Understanding the stratosphere-troposphere exchange processes through the direct measurements of vertical air motion over central Himalayas using 206.5 MHz Stratosphere-Troposphere Radar

By

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Background

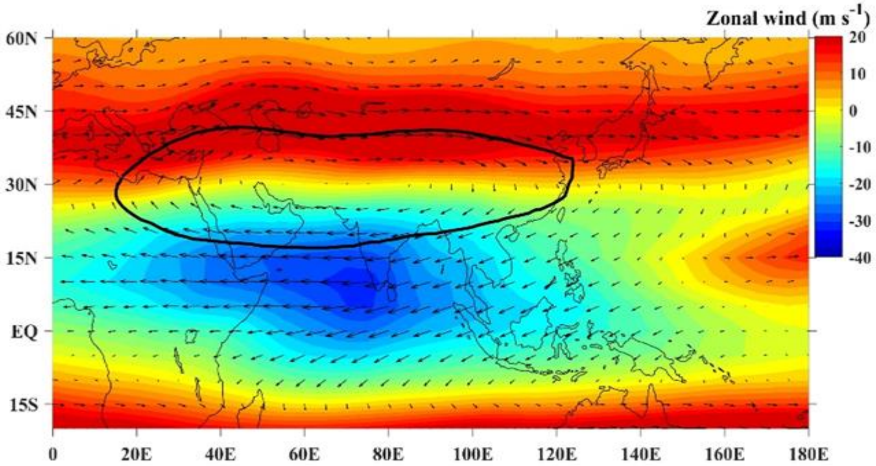


Figure 1. *Intensity map of zonal wind along with wind vectors at 150 hPa during July showing the region of Asian Summer Monsoon.*

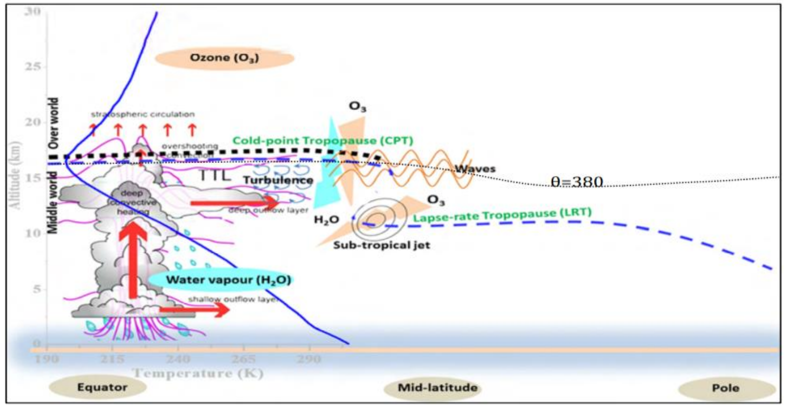


Figure 2. *Different processes leading to stratosphere-troposphere exchange. (Courtesy : Suneeth)*

- The Asian Summer Monsoon(ASM) is one of the most significant climatological features on earth. It being more pronounced than other monsoon systems.

- A very significant feature of this ASM is the associated cyclonic convergence at the lower levels and corresponding anticyclone and divergence at the higher levels (~200-100 hPa levels) extending from around ~15°-45° N and 20°-120° E, which stays active significantly through the months of June to September.

- ASMA is facilitated as a result of the thermal contrast due to the high Tibetan Plateau (TP) and is driven by the diabatic heating due to persistent deep convection of the South Asian monsoon region.

- It plays an important part as a mixing vessel of tropospheric and stratospheric air masses and facilitates Stratosphere-troposphere exchange processes through vertical exchange of momentum and energy between air masses.

Motivation of study

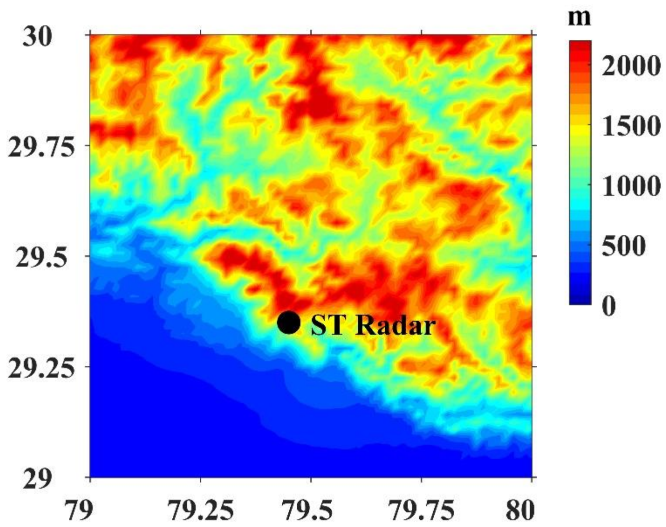


Figure 3. *Orography of Nainital region and the ARIES ST Radar*

Figure 4. *ARIES ST Radar (Nainital)*

- *Nainital* in the central Himalayan region is a region of interest owing to it's location inside the ASMA during the monsoon months and the presence of strong STJ above it in the winter.
- Extensive studies have been done based on balloon-borne in situ and satellite based measurements but direct, precise and high resolution measurement of vertical velocity had not been done.
- The 206.5 MHz ARIES ST Radar (29.35°N, 79.45°E) provides high resolution wind data especially the vertical component *w*.

The radar has facilitated some event based studies often spanning days and weeks in the recent past but there are no long term study as of yet.

The unique topography of this region brings new opportunities along with challenges!

The aim is to utilise the long term radar data to characterise the climatology of w and understand it's direct role in the prevailing dynamics and STE processes.

Overview of the prevailing dynamics of the region

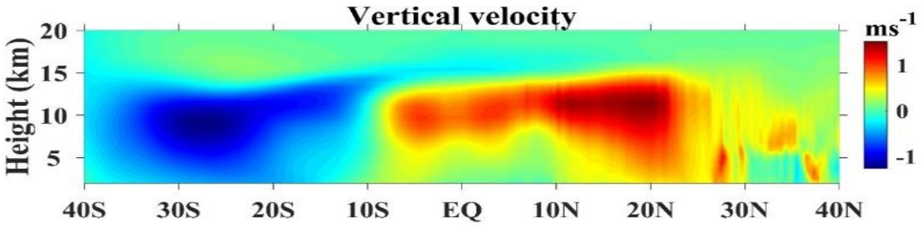


Figure 5. *Climatology of vertical velocity over Indian Subcontinent during JJAS*

