Future Projection of Indian Summer Monsoon Variability under a High emission Climate Change Scenario using CMIP5 Climate Models



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Indian Summer Monsoon Variability

- The Indian summer monsoon (ISM) rainfall during June to September (JJAS) contributes ~75% of the annual rainfall over Indian subcontinent.

- Most dominant modes of ISM variability:
  - Interannual (strong and weak monsoon).
  - Intraseasonal (active/break cycles).

- Indian subcontinent is one of the most susceptible regions of large scale hydro-climatic extremes: droughts, floods and extreme events.

- Understanding and predicting the extreme behaviour of ISM variability is highly essential.

Future: ISM in a changing climate

- ISM is highly sensitive to global warming, and recent increase in anthropogenic Greenhouse gas (GHG) emissions could further amplify its extreme behavior.

- Understanding how ISM will change under anthropogenic warming remains a great challenge.

- Climate models could be useful tools for future projection.

- Model projections on how extreme ISM variability will change GHG-induced warmer climate remains elusive.

- CMIP5 multi-model data archive gives an opportunity to evaluate and estimate future ISM under warmer climate.

Objectives of the study

- To evaluate the fidelity of CMIP5 models in simulating the basic features of ISM variability of the present climate.

- To estimate the potential impact of enhanced anthropogenic GHG-induced warming on the possible future changes in ISM variability.

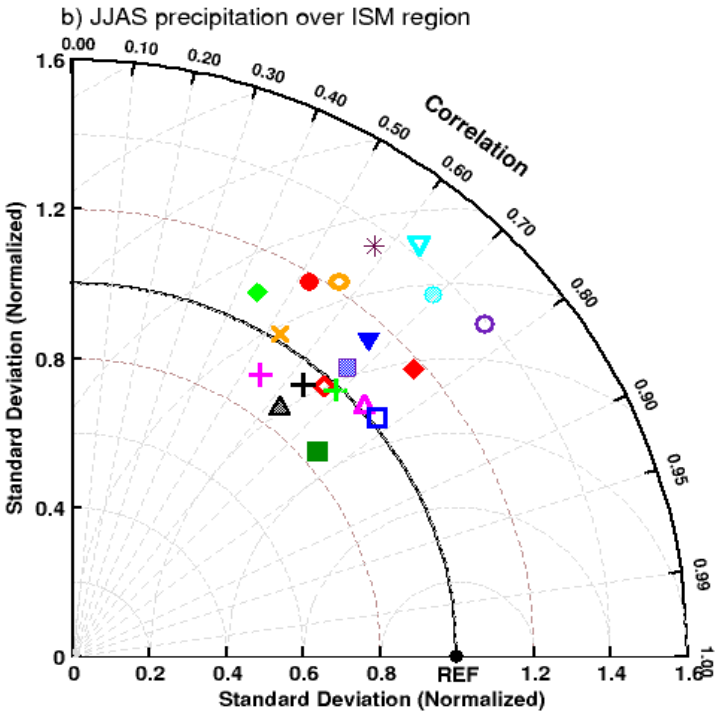
CMIP5 multi-model data archive

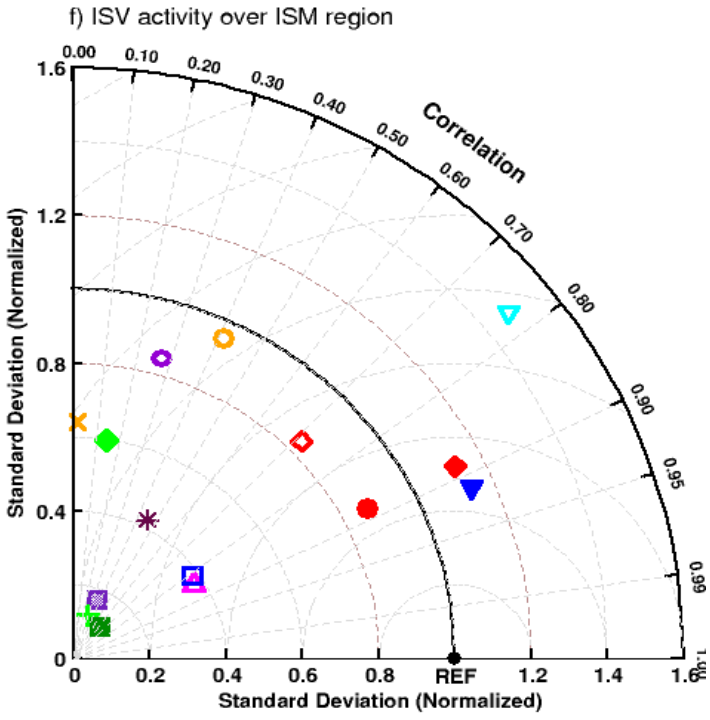
The historical (1951-1999) and future (2051-2099) simulations under the strongest Representative Concentration Pathway (RCP8.5) have been analyzed for this purpose.

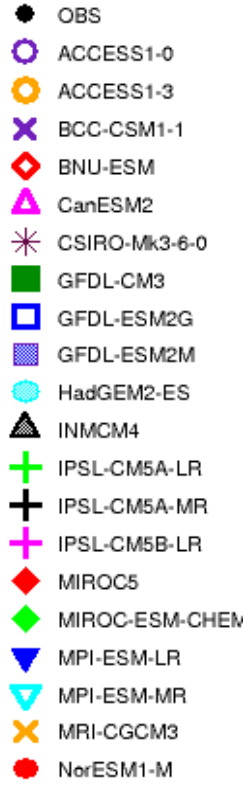
Selection of Most Reliable CMIP5 Models using Taylor Diagrams

Representation of basic monsoon characteristics:

- JJAS precipitation over IND region
- JJAS precipitation over ISM region
- JJAS std. precipitation over ISM region
- Seasonal Cycle over IND region
- Seasonal migration over Indian longitudes
- ISV activity over ISM region







Sharmila et al. 2015

Table Model performance criteria used to select better CMIP5 models in simulating basic characteristics of Indian summer monsoon for this study.

