# Asian Summer Monsoon Changes at Different Levels of Global Warming : A multi-RCM study

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# Backgrounds

- Paris Climate Agreement (2015)
- Rising public interest in global warming at specific levels (1.5 and 2.0°C)
- Most studies based on global climate simulations

# Major questions

- Understanding Asian summer precipitation change at specific warming levels (1.5, 2.0, 2.5, 3.0°C)
- Examine the potential uncertainty in multi-RCM future projection

# Data

| INSTITUTIONS. | Regional Climate Model | Global Climate Model (Boundary Forcing) | | |
|---|---|---|---|---|
| | | GFDL-ESM2M | HadGEM2-AO | MPI-ESM-LR |
| **NIMS** | HadGEM3-RA | | ● | ● |
| **KNU** | RegCM | | ● | |
| **PNU** | WRF | ● | | ● |
| **UNIST** | MM5 | | ● | ● |
| **POSTECH** | CCLM | | ● | ● |

- Regional Climate Model follows CORDEX-EAS (25km) Phase II experimental domain
- Data details are described on : http://cordex-ea.climate.go.kr

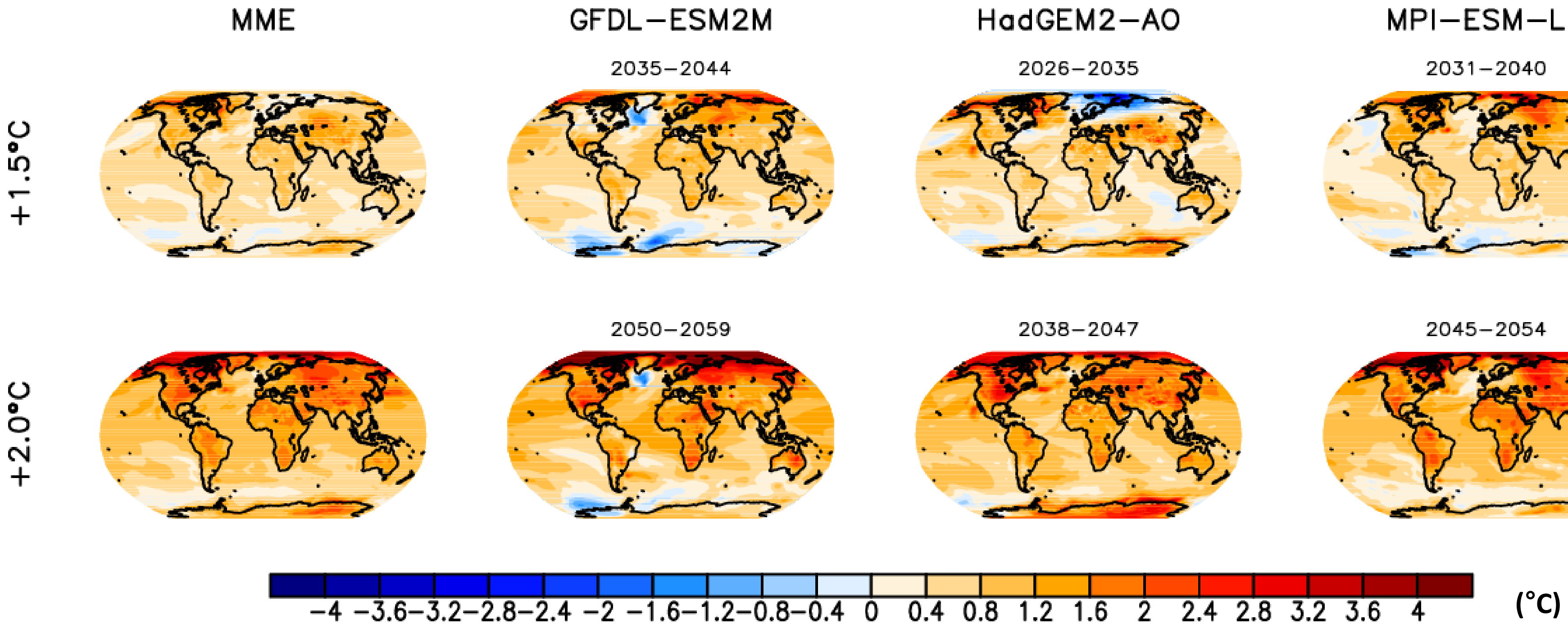
# Method I

- **Global Warming at Specific Levels**

(1) Based on IPCC SR (2018), we assume "global warming in recent decade (2006-2015) are +0.87 warmer than pre-industrial conditions (relative global warming).

(2) We select a decade based on boundary GCM data under RCP85, when relative global warming reaches +1.5, +2.0, +2.5, +3.0°C from pre-industrial conditions.

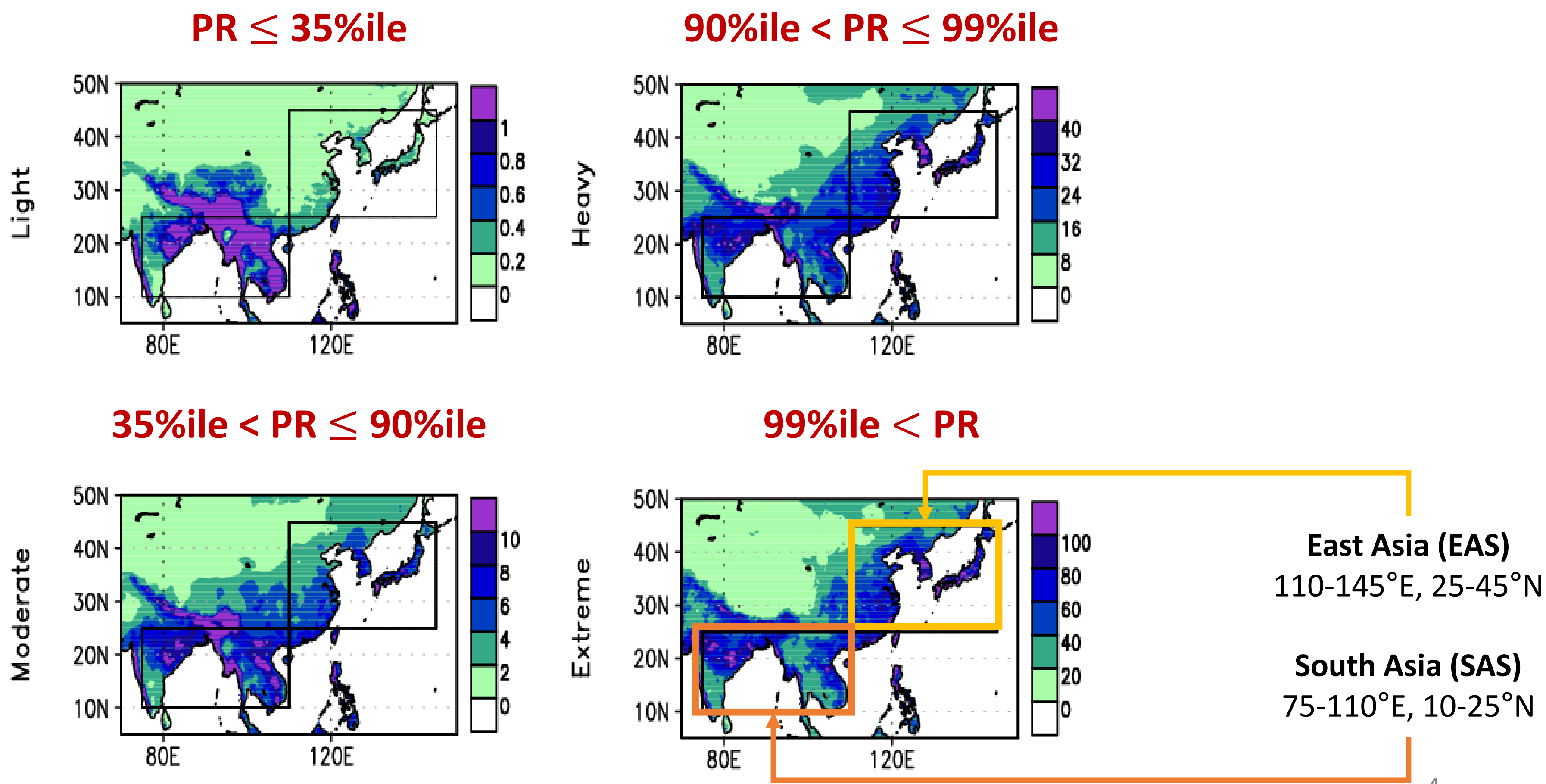
**e.g) Surface Air Temperature (TAS, 2m) at +1.5 and +2.0 warming**



