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for Climate Physics

Understanding the roles of global warming and natural variability on monsoon rainfall

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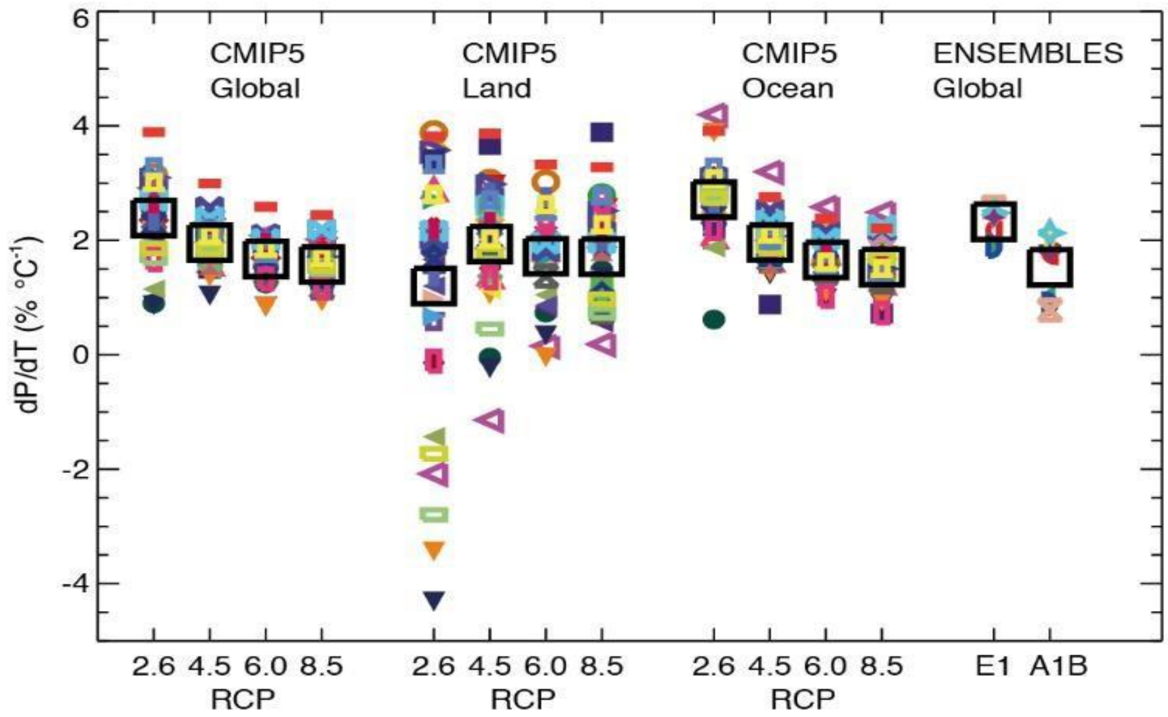
Background: About 2% of DP/DT in terms of RCPs

- Smaller than the C-C rate of atmospheric water vapor. Sensitivity on global and ocean
- Large range of sensitivity in RCP 2.6 over land
- Non-linear effect

