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# Change in characteristics of Monsoon low pressure systems under a warming climate

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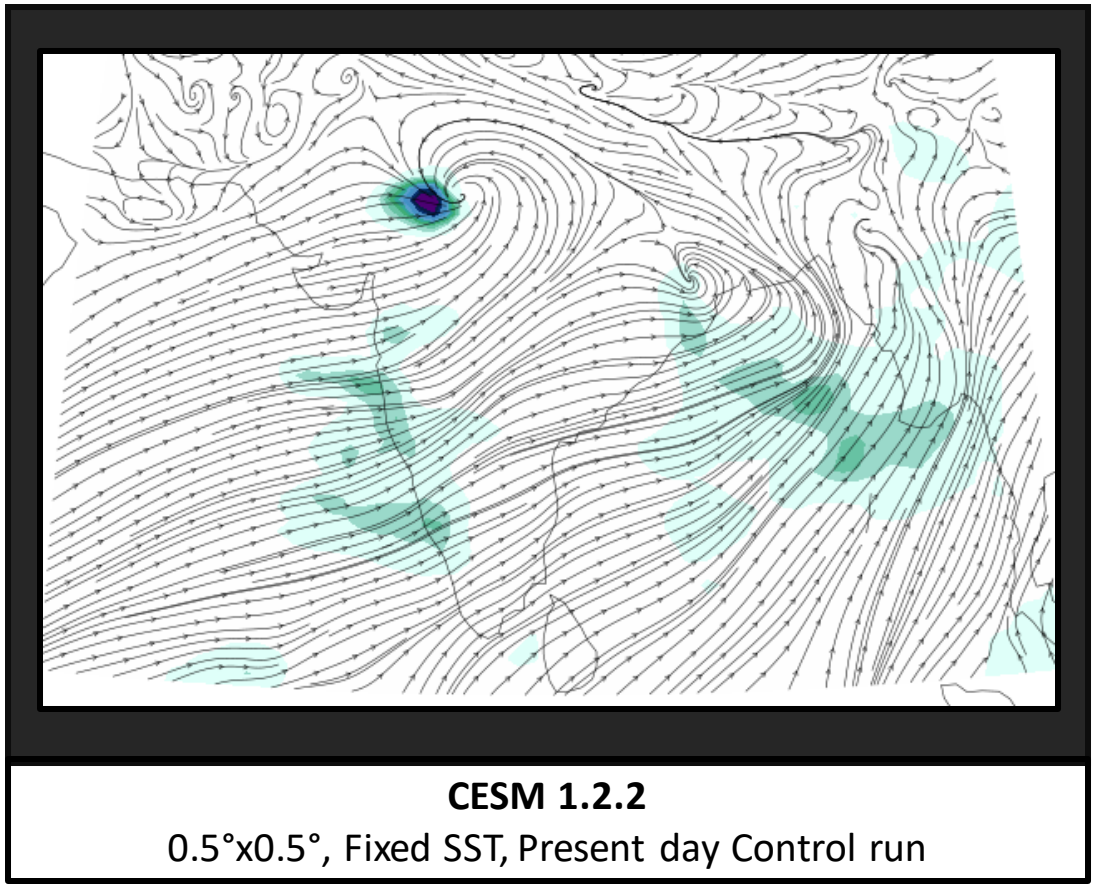
# Indian Monsoon

- Derived from Arabic word '*Mausam*' for season : seasonal change in direction of wind over Arabian Sea.
- Spanning: June – September
- Copious Rain -ISMR : 85cm (80% of annual precipitation)
- Manifestation of seasonal migration of ITCZ in response to seasonal variation in solar radiation.

# Low Pressure systems

- Synoptic scale tropical disturbances which periodically form in quasi stationary monsoon trough during southwest Indian Monsoon Season.
- Major Rain bearer for the country (more than 50% of monsoon precipitation)
- Form mostly over northern Bay of Bengal.

| Properties | Values |
|---|---|
| Direction | West –Northwest |
| Average Speed | 170 km/day |
| Lifetime | 3-6 days |
| Length Scale | 1000-2000 km |
| Vertical Scale | 9 km |
| Frequency | 14 / season |