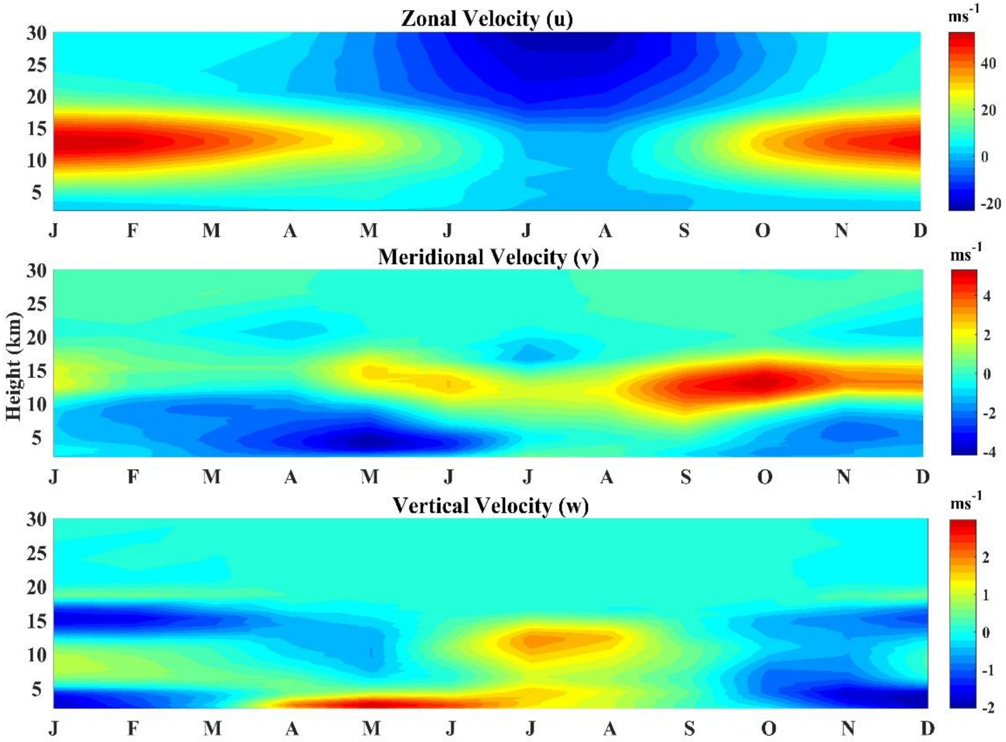


Figure 6. *Climatology of wind velocity over Nainital from 1979-2023 using ERA5 reanalysis data*

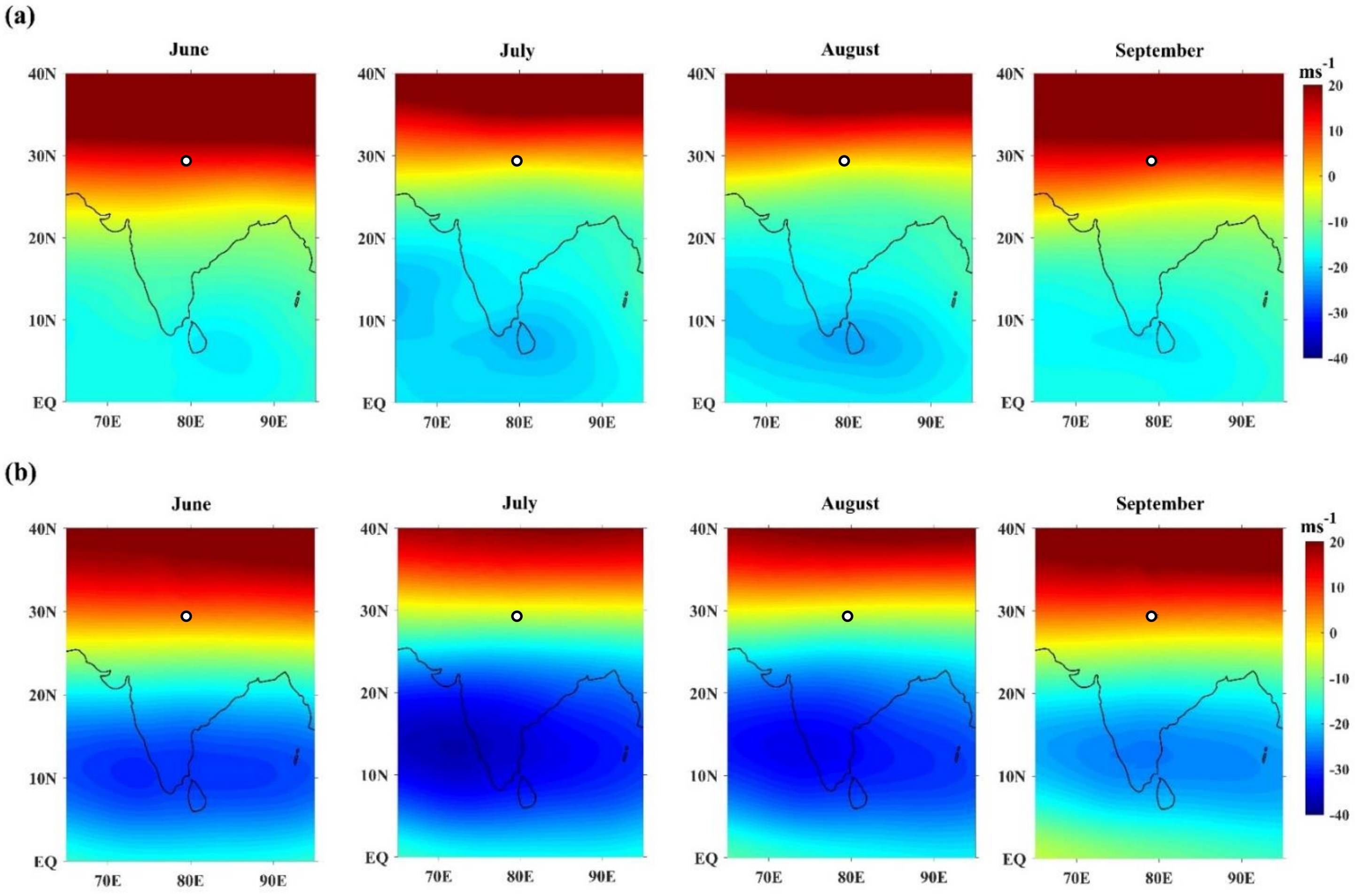
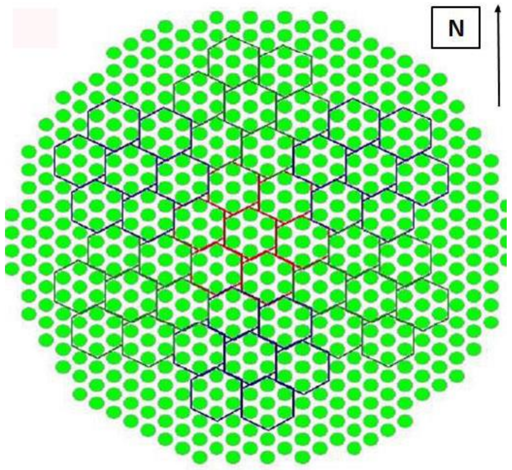