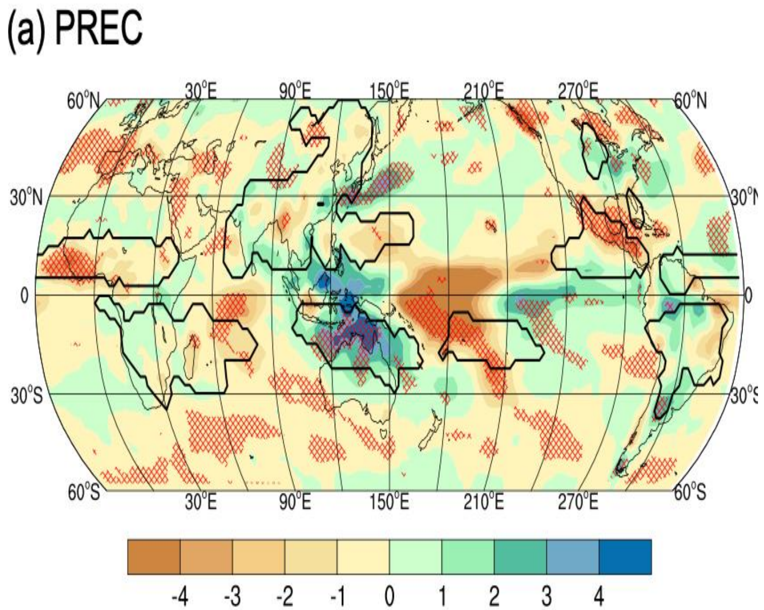


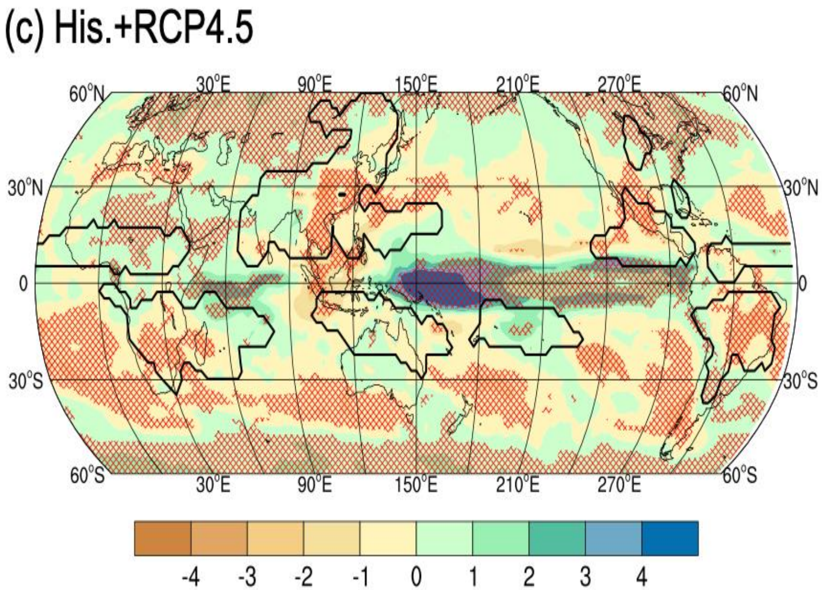
IPCC, 2013

What are drivers for global monsoon precipitation

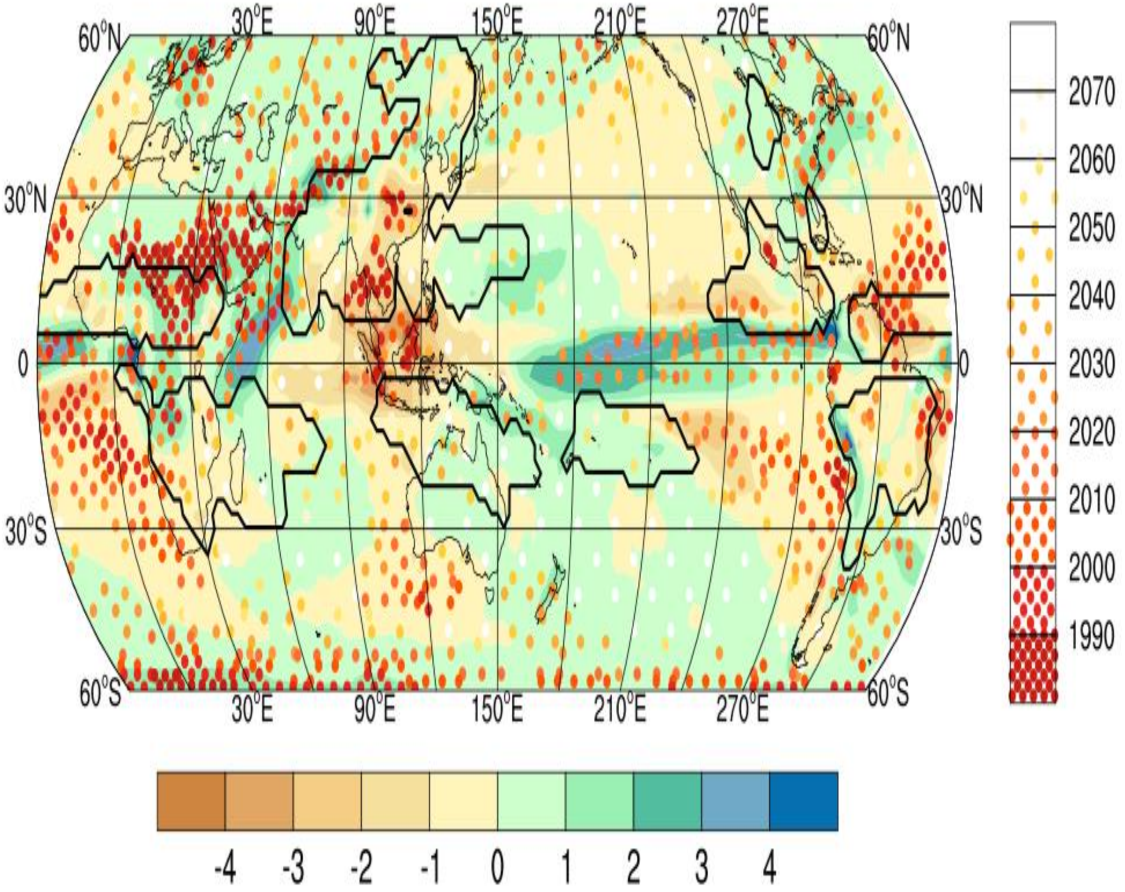
OBS vs Simulation in Linear trend of annual global rainfall. (left) NOAA's precipitation reconstruction (PREC) dataset (1958-2015), (right) multi-model mean (MMM) of 12 models in CMIP5 under the historical run (1958-2005) and RCP4.5 (2006-2015) run

