आर्यभट्ट प्रेक्षण विज्ञान शोध संस्थान
ARYABHATTA RESEARCH INSTITUTE OF OBSERVATIONAL SCIENCES
(AN AUTONOMOUS INSTITUTE UNDER DST, GOVT. OF INDIA)

Quantifying Momentum Flux Exchange in the UTLS region during deep convective processes over the central Himalayas using VHF Radar

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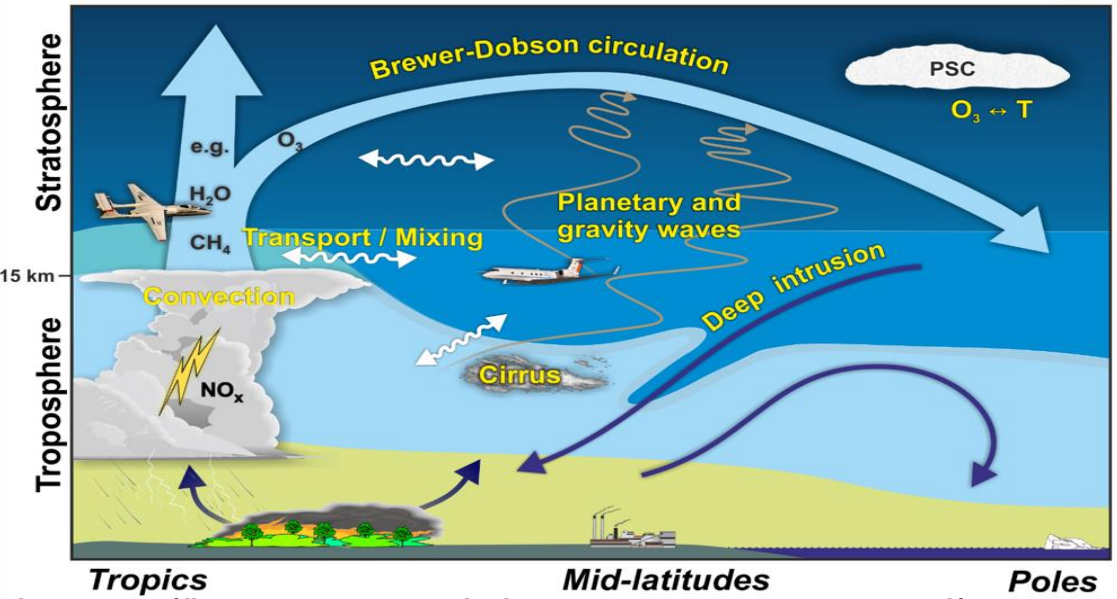
Motivation



https://www.gfdl.noaa.gov/wp-content/uploads/2019/12/06_Lin_FINAL_VERSION.pdf

Growth of Cumulus tower over mountains

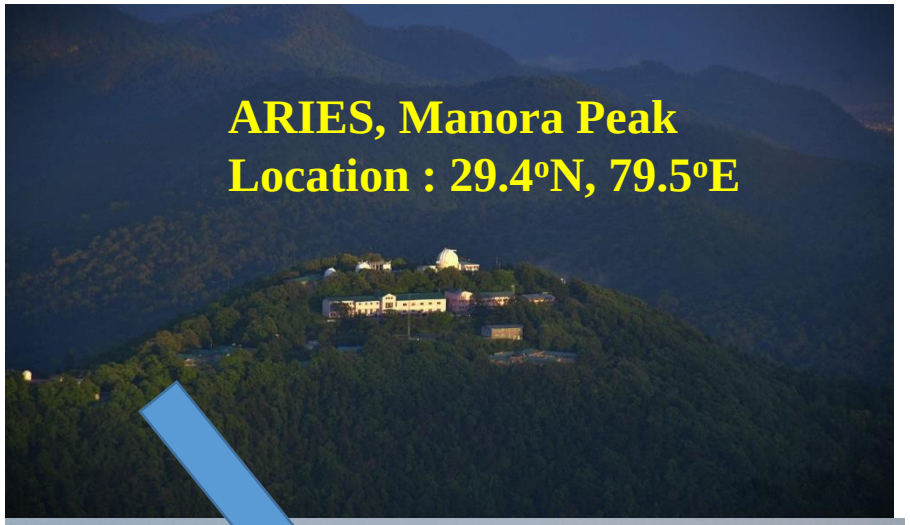
Alternate bands of clouds and clear air due to wave propagation