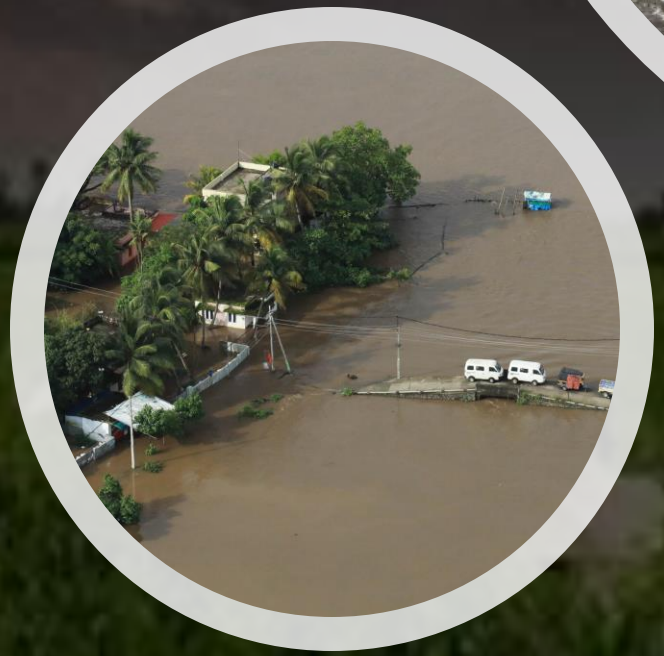


**CESM 1.2.2**

0.5°x0.5°, Fixed SST, Present day Control run

# Low Pressure Systems

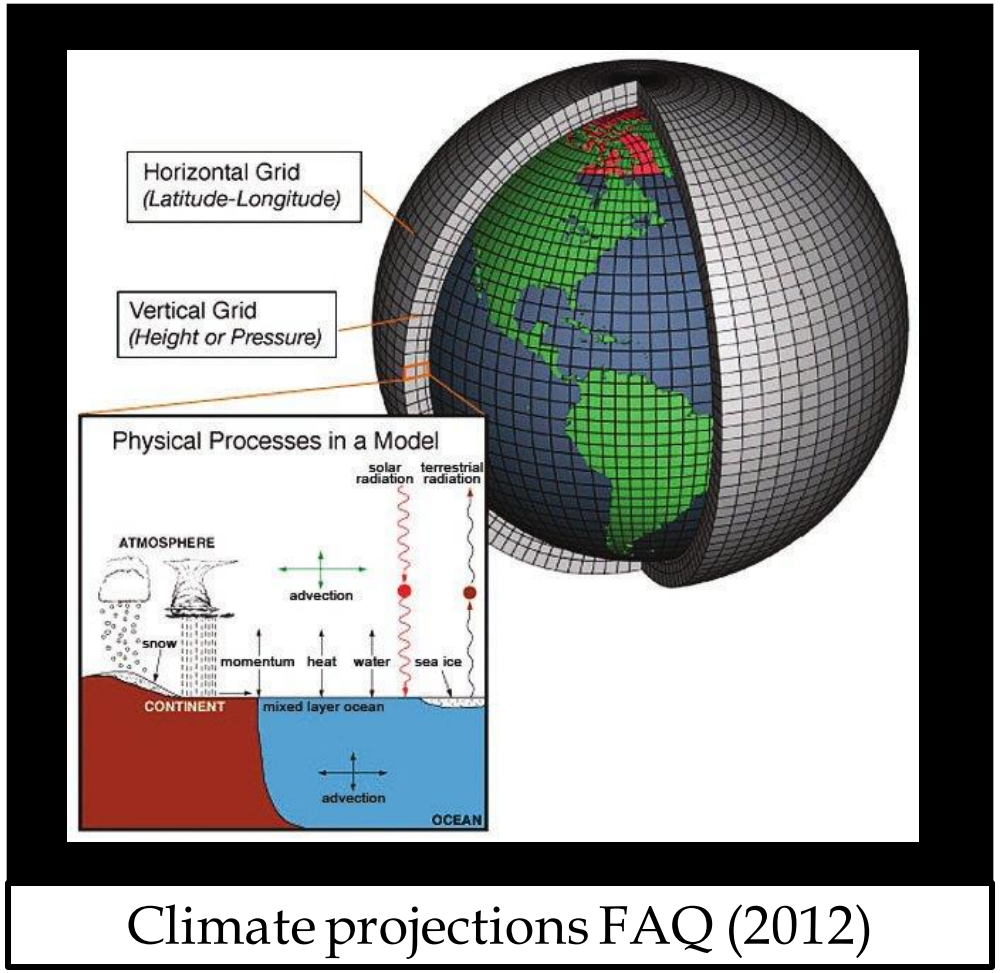
- Provide copious rain for agriculture depended India.
- But triggers floods causing disastrous effects at many locations
- 78% of extreme precipitation events in the country are LPS related (Thomas et al. 2021)
  - Uttarakhand flood in 2013,
  - Kerala flood in 2018



# Global Climate Models

- Have been used to understand behavior of tropical systems under warming climate.

- Inconsistency in LPS statistics
  - Non-significant change in the number of depressions over BoB under quadrupling of $CO_2$ (Stowasser et al. 2009).
  - Weakening of LPS activity and poleward shift under RCP8.5 scenario (Sandeep et al. 2018).
  - No significant change in number and spread of depressions under RCP8.5 scenario (Rastogi et al. 2018).