CMIP5 Models	Rainfall simulation (Historical) Criteria : CC>0.5 and 0.8<NSD>1.2						Total (out of 6)
	JJAS (IND)	JJAS (ISM)	JJAS std dev.	Seasonal cycle	Seasonal migration	ISO Variance	
ACCESS1-0	-	-	+	+	-	-	2
ACCESS1-3	-	-	+	-	-	-	1
BCC-CSM1-1	-	-	-	-	-	-	0
BNU-ESM	**+**	**+**	**-**	**+**	**+**	**+**	**5**
CanESM2	+	+	-	-	+	-	3
CSIRO-Mk3-6-0	-	-	+	-	-	-	1
GFDL-CM3	+	+	-	+	-	-	3
GFDL-ESM2G	+	+	-	+	+	-	4
GFDL-ESM2M	-	+	-	+	+	-	3
HadGEM2-ES	-	-	+	-	-	-	1
INMCM4	+	+	-	+	+	-	4
IPSL-CM5A-LR	-	+	-	-	+	-	2
IPSL-CM5A-MR	-	+	-	-	+	-	2
IPSL-CM5B-LR	-	+	-	-	+	-	2
MIROC5	**-**	**+**	**+**	**+**	**+**	**+**	**5**
MIROC-ESM-CHEM	-	-	-	+	+	-	2
MPI-ESM-LR	**-**	**+**	**+**	**+**	**+**	**+**	**5**
MPI-ESM-MR	-	+	-	+	-	-	2
MRI-CGCM3	-	-	-	+	-	-	1
NorESM1-M	**-**	**+**	**+**	**+**	**+**	**+**	**5**

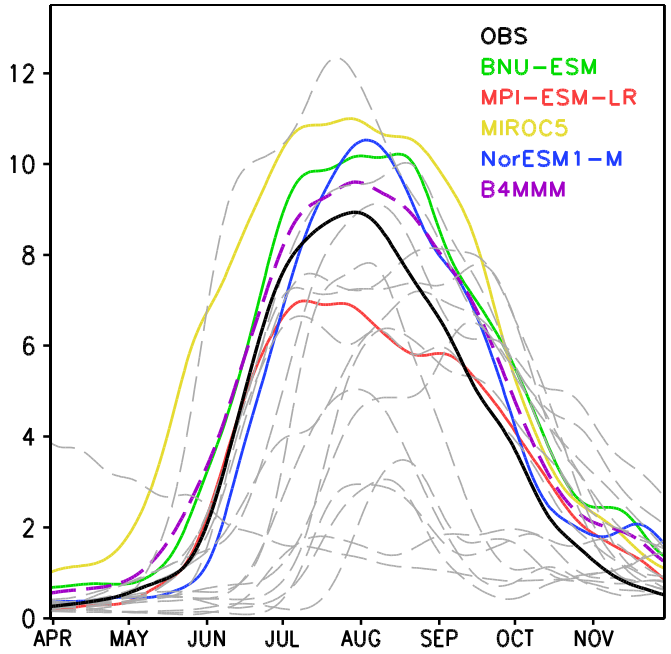
Best Models

BNU-ESM MPI-ESM-LR

MIROC5 NorESM1-M

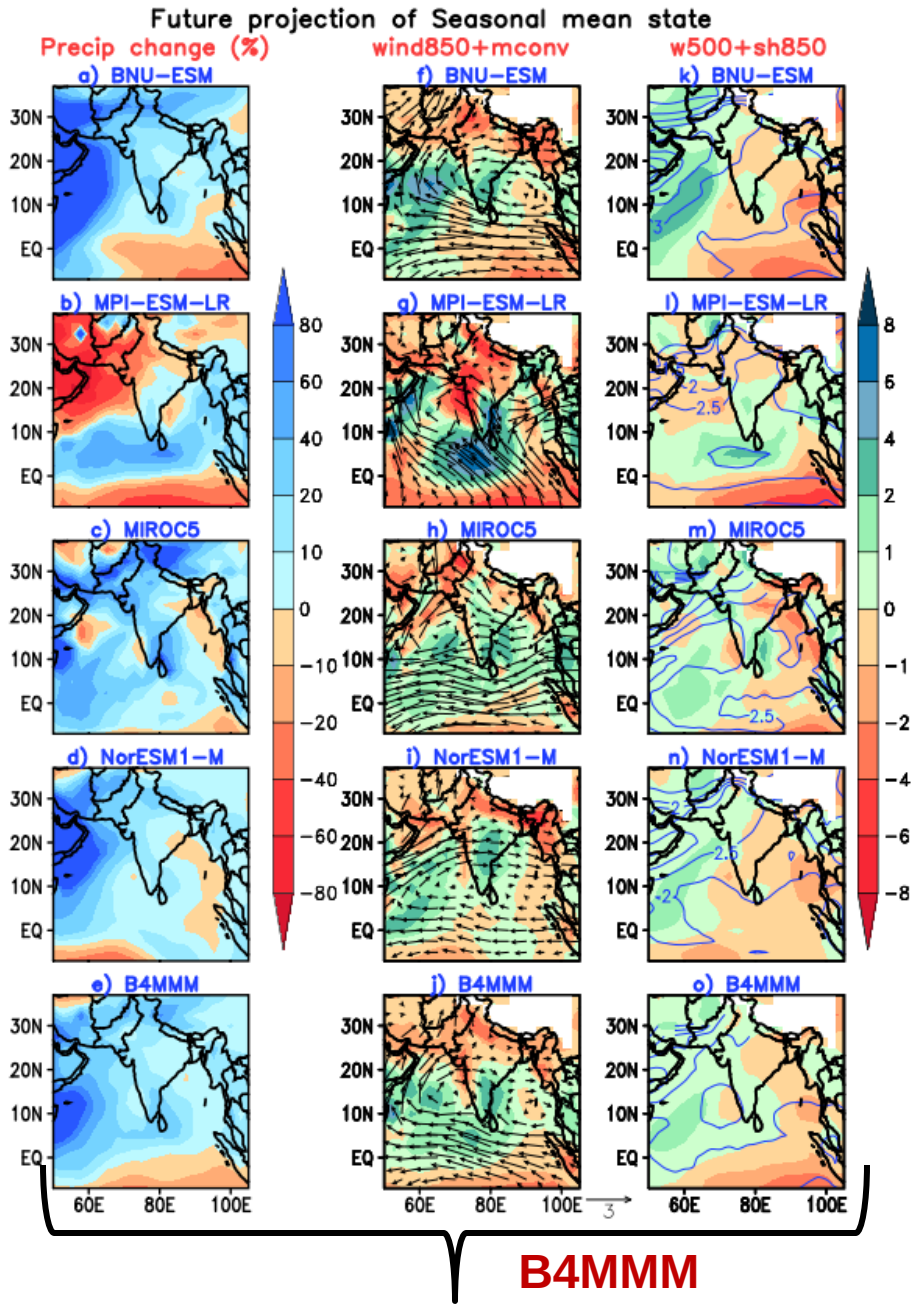
Best 4 multi-model mean

B4MMM



Seasonal cycle

Projected Change: Seasonal Mean



- B4MMM projects 10-25% relative increase in mean JJAS rainfall over Indian subcontinent.
- Primarily driven by the intensified low level moisture convergence due to enhancement of atmospheric moisture content.
- While the dynamical processes may tend to suppress the increase in rainfall over south-eastern zone