# Method II

- **Light, Moderate, Heavy, Extreme precipitation in summer season (JJA)**

Compute daily precipitation (PR) percentile (%ile) values at
35%ile, 90%ile, 99%ile from summer days of climate model simulations




***APHRODTIE V1901 0.25 deg (2006-2015)**

# Method III

- **Intensity**

Difference in precipitation group (light, moderate, heavy, extremes) between warming worlds (1.5, 2.0, 2.5, 3.0) and historical (2006-2015) periods.

$$\Delta Intensity \;=\; PR_{warming\ worlds} - PR_{histoircal}$$

*PR: Light, Moderate, Heavy, Extreme precipitation*

- **Frequency**

Relative change in precipitation group (light, moderate, heavy, extremes) at warming worlds (1.5, 2.0, 2.5, 3.0), based on historical (2006-2015) precipitation frequencies (unit is %).

$$\Delta Frequency \;=\; \frac{\left(Days_{warming\ worlds} - Days_{historical}\right)}{Days_{historical}} \times 100$$

*Days: PR threshold uses historical periods (2006-2015)*

- **Uncertainty (Future projection variance)**

Relative contributions of boundary GCM forcing (BGF) and RCM itself (RCM) are assumed :

$$BGF\_VAR = Variance\ of\left[E(RCMs\ of\ GCM1), E(RCMs\ of\ GCM2)\ \ldots\right]$$

$$RCM\_VAR = Variance\ of\left[E(RCM1\ of\ GCMs), E(RCM2\ of\ GCMs)\ \ldots\right]$$

$$TOTAL\_VAR = BGF\_VAR + RCM\_VAR$$

# Uncertainty Example

## Extreme case, +1.5°C, EAS, intensity

**1** Calculate each RCMs projection

| Regional Climate Model | Global Climate Model (Boundary Forcing) | | |
|---|---|---|---|
| | GFDL-ESM2M **(G1)** | HadGEM2-AO **(G2)** | MPI-ESM-LR **(G3)** |
| HadGEM3-RA **(R1)** | | 6.2 mm/d | 3.6 mm/d |
| RegCM **(R2)** | | 7.6 mm/d | |
| WRF **(R3)** | 5.3 mm/d | | 8.0 mm/d |
| MM5 **(R4)** | | 9.9 mm/d | 7.0 mm/d |
| CCLM **(R5)** | | 7.8 mm/d | 6.5 mm/d |

**2B**
Average of RCM groups

| Regional Climate Model | GCMs' average |
|---|---|
| HadGEM3-RA **(R1)** | 4.9 |
| RegCM **(R2)** | 7.6 |
| WRF **(R3)** | 6.7 |
| MM5 **(R4)** | 8.5 |
| CCLM **(R5)** | 7.2 |

**2A**
Average of GCM groups

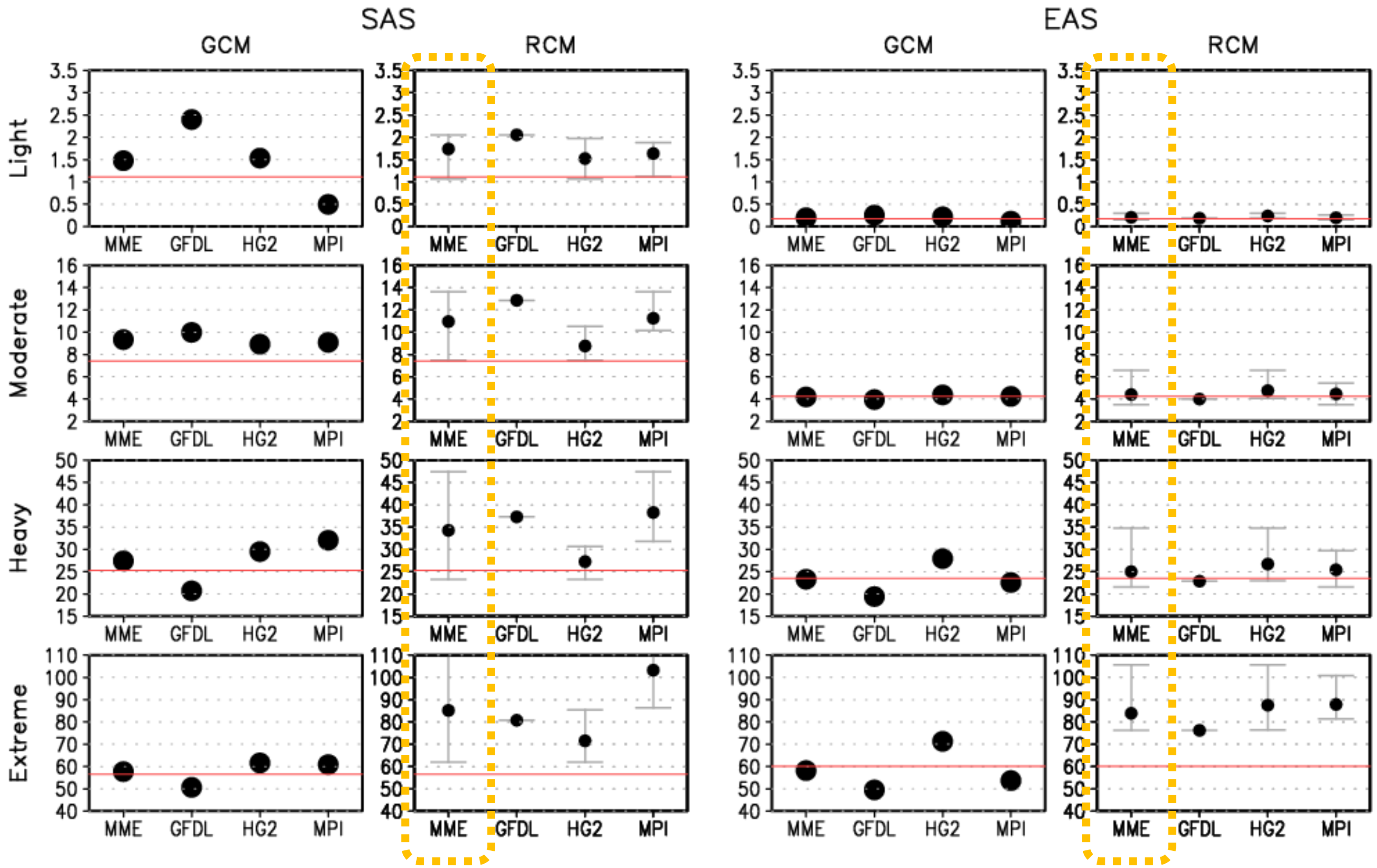
| | Global Climate Model (Boundary Forcing) | | |
|---|---|---|---|
| | GFDL-ESM2M **(G1)** | HadGEM2-AO **(G2)** | MPI-ESM-LR **(G3)** |
| **RCMs' average** | 5.3 | 7.9 | 6.3 |

