Distinctive South and East Asian Monsoon Circulation Responses to Global Warming

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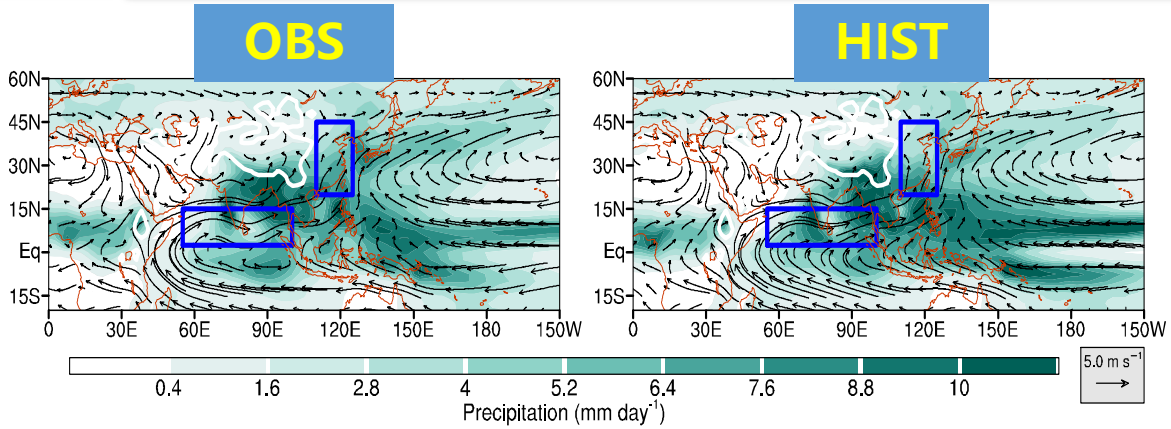
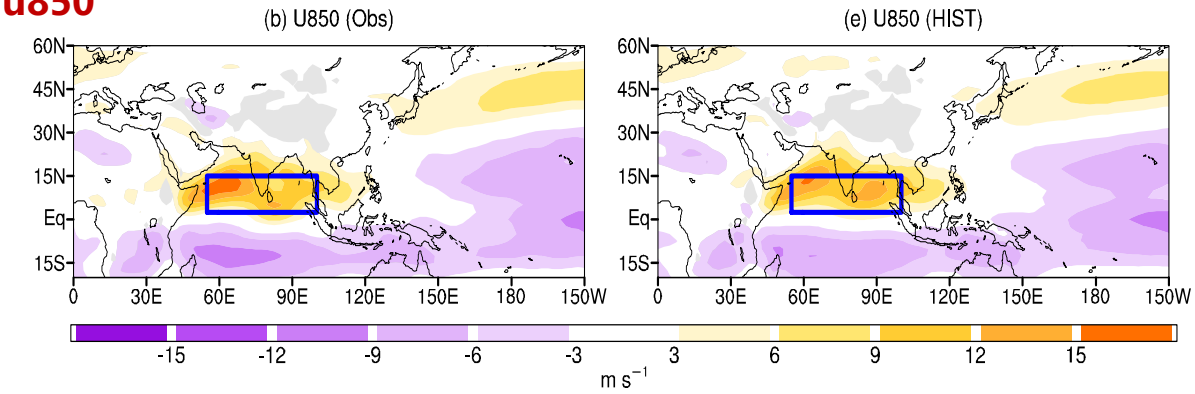
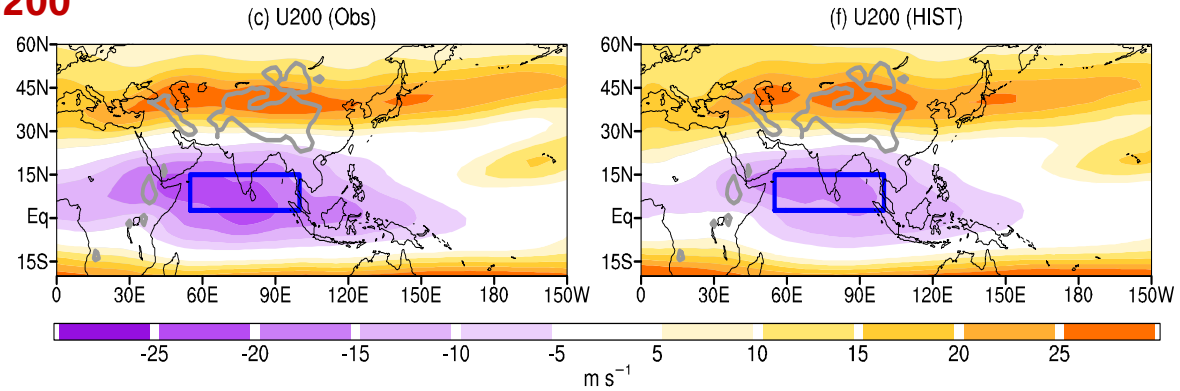
Observed & Simulated Asian Summer Monsoon Circulation



u850



u200



Precip. JJA (shaded)
850hPa wind (vector)

SASMI: 2.5N-15N, 55E-100E

EASMI: 20N-45N, 110E-125E

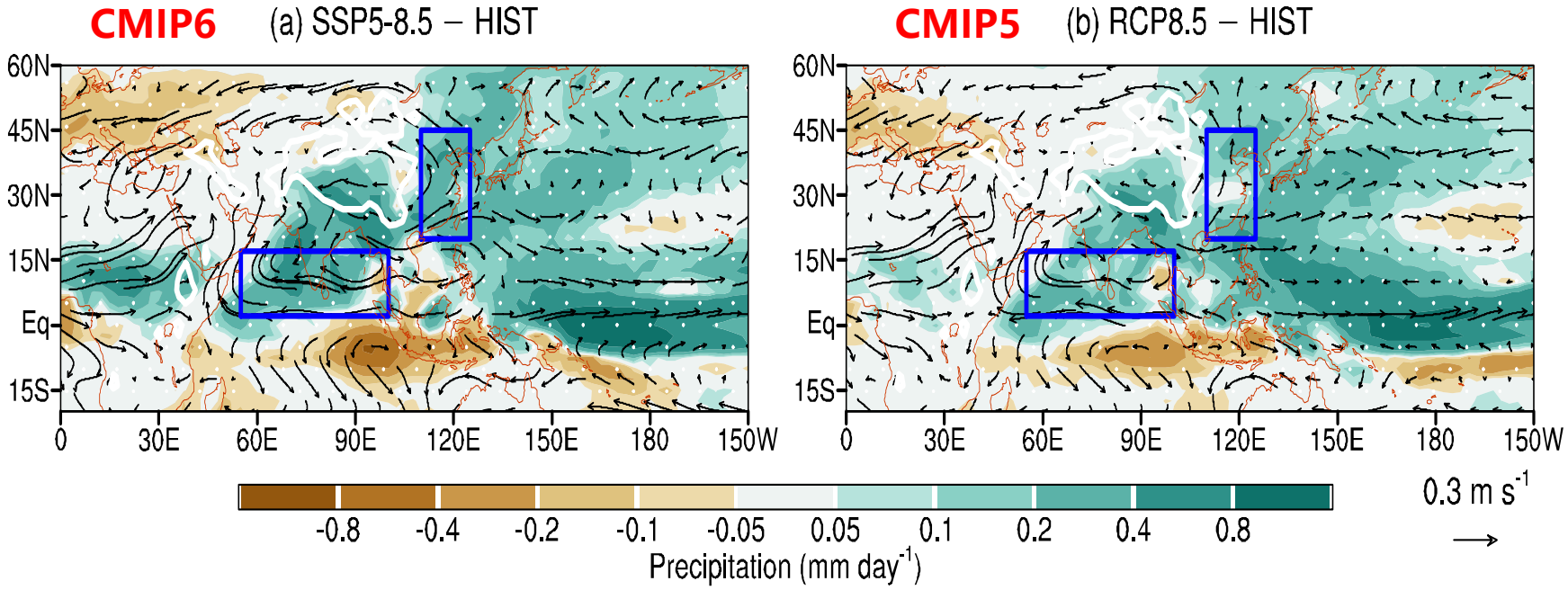
Question: How will the ASM circulation change under global warming?