Projected Change : All India Rainfall

Table Mean *all-India summer monsoon rainfall (ISMR) and interannual standard deviation (SD) for selected models.*

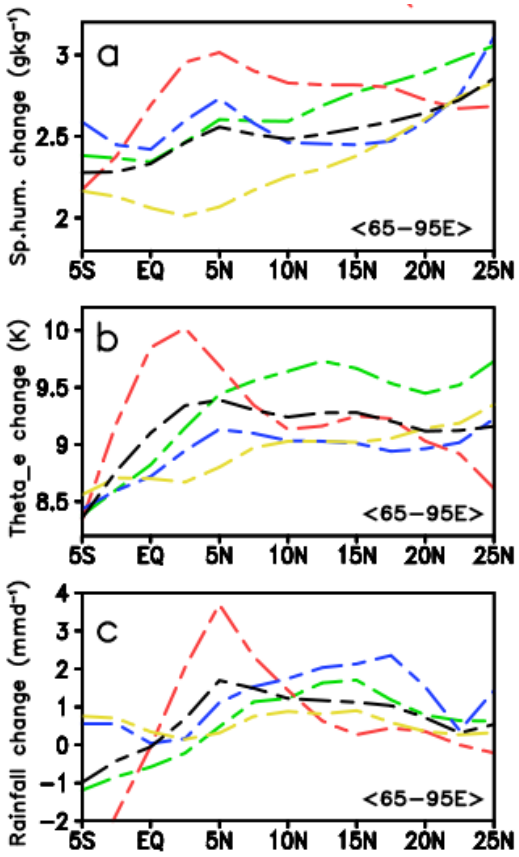
Model	Historical (1951-1999)		RCP8.5 (2051-2099)	
	Mean	SD	Mean	SD
Observed	**856.14**	**85.35**	-	-
BNU-ESM	810.73	70.86	938.54	82.85
MPI-ESM-LR	642.33	59.86	656.69	78.68
MIROC5	1013.24	85.82	1149.04	82.23
NorESM1-M	882.60	89.03	971.85	91.73
B4MMM	**837.23**	**76.39**	**929.03** ↑	**83.87** ↑

- B4MMM well agrees with OBS in simulating present climate ISMR and its interannual standard deviation (SD).

- Future Projection under RCP8.5 scenario suggests increased ISMR and SD in future climate.

Contributing Factors: Dynamical & Thermodynamical

Positive Effect



Anthropogenic Global Warming

↓

Increase in Moisture

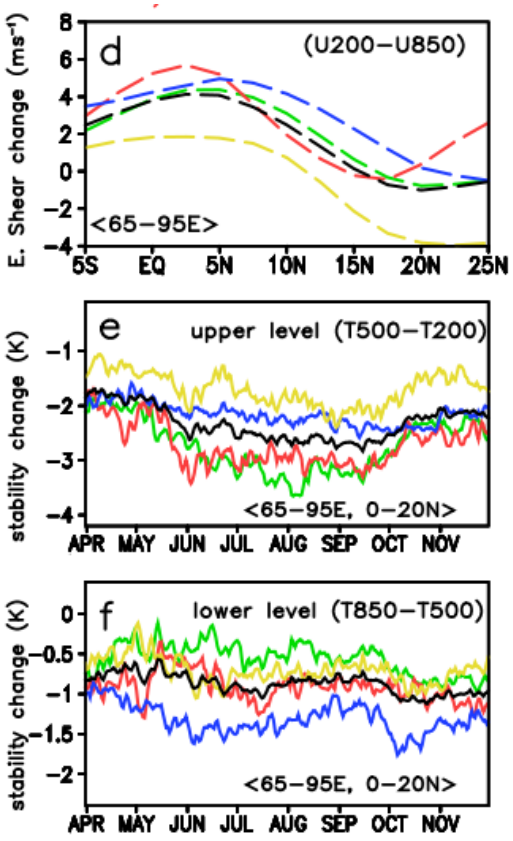
↓

Increase in instability

↓

Increase in monsoon rainfall

Opposing Effect



Anthropogenic Global Warming

↓

Gradual reduction of dry static stability of atmospheric column

↓

Weakening of Vertical Easterly Shear

↓

Increased rainfall offset by weakening of large scale circulation

BNU–ESM
MPI–ESM–LR
MIROC5
NorESM1–M
B4MMM

- The rainfall change is not large enough compared with the increase in thermodynamical conditions over Indian region.

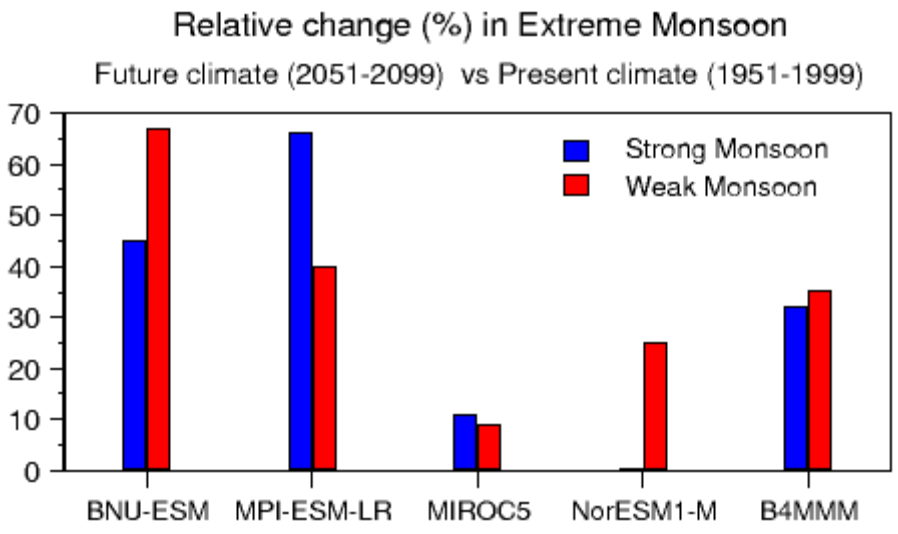
Relationship: Rainfall & Dynamical Indices

Table Correlation between ISM rainfall Index & dynamical indices and its future projection under RCP8.5 scenario