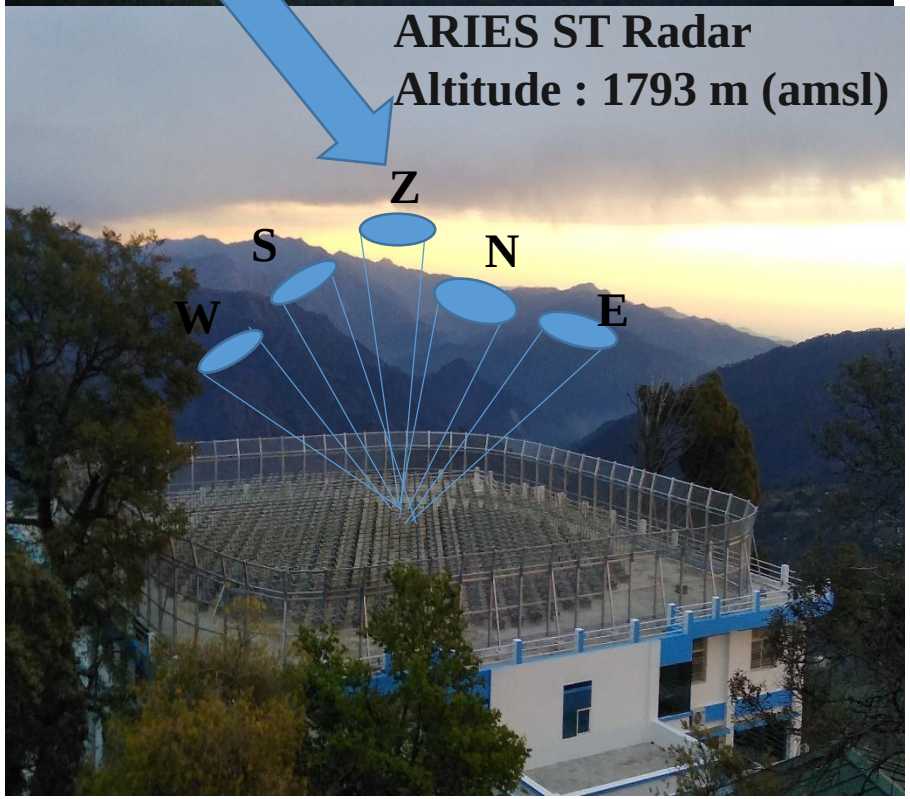
- Deep convective processes provide the efficient pathways for the transport of the tropospheric airmass to the stratosphere.
- Transported trace species are confined in the UTLS region by the ASM anticyclone and affects the radiative balance of the atmosphere.
- Large scale circulations like Brewer Dobson are driven by the dissipating waves of tropospheric origin. Hence, it is required to estimate the wave forcing through its momentum flux budget.
- Planetary waves : can be conveniently studied using satellite datasets.
- Internal gravity waves: Most important contributor to the momentum budget in summer/ winter hemisphere (Houghton, 1976). These are usually generated by deep convective processes.
- Probing of internal gravity waves requires the finer spatiotemporal resolution which is given by the Radar.

Stratosphere Troposphere Radar over Himalayan Region

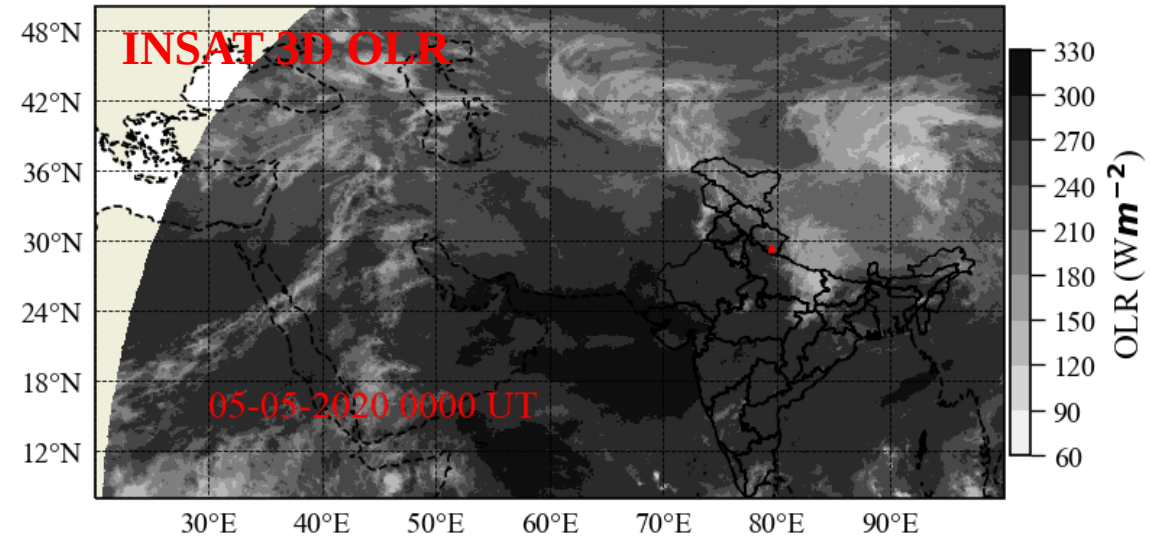
Operating Frequency	206.5 MHz
Power Aperture Product	1 x 10^8 Wm^2
Peak Transmitting Power	235.2 kW
Half Power Beam Width	3.3^o
Scan Angle (Azimuth)	0^o – 360^o
Scan Angle (Off-Zenith)	0^o – 30^o
Vertical Resolution	37.5 m, 75m, 150m
Height Coverage	0.5 km – 20 km (Nominal)
Mode of Operation	DBS