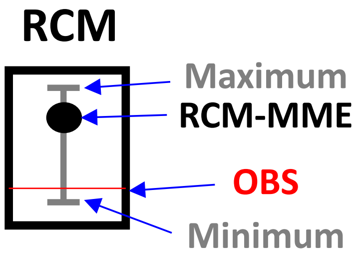
| | | | |
|---|---|---|---|
| **BGF VARIANCE** | Variance of (2A) | 1.2 $(mm/d)^2$ | 44% |
| **RCM VARIANCE** | Variance of (2B) | 1.4 $(mm/d)^2$ | 56% |
| **TOTAL VARIANCE** | Sum of two | 2.6 $(mm/d)^2$ | 100% |

Concept is similar to Deque et al. (2007),
except for the "missing data reconstruction" and considering covariance

# Result

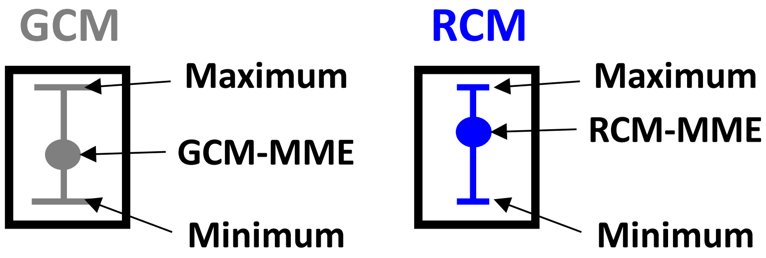
**HIST (+0.87 degC in OBS, 2006-2015)**



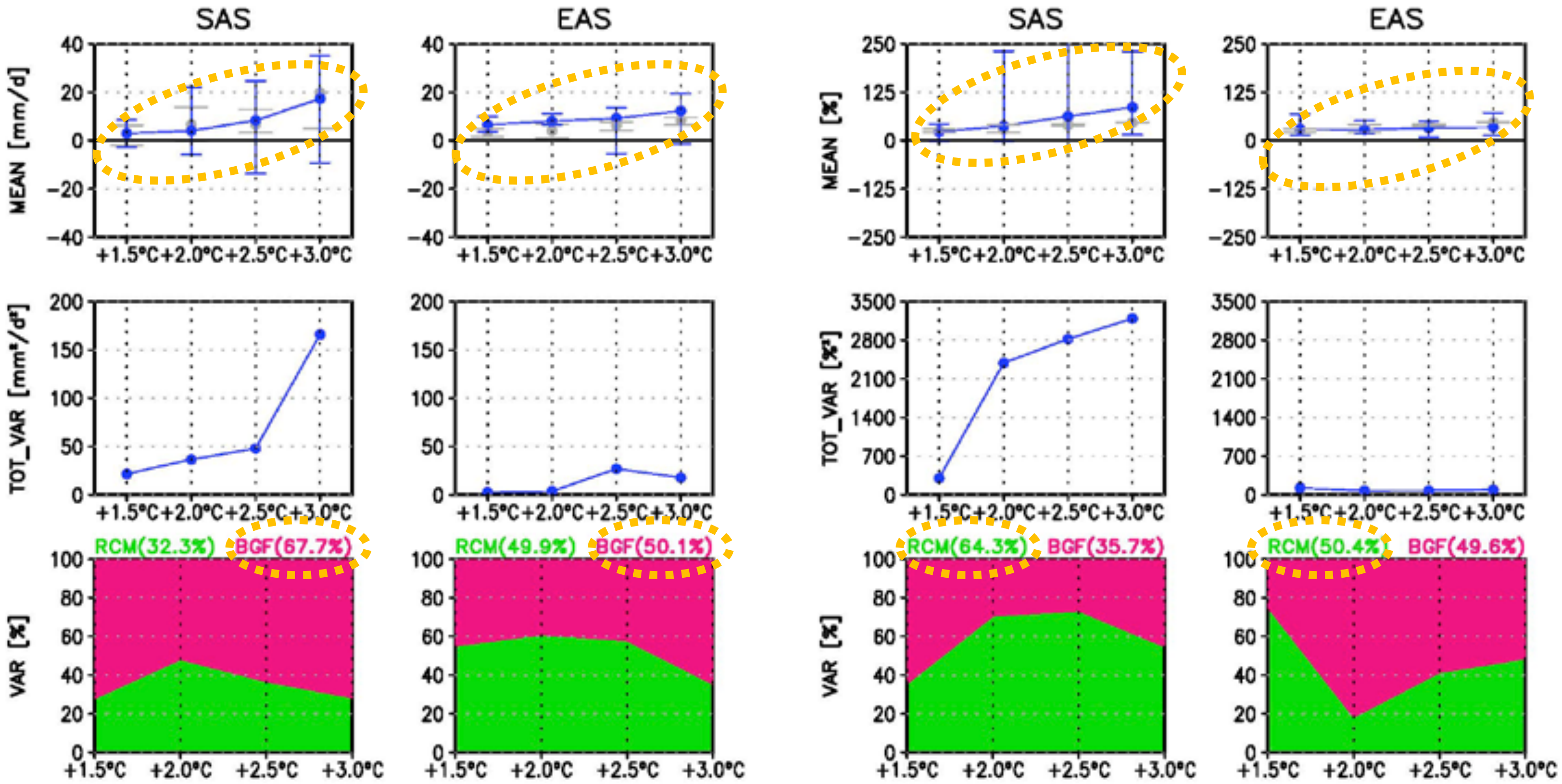

- ❖ In general, RCMs overestimate precipitation.
- ❖ Multi-RCM have large uncertainty ranges over SAS > EAS

