Relative Roles of Convection and Advection in the Sustenance of the Asian Summer Monsoon Anticyclone

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Stratosphere-Troposphere Interactions and Prediction of Monsoon Weather Extremes (STIPMEX),

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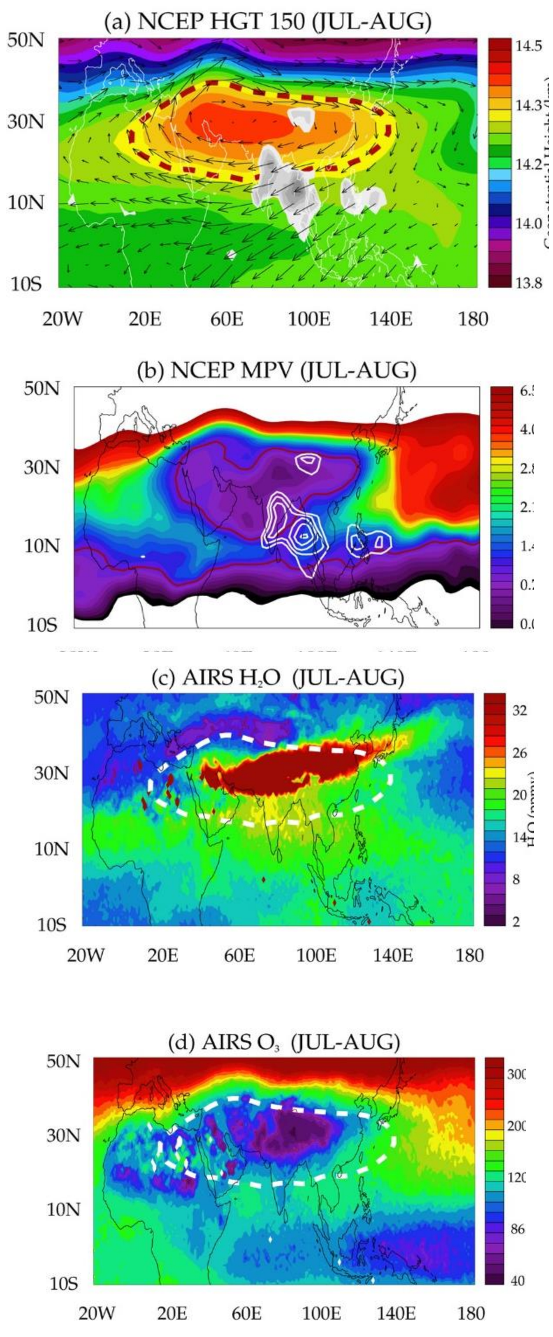
Introduction:

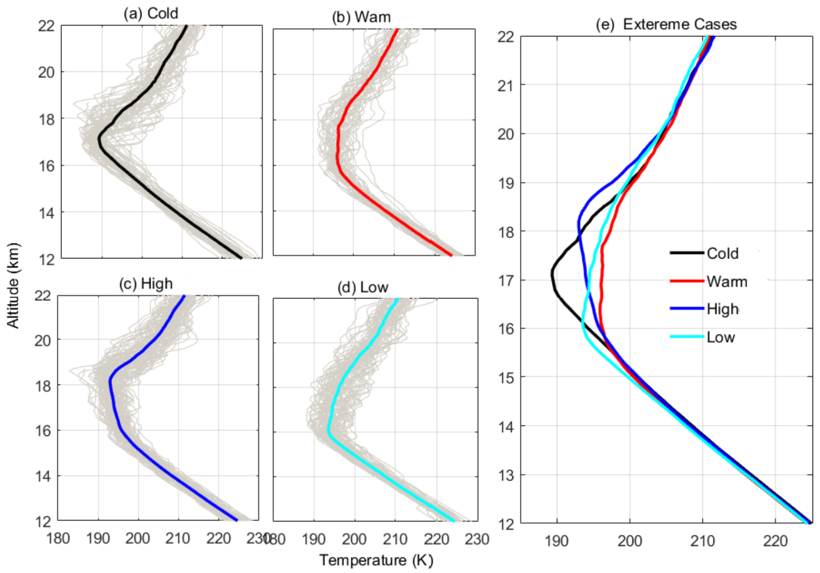
- SPITMEX Workshop brought Upper tropospheric and Asian Monsoon Scientists together to understand its global connection.
- Though, the Asian Summer monsoon circulation is part of the monsoon, it is hardly dealt with in monsoon studies. ASMA has become one of the hot topics in the last two decades due to the availability of the MLS data which provided the signature surface pollution reaching the lower stratosphere
- After the work of Randel et al (2006) as well as several follow-up studies, it is realized that ASMA plays a vital role in pollutant transport during the monsoon season
- After this workshop, ASMA will not only be important for the gateway of the pollutant transport to the lower stratosphere, and hope that there will be several works in establishing a link between the monsoon dynamics and stratospheric dynamics and exchange processes.
- Though there has been plenty of effort in connecting the monsoon to upper tropospheric research they are still meager.
- As SW monsoons are directly connected to the Indian economy, Indian policymakers mainly focus on monsoon studies, and the upper tropospheric and lower stratospheric research is not sufficiently explored.



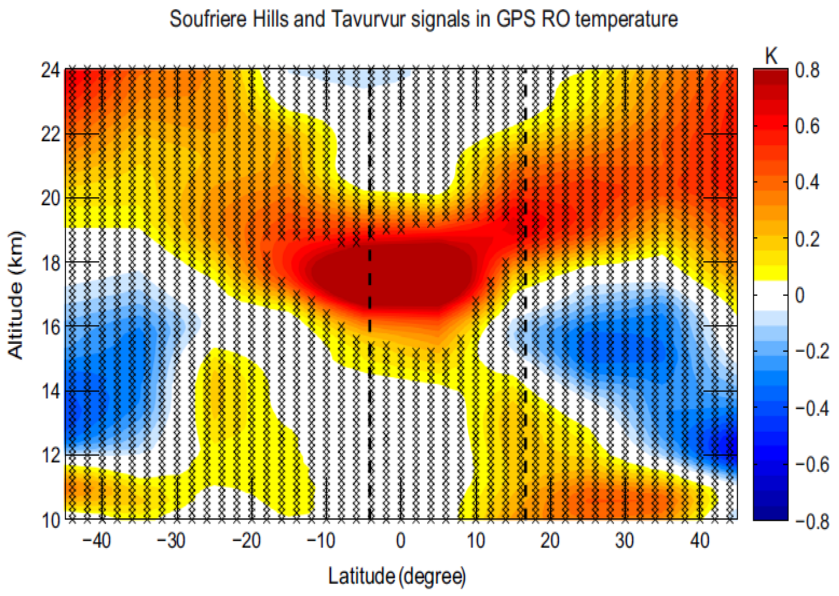
Randel et al (2006), JGR - Atmosphere

Introduction:

- Though there have been several works establishing the role of the monsoon/convection on the stratosphere-troposphere exchange process as well as to understand the tropopause variability. However still the tropopause height can not be modelled as several aspects on the short term scales are not clear.
- It has been already understood that stronger convection leads to frequent occurrence of the coldest tropopause. Recently, we examined the variability in extreme cases of the tropopause showing a distinct thermal structure.
- Such thermal structures result due to several extreme weather conditions including the occurrence of the tropical cyclone and thunderstorms etc. The thermal strictures due to cloudiness associated with tropical cyclone is well reported by Biondi et al.,(2013).
- The anomalous temperature changes were also well recognized due to major volcanic eruptions, however, during 2000 there were several volcanic eruptions which had increased the load of stratospheric aerosol (Vernier et al. 2011). These authors observed the presence of ATAL which is being investigated in the great extent.
- Mehta et al., (2015) reported the impact minor volcanic on the UTLS temperatures.