588 Tx /Rx Modules
Active Aperture Phased Array

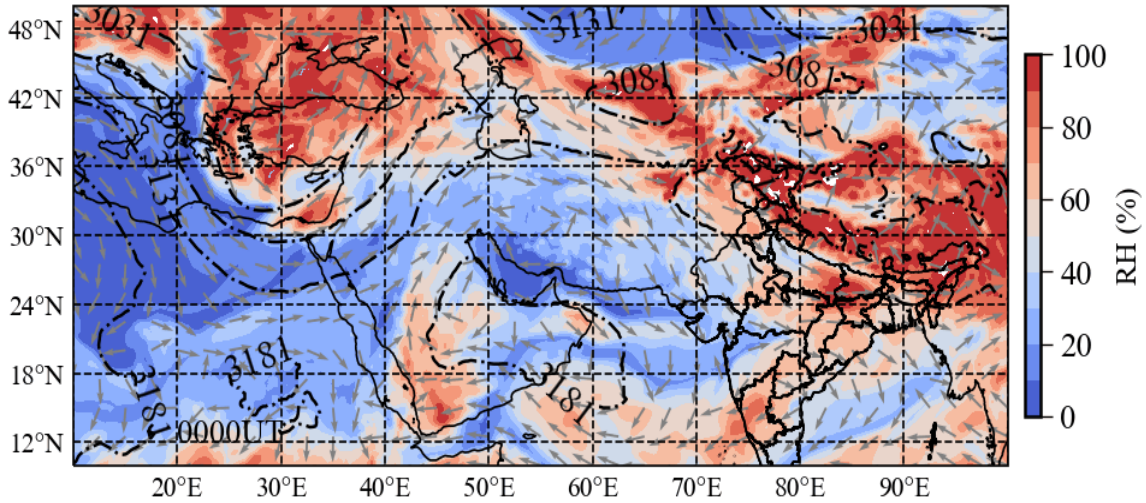




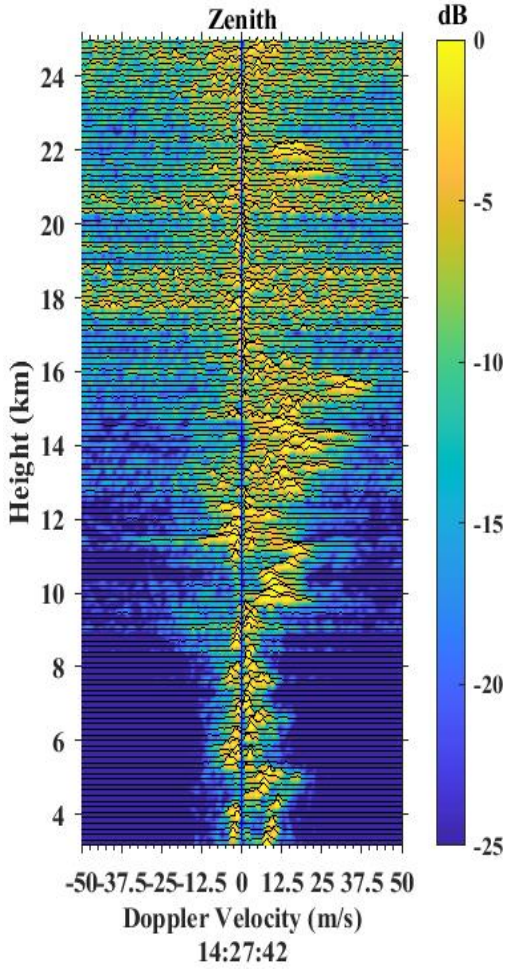
An Intense Deep Convective Precipitation System