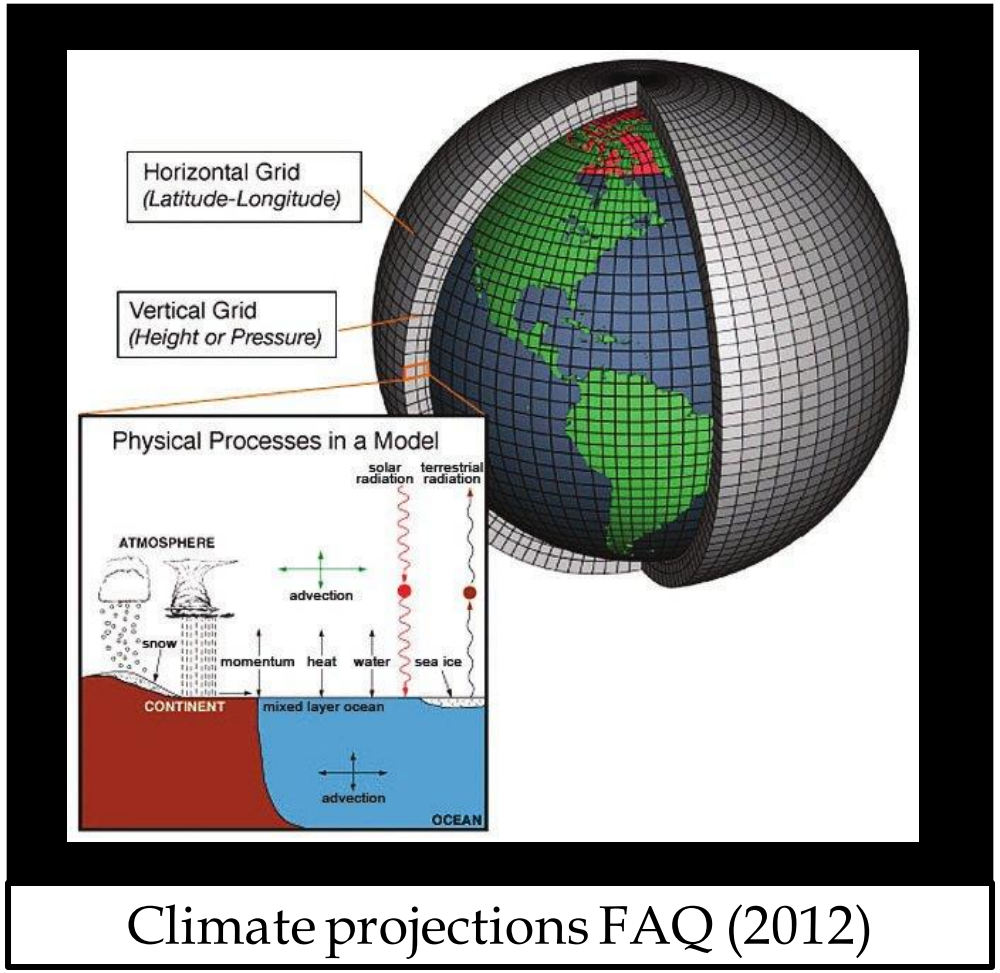



Climate projections FAQ (2012)

# Model Details

## Community Earth System Model 1.2.2 (CESM 1.2.2)

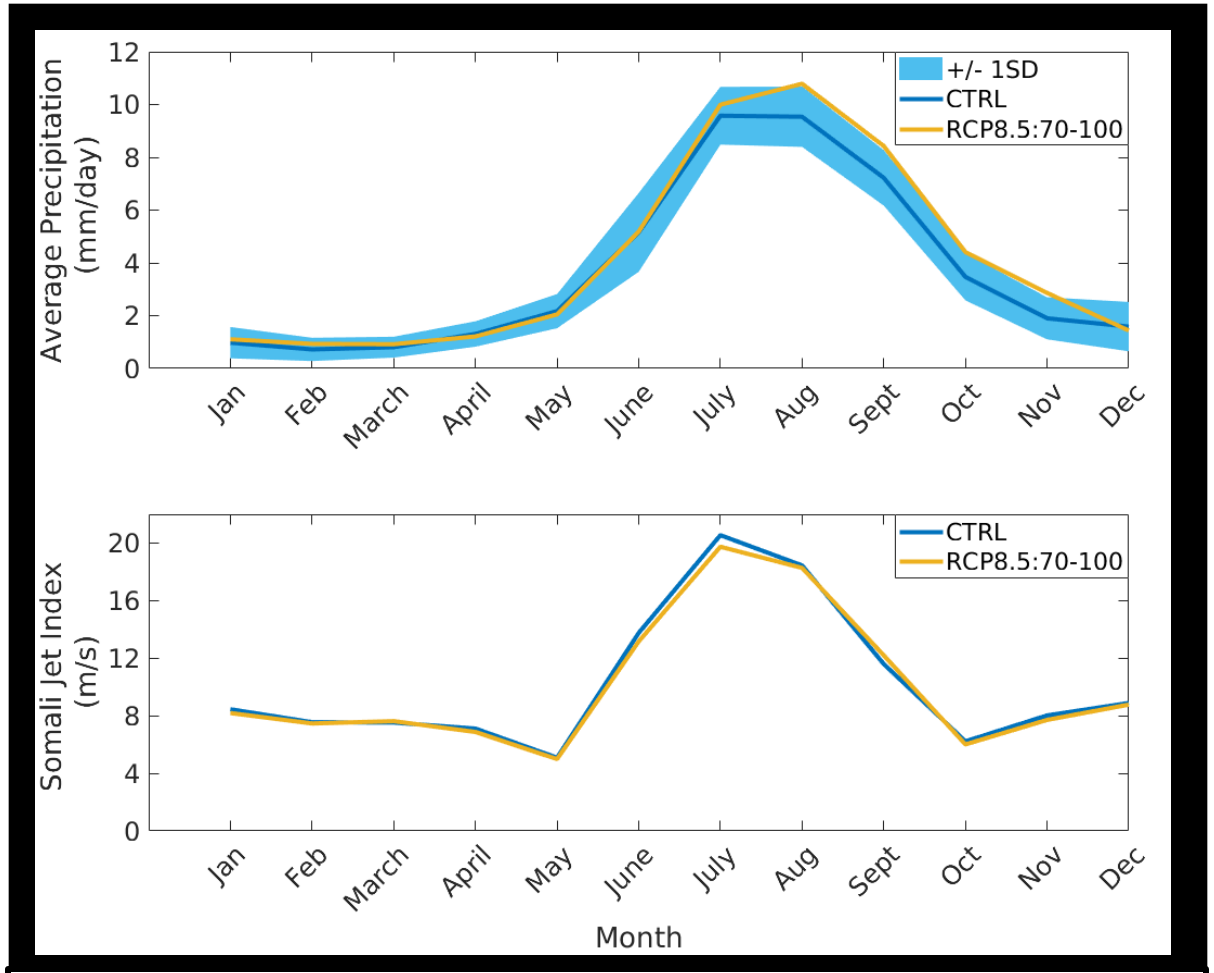
- Compset : B_2000_CN ( fully coupled)
- Resolution : 0.9°x1.25°
- Atmospheric Component : CAM4
- Vertical Levels : 26
- Land Component : CLM4
- Ocean Component : PoP2
- Sea Ice Component : CICE4
- Time Scale : 6-hourly
- Time Period : 37 years
- Spin-up : 201 years
- Experiments




Climate projections FAQ (2012)

- **CTRL** : Present-day control simulation
- **RCP8.5_70-100** : RCP8.5 scenario for the period 2070-2100