Experiment	Model	WY Index	WF Index	MH Index
Observed (1951-1999)	-	**0.53**	**0.78**	**0.68**
Historical (1951-1999)	BNU-ESM	0.29	0.72	0.49
	MPI-ESM-LR	0.41	0.64	0.61
	MIROC5	0.12	0.39	0.67
	NorESM1-M	0.28	0.80	0.68
	B4MMM	**0.28**	**0.65**	**0.61**
Future Projection (RCP8.5) (2051-2099)	BNU-ESM	-0.47	0.52	0.35
	MPI-ESM-LR	0.15	0.74	0.52
	MIROC5	-0.24	0.44	0.36
	NorESM1-M	0.19	0.55	0.48
	B4MMM	**-0.09** ↓	**0.56** ↓	**0.43** ↓

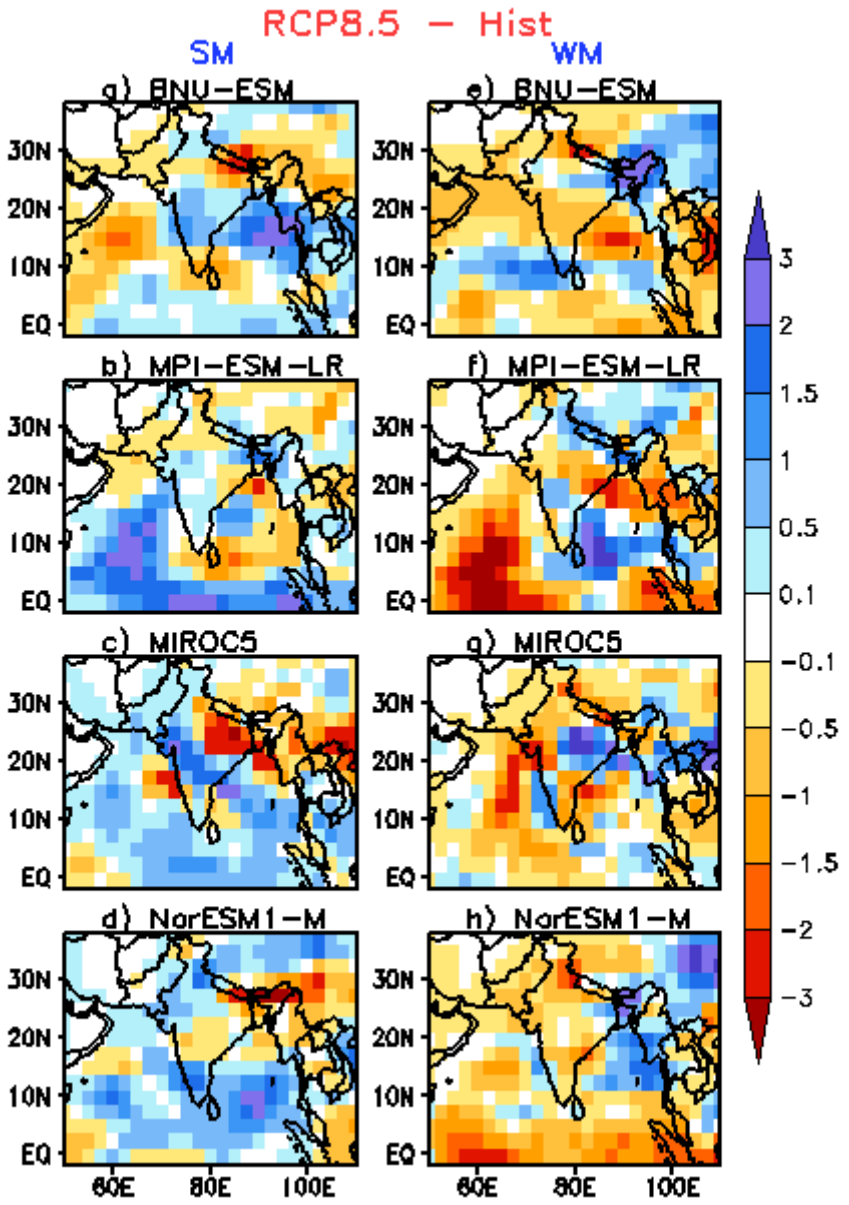
- Future correlations between DMIs and ISM rainfall will be further reduced, following the future weakening of the large scale circulation associated with enhanced ISMR in a warmer climate.

Projected change: Extreme Monsoon

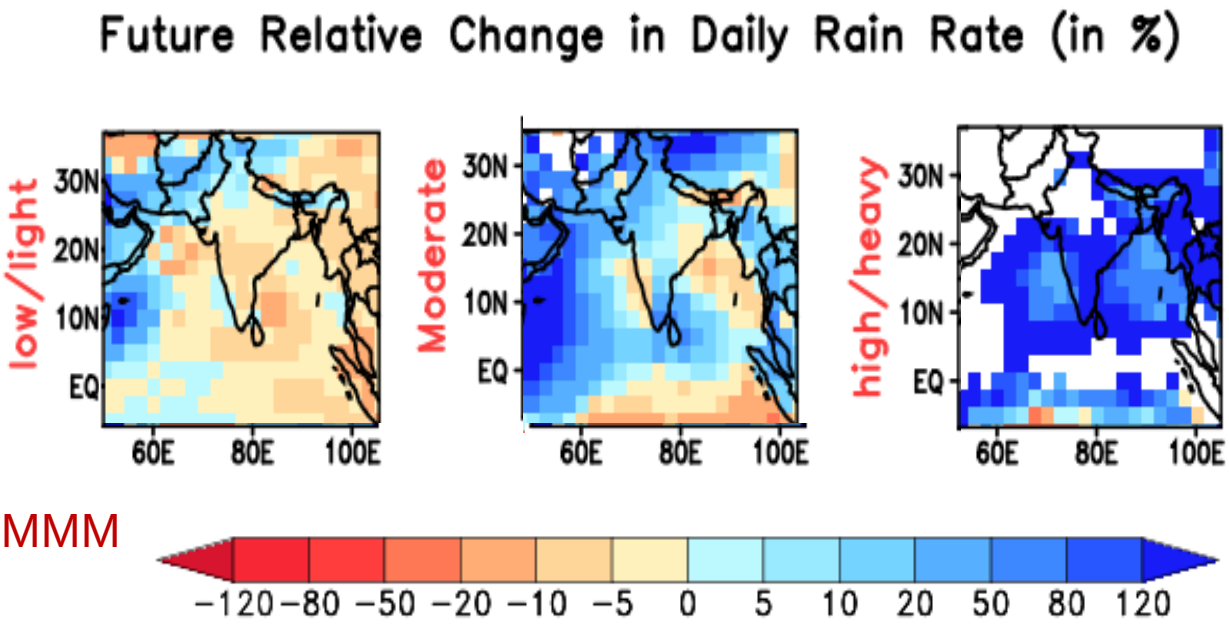


▲ B4MMM projects >30% relative increase in both **SM** and **WM** in future warmer climate.