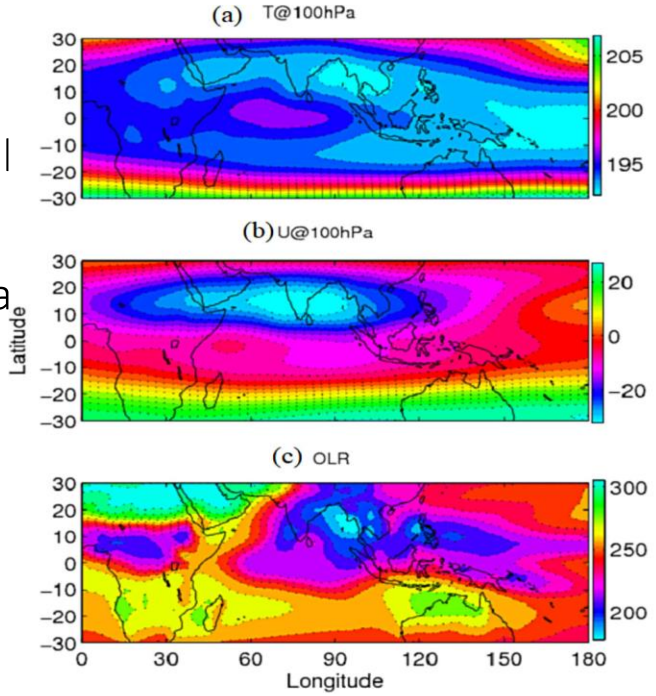
Vanmathi and Mehta (2022), Clim. Dyn.

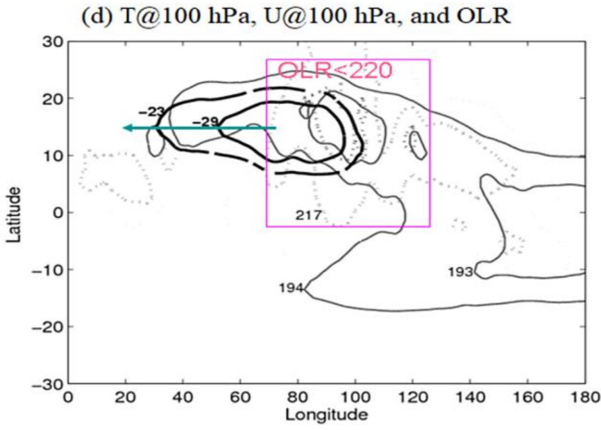


Mehta et al.(2015), JASTP

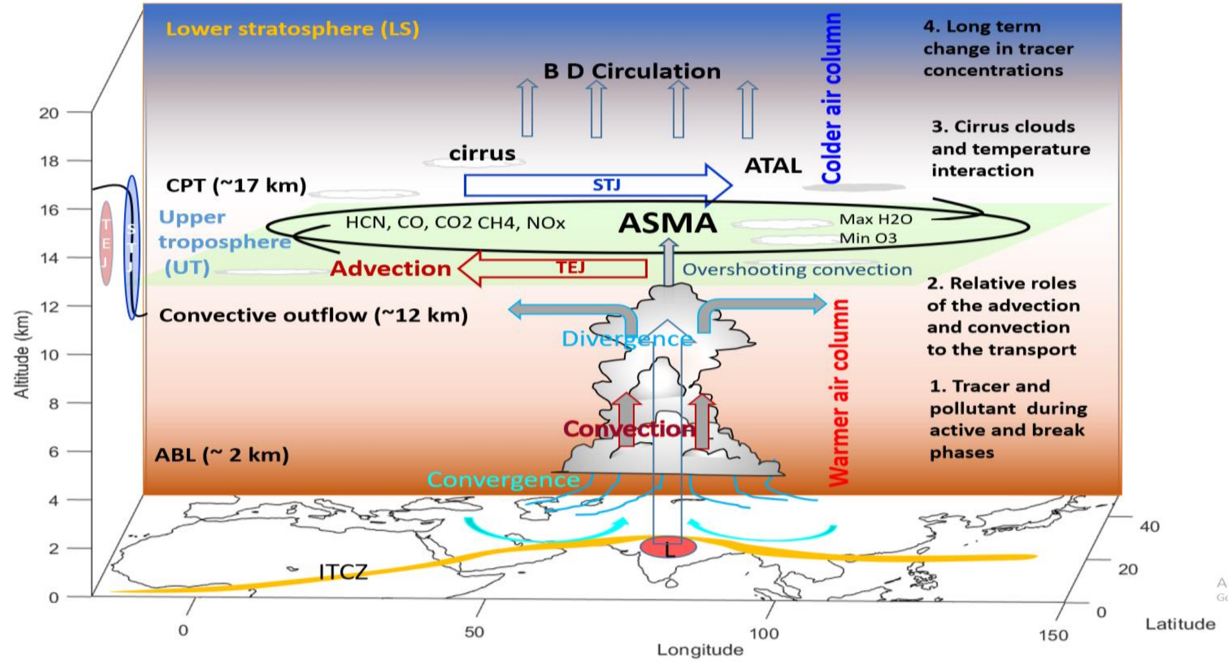
Introduction:

- Over the Asian summer monsoon, the tropical easterly jet streams mostly occur at about the same altitude as the tropical tropopause during the monsoon season. Most of the time, the zonal wind profile and temperature show often similar patterns connected through the thermal wind equation. Mehta (2024) reported that tropopause height and TEJ height often vary in similar phase.
- The Asian monsoon undergoes intraseasonal oscillation of active and break phases. These weather conditions during the monsoon must have significant impact on the upper troposphere via ASMA and hence it could also affect the pollutant transport. This research proposal including other objectives the relative roles of the advection and convection, cirrus cloud and temperature interactions were coined together to peruse it under the **Scheme for Promotion of Academic and Research Collaboration (SPARC),** Govt of India.
- The ASMA is well define using the fixed GPH on the pressure level, Montgomery stream function on isentropic level etc. While using fixed GPH to define the ASMA on shorter scale we encounter problems as the closed being extend beyond the Asian summer monsoon and hence proposed a new definition to study the ASMA on shorter scale and understand the role of the active and break phases.