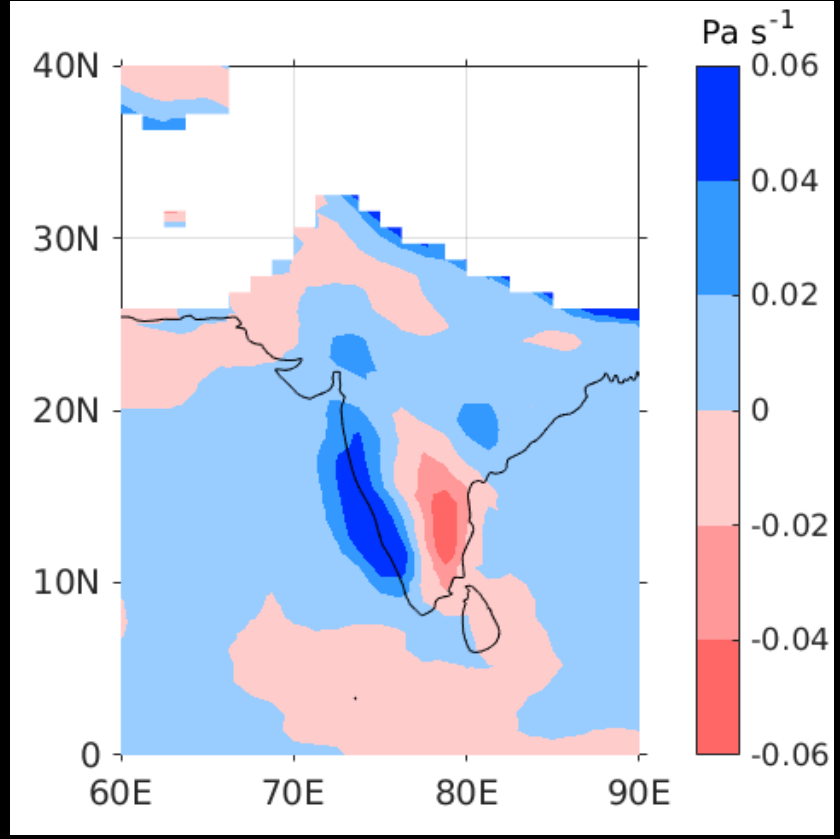
# General Monsoon Behavior



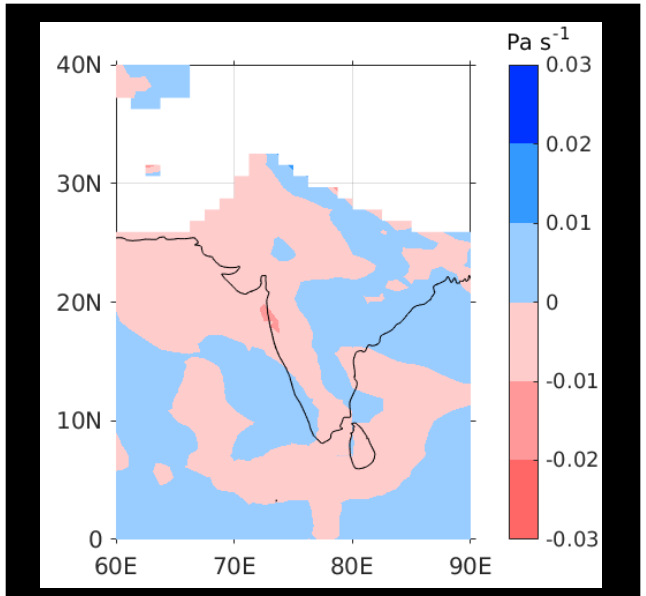

Seasonal cycle of precipitation (mm/day) and Somali jet Index (m/s) over India

- Monsoon Rainfall
  - CTRL = 96.4 ± 7.5 cm (70.9%)
  - RCP8.5 = 105.2 ± 8.5 cm (69.8%)
- Precipitation increase is larger in the late summer monsoon and post monsoon period (August-December).
- Somali Jet Index (SJI): Calculated as kinetic energy of winds at 850hPa averaged over 50°-65°E and 5°-15°N.
- Slight decrease in SJI is simulated in monsoon circulation under warming climate.

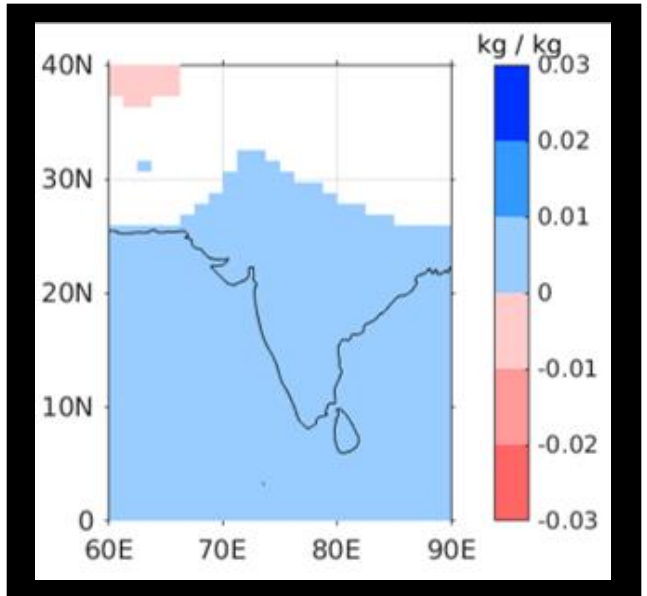
# General Monsoon Behavior




Anomaly in mean monsoon vertical moisture flow ($wq_v$; Pa/s) at 900hPa of RCP8.5_2070-2100 relative to CTRL



