# Indian summer monsoon variability and its relation with Indo-Pacific oceans in the Last Millennium – a PMIP view

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**with**

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**Late Rengaswamy Ramesh**

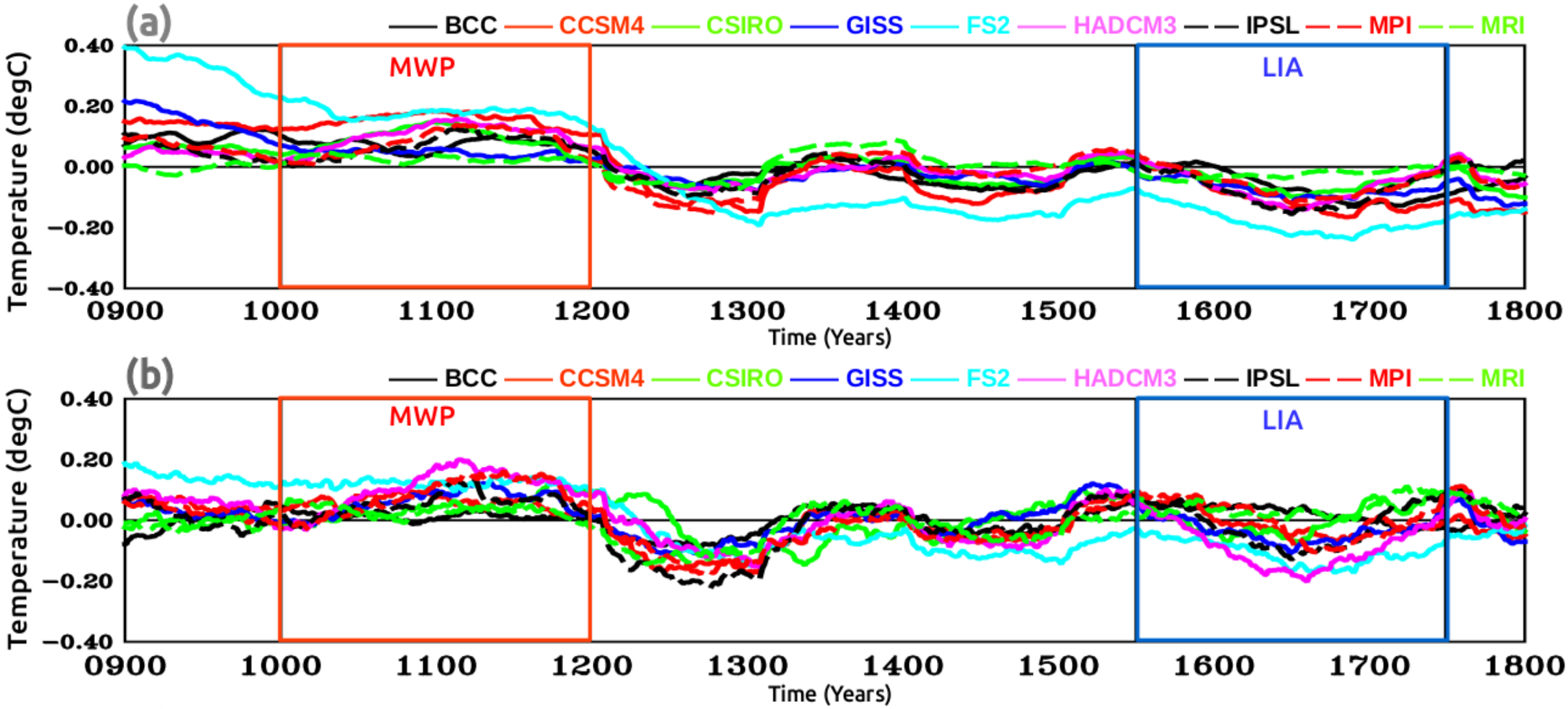
# Project Objectives

- **Understanding Indian monsoon variability during the last millennium (LM), particularly the medieval warm period (MWP)- also known as medieval climate anomaly (MCA)- and little ice age (LIA) *through PMIP3 data analysis***

- **Exploring the likely association of the tropical Indo-pacific variability of the Indian summer monsoon with during the last LM**

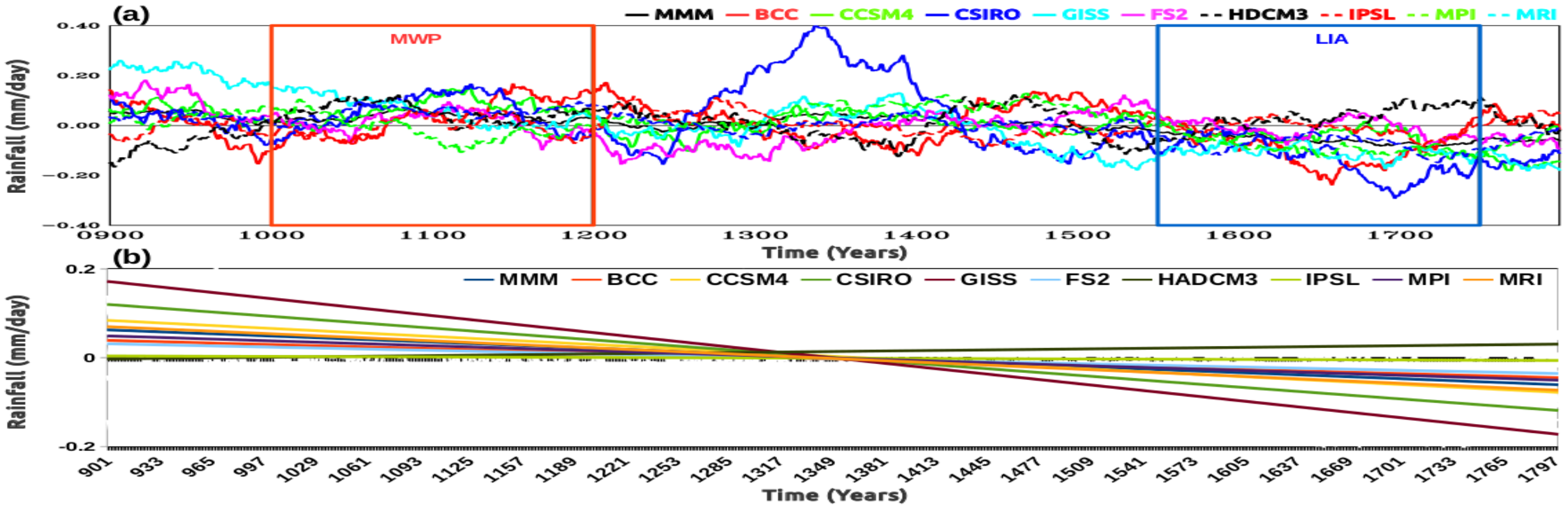
- **The relevance of the slow variations in the tropical Easterly Jet for Indian summer monsoon; the northeast region stands out.**

- ***Implications of background external forcing changes during the Mid-Holocene – PMIP analysis and AGCM experiments.***




101-year running mean anomalies of near-surface air temperature (°C) obtained by area-averaging (a) globally, and (b) over the Indian Region

