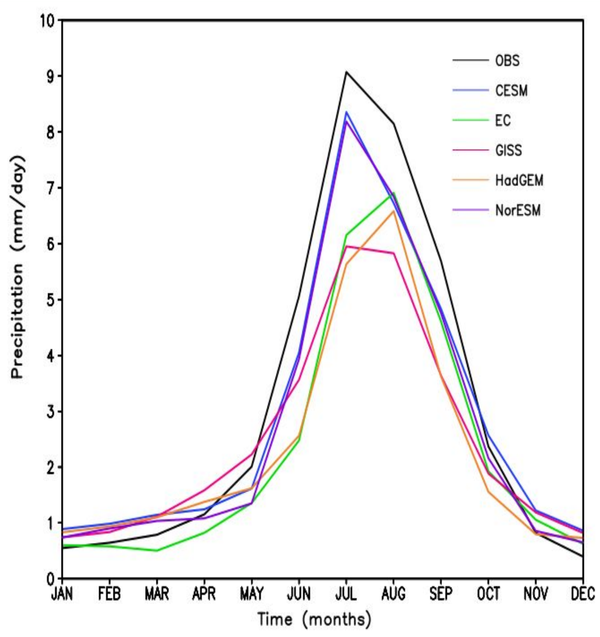


Figure 1: Annual cycle of precipitation (mm/day) over Indian landmass from CMIP6 models simulation and observations for the recent period (1914-2013).

- All CMIP6 models are well able to capture the annual cycle of precipitation over India in the recent period.
- Peak rainfall in July is very well simulated by CESM, GISS & NorESM models compared with observations
- Rainfall magnitudes are slightly underestimated by all models.

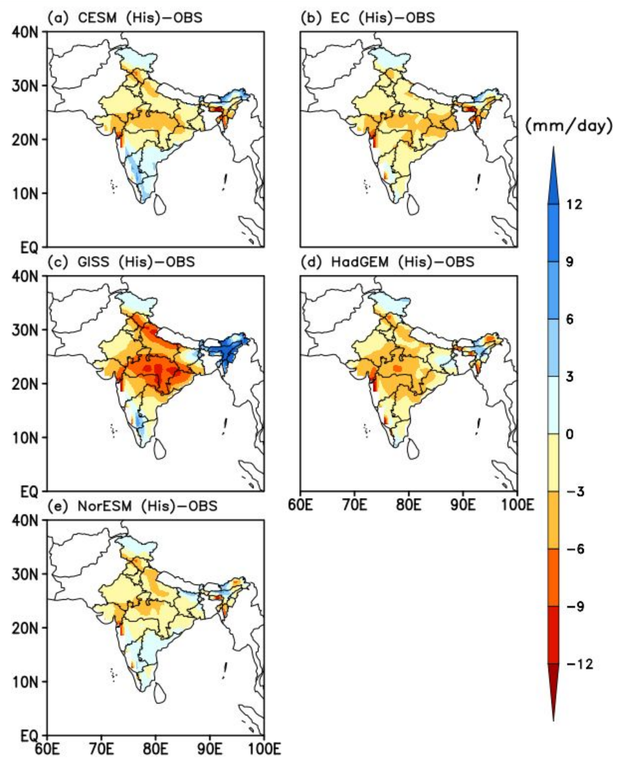
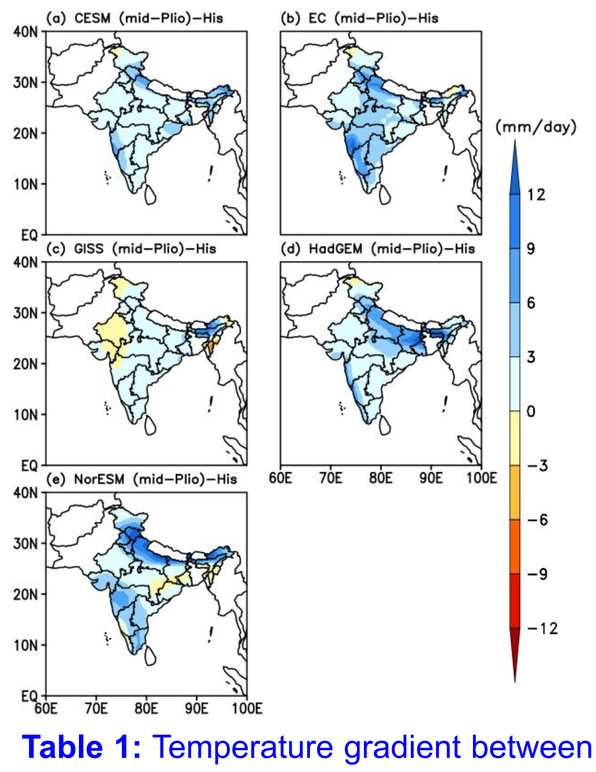


Figure 2: Seasonal (JJAS) precipitation anomalies (model-observation) over the Indian landmass from CMIP6 models historical run and observations for the recent period (1914-2013).

- Slight underestimation (except GISS) is simulated over central parts of India from all the models with observations.
- Slight overestimation is simulated over north-east and southern parts of India from all the models (except GISS).

All CMIP6 models reasonably well simulated the JJAS mean precipitation over India with more than a 60 % fraction compared with observations.

ISMR during the warm mid-Pliocene relative to recent Historical period



- Wet anomalies in precipitation between mid-Pliocene and recent Historical period is observed over most parts of India from all models simulation (some drier conditions are observed over N-W parts of India from GISS) indicating stronger monsoon conditions during the warm mid-Pliocene relative to recent Historical period..
- Mean JJAS rainfall over India is found to be higher during the warm mid-Pliocene than the recent period from all models.
- The results are consistent with the previous studies (both proxy and modeling).

