2024 CESM Paleoclimate Working Group Meeting

# PDO and AMO Modulation of the ENSO-Asian Summer Monsoon Teleconnection during the Last Millennium

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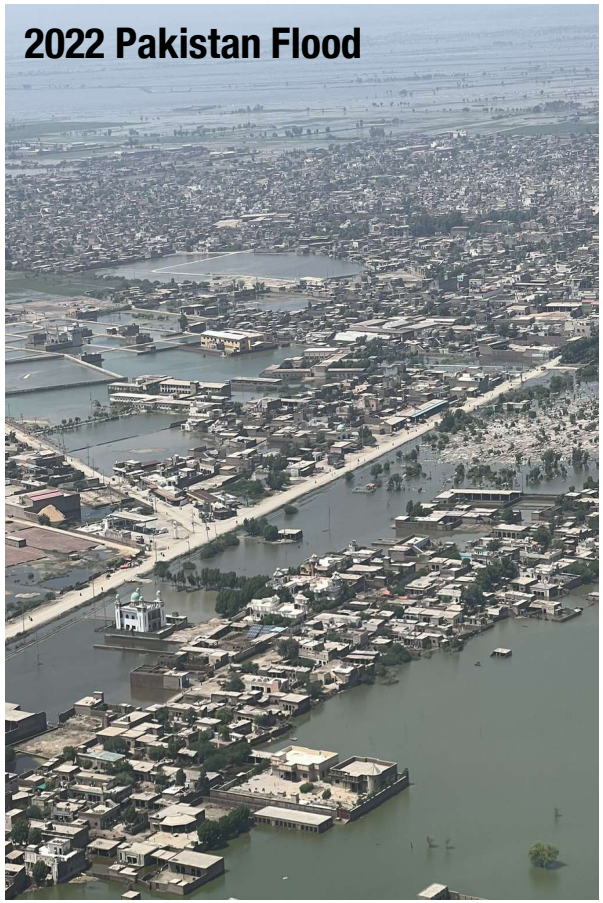
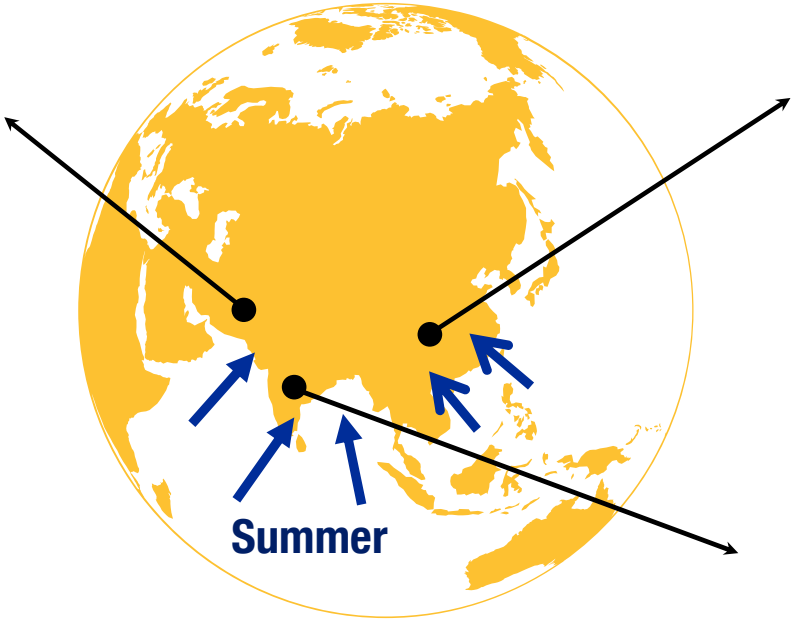
THE HEBREW UNIVERSITY OF JERUSALEM

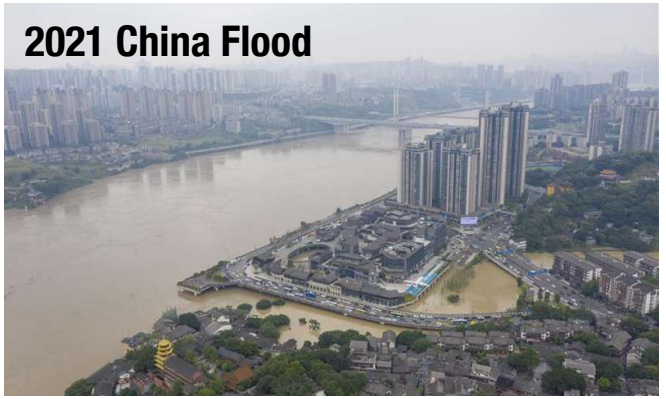
# Asian Summer Monsoon Has Profound Socio-Economic Impacts