Figure 7. *Zonal velocity over the Indian Summer Monsoon region during JJAS at (a) 12 km (b) 16 km heights clearly showing the reversal of direction of wind around ASMA and the linked TEJ in the lower latitudes , white circle marked is ARIES ST Radar (29.35°N, 79.45°E)*

The 206.5 MHz ST radar



Location	29.45°N, 79.45°E
Probing Frequency	206.5 MHz
Antenna array	588 3-element Yagi-Uda antennae in 12 hexagonal clusters in a quasi circular array
Peak power	235 kW
Antenna aperture	419 m^2
Max duty cycle	13 %
Beam width	3.3°

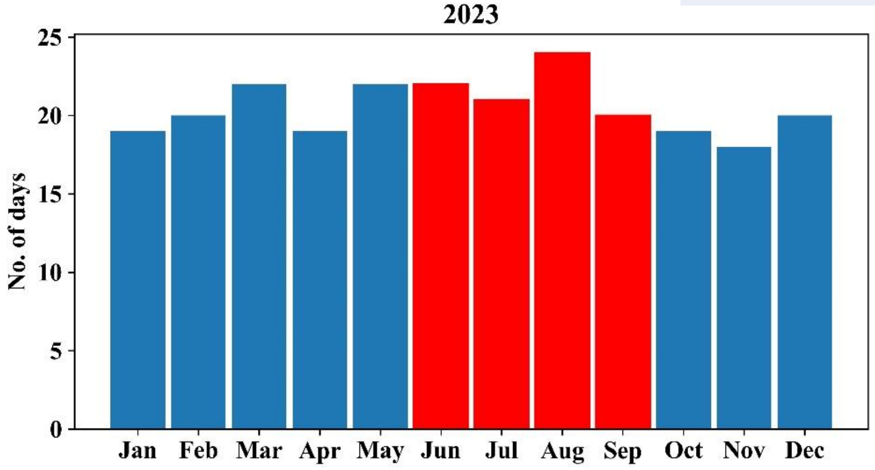


Figure 8. *Data availability for 2023, similar statistics are seen for 2021 and 2022 too.*

- Long term data across all months of a year is available from 2021 onwards.
- Special experimental campaigns and event based cases are present too.
- General time of operation is from 9 LT to 18 LT, besides some diurnal runs in some months.