Projected SASM and EASM changes in CMIP6/5 models

- 30 CGCMs from CMIP6 (HIST, SSP5-8.5; SSP2-4.5)
- 30CGCMs from CMIP5 (HIST, RCP8.5, RCP4.5)

20C **: 1950-1999**

21C **: 2050-2099**



- **Increased rainfall (shaded) in SA and EA**
- **Strengthened EA southerly but weakened SA westerly !**

Change of the SASM & EASM Circulation Indices

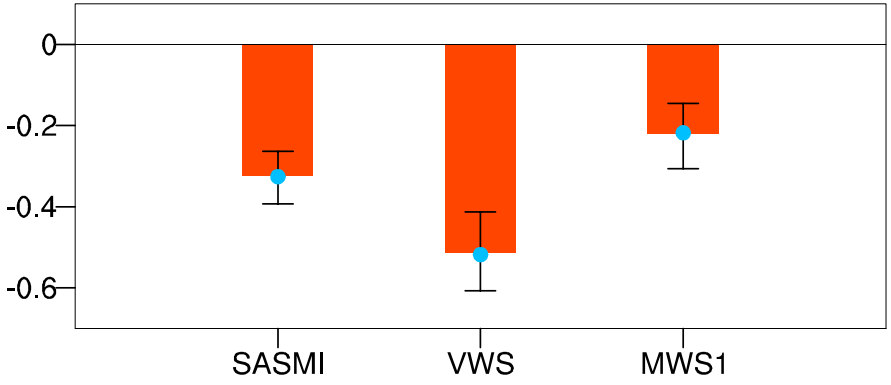
SASM metrics

- **SASMI**=U850(2.5°N-15°N, 55°E-100°E)
- **VWS**= U850(2.5°N-15°N, 55°E-100°E) – U200(2.5°N-15°N, 55°E-100°E)
- **MWS1**=U850(5°N-15°N, 40°E-80°E) – U850(20°N-30°N, 70°E-90°E)

EASM metrics

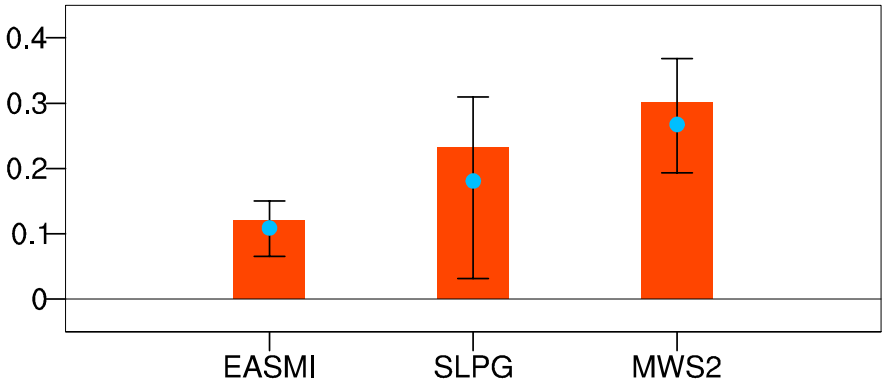
- **EASMI**=V850(20°N-45°N, 110°E-125°E)
- **SLPG**=SLP(25°N-50°N, 130°E-150°W) – SLP(25°N-50°N, 30°E-110°E)
- **MWS2**=U850(22.5°N-32.5°N, 110°E-140°E) –U850(5°N-15°N, 90°E-130°E)

Change of SASM metrics



➔ **All Weakened !**

Change of EASM metrics

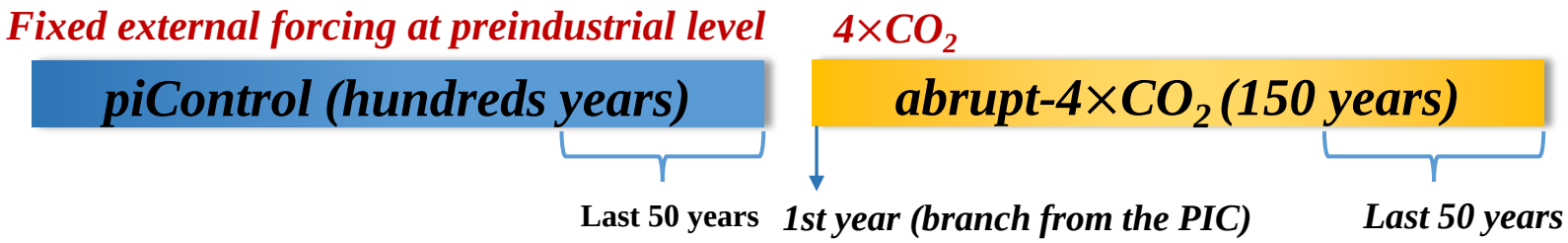


➔ **All Strengthened !**

Bars: MMM (Multi-model median); **Dots: MME (Multi-model ensemble mean)**

What causes distinctive SA & EA circulation changes?