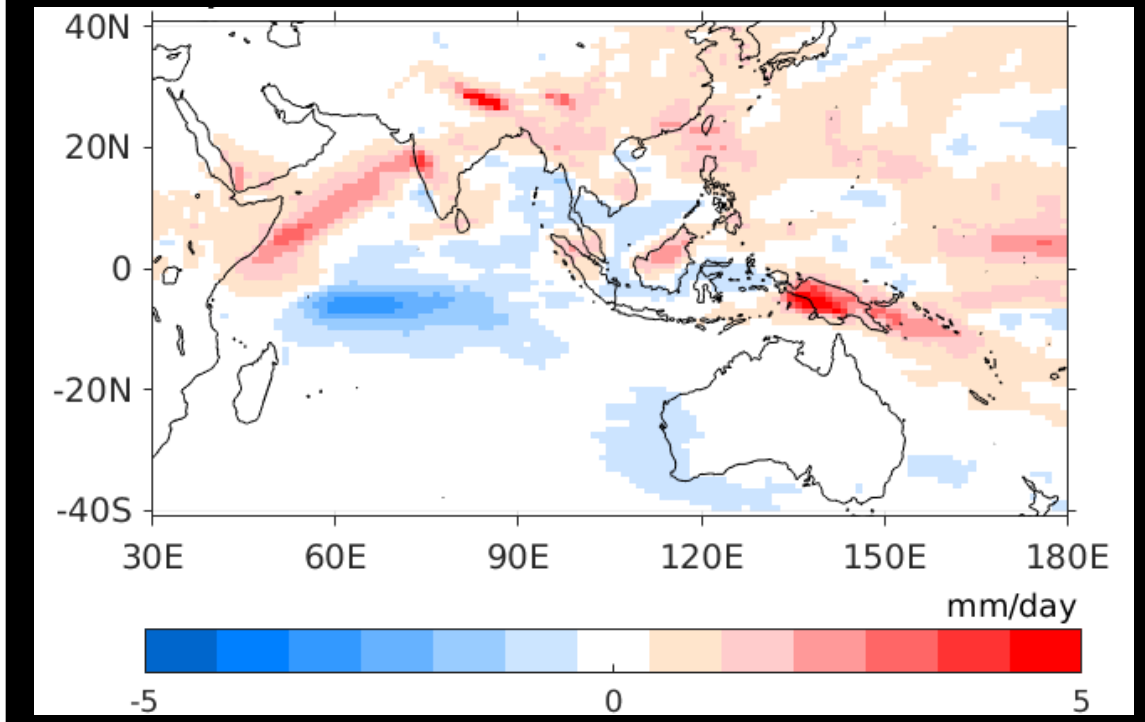

Anomaly in mean monsoon vertical flow (w; Pa/s)




Anomaly in mean specific humidity ($q_v$; kg/kg)

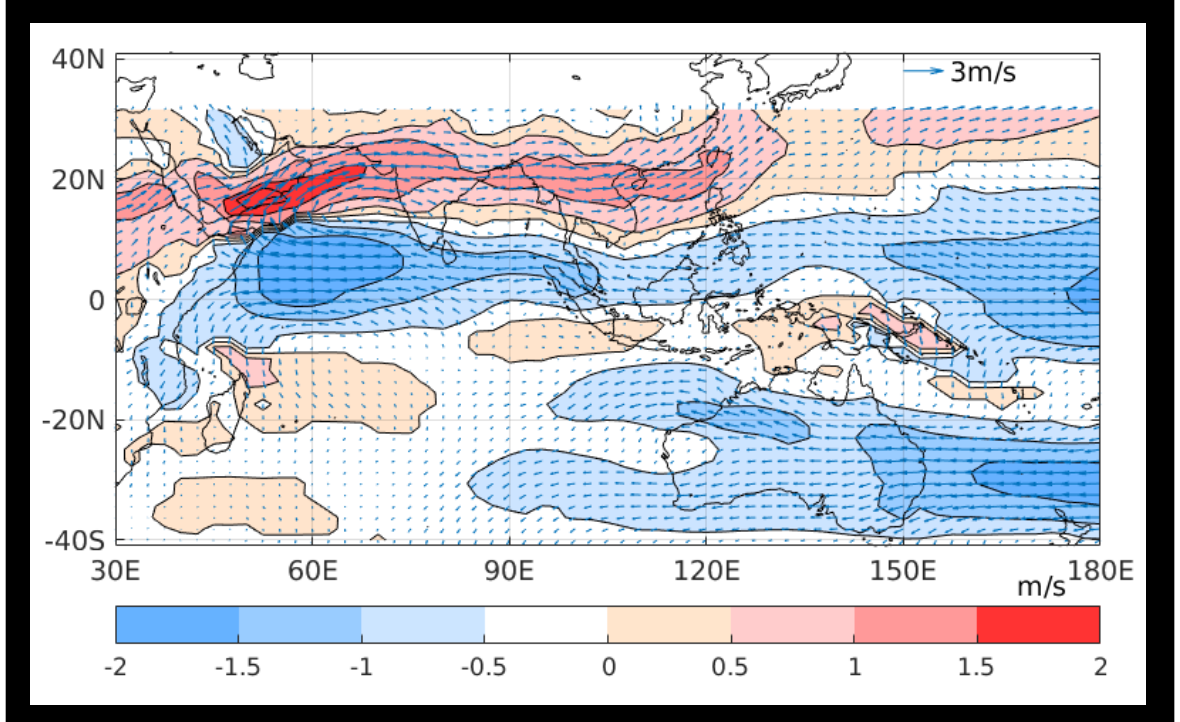
- More moisture convergence (measured in terms of $wq_v$) occurs over India under warming climate.
- Larger contribution towards convergence comes from larger moisture content.

# General Monsoon Behavior




Anomaly in mean monsoon precipitation (mm/day) of RCP8.5_2070-2100 relative to CTRL

Negative precipitation anomaly exist over equatorial Indian ocean.