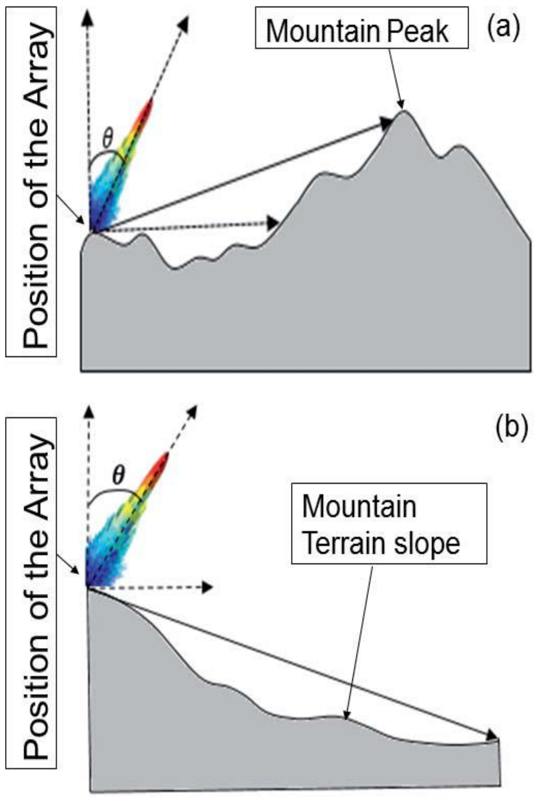
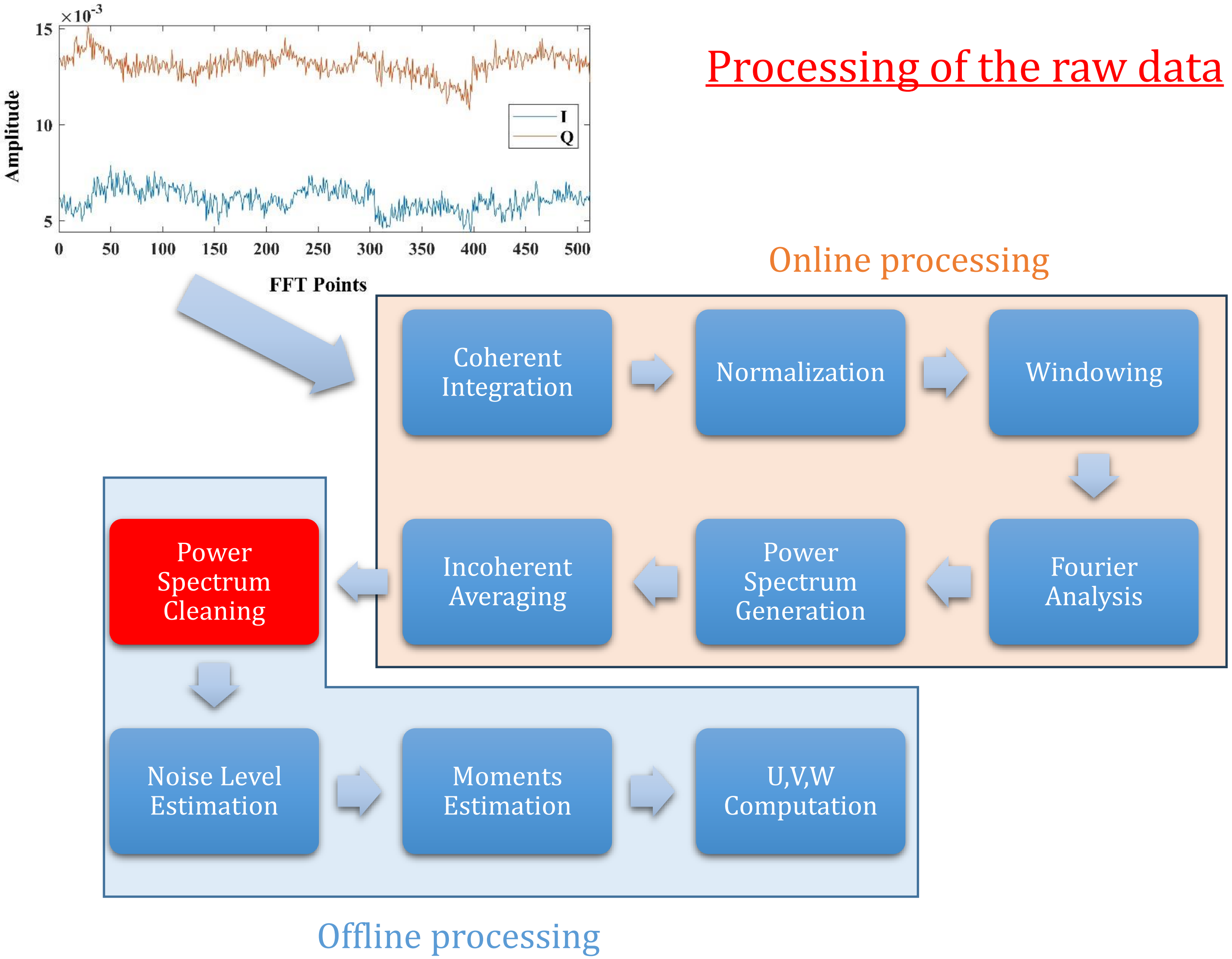
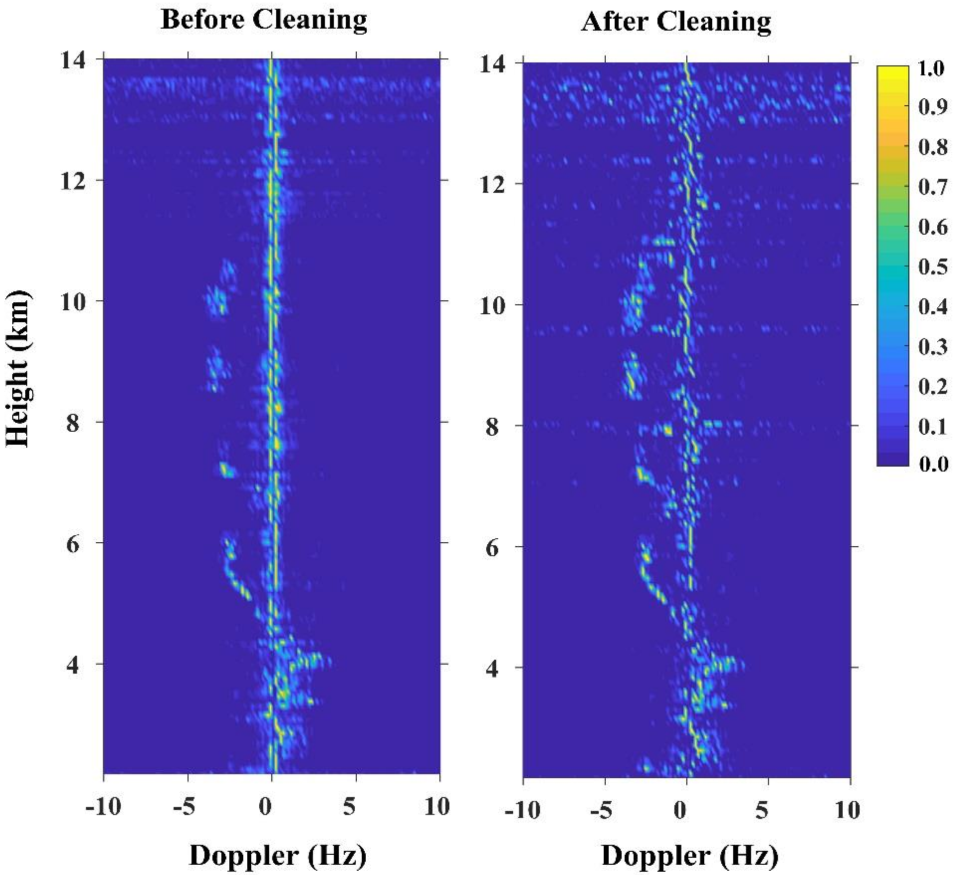


Figure 9. *Topographical challenges around the radar site (a) towards north (b) towards south east (Bhattacharjee et al. 2020)*

