Structure, Characteristics and Simulation of Monsoon low-pressure systems in CFSv2 coupled model

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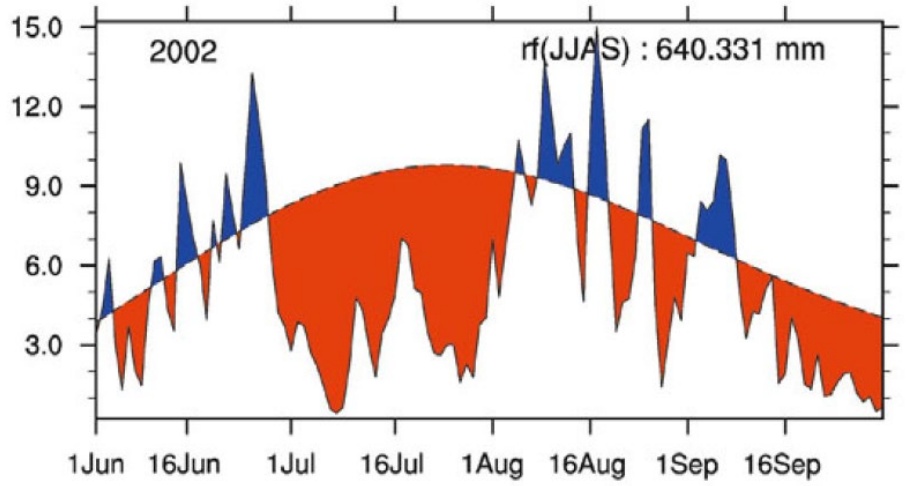
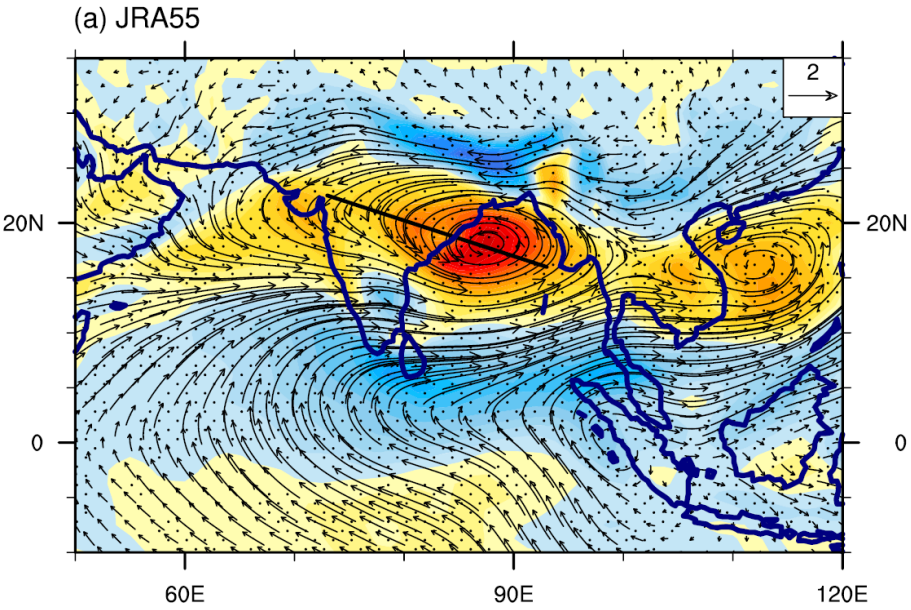
Discussion meeting on Synoptic Systems of the Monsoon

17th December, 2019

Seasonal Mean Monsoon, ISOs and low-pressure systems





The active minus break composite wind anomalies (m s^{-1}, vectors) and the associated vorticity (s^{-1}, shading) at 850 hPa during June through September for JRA55

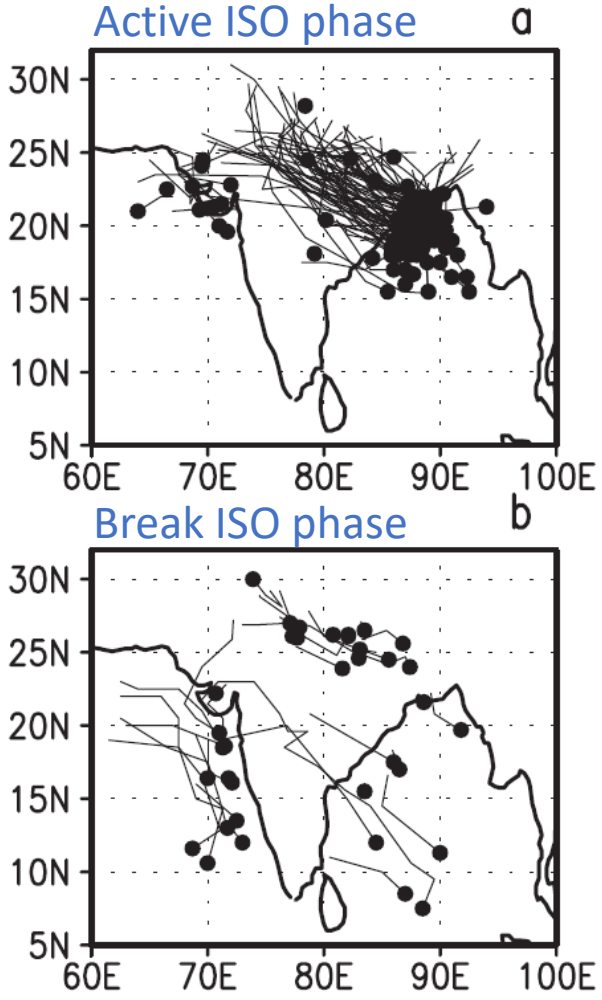


Figure 4. Tracks of LPS for the period 1954–1983 during extreme phases of monsoon ISO. (a) 'Active' ISO phase (MISI > +1) and (b) 'Break' ISO phase (MISI < −1). Dark dots represent the genesis point and their lines show the tracks.

Goswami & Ajayamohan, 2003

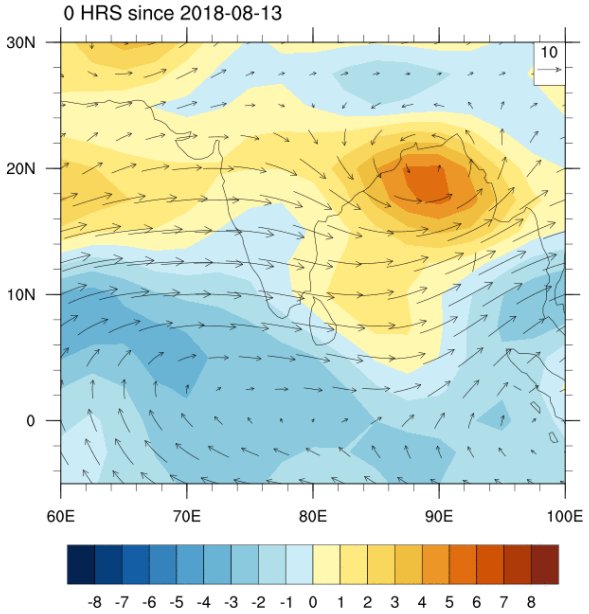
- ISMR is punctuated by series of active and break episodes of enhanced and suppressed rainfall, respectively.
- The modulation of large scale flow by the ISO during an active phase
  - Increases the frequency of occurrence of LPS
  - Spatially clusters the track of the LPS along the monsoon trough.
- The enhancement of shear and low level cyclonic vorticity in this region in the positive phase of the ISO increases the probability of genesis of LPS.
- These LPS bring copious amount of rainfall to Indian sub-continent.

What are monsoon Low Pressure Systems (LPS)?

- Synoptic scale lows and depressions.
- The main rain producing systems over the Indian monsoon region.
- Typical time and length scales of 3–5 days.
- The LPS and non-LPS days composite indicates enhanced rainfall activity over Central India and Western Ghats.

IMD definition for LPS

Low pressure Area (LOPAR)/ well marked LOPAR	Area in the atmosphere in which the pressures are lower than those of the surrounding region at the same level and is represented on a synoptic chart by a system of one closed isobar (wind speed on the surface < 17 Knots (Kts) when the system is at sea or one closed isobar in the radius of 3 Deg. from the centre over land).
Depression	Intense low pressure system represented on a synoptic chart by two or three closed isobars at 2 hPa interval and wind speed from 17 to 27 Kts at sea and two closed isobars in the radius of 3 Deg. from the centre over land.
Deep Depression	Intense low pressure system represented on a synoptic chart by two or three closed isobars at 2 hPa interval and wind speed from 28 to 33 Kts at sea and three to four closed isobars in the radius of 3 Deg. from the centre over land.



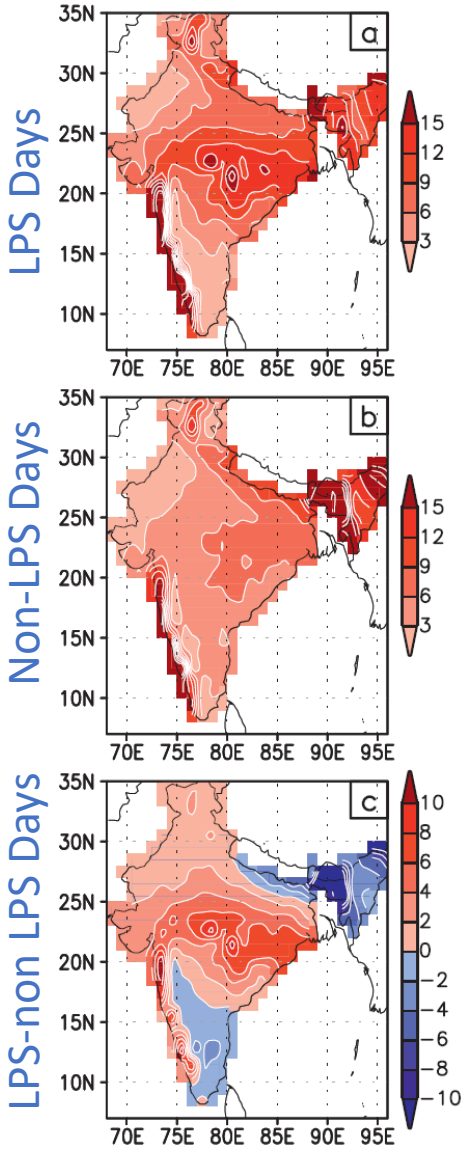


FIG. 3. Composites of daily precipitation (mm day^{-1}) during (a) LPS days, (b) non-LPS days, and (c) difference between LPS-days composite and non-LPS-days composite. The composites are calculated for JJAS 1901–2003.