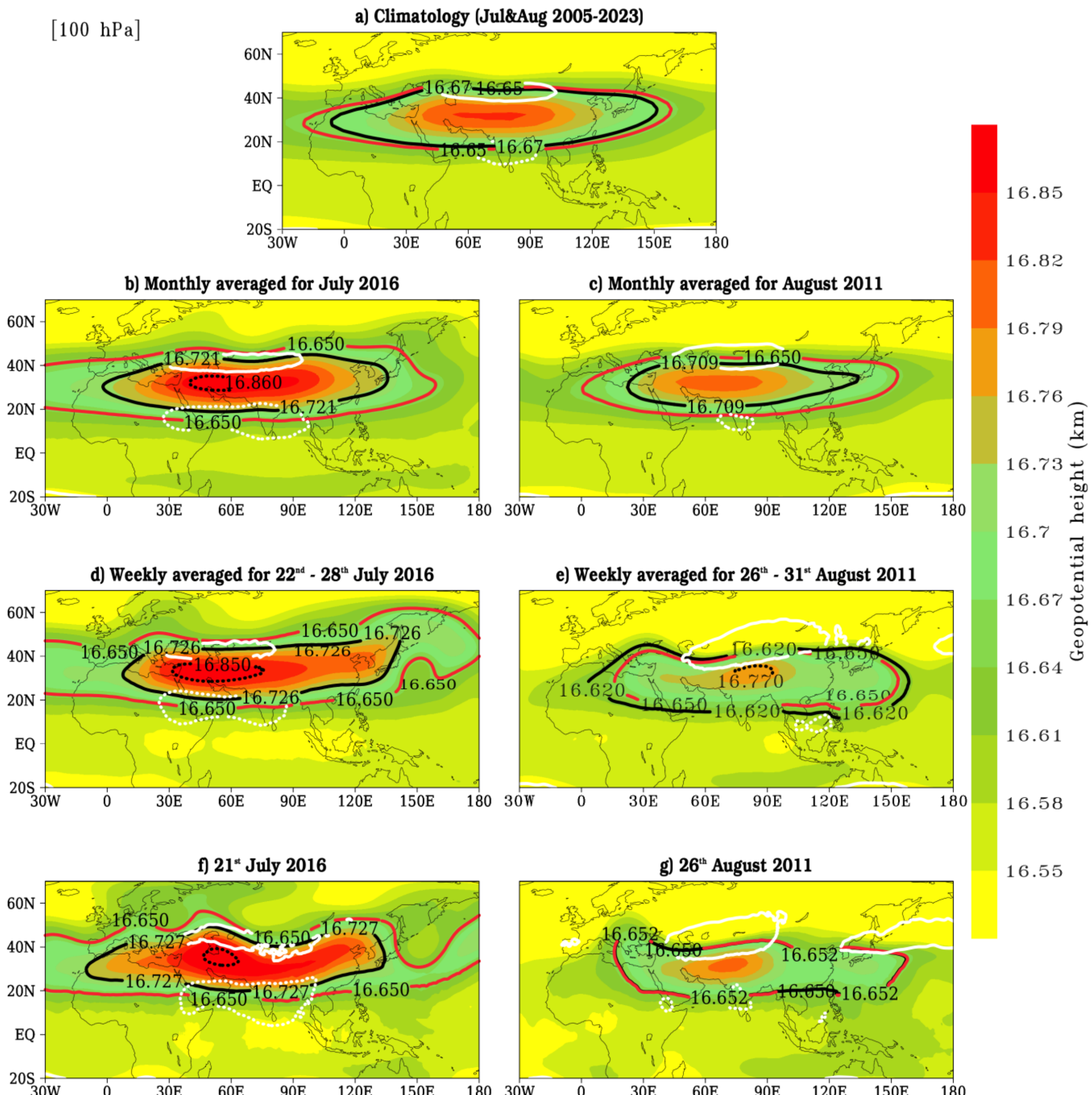


Mehta (2024), Atmos. Sci. Lett.



Mehta et. Al. 2020, SPARC News Letter 55

Introduction:



The ASMA can be identified using various diagnostics such as winds and divergence, potential vorticity, the Montgomery stream function, or geopotential height. Its representation based on the commonly-used existing method that takes a climatological range of the geopotential height (GPH) at a given pressure level is not robust and fails in several circumstances.

In this study, we propose a new GPH method to define the ASMA for the active and break phases of the monsoon based on the GPH values at the tropical easterly jet (TEJ) and subtropical westerly jet (STJ) locations.

The proposed method compares the GPH values at the locations corresponding to the windspeed maxima of TEJ and STJ at 100 hPa with the maximum GPH at 100 hPa and selects the one with the minimum difference to define the ASMA extent.

(Musaid, Mehta et ., 2022, IJOC, under review)

Introduction:

One of the important features appearing as the response to the diabatic heating caused by the Asian summer monsoon is the upper-level anticyclonic circulation generally referred to as the Asian Summer Monsoon Anticyclone (ASMA) (Gill, 1980; Rodwell and Hoskins, 1995; Randel and Park, 2006; Park et al., 2007; Ploeger et al., 2015a; Amemiya and Sato, 2018; Siu and Bowman, 2019; Honomichl and Pan, 2020; Tweedy et al., 2021; Ueda et al., 2022; Lau and Kim, 2022).

The ASMA is characterized by enhanced concentrations of carbon monoxide (CO) and several other tracers such as methane (CH4), water vapor (H2O), and by reduced concentrations of ozone (O3). The polluted and wet lower tropospheric air is transported upward, resulting in these concentration anomalies in the ASMA region (Randel and Park, 2006; Park et al., 2007; Randel et al., 2010; Pan et al., 2016; Von Hobe et al., 2021; Lau and Kim, 2022; Kumar et al., 2023)

Investigation of detailed pathways from the boundary layer to the ASMA is currently the area of active research. Bergman et al. (2013) investigated the pathway and identified a vertical conduit in the region from the Tibetan Plateau to the Bay of Bengal. Based on model simulations, Pan et al. (2016) proposed a chimney and blower model. The chimney model can explain the vertical lofting of tracers near the Tibetan Plateau and their outflow in the UTLS, along with the east-west oscillation of the ASMA. At the same time, the blower model is discussed in light of the isentropic meridional transport of tracers trapped within the ASMA into the extra topical UTLS region.

The transport of tracers and airmasses within the ASMA was discussed in terms of the spiral structure of the anticyclonic circulation emphasizing advective transport (Randel and Park, 2006; Vogel et al., 2019; Legras and Bucci, 2020). However, the relative roles of advection and convection in the formation and sustenance of the ASMA have not been explored yet.

Our Objectives in this study are as follows:

- Characterize the level of convective outflows over the ASMA region which is important for the vertical transport of air
- Analyze the spatial distribution of zonal and meridional winds and temperature at different levels
- Demonstrate the advective and convective terms and their distinct features, particularly over the Indian and West Pacific (WP) regions.

Dataset:

The ECMWF 5th generation reanalysis (ERA5) dataset (Hersbach et al., 2020) for the period 1991 to 2020.

GPS RO data from the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) for the period 2011-2020.