Data Analysis and Spectral Cleaning

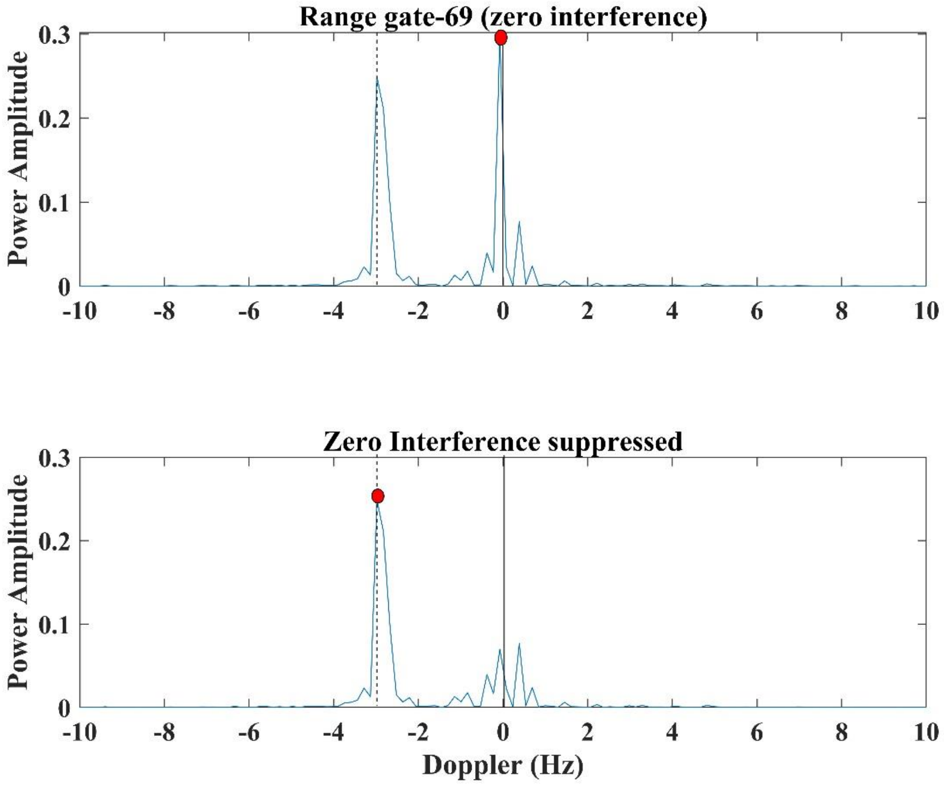




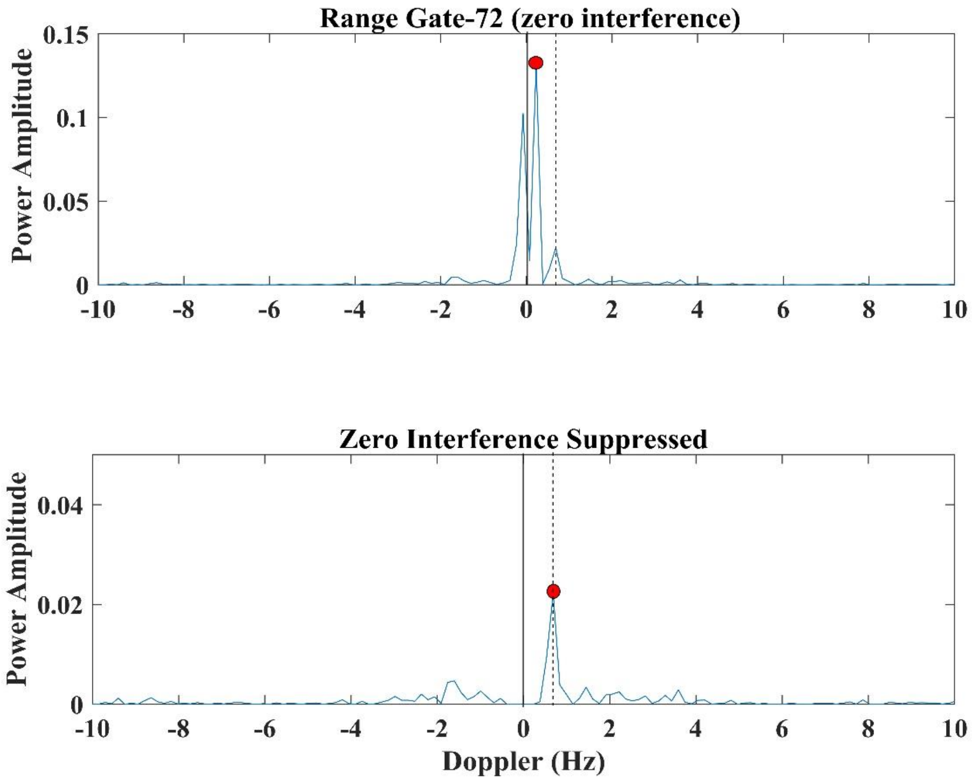
Presence of clutter mainly due to the terrain makes cleaning of the spectrum necessary to obtain a correct profile .

Suppression of Clutter

(a) East 15° Beam



(b) Zenith Beam



One main source of error is the zero interference induced due to the terrain besides clutter.

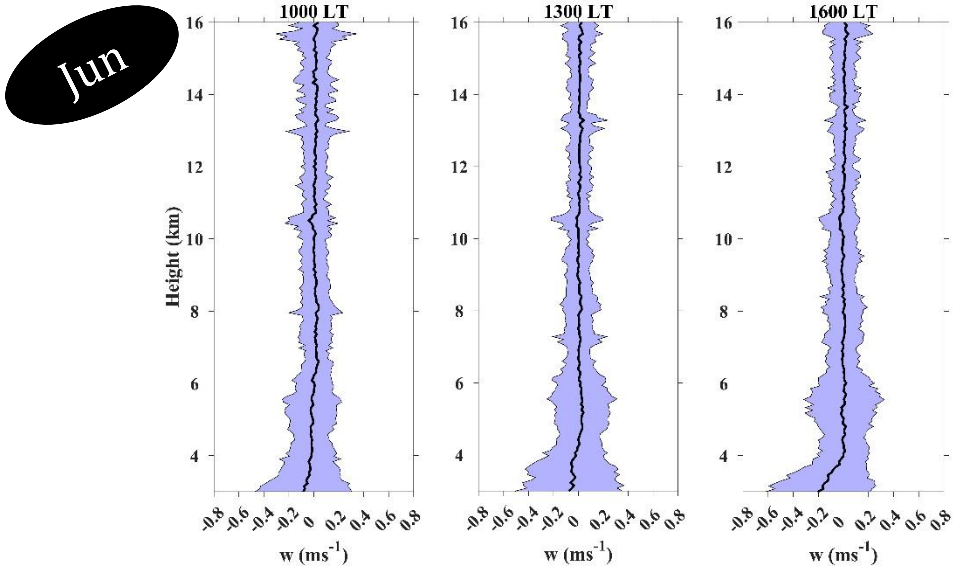
Unless this is tackled, we would infer wrong Doppler profiles.

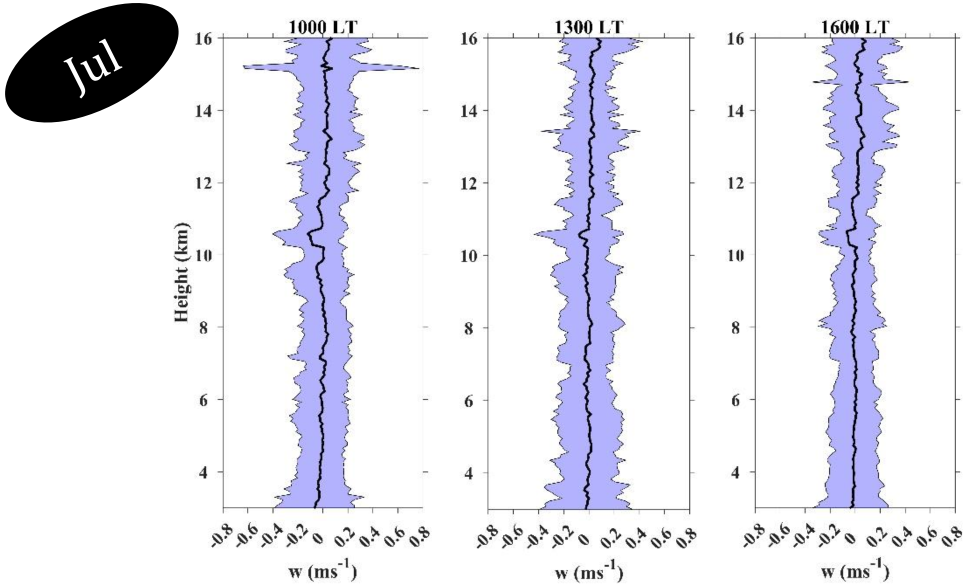
An algorithm was developed to somewhat suppress this to get a better trace of the signal for both zenith and off zenith cases.