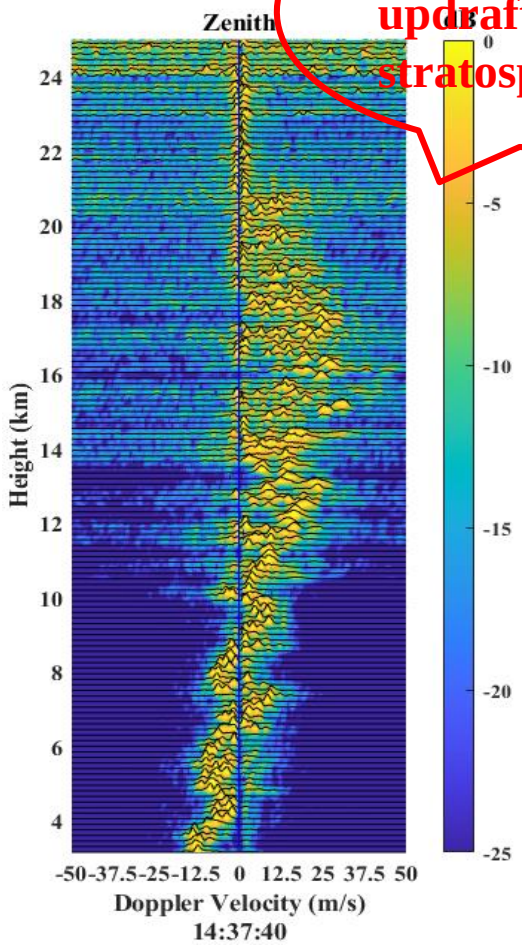


ERA5 Reanalysis



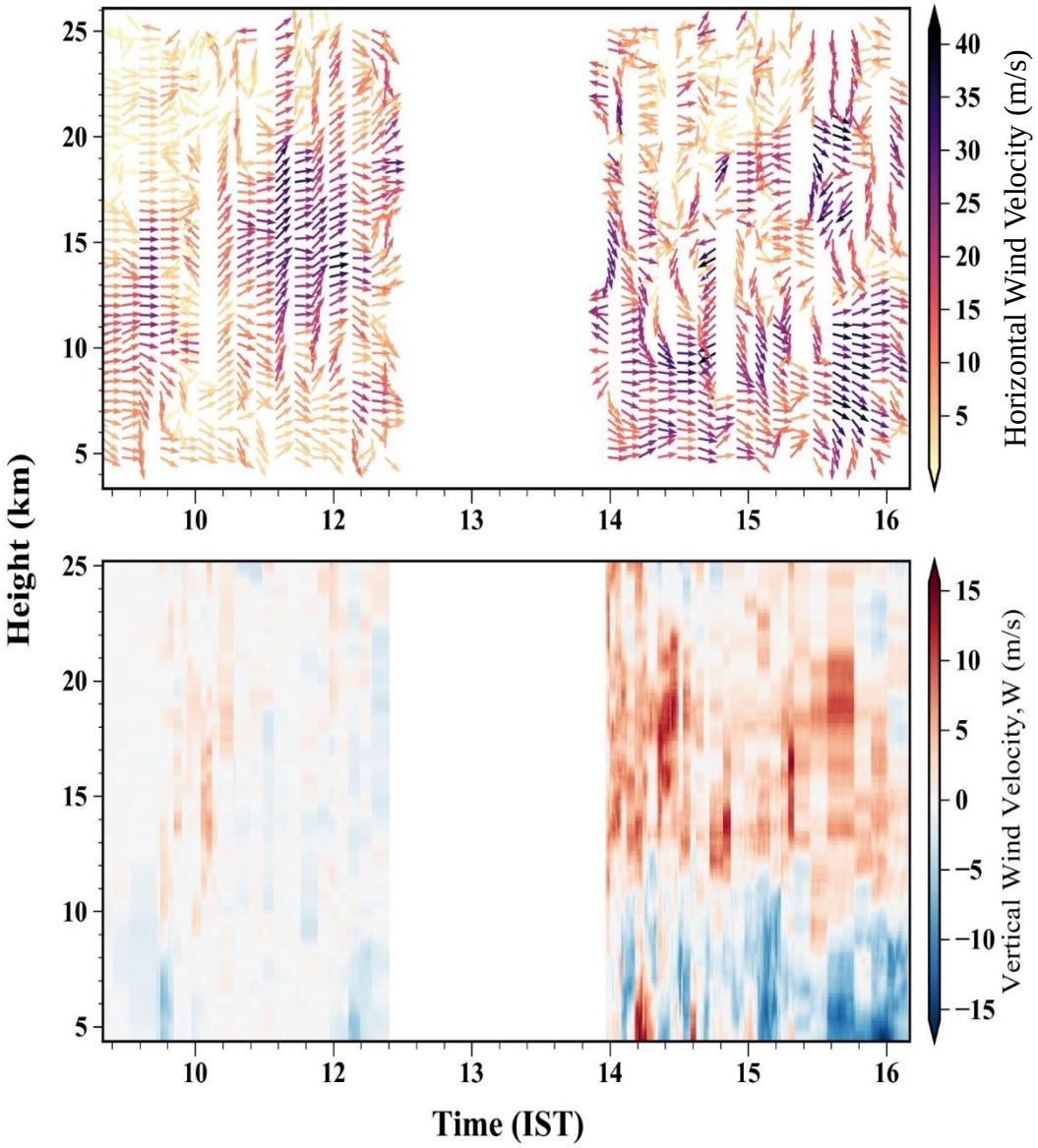
ST Radar Power During Convective Precipitation