# Result




- **Extreme precipitation change**

**Intensity (mm/day)** **Frequency (%)**

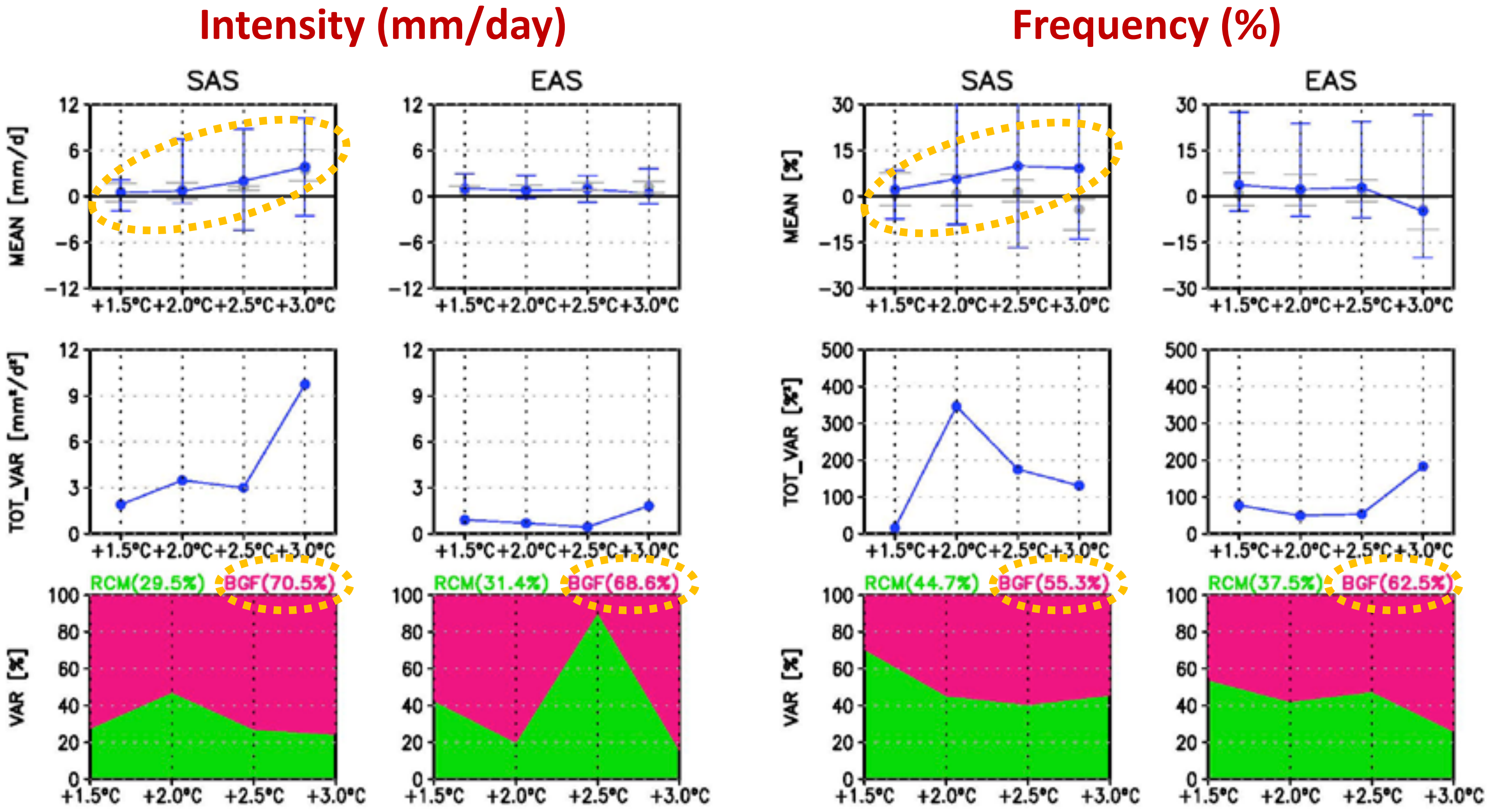



❖ Extreme precipitation intensity and frequency gradually increases
❖ Future projection uncertainties are larger for SAS, than EAS
❖ Intensity : BGF > RCM, Frequency : RCM > BGF