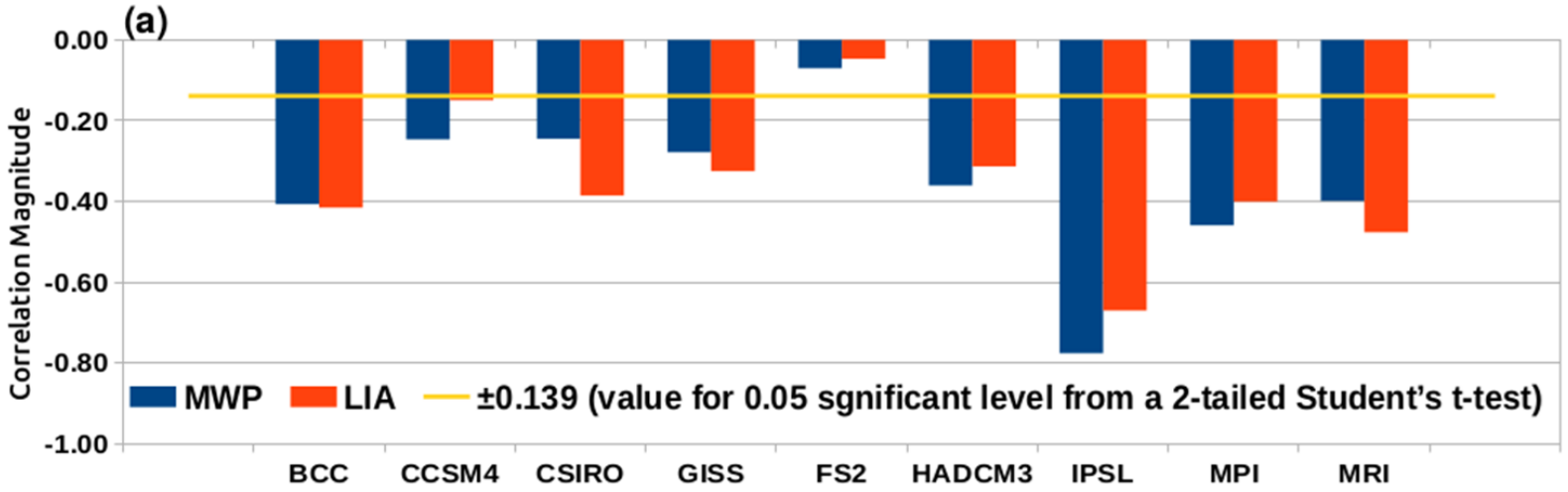
**Tejavath et al. (2019) Climate Dynamics**




***(a) 101-year running mean anomalies of ISMR (mm/day)(b) Linear trend lines of the area-averaged ISMR during LM, as simulated by the nine PMIP3 models.***

- **A statistically significant (at 0.10 levels) but moderate decreasing trend in area-averaged ISMR in four models, and a weaker decreasing trend in four more models throughout the LM, in agreement with findings from several proxy records.**
- ***Area-averaged ISMR is defined as the JJAS land rainfall rea-averaged over*** *65°E–95°E; 10°N–30°N.*
- **A wet and warm Indian monsoon during MWP, and a cool and dry LIA.**

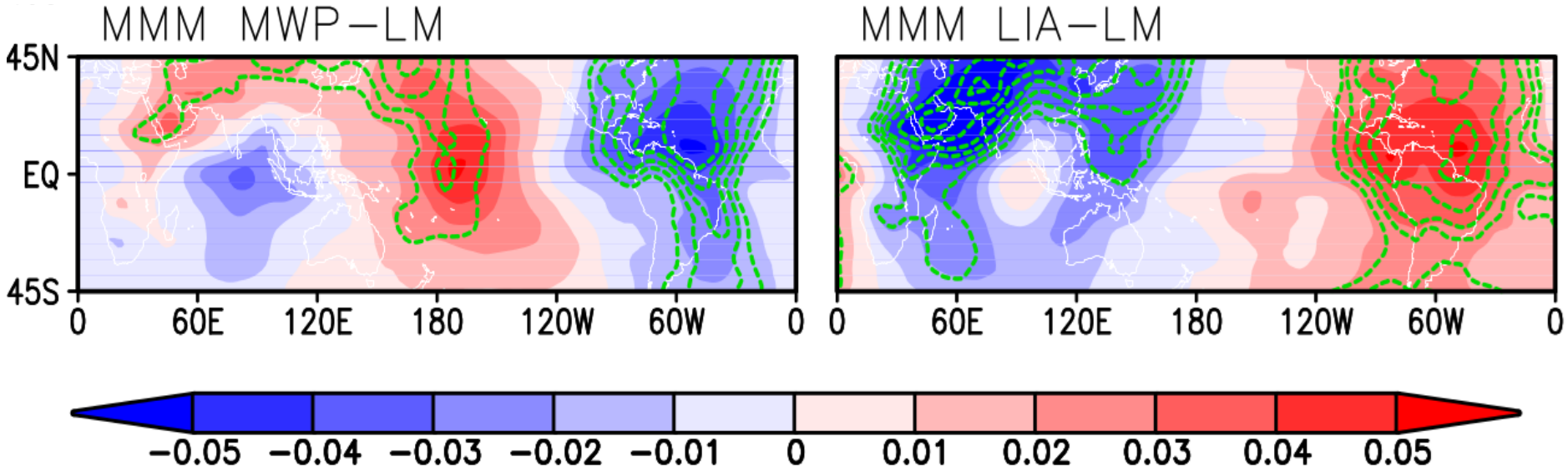
*Tejavath et al Clim. Dyn. (2019)*




**7 out of 9 PMIP3 models simulate a relatively wet (dry) MWP (LIA) Indian monsoon.**

**Significant Monsoon-ENSO correlations during MWP and LIA; more El Ninos in MWP.**

**Centennial background changes in the Walker circulation reduced the ENSO impacts through the LM**




**Simulated multi-model average of JJAS 850hPa velocity potential ($m^2\ s^{-1}$) differences for MWP & LIA relative to Last Millennium. Contours indicate statistically significant signals.**

# Summer monsoon over northeastern India during the last millennium

## Why?

No significant trend in the NESME in the last 4-5 decades. (Soraisam et al., 2018).

No correlations with ENSO (Soraisam et al., 2018).

Extreme rainfall events decreasing (Goswami et al., 2017), but subject to data uncertainty (Soraisam et al., 2018).

The gravest EOF of SMR -> NESMR out of phase with the rest of ISMR.

Reconstructed Asian summer Precipitation dataset for the 1470–2013 period shows more linked to western/SE China, and southern Japan.

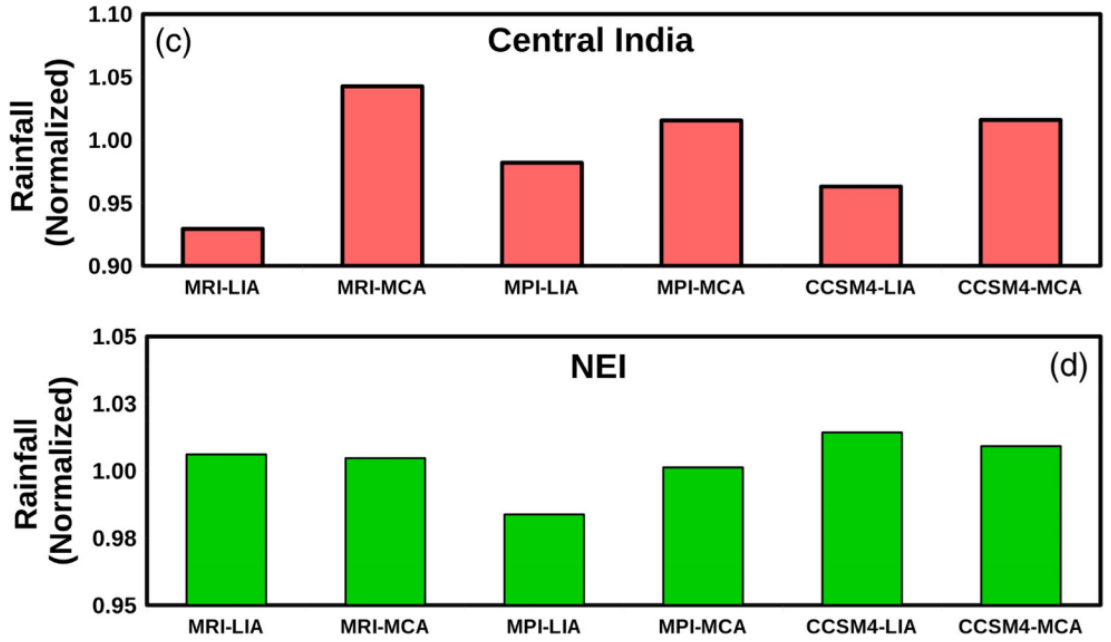
***So, the variability of the summer monsoon rainfall over the NEI is not always synchronized and related to that over rest of the Indian region.***