Figure 3: JJAS precipitation (mm/day) anomalies between mid-Pliocene and historical run of CMIP6 models.

Table 1: Temperature gradient between Indian landmass and Arabian Sea (TGIA) at 850 hPa during mid-Pliocene and Historical periods from CMIP6 models.

Models/ TGIA (℃)	CESM	EC	GISS	HadGEM
mid-Pliocene	3.71	3.76	6.20	4.09
Historical	3.13	2.59	4.82	3.20

More evaporation from the ocean and higher moisture holding capacity of warm air due to higher concentration of CO_2, in addition the enhanced temperature gradient between Indian Landmass and Arabian Sea is found in the mid-Pliocene than the recent historical period led to higher precipitation conditions over the India during the warm mid-Pliocene.

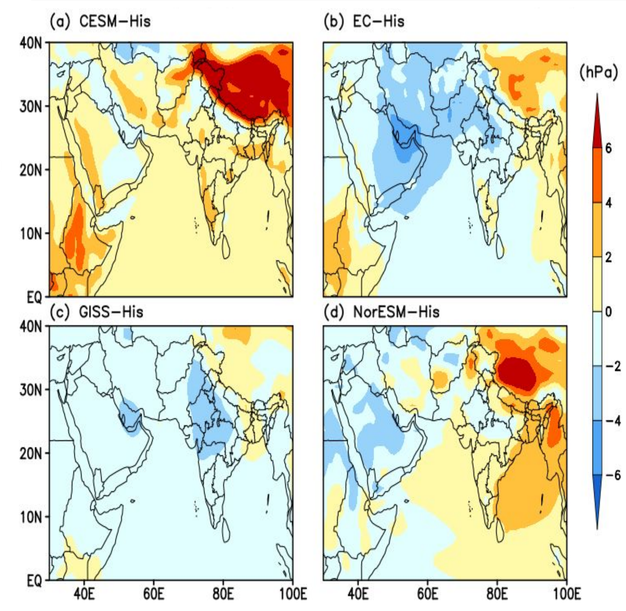


Figure 4: Mean Sea Level Pressure (MSLP) anomalies between mid-Pliocene and historical run of CMIP6 models during the month of May.

Monsoon Feature: 1. Monsoon trough

- Monsoon trough is along the central Pakistan to the foothills of the Himalayas during both mid-Pliocene and recent historical period.
- Intensification of monsoon trough during the mid-Pliocene than the recent historical runs along the trough line from by 4 hPa from EC and GISS & of 2 hPa from CESM and NorESM indicating intensified ISM conditions.

Monsoon Feature: 2. Wind Circulation

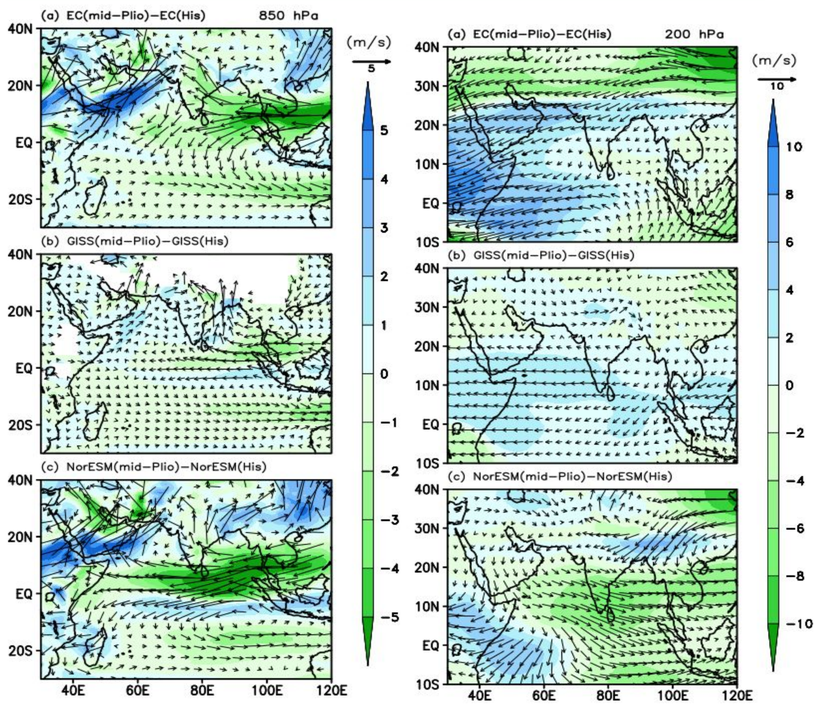


Figure 5: wind (m/s) anomaly between mid-Pliocene and historical run of CMIP6 models at 850 hPa.

Figure 6: wind (m/s) anomaly between mid-Pliocene and historical run of CMIP6 models at 200 hPa.

Table 2: Mean Monsoon Hadley Index (MHI) from different models of CMIP6 during mid-Pliocene and historical period.

MHI (m/s)/ models	Mid-Pliocene	Historical
EC	0.67	-1.63
GISS	1.41	0.57
NorESM	2.23	-0.09

Conclusions

- ISMR is found to be stronger during the warm mid-Pliocene climate relative to recent period from all the CMIP6 models that is consistent with the previous proxy and modeling studies .
- The intensified monsoon synoptic features such as monsoon trough and wind circulation at lower and upper levels are found during the mid-Pliocene relative to recent period from all model runs corresponds to stronger monsoon conditions.
- Stronger monsoon conditions during the warm mid-Pliocene relative to recent period are mainly supported by the intensified land-ocean temperature contrast between the Indian landmass and Arabian Sea due to high concentration of CO_2 during the mid-Pliocene relative to recent period.

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