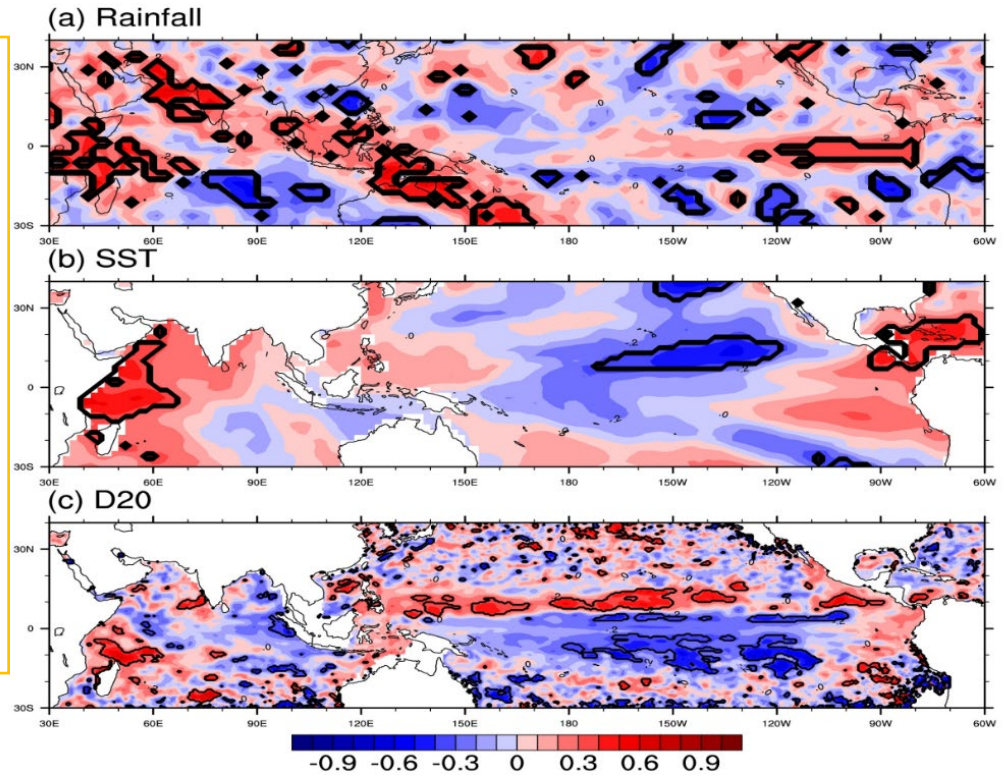
Krishnamurthy & Ajayamohan, 2009

Mechanisms for westward propagation

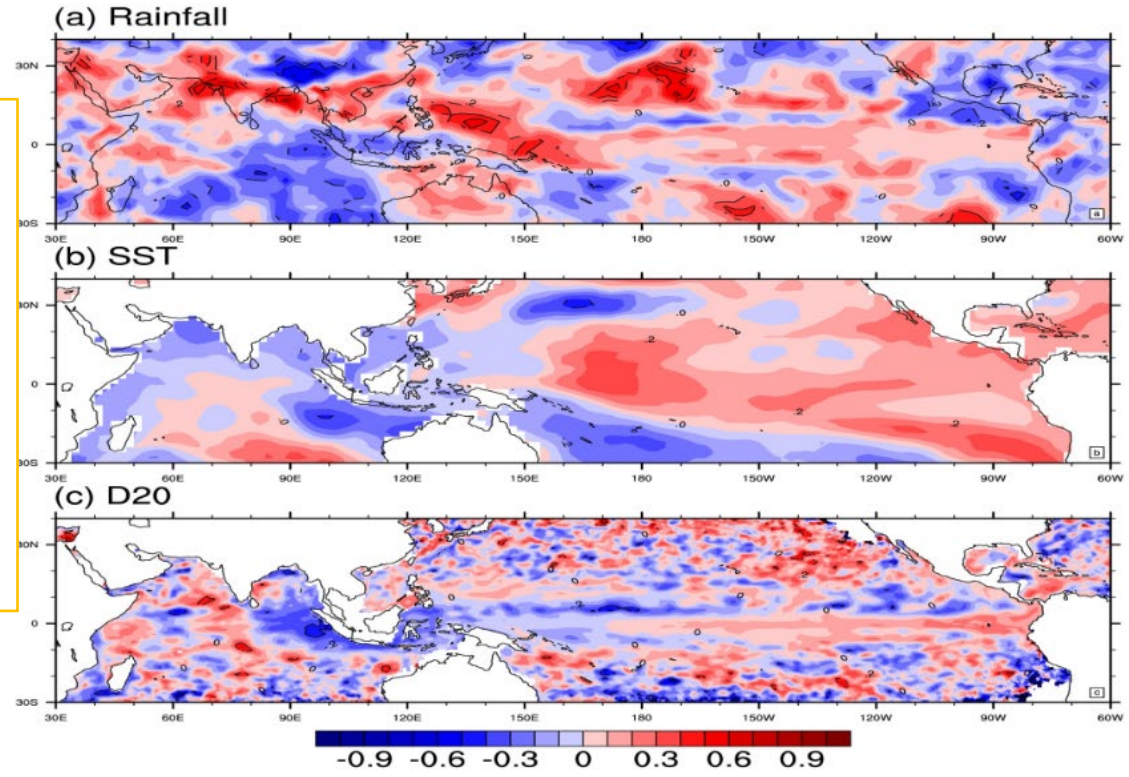
- The MD vortex interacts with westward vertical shear to produce ascent and vortex stretching to the west of the vorticity maximum. This interaction can be represented by an approximate form of the quasi-geostrophic omega equation (e.g. Sutcliffe, 1947; Trenberth, 1978):
- The low-level vortex stretching that has been argued to shift the MD vorticity maximum to the west.
- Rao and Rajamani (1970) showed that quasi-geostrophic lifting could produce ascent west of the peak relative vorticity. They argued that this ascent produces low-level vortex stretching that shifts the vorticity maximum to the west.
- Sanders (1984) showed that the quasi-geostrophic omega equation applied to field program observations predicted ascent west of the vortex centre, with the resulting vortex stretching providing an estimate of the storm's westward motion.
- The occurrence of maximum precipitation and ascent to the west and southwest of the vortex centre has been confirmed by multiple studies (Godbole, 1977; Saha and Chang, 1983; Sikka, 2006).
- Chen et al. (2005) confirmed that vortex stretching in this ascending region provides a positive vorticity tendency west of the vortex centre.
- Boos et al. (2015) show that low-level vortex stretching has a spatial structure inconsistent with the observed propagation and is balanced by other terms in the low-level vorticity budget.
- Instead, monsoon depressions are shown to consist of potential vorticity maxima that have peak amplitude in the middle troposphere and propagate westward by nonlinear, horizontal adiabatic advection.
- The precipitating ascent in monsoon depressions makes a more minor contribution to the total storm motion and primarily acts to maintain the upright structure of the vortex.

LPS, large scale monsoon features & extremes

Correlation b/w LPS days and JJAS mean fields



Correlation b/w extreme rainfall over CI and JJAS mean fields

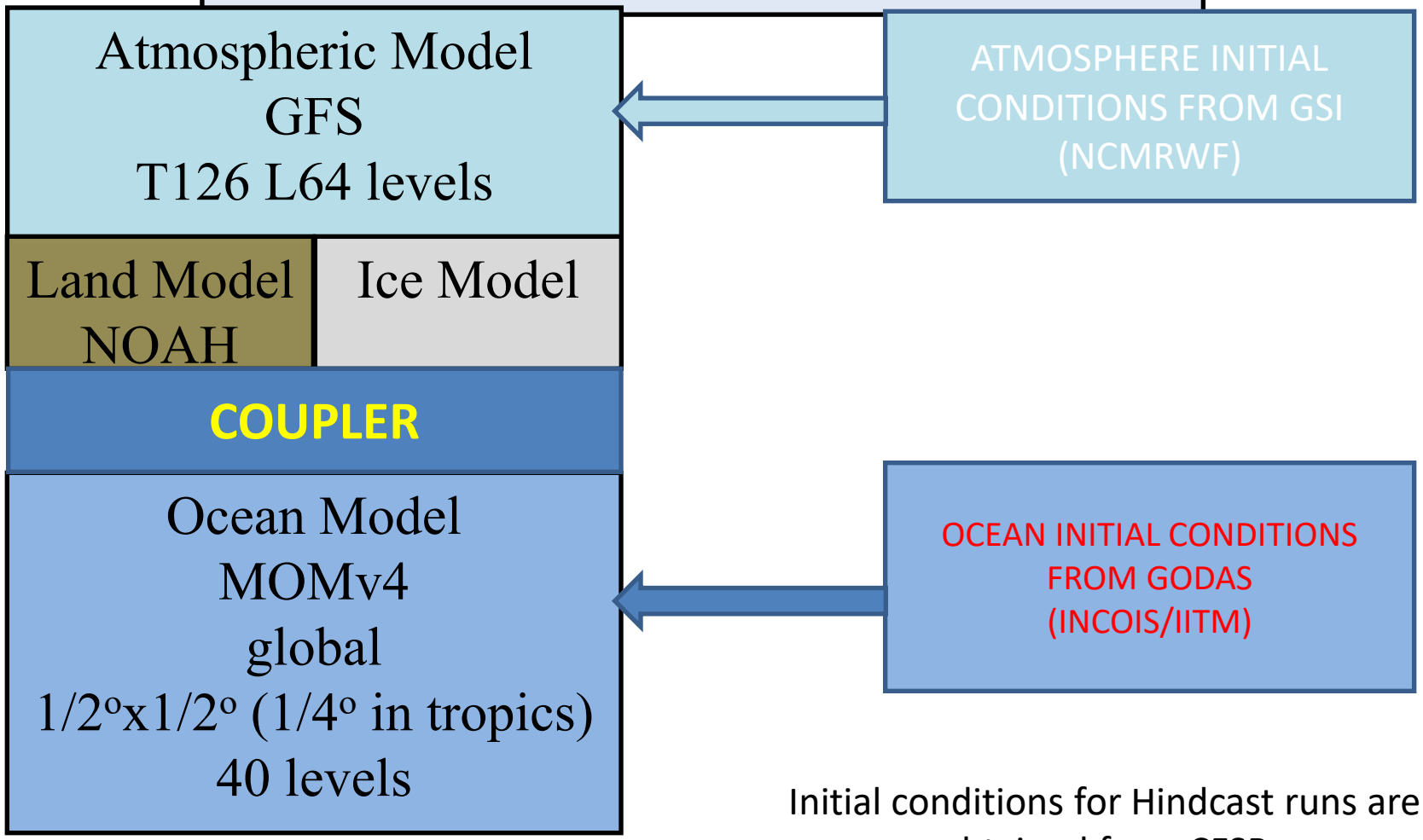


- Number of LPS days is well correlated with
  - Rainfall over India with a tilted band structure, somewhat similar to that seen at ISO time scales
  - SSTs over western IO and central Pacific indicating association with large scale circulation
  - Ocean sub-surface.
- The association of extreme rainfall events over CI is also found to be correlated to the large scale monsoon features.