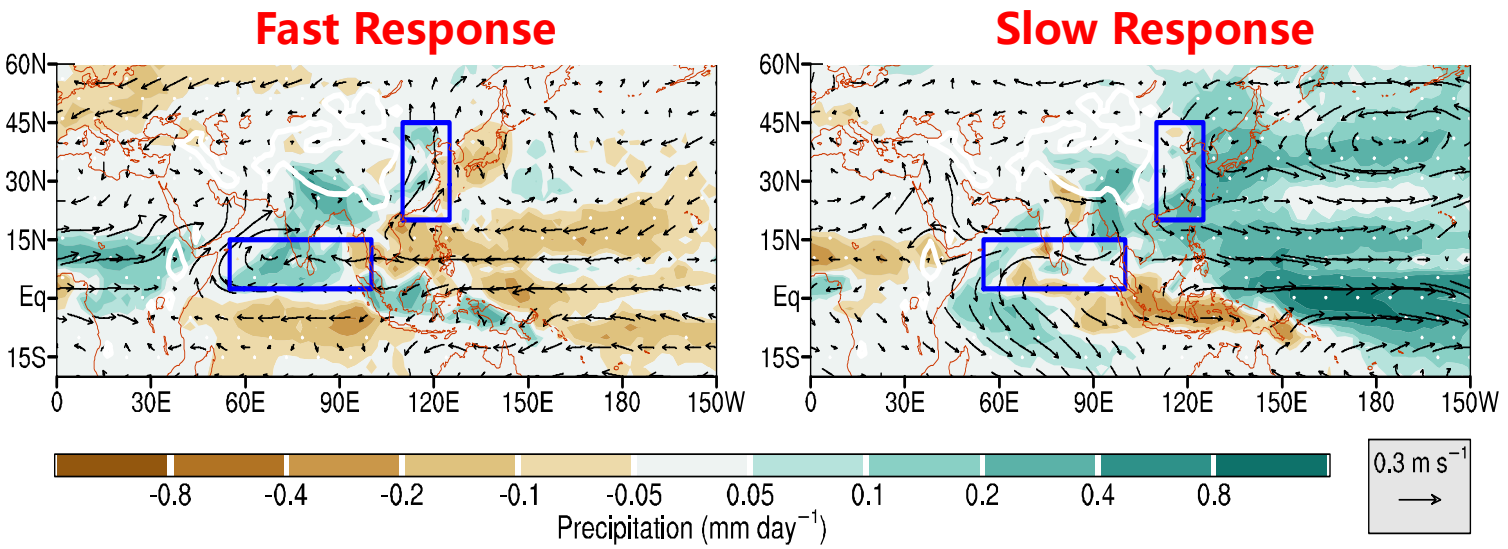
➢ *piControl, abrupt-4×CO_2* **experiments: 42 CGCMs from CMIP6**

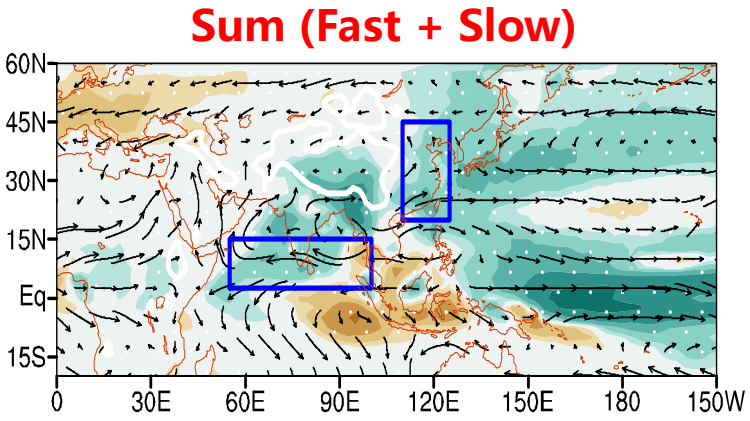


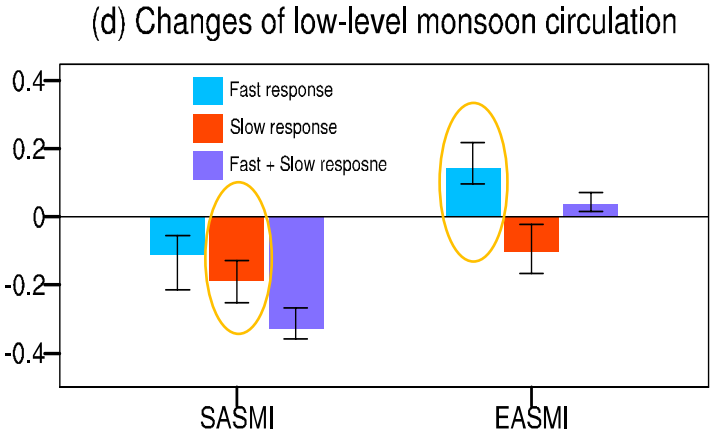
***Decomposing the total response to (Mitchell 1983; Bony et al. 2013; Shaw and Voigt 2015)**

- **Fast response**: *abrupt-4×CO_2 (1st year) - piControl (last 50 years)*
- **Slow response**: *abrupt-4×CO_2 (last 50 years) - abrupt-4×CO_2 (1st year)*

Changes of ASM circulation in the fast and slow responses



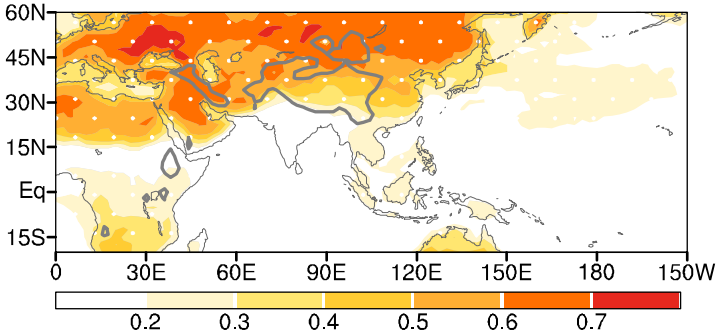




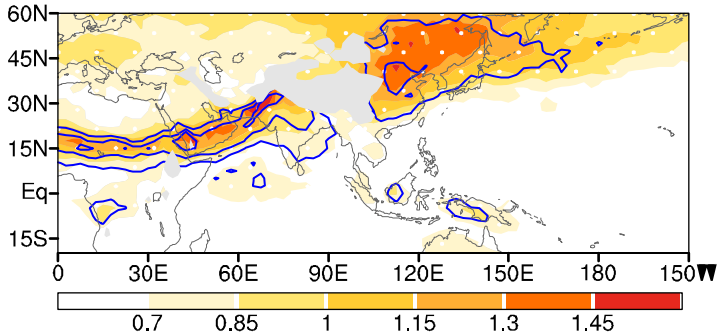
- The **strengthened EASM** circulation is dominated by the **fast process** !
- The **weakened SASM** circulation is dominated by the **slow process** !

Why is the EASM circulation strengthened in the fast response?