Methodology:

We use the thermodynamic energy equation to understand the relative roles of advection and convection in the ASMA. The advective and convective terms (Dwivedi et al., 2020; Kakkanattu et al., 2023) are calculated in K/day using the ERA5 daily mean datasets.

$$\text{Advective term} = -\left(u\frac{dT}{dx} + v\frac{dT}{dy}\right) \times 86400 \qquad \text{Convective term} = -\left(w\frac{dT}{dp}\right) \times 86400$$

We have also obtained the level of neutral buoyancy (LNB) to understand the upper bound for actual convective development using moist static energy (MSE) profiles based on the parcel theory (Takahashi et al., 2017).

$$\text{MSE} = C_pT + gz + L_vq.$$

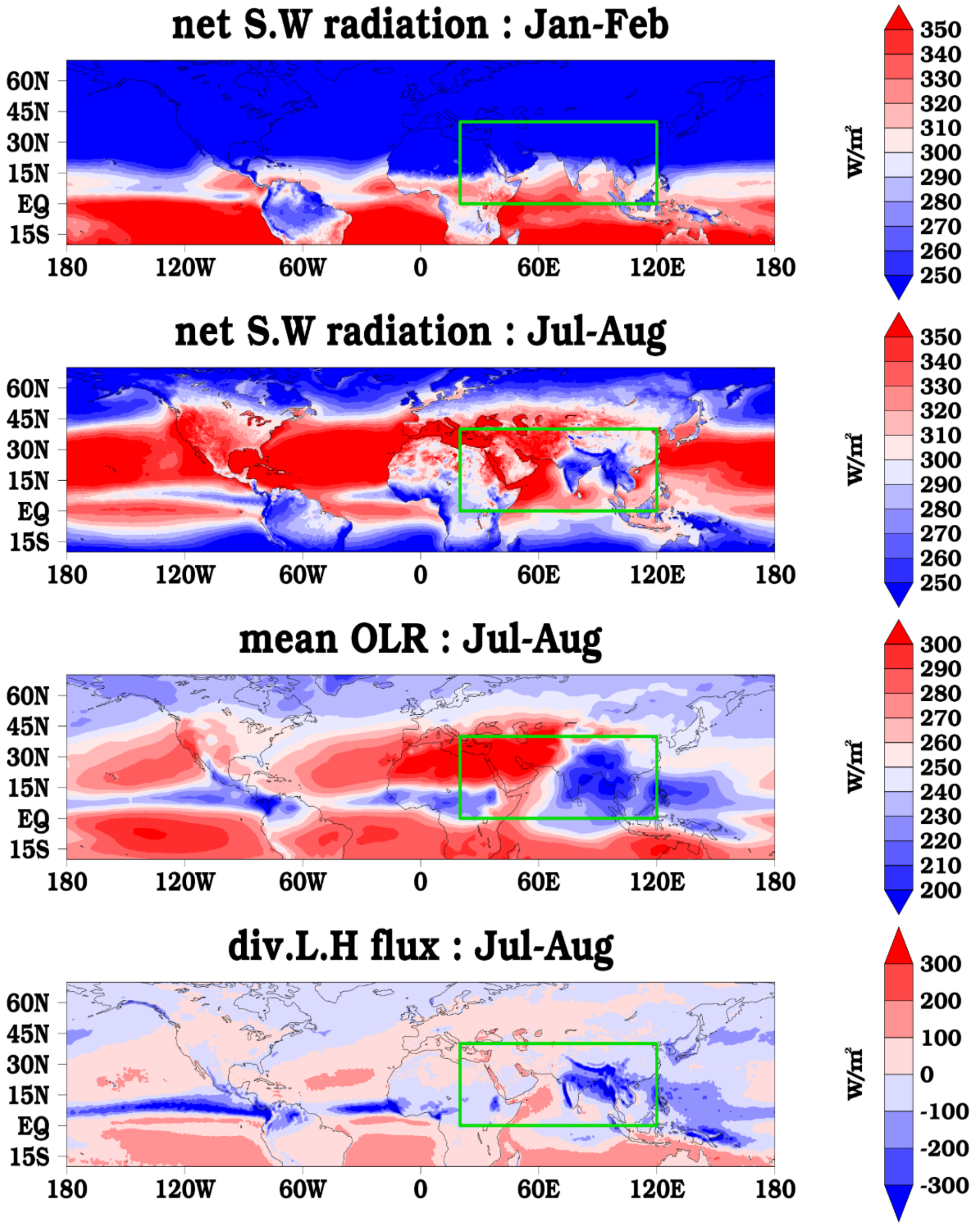
Results: Diabatic Heating analysis

we analyze the mean radiation and energy fluxes to better understand the heat balance and the surface forcing that enables the ASM circulation.
This figure shows the global map of the mean net shortwave radiation calculated as the difference between incoming and outgoing solar radiation fluxes at the top of the atmosphere averaged over January and February of 2011 to 2020.

The difference in the mean net shortwave radiation fluxes divides the region covering the ASMA into wet and dry surfaces towards its east and west sides, respectively.

The mean divergence of the columnar integrated latent heat flux (negative values; 100 and 200 W/m^2) depicts the distribution of the diabatic heating in response to deep convection.

It further indicates that the primary heat source to the east of the ASMA is convection while that to the west of it is mainly dominated by radiation.
The ASMA region clearly marked three major converging belts: the western Ghats, the southern flanks of the Himalayas, and the tip of the monsoon depression from central India to the eastern Bay of Bengal.