***How about the MWP & LIA? Proxies suggest a warm and humid MWP.***

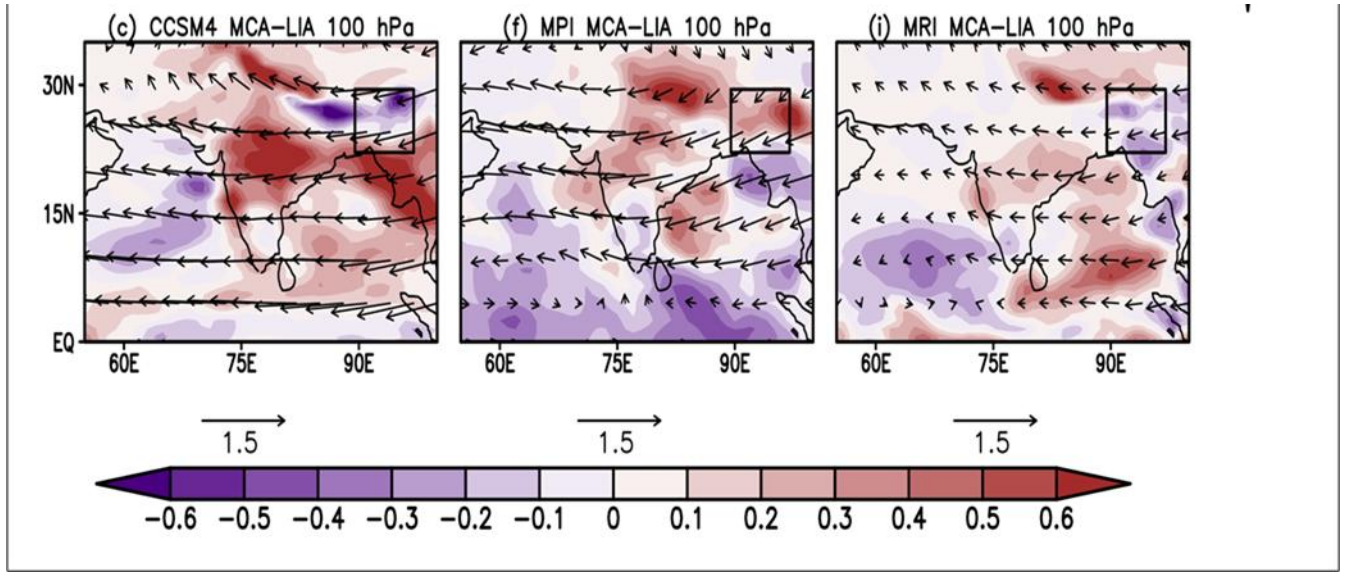
## DATA

Models -PMIP3: MPI, MRI & CCSM4), and a few ECHAM simulations

Period studied: Medieval Warm period (935 CE – 1034 CE) & Little Ice Age (1735 CE – 1834 CE).




Interestingly, Relatively Less Weakening of the Summer Monsoon Rainfall over NEI from the MWP to LIA
(Also, simulated ENSO-NEISMR is insignificant)




**Simulated 100 hPa circulation and zonal wind (m/s) by three relatively higher resolution models**

**Changes in the simulated tropical easterly jet strength are not as important as for the core monsoon region.**

Ashok et al., Int. J. Climatol., 2021

# Indian summer monsoon during mid-Holocene: Sensitivity experiments

- **Proxy and modelling based studies show monsoon strength have changed in proportion with changes in insolation on orbital scales (Kutzbach, 1981; Kutzbach et al., 2008; Kathayat et al. 2016).**
- **Various mechanisms have been proposed for ISM variability during the Holocene period apart from changes in the orbital parameters (e.g., Precession).**
- **A proxy reconstruction study by Dixit et al. (2014) shows that solar insolation played a significant role in strengthening the ISM during the early Holocene period.**

***Tejavath et al. (2021) Front. E. Sci.***

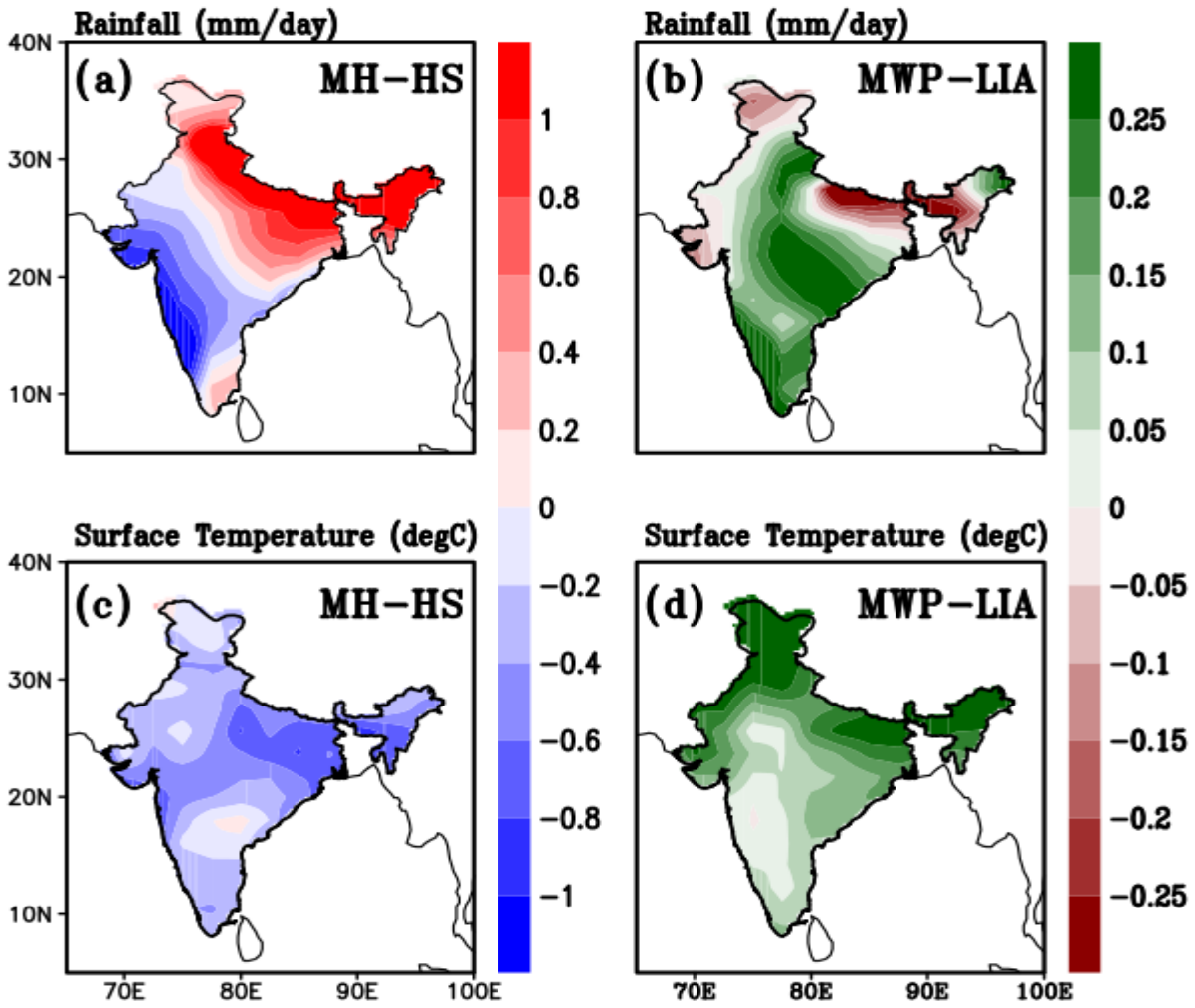
- We have carried out multiple ensemble AGCM simulations for three (MH, MWP and LIA) different climate periods.
- Each simulations is about 30-year length with specific forcing, or pre-industrial external solar forcing.
- We followed PMIP3 protocol, details can be found at <https://wiki.lsce.ipsl.fr/pmip3/doku.php/pmip3:index> and in next slide.