# Result



- **Heavy precipitation change**

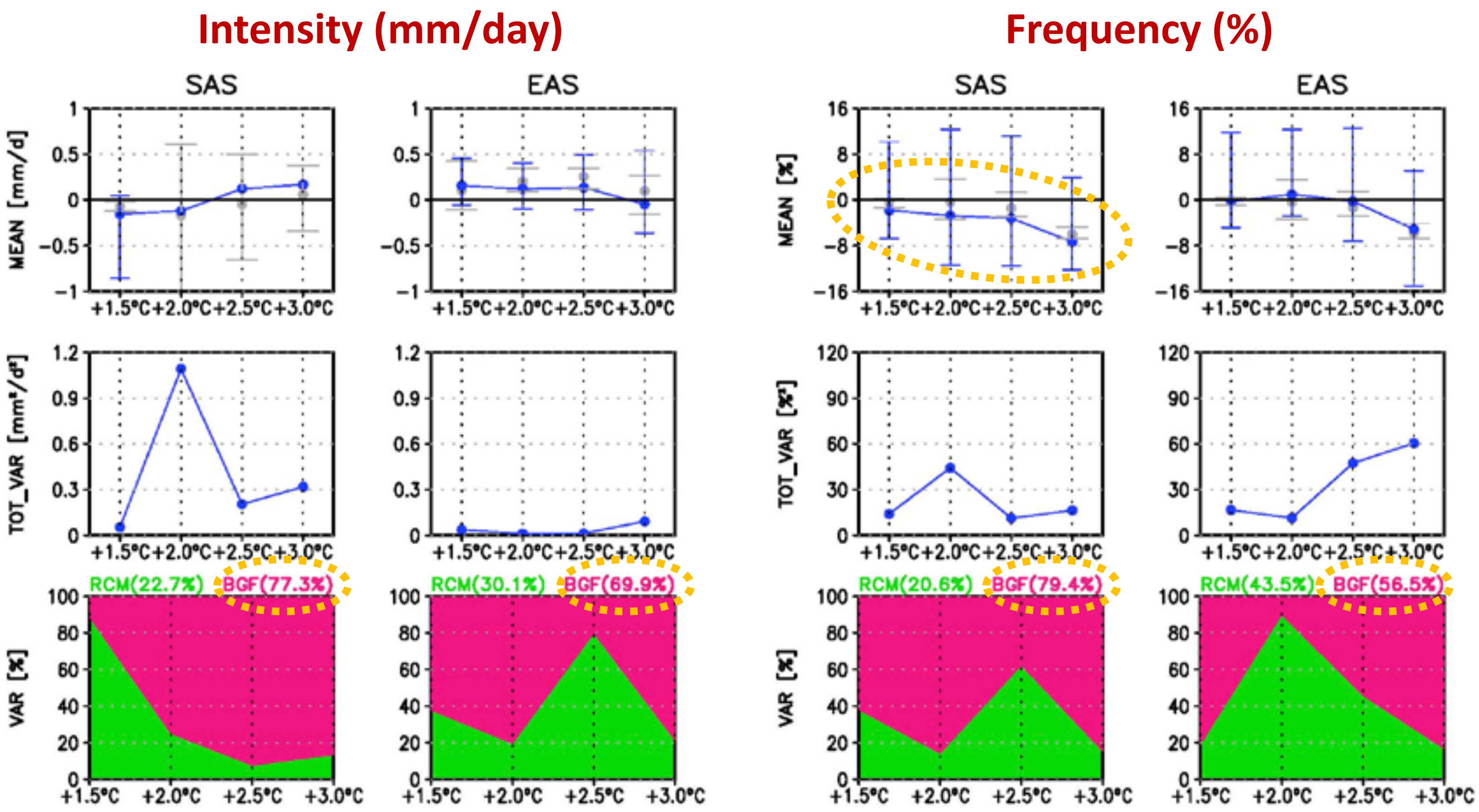



❖ In general, heavy precipitation intensity and frequency increases
❖ Relatively larger contributions from BGF to projection uncertainties

Result

- **Moderate precipitation change**

**Blue line : RCM-MME**
**Grey dots : BGF-MME**

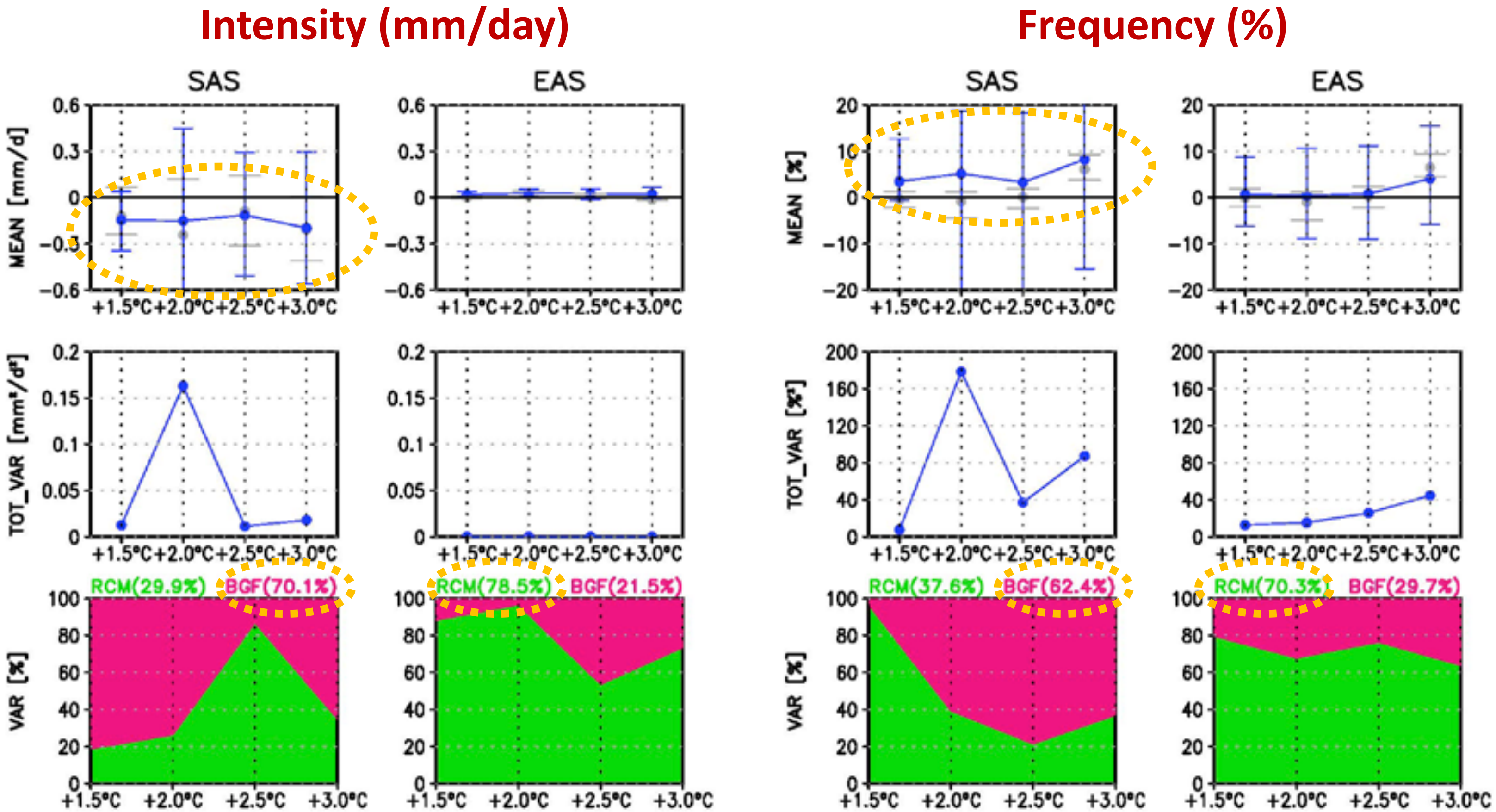



❖ Moderate precipitation frequency over SAS decrease gradually
❖ Relatively larger contributions from BGF to projection uncertainties

# Result

- **Light precipitation change**

Blue line : RCM-MME
Grey dots : BGF-MME




❖ Light precipitation weakened but more frequently happen in SAS
❖ Light precipitation frequency changes are opposite to moderate cases
❖ Larger total uncertainty over SAS, and BGF (RCM) contributes more SAS (EAS).

# Summary

## ① Intensity

- ✓ Extreme and heavy precipitation intensity increase (both GCM & RCM projections)
- ✓ Additional half a degree warming make more intensified extreme events.

## ② Frequency

- ✓ Extreme precipitation frequency increase (both GCM & RCM projection)
- ✓ Additional half a degree warming make more frequent extreme events.

## ③ Uncertainty (Future projection variance)

- ✓ In most cases, South Asia future projection have more uncertainty than East Asia
- ✓ For moderate and heavy precipitation, boundary GCM forcing (BGF) have larger contributions than RCMs.