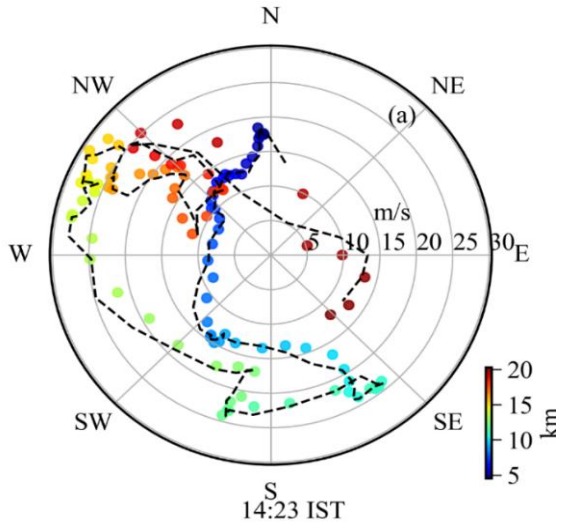


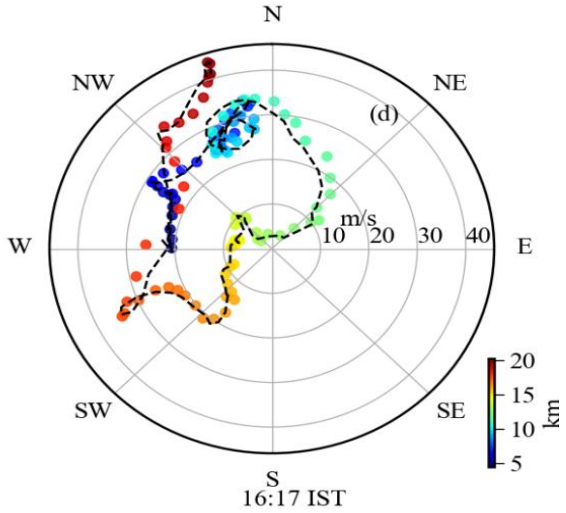


Penetration of updrafts in the stratosphere

Variation of Wind Field during Convection





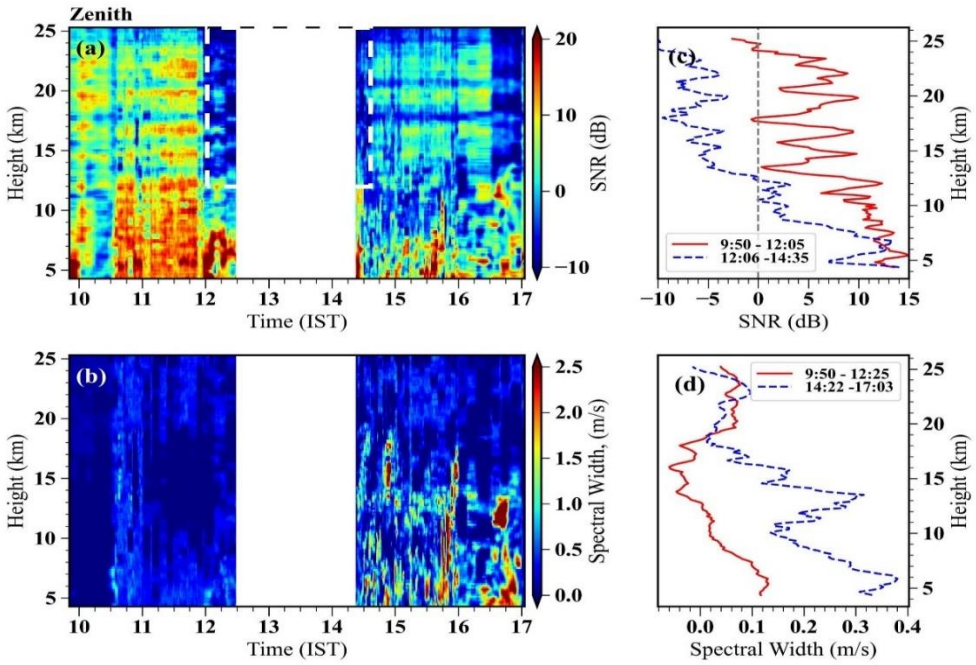


- Penetrative convection in the Upper Troposphere and Lower Stratosphere region
- Separation of updrafts and downdrafts regions.

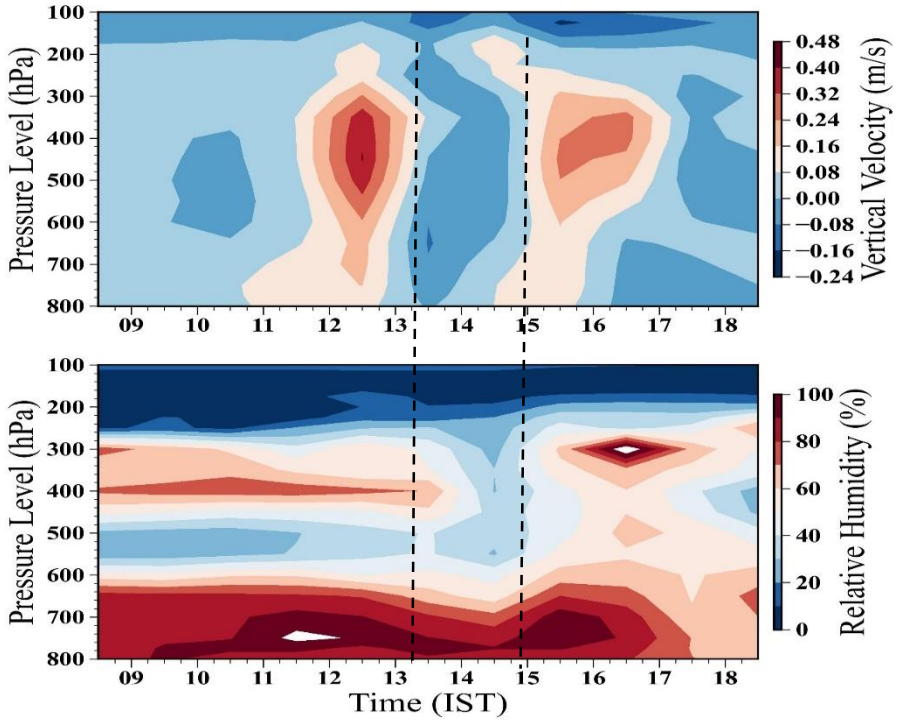
- Enhancement of wind speed in upper and lower tropospheric levels