# model setup

- Community Atmospheric Model Ver5 (CAM5) with Data Ocean Model (DOCN)
- Model resolution 1.9x2.5xL30 (Lat x Lon x Vertical levels)
- Cloud Microphysics Scheme – MG1 (Morrison and Gettelman, 2008)
- Dynamical core – FV (Finite-volume)
- Initial conditions – CMIP5/PMIP3 (brief details in next slide)
- AGCM simulation length – 30years each

*Tejavath et al. (2021) Front. E. Sci.*

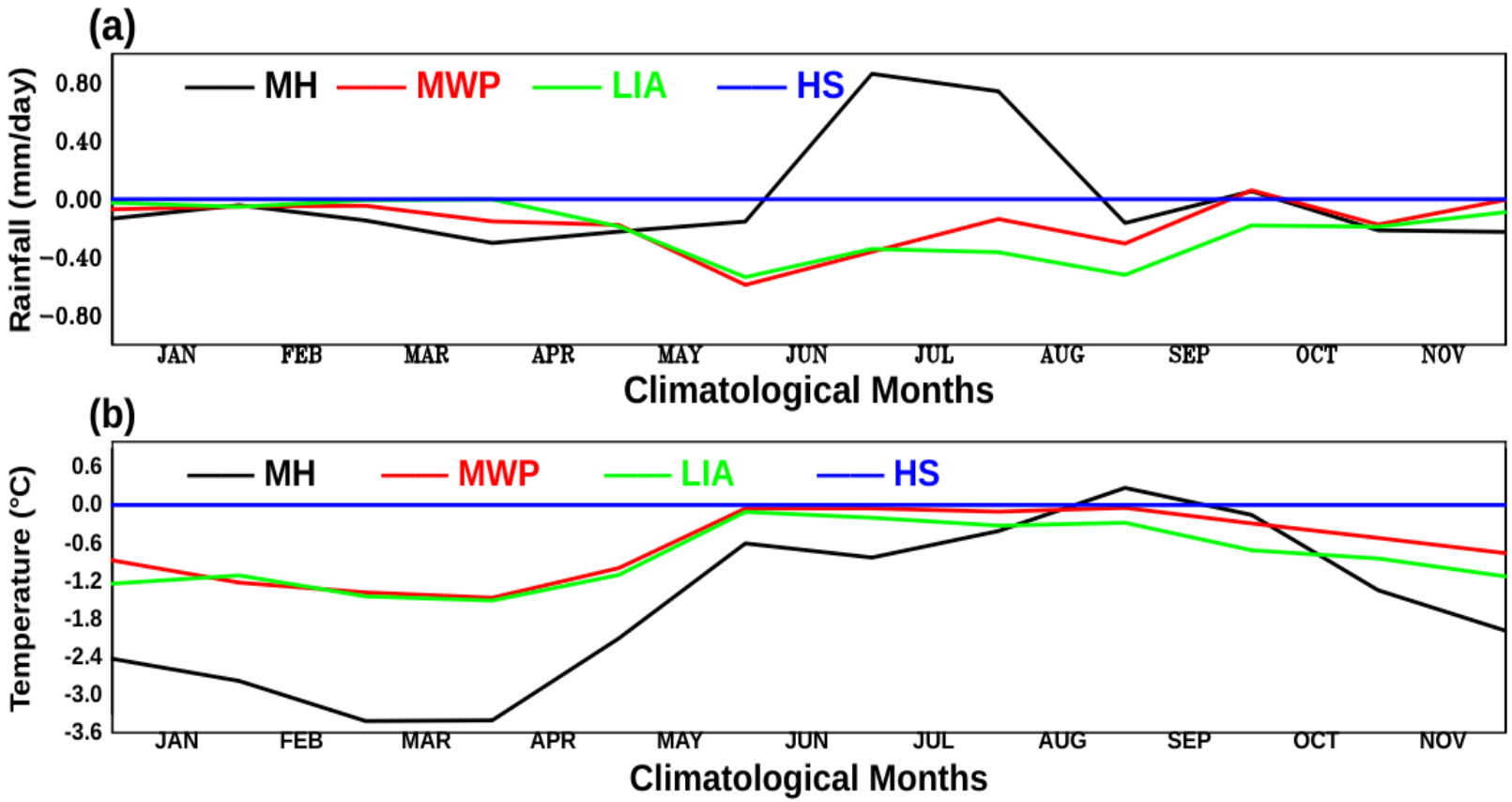
# Rainfall and Surface Temperature differences




- During MH, northern India received surplus summer monsoon rainfall during MH compared to HS.
- During MWP, the Indian region was warmer and wetter compared to LIA.
- These results are in conformation with the available studies.