Source: https://en.wikipedia.org/wiki/2022_Pakistan_floods




**Monsoon rainfall prediction is of great significance**

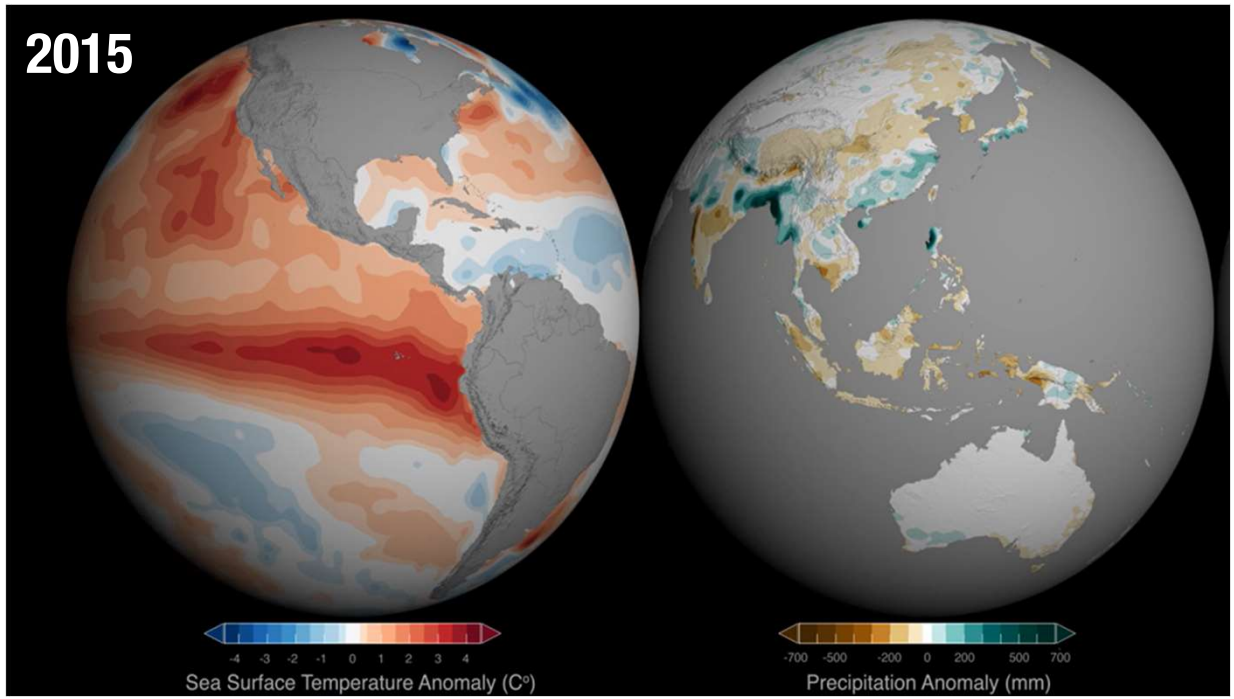



*Source*: https://www.globaltimes.cn/content/1201803.shtml

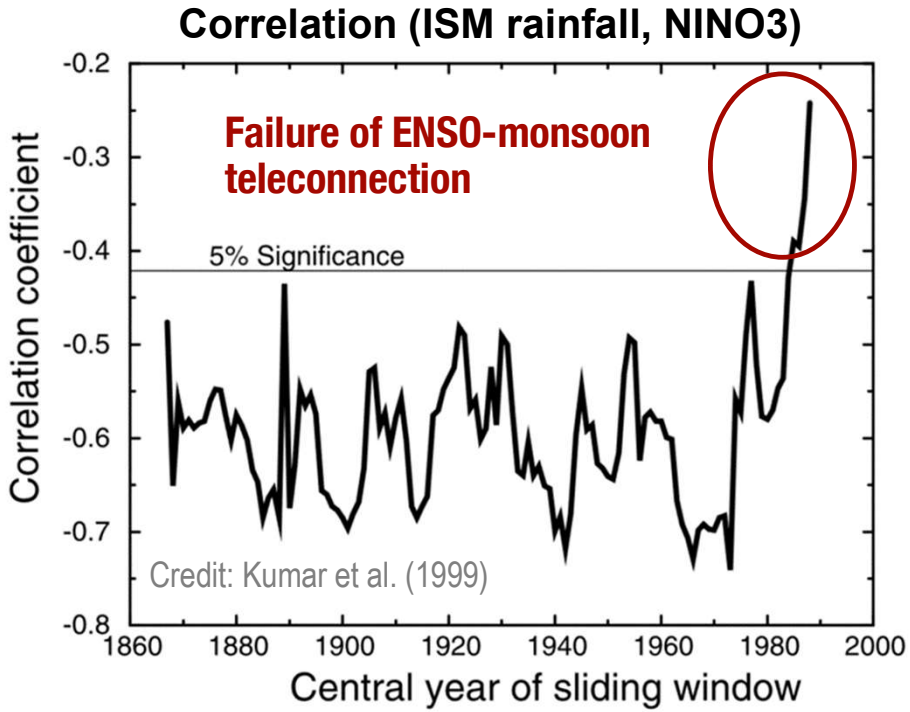

Source: https://www.americanscientist.org/article/the-life-and-possible-death-of-the-great-asian-monsoon

# ENSO-Monsoon Teleconnection is Crucial for Monsoon Prediction

## BUT NOT ALWAYS RELIABLE




Source: NASA Scientific Visualization Studio

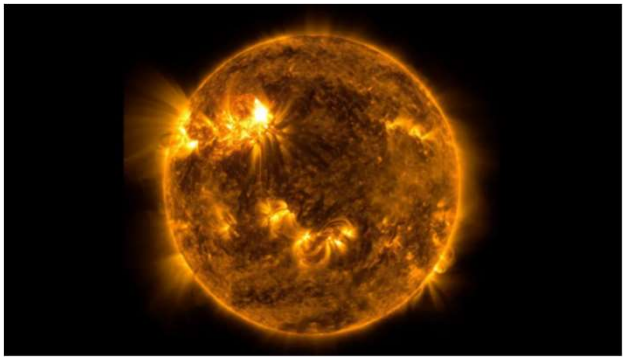


# How did the ENSO-Monsoon Teleconnection Change in the Past?

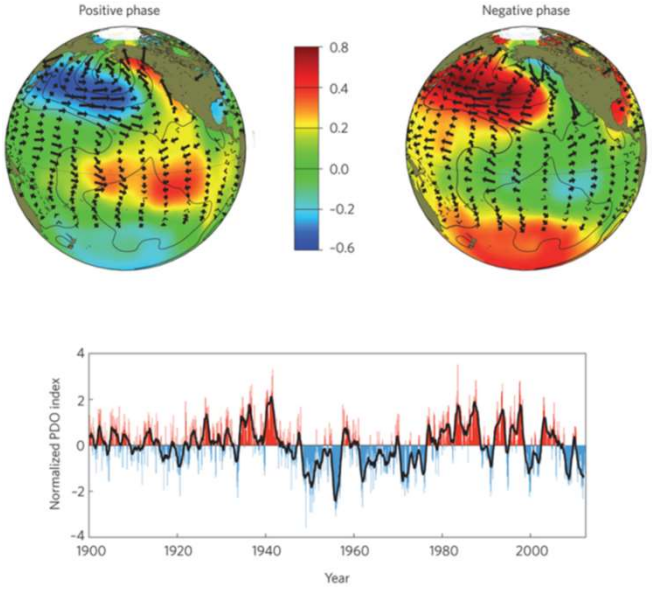
- **Anthropogenic Warming** (e.g., Xu et al., 2023)
- **Natural External Forcing** (e.g., Du et al., 2023)
- **Internal Climate Variability** (e.g., Shi & Wang, 2018; Hau et al., 2023)

**-Our Focus!**

Source: iStock.



Source: SDO/NASA



# How did the ENSO-Monsoon Teleconnection Change in the Past?

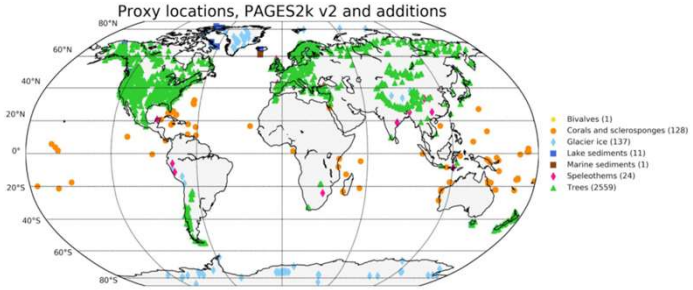
**Last Millennium** | **Pacific Decadal Oscillation (PDO)** | **Atlantic Multi-Decadal Oscillation (AMO)**

- How do the PDO and AMO, in combination with ENSO, influence the Asian Summer Monsoon (ASM) variability?
- How do the PDO and AMO influence the ENSO-monsoon relationship (correlation strength)?
- Can we improve ASM prediction using insights from the Last Millennium?

# Methods: Paleoclimate Data Assimilation

**LMRv2.0 : Last Millennium Reanalysis version 2.0 (Tardif et al., 2019)**

### Temperature-sensitive proxies

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### CCSM4-LM

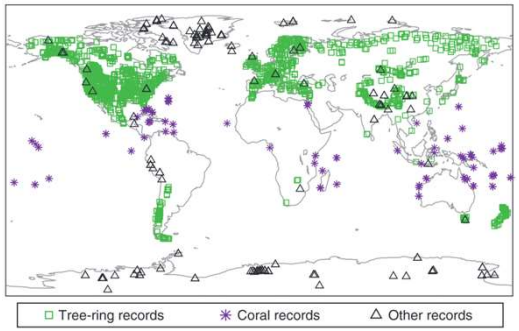
✓Global gridded data

✓Multiple variables

✓Constrained by both physical laws and proxy records

**PHYDA : Paleo Hydrodynamics Data Assimilation Product (Steiger et al., 2018)**

### Hydroclimate-sensitive proxies

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### CESM-LME

# Methods: CESM-LME

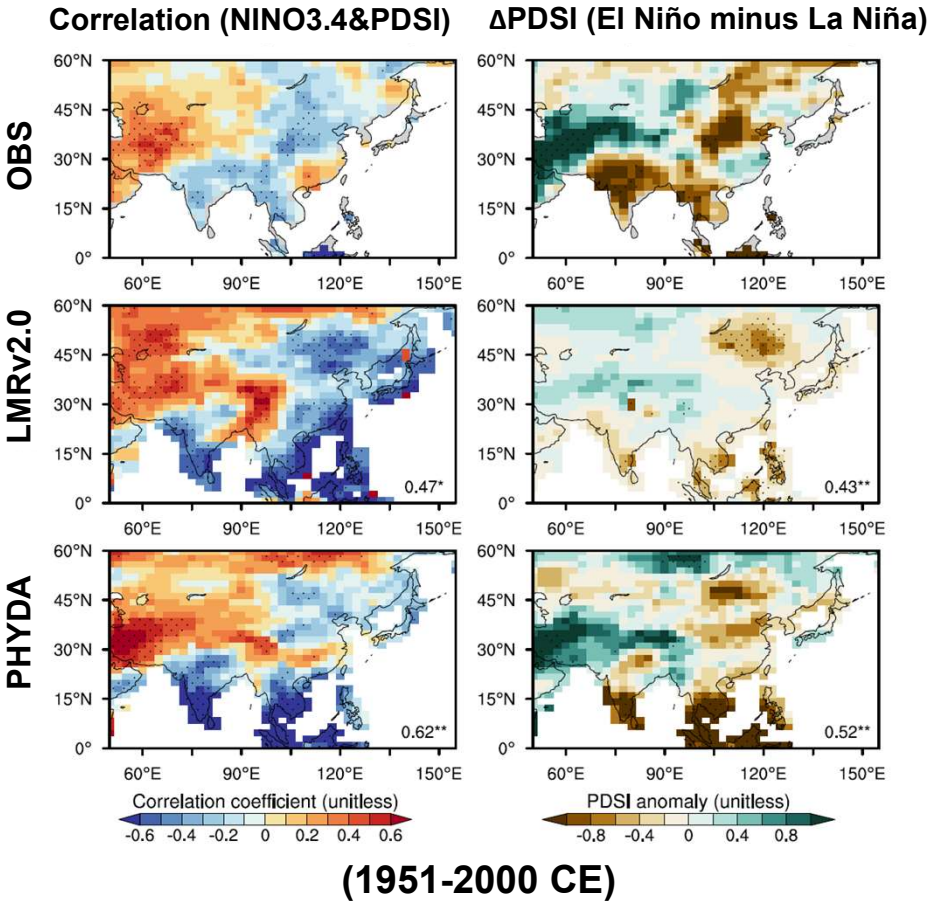
**Table 1. CESM-LME simulations. Additional information about the simulations including the forcing datasets, saved variables, diagnostics, model support and known issues can be found at the CESM-LME website (www2.cesm.ucar.edu/models/experiments/LME).**