- 'Veering' of winds from lower to upper tropospheric levels ----- Warm air advection

Weakening of Tropopause Structure and Stratosphere Troposphere Exchange

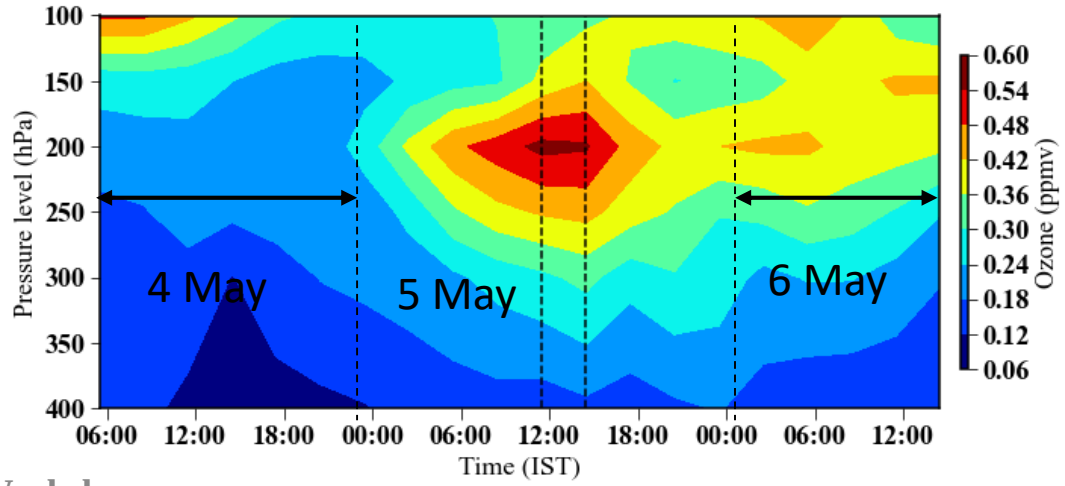


ERA5 vertical velocity and RH over the radar site



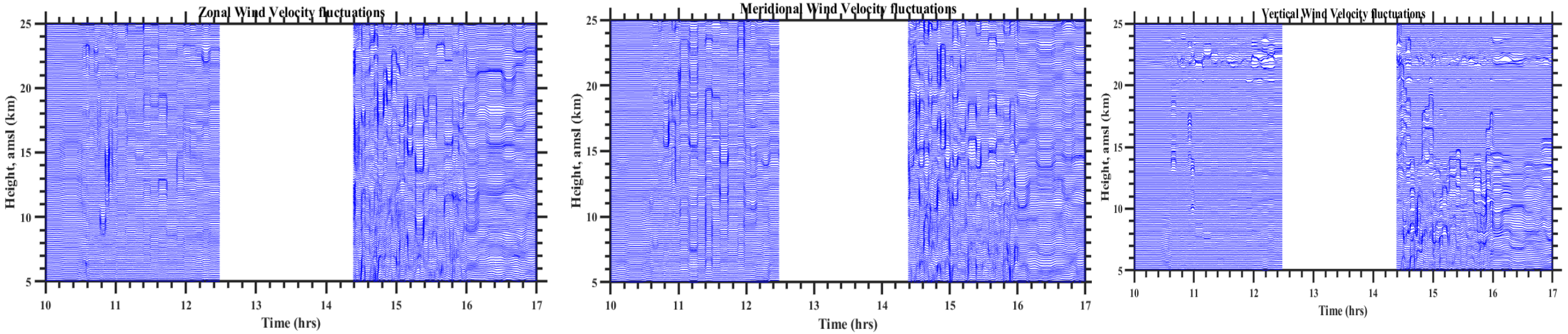
- Depletion of echo power in the regions of intense convective activity
- Weakening of stable layers around tropopause region.
- Enhanced turbulent mixing in UTLS region
- Intrusion of the drier stratospheric airmass and enhancement in O3 mixing Ratio up to mid-tropospheric levels