- JJAS mean SM (WM) could be wetter (drier) over the core monsoon zone, indicating severity of extreme monsoon in future climate ►
- Geographically uncertain among models.



Projected change: Daily timescale



low: <10 mm day^{-1}

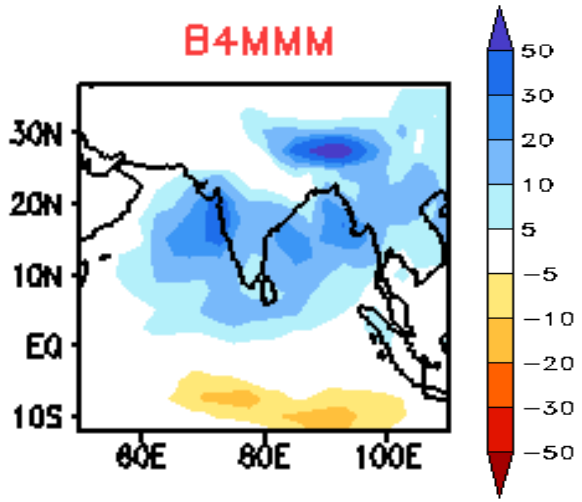
moderate: 10–40 mm day^{-1}

heavy: >40 mm day^{-1}

▲ Probability distribution function (PDF) of daily rainfall at each grid over ISM domain.

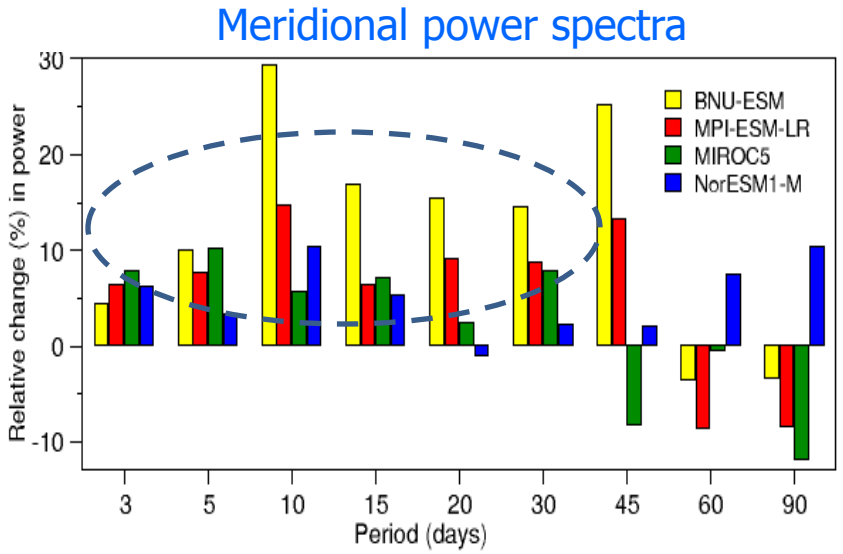
- The daily variability of ISM could be largely associated with a decrease in low-to-moderate rain-rate and increase in heavy rainfall events over Indian land and adjoining oceanic regions, indicating the rising climate-related vulnerability over Indian subcontinent.

Projected change: Intraseasonal



▲ Projected future changes (%) in the intraseasonal activity (ISV) using 10-90 day band-pass filtered daily simulated rainfall under RCP8.5 scenario.

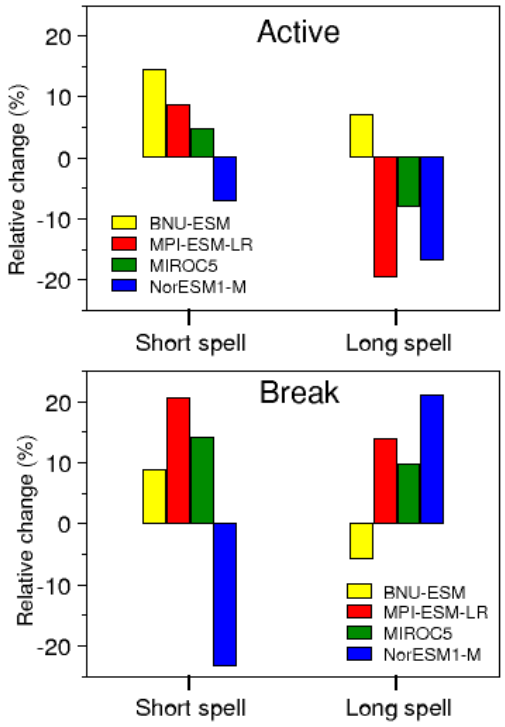
- Future ISV might enhance over IND region
- Large relative increase in ISV activity over adjacent oceanic regions.
- North-south asymmetry in ISV activity over ISM region



▲ Projected relative changes (%) in the meridional power spectra (*northward component*) of daily precipitation averaged over wave-numbers 1-2 over Indian domain.

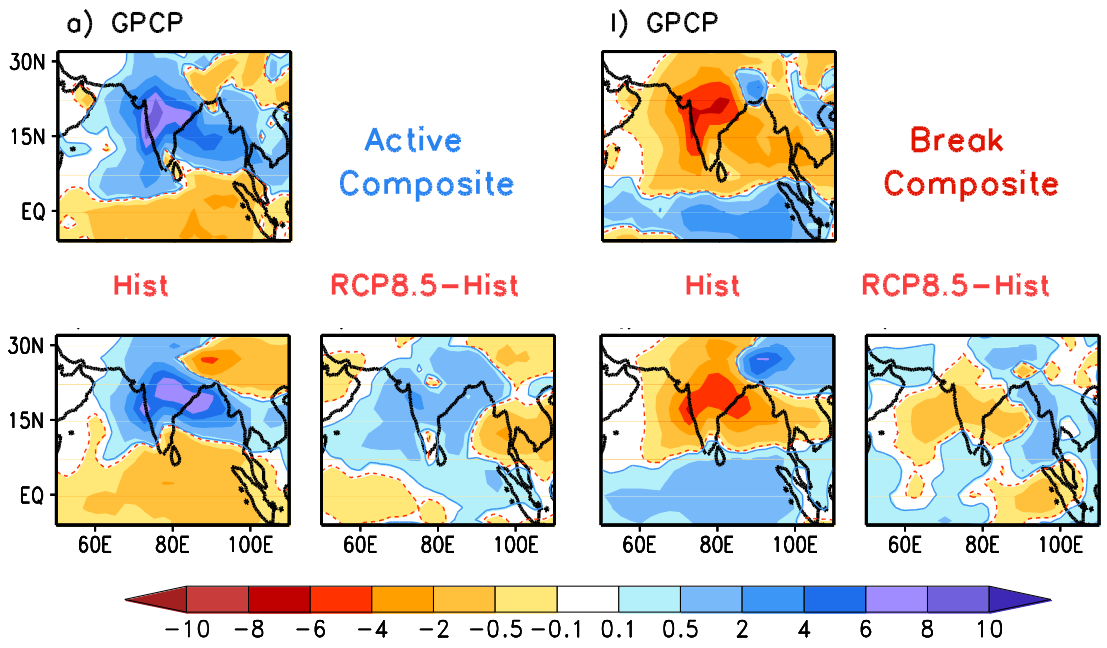
- Relative future enhancement (~10%) higher frequency (below 30 day).
- A possible periodicity shift (from lower to higher frequency) of the dominant ISV modes