Unanswered questions…

- To what extent LPS control the amount of seasonal mean monsoon rainfall?
- Studies of synoptic scale systems and the associated biases in a seasonal prediction framework have been lacking.
- Scale interactions between synoptic scale systems and seasonal mean monsoon.
- Effect of mean state in controlling the LPS structure.
- Impact of coupled ocean-atmosphere dynamics tropical basins on LPS structure.

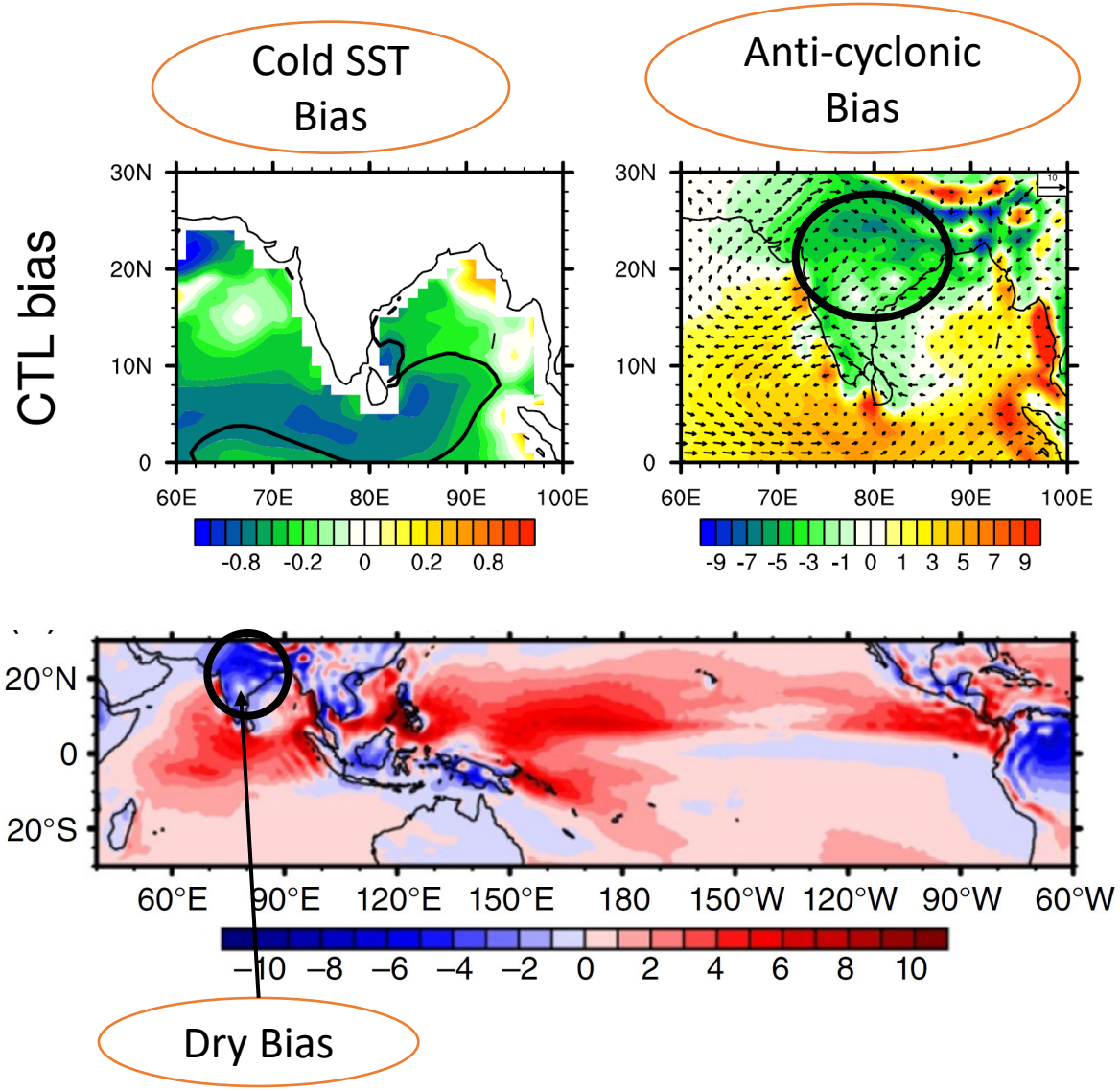
IITM CFS Model
(a.k.a) Monsoon Mission Model
Seasonal Prediction



Initial conditions for Hindcast runs are obtained from CFSR

(Original model is adopted from NCEP)

Seasonal mean biases in CFSv2



- CFSv2 suffers from a systematic cold bias in the Indian Ocean basin.
- An anti-cyclonic mean bias exists over Indian landmass.
- These mean biases in SSTs and circulation translates to a dry bias over Indian landmass.
- **How do these biases effect the simulation of LPS in the model?**

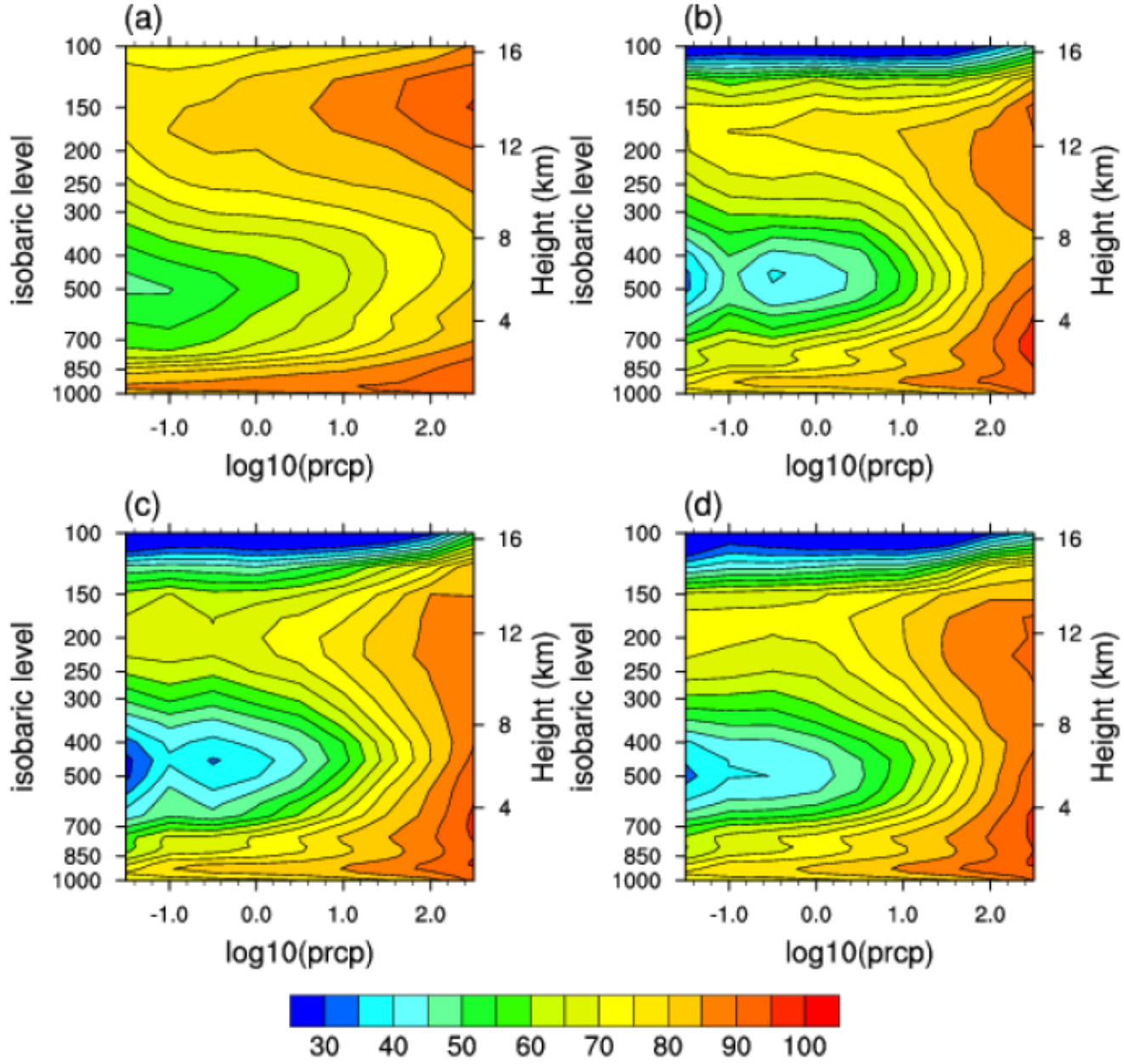
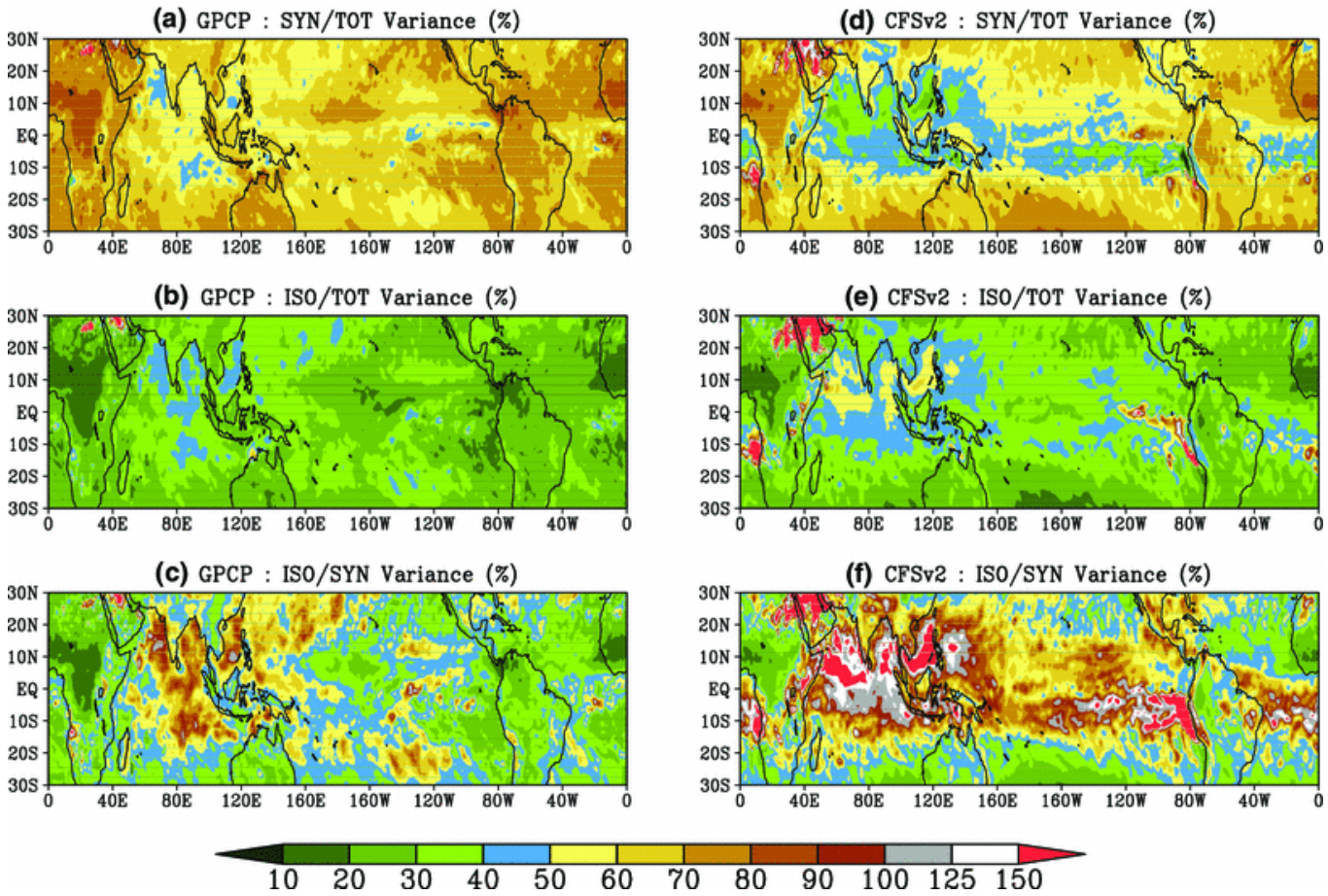