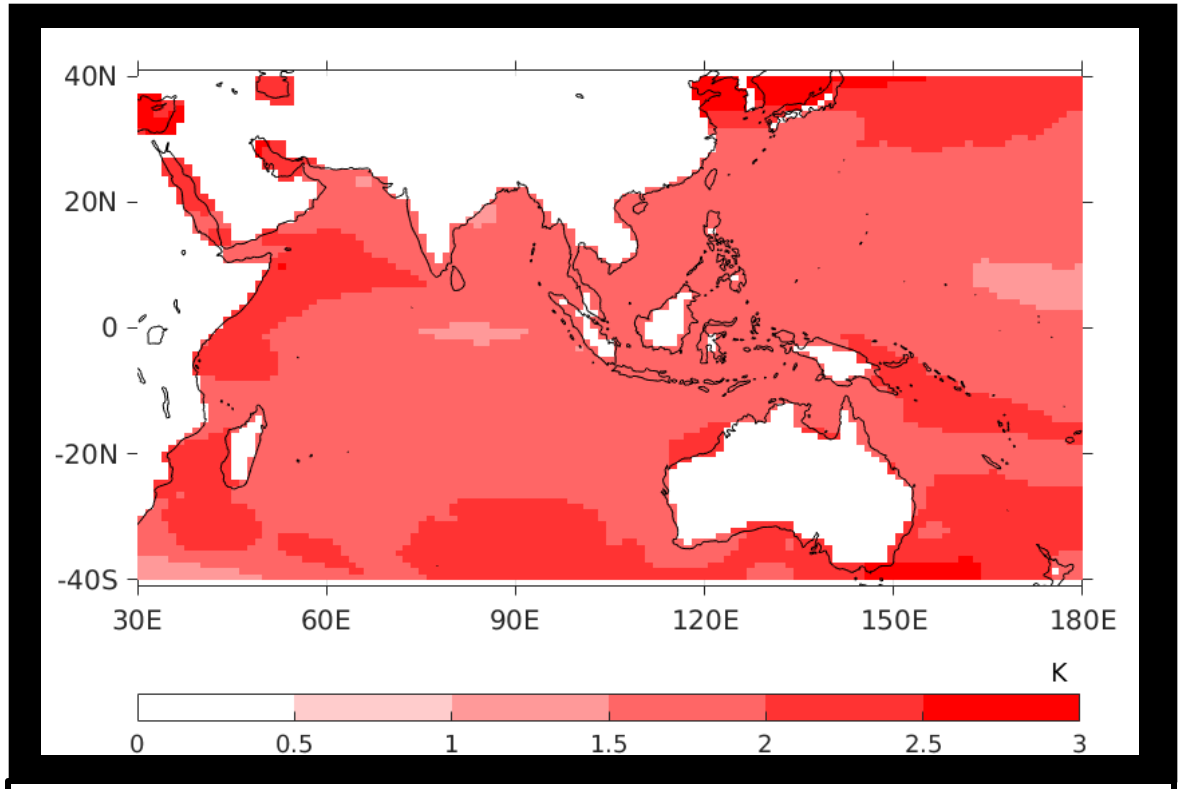



Anomaly in mean 850mb wind (m/s) of RCP8.5_2070-2100 relative to CTRL

A pair of anticyclones over west Indian ocean

# General Monsoon Behavior

- Southern component of anticyclone weakens the climatological cross-equatorial flow and limits up-welling off Somalia.
- Easterly anomalies over the south Arabian sea opposes the climatological westerlies and deepens the thermocline.
- Both reduce the upwelling over Somalia and increase SST.
- Enhanced evaporation over the Arabian sea leads to an increase in rainfall over peninsular parts of India.



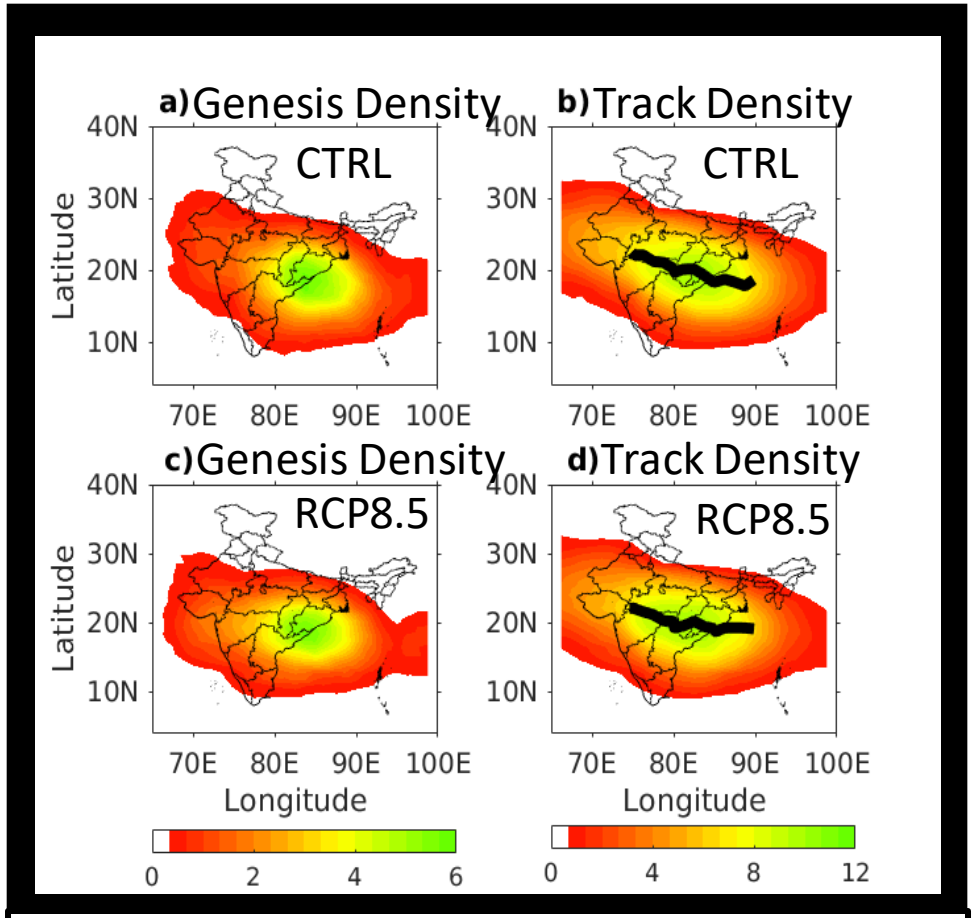

Anomaly in sea surface temperature (K) of RCP8.5_2070-2100 relative to CTRL

# Genesis and Track Density

- **Genesis Density**: Number of genesis per year within 500km radii of the location.
- **Track Density**: Number of tracks per year within 500km radii of the location.