Relative roles of global warming and natural variability



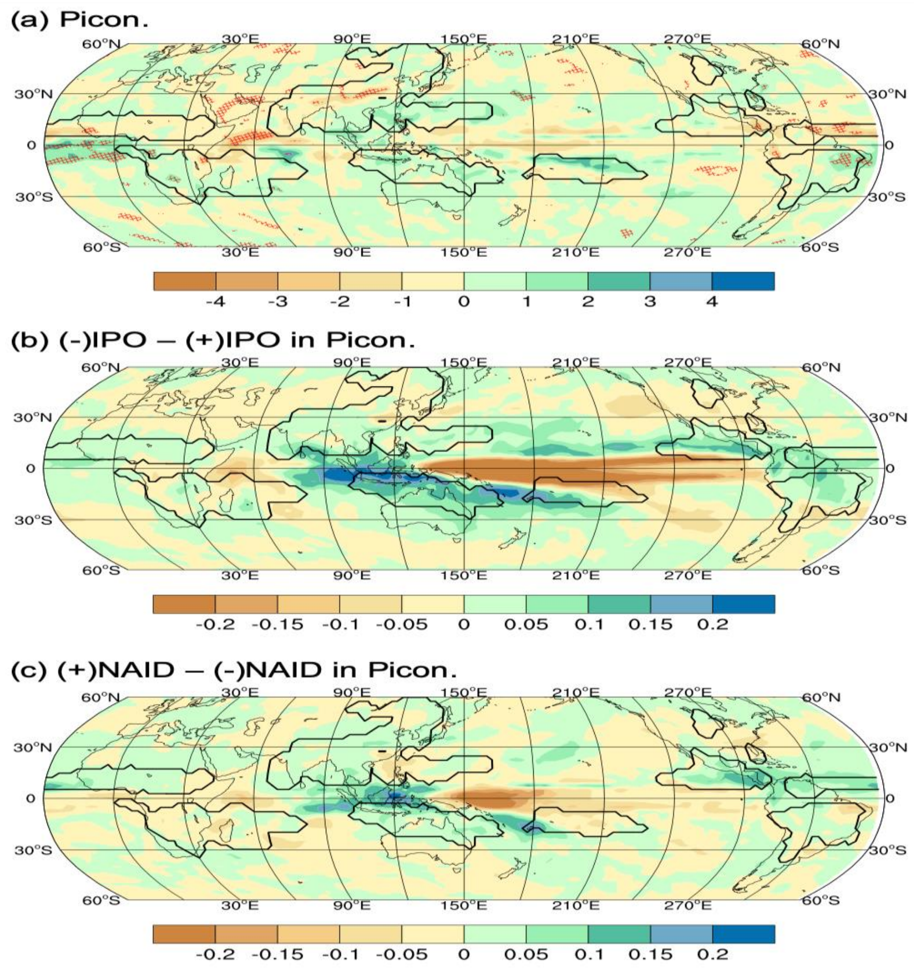


Assessing Signal to Noise



(TOE) (Time of Emergence)
the linear temporal trend predicts that the signal-to-noise (SNR) ratio exceeds 1 for the first time. Changes in precipitation by the anthropogenic forcing is detected over the northern African and Southeast Asian monsoons from the 1990s

Ha, Kim, Chung et al., ERL
under revision

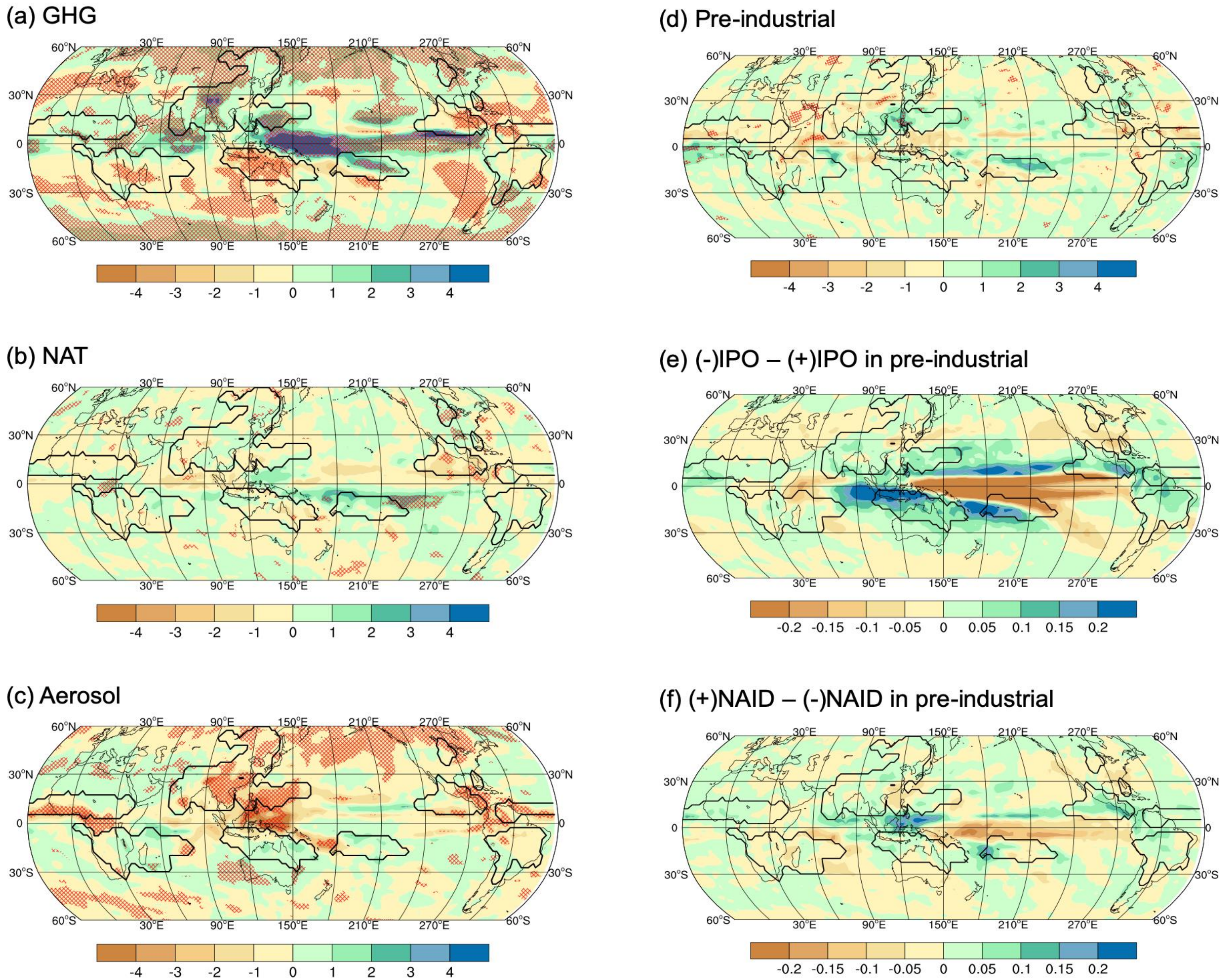


Understanding role of Natural Variability from Pre-industry Run (Picon)