Figure 8. Composite of vertical profile of relative humidity (%, shaded) with respect to precipitation for MISO events for (a) Observation; (b) T62; (c) T126, and (d) T382.

Tirkey et al. 2019

Biases in CFSv2: Under-estimation of synoptic variance



Goswami et al. (2014)

- In the observations, at least 50 % of the total ISV is explained by the synoptic component (Fig. a).
- Large scale (LS, mostly from ISOs) explains a maximum of 40 % mostly within the ISM region.
- CFSv2 underestimates the contribution from SYN (Fig. d) and overestimates the same for the LS component (Fig. e).
- In observations, LS has its maximum over the ISM region where it contributes almost as much as SYN (Fig. c).
- The CFSv2 systematically overestimates the LS contribution relative to SYN over much of the tropics (Fig. f)

Algorithm to track LPS

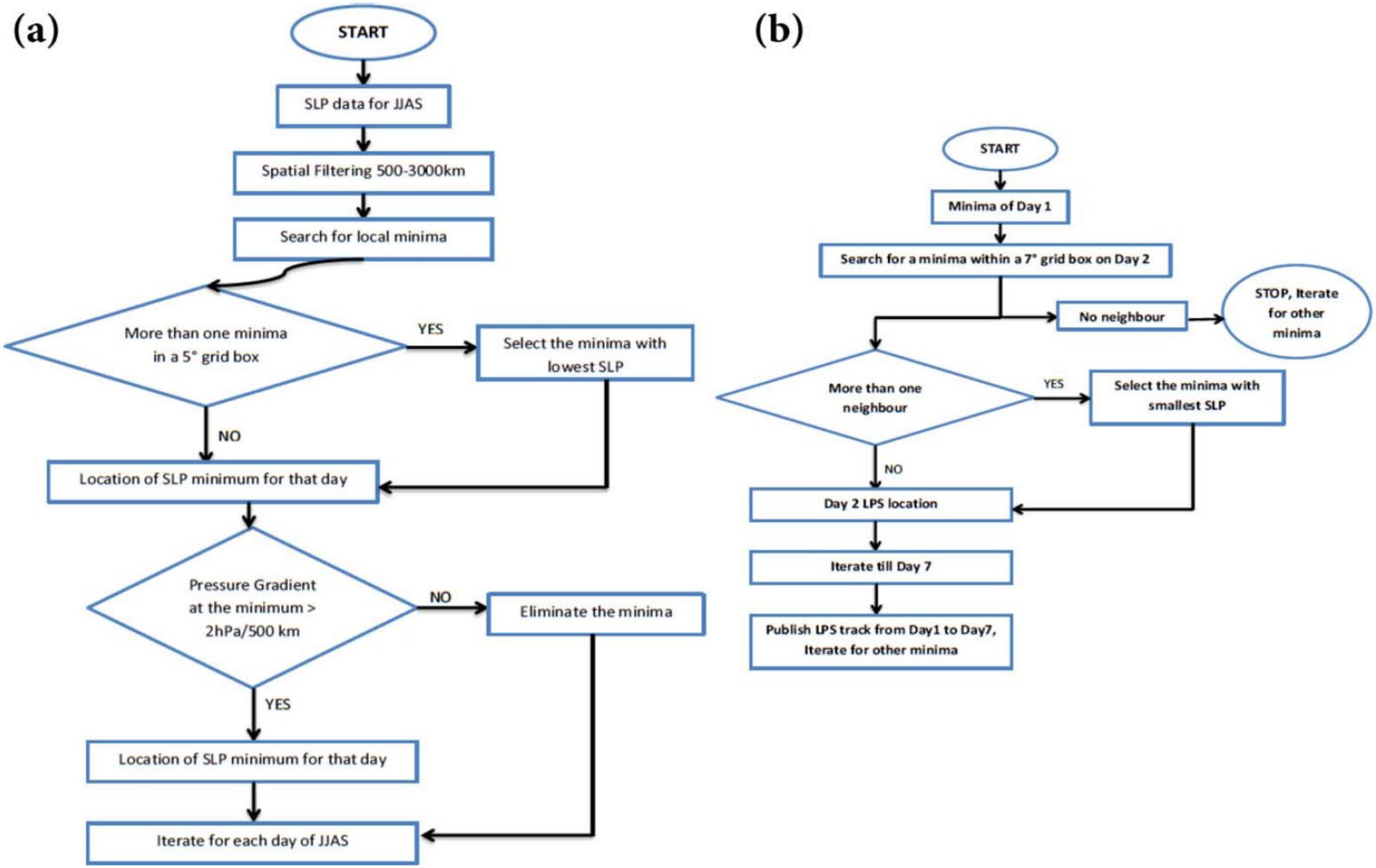
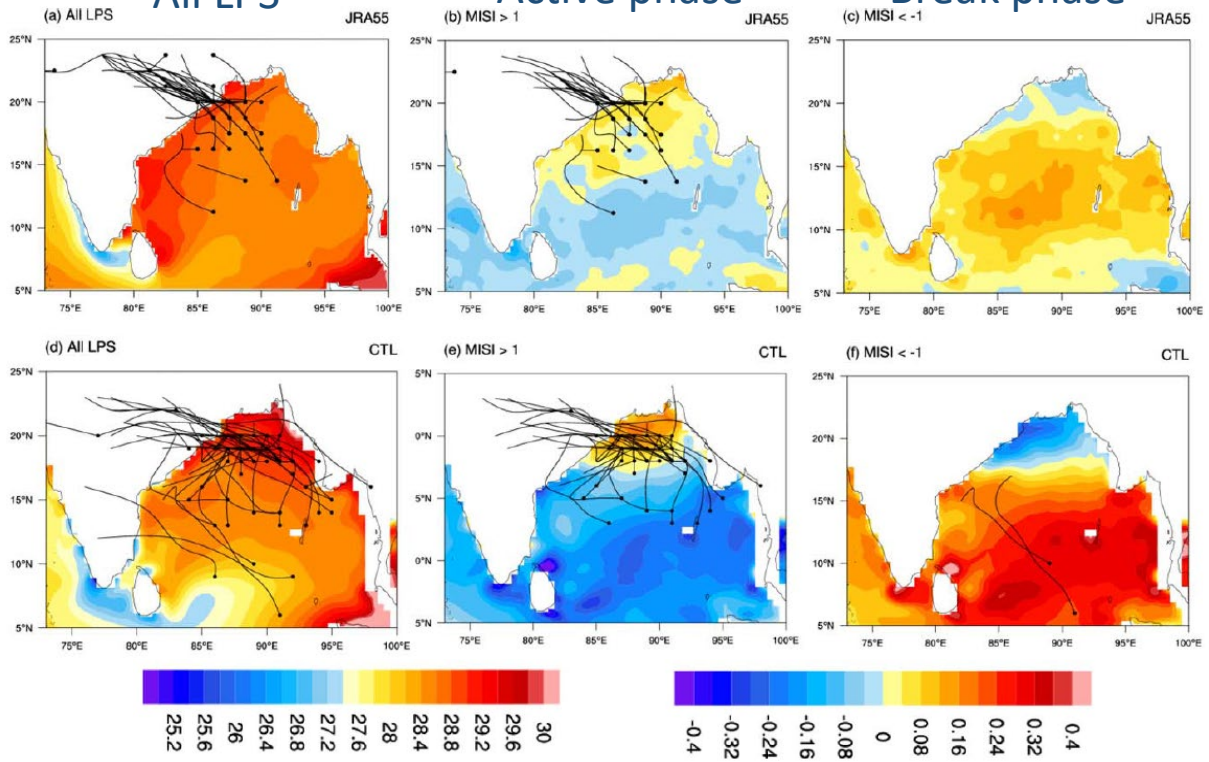