Projected change: Active/ Break



Short Spells → 3-4 days

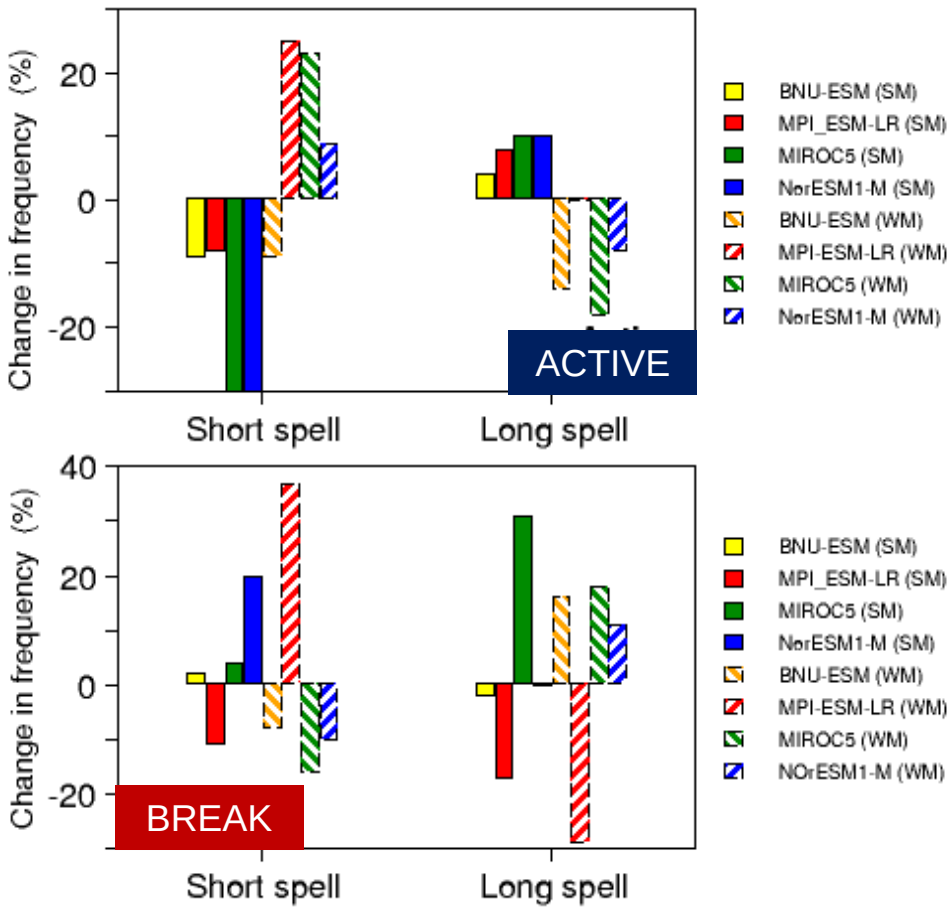
Long spells → > 7days



▲ Active /Break composite of 10-90 day filtered daily precipitation anomalies and projected changes under RCP8.5 for B4MMM

- Relative increase of ~5-15% in short active spells.
- Relative increase of 10-20% in both short and extended breaks
- The precipitation anomalies during active/break episodes could be more intense and regionally extended.

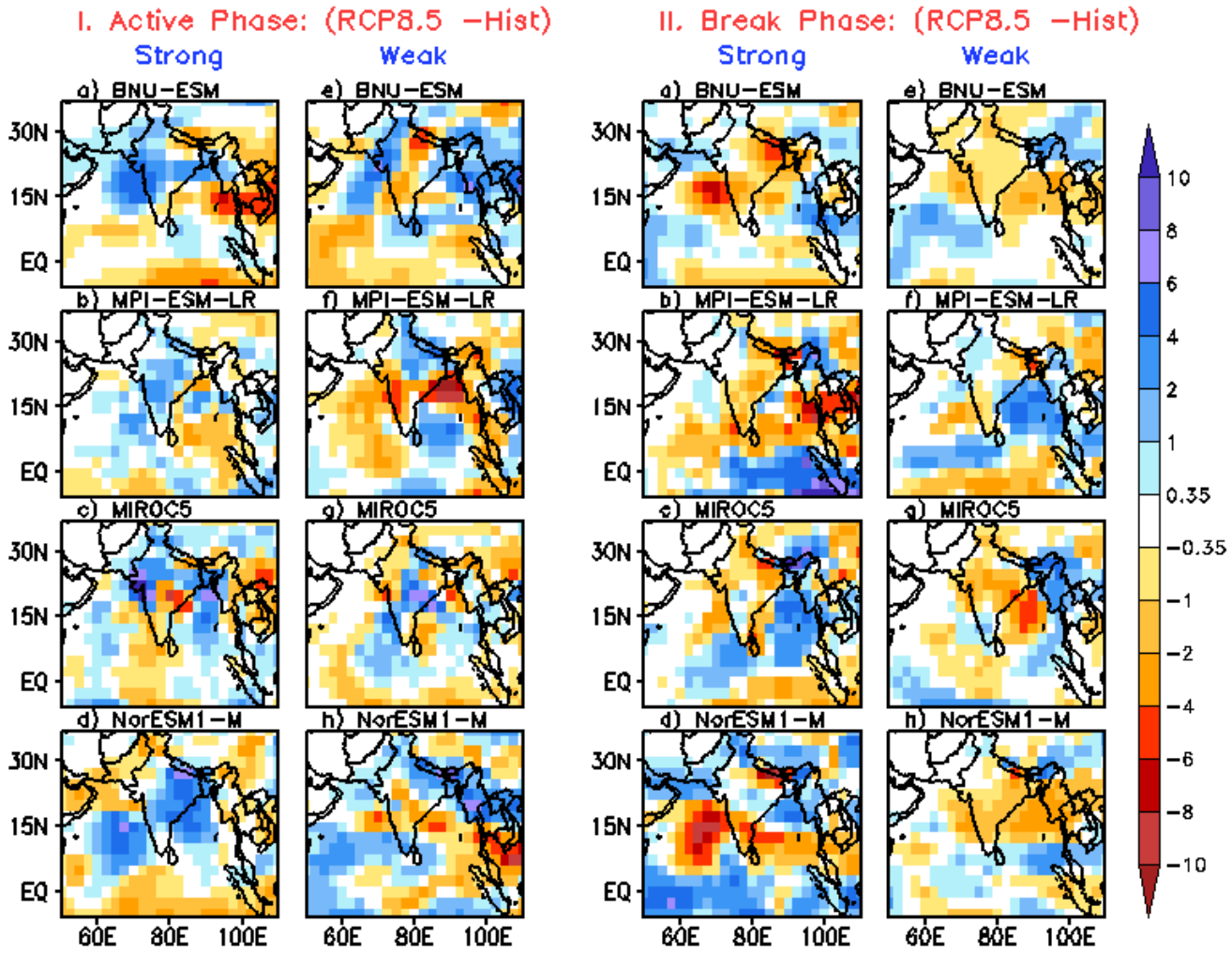
Projection: Active/Break during Extreme Monsoon