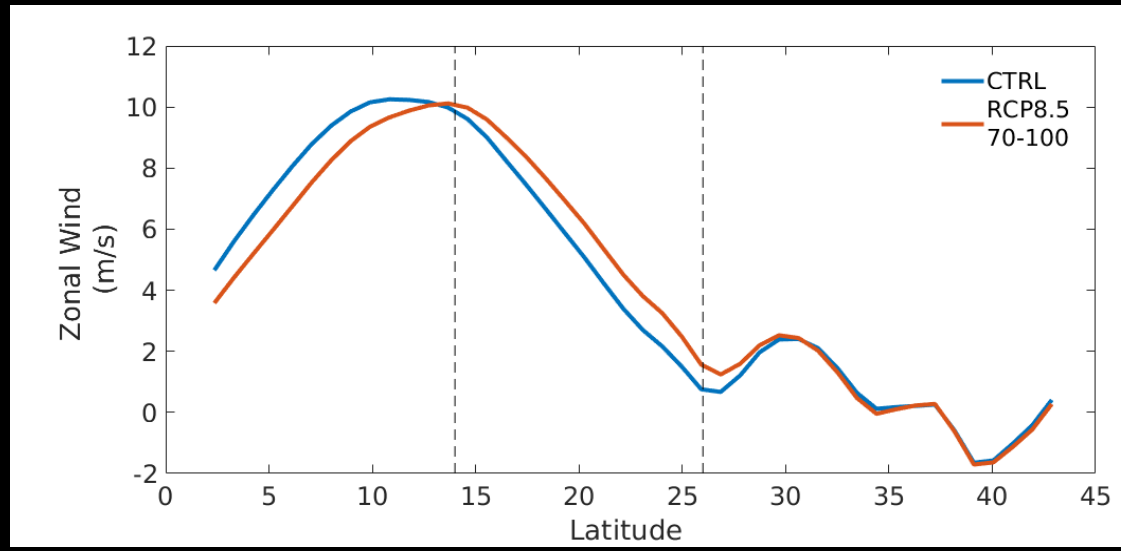
**Average numbers per year**

| Model | LPS | Lows | Depressions | Deep depressions | LPS days |
|---|---|---|---|---|---|
| CTRL | 13.6 ± 2.6 | 8.0 ± 3 | 4.6 ± 1.8 | 1.0 ± 0.8 | 63.1 ± 8.9 |
| RCP8.5_ 70-100 | 13.9 ± 2.4 | 7.3 ± 2.2 | 5.2 ± 2.1 | 1.4 ± 1.0 | 62.3 ± 11.6 |




Genesis and track Density

# Insignificant change in LPS activity?




Mean 850 hPa zonal winds averaged over the longitudinal belt 70°E-90°E

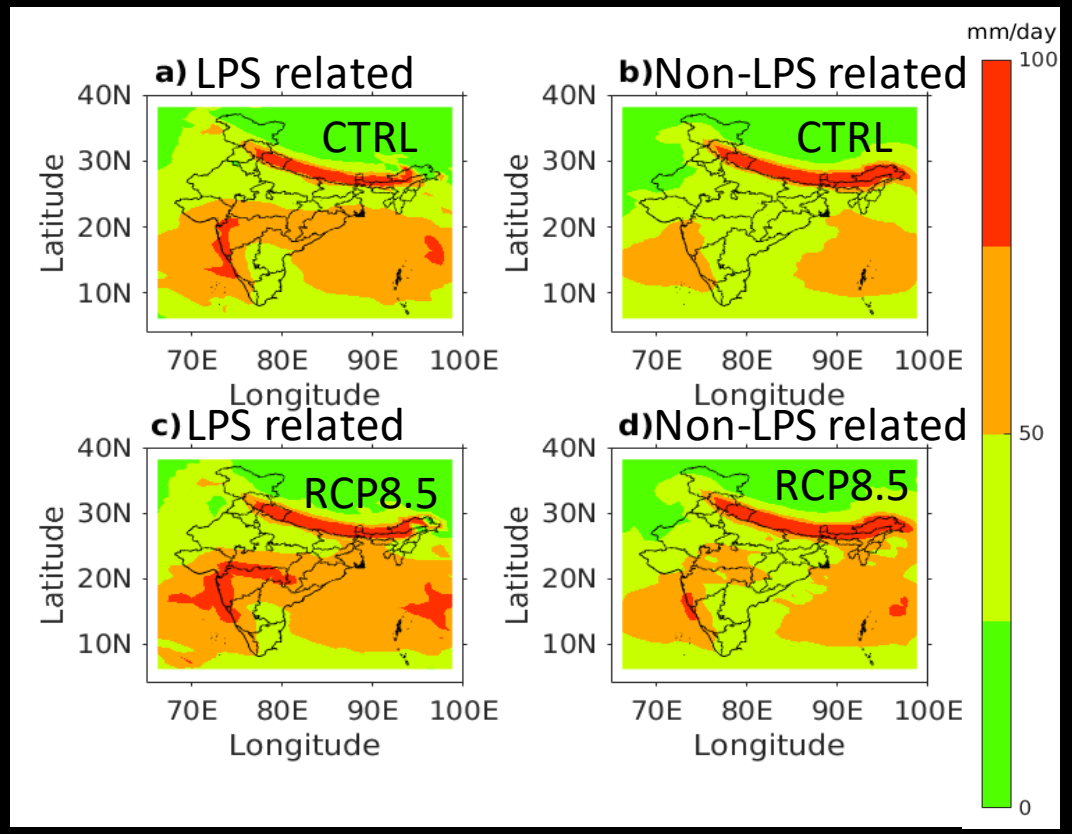
- Barotropic Shear ($\partial U/\partial y$) : slope of mean zonal wind between 14°N to 26°N. *Decrease in magnitude and poleward shift in latitudinal extent under warming climate.*
- Specific humidity between 850-500hPa ($Q_{850\ to\ 500}$): averaged over 80°E-100°E, and 10°N-30°N. *Increase in magnitude over Indian mainland under warming climate.*