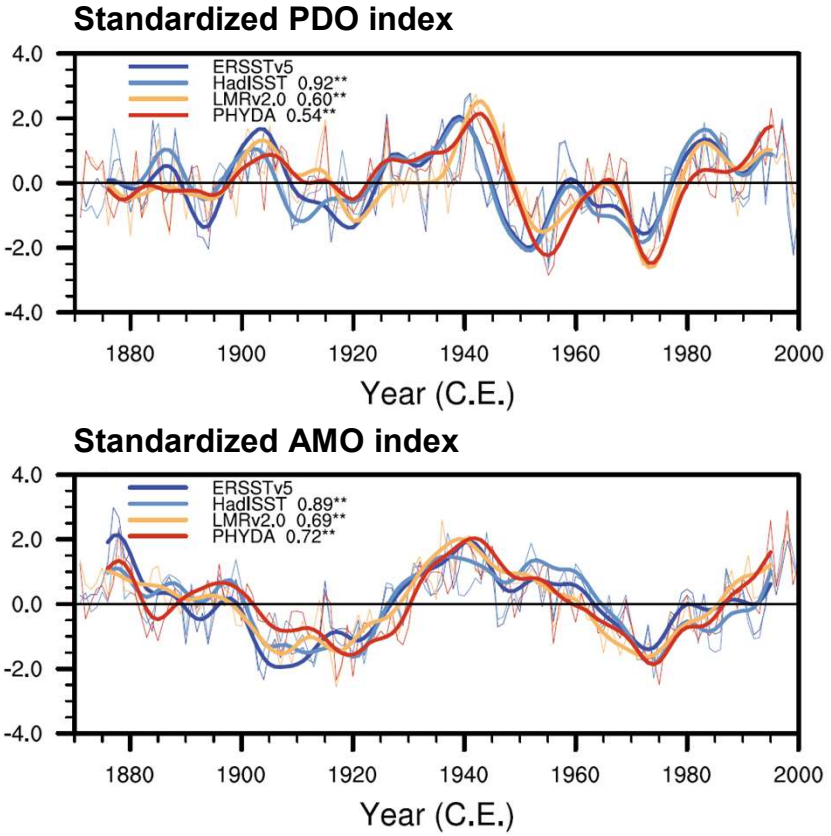
| Expt | No. of runs | Solar variability | Volcanic eruptions | Land use | GHGs | Orbital changes | Ozone–aerosols |
|---|---|---|---|---|---|---|---|
| Full forcings | 10 | Transient 850–2005 | Transient 850–2005 | Transient 850–2005 | Transient 850–2005 | Transient 850–2005 | Transient 1850–2005 |
| Solar only | 4 | Transient 850–2005 | None | * | * | * | 1850 |
| Volcanic only | 5 | * | Transient 850–2005 | * | * | * | 1850 |
| Land use only | 3 | * | None | Transient 850–2005 | * | * | 1850 |
| GHG only | 3 | * | None | * | Transient 850–2005 | * | 1850 |
| Orbital only | 3 | * | None | * | * | Transient 850–2005 | 1850 |
| Ozone–aerosol only | 2 | * | None | * | * | * | Transient 1850–2005 |

* Fixed at 850 values.

Credit: Table 1 in Otto-Bliesner et al. (2016)

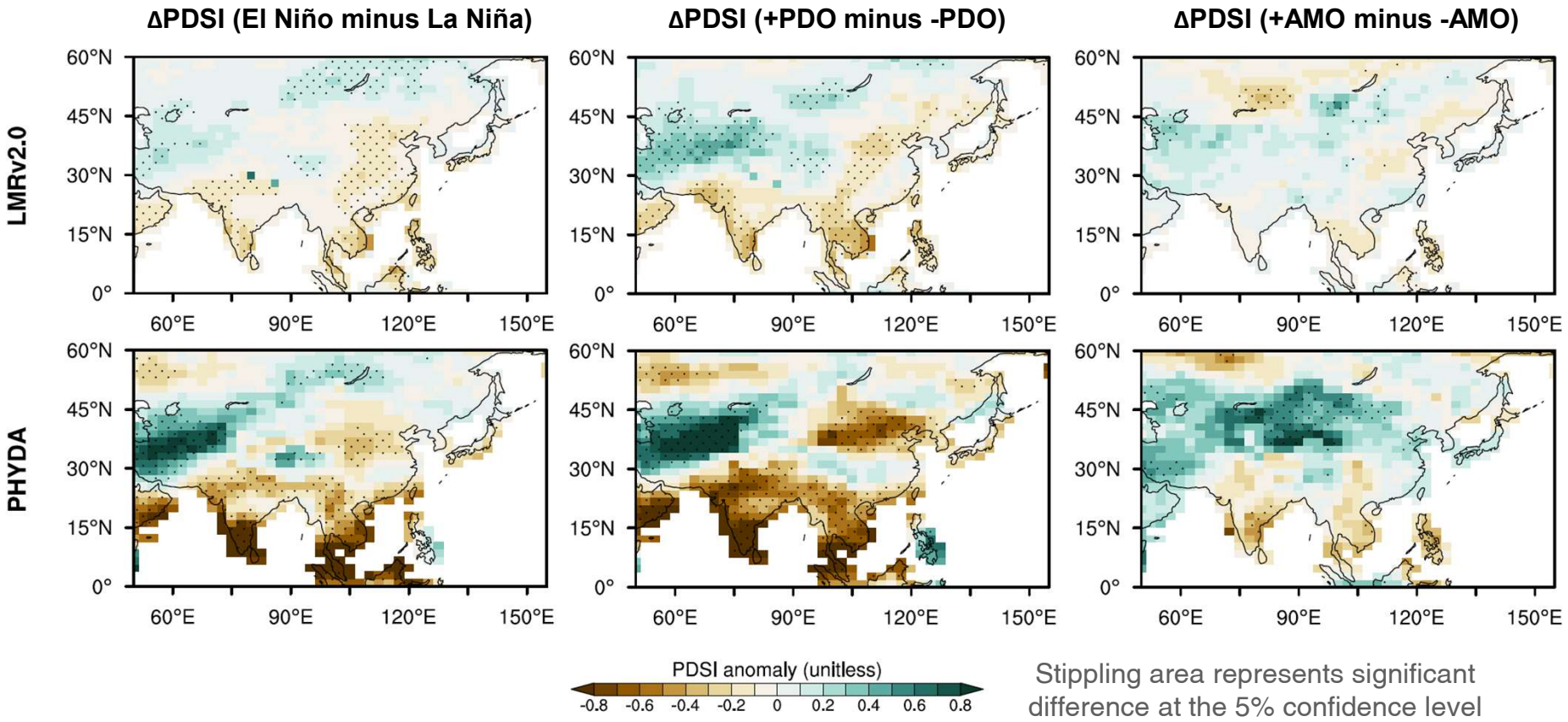
# Q0: Are the Paleoclimate Data Assimilation Products reliable for this study?