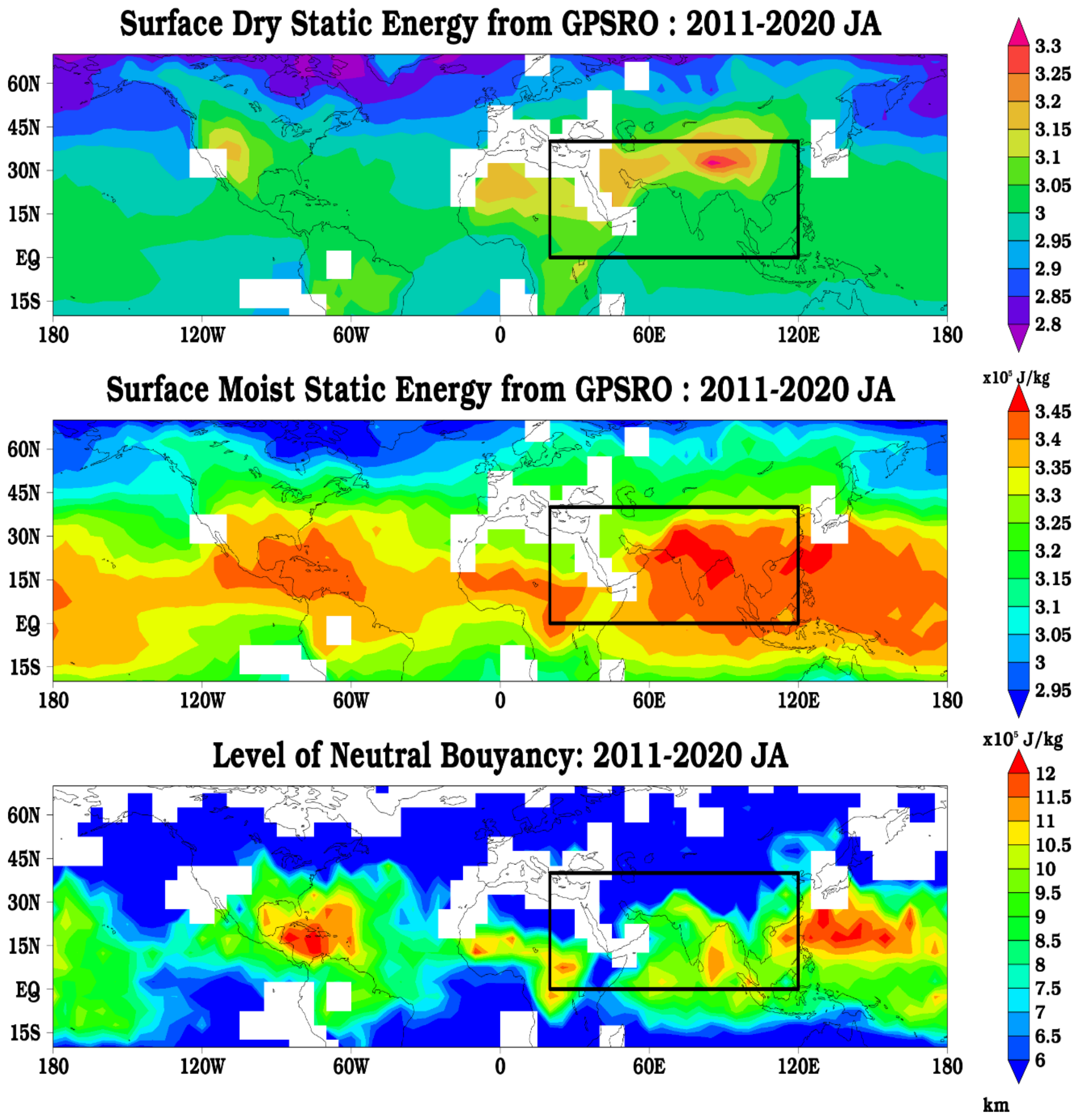
Results: Convective outflow level

The surface mean dry static energy (DSE) map shows higher value over the Tibetan plateau region with a value of ~ 3.3×10^5 J/kg. The high values extend further to the Iranian plateau and the deserts in the African region.

Consistent with the latent heat flux convergence, the surface MSE is also highest (>3.45×10^5 J/kg) over the South Asian (Indo-Gangetic Plain) and WP region

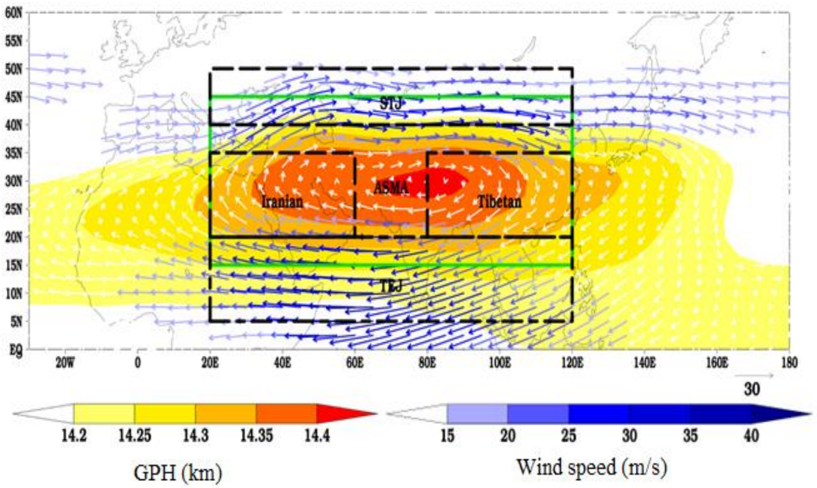
The LNB map suggests that the WP, NAM regions, African regions have the outflow ~12 over the Bay of Bengal and the central Indian region was relatively lower at ~ 11.5 km.

This indicates that the vertical upliftment of lower tropospheric air through the convective system over the ASMA region is redistributed at approximately 11 km (~ 200hPa) (Mehta et al., 2008; Gettelman et al., 2010; Paulik and Birner, 2012).



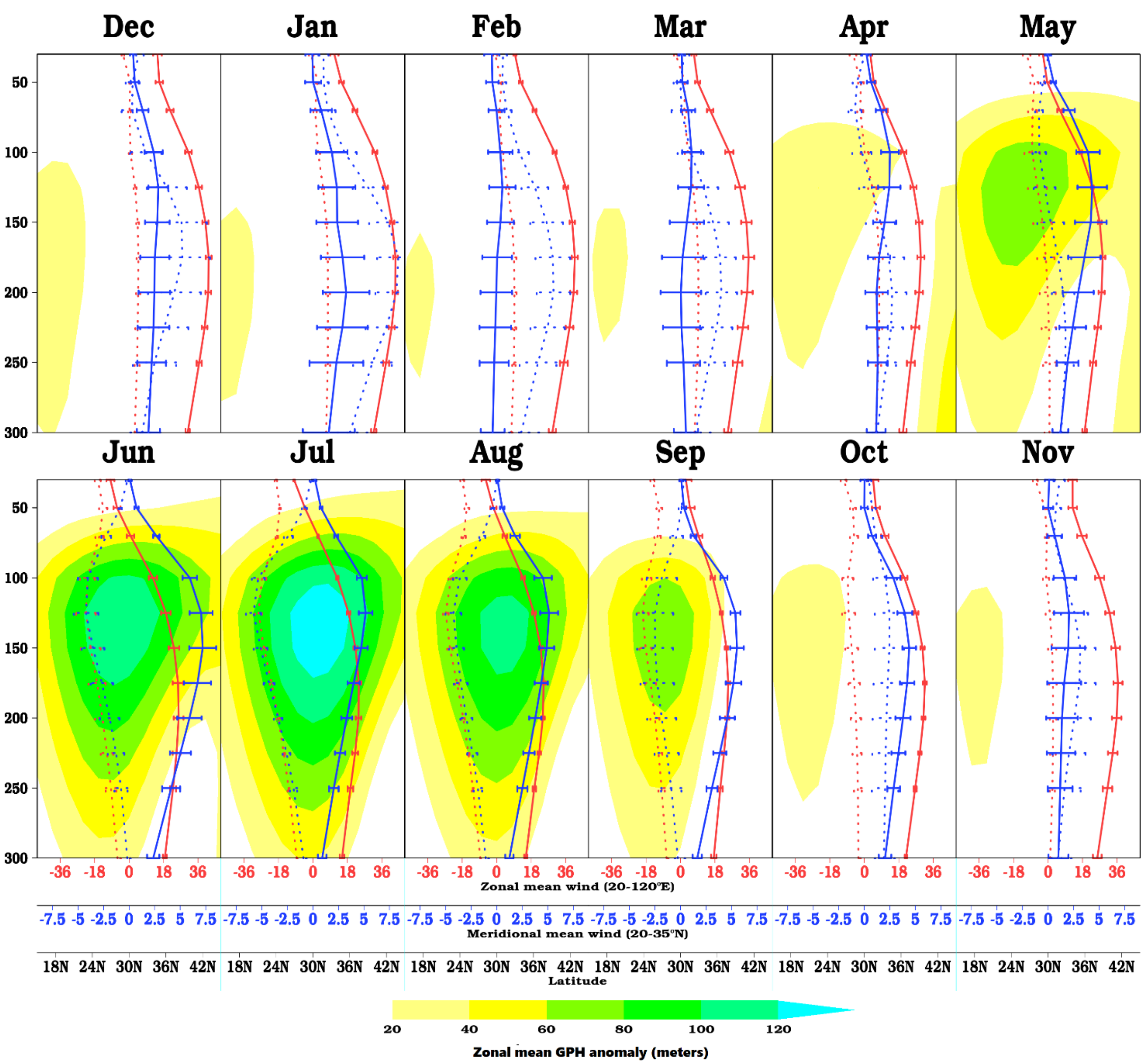
- Higher MSE over the Indian region.
- Higher LNB over the WP region.