▲ Projected changes (%) in the frequency of active-break spells during SM (solid lined bar) and WM (dash lined bar) under RCP8.5

- Longer active spells could be more frequent, while breaks will be fewer and shorter, leading to wetter SM in future.
- In contrast, WM could be drier due to the high propensity of extended breaks and short active spells in response to enhanced GHG
- Risk of increase in severe hydro-climatic conditions over Indian subcontinent in future warmer climate.

Projection: Active/Break during Extreme Monsoon



Projection of ISV during extreme monsoon indicates that SM might be wetter in future due to increase in longer active spells with decreasing break spells whereas WM might be drier with increase in very long breaks and shorter actives in future.

- During extreme monsoon, ISV might be more severe and intense in future climate. However, the projected changes are variable geographically among the selected models and therefore still uncertain.

Concluding Remarks

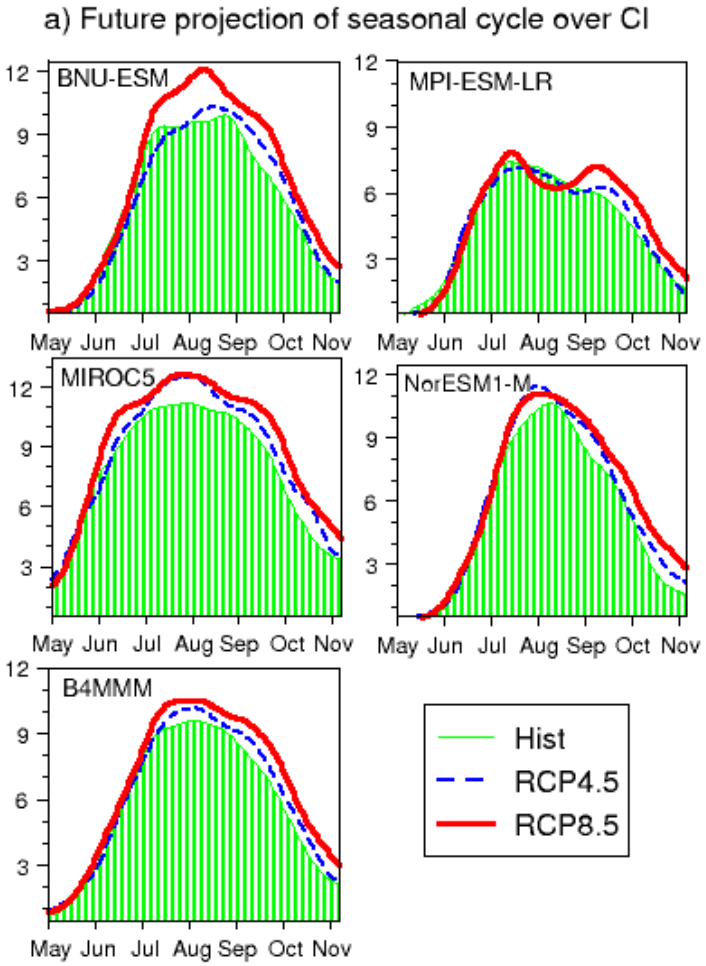
Under GHG-induced warmer climate the CMIP5 models project:

- Substantial change in ISM variability primarily governed by thermodynamic conditions, offset by weakening of large scale circulation.
- Increase in heavy rainfall events (>40mm day^{-1}).
- Increase in severity and frequency of extreme monsoon years.
- Active/Break cycles could be more intense and regionally extended.
- Strong (weak) monsoon could be wetter (drier) in future due to longer active (break) spells. However, the projected changes are geographically variable among the models.
- The results suggest the requisite of profound adaptation measures and better policy making in future.