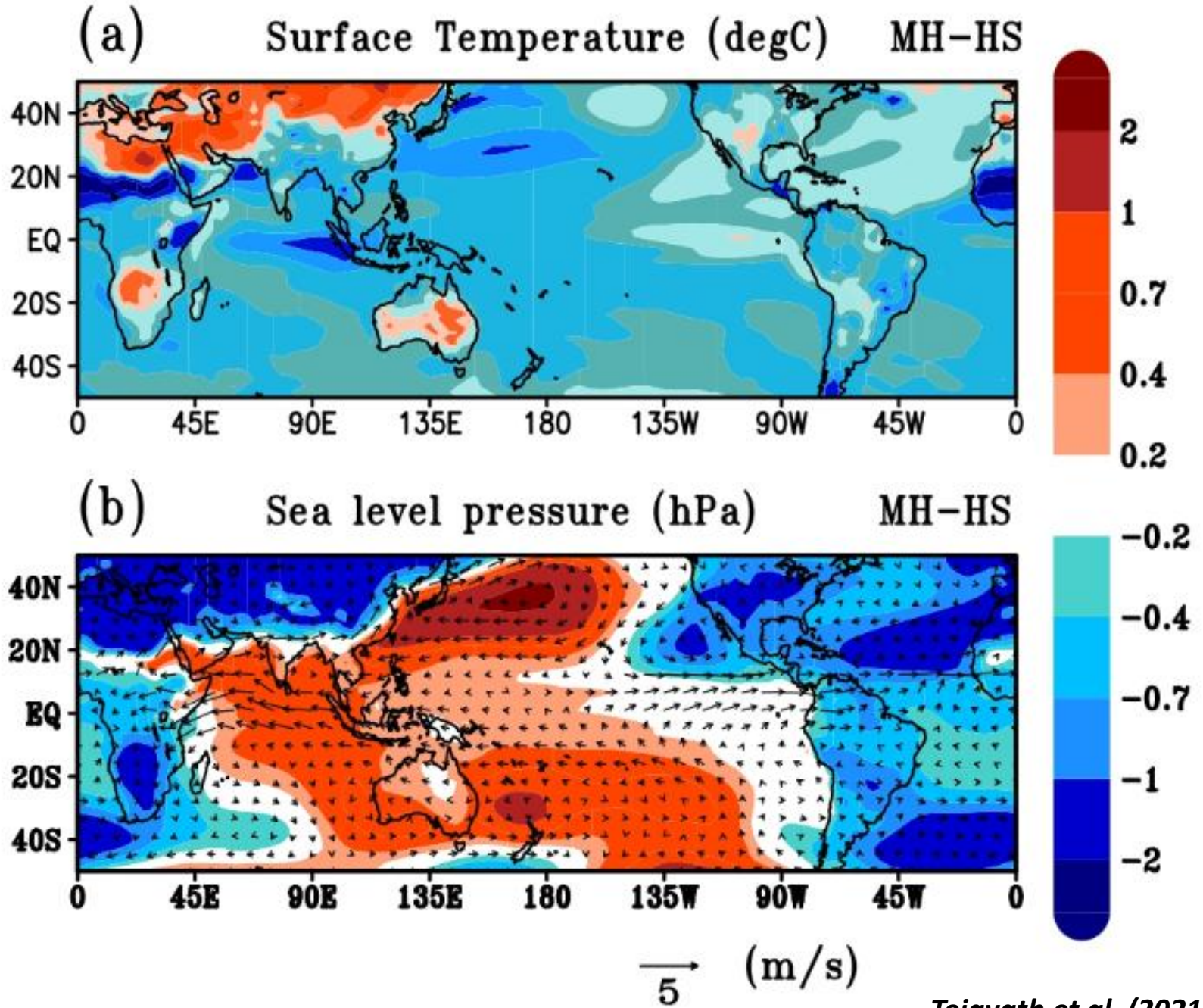
*Tejavath et al. (2021) Front. E. Sci.*

# Difference from the Historical simulations




***AGCM simulations are able to reproduce the excess rainfall during the Mid-Holocene (6kyr BP) than the Historical as seen in few proxy-based observations and PMIP3 simulations.***

*Tejavath et al. (2021) Front. E. Sci.*




*Tejavath et al. (2021) Front. E. Sci.*

***We have carried out few AGCM simulations for the Mid-Holocene (6 kyr BP) time period with Historical (Present-day), 8.2 kyr BP and for 21 kyr BP (LGM) time periods.***

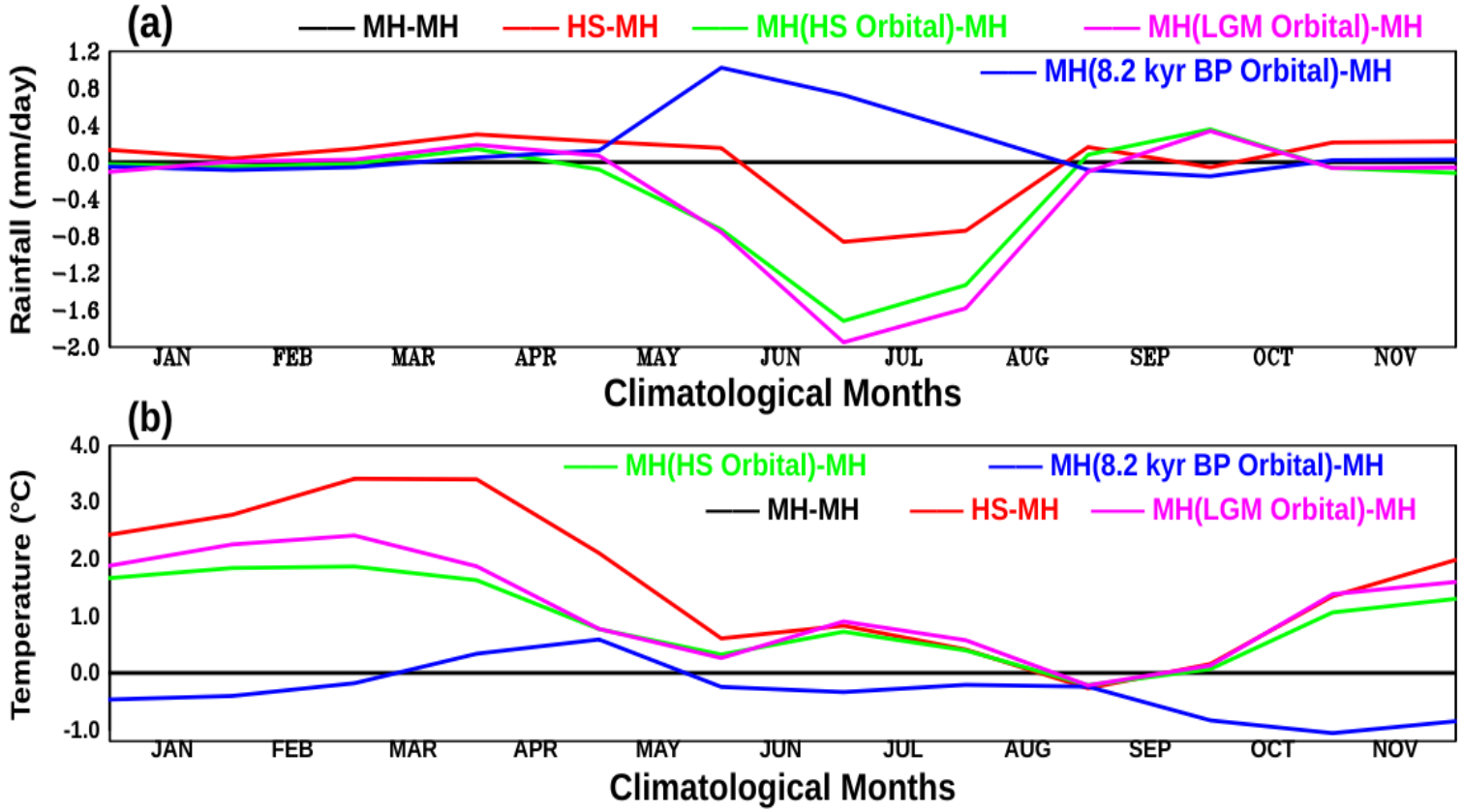
***We have calculated Orbital parameters using following method mentioned by PMIP3. <https://wiki.lsce.ipsl.fr/pmip3/doku.php/pmip3:index>***

| Parameter | Linear approximation |
|---|---|
| Eccentricity | 0.017475 - 0.000000382 * Year |
| Obliquity | 23.697 - 0.000128 * Year |
| PERI-180 | 68.79 + 0.0170 * Year |

***Tejavath et al. (2021) Front. E. Sci.***

| Parameters | Time Period | | | |
|---|---|---|---|---|
| | MH | HS | 8.2 kyr BP | 21 kyr BP |
| Eccentricity | 0.018682 | 0.016724 | 0.019199 | 0.018994 |
| Obliquity | 24.105° | 23.446° | 24.222° | 22.949° |
| PERI-180 | 0.87° | 102.04° | 319.495° | 114.42° |