Results: Wind around ASMA



The monthly mean meridional wind averaged over the Iranian Plateau (v_{ip}) region in the west of the ASMA region flows northward while over the Tibetan Plateau (v_{tp}) in the east of the ASMA region flows southward between 100 hPa to 150 hPa during the monsoon months.

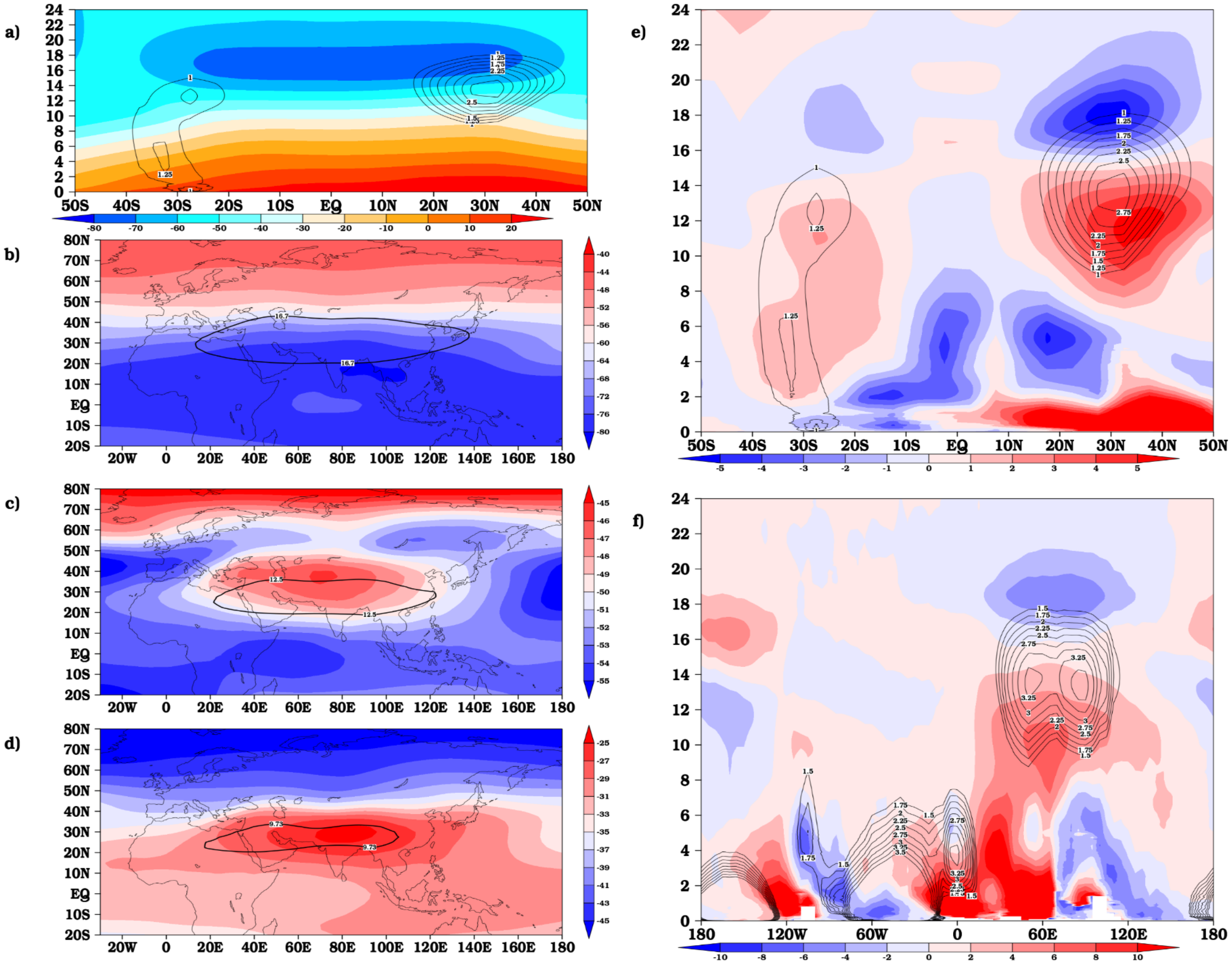
Both v_{ip} and v_{tp} are related to the variability in the strength of easterlies (TEJ) and westerlies (STJ) during the summer monsoon.



- Solid Red: Poleward side (includes STJ)
- Dotted Red: Equatorward (includes TEJ)
- Solid Blue: Western side (Iranian plateau)
- **Dashed Blue: Eastern side (Tibetan plateau)**

Results: Temperature distributions around ASMA

- **a**: mean GPSRO temperature 2011-2020 JA. The contours show the zonal anomaly of pressure averaged between 20°-120°E longitudes.
- **b, c, and d**: mean temperature at 100 hPa, 200 hPa, and 300 hPa using ERA5 during 1991 – 2020 JA. The contours in the figure show the GPH extent at each level.
- **e:** mean GPSRO dry air temperature zonal anomaly
- **f:** mean GPSRO dry air temperature meridional anomaly. The contours in the figure show the zonal anomaly of pressure averaged between 25°- 40°N latitudes.