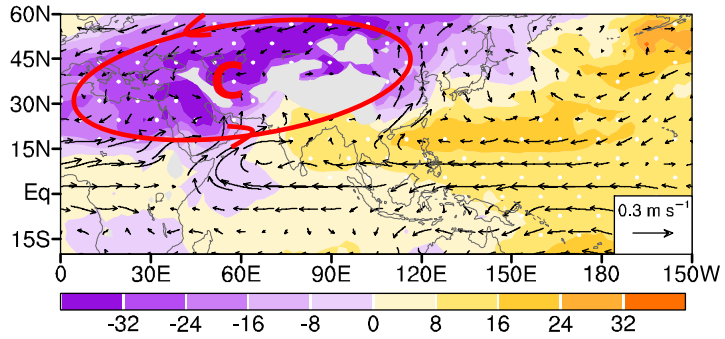
TS



θ_e & q850

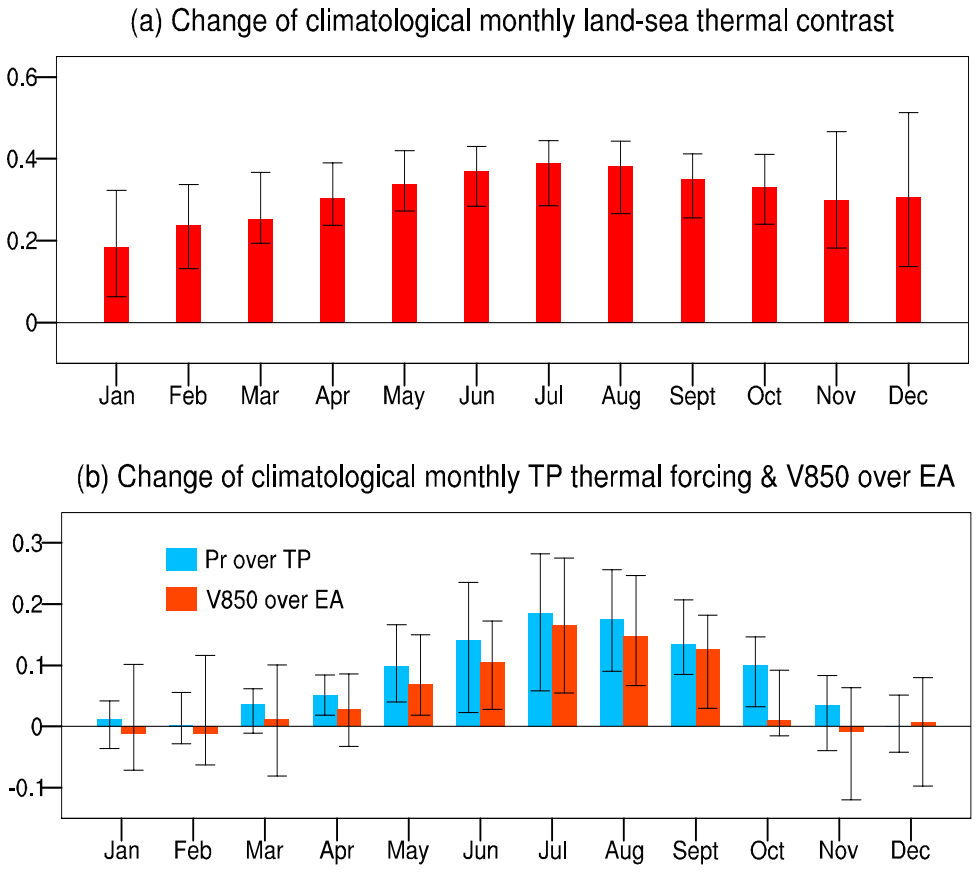


SLP & uv850

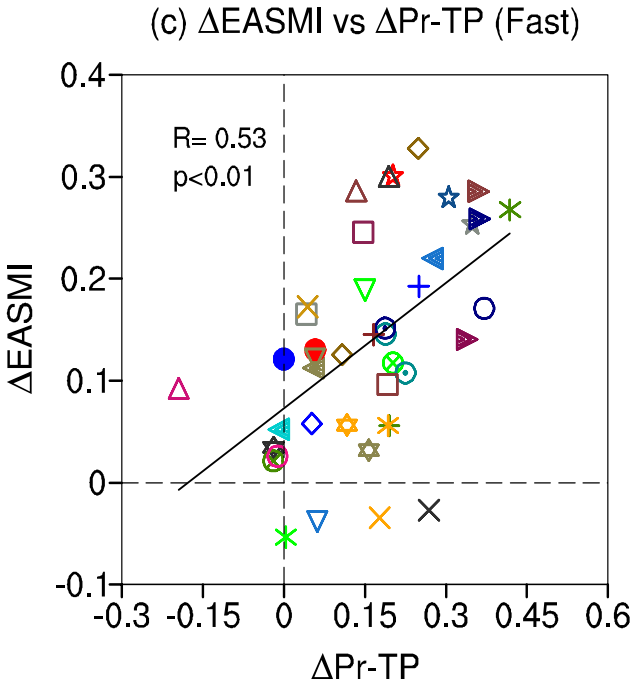


Fast land warming ➔ Large-scale surface low pressure anomaly in Eurasia ➔ Low-level cyclonic flow ➔ Strengthened southerly in EA

Role of Tibetan Plateau (TP) Thermal Forcing

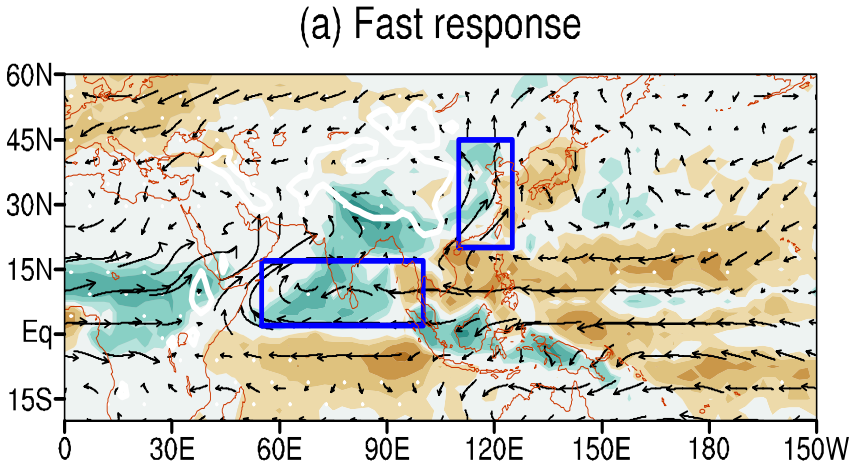


EASMI vs. Precip (TP)



➔ **Enhanced EA southerly occurs primarily in boreal summer** while the Eurasian land warming happens throughout the year.

Why is the SASM circulation weakened in the fast response?