Monsoon LPS are moist barotropic instabilities which draws initial energy from barotropic shear and later from latent heat.

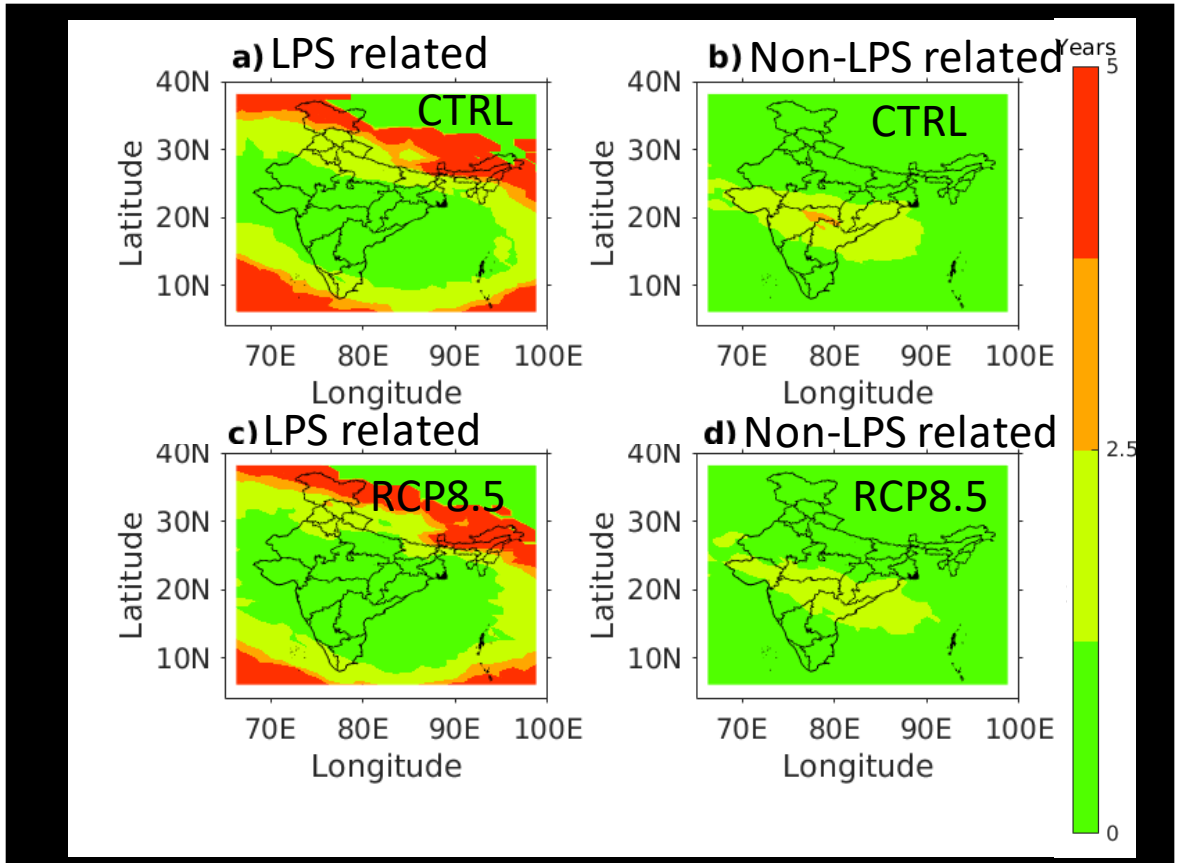
| Model | $\partial U/\partial y$ ($s^{-1}$) | $Q_{850\ to\ 500}$ (g/kg) |
|---|---|---|
| CTRL | -0.78 | 8.8 |
| RCP8.5_ 70-100 | -0.75 | 10.4 |

**Combined effect of the weakened barotropic shear and enhanced moisture content likely cause insignificant change in the LPS frequency under a warming climate.**

# Extreme Precipitation




Average extreme precipitation (daily precipitation greater than 95th percentile; mm/day)




Return period of extreme precipitation events (daily precipitation greater than 95th percentile; years)

# Extreme Precipitation

- CTRL simulation: average extreme precipitation above 50mm/day
  - associated with LPS: 43.5% of total Indian mainland
  - Not associated with LPS: 17.8% of total Indian mainland

- The number of locations with extreme precipitation greater than 50 mm/day increases by 25% when associated with LPS under warming climate.

- The increase in the number of extreme events not associated with LPS reduces the return period of such extremes under a warming climate but are still not as frequent as those associated with LPS .

# Conclusions

- CESM1.2.2 is used to investigate the effect of climate change corresponding to the RCP8.5 scenario on LPS characteristics during the summer monsoon season over India.

- The enhancement in monsoon precipitation (9.2%) is attributed to enhanced moisture convergence over India primarily due to enhanced moisture content.

- Under the RCP8.5 scenario, there are no significant change in the simulated number of LPS and spatial pattern of its characteristics over the Indian subcontinent.

- The insignificant change in the number of LPS over India under a warming climate is a combined effect of weakened barotropic shear and increased atmospheric moisture content.

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