



Indian Institute of Science,  
Bengaluru-560012

# MTech Project Presentation

Multimodal Analysis of Robust Changes in the South  
Asian Summer Monsoon under warming climate

**Supervisor: Prof. Govindasamy Bala**

**Co-Supervisor: Prof. Ravi Nanjundiah**

**Presented by: Kartik Soni**

CAOS 2022-24



# Introduction & Motivation

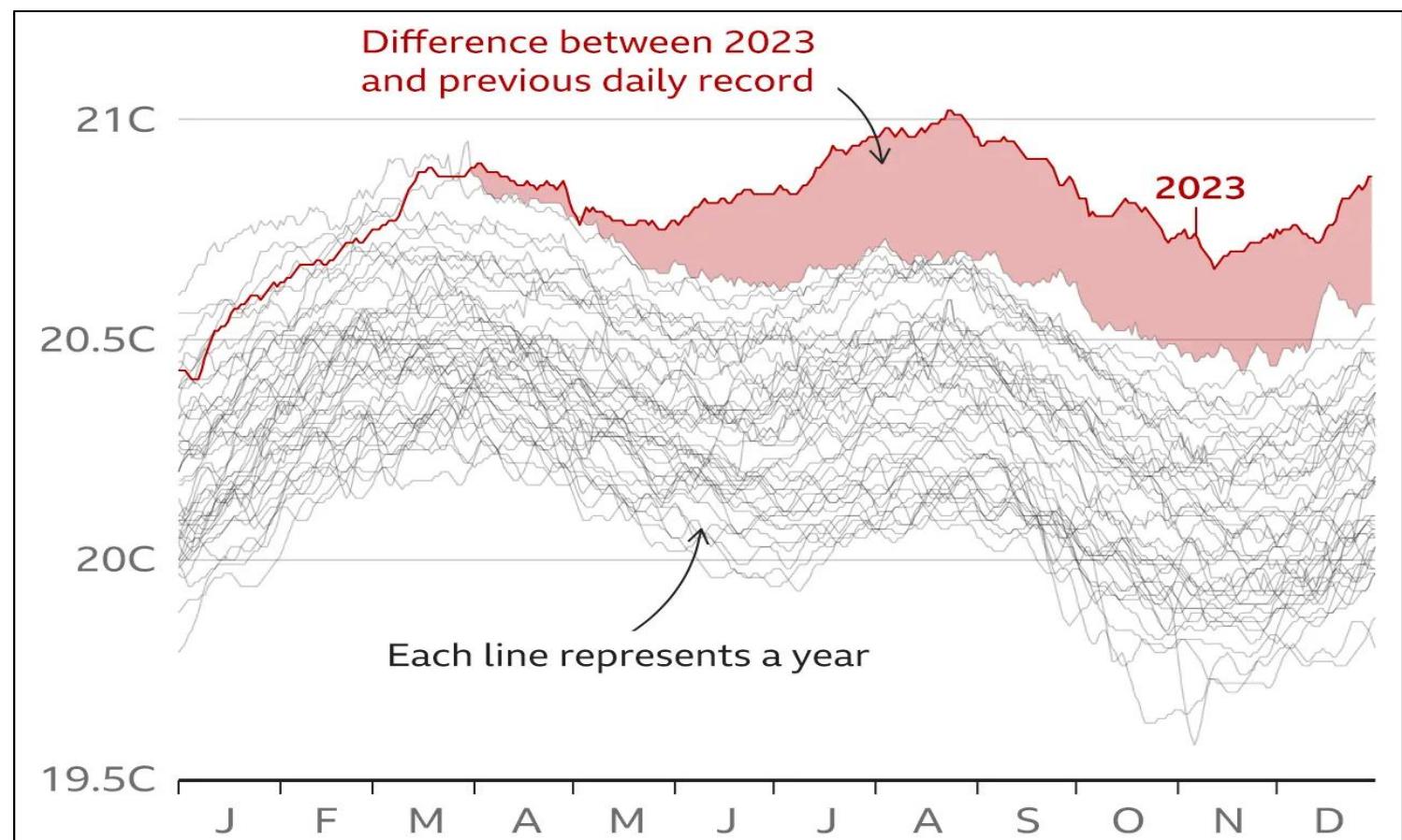
## Introduction:

- The Asian monsoon, a significant seasonal climatic phenomenon in the tropics, plays a crucial role in shaping weather patterns.
- Understanding future changes in monsoon rainfall is essential for India's agriculture and has profound impact on its flora and fauna.

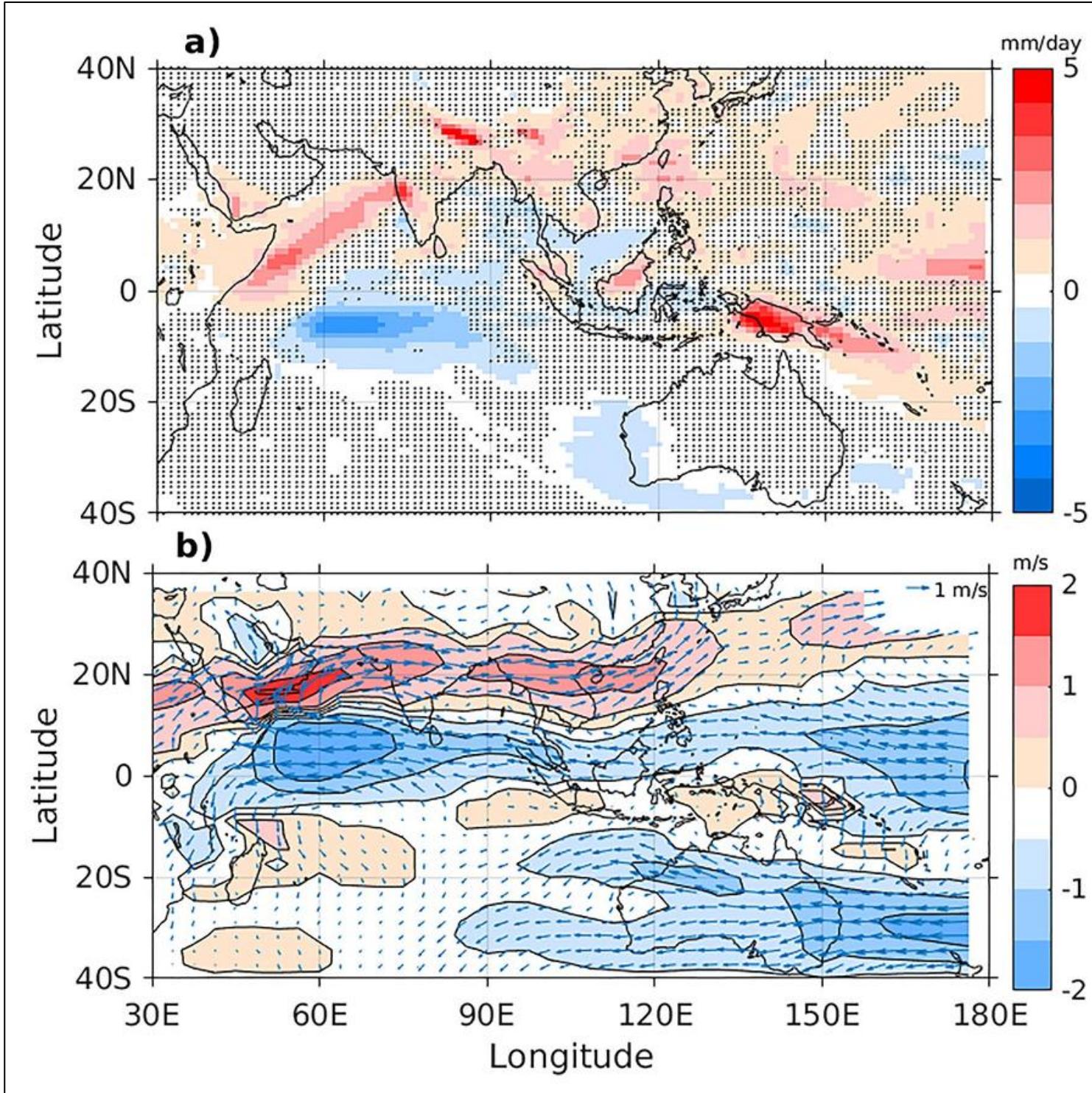


## Motivation:

- Climate models are subject to uncertainties and biases, which can significantly impact the accuracy of climate change projections.
- A multi-model approach helps to account for the uncertainties and biases in individual models.



# Introduction & Motivation



How do the characteristics of monsoon low pressure systems over India change under a warming climate? A modeling study using the NCAR CESM

Tresa Mary Thomas<sup>1</sup> · Govindasamy Bala<sup>1,2</sup> · Srinivas Venkata Vemavarapu<sup>1,3</sup>

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- This weakening of Indian monsoon is associated with **anticyclonic anomalies** straddling the equator at the low level.
- This study was probably the **first to suggest** the potential link between the changes in **LPS activity and low level meridional shear** under climate change.

# Experimental Setup

## List of CMIP6 models

### Data Used:

- CMIP6
- ERA5

### Experiments:

- Historical
- Abrupt-4xCO<sub>2</sub>
- Preindustrial Control

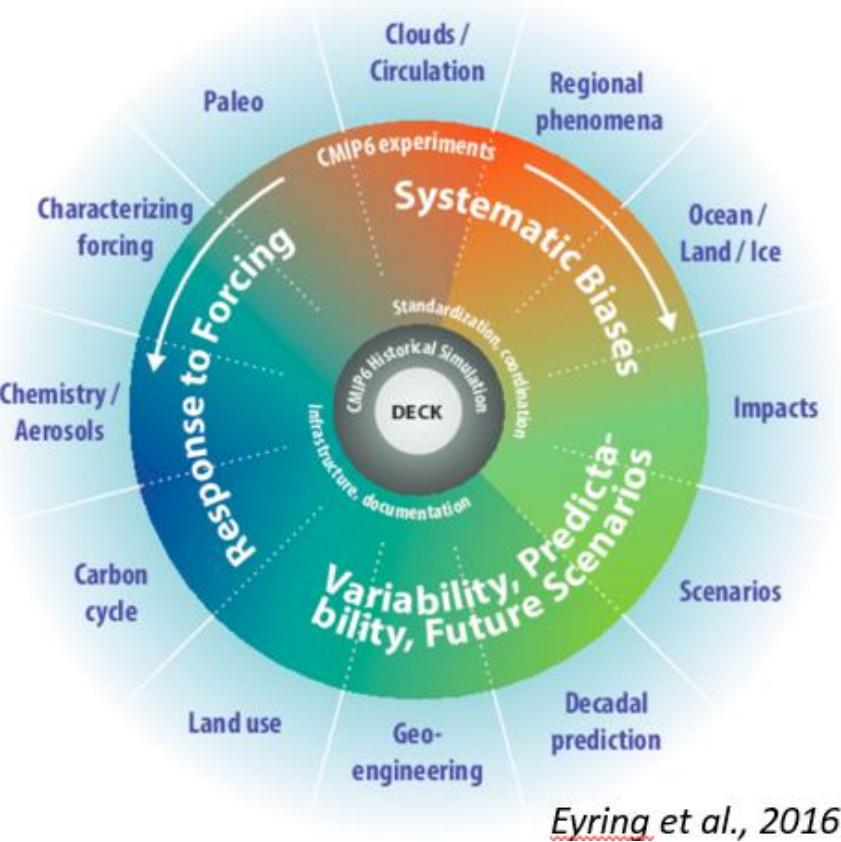
### Abrupt 4xCO<sub>2</sub> Experiment:

- Estimating Climate Sensitivity
- Investigating Climate Feedbacks
- Amplified Clear Signal from models

All the Models regridded to 64 x 128

“The abrupt-4xCO<sub>2</sub> experiment is like a magnifying glass for climate change. It allows us to study the potential impacts of high CO<sub>2</sub> levels in a controlled setting.”