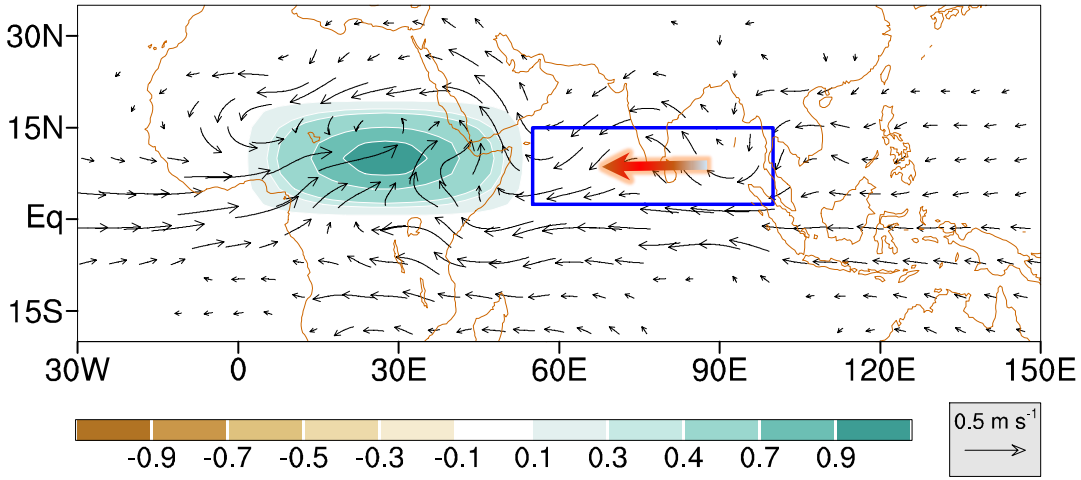


Enhanced North African monsoon

⬇

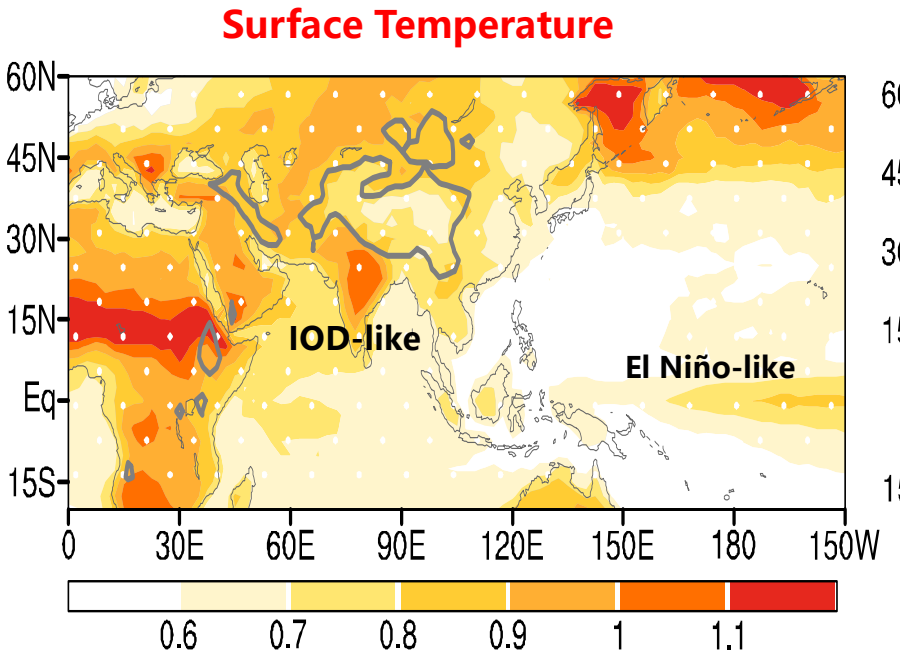
SASM easterly
(Gill response)

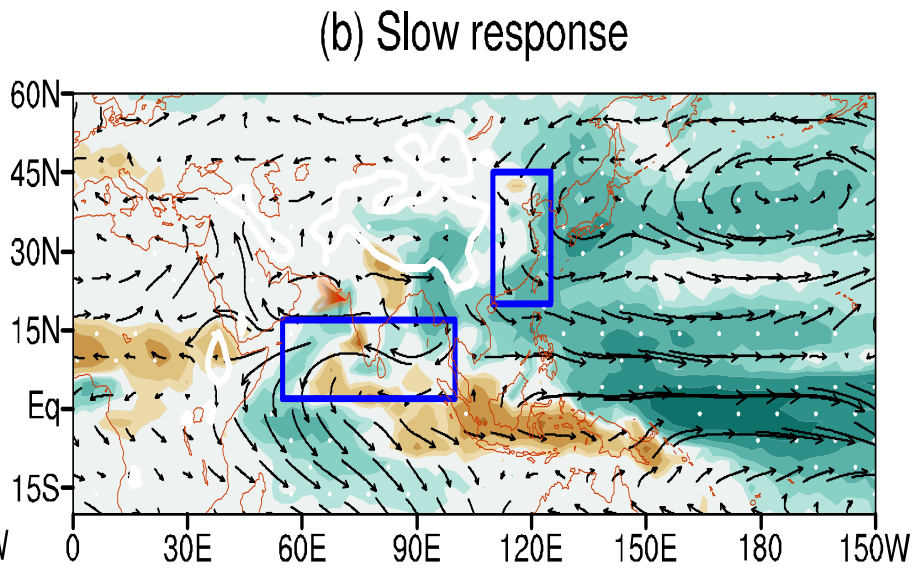
AGCM simulation



← 850hPa wind response to a prescribed positive heating over North Africa in an anomaly AGCM

Why is the SASM circulation weakened in the slow response?





El Niño-like SST warming in equatorial Pacific

➔

Weakened Walker circulation

➔

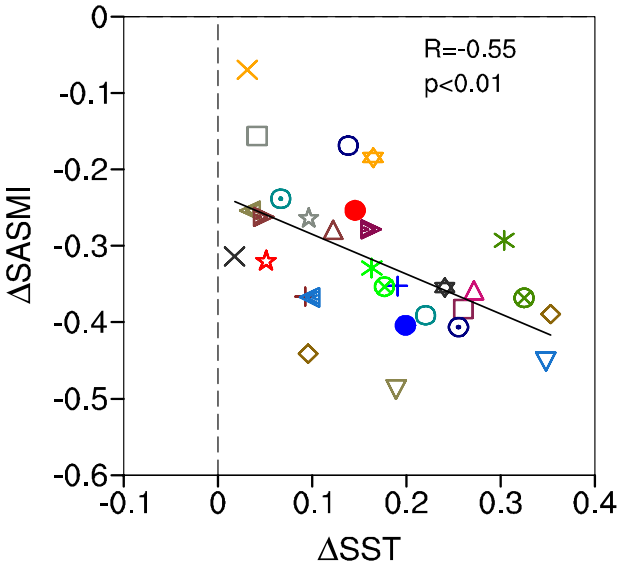
Suppressed convection over the MC

➔

Easterly anomaly over the northern IO (Gill response)