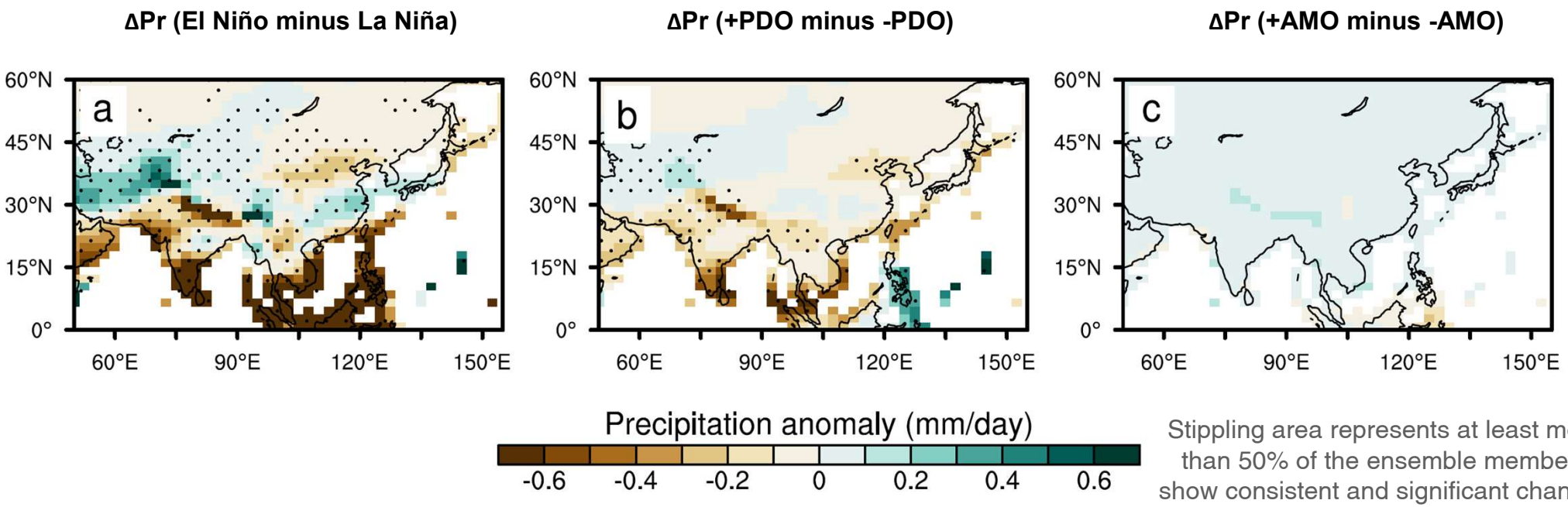

**Answer: Yes!**

# Q1: How do the PDO and AMO, in combination with ENSO, influence Asian Summer Monsoon (ASM) variability?




**Warm (cold) phases of the ENSO/PDO/AMO are associated with drier (wetter) conditions**

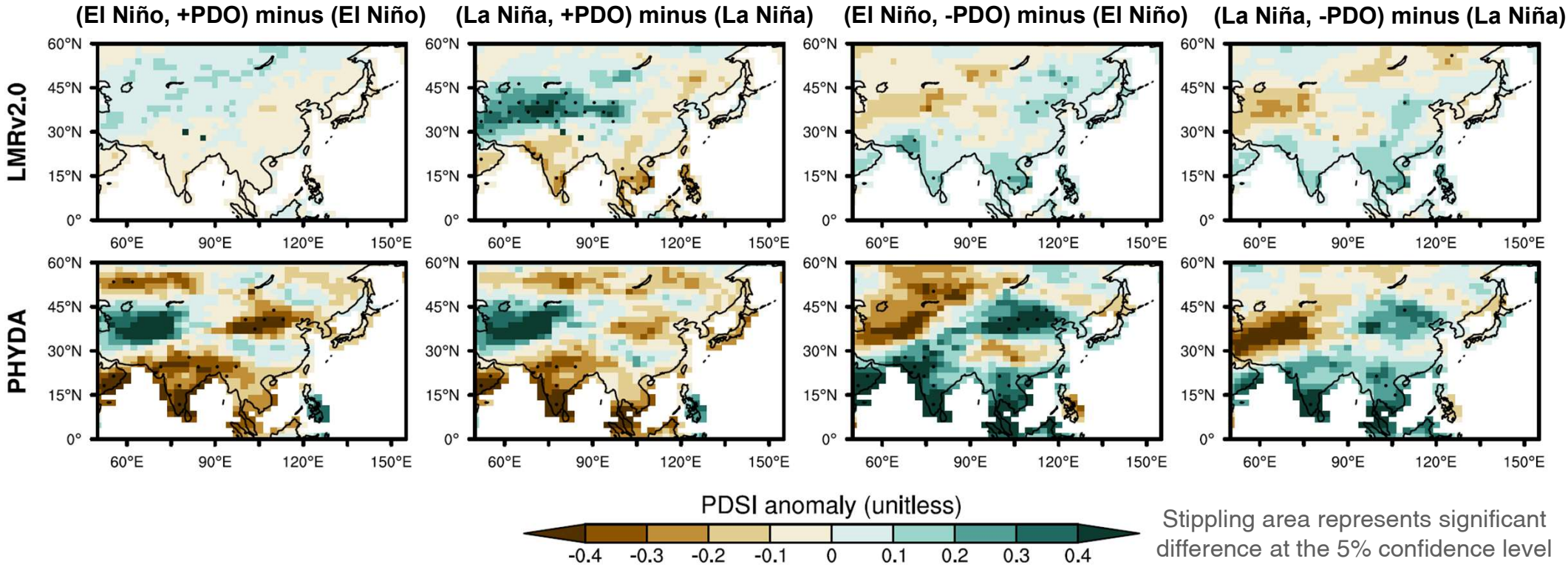
# CESM-LME: individual influence of ENSO/PDO/AMO on ASM




Stippling area represents at least more than 50% of the ensemble members show consistent and significant changes

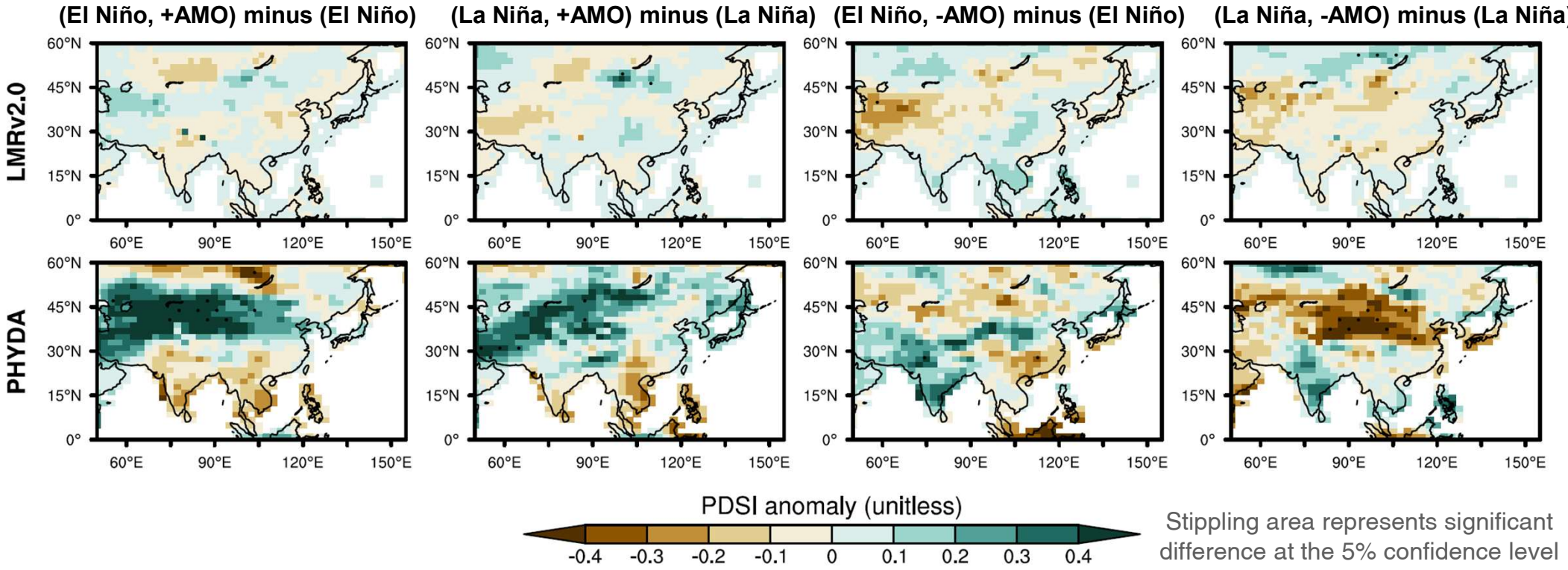
**The Paleo-DA products results are consistent with the CESM-LME**