### Coupled Model Intercomparison Project Phase 6

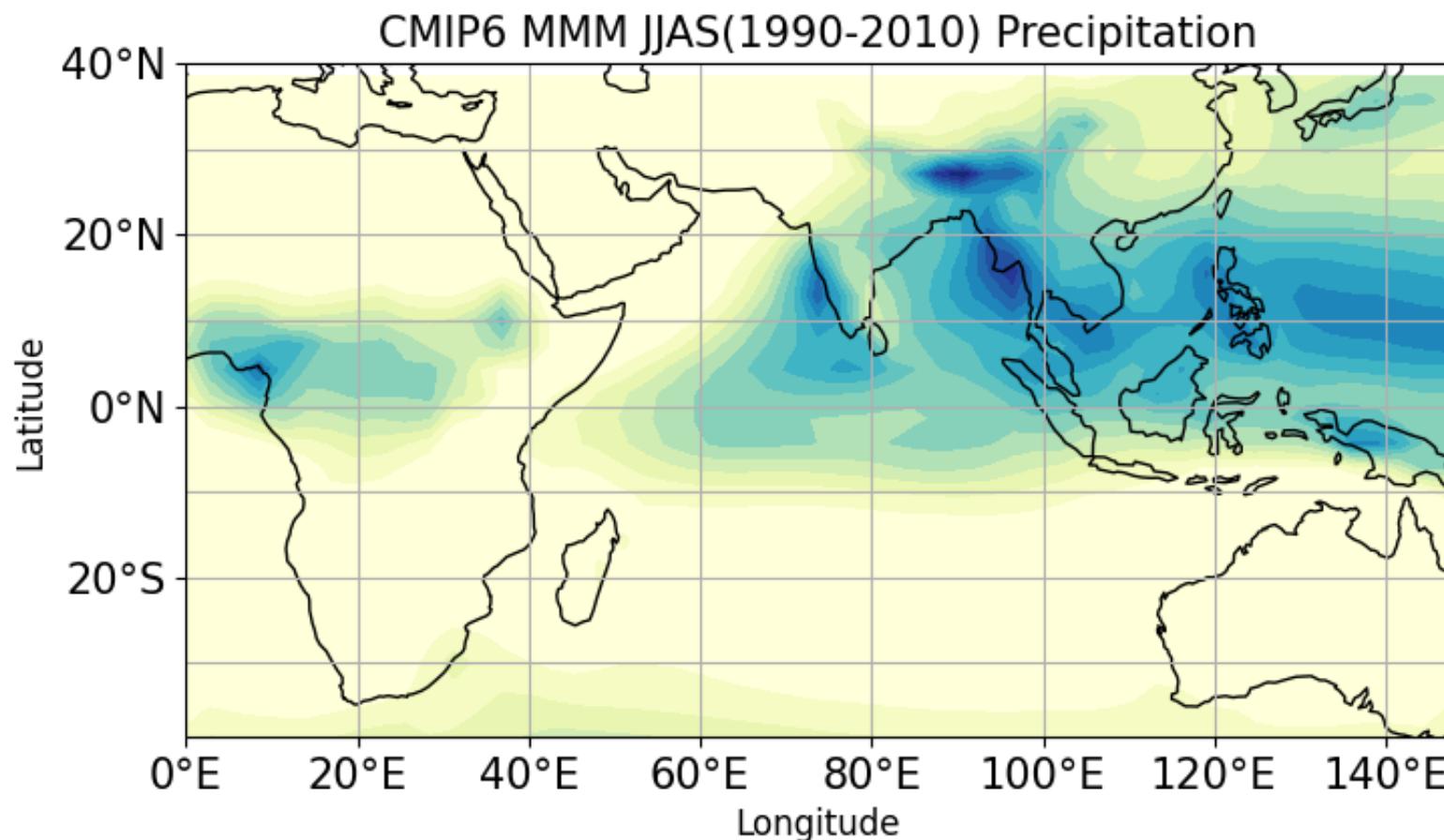
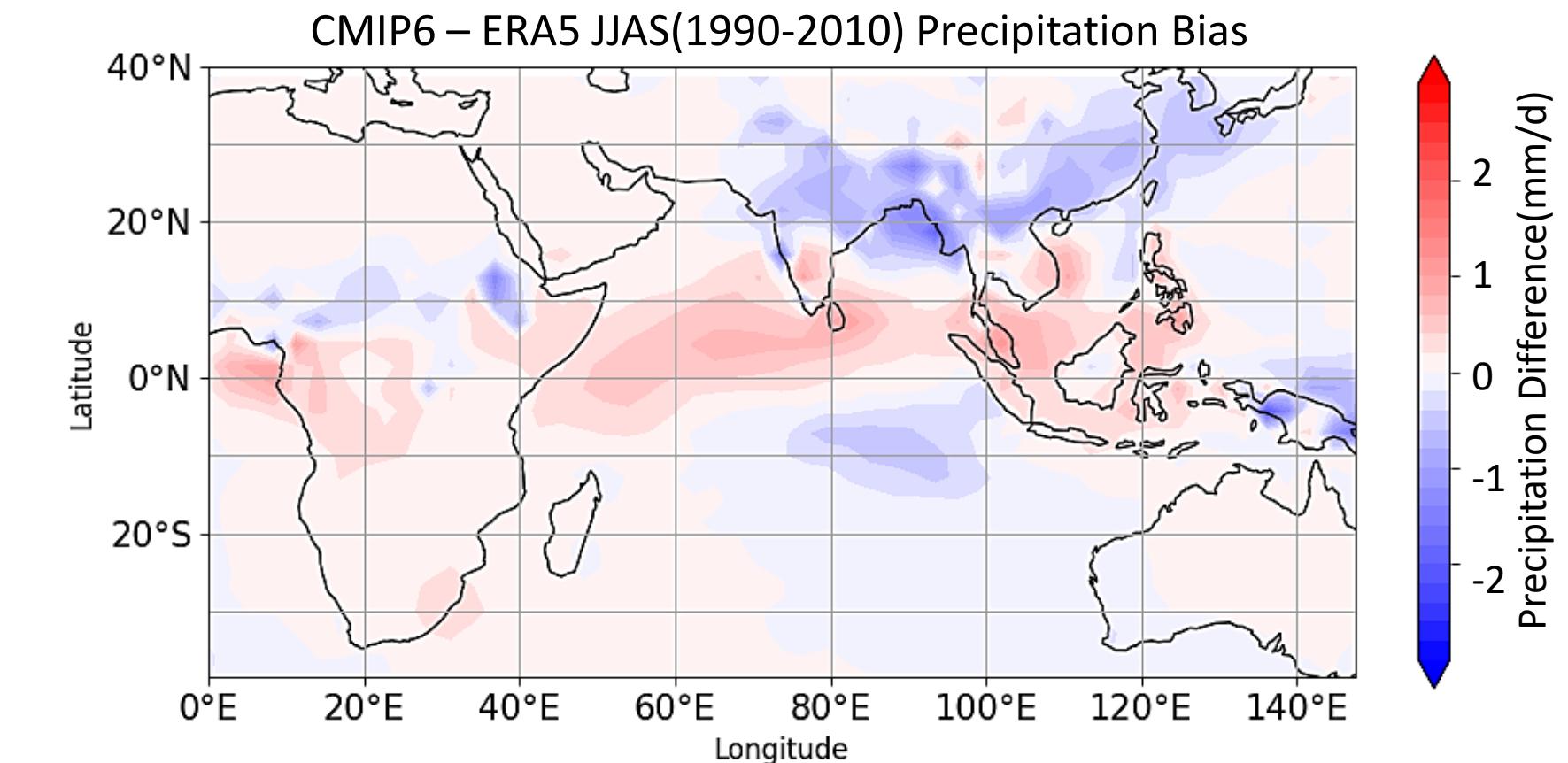
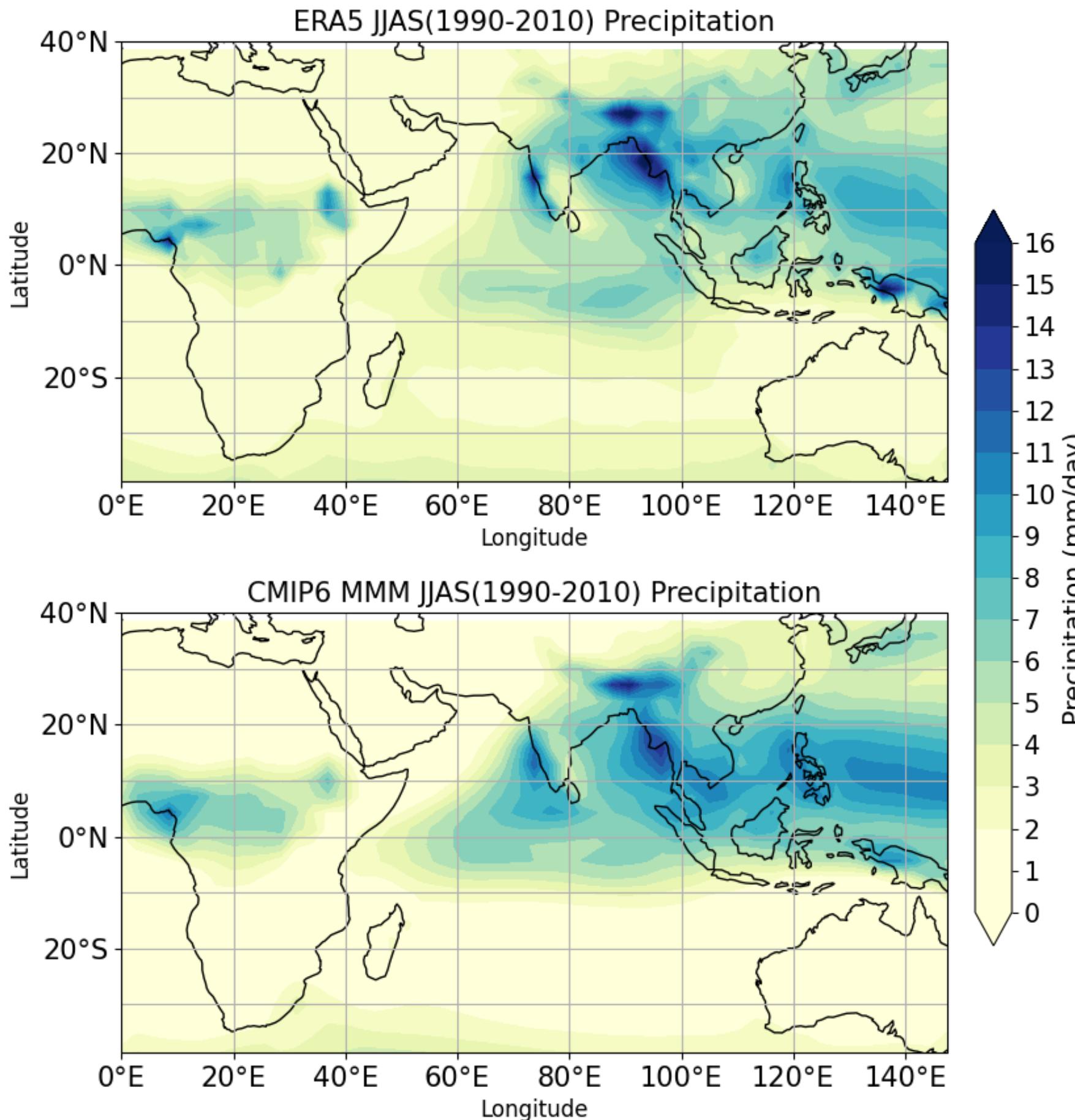


### Key Variables:

- Air Temperature (**ta**)
- Vertical Velocity (**wap**)
- Horizontal Winds (**ua**, **va**)
- Sea Surface Temperature (**ts**)
- Specific Humidity (**hus**)
- Precipitation (**pr**)
- Total Cloud Fraction (**clt**)

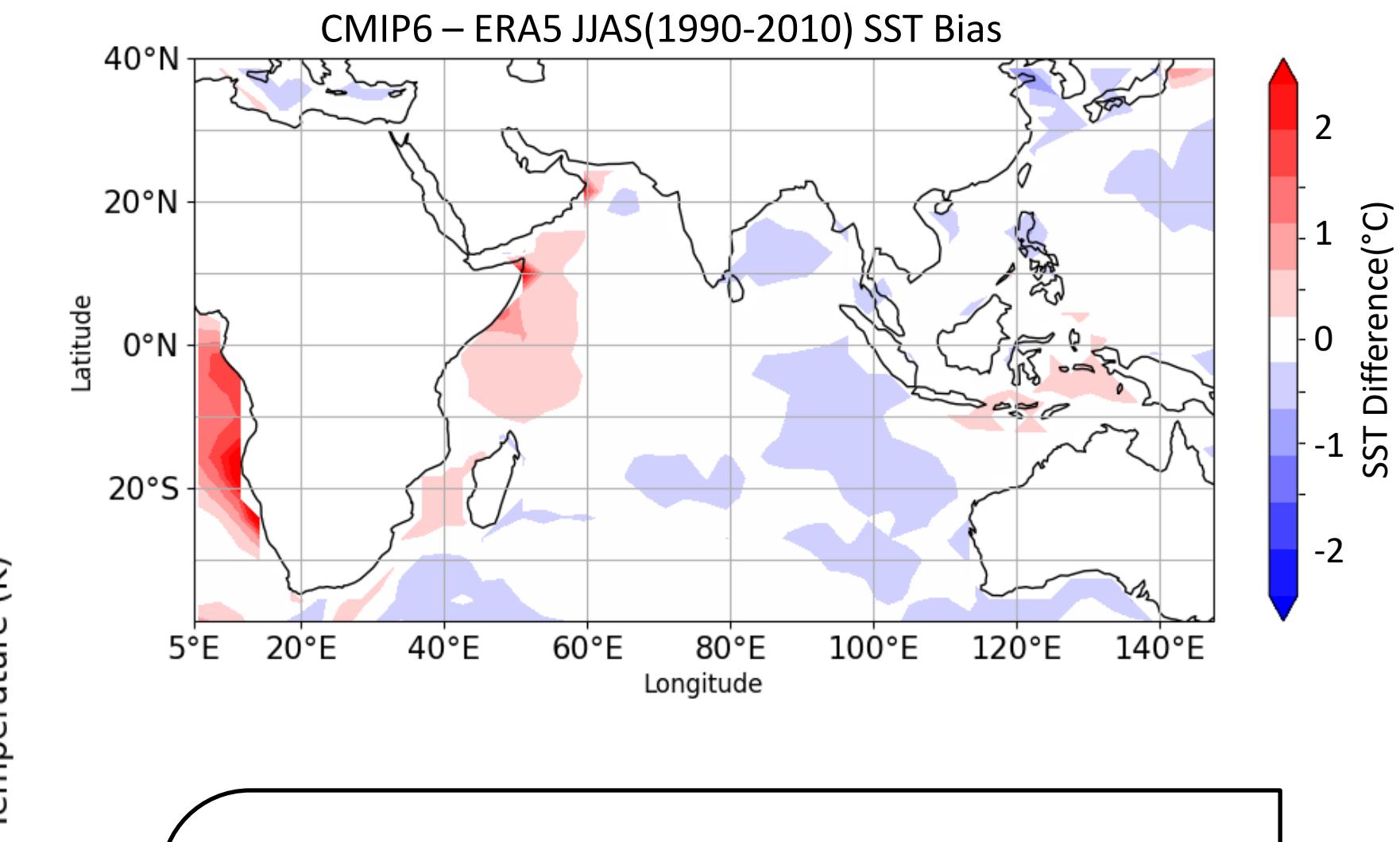
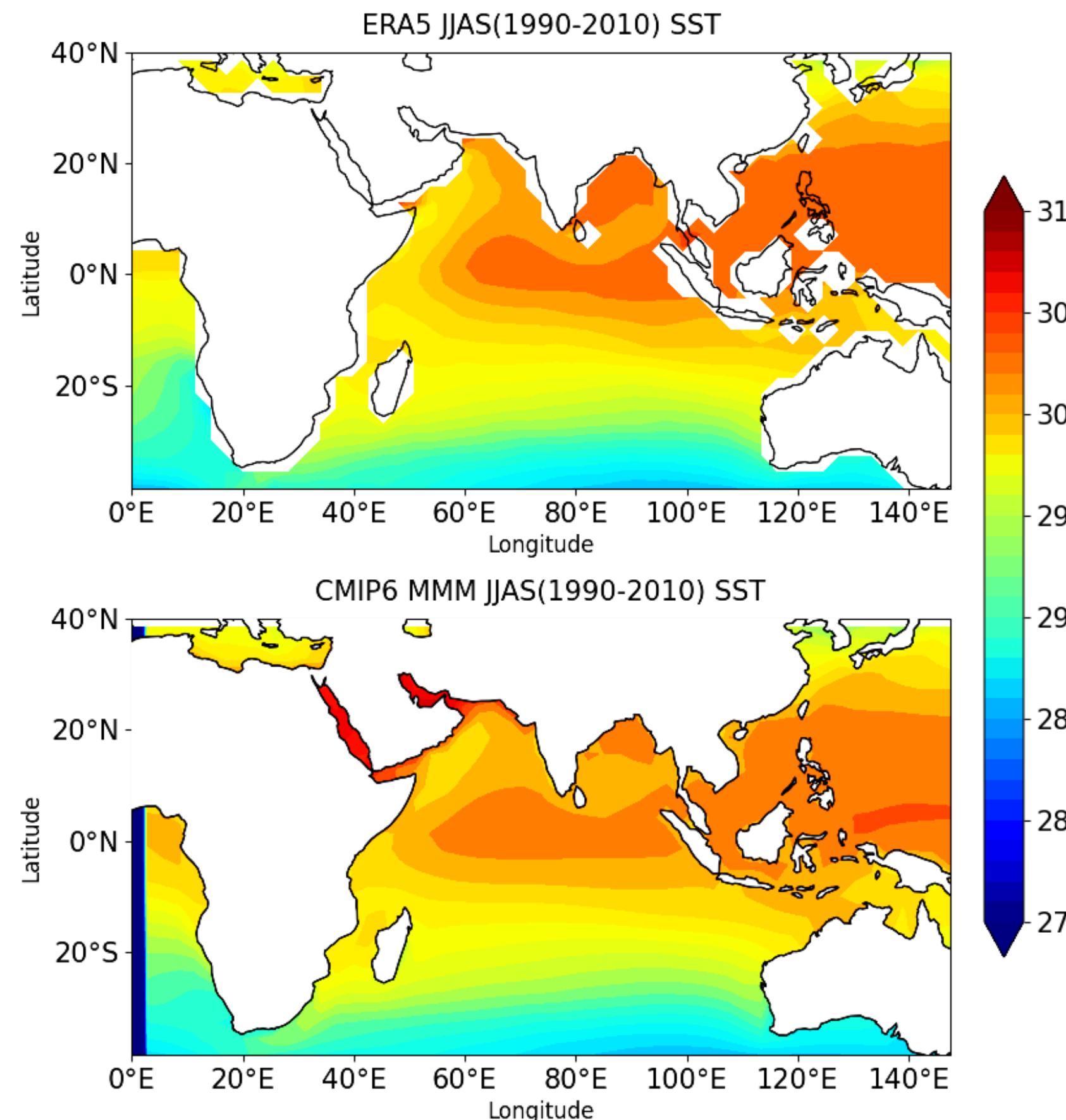
Sno.	Model	Resolution (lat x lon)	Country of Origin
1	<b>AWI-CM-1-1-MR</b>	192 x 384	South Korea
2	<b>BCC-CSM2-MR</b>	160 x 320	USA
3	<b>CAMS-CSM1-0</b>	160 x 320	Germany
4	<b>CanESM5</b>	64 x 128	Canada
5	<b>CESM2</b>	192 x 288	USA
6	<b>CESM2-FV2</b>	96 x 144	USA
7	<b>CESM2-WACCM</b>	160 x 320	China
8	<b>CESM2-WACCM-FV2</b>	96 x 144	USA
9	<b>E3SM-1-0</b>	180 x 288	China
10	<b>EC-Earth3-Veg</b>	256 x 512	EU
11	<b>FGOALS-g3</b>	80 x 180	China
12	<b>GFDL-ESM4</b>	192 x 288	UK
13	<b>GISS-E2-1-G</b>	90 x 144	Germany
14	<b>GISS-E2-1-G-CC</b>	90 x 144	USA
15	<b>GISS-E2-1-H</b>	90 x 144	USA
16	<b>HadGEM3-GC31-MM</b>	160 x 320	UK
17	<b>IITM-ESM</b>	94 x 192	India
18	<b>INM-CM4-8</b>	120 x 180	Russia
19	<b>INM-CM5-0</b>	120 x 180	Russia
20	<b>IPSL-CM6A-LR</b>	143 x 144	France
21	<b>KACE-1-0-G</b>	289 x 384	USA
22	<b>KIOST-ESM</b>	192 x 192	South Korea
23	<b>MIROC6</b>	128 x 256	Japan
24	<b>NESM3</b>	96 x 192	China
25	<b>NorCPM1</b>	96 x 144	Norway
26	<b>TaiESM1</b>	192 x 288	Taiwan