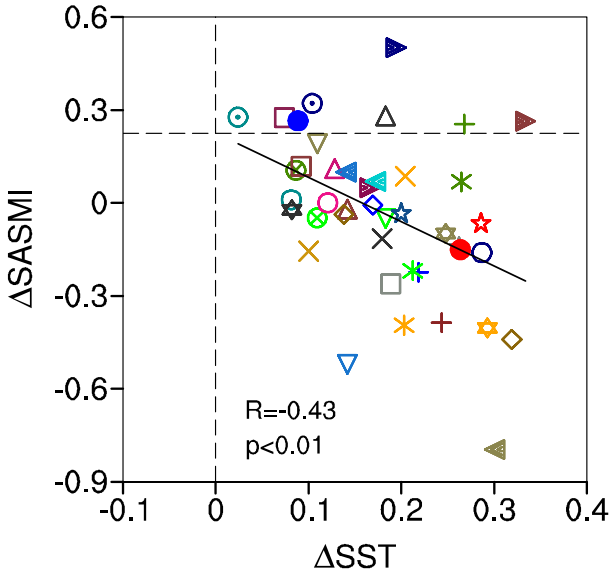
SSP5-8.5

SASMI vs SST Pattern



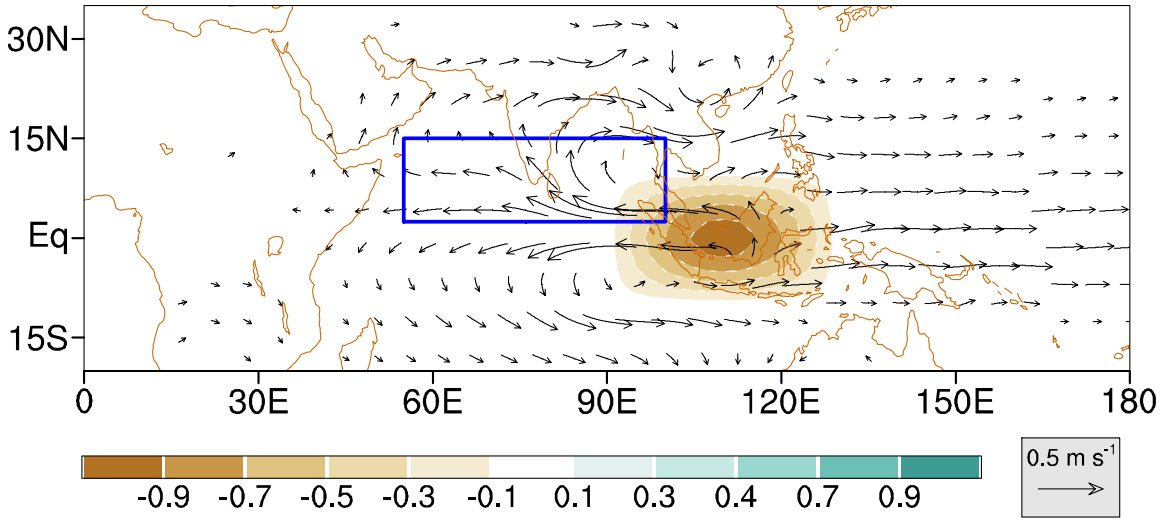
Slow Response

SASMI vs SST Pattern



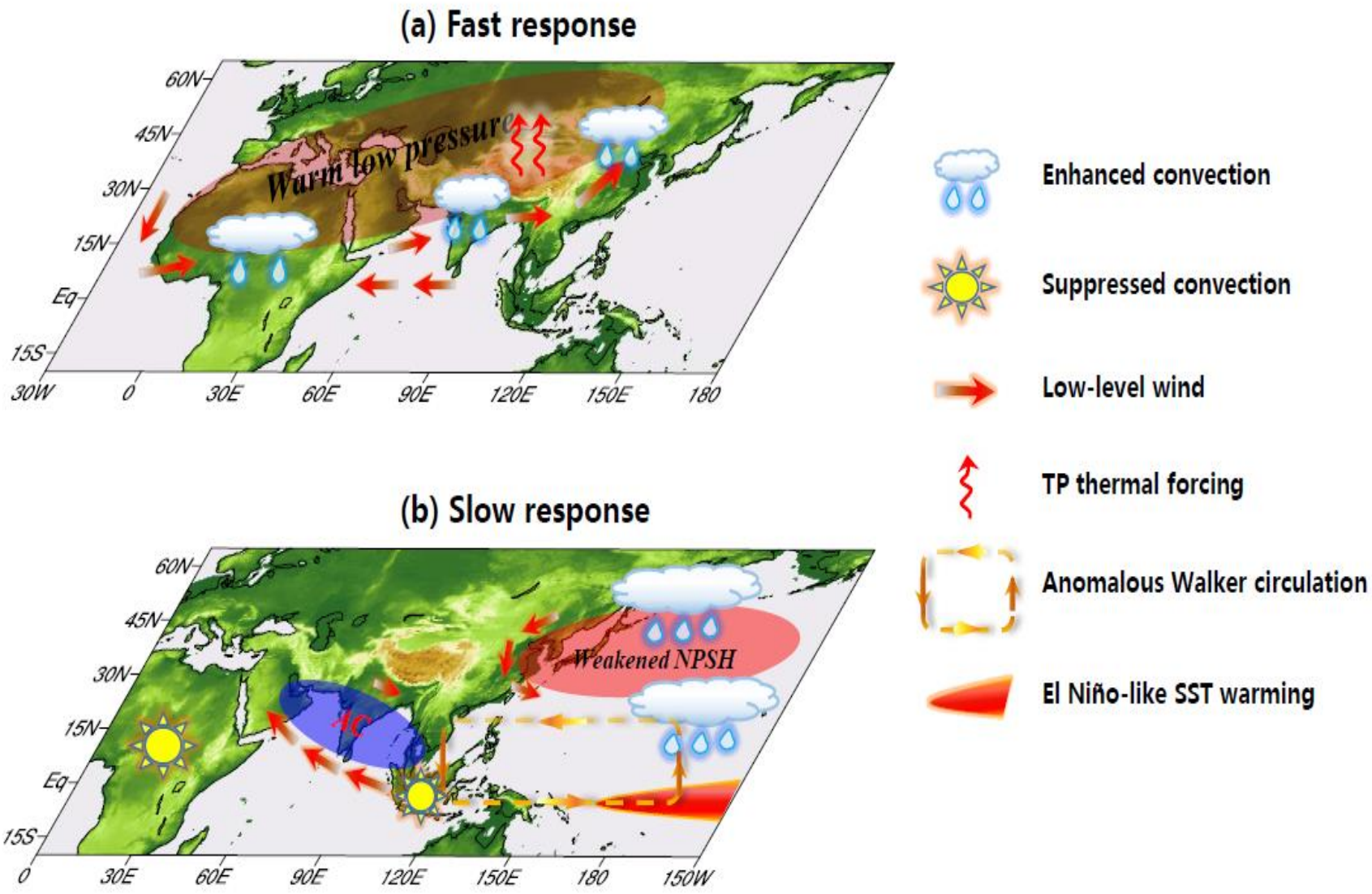
➔ Both CMIP6 and Slow simulations show a **robust inter-model relationship between the SASMI and SST warming pattern.**

Gill Response



➔ 850hPa wind response to a prescribed negative heating over MC in an anomaly AGCM

Schematic Diagram of EASM & SASM Circulation Changes

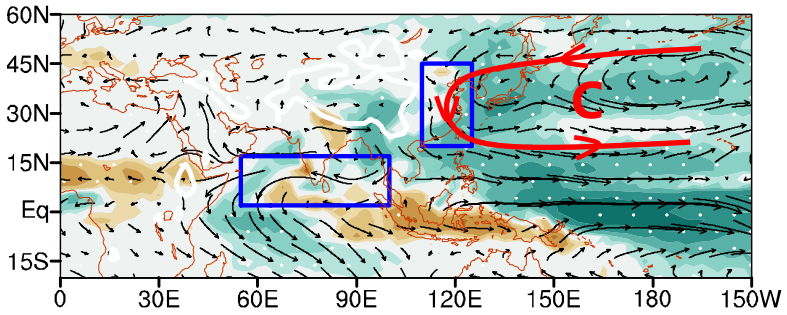


EASM (SASM) circulation change dominated by fast (slow) response !