## Q1: How do the PDO and AMO, in combination with ENSO, influence Asian Summer Monsoon (ASM) variability?



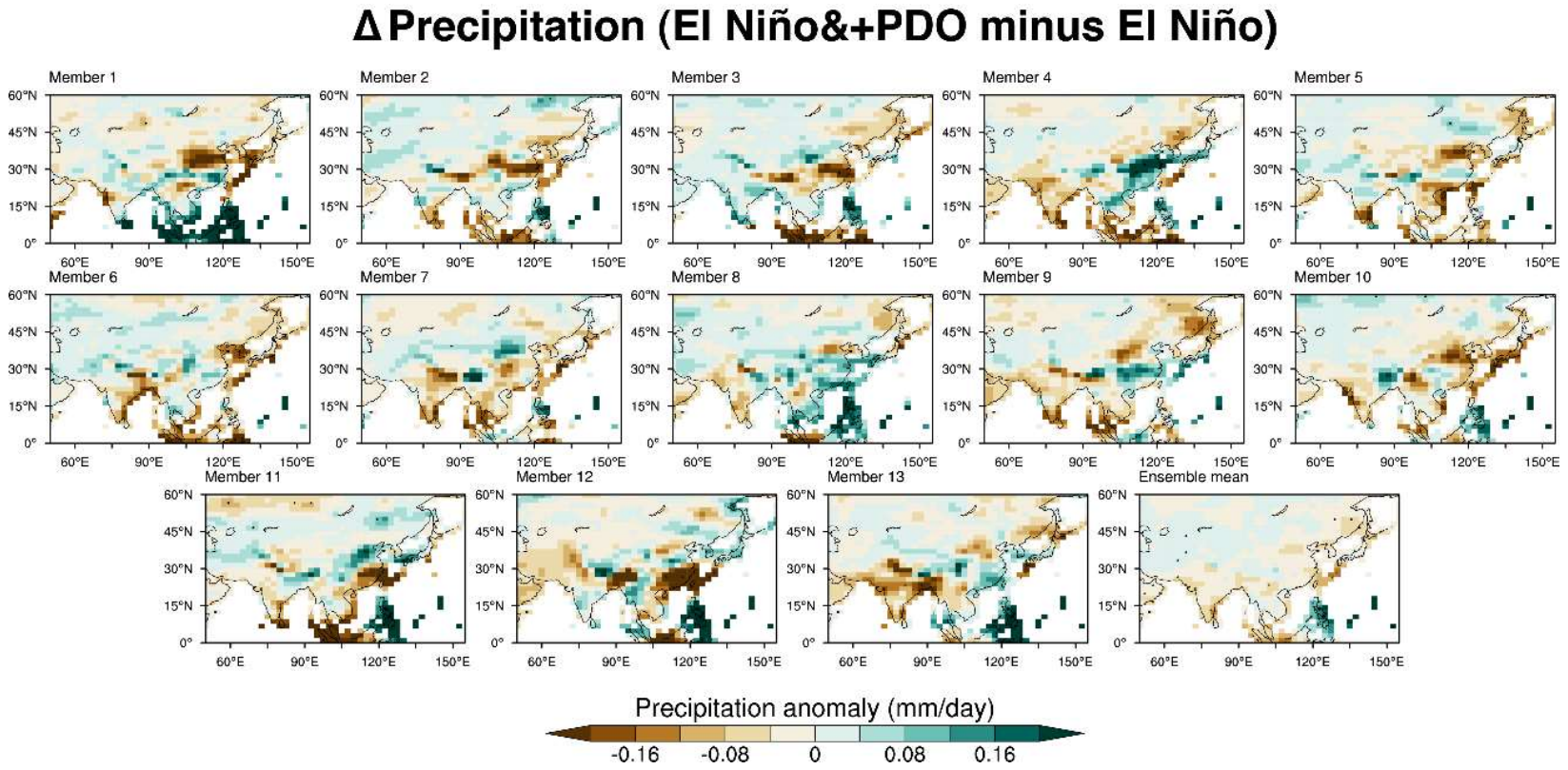

**PDSI anomalies in South and Southeast Asia are enhanced when El Niño (La Niña) under the warm (cold) phase of the PDO, while the opposite combination results in a neutralizing effect**