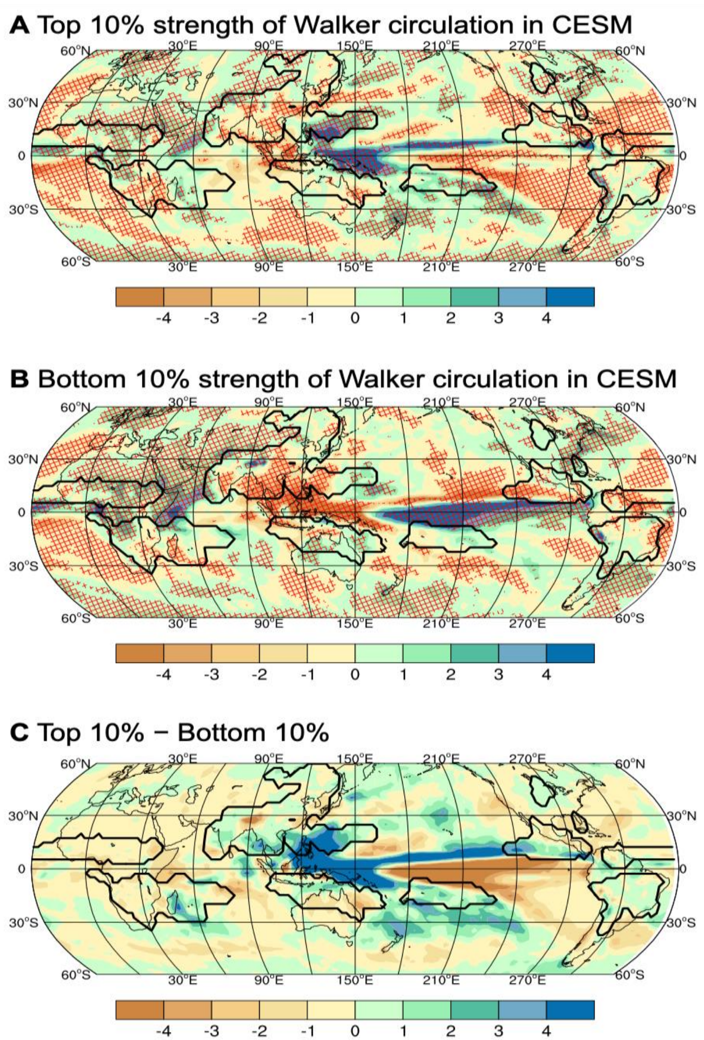
Interdecadal Pacific Ocsillation (IPO) and a North Atlantic-south Indian Ocean dipole (NAID) by Wang etal(2018)

The wet Indonesian-Australian monsoon and dry central Pacific in PREC can be caused by the natural variability

Ha, Kim, Chung et al., ERL, revised


(a) GHG
(b) NAT
(c) Aerosol
(d) Pre-industrial
(e) (-)IPO – (+)IPO in pre-industrial
(f) (+)NAID – (-)NAID in pre-industrial
60°N
30°N
0
30°S
60°S
30°E
90°E
150°E
210°E
270°E
-4 -3 -2 -1 0 1 2 3 4
-0.2 -0.15 -0.1 -0.05 0 0.05 0.1 0.15 0.2

Role of Walker circulation



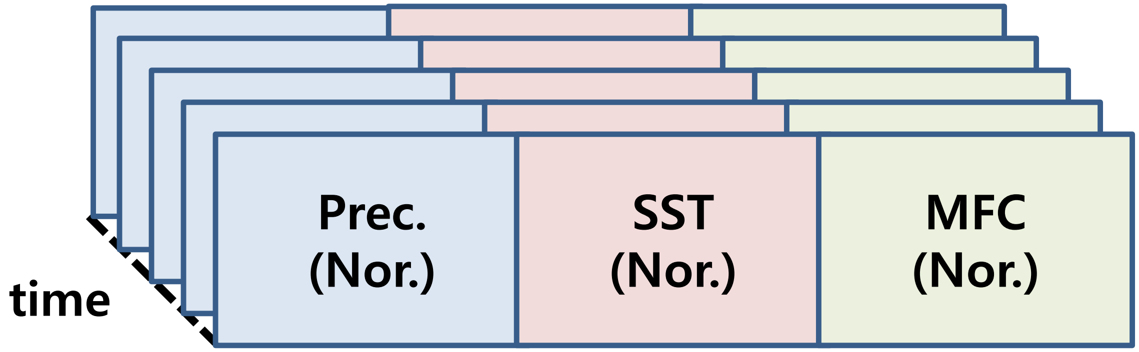
Kim& Ha(2018), Chung et al.(2019), strength and extension of Walker circulation have been responsible for the change in rainfall. This result implies that changes in the Walker circulation with GW and natural variability can be caused for the change in monsoon.

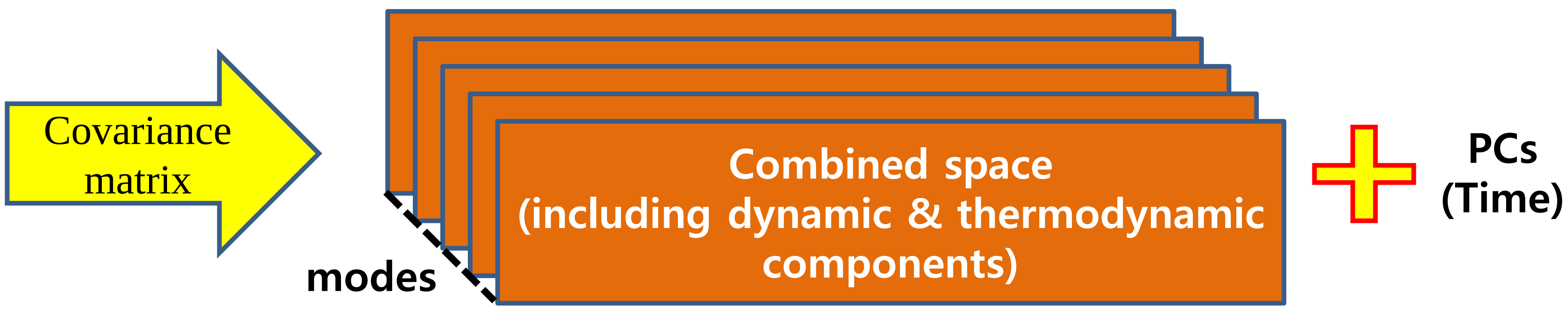
Figure. Composed mean annual precipitation from (b) the top 10% and (c) the bottom 10% based on the strength of Walker circulation in CESM 40 Large Ensemble members.