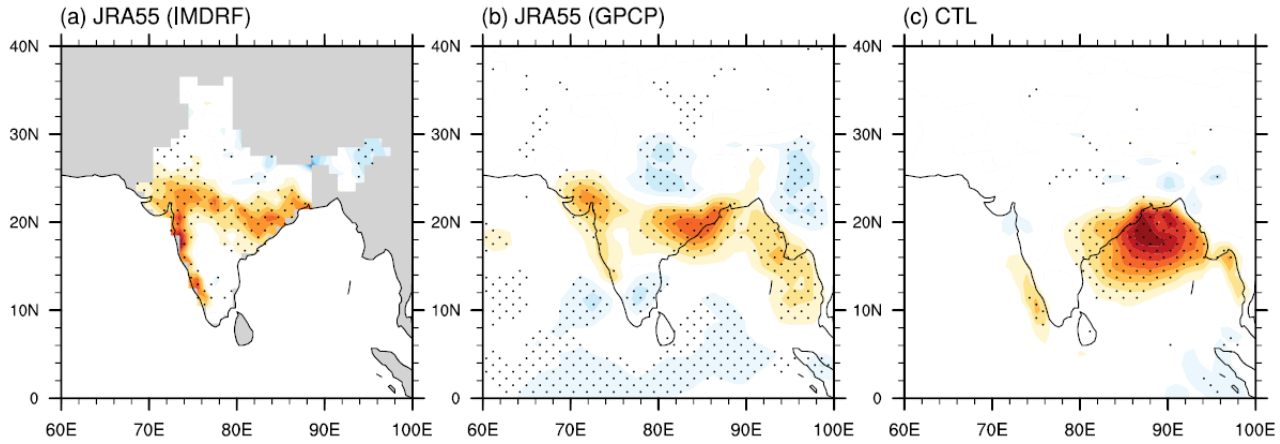
Figure 1. (a) Flowchart illustrating the steps used to detect LPS locations and (b) flowchart illustrating the steps used to generate LPS tracks.

Biases in CFSv2

All LPS | Active phase | Break phase



LPS – non LPS days rainfall



✓ **The Good**

- The CTL run simulates realistic north-westward propagation of LPS over central India
- The spatio-temporal clustering of LPS during the monsoon active phase is captured well.
- The modulation of SSTs by MISOs is captured well in model.

X **The Bad**

- The number of systems propagating inland beyond 82°E is rather restricted in the CTL run as compared to reanalysis.
- The spread in the genesis location of LPS is more.
- Analysis of LPS lifetime suggests that in reanalysis, they spend about **18% of their lifetime over ocean and the rest 82% over land.**
- However, in the CTL run, they spend only **57% of their lifetime over land and the rest over ocean.**
- The limited (excessive) lifetime over land (ocean) causes weaker (stronger) precipitation over land (ocean).

Experiment Design

	CTL run	ISLAB run	PSLAB run
Number of ensembles	5	5	5
Initialization	05,10,15,20,25 February each year at 00UTC	05,10,15,20,25 February each year at 00UTC	05,10,15,20,25 February each year at 00UTC
Run length	9 months	9 months	9 months
Active Ocean Dynamics	Throughout the globe	Throughout the globe except the Tropical Indian Ocean, 30°S to 30°N; 45°E to 120°E)	Throughout the globe except the Tropical Pacific Ocean, 30°S to 30°N; 120°E to 75°W)
Anomaly Correlation Coefficient of ISM rainfall over landmass (Standard Deviation)	0.53(0.5)	0.51(0.36)	0.14(0.25)

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Ankur Srivastava, Suryachandra A. Rao, D. Nagarjuna Rao, Gibies George, Maheswar Pradhan

- Three sensitivity experiments were designed, which alter the seasonal mean state in the model.
- The effect of the different mean state in the models on monsoon LPS is studied.
- A five-member ensemble for the period 1981-2009 was carried out.

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Indian summer monsoon prediction and simulation in CFSv2 coupled model

Gibies George,[1] D. Nagarjuna Rao,[1] C. T. Sabeerali,[1,2] Ankur Srivastava[1] and Suryachandra A. Rao[1,*]
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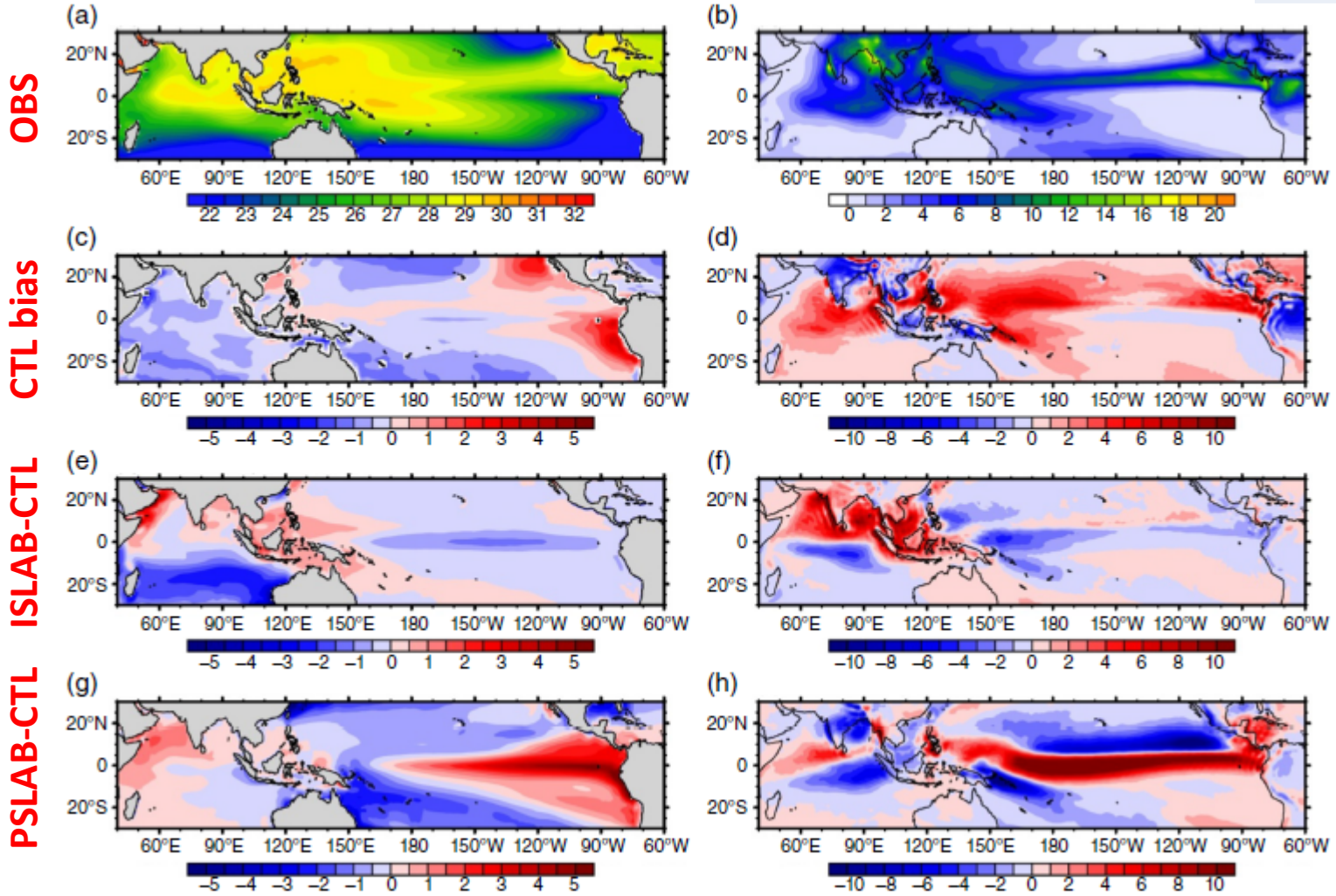
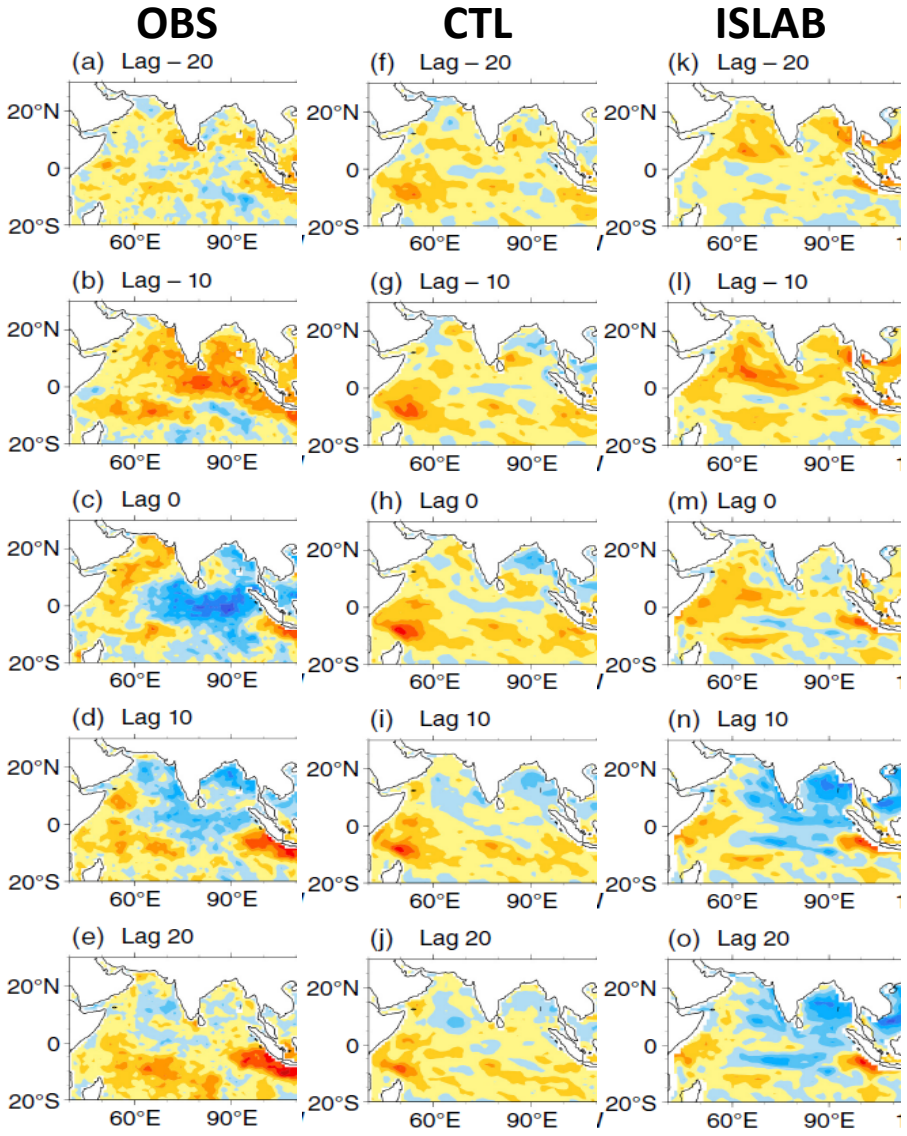
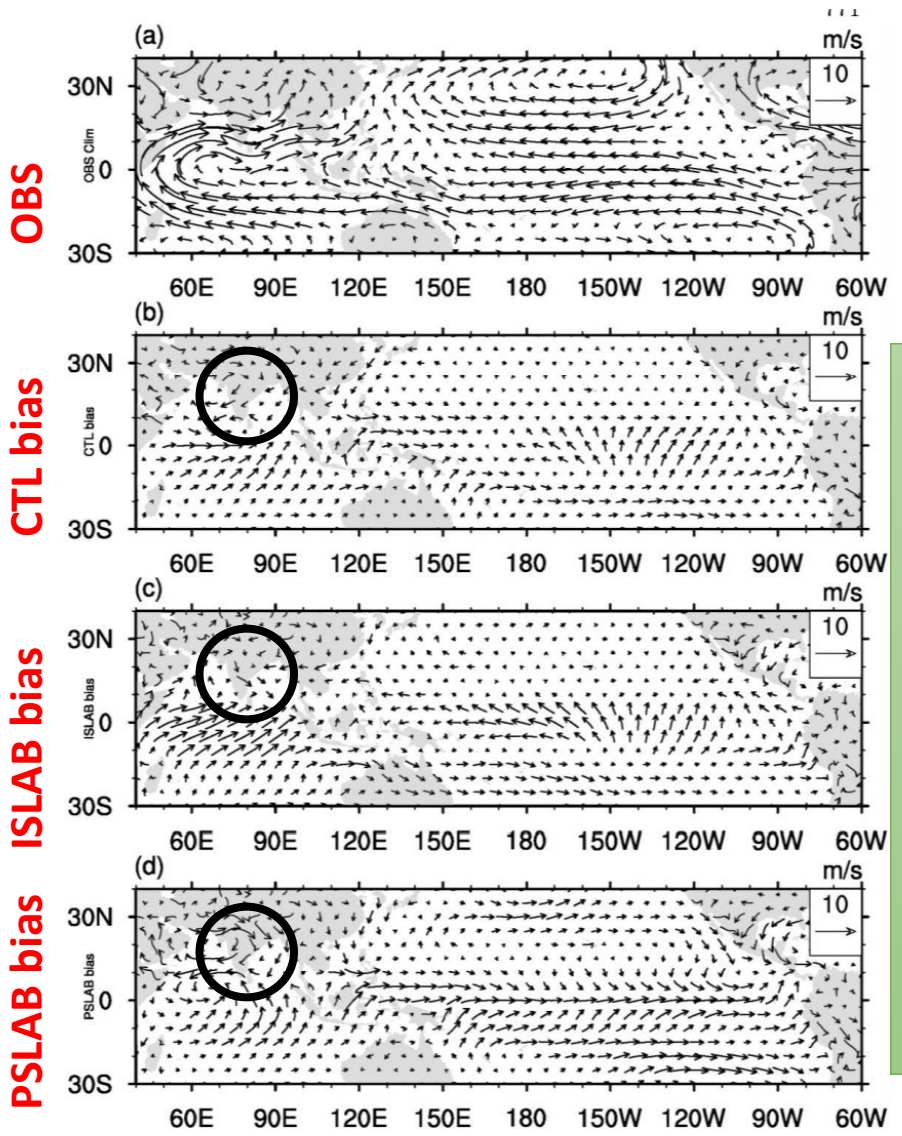
[2]*The Center for Prototype Climate Modeling, New York University, Abu Dhabi, UAE*