Thank you

Why is the EASM circulation weakened in the slow response?

(b) Slow response **Pr & uv850**



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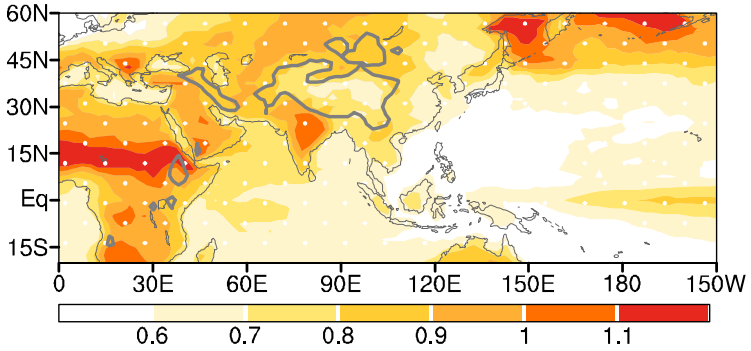
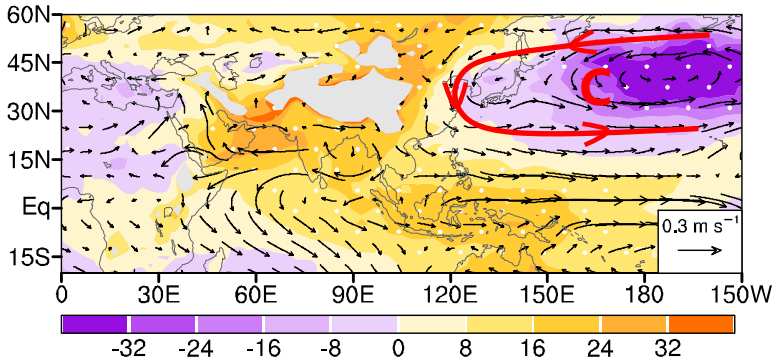
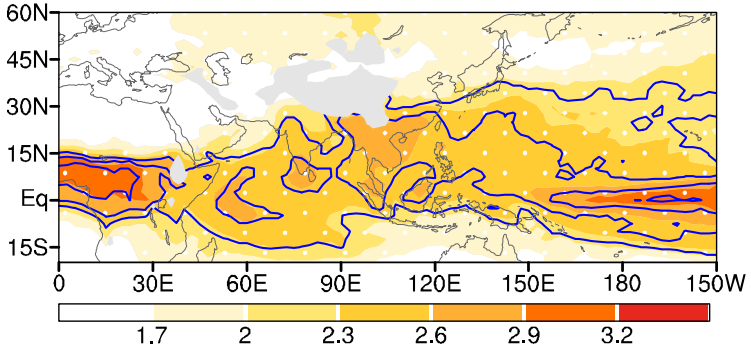


SLP & uv850



θ_e & q850



Greater increase of moisture in the ocean than over the land leads to enhanced convective instability /precipitation over the tropical and subtropical oceans

➔

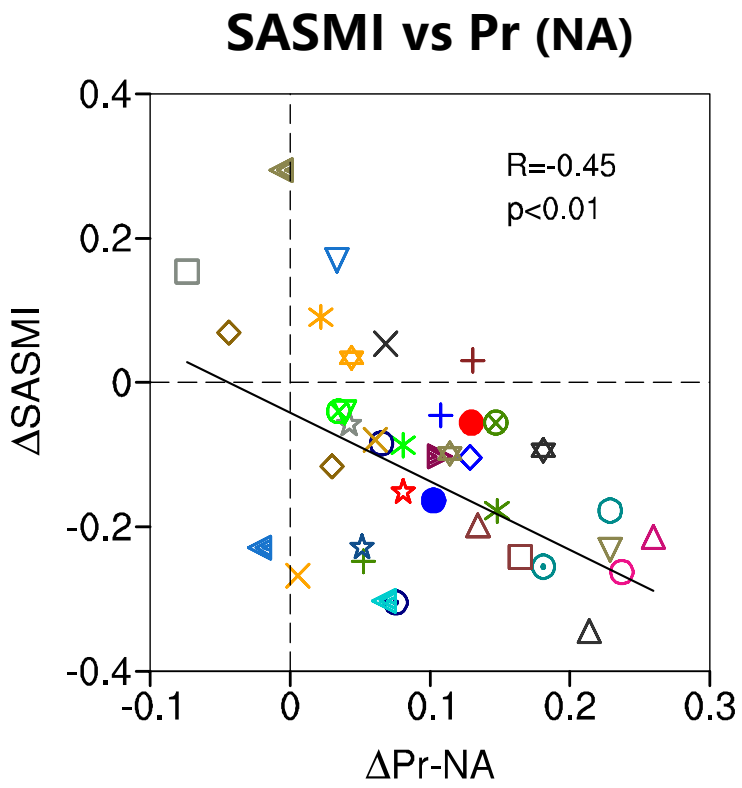
A low-level cyclonic circulation anomaly in the subtropical Pacific