Multi-variate EOF (MVEOF) analysis to identify dominant modes

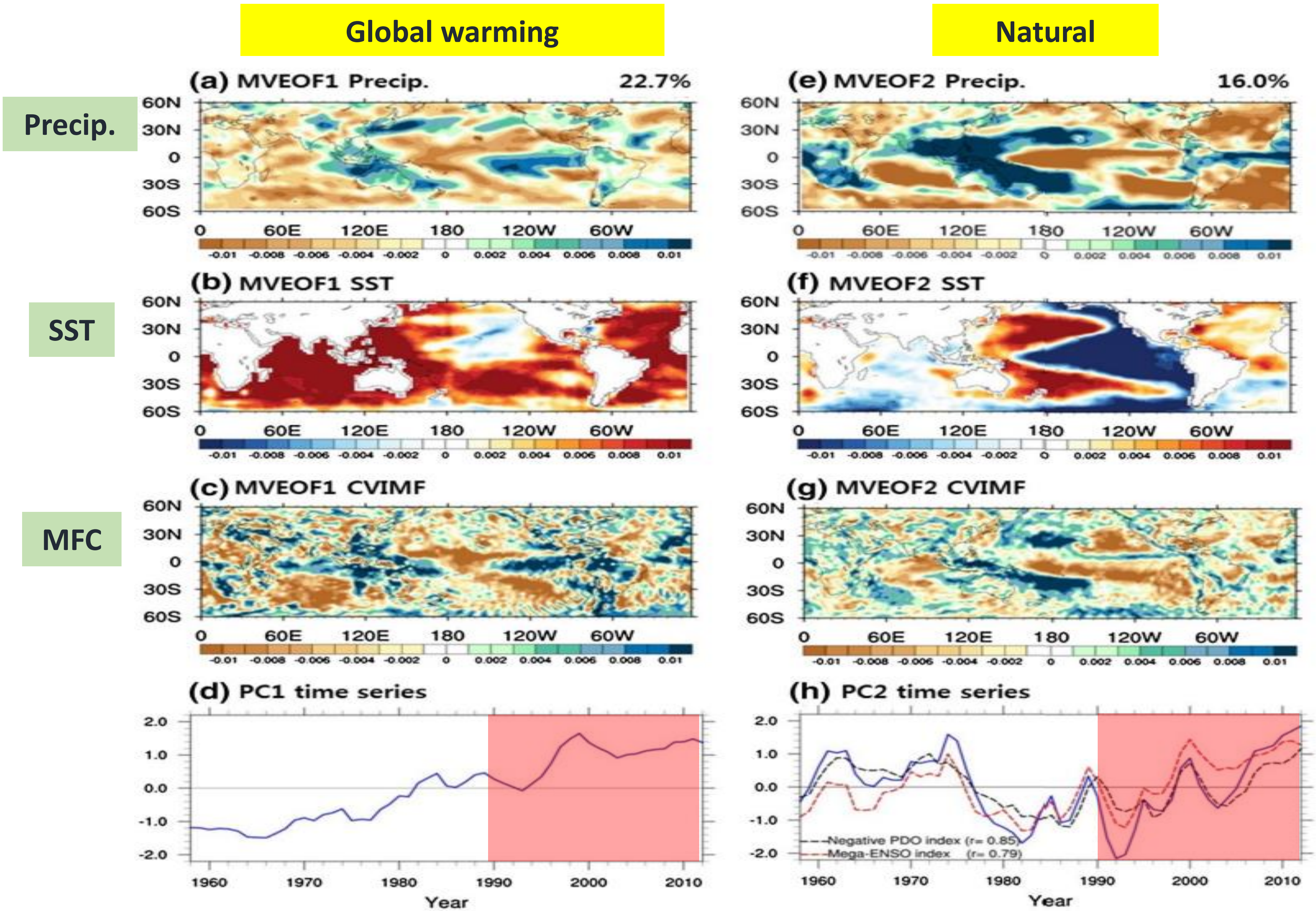
MVEOF analysis : Apply to determine the field relationship of the multi-variables

1. **Selecting variables : Precipitation, SST (forcing) , Vertical integrated Moisture flux convergence (MFC) (mechanism)**
2. **Normalization of each variable** for the same variability between variables
3. **Combining normalized variables**
4. **Identification of principal coupling mode** through **a covariance matrix from combined data (multi-variables) 5. Causal link analysis**