CAMS Data of O_3 Mixing Ratio

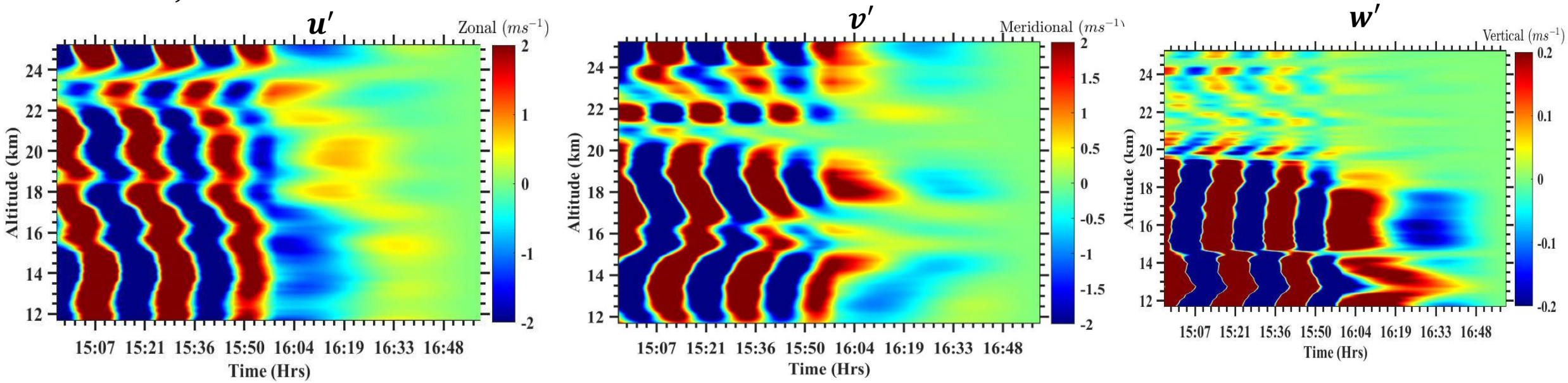


Generation of Internal Gravity Waves due to Penetrative Convection

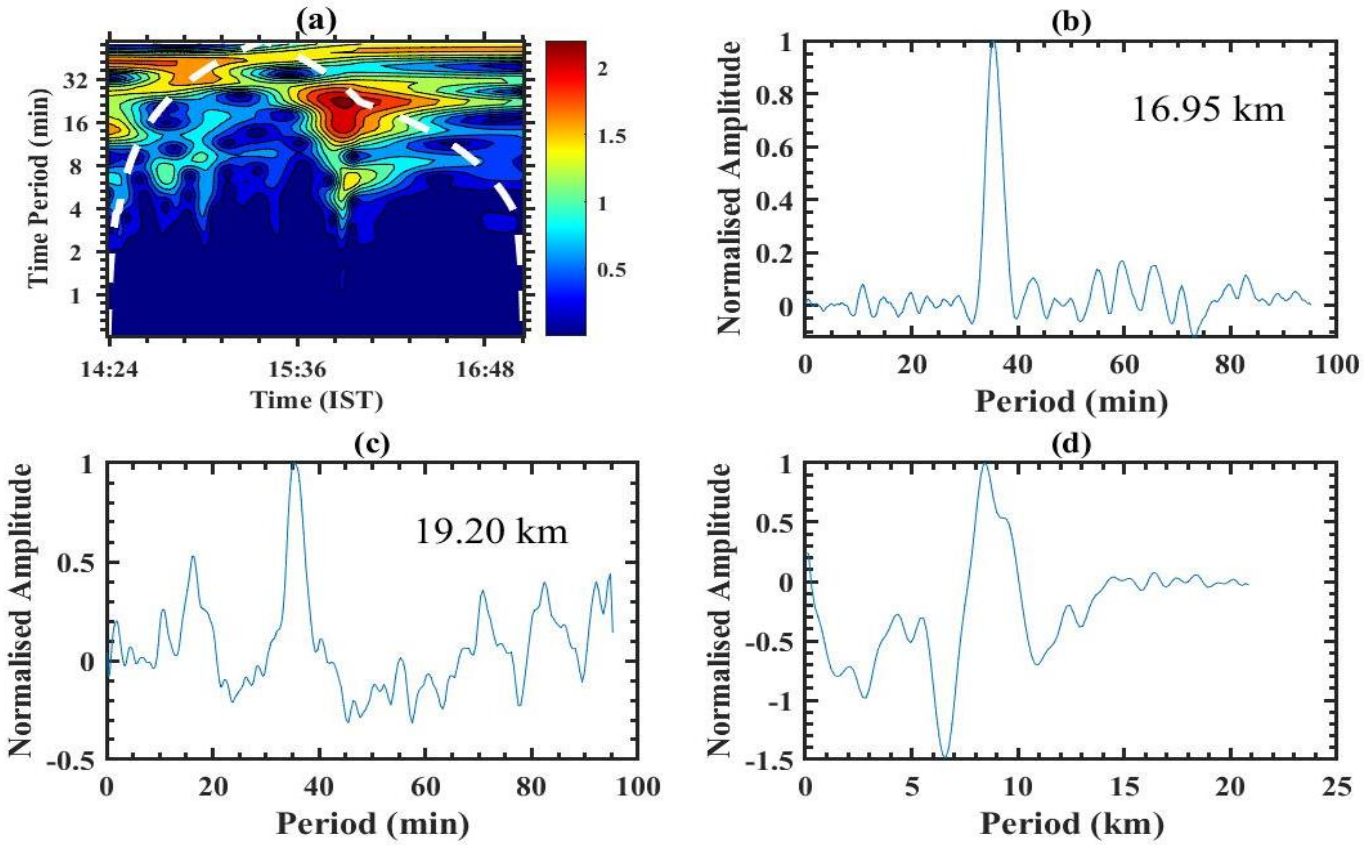
Normalised Zonal, Meridional and Vertical Wind Pertubations