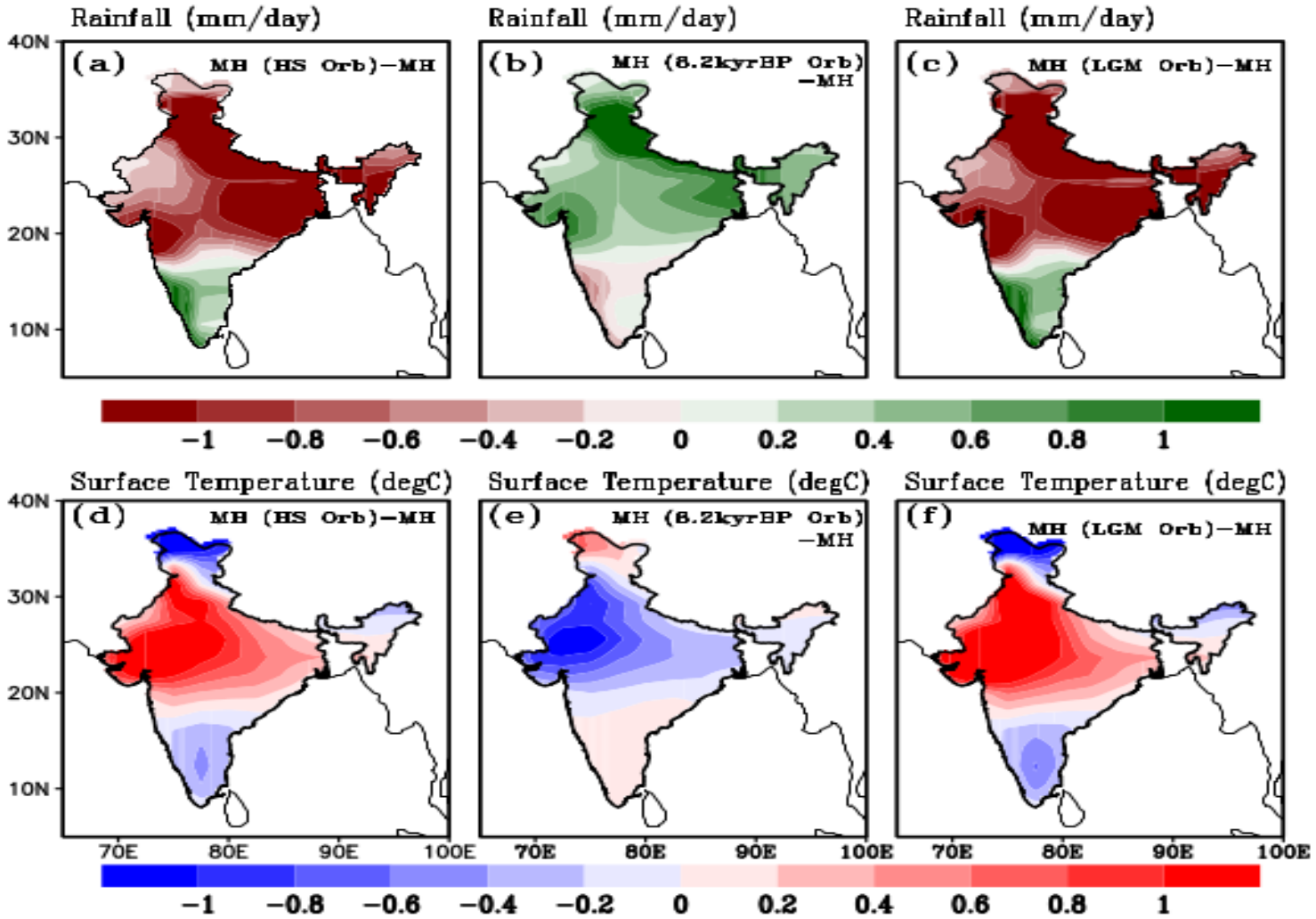
# Difference from the MH sensitivity experiments and HS to MH simulations




*Tejavath et al. (2021) Front. E. Sci.*

- **MH with HS and LGM maximum orbital values Indian region received deficit summer monsoon rainfall.**
- **MH with 8.2 kyr BP orbital values Indian region received surplus summer monsoon rainfall.**

# Difference from the MH sensitivity experiments to MH simulations



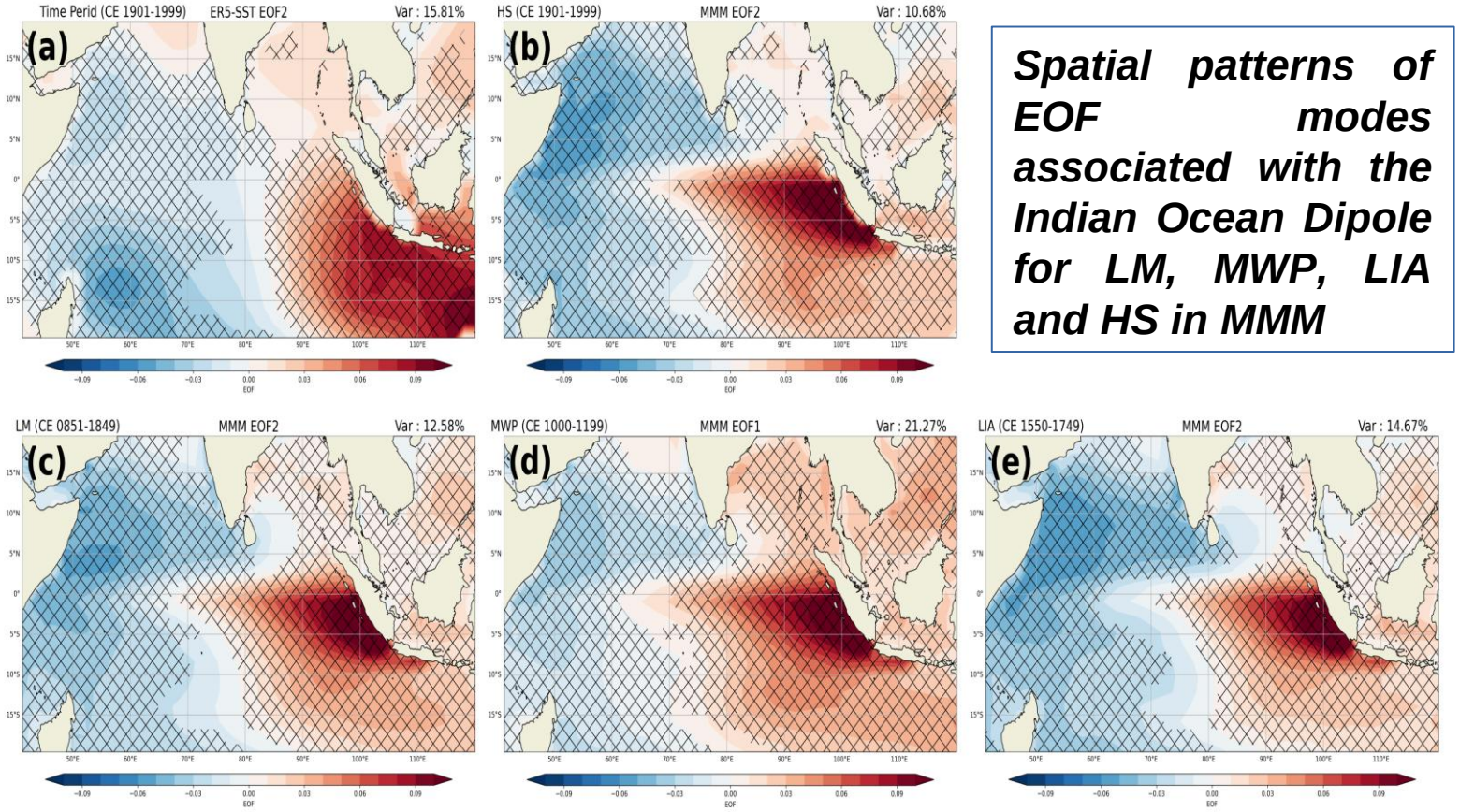

**MH with HS and LGM maximum orbital values North Indian region received deficit summer monsoon rainfall and Southern India received surplus and vice-a-versa with 8.2 kyr BP orbital values Indian region received surplus summer monsoon rainfall.**