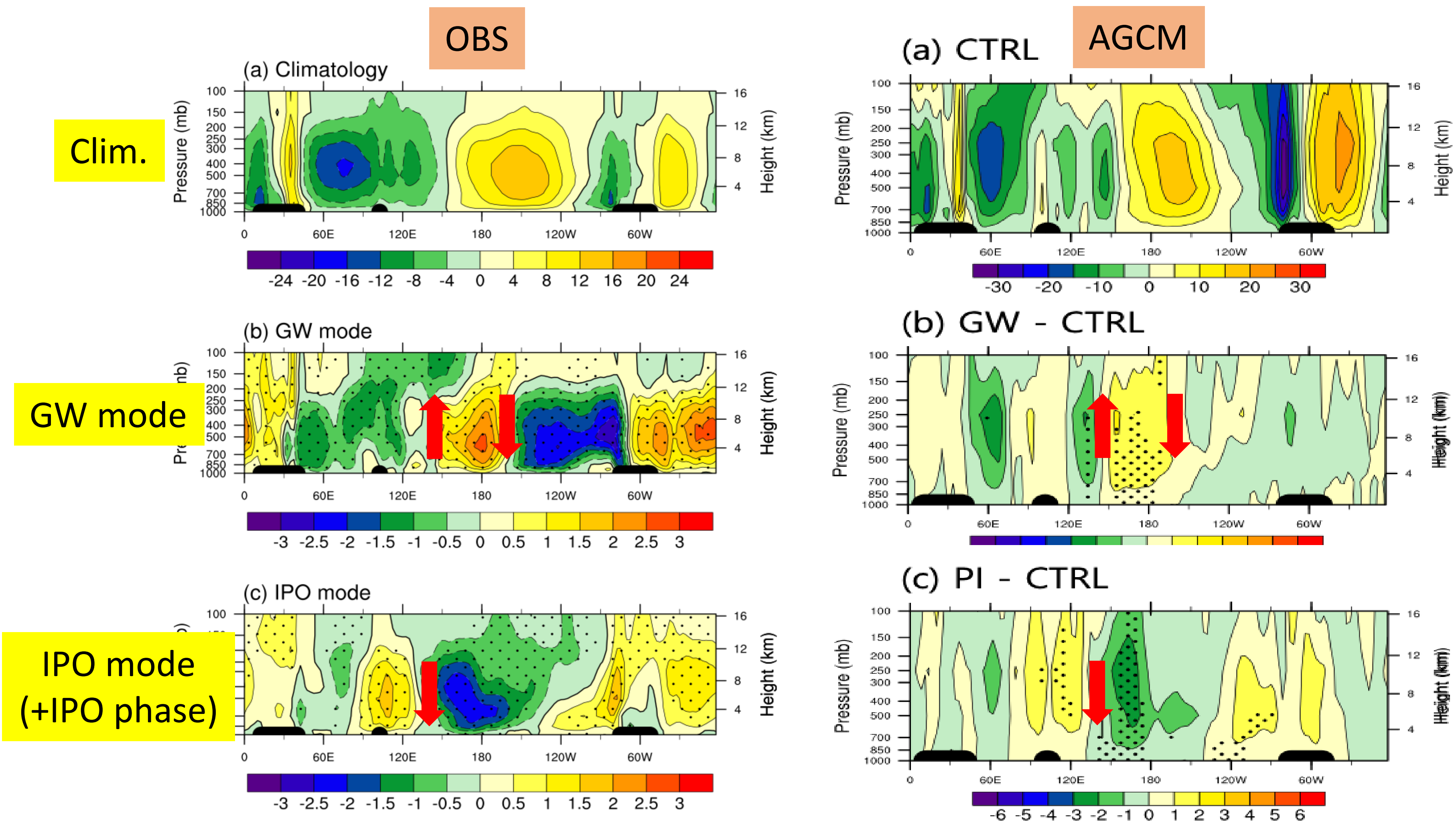




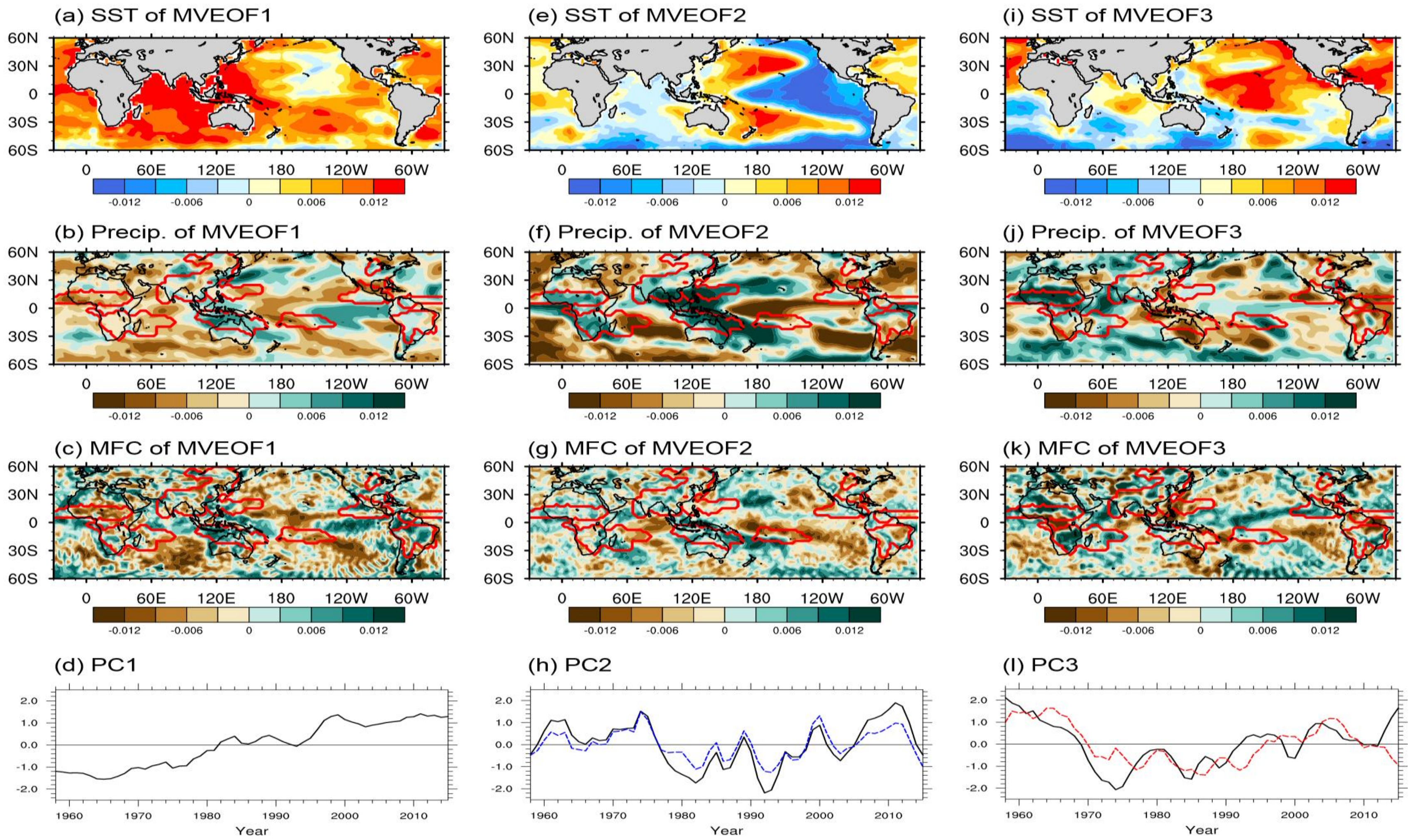
Observed decadal changes of global and western Pacific precipitation associated with global warming SST mode and-IPO SST mode