# Thank you for listening

Q&A

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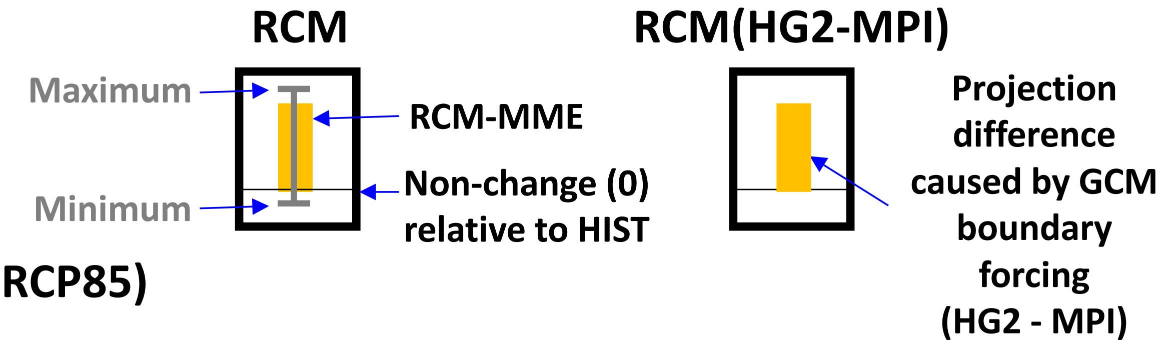
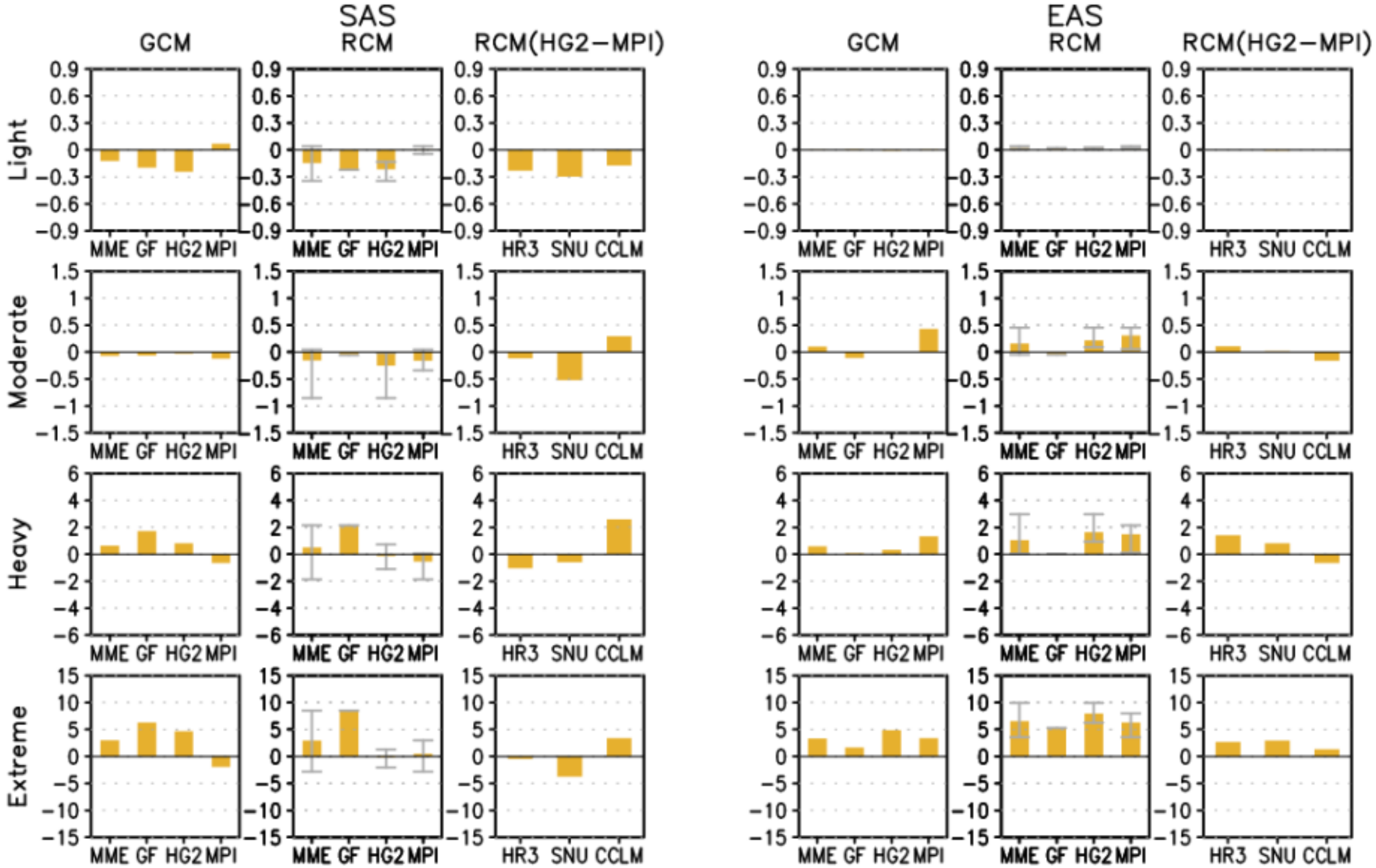
# Supplementary