*Tejavath et al. (2021) Front. E. Sci.*

# Summary of Monsoonal variations from the PMIP3

- ***The Centennial variations in the tropical Indo-pacific walker circulation, and those in the TEJ played a major role in the manifestation of warm and wet Indian summer monsoon during the MWP/MCA relative to the LIA.***
- ***However, the simulated summer monsoon in the northeast India does not exhibit any such multi-centennial variations, which does not agree with several proxy analyses results. <u>This aspect needs rigorous examination both from modelling and proxy data perspectives.</u>***
- ***Our PMIP3 analysis and sensitivity experiments carried out with CESM indicate that orbital parameters played a major role in a stronger than current day monsoon during mid-Holocene. The model sensitivity to ENSO was weak.***

# Indian Ocean Dipole Statistics through last millennium – a PMIP3 view

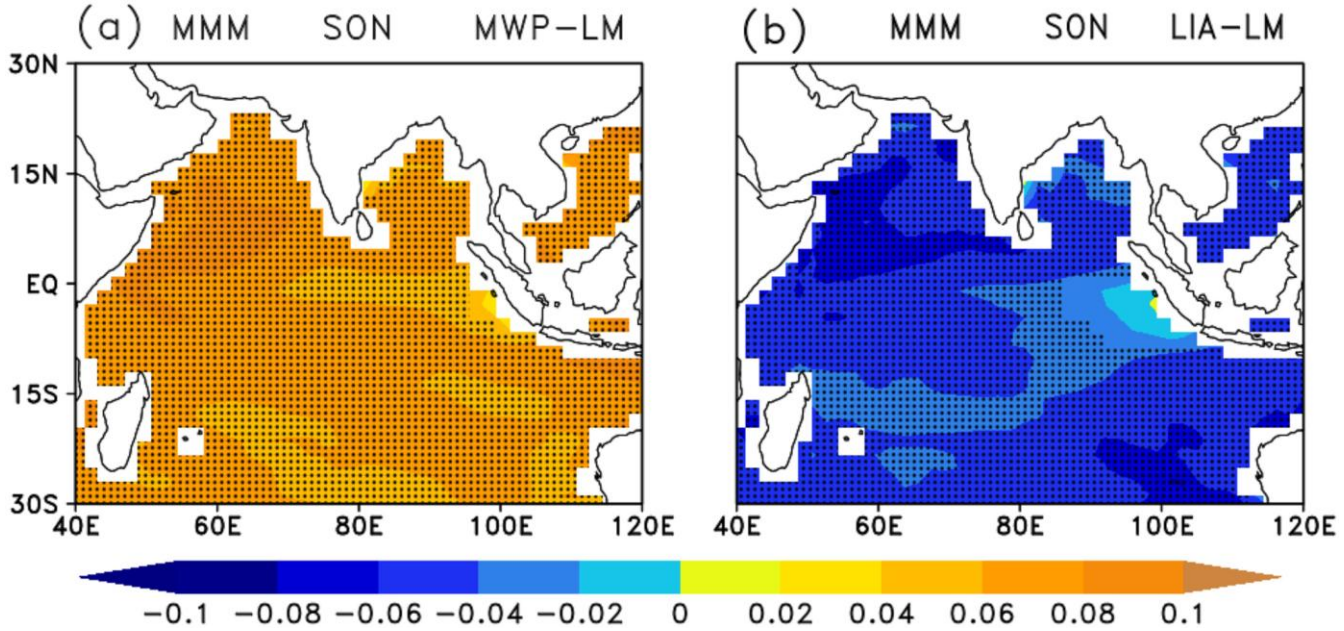



***Spatial patterns of EOF modes associated with the Indian Ocean Dipole for LM, MWP, LIA and HS in MMM***

**Tejavath et al., Geophys. Res.Lett., 2024**

***The PMIP3/CMIP5 models were able to simulate the IOD patterns and variability (not shown) in comparison with the observational datasets over the historical period***

# Indian Ocean Dipole Statistics through last millennium – a PMIP3 view

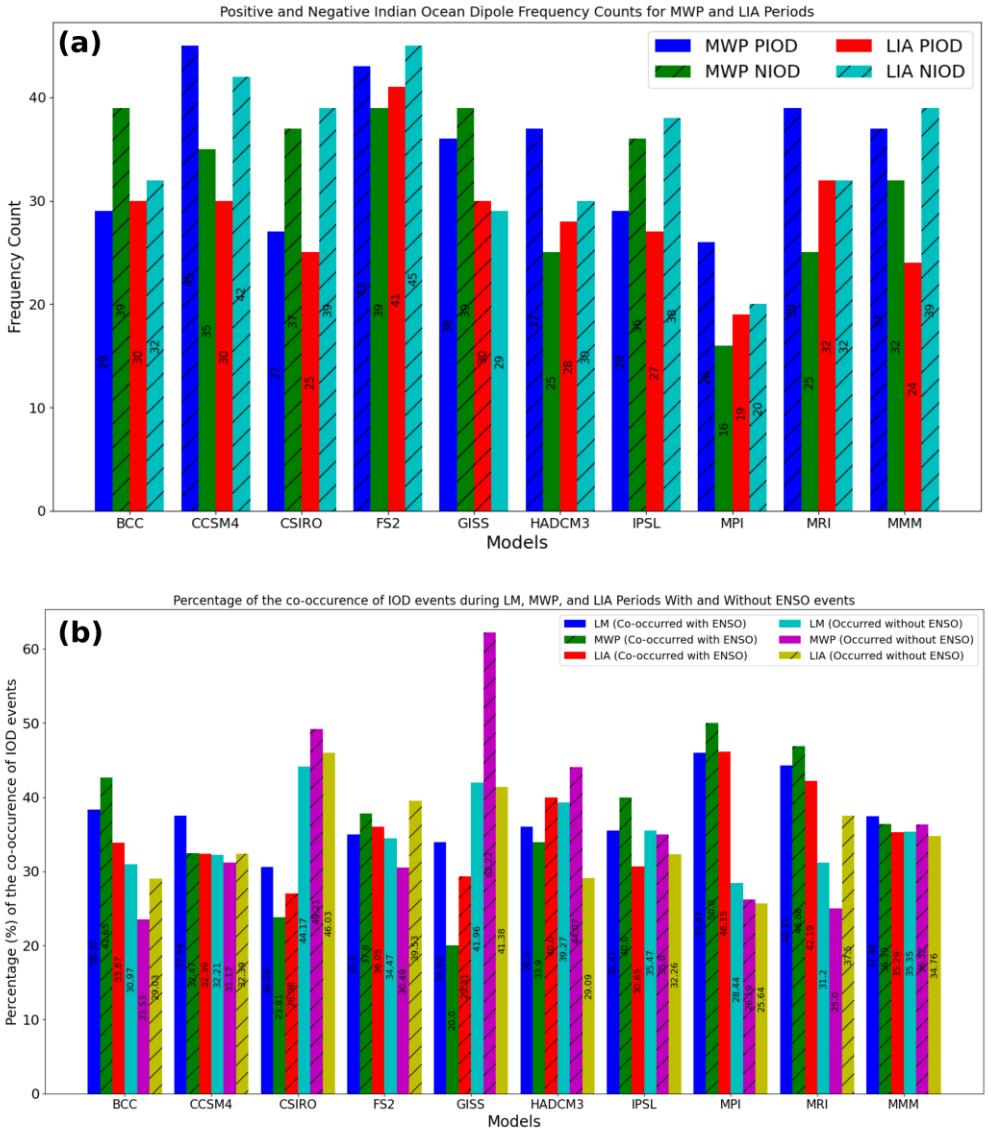



Sea surface temperature (SST; °C) anomalies for the boreal fall (September–October–November; SON) season over the Indian Ocean during the (a) Medieval Warm Period (MWP; CE 1000–1199) and (b) Little Ice Age (LIA; CE 1550–1749). The striping over the Indian Ocean region shows a significance of 95% from a two-sample mean t-test, where one sample is the last millennium and the other is MWP and LIA, respectively.