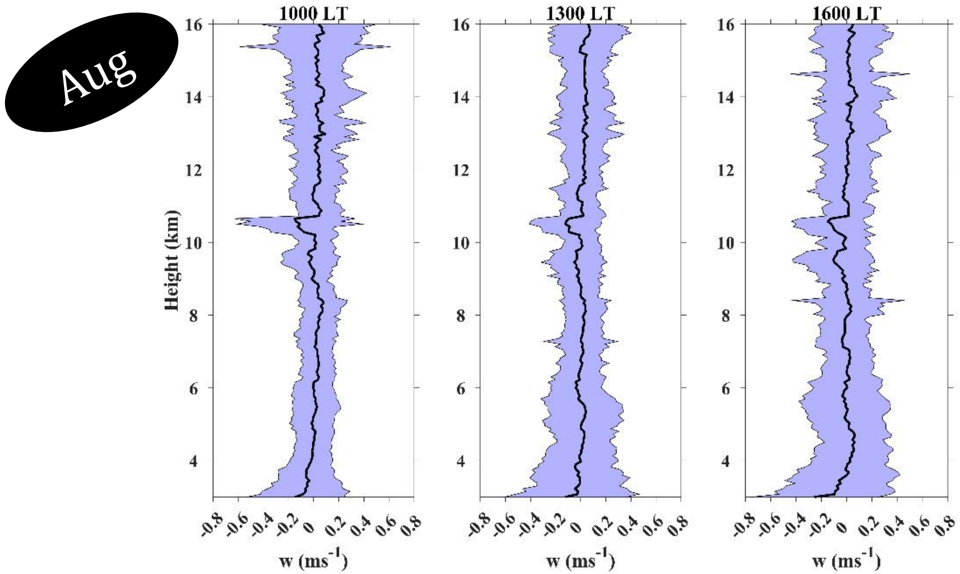
Results

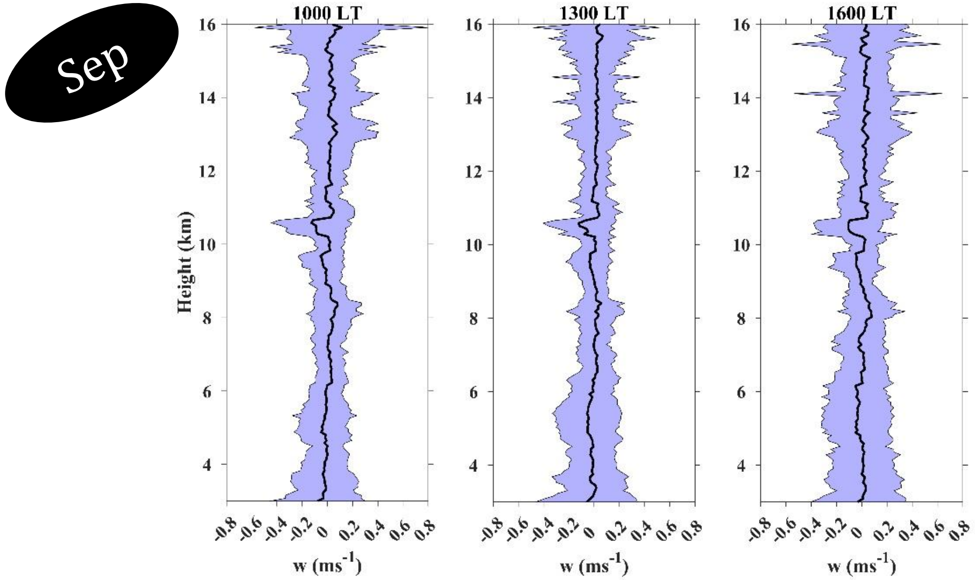
Analysis for the months of June, July, August and September (JJAS) 2023 has been compiled and their characteristics discussed here.

Monthly vertical velocity at different times of the day









Mean *w* for monsoon months

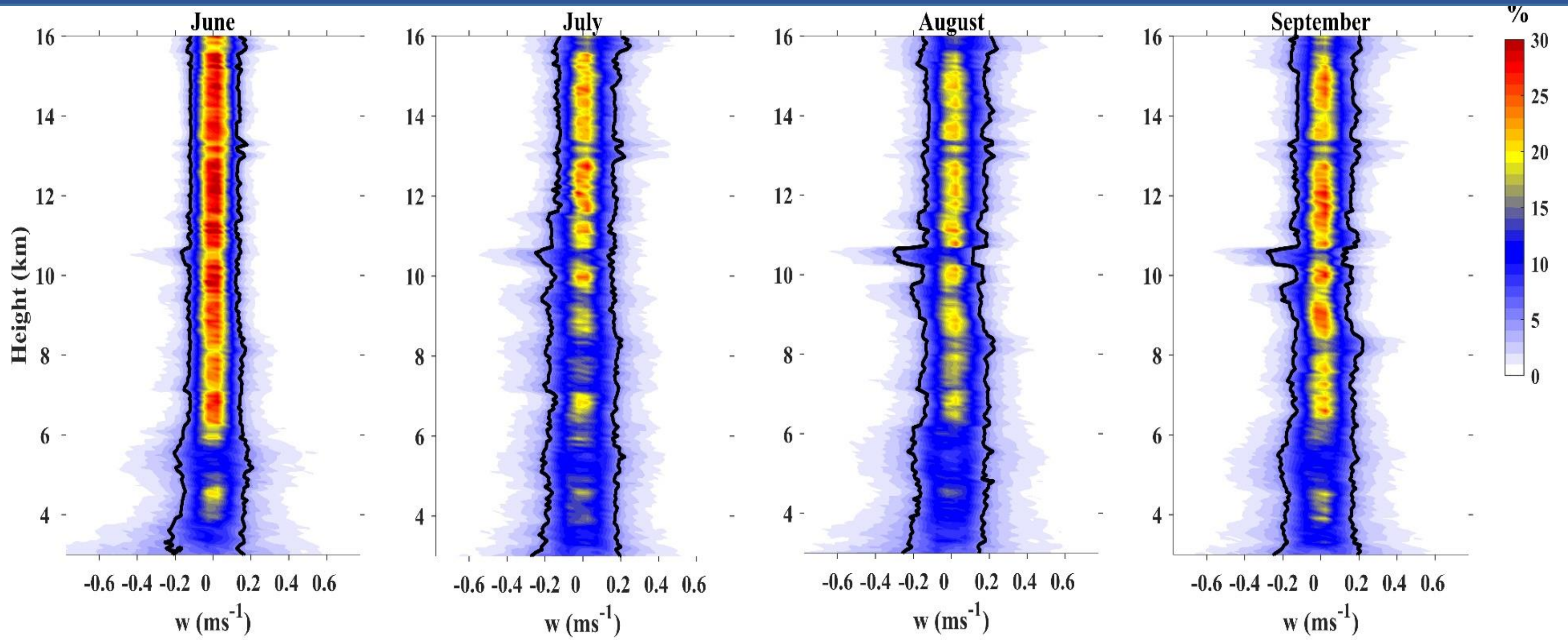


Figure 10. *CFAD showing the percentage occurrence of vertical velocity for each month during monsoon 2023.*