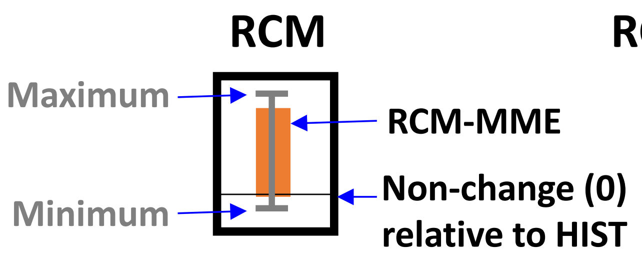


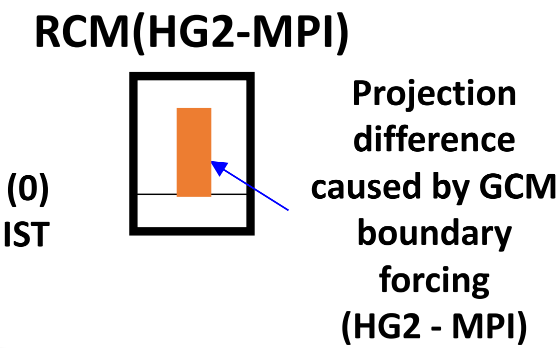

**+1.5°C Worlds (around 2030s under RCP85)**



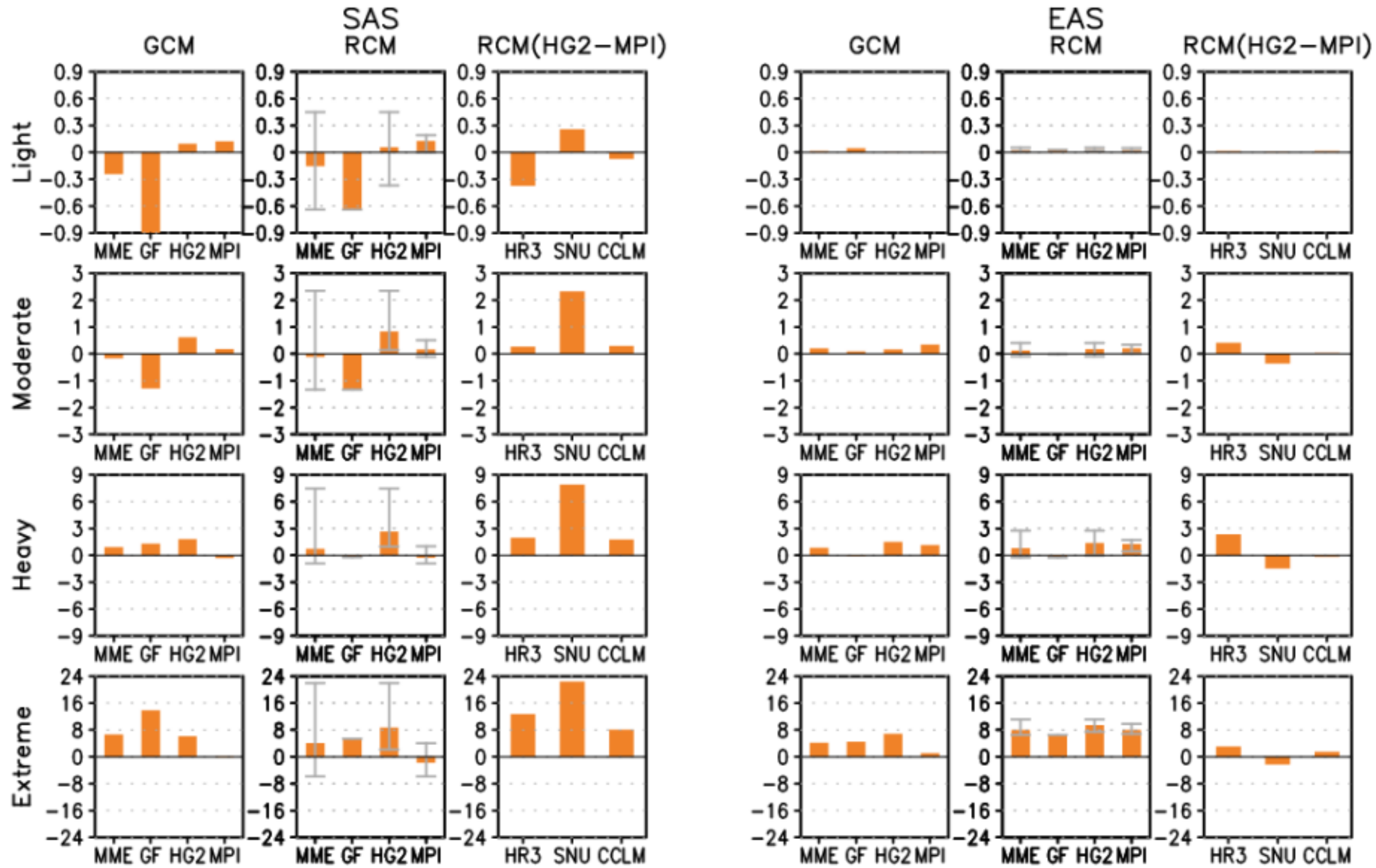

- ❖ In general, GCM & RCM have more uncertainties over SAS regions (pos/neg)
- ❖ Heavy and extreme precipitation strengthened over EAS regions
- ❖ RCMs project different intensities, depending on type of boundary forcing