	ACC	SD
OBS	-	0.62
CTL	0.5	0.5
ISLAB	0.36	0.36
PSLAB	0.25	0.25



- **Inadequate representation of the Indian Ocean coupled dynamics in CFSv2.**
- **Overestimation of southward meridional heat transport in CFSv2 causes the cold bias.**
- A slab ocean over Indian Ocean causes the suppression of cold bias in the Indian Ocean.
- The prediction skill of the all India summer monsoon rainfall (AISMR) in CFSv2 basically comes from the ENSO-Monsoon teleconnection.
- The Indian Ocean coupled dynamics do not have a crucial role in controlling the prediction skill of the AISMR, but they control its inter-annual variability.
- Suppression of Pacific Ocean coupled dynamics causes a perennial El-Nino bias.

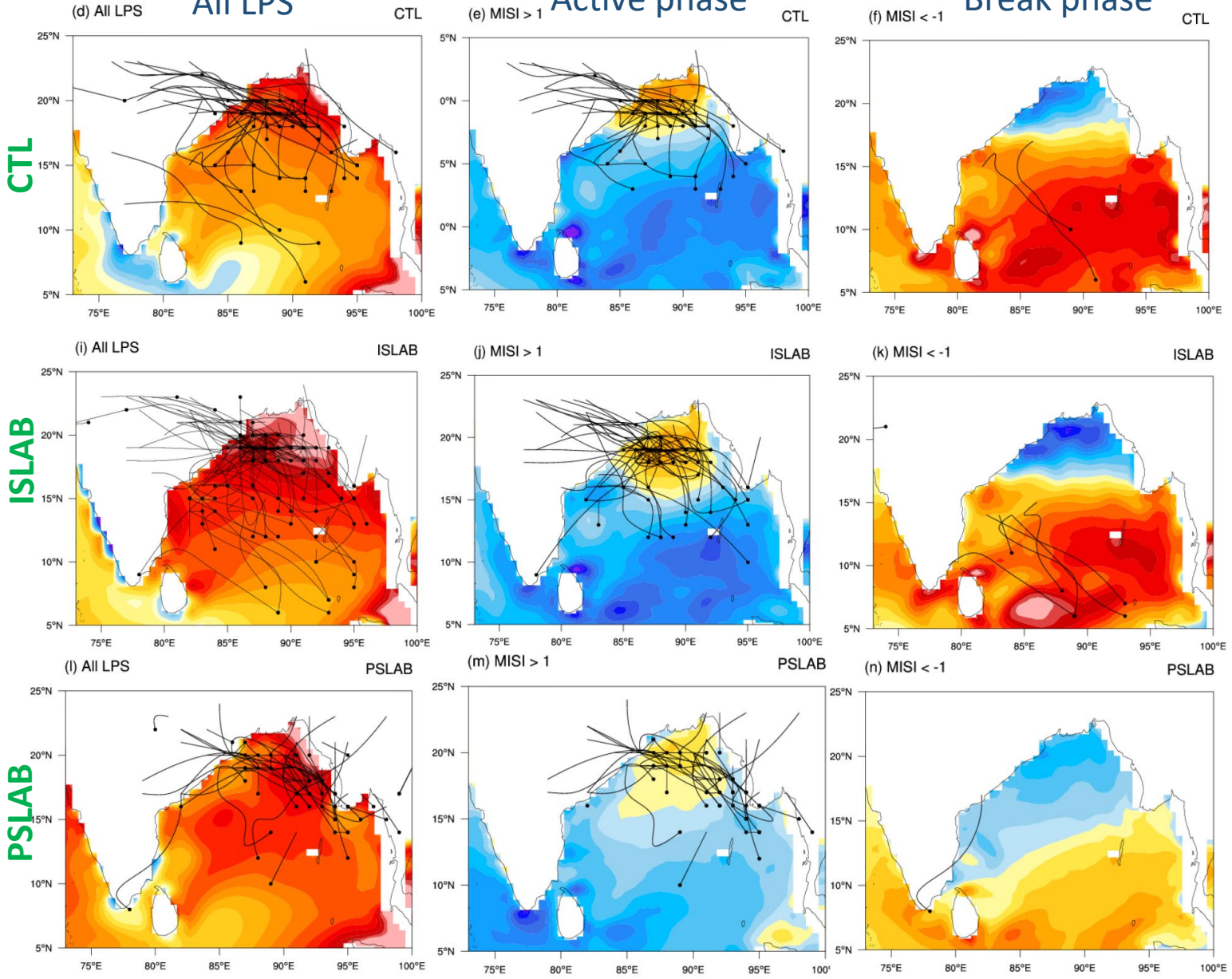




- CTL run exhibits anti-cyclonic bias over India
- This circulation bias vanishes in ISLAB run.
- PSLAB run simulates much stronger anti-cyclonic bias due to perennial El-Nino induced subsidence.