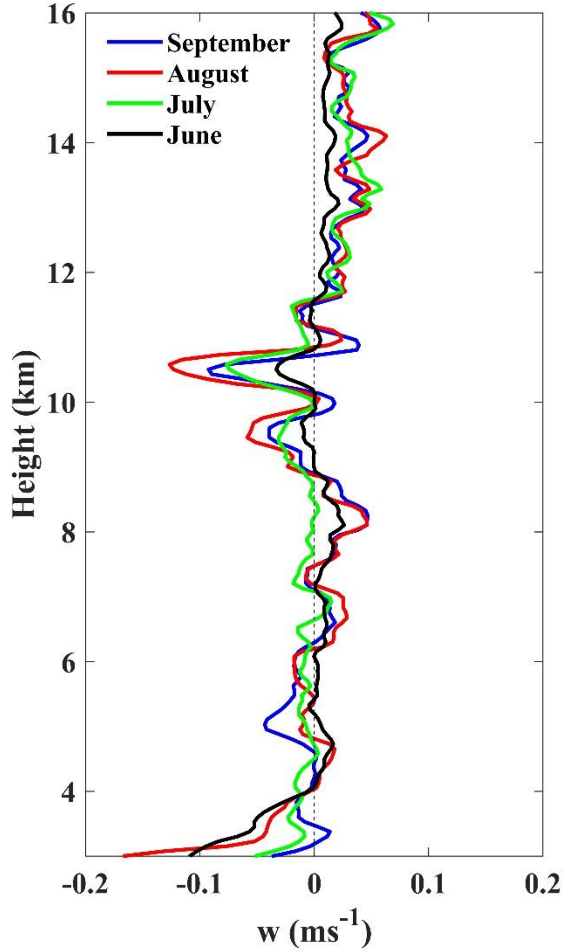


Figure 11. *Mean w profiles for JJAS 2023*

- Strong downdrafts are noted in the lower heights for all the four months.
- Greater spread in percentage occurrence of w is noted for higher heights in July, August as compared to June and September.
- A layer of strong downdraft is noted between 10-11 km for the months.
- Higher heights show slight updraft characteristics.

Mean *w* at different time periods of a day during monsoon

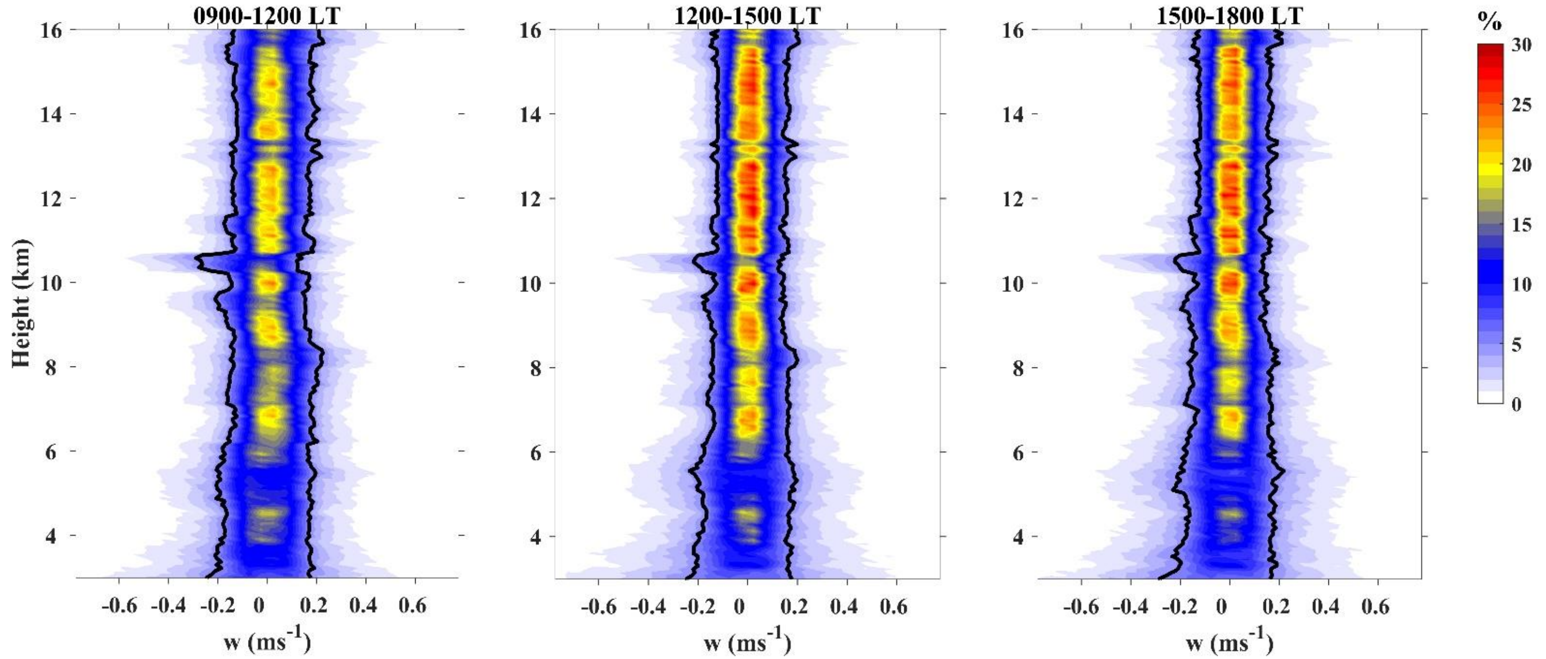


Figure 12. *CFAD showing the percentage occurrence of vertical velocity for three different time periods during JJAS*

- Downdraft strength below 6 km is similar for all the early noon, afternoon and evening time.
- Spread in percentage occurrence of w is minimum for 12-15 LT as compared to 9-12 LT and 15-18 LT.
- Similar downdraft characteristics at 10-11 km exists for all the three time periods.