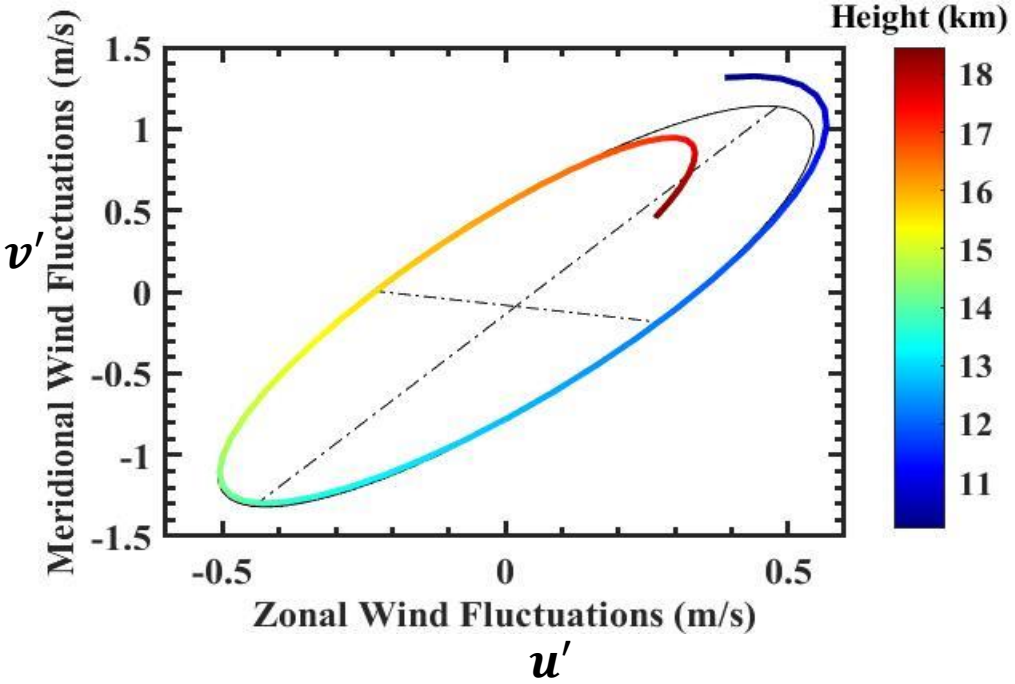


Filtered Zonal, Meridional and Vertical Wind Perturbations



Generation of Internal Gravity Waves due to Penetrative Convection





Polarisation relation for internal gravity wave

$$\frac{v'}{u'} = -i\left(\frac{f}{\omega}\right)$$ *Gubenko, 2008*

- Observed period of gravity wave 35 minutes in UTLS region.
- Vertical Wavelength of ~ 8 km.
- Elliptical polarisation from the hodograph confirming the presence of gravity wave
- Clockwise rotation denoting upward propagation of wave from mid – troposphere to the lower stratosphere.

Momentum flux estimation using Radar

Vertical flux of horizontal momentum

$$P = (\rho\overline{u'w'}, \rho\overline{v'w'})$$

Navier Stokes Equation

$$\frac{D\vec{u}}{Dt} = -\frac{1}{\rho}\vec{\nabla}p - 2\vec{\Omega} \times \vec{u} + \vec{g} + \frac{1}{\rho}\vec{\nabla}\mathcal{F}$$

Eliassen Palm (EP) Flux

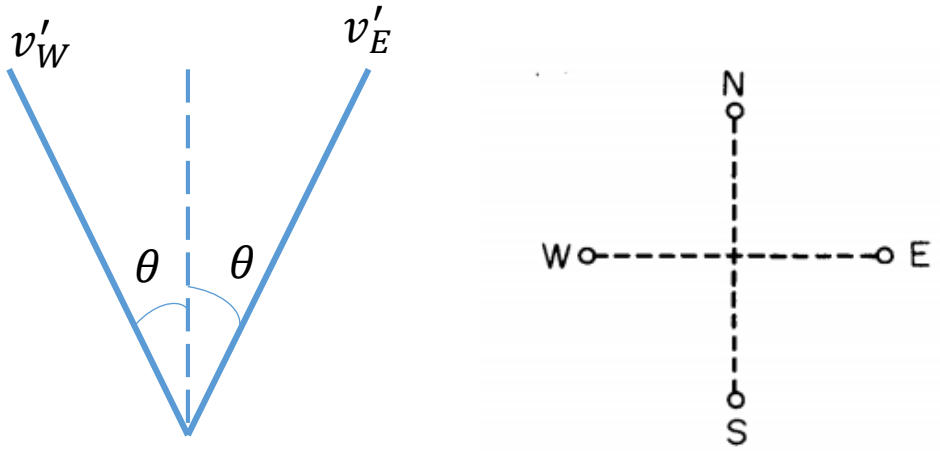
$$\mathcal{F} = -(0, \rho\overline{u'v'}, \rho\overline{u'w'})$$

Reynold's Stress

$$\overline{u'w'} = -K\frac{\partial\bar{u}}{\partial z} \qquad \overline{v'w'} = -K\frac{\partial\bar{v}}{\partial z}$$

K – Eddy Diffusivity Coefficient

Symmetric Beam Method



Zonal Component of momentum flux, $\overline{u'w'} = \frac{\overline{V_E'^2} - \overline{V_W'^2}}{2Sin\ 2\theta}$