# Q1: How do the PDO and AMO, in combination with ENSO, influence Asian Summer Monsoon (ASM) variability?



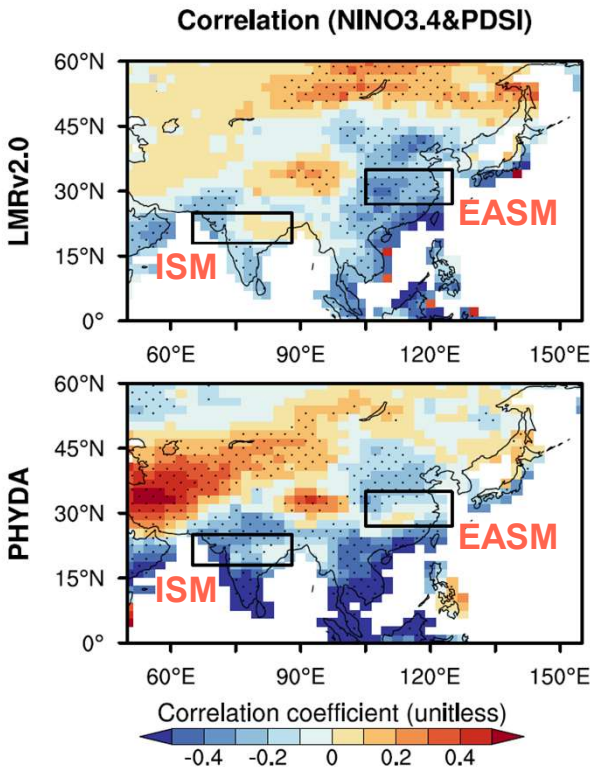

**The compounding effects of AMO and ENSO on the ASM do not differ significantly from the individual effects of ENSO**

# CESM-LME: compounding effects of ENSO and PDO relative to ENSO alone

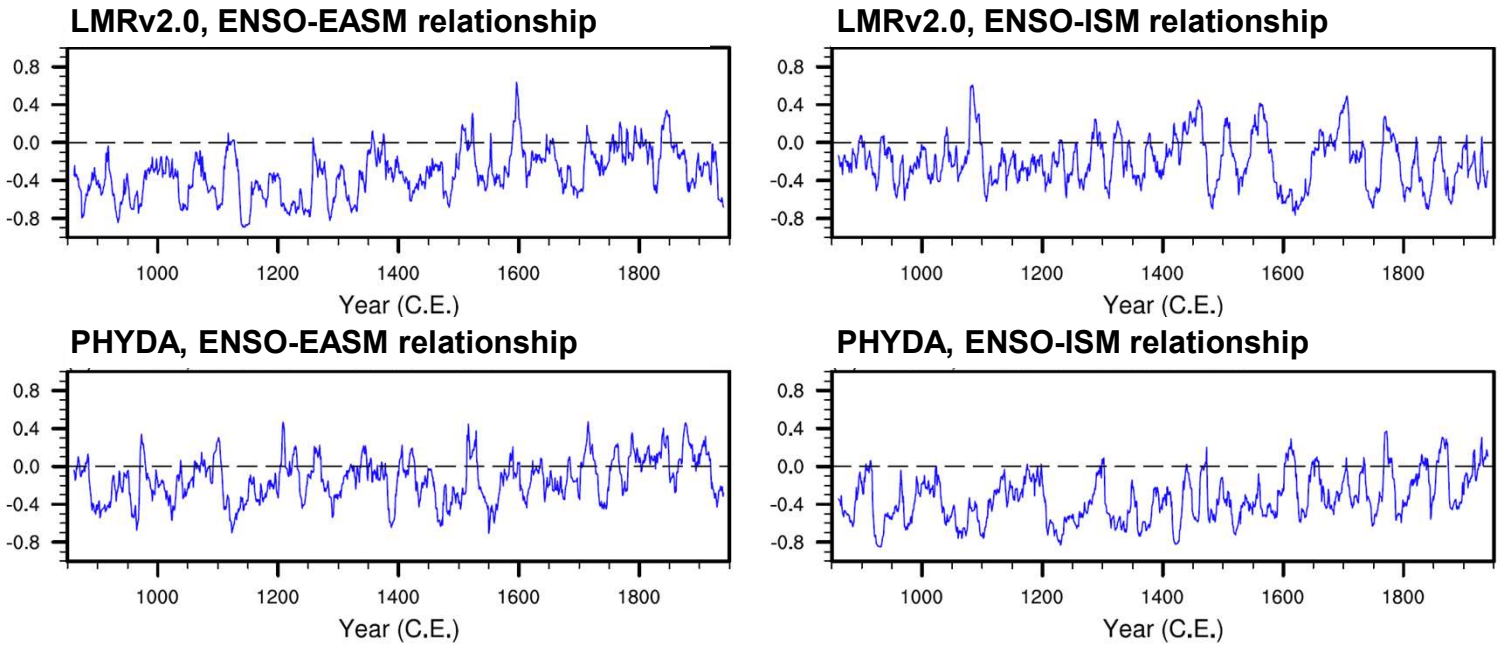



**Climate models show little distinction between the compounding effects of the PDO/AMO and ENSO and the average effects of ENSO on the ASM**

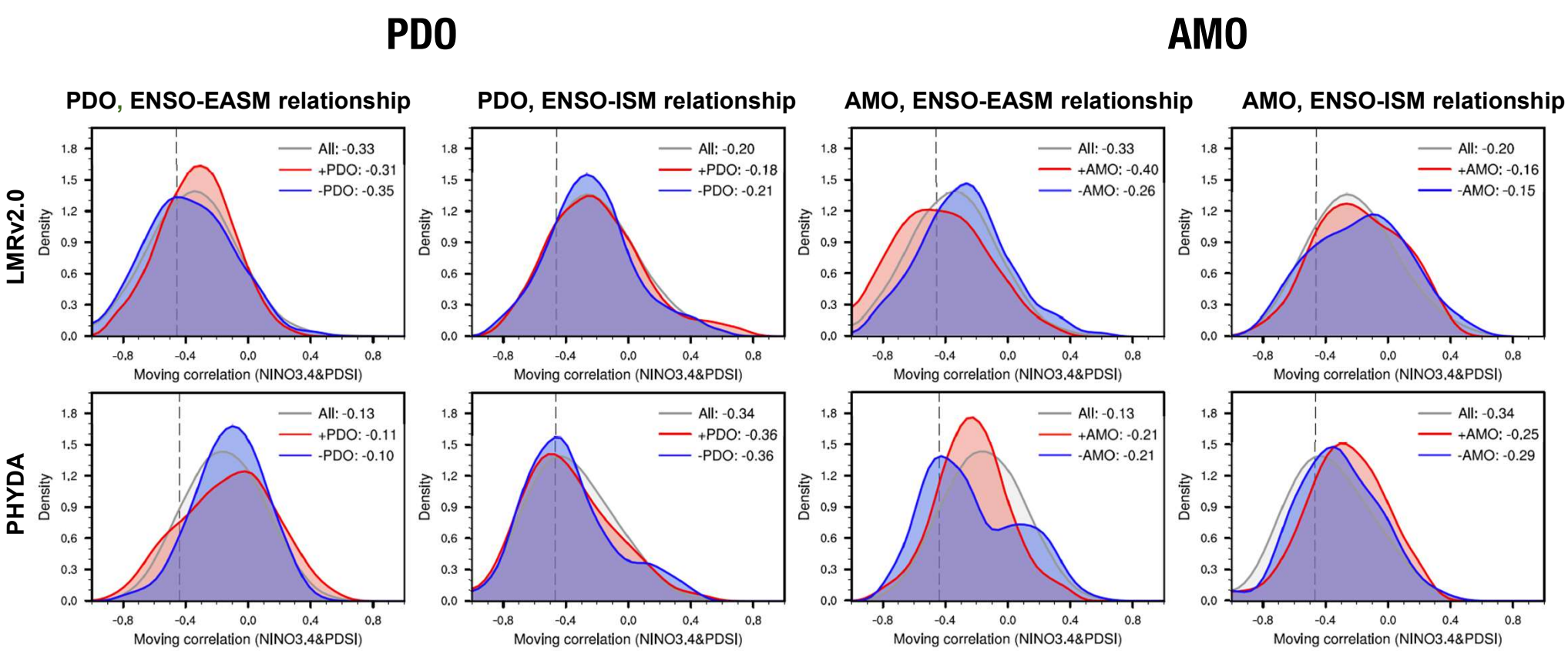
# Q2: How do the PDO and AMO influence the ENSO-monsoon relationship (correlation strength)?




## 21-year sliding correlations between NINO3.4 index and regional mean PDSI



# Q2: How do the PDO and AMO influence the ENSO-monsoon relationship (correlation strength)?

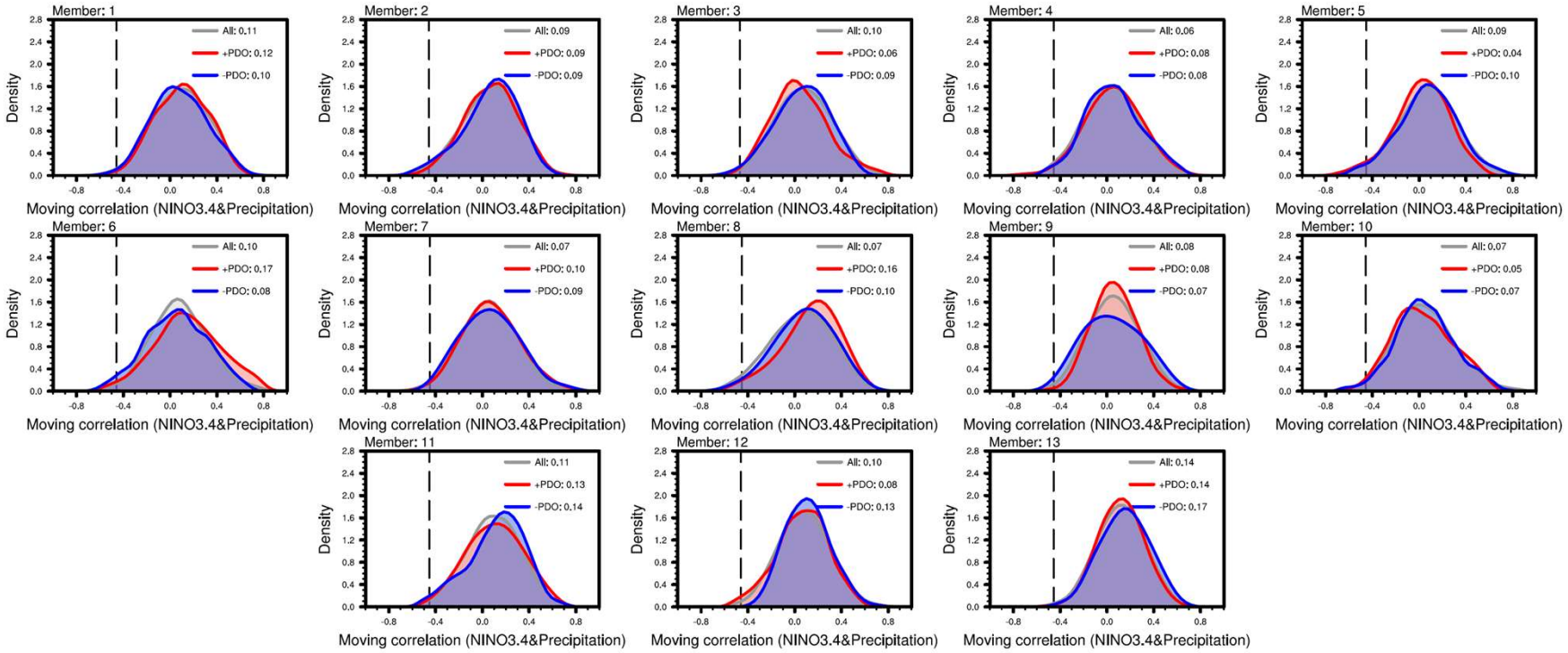



**Differences in the mean ENSO-monsoon correlations between warm and cold phases of PDO/AMO are NOT statistically significant**