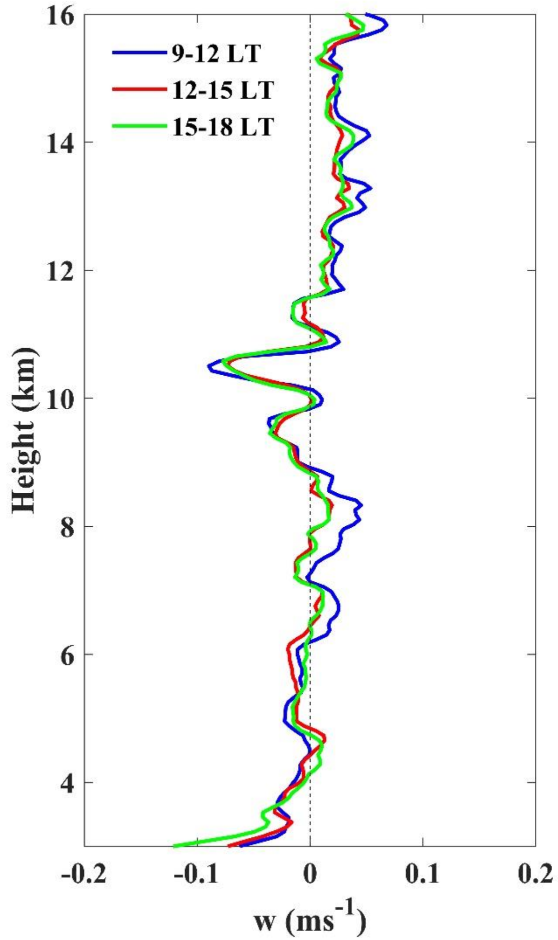


Figure 13. *Mean w profiles for 9-12 LT, 12-15 LT, 15-18 LT for monsoon period.*

Evidence of stratosphere-troposphere interaction process

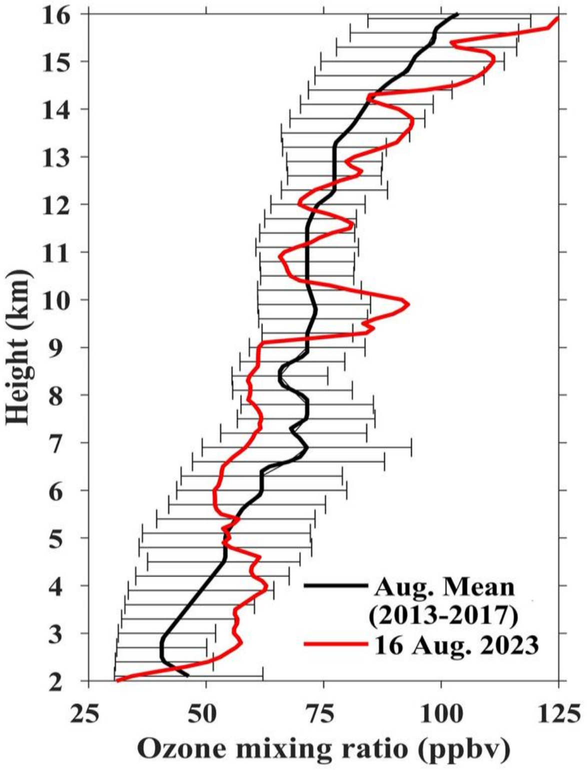


Figure 14. *Height profiles of ozone mixing ratio at 1:30 IST on 16 August. 2023 along with 5-years mean.*

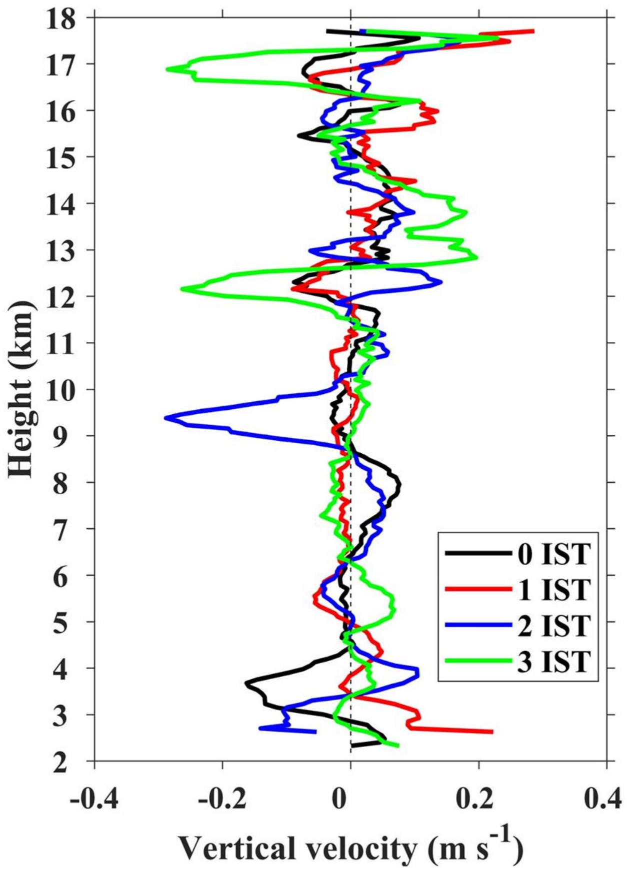


Figure 15. *Height profiles of mean vertical velocity at different timing on 16 August 2023.*

- A remarkably high ozone concentration in the upper and middle troposphere region is observed inside the Asian Summer Monsoon Anticyclone (ASMA) region.
- Corresponding to this enhanced layer of ozone, a layer of low RH was also detected, implying ozone rich and dry air from stratosphere.
- ST-radar observations shows the presence of strong downdrafts (~9-10km) in the vicinity of enhanced ozone.

Conclusion and further plans

- The present study shows the direct measurement of vertical air motion during the Indian Summer Monsoon over the central Himalayan, which is inside the ASMA region.

- Analysis shows the presence of downdrafts below 4 km, updrafts between 7-9 km and strong downdrafts between 10-11 km. Above the 12 km, which corresponds to Convective tropopause (COT), updrafts were always observed. These observations were consistent for all the four months, i.e. June-September.

- Preliminary analysis shows that the air parcel from the surface to the upper troposphere and lower stratosphere over the Central Himalayan also goes in ***two step process*** as proposed earlier for tropics.

- The results shown here cover a single year analysis, but in order to have a more complete picture, this analysis will be extended over a period of five years.

- In addition, balloon borne experiments over Nainital have been conducted alongside space observations of ozone and water vapour, analysis for which are underway.

Thank you !