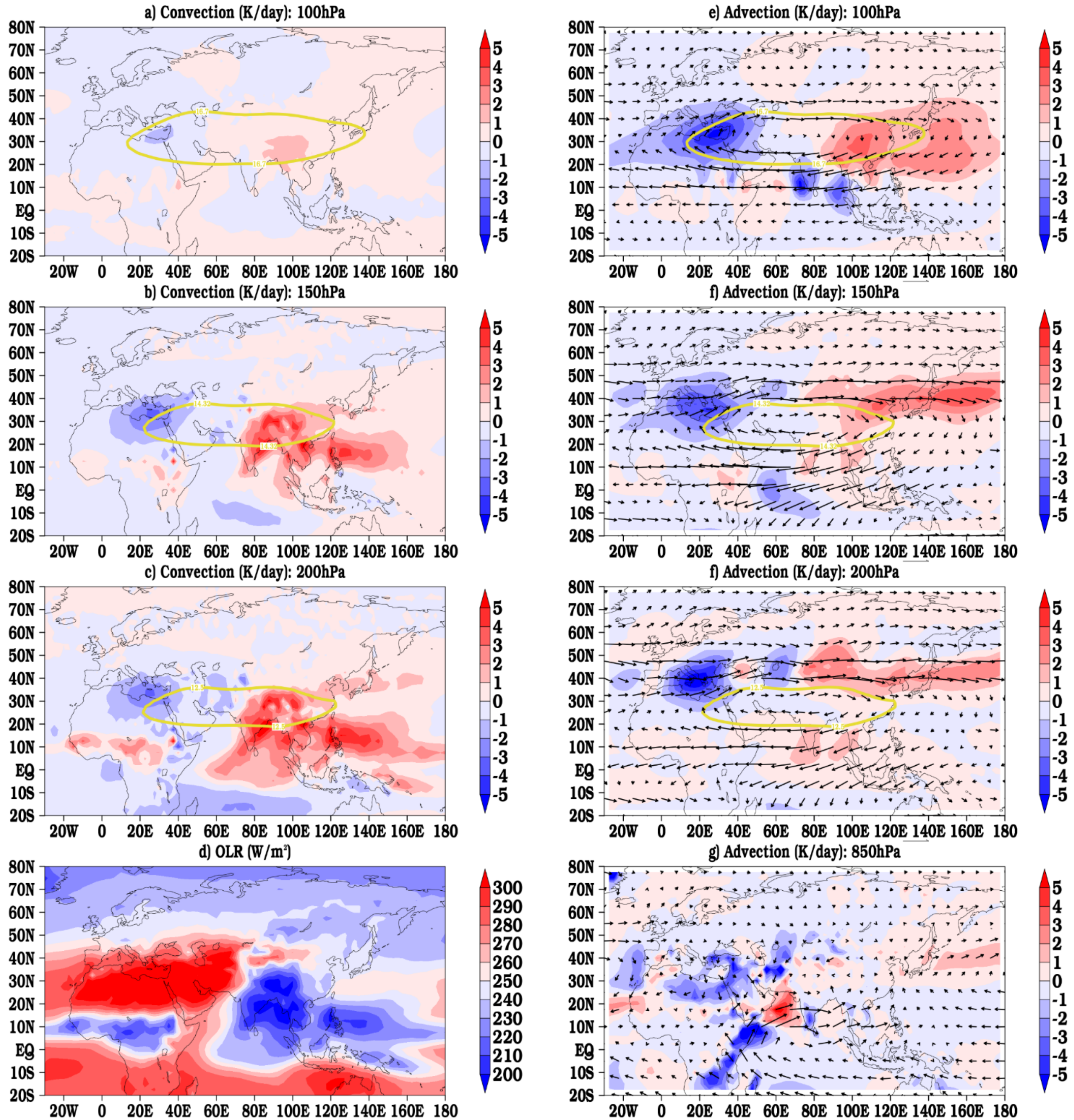


Results: Convection and Advection

To understand the formation and sustenance of the ASMA, we have calculated the advective and convective terms using thermodynamic equation. Positive and negative values of convective terms indicate convection and subsidence, while positive and negative values of advective terms indicate warm and cold advections, respectively.

It clearly demonstrates the cold advection between 0° - 70° E longitudes while the warm advection to the east of 70° E longitudes.

It indicates that the ASMA is associated with the cold advection on its western edge and the warm advection on the eastern edge.

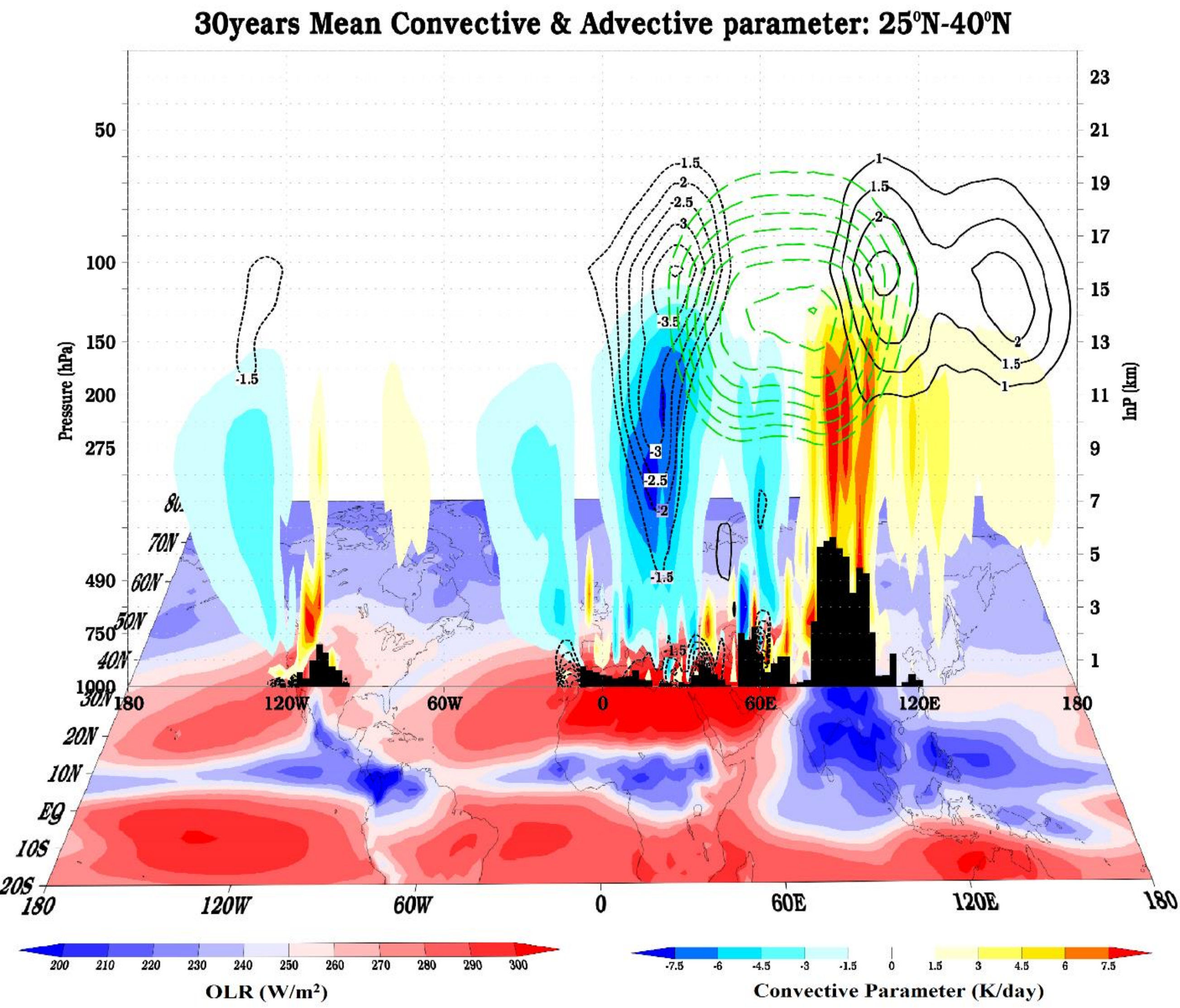


Results:

It shows the height–longitude cross-section of the convective and advective terms from surface to 30 hPa, averaged over 25° N-40° N latitudes, extending globally from 120° W longitude to the east.