- ***The Multi-model SON SSTA display a positive IOD-like background during the MWP and a negative IOD-like pattern during the LIA in comparison to the LM-mean.***

Geophysical Research Letters, Volume: 51, Issue: 16, First published: 20 August 2024, DOI: (10.1029/2024GL110112)

- Majority of the models simulate more pIODs during the MWP and more nIODs during the LIA.
- However, higher number of strong positive IOD events are simulated relative to the negative IODs during the LIA, in agreement with proxy-observations, apparently owing to increased coupled feedback during positive IODs.
- From the MWP to the LIA, the co-occurrence of IOD events with ENSO slightly decreased from the MWP to the LIA showed a slight decrease (36.39%, and 35.29%).
- In LIA, this change is mainly more prevalent for negative IODs during the LIA.

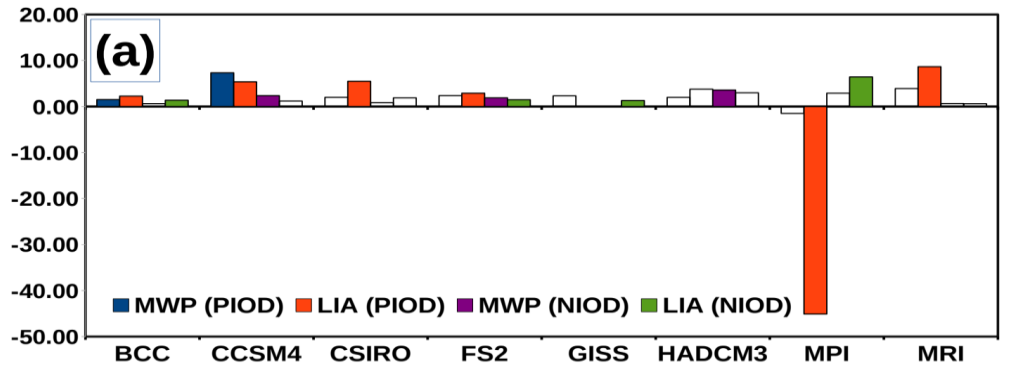



Frequency and Percentage of the co-occurrence of IOD events during the boreal fall (September-October- November) season with and without a co-occurring ENSO

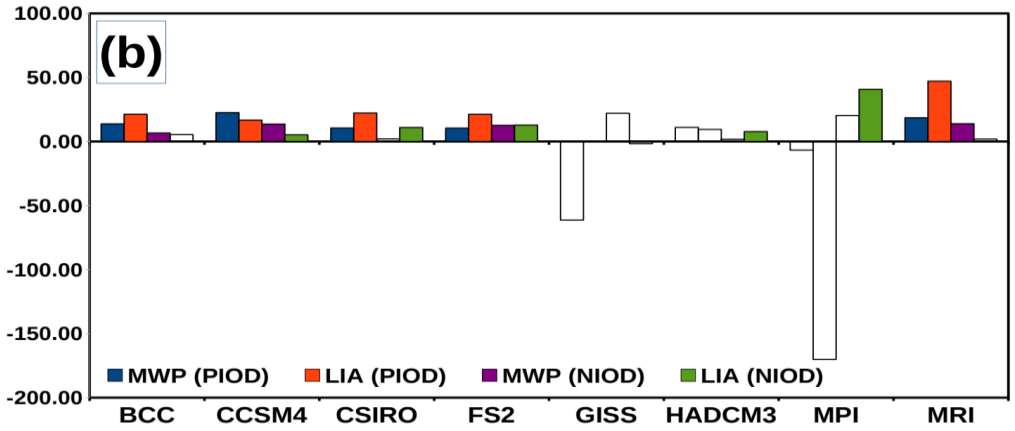
# *Feedback strengths*

Feedback strengths decreased from MWP to LIA in majority of the PMIP3 models

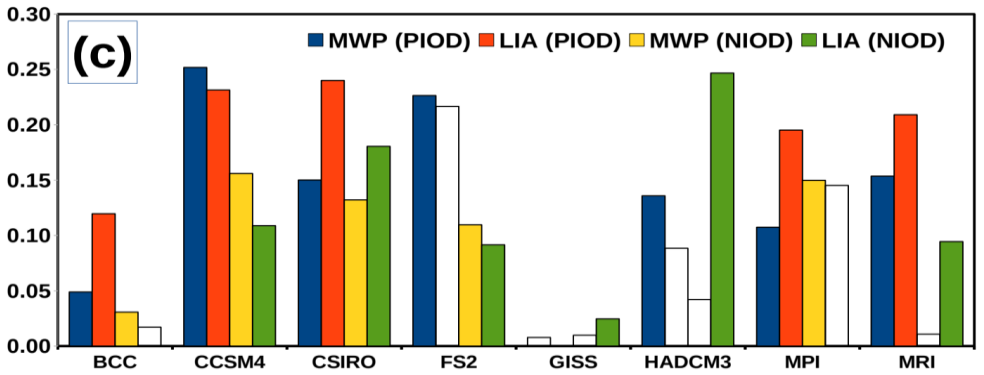
The coupling strength of pIODs increased from the MWP to the LIA, while it remained unchanged for negative IODs, aligning with the rise in the number of strong pIOD events during the LIA even with the nIOD background.




*Air-sea coupling strength*




*Wind-thermocline coupling strength*




*Thermocline-subsurface temperature.*

# Take away points from the LM IOD analysis

- Simulations indicates relatively more positive (negative) IOD events in medieval warm period, CE 1000-1200 (Little Ice Age, CE 1550-1749).
- The frequency of strong pIOD events in the LM is 250% higher than strong nIOD events, with 35% of IOD events occurring independently of ENSOs, slightly less during the LIA
- Despite negative IOD-like background conditions in the LIA, models and paleo-data show more stronger positive IODs.
- The simulated centennial changes in positive and negative IOD frequencies are associated with changes in coupled ocean atmospheric feedback mechanisms.
- There are significant changes in feedback mechanisms of IODs from the MWP to LIA

# Publications from our paleo-research


Ashok, K., Soraisam, B., Tejavath, C. T., & Cubasch, U. (2021). Summer monsoon over northeastern India during the last millennium. International Journal of Climatology, 1–12. https://doi.org/10.1002/joc.7332

Tejavath, C.T., Ashok, K., Chakraborty, S. et al. (2019). A PMIP3 narrative of modulation of ENSO teleconnections to the Indian summer monsoon by background changes in the Last Millennium. Clim Dyn 53, 3445–3461 (2019). https://doi.org/10.1007/s00382-019-04718-z

Tejavath, C.T., Ashok, K., Chakraborty, S. et al. (2021). The Importance of the Orbital Parameters for the Indian Summer Monsoon During the Mid-Holocene, as Deciphered From Atmospheric Model Experiments. Frontiers Ear. Sci., Volume 9 - 2021 | https://doi.org/10.3389/feart.2021.631310

Tejavath, C. T., Pankaj Upadhyay and K. Ashok, (2020). The past climate of the Indian region as seen from the modelling world. Curr. Sci., 120, pp. 3160320. https://www.jstor.org/stable/e27229844



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