Sharmila et al. (2015) Global and Planetary Change, 124: 62-78

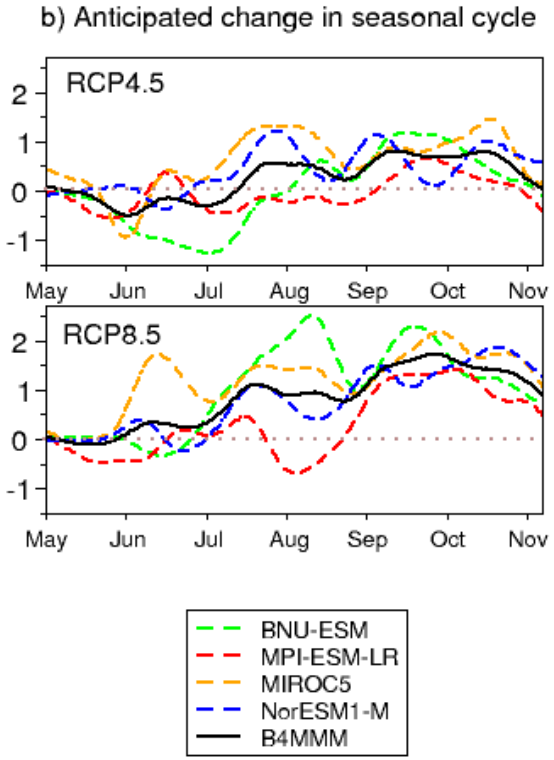
Thank You

Projected Change: Seasonal cycle

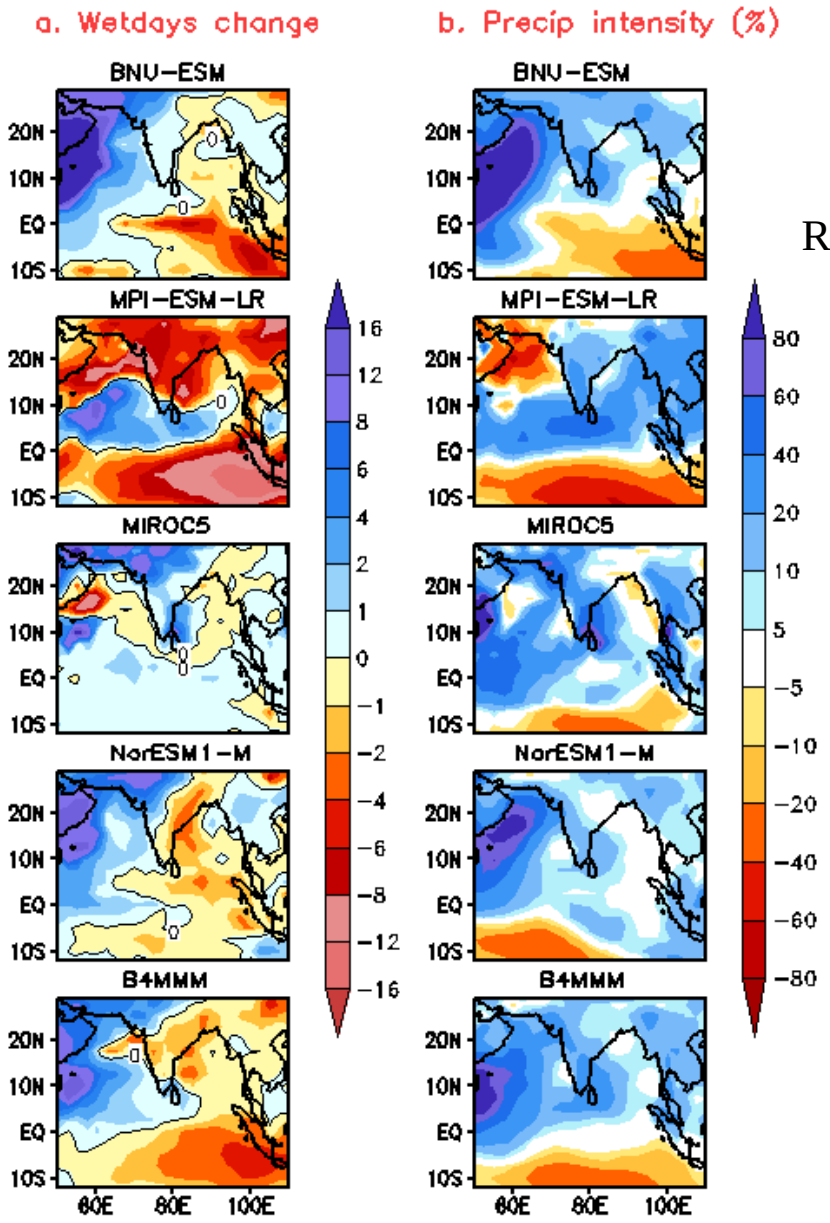


B4MMM suggests that rainfall magnitude is likely to increase in future and the duration of the rainy season may also lengthen due to delayed withdrawal although not much changes in monsoon onset is expected.

Likelihood of future changes in both magnitude and evolution is more robust and consistent among the selected models under RCP8.5 scenario compared to RCP4.5.



Future Projection: Rainfall Intensity

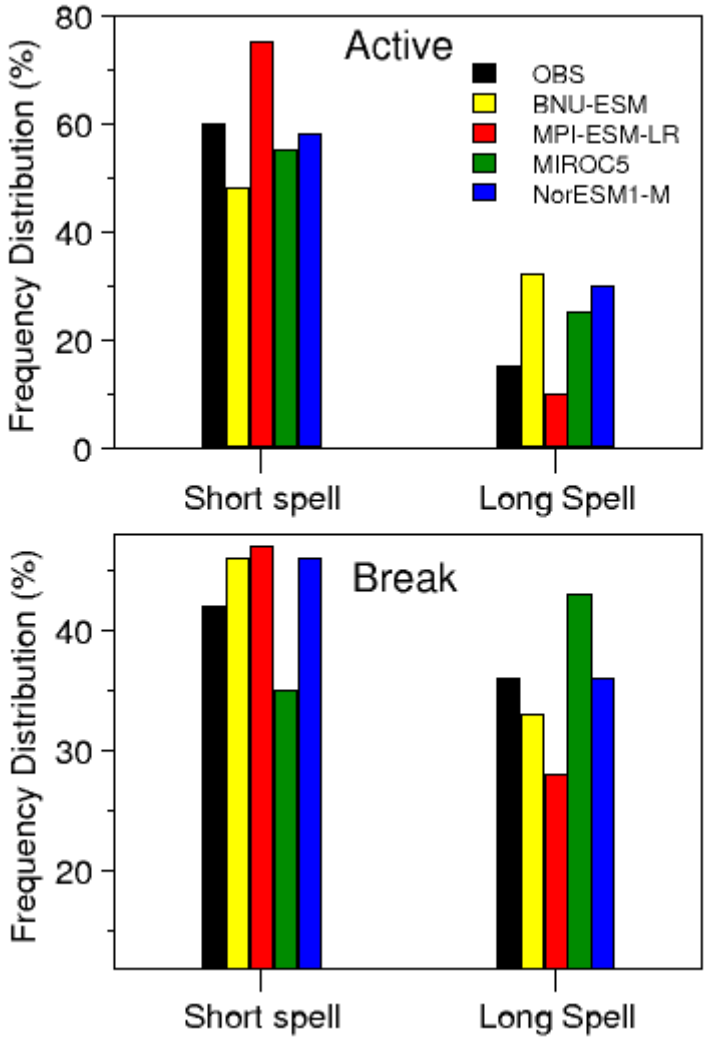


Rainfall exceeds 0.1 mm/day on a given day
→ Wet Day

$$\text{Rainfall Intensity} = \frac{\text{total seasonal rainfall}}{\text{no. of wet days per season at each grid}}$$

- Wet days over Indian region might be reduced with uncertainty among the models
- Positive change in rainfall intensity over IND region
- A large north-south asymmetry in relative change of rainfall intensity is indicated over ISM region

Historical Simulation: Active & Break Spells



- Frequency distribution (in percentage) for active/break spells simulated from historical runs of all selected models are almost comparable with OBS.