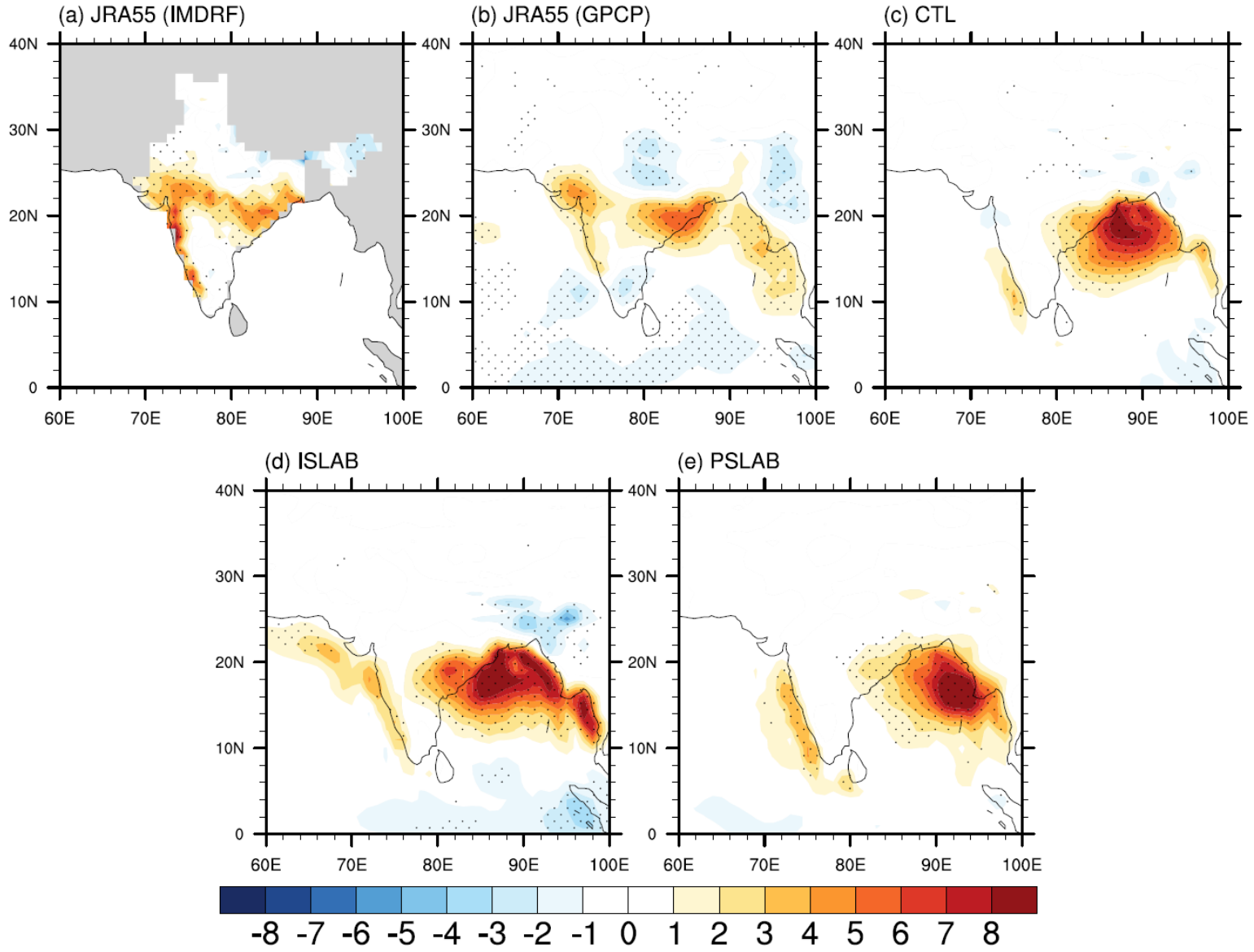
X The SST–precipitation lead–lag relationship in the warm pool regions (Bay of Bengal, Eastern Equatorial Indian Ocean and Northwest Pacific) are not captured in the CTL due to strong cold bias (up to −1 degC).

✓ However, in ISLAB run due to better simulation of SSTs in the warm pool regions, the lead–lag relationship of air–sea interaction is reasonably simulated.



- Spatial clustering of LPS by the monsoon ISOs along the monsoon trough region is well captured by the CFSv2.
- Deeper and frequent propagation of such systems over land in ISLAB run.
- Realistic simulation of the modulation of SSTs by the monsoon active-break cycles.
- **The LPS in ISLAB run spend 76 % of their lifetime over land when compared to 57 % in CTL run, and 82 % in observations.**

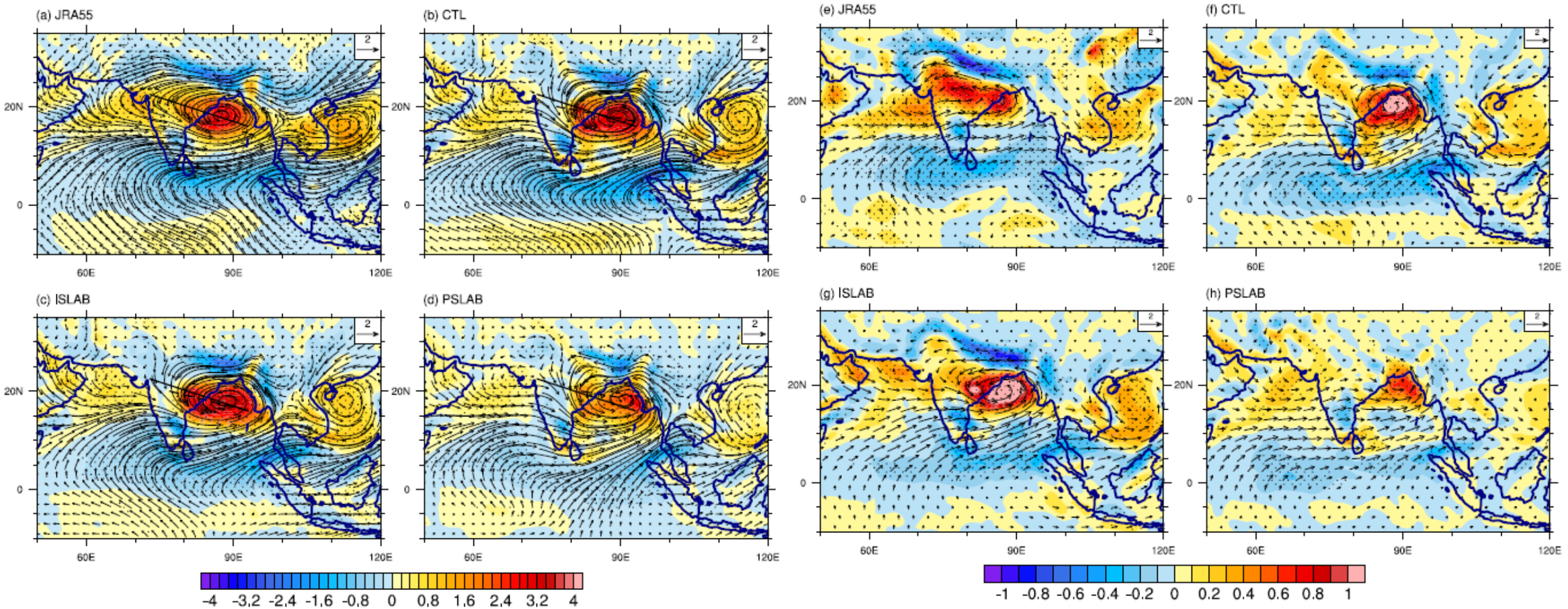
LPS associated rainfall



- CTL run does not simulate the associated heavy rainfall events over central India.
- Deeper and frequent propagation of such systems over land in ISLAB run resulting in better simulation of the associated rainfall.
- Weak precipitation associated with LPS over landmass in PSLAB run owing to the perennial El-Nino forced subsidence over Indian landmass.