It can be seen that the WP region (120° -160° E) and the North American region (~90° -60° W) show the highest LNB, which is similar to the findings from (Takahashi et al., 2017).

The figure further illustrates a stronger convective term, with a positive magnitude of up to 5 K/day and a negative magnitude reaching up to 4 K/day above the mean LNB levels.
The mean advective term has a core magnitude higher than 2.5 K/day for a positive term and up to 4 K/day for a negative term. It is further understood that the advective term has a vertical extent up to 70 hPa or ~20 km in altitude, with the negative term having more extended to the lower levels.



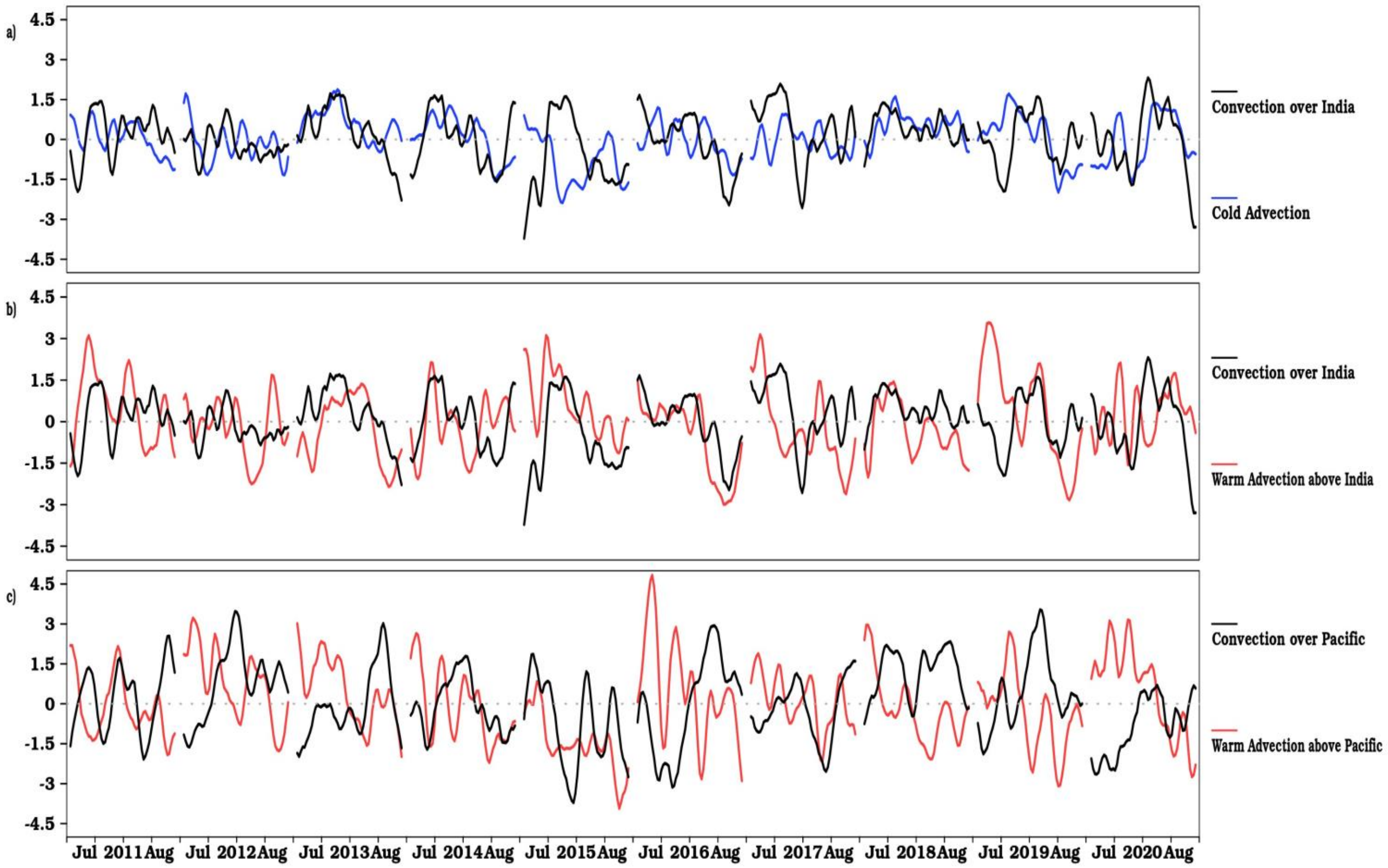
Results: The relative role

The day-to-day relationship between the convection over the Indian region and the cold advection over the 0-55 E. It can be seen that the variability of cold advection is very well aligned with the convective patterns over India.

The convection and warm advection variability above the Indian region. The convection and warm advections over the Indian region are related for all the years except the years 2017 and 2019.

The relationship between the convection and warm advection over the WP. It is observed that the convection and advection over WP are mostly out of phase except for a few years.

Thus, it indicates that the wind variability at the upper troposphere is strongly influenced by the convection over the Indian region in contrast to the WP region.



5-day (±2days) running mean anomaly of

- Cold advection: averaged between 0°-55°E longitude.
- Warm advection above India: averaged between 75°-110°E longitude.
- Warm advection above Pacific: averaged between 110°-145°E longitude.
- Convection over India: (OLR/10) averaged between 70°-110°E longitude.
- Convection over Pacific: (OLR/10) averaged between 110°-155°E longitude.

Cold advection and convection are shown by negative of their anomalies.

Summary

- The important findings from this study are as follows:

1. The meridional and zonal winds bounding the ASMA and the vertical motion underneath play a crucial role in its formation and sustenance.
2. The ASMA is thermodynamically characterized by the warm advection to the east and the cold advection to the west across the altitude and the convection underneath which degrades with altitude.
3. The convective outflow level is deeper over the WP region (~11.5 km) compared to the Indian region (10 km) even though later is frequent convection during the summer monsoon season.
4. The ASMA region is characterized by a core of cold advection to its eastern edge and two cores of warm advection to its western edge. The cores of the warm advection in the west are stronger over the Indian region and weaker over the WP region. The warm advection extends vertically from ~200 hPa to ~70 hPa, whereas the cold advection extends from ~500 hPa to ~70 hPa.
5. The cold advection is associated with the subsidence region while the warm advection is associated with the convective region over the Indian monsoon and WP regions. Convection mainly dominates over the Indian and WP regions. The cold advection over the subsidence region and warm advection over the Indian region is closely related to the convection over the Indian region and vice-versa.

Thank you for your kind attention