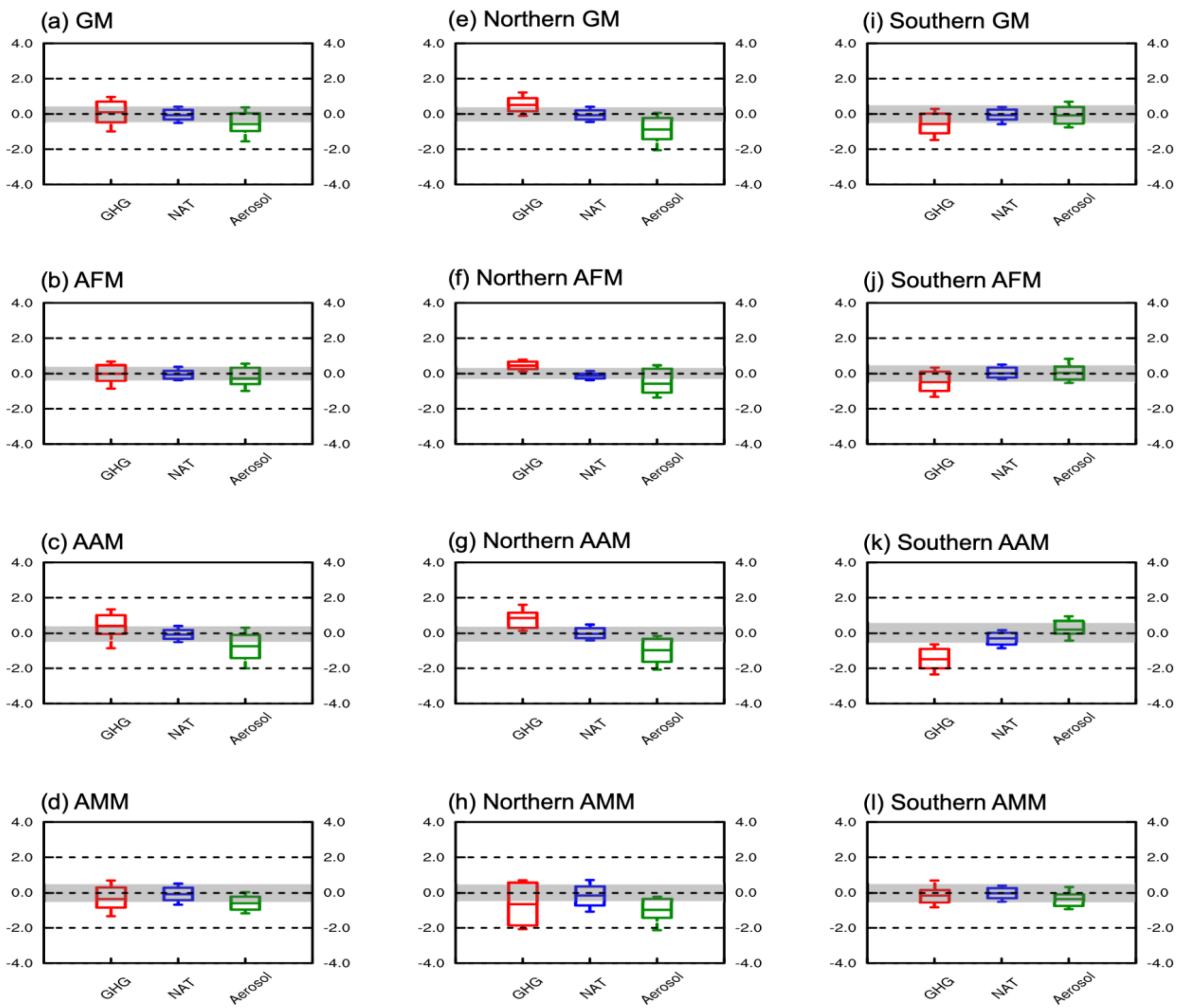
Walker circulation change by the GW and IPO modes



- The wet Indonesian-Australian monsoon and dry central Pacific in the observation can be caused by **the westward shifted Walker circulation** due to the GW mode.
- The IPO mode can relate to increase/decrease precipitation through **the weakening/strengthening of the Pacific Walker circulation**.