# Supplementary



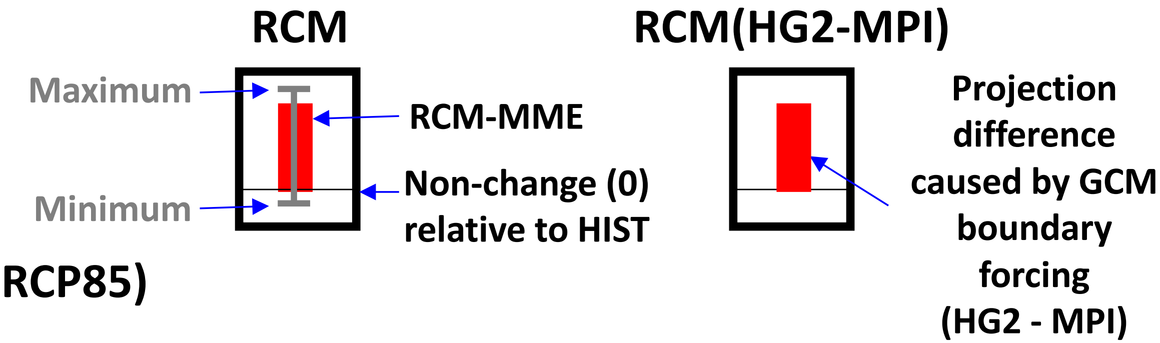




**+2.0°C Worlds (around 2040s under RCP85)**

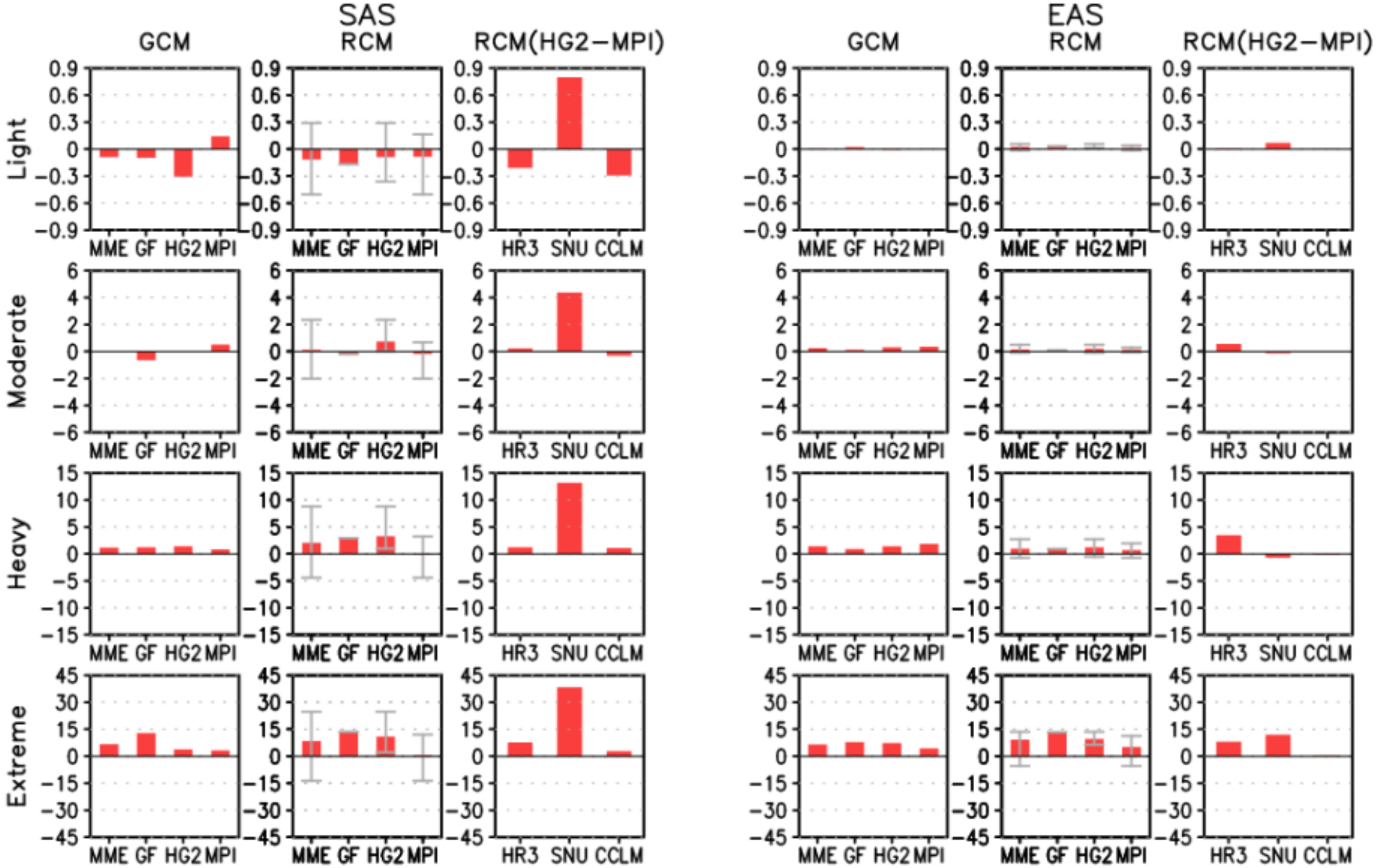



- ❖ Except for extreme, RCMs' projection are similar to boundary forcing GCM
- ❖ Boundary forcing impacts on projection is much larger for SAS than EAS.

# Supplementary

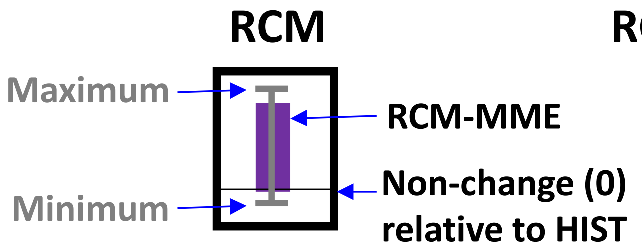


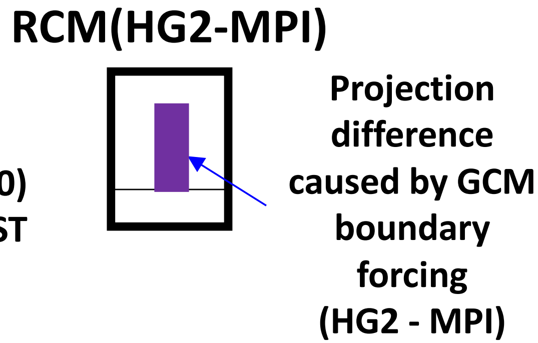

**+2.5°C Worlds (around 2050s under RCP85)**



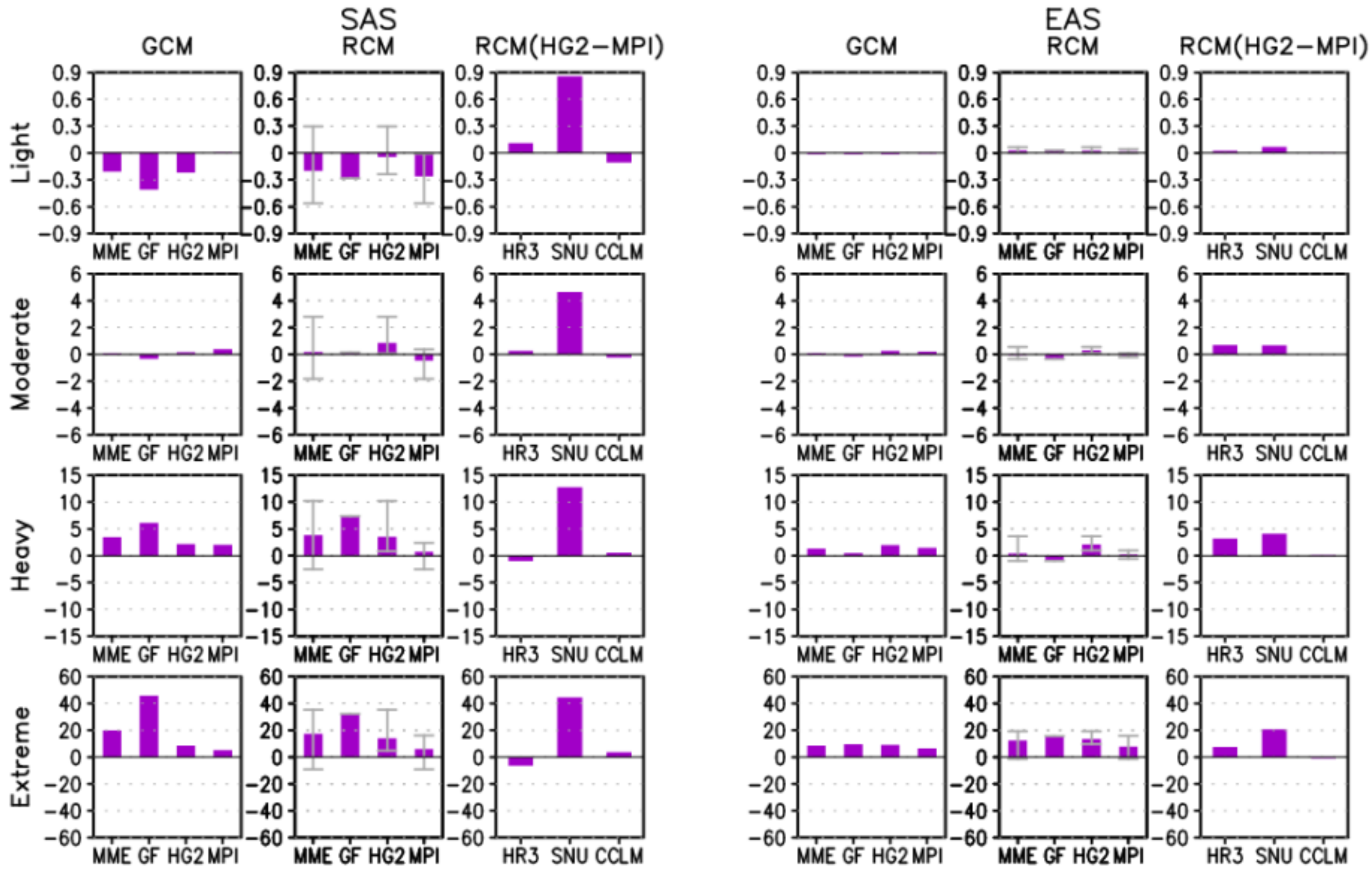

- ❖ In general, weakened or not much changes for light and moderate PR in MME sense
- ❖ GCMs and RCMs agree on intensification of heavy and extreme precipitation as global temperatures rises

# Supplementary




**+3.0°C Worlds (around 2060s-2070s under RCP85)**




- ❖ The most sever extreme intensities are projected by GCMs and RCMs in MME sense
- ❖ SNU-MM5 are much sensitive to boundary GCM, while
  CCLM are less sensitive to boundary GCM in most cases.