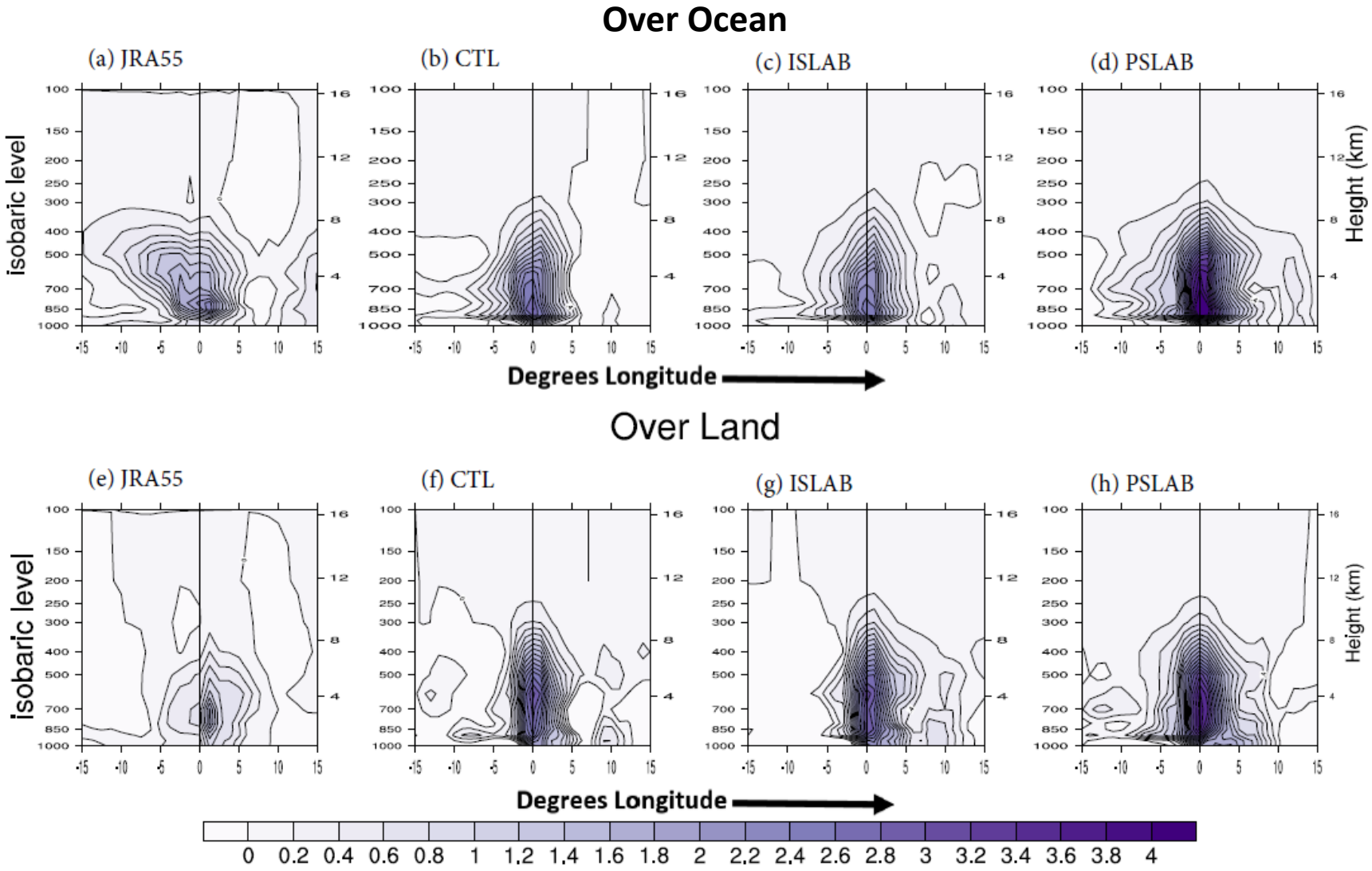
Active minus Break

LPS minus non-LPS



- A large cyclonic vorticity center sits over the BoB and extends north-westwards upto the north-west frontiers of the Indian sub-continent.
- The north-west extension of cyclonic vorticity along the monsoon trough at low levels and the associated meridional wind shear is responsible for clustering of LPS.
- Restricted north-west extension of the low-level cyclonic vorticity in CTL which improves in ISLAB run.

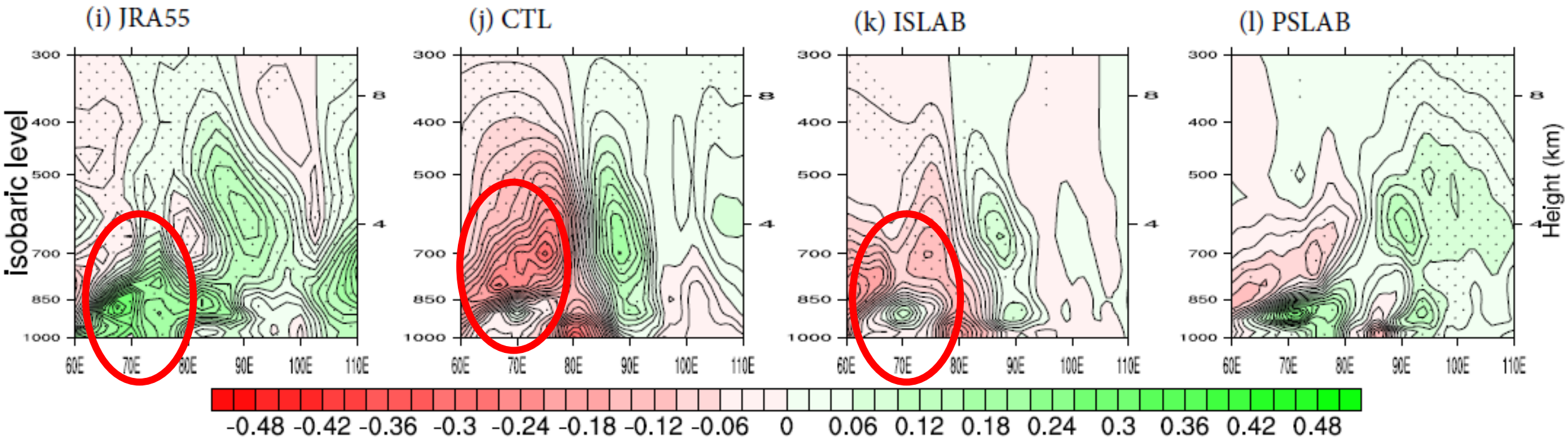
LPS centered specific humidity profile



- The profile over ocean shows availability of moisture upto 300 hPa with a maximum occurring at 850 hPa in the eastern sector.
- Clear westward tilt of the profile is also apparent in the western sector.
- The westward axial tilt is weaker in CTL run.
- Even though the clear westward tilt of the profile in ISLAB run is weak, the extension in the western sector is more as compared to the CTL run.

Low-level convergence is mainly in the west northwestward sector relative to the low-pressure centre and used this to explain the west northwestward propagation of the systems (Godbole, 1977).

LPS days composite specific humidity



- Positive anomalies across the Indian longitudes with maximum occurring over the Arabian Sea at 850 hPa.
- Due to the moisture laden monsoon winds during LPS days.
- Negative anomalies spanning 60-80 E in CTL run.
- Due to improved mean state in ISLAB run, there is enhanced moisture availability to LPS from the monsoon flow.

Summary and Conclusions

- Spatial clustering of LPS by the monsoon ISOs along the monsoon trough region is well captured by the CFSv2 CTL run.
- CTL run has difficulties in simulating the associated rainfall events over central India.
  - Partly due to anti-cyclonic mean bias.
  - Restricted north-west extension of low-level cyclonic vorticity and the associated modulation of meridional wind shear linked to ISOs.
- The ISO linked SSTs are reasonably simulated.
- Better mean state simulation in ISLAB run results in an improved LPS structure in the model.
- Strong anti-cyclonic mean bias over Indian longitudes restricts the propagation of LPS over the landmass in PSLAB run, and distorts the ISO structure in the PSLAB run.

Summary and Conclusions

- Improper representation of active ocean dynamics in the IO and the associated air-sea interactions translate to intra-seasonal and synoptic scales as well, in addition to the seasonal mean.
- Improvements in the active ocean dynamics (which can reduce the seasonal mean bias in the Indian Ocean and improves the associated air-sea interactions) improves the overall simulation of synoptic scale systems.

Thankyou.

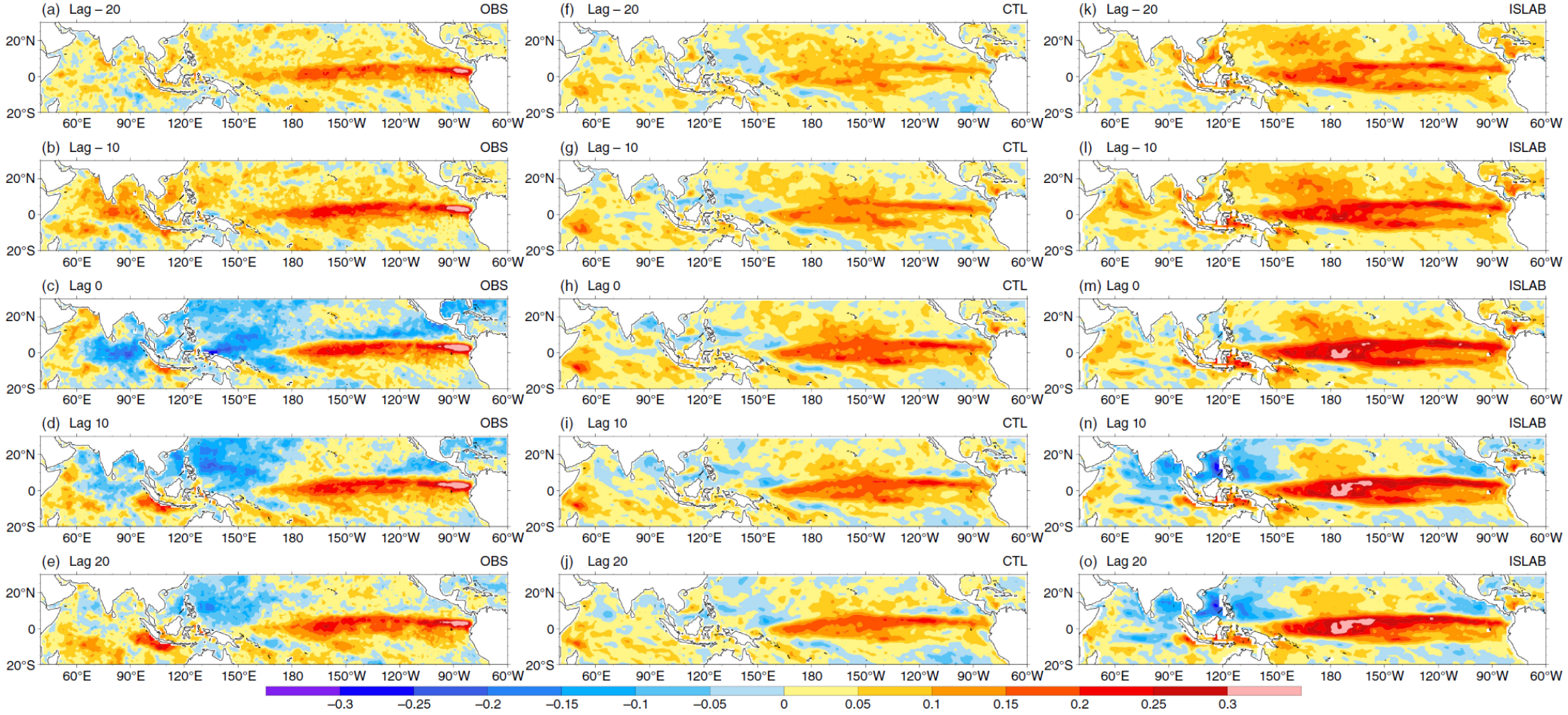


Figure 2. Spatial map of lead–lag relationship between SST and precipitation at each grid point for observation (left panel), CFSv2 CTL run (middle panel) and ISLAB run (right panel). First row marked as lag −20 indicate that the SST lead 20 days before the precipitation peak and similarly bottom row marked lag 20 indicate the SST lag 20 days after the precipitation peak.

- The SST–precipitation lead–lag relationship in the warm pool regions (Bay of Bengal, Eastern Equatorial Indian Ocean and Northwest Pacific) are not captured in the CTL due to strong cold bias (up to −1 degC).
- However, in ISLAB run due to better simulation of SSTs in the warm pool regions, the lead–lag relationship of air–sea interaction is reasonably simulated.