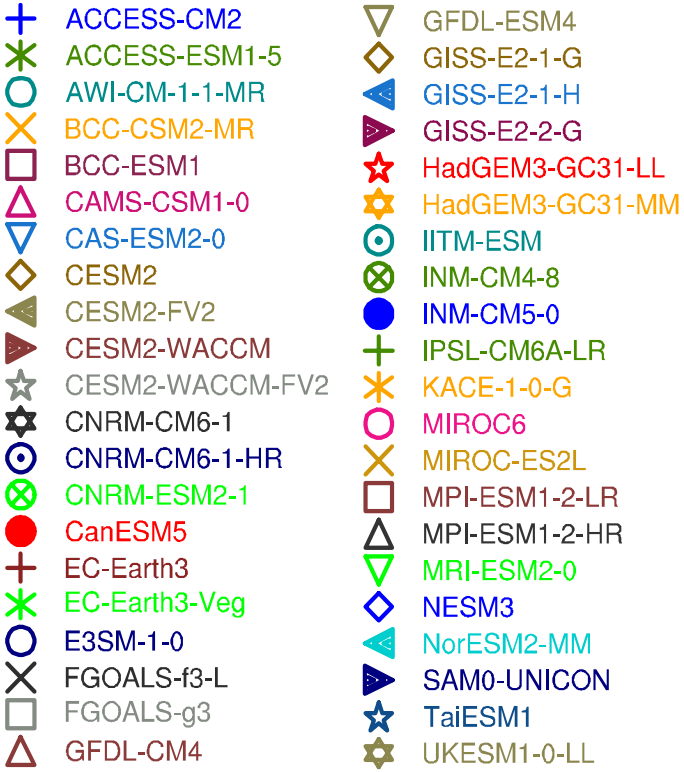
➔

Weakened NPSH

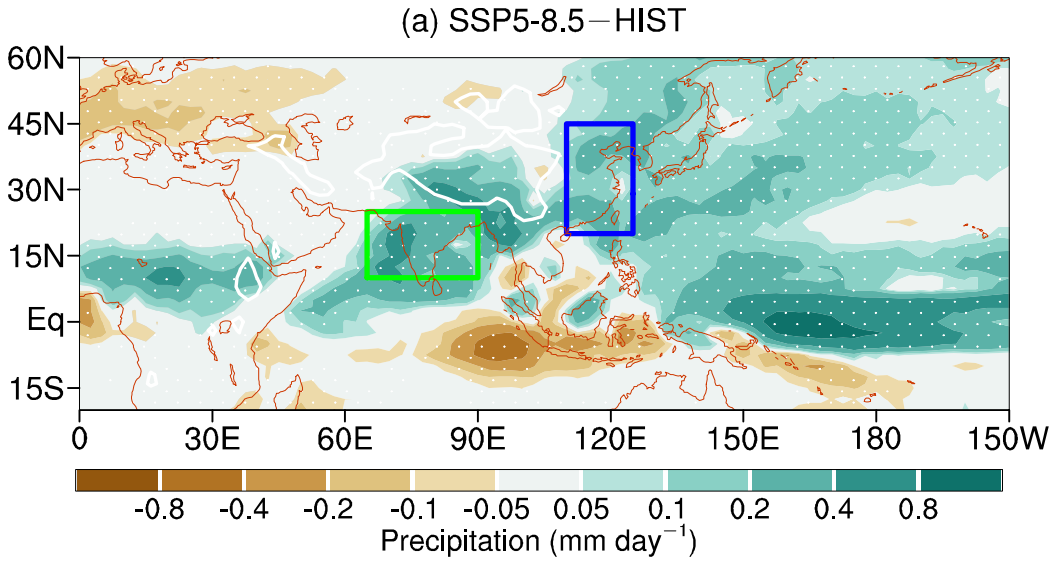
* Inter-model diagnose: SASMI vs Pr(NA)

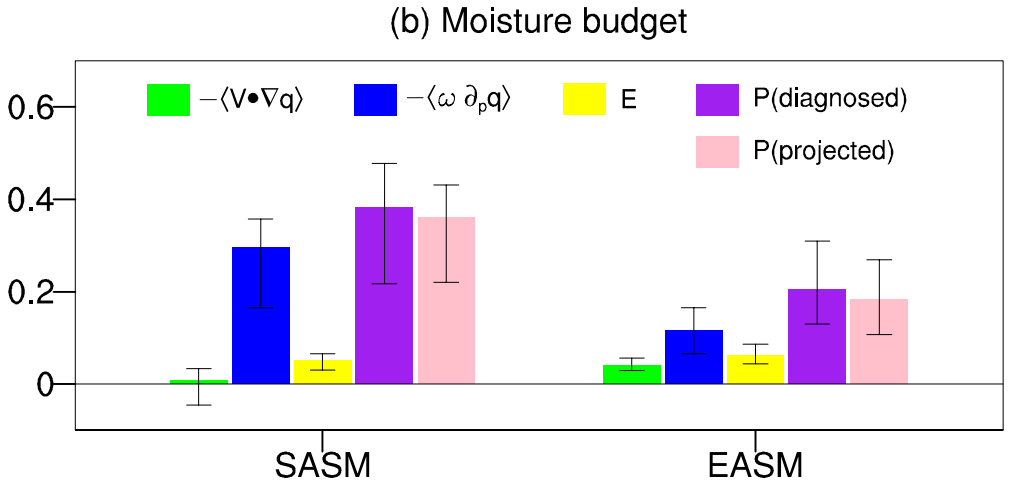
Fast Response





*Moisture budget for the change of the ASM rainfall in CMIP6 models





- **South Asia :**
  10°N-25°N, 65°E-90°E

- **East Asia :**
  20°N-45°N,110°E-125°E

$$P = -\langle V_h \cdot \nabla q\rangle - \left\langle \omega \frac{\partial q}{\partial p} \right\rangle + E$$

* Reasons for the choice of the ASM circulation indices

(1) SASM metrics

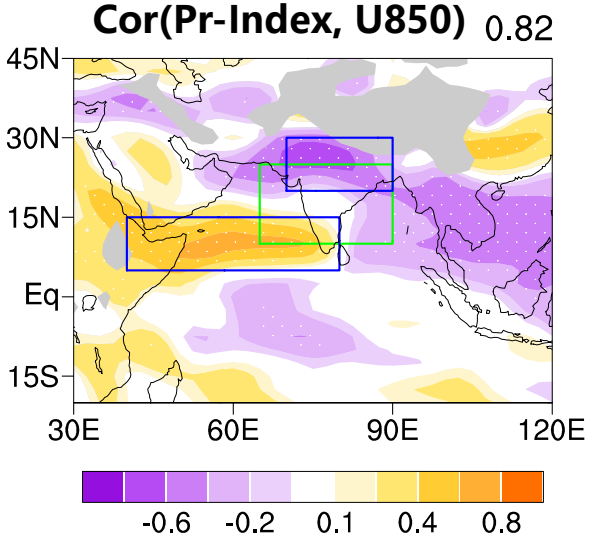
- **SASMI**=U850(2.5°N-15°N, 55°E-100°E)

The maximum climatological zonal wind is just located over this region (P9).

- **VWS**= U850(2.5°N-15°N, 55°E-100°E)- U200(2.5°N-15°N, 55°E-100°E)

VWS is a transformation of the WY-Index (Webster and Yang 1992), and has been widely used to study the SASM.

- **MWS1**=U850(5°N-15°N, 40°E-80°E) – U850(20°N-30°N, 70°E-90°E)



MWS is same as the ISMI defined by Wang et al. (2001), which perfectly reflects the variation of the Indian monsoon rainfall.

(2) EASM metrics

- **EASMI**=V850(20°N-45°N, 110°E-125°E)

Directly measure the intensity of the meridional wind over EA.
(e.g., Zhang et al. 1996; Wu and Ni 1997).

- **SLPG**=SLP(25°N-50°N, 130°E-150°W) – SLP(25°N-50°N, 30°E-110°E)

SLPG is a transformation of the Guo-Index (Guo 1983), reflecting the large scale thermal contrast between Eurasian continent and North Pacific.

- **MWS2**= U850(22.5°N-32.5°N, 110°E-140°E) – U850(5°N-15°N, 90°E-130°E)

MWS2 is the reversal of the WF-Index (Wang and Fan 1999), which is an excellent index to measure the tropical and subtropical climate variability over EA (Lee et al. 2005; Wang et al. 2008).