# ERA5 VS CMIP6 (Precipitation)

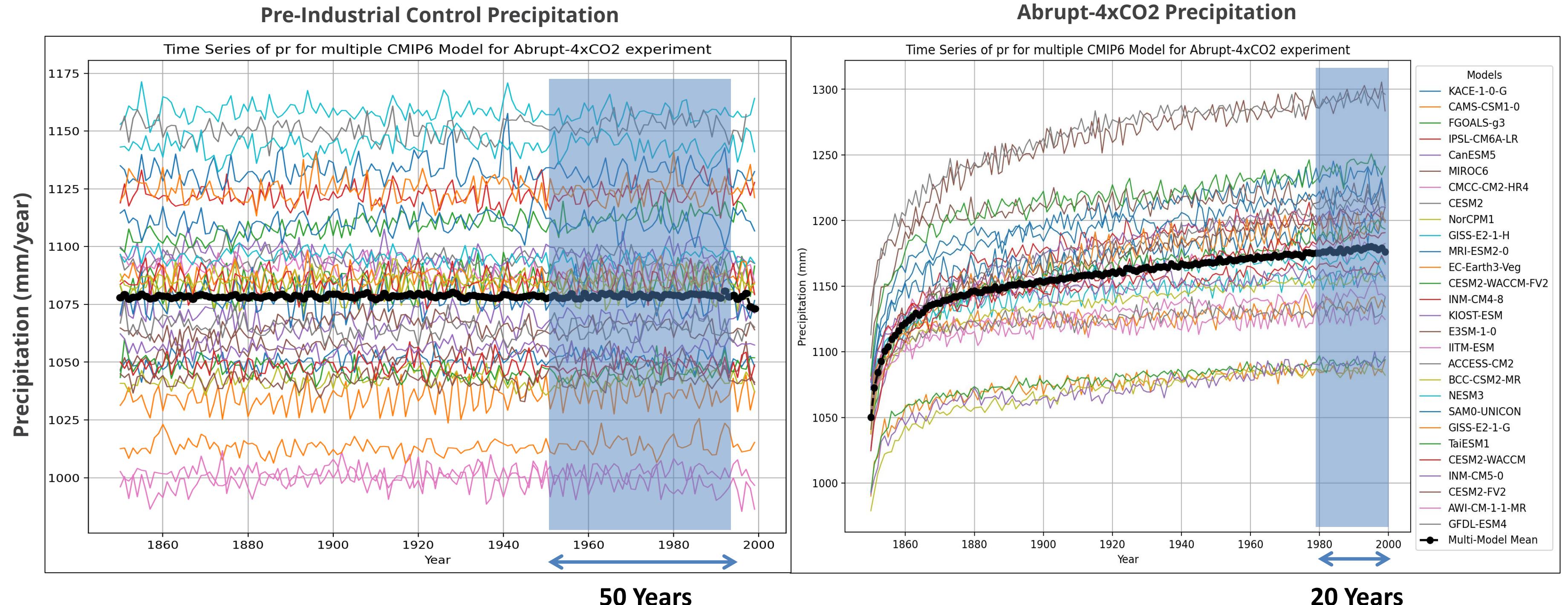


- Broadly Similar Spatial Distribution
- Models tend to have a **dry bias** the Indian subcontinent and parts of Southeast Asia(land), and a **wet bias** over the equatorial IO and parts of the western Pacific (oceans).

# ERA5 VS CMIP6 (SST)



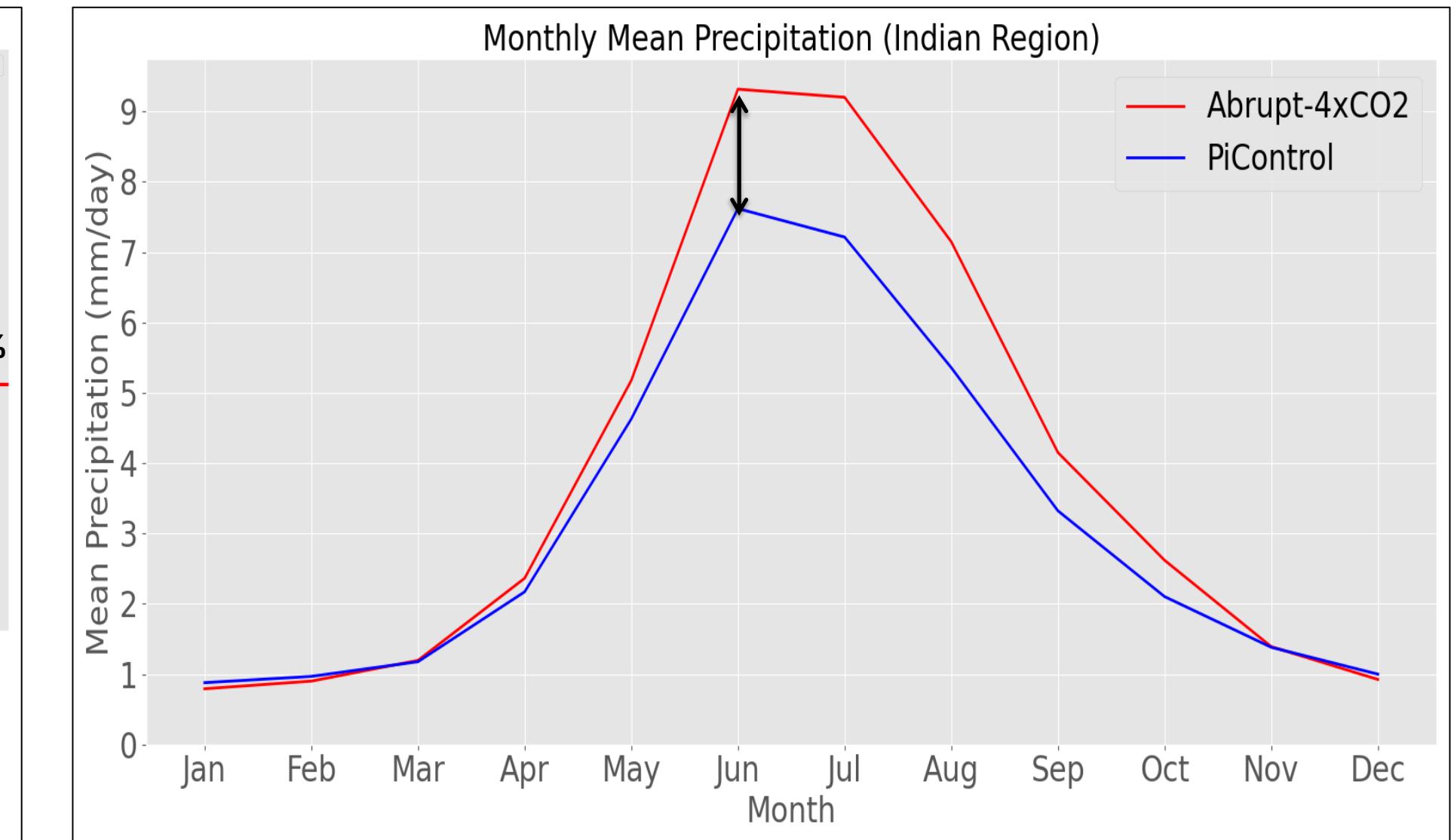
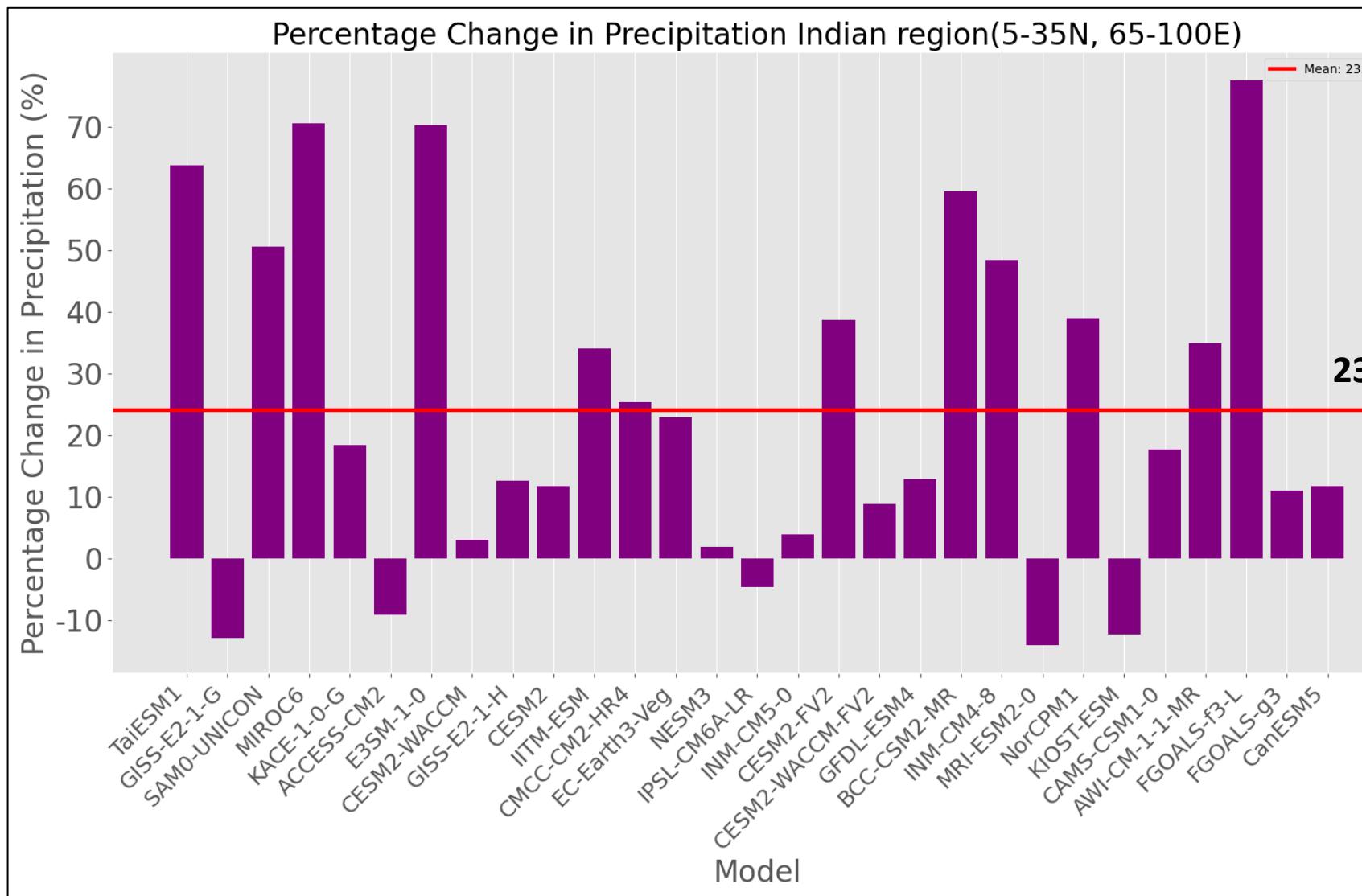
- The CMIP6 MMM generally shows slightly **cooler SSTs** than ERA5, particularly in the warm pool regions and **warmer SSTs** than ERA5 near the Somali coast areas (Possibly due to the upwelling zone).
- Similar spatial distribution so we can rely on these models for our experimentations!



- PiControl (Last 50 years JJAS Mean)
- Abrupt-4xCO<sub>2</sub> (Last 20 years JJAS Mean)

Anomaly everywhere now would be  
the difference of these two.

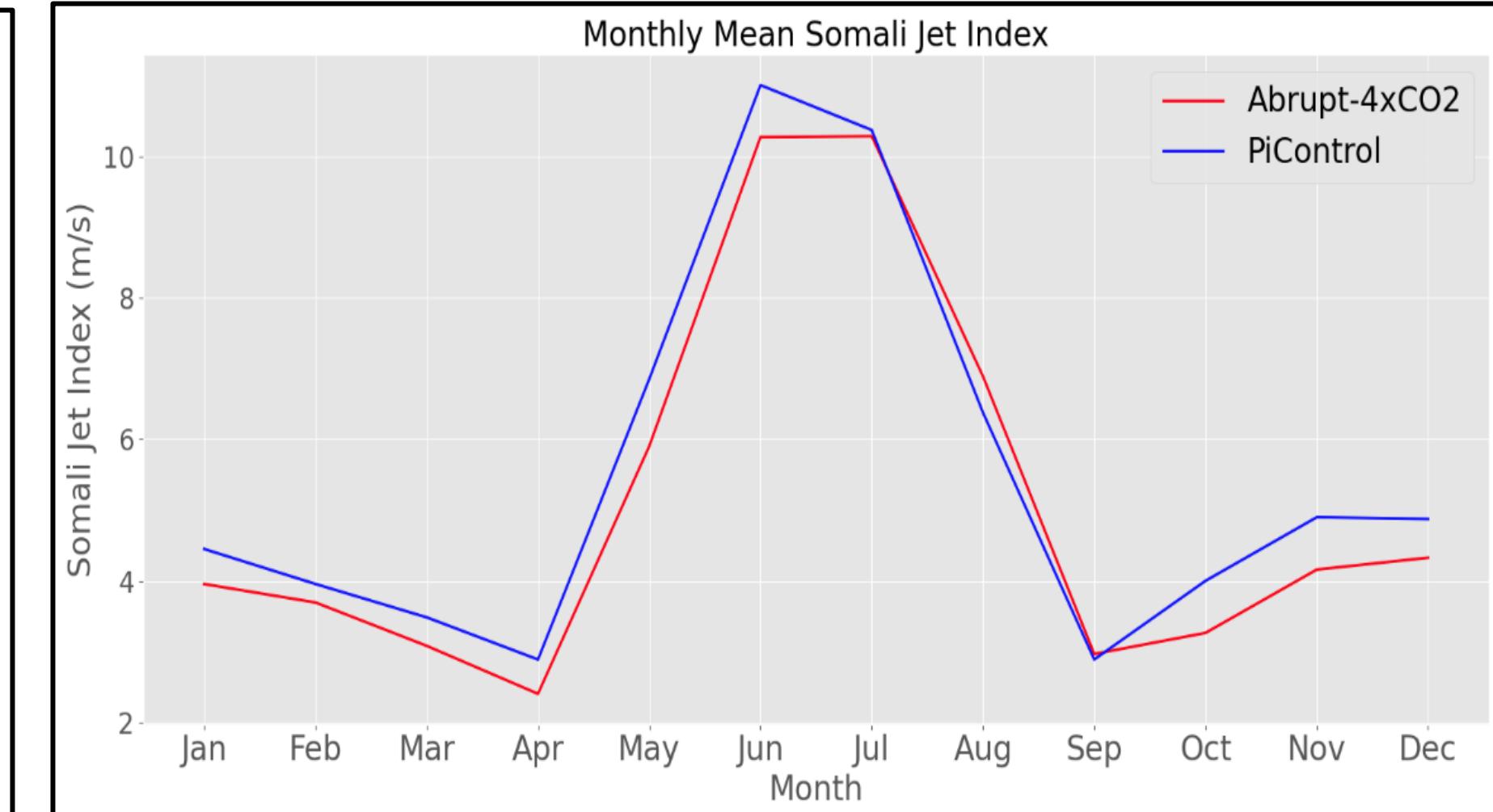
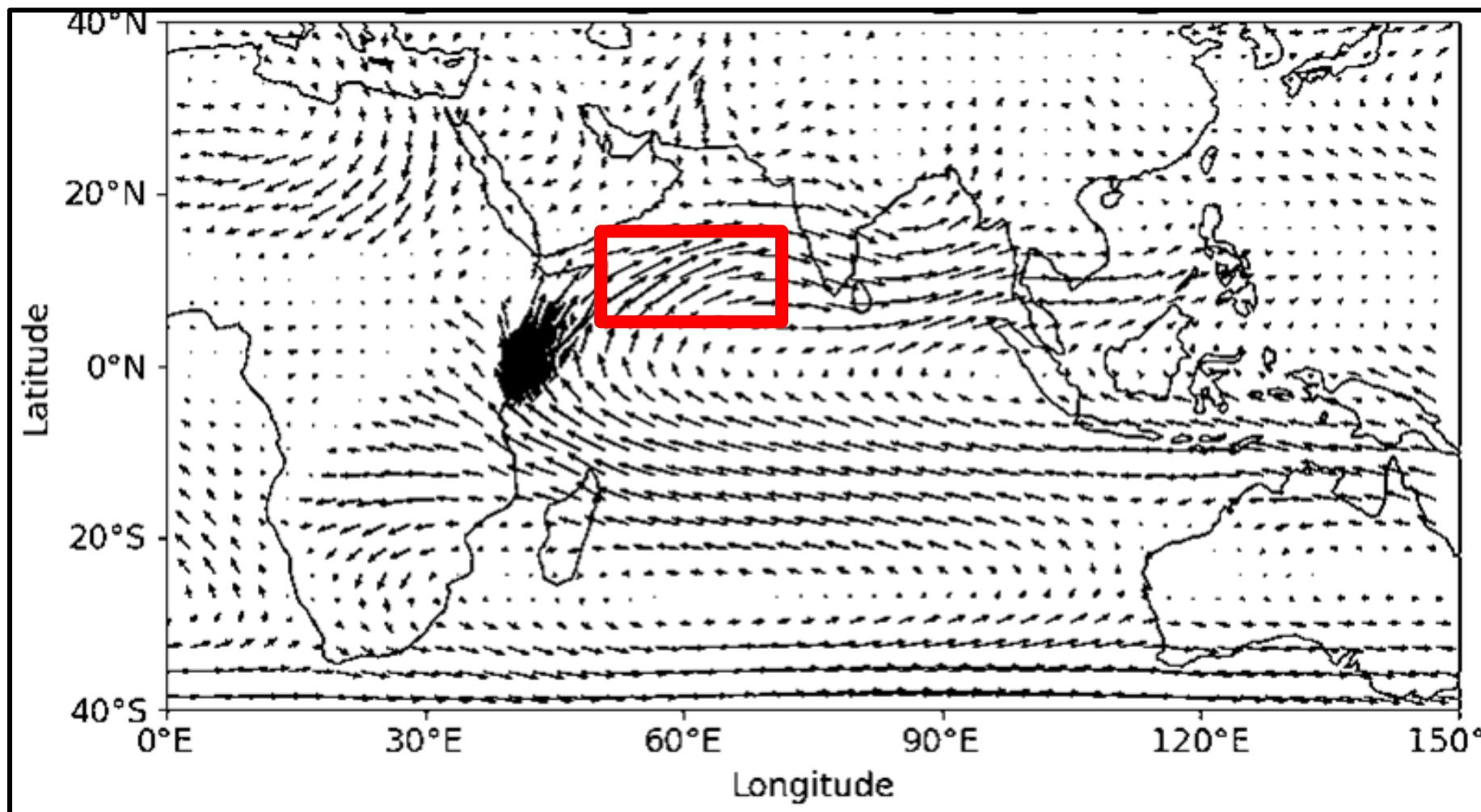
## Precipitation Changes



- There is significant variability in projected precipitation changes across different climate models.
- The multi-model mean (Red line) indicates a 23% increase in mean precipitation over the Indian region.
- The Warming scenario leads to a significant increase in precipitation during the monsoon months
- It potentially indicates intensification of the monsoon system.

# Results & Observations

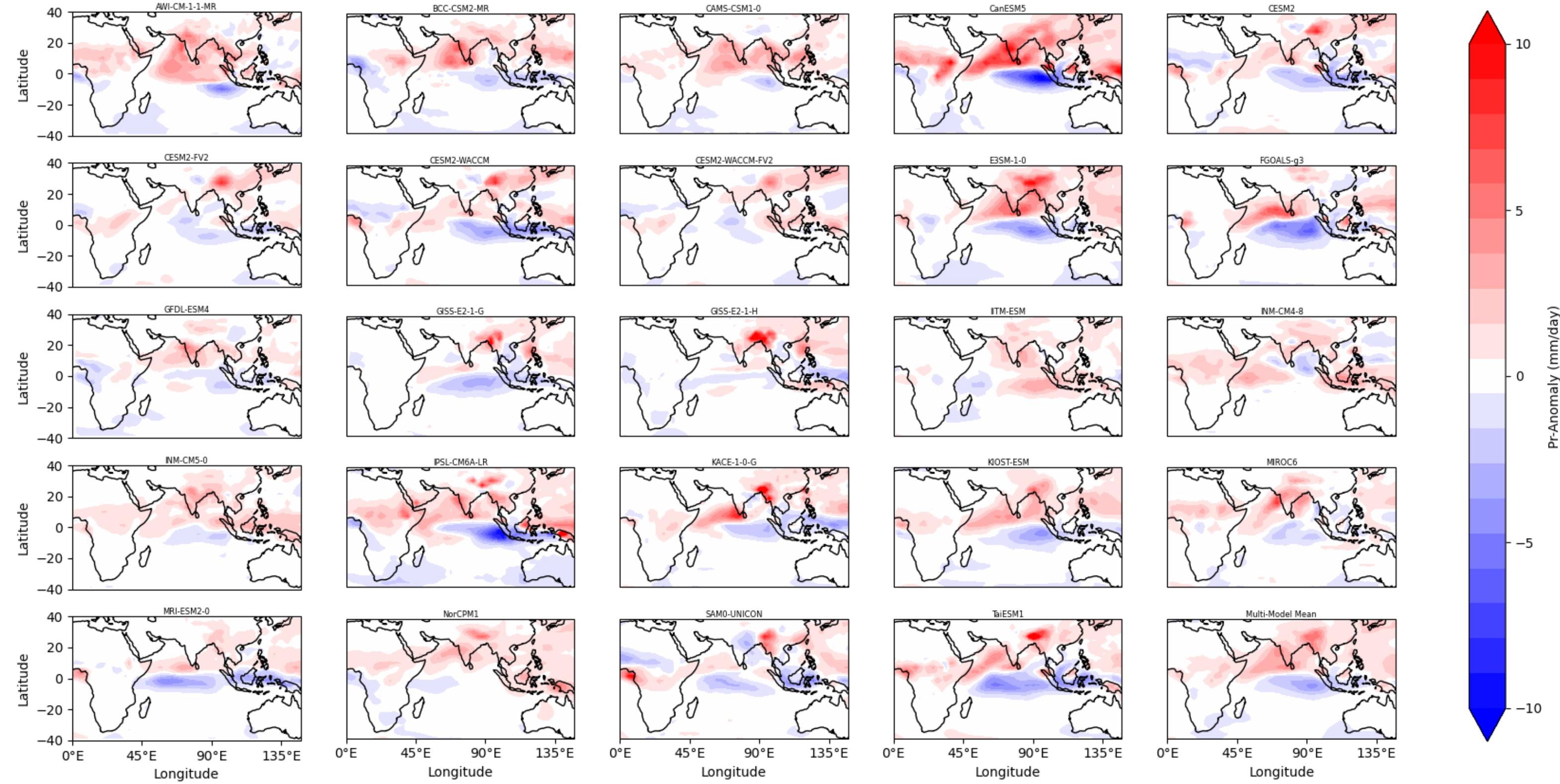
Somali Jet Index



- The strength of monsoon circulation is measured in terms of the mean kinetic energy of low-level jets, called the Somali jet.
- Somali Jet Index (SJI) is calculated over the Arabian sea ( $50^{\circ}$ – $65^{\circ}$ E and  $5^{\circ}$ – $15^{\circ}$ N) (Red Box).
- The warming scenario shows a **weakening** of the monsoon circulations.

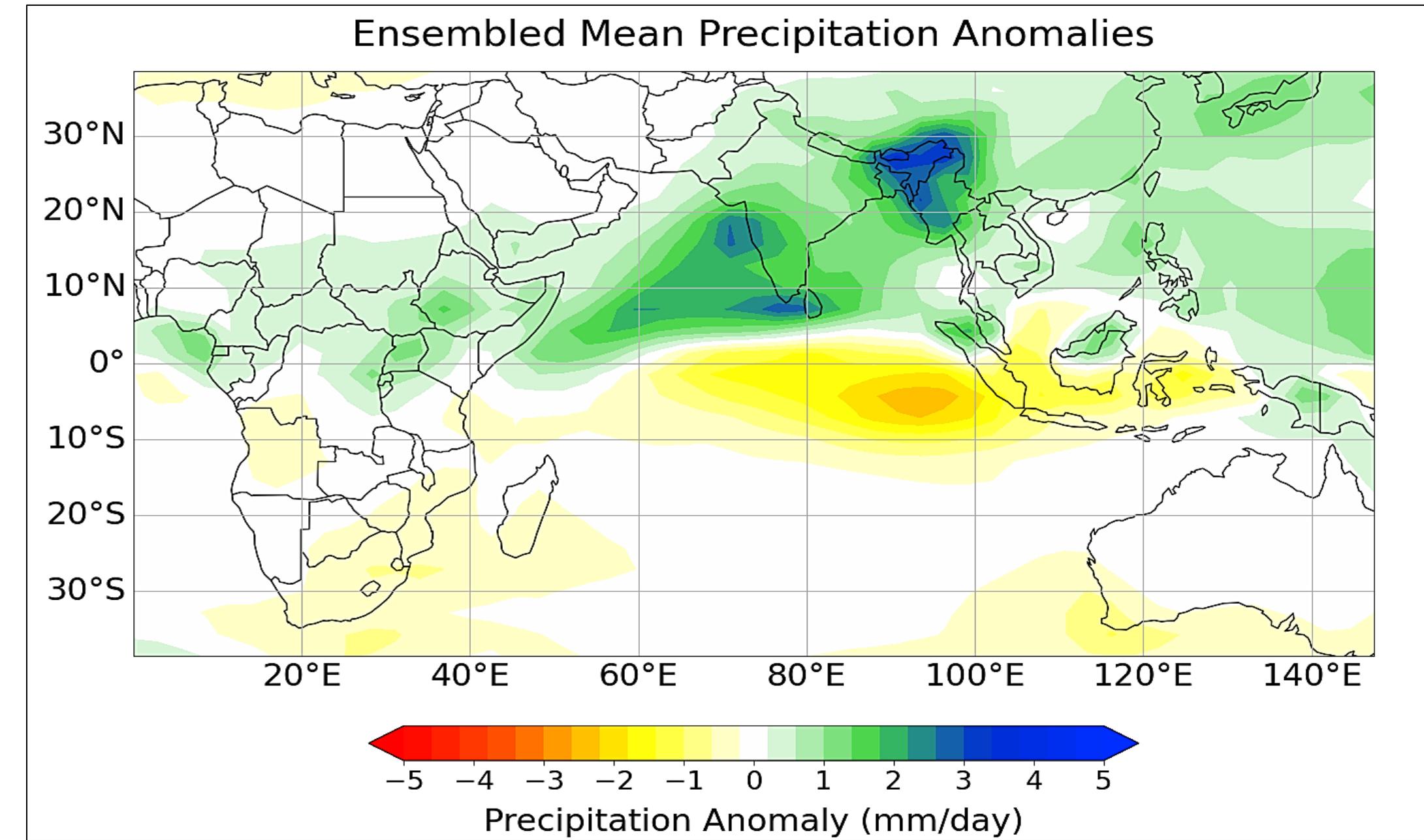
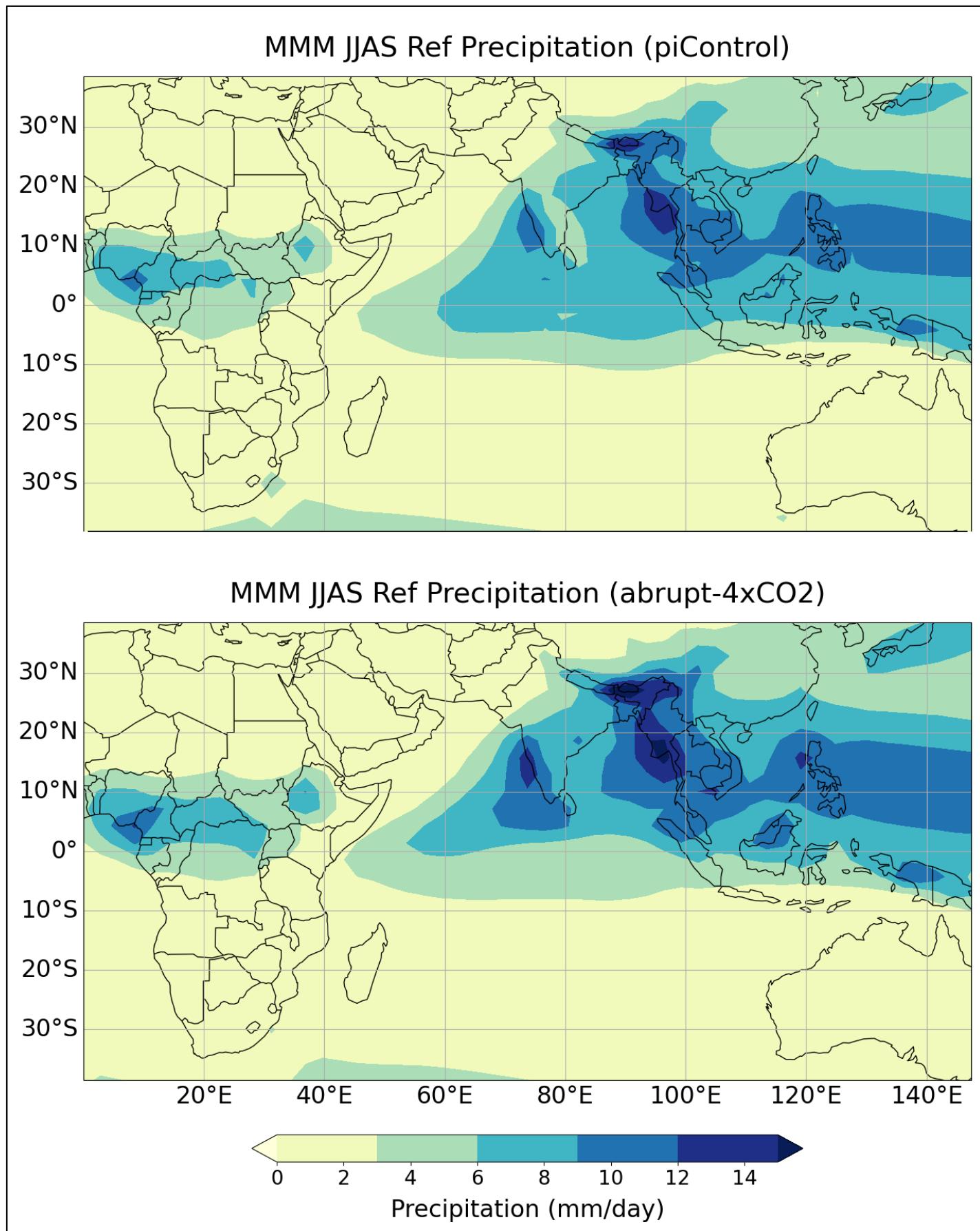
# Results & Observations

Multi-model plot of precipitation



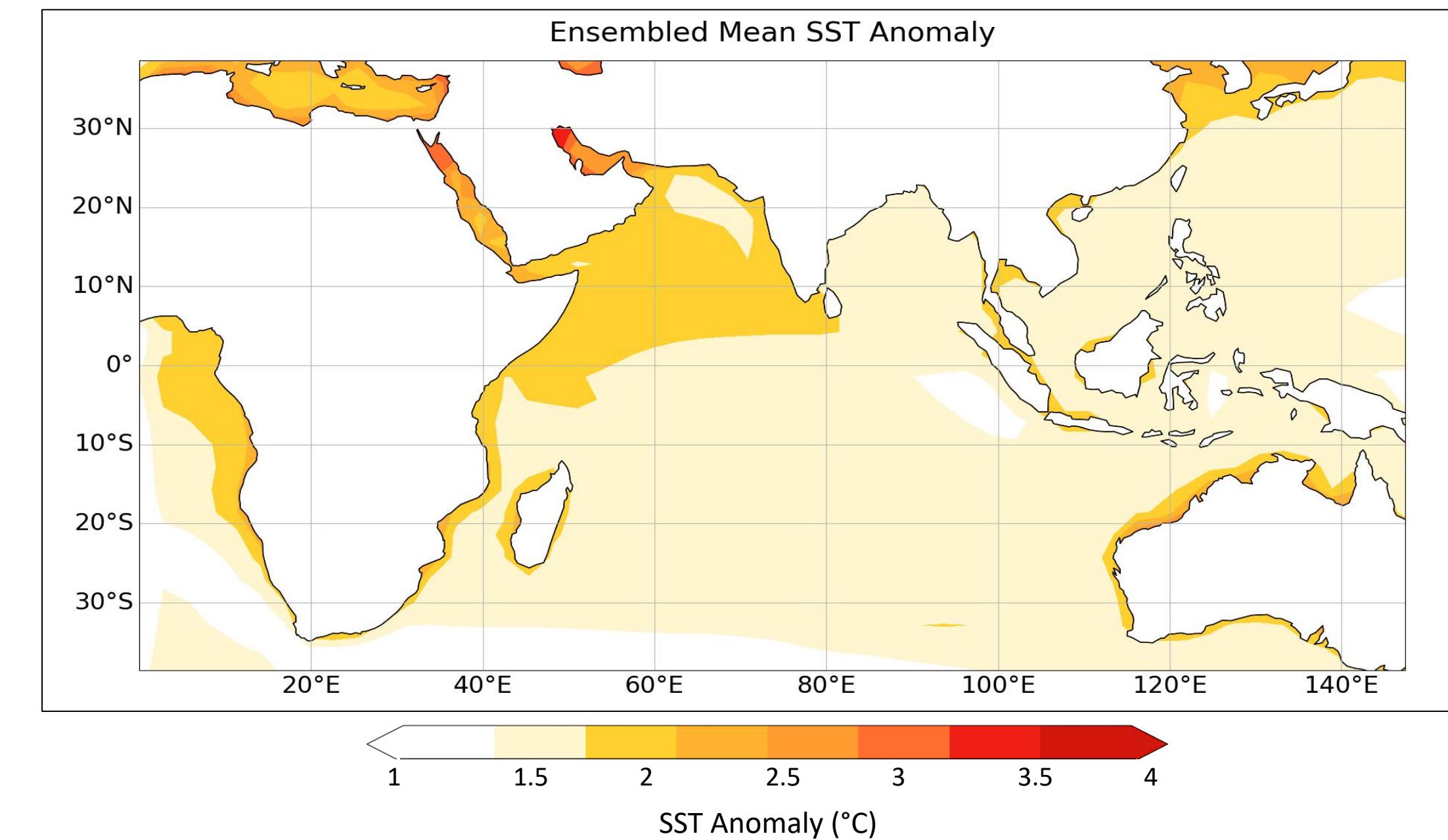
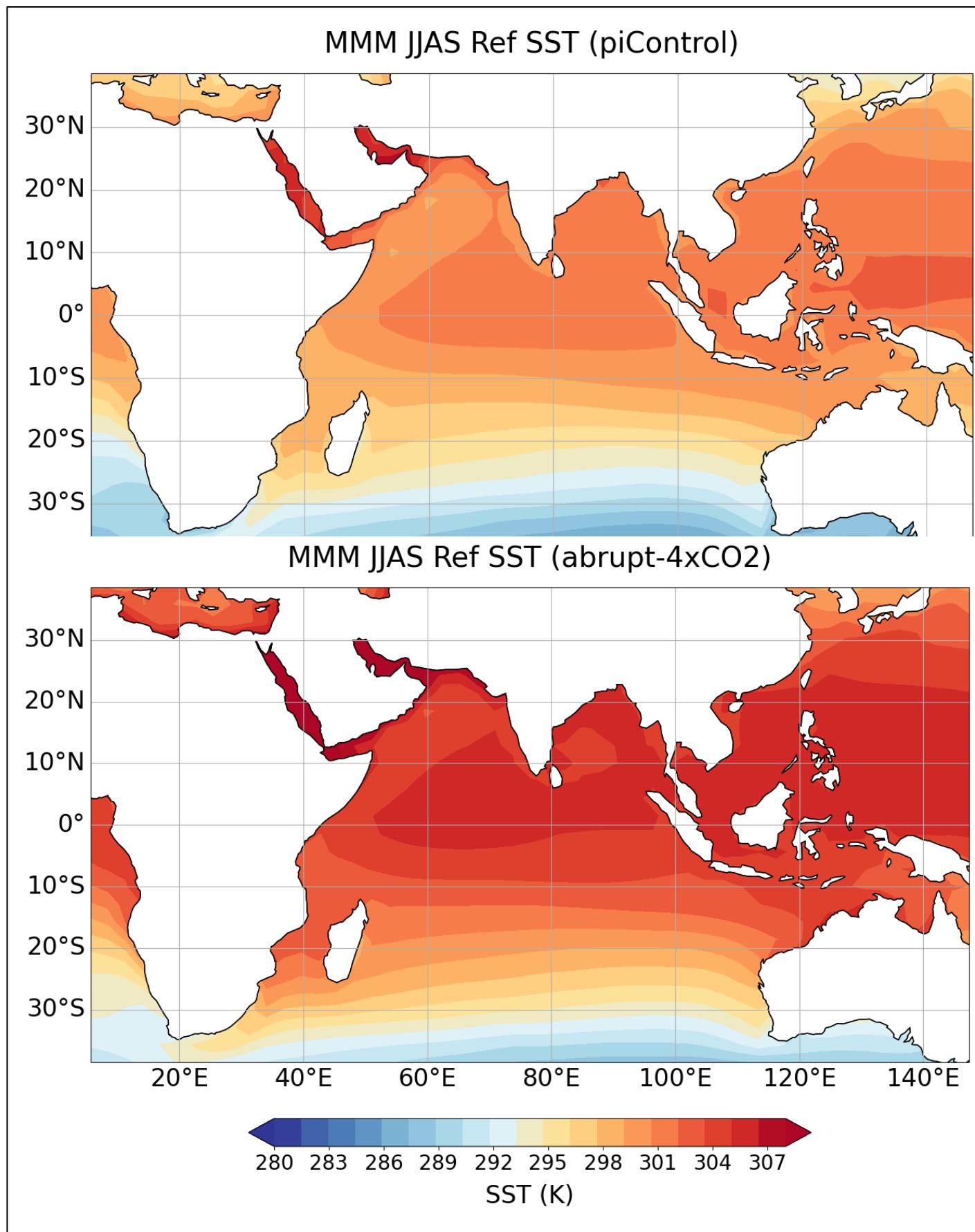
Pretty Robust pattern of precipitation anomaly throughout models let's look at **Ensembled mean** for better Clarity

# Results & Observations



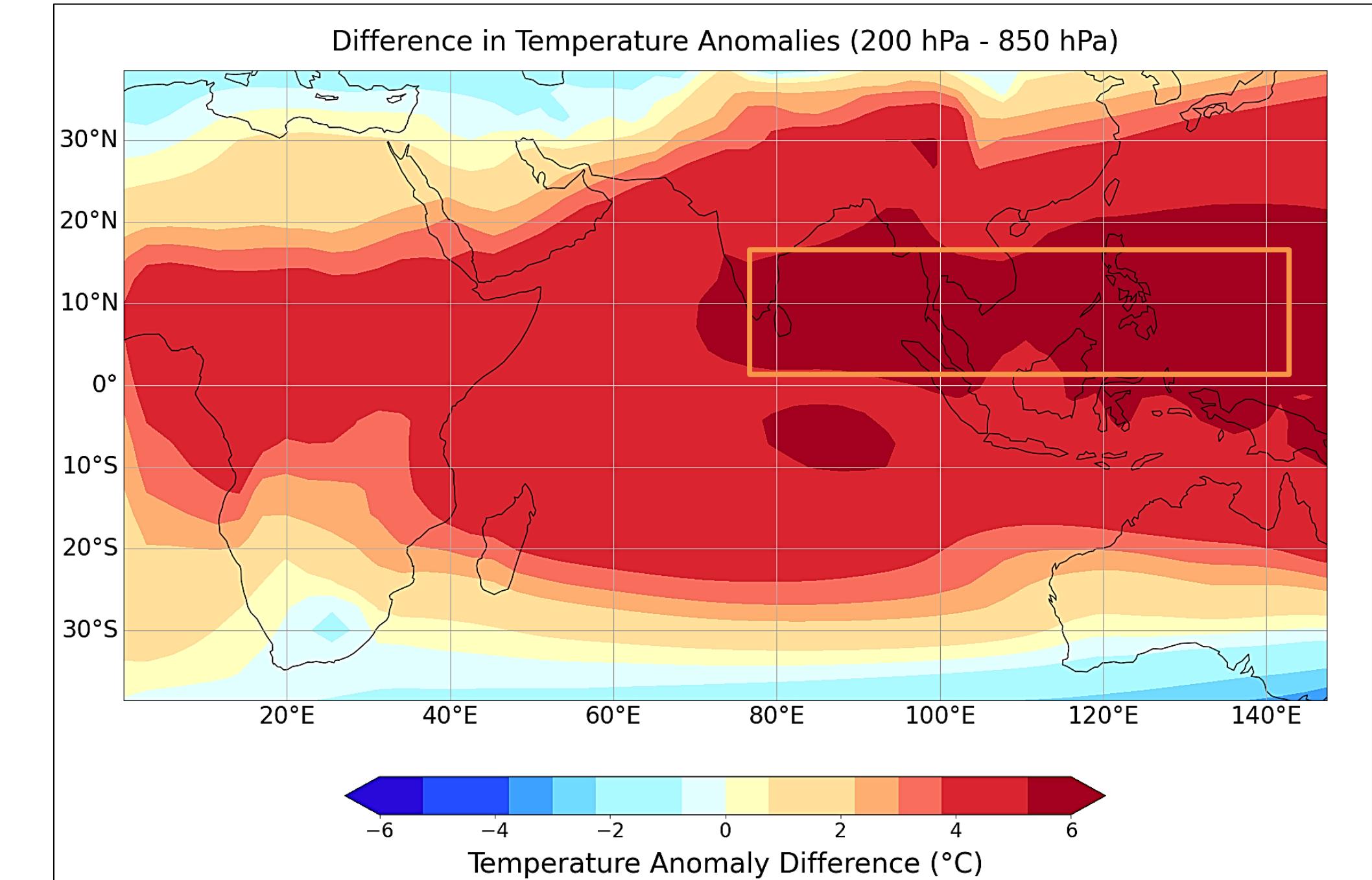
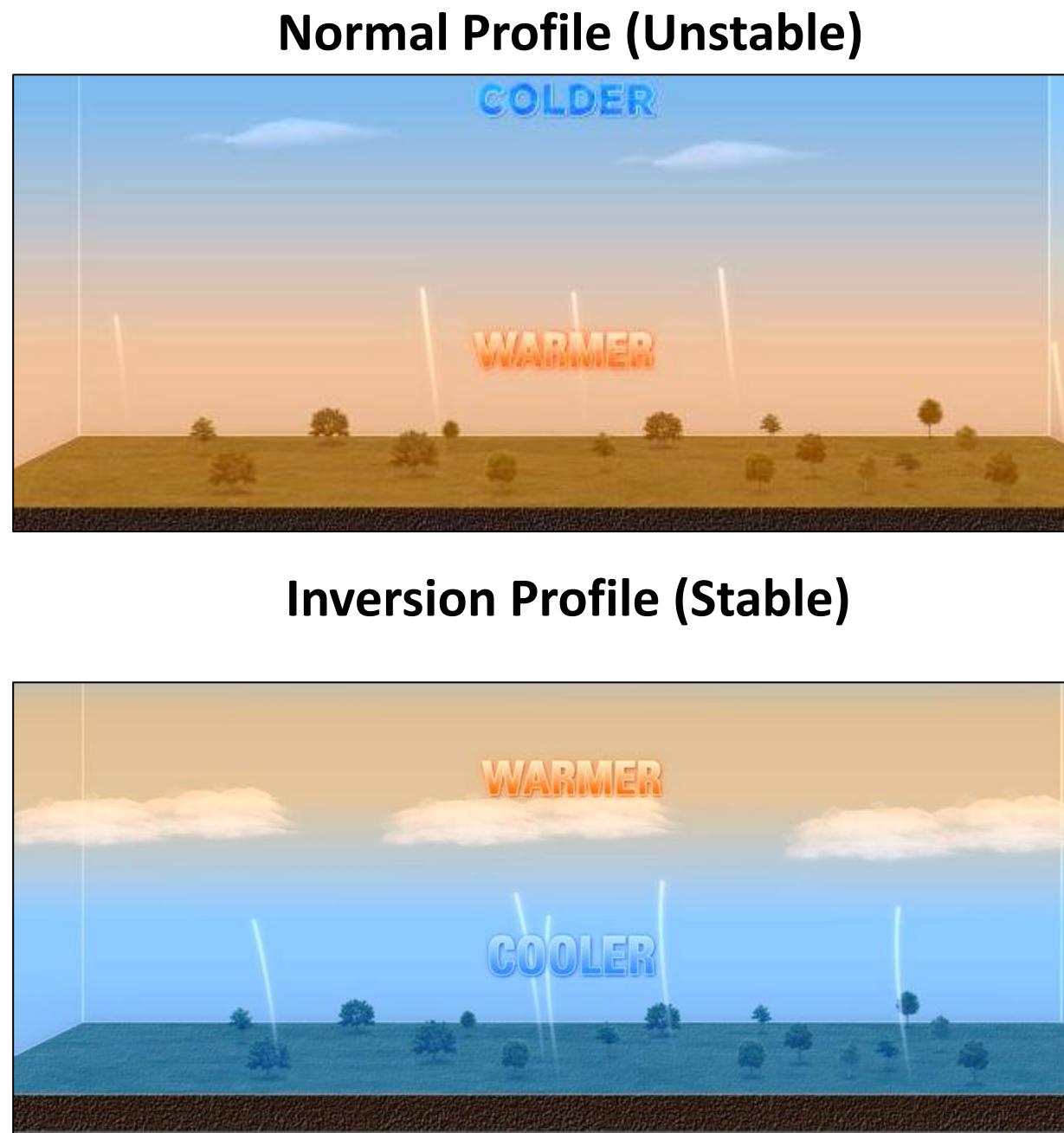
- Can see the **distinct pattern of ISMR (JJAS) precipitation**.
- There could be increase in the frequency and intensity of extreme events, such as floods(North-East India, Western Ghats) and droughts (Indonesia).
- An interesting pattern is the presence of a **dipole of anomaly** is across equator.

# Results & Observations



- The pattern of SST anomaly is clearly showing a warm pool in western IO which is similar to the **Positive Indian Ocean Dipole (IOD) pattern**.
- The **enhanced evaporation** over the Arabian sea could be the leading factor to increase in precipitation over India.

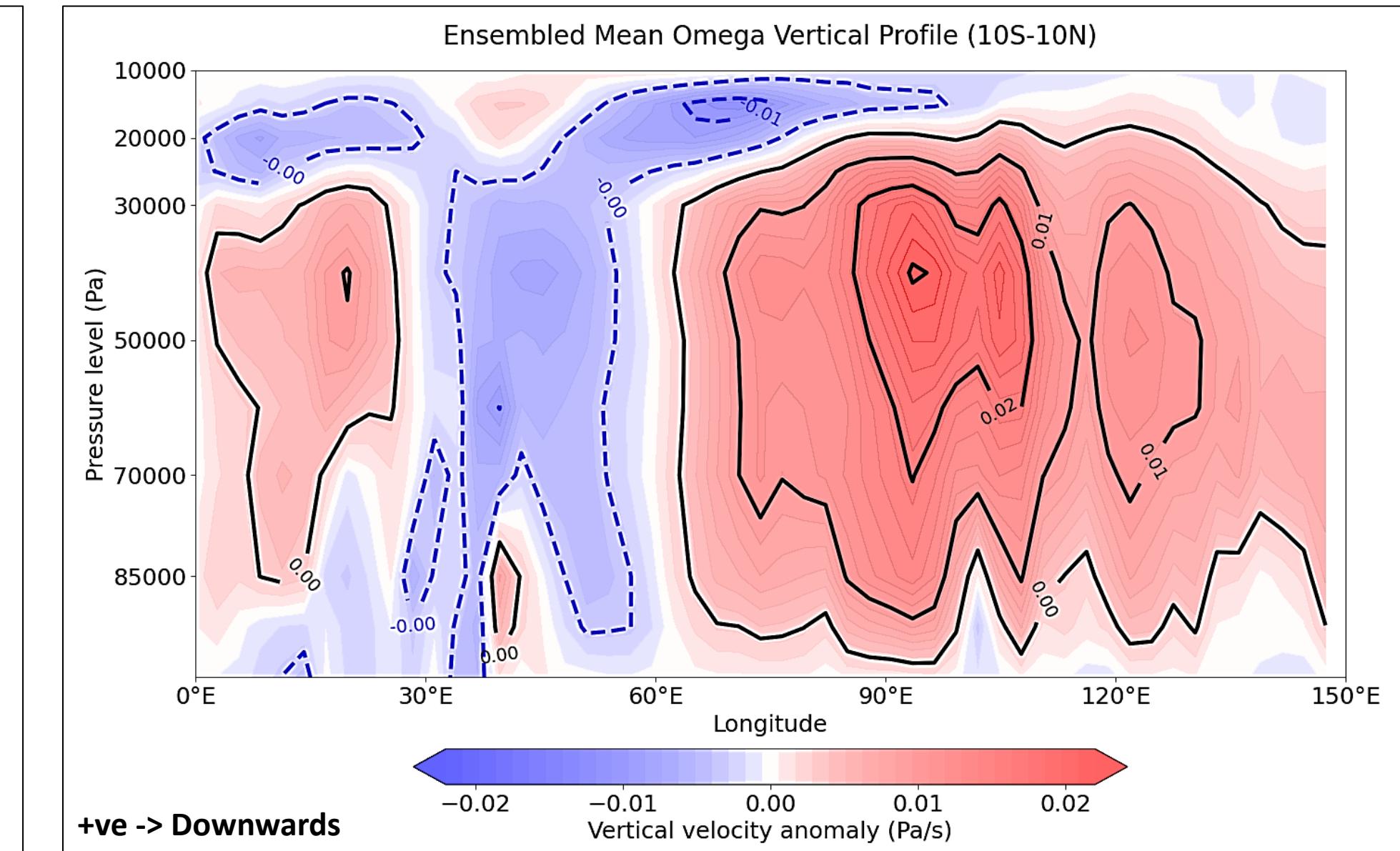
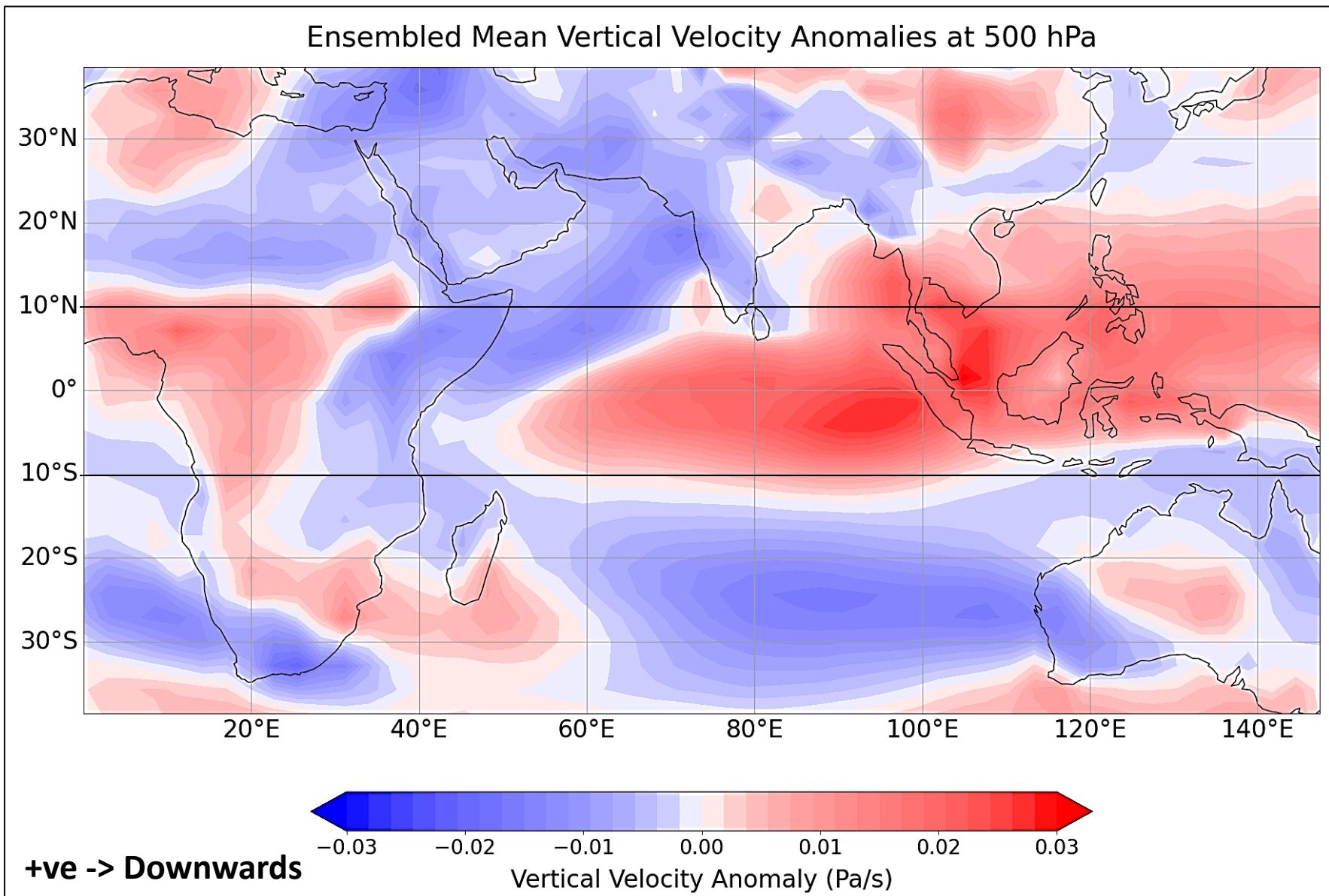
# Results & Observations



- A normal atmospheric temperature profile, where temperature decreases with altitude. This creates instability, allowing warm air to rise and potentially form clouds and precipitation.
- There is larger warming at **200 hPa relative to 850 hPa** which **indicates increased atmospheric stability**, making it more difficult for air to rise and form clouds or precipitation.

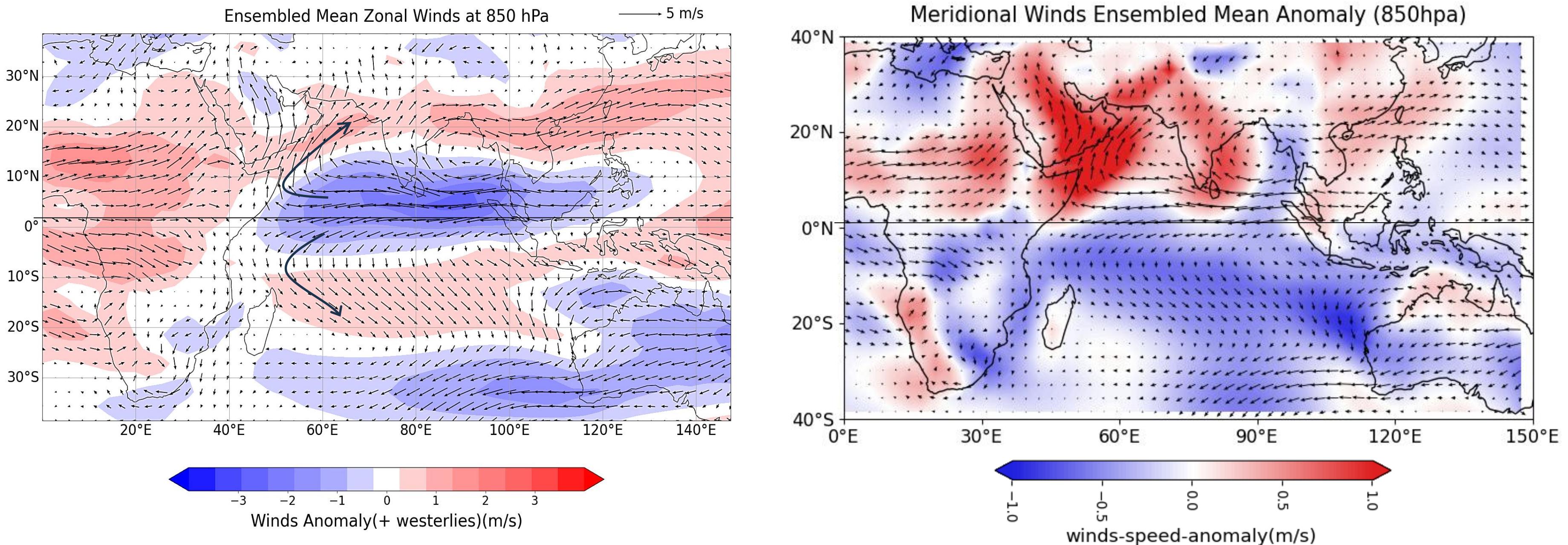
# Results & Observations

## Omega/Vertical Velocity



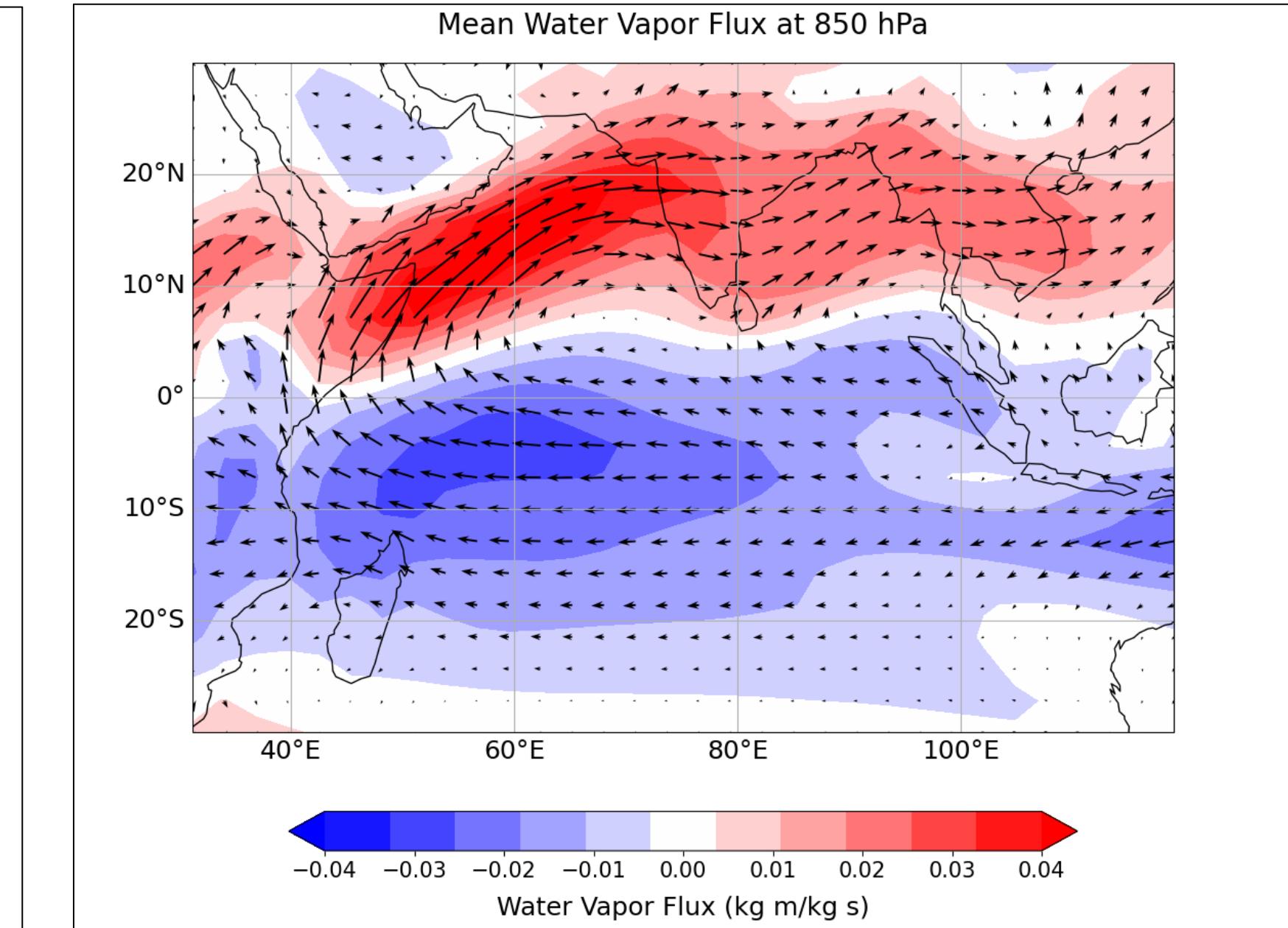
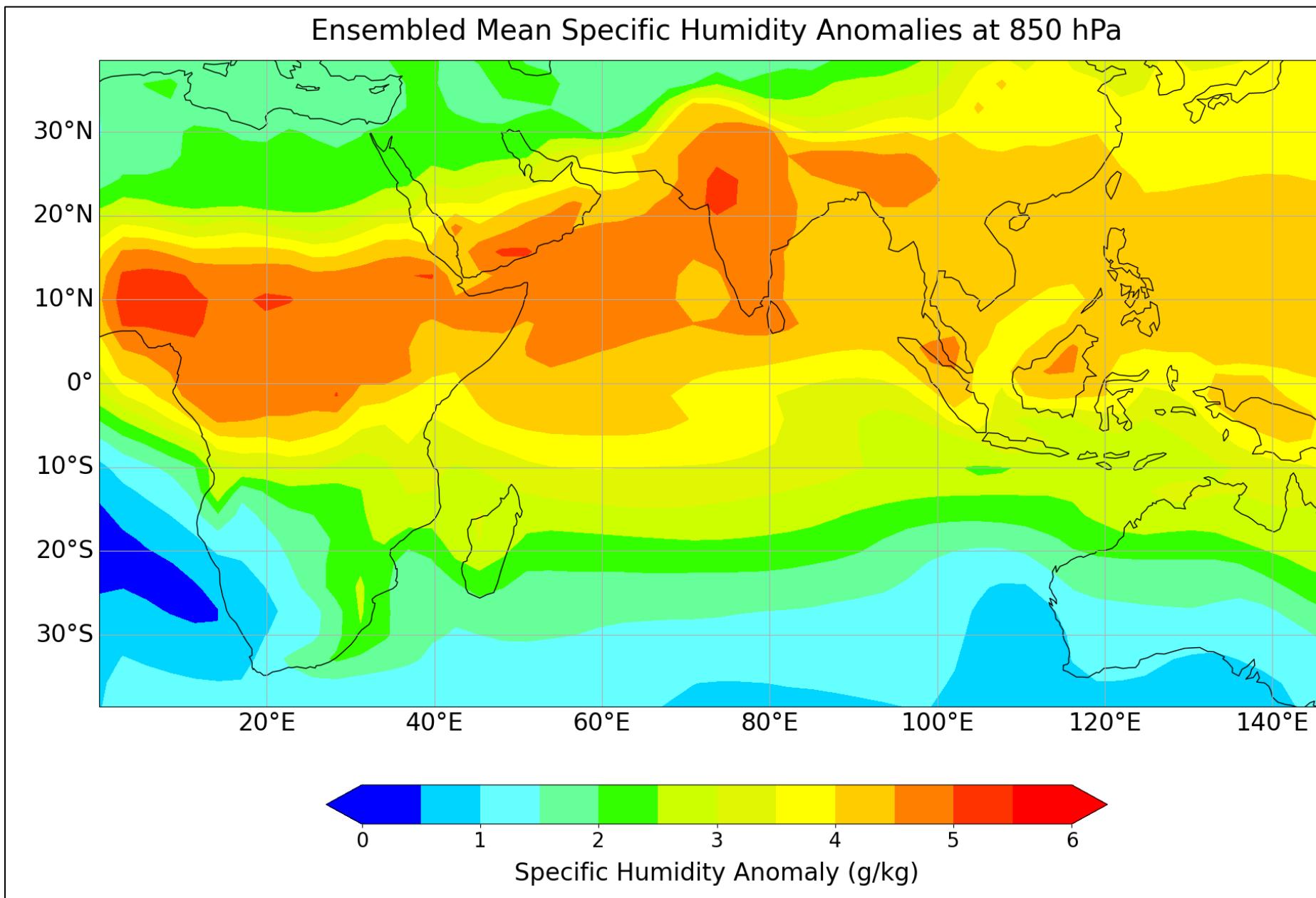
- There's a **positive anomaly in the vertical velocity** in that region which will suppress the convection impacting rainfall
- Also, near the Arabian sea there's an increase in the vertical motion enhancing the convection formation.
- For the tropics (10N-10S), the vertical profile of omega shows where and how much **overturning circulations** are changing with the warming climate. (Will look at walker circulation and global aspect later).

# Results & Observations



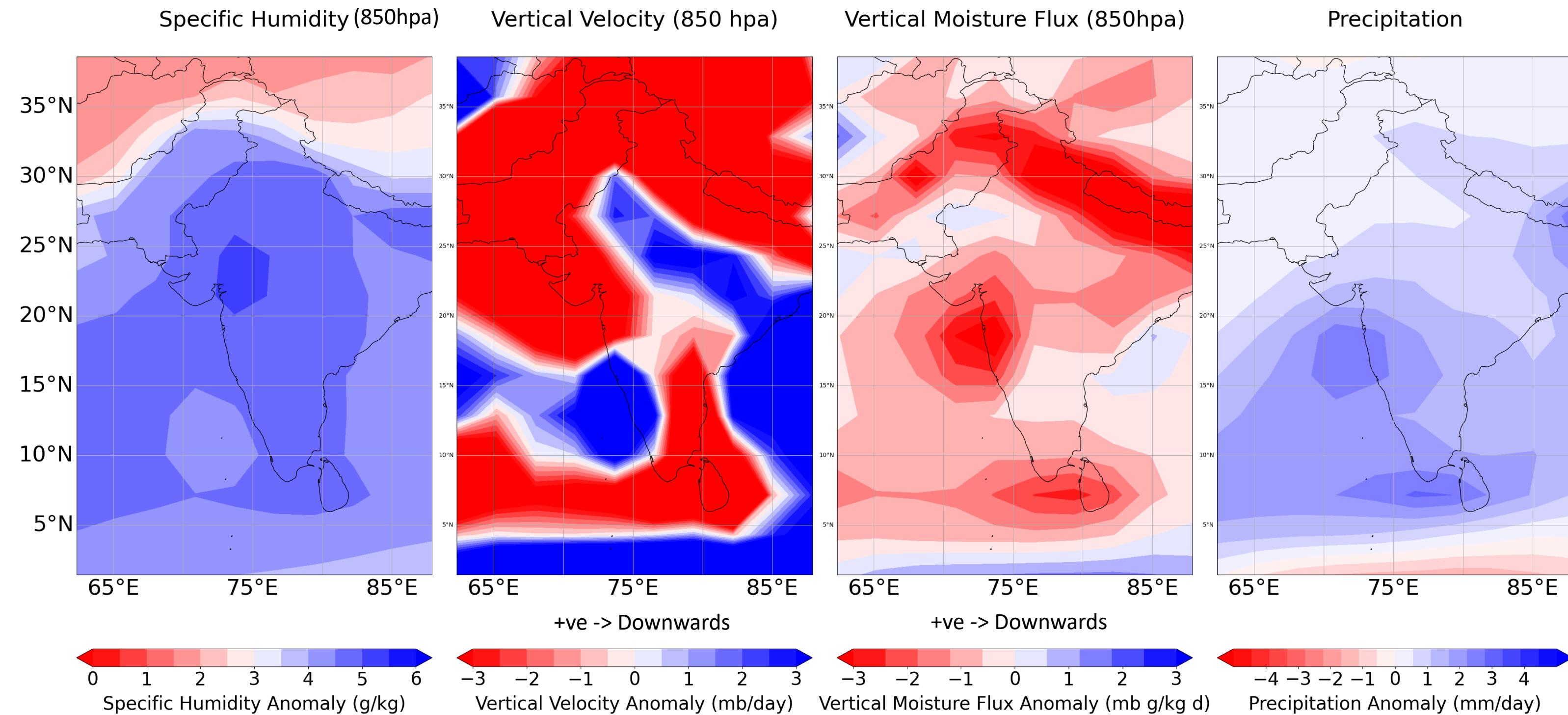
- The **strong easterlies** influences the cross-equatorial flow of moisture and potentially weaken the monsoon circulation.
- Formation of **twin anticyclonic anomalies** on either side of equator leads to suppressed convection on equatorial IO.
- The presence of **strong westerlies** over the **Arabian Sea** and northern IO will be driving the moisture for the ISMR.
- Divergent Pattern across the Equator in the Meridional wind

# Results & Observations



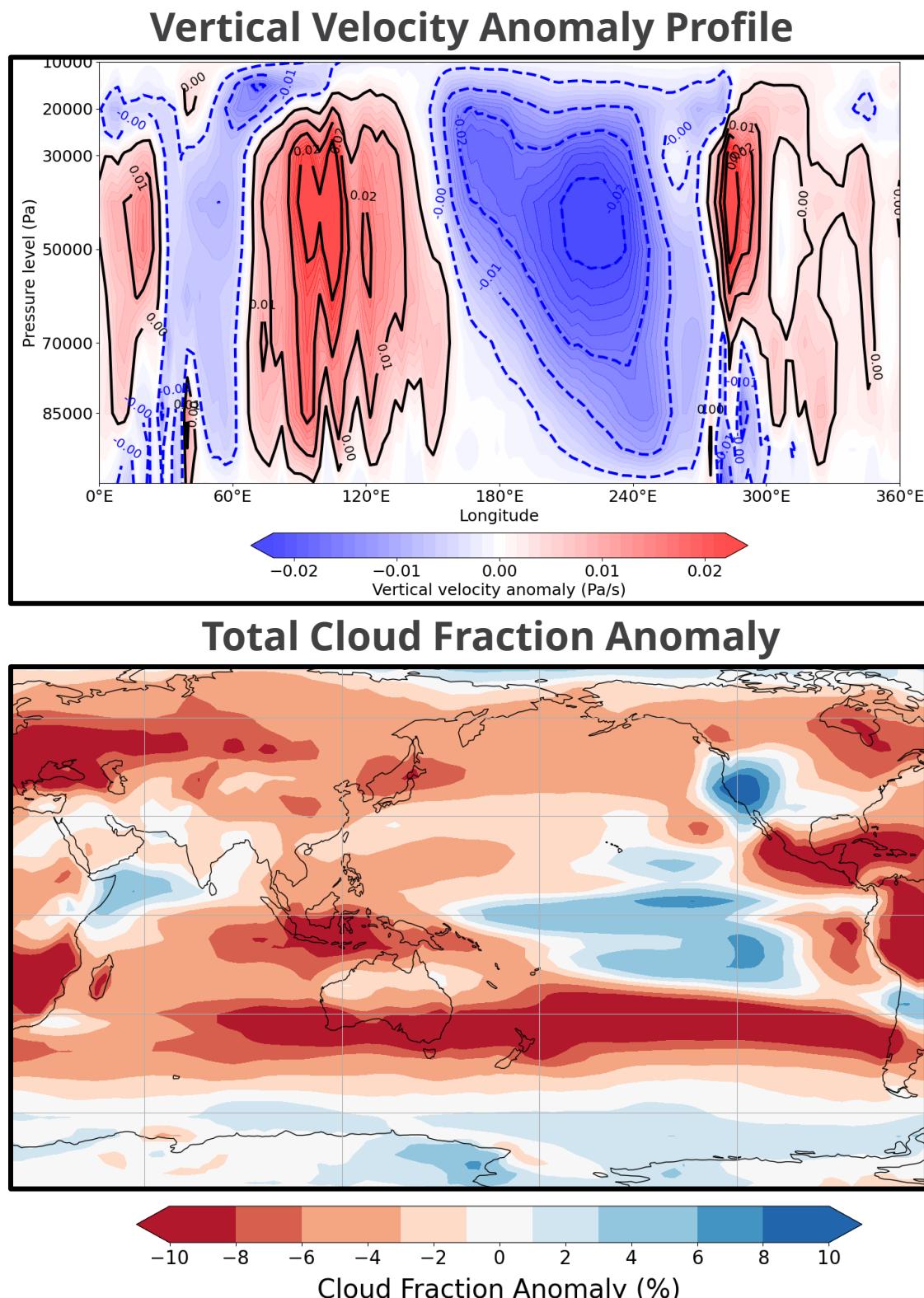
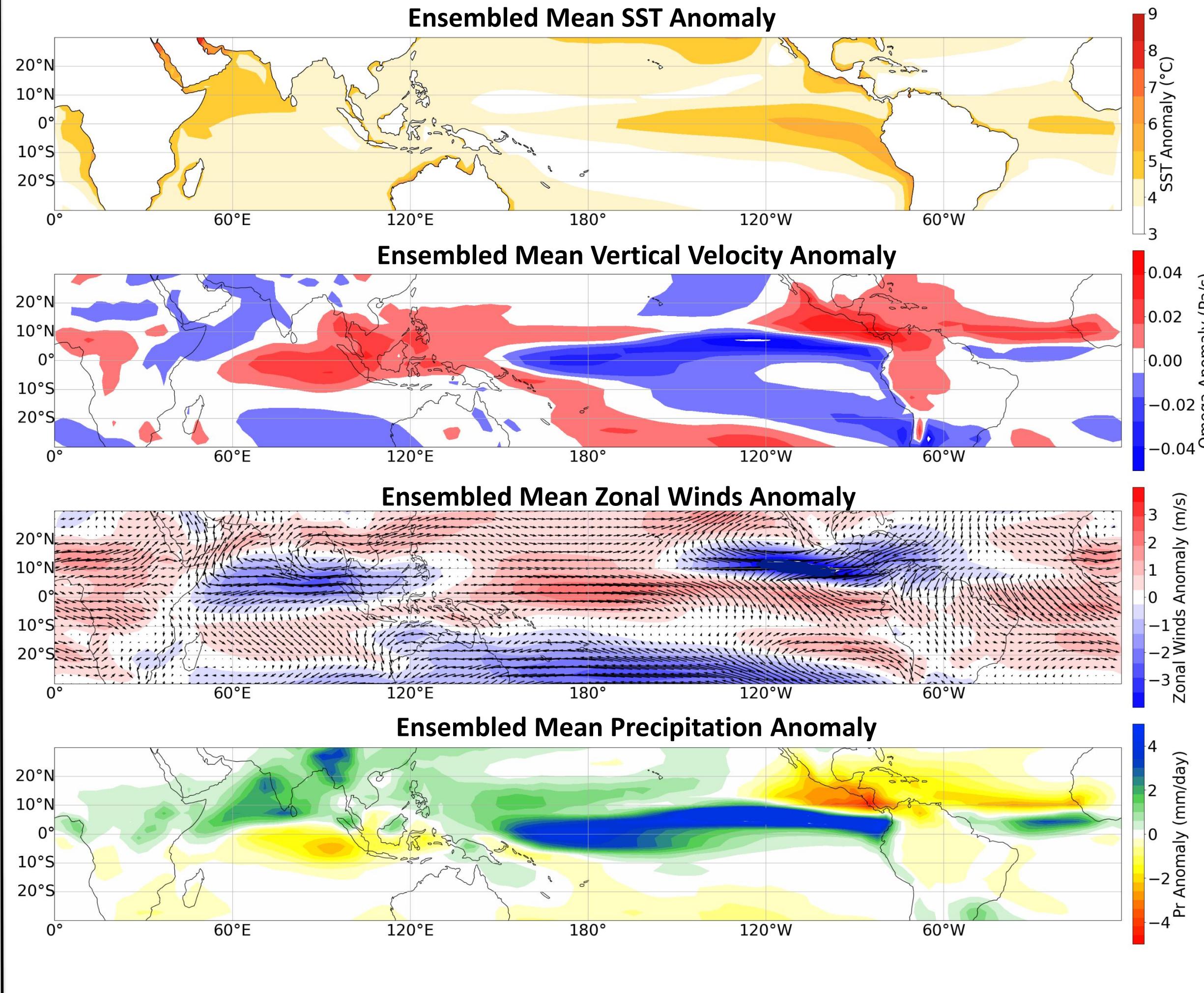
- There's a **positive specific humidity** anomalies over most of the Indian subcontinent and surrounding oceans. This indicates an increase in moisture content in the region which will enhance the overall ISMR.
- Also, the Arabian sea region is having more moisture due to larger SSTs.
- The **strong westward flow of moisture (arrows)** is converging into Indian region would lead to increased rainfall.

# Results & Observations

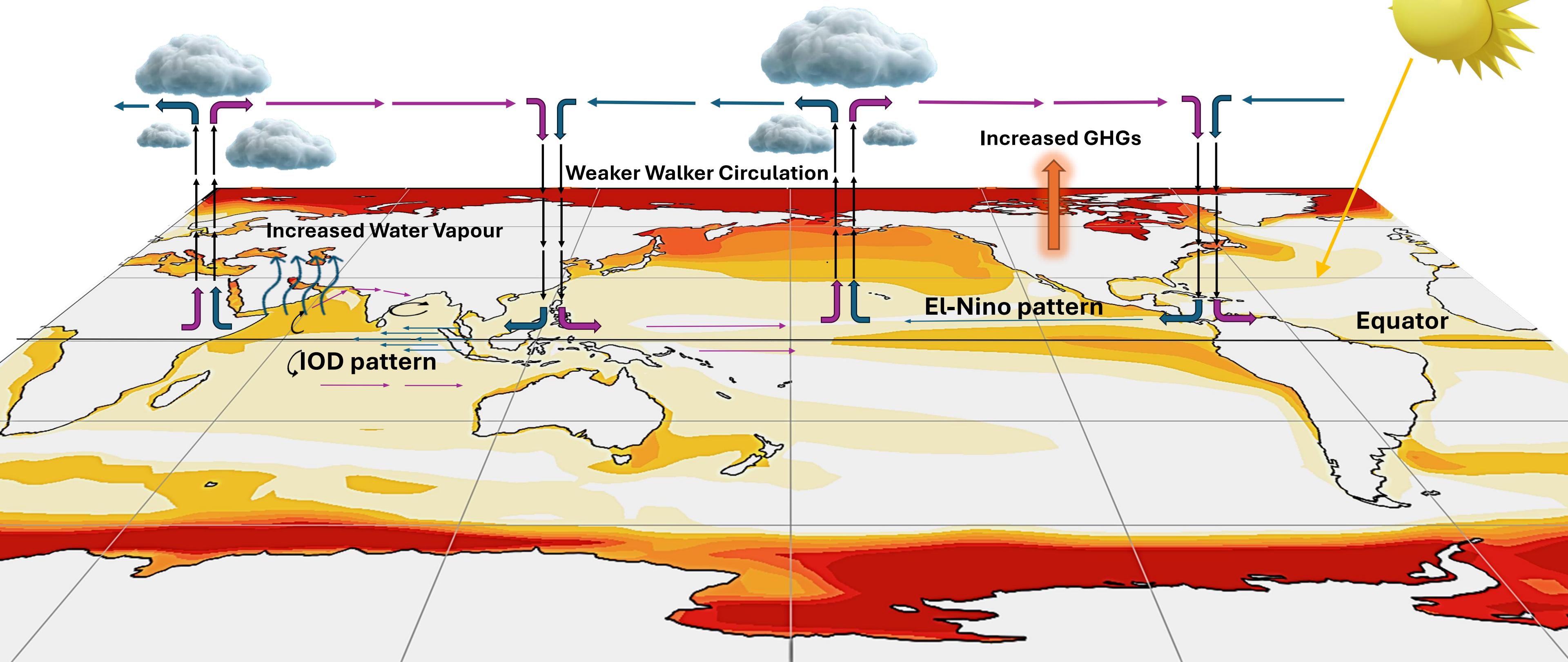


- Increase in Specific humidity along with vertical velocity increase gave the proper account for vertical moisture flux (indicates transport of moisture from ocean to atmosphere) and hence enhanced precipitation.

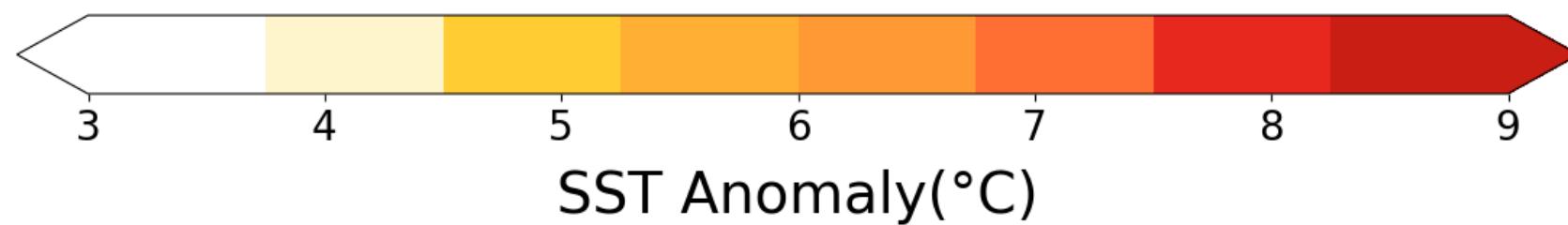
# Global Perspective



# Robust Changes Schematic



- Easterlies: ←
- Westerlies: →
- Anti-cyclonic circulation ↗



Thank You!