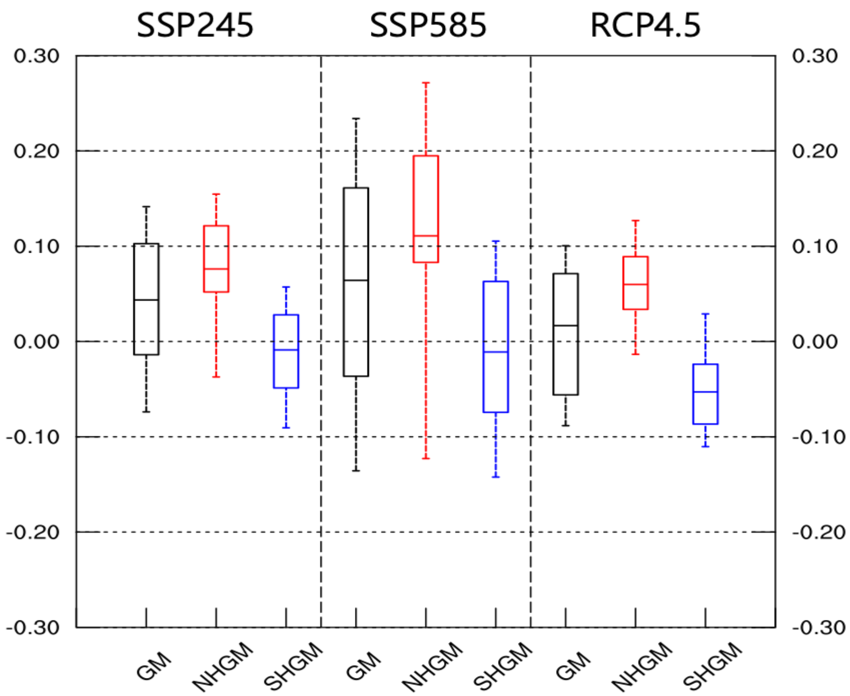
The three multi-variate EOF modes of the 3-year averaged annual mean SST, rainfall and MFC during the period 1958-2015 over the globe (60°S-60°N, 0°-360°). Left panels: first multi-variate EOF modes; middle panels: second multi-variate EOF modes; right panels: third multi-variate EOF modes. (a,e,i) : SST; (b,f,j) : rainfall; (c,g,k): MFC; (d,h,l) : principal components (PCs) of three coupling modes. The three coupling modes account for 21.9%, 14.7%, and 8.9% of the total variance, respectively. The global monsoon domains (red solid lines) are defined according to Wang and Ding (2006) using PREC. The blue and red dashed lines (h, l) denote a negative IPO index and NAID index, respectively.



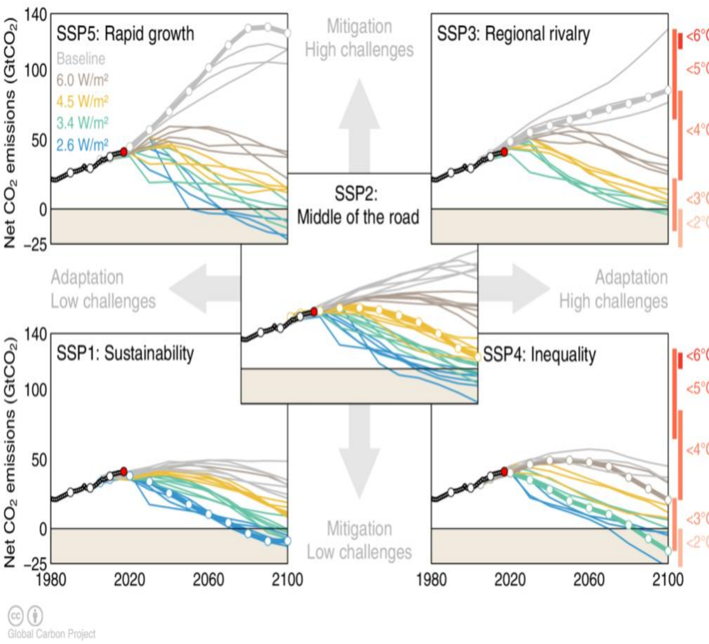
GHG forcing increases and decreases land rainfall over the northern and southern GM. The asymmetry between NH and SH parts by GHG can be detected over the AFM and AAM regions. In the northern AMM, the land monsoon rainfall decreased by GHG and aerosol forcing. The aerosol forcing causes a decreasing rainfall over the monsoon regions, except for the southern AAM.

Asymmetry of NH-SH of increasing monsoon in NH and decreasing monsoon in SH for RCP 4.5 weaken due to no significant change in SH for SSP245 & SSP585

Here we show that the intermodel spread in SSP585 are increased in NH and SH compared to SSP245



Shared Socioeconomic Pathways
Chart via Glen Peters and Robbie Andrews and the Global Carbon Project



Summary

- We have found that emerging times of anthropogenic signals are detected in the northern African and Southeast Asian monsoons from the 1990s with the use of the CESM Large Ensemble Project. The westward shift and strengthening of PWC are caused by the global warming SST pattern in the global warming mode and IPO SST pattern in the natural mode.

- Here we show that the asymmetry between Northern Hemisphere (NH) and Southern Hemisphere (SH) parts is detected over the AFM and AAM regions. However, the land monsoon rainfall in the northern AMM is decreased by a combination of GHG and aerosol forcing and southern AMM is increased by GW and IPO. In general, the aerosol forcing causes a decreasing rainfall over the monsoon regions.

- Asymmetry of NH-SH of increasing monsoon in NH and decreasing monsoon in SH for RCP 4.5 weaken due to no significant change in SH for SSP245 & SSP585. Here we show that the intermodel spread in SSP585 are increased in NH and SH compared to SSP245