## Q2: How do the PDO and AMO influence the ENSO-monsoon relationship (correlation strength)?

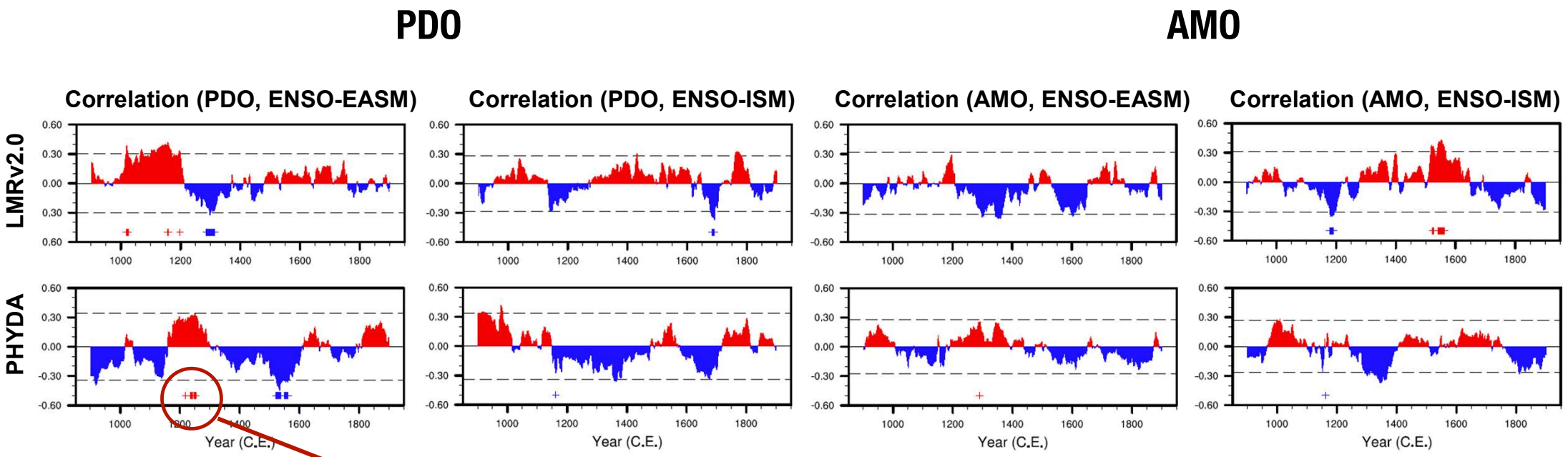
**CESM-LME:**

Influence of PDO on the ENSO-EASM teleconnection




**Differences in the mean ENSO-monsoon correlations between warm and cold phases of PDO/AMO are NOT statistically significant**

# Q2: How do the PDO and AMO influence the ENSO-monsoon relationship (correlation strength)?

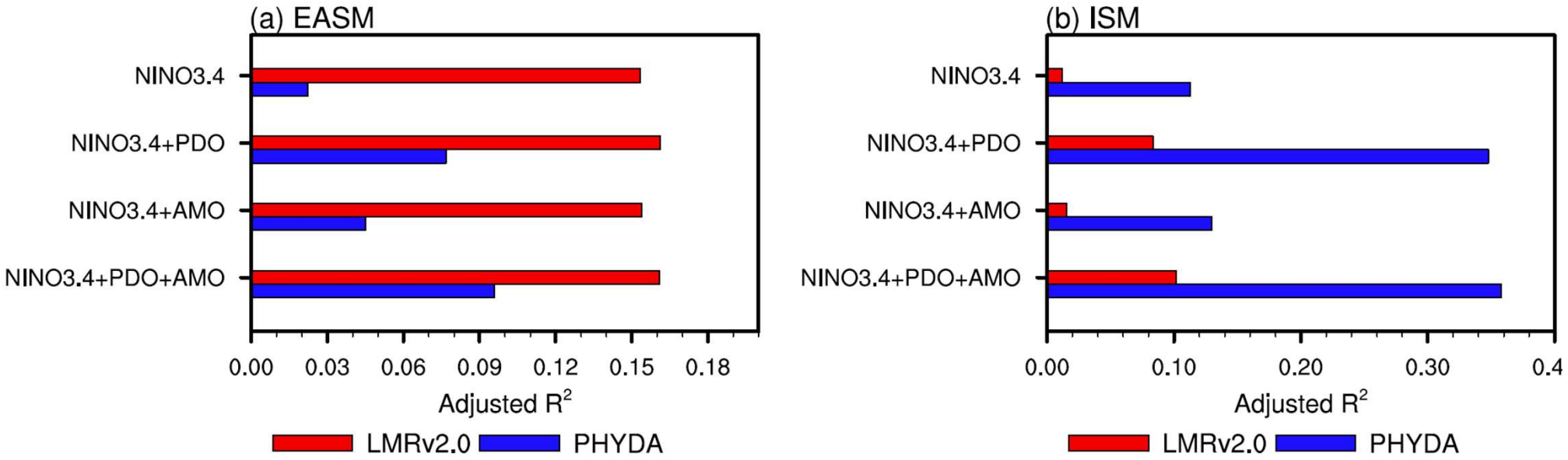



The central year of the 101-year sliding window, during which period the correlation between the PDO/AMO index and the ENSO-monsoon relationship is statistically significant

**Significant influence of the PDO/AMO on the ENSO-monsoon relationship occurred only over a limited period within the last millennium**

## Q3: Can we improve ASM prediction using insights from the Last Millennium?

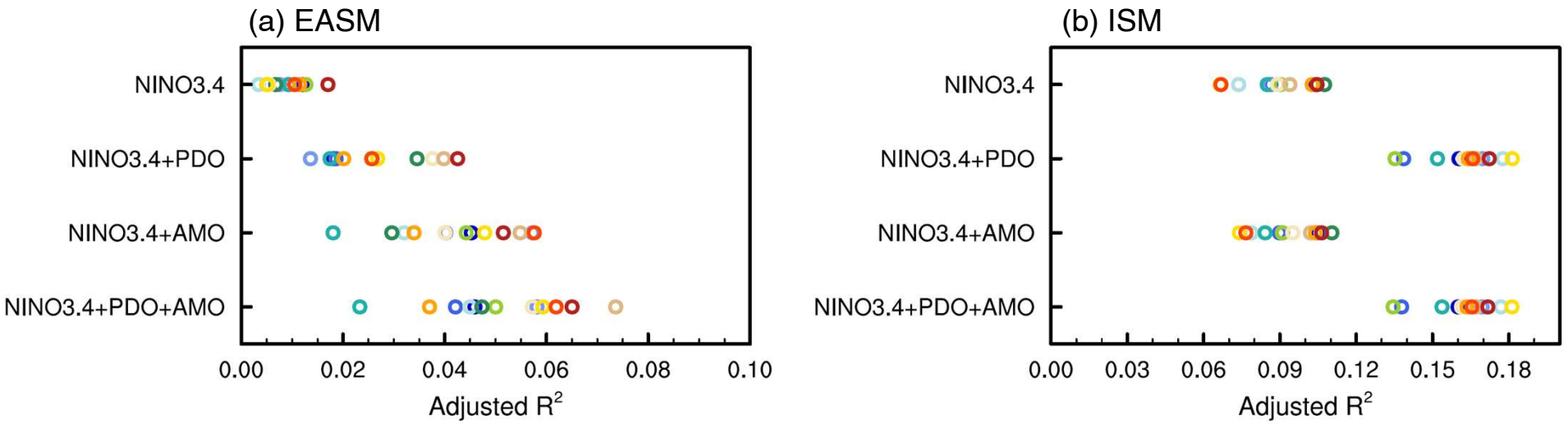
Adjusted $R^2$ for different linear regression models for monsoon prediction




**Incorporating the PDO in addition to ENSO improves the prediction skill for the ISM whereas the inclusion of the AMO makes little difference**

## Q3: Can we improve ASM prediction using insights from the Last Millennium?

**CESM-LME:** Adjusted $R^2$ for different linear regression models for monsoon prediction




**Incorporating the PDO in addition to ENSO improves the prediction skill for the ISM whereas the inclusion of the AMO makes little difference**

## Take Home Messages:

- **The PDO impacts ASM variability more than the AMO, and its consideration yields improved Indian summer monsoon predictions**

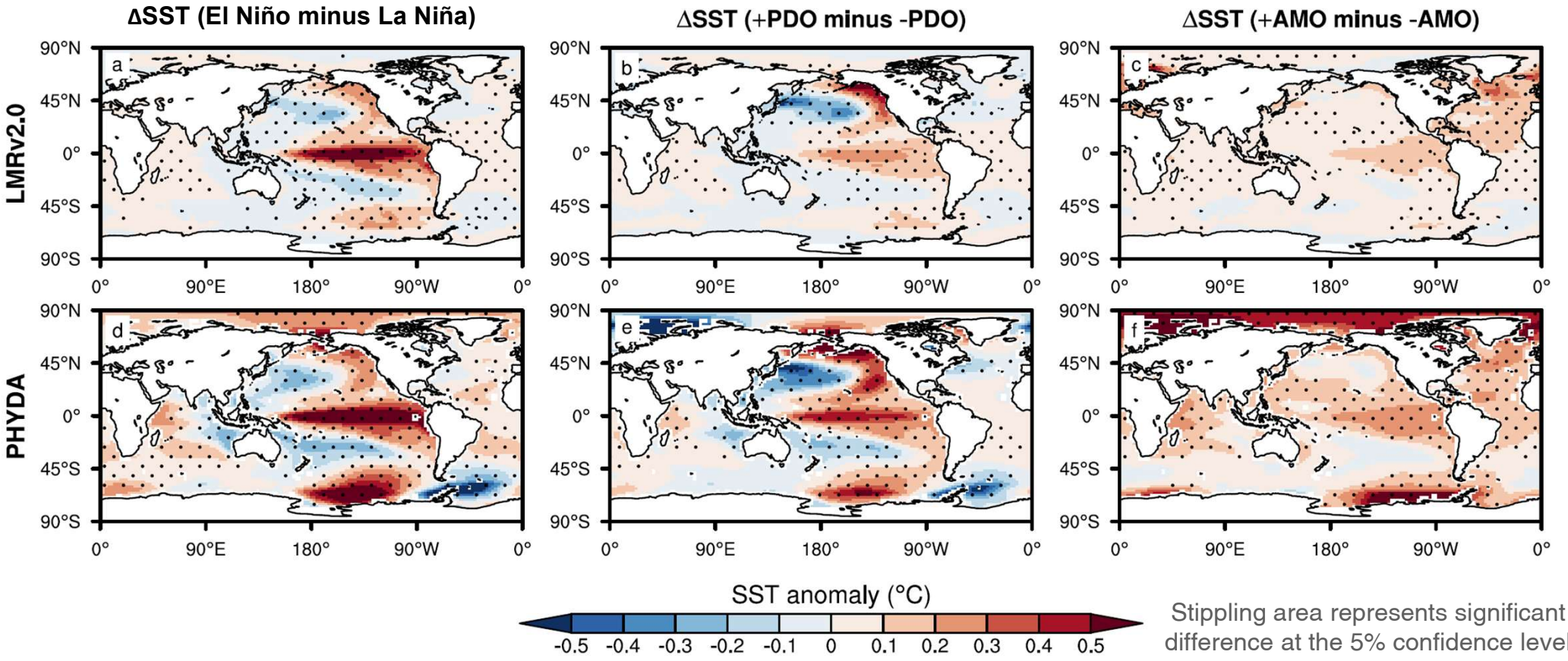
  The dry (wet) anomalies caused by El Niño (La Niña) in India will be enhanced during the positive (negative) PDO phases due to compounding effects

- **The influence of the PDO and AMO on the ENSO-ASM relationship is non-stationary across the last millennium**

- **Paleo-DA products generate similar results as in CESM-LME**

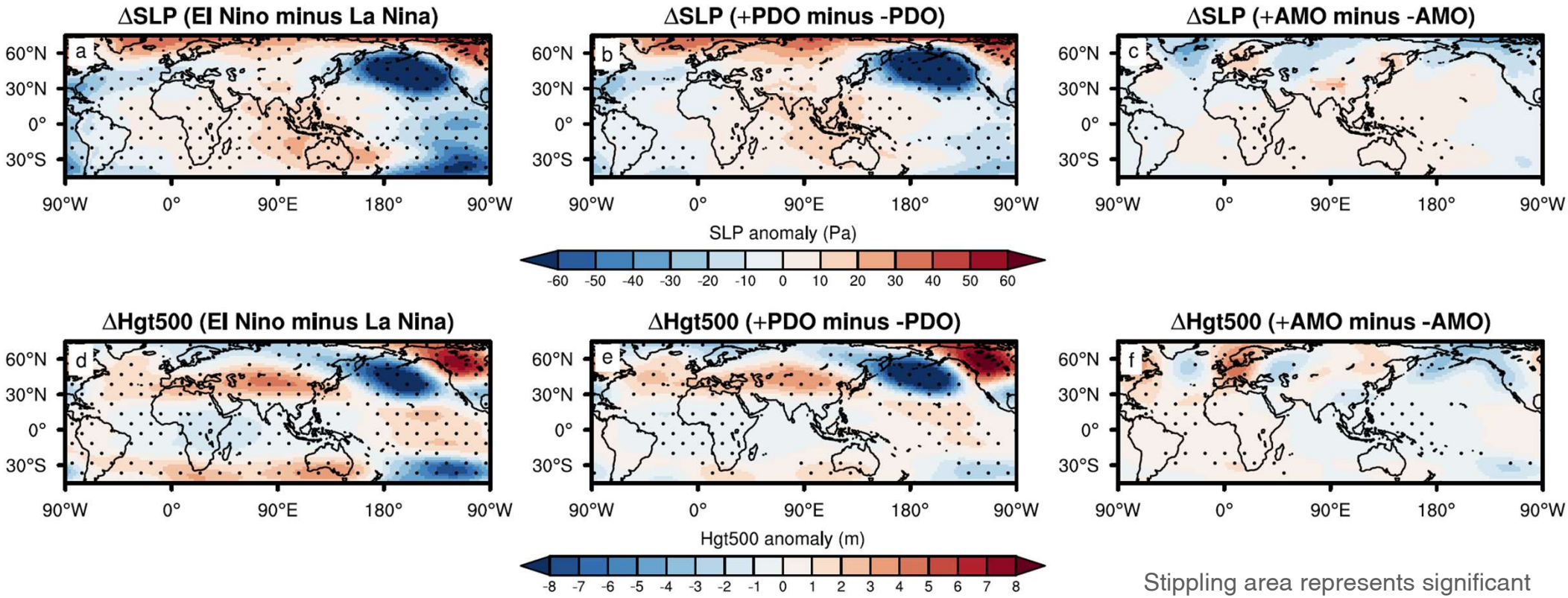
Wang, N., Dee, S., Hu, J., Steiger, N., & Thirumalai, K. (2024). PDO and AMO Modulation of the ENSO–Asian Summer Monsoon Teleconnection During the Last Millennium. *Journal of Geophysical Research: Atmospheres*, *129*(1), e2023JD039638.

# Sea surface temperature pattern related to ENSO, PDO, and AMO




Stippling area represents significant difference at the 5% confidence level

# Sea level pressure and 500-hPa geopotential height patterns related to ENSO, PDO, and AMO




Stippling area represents significant difference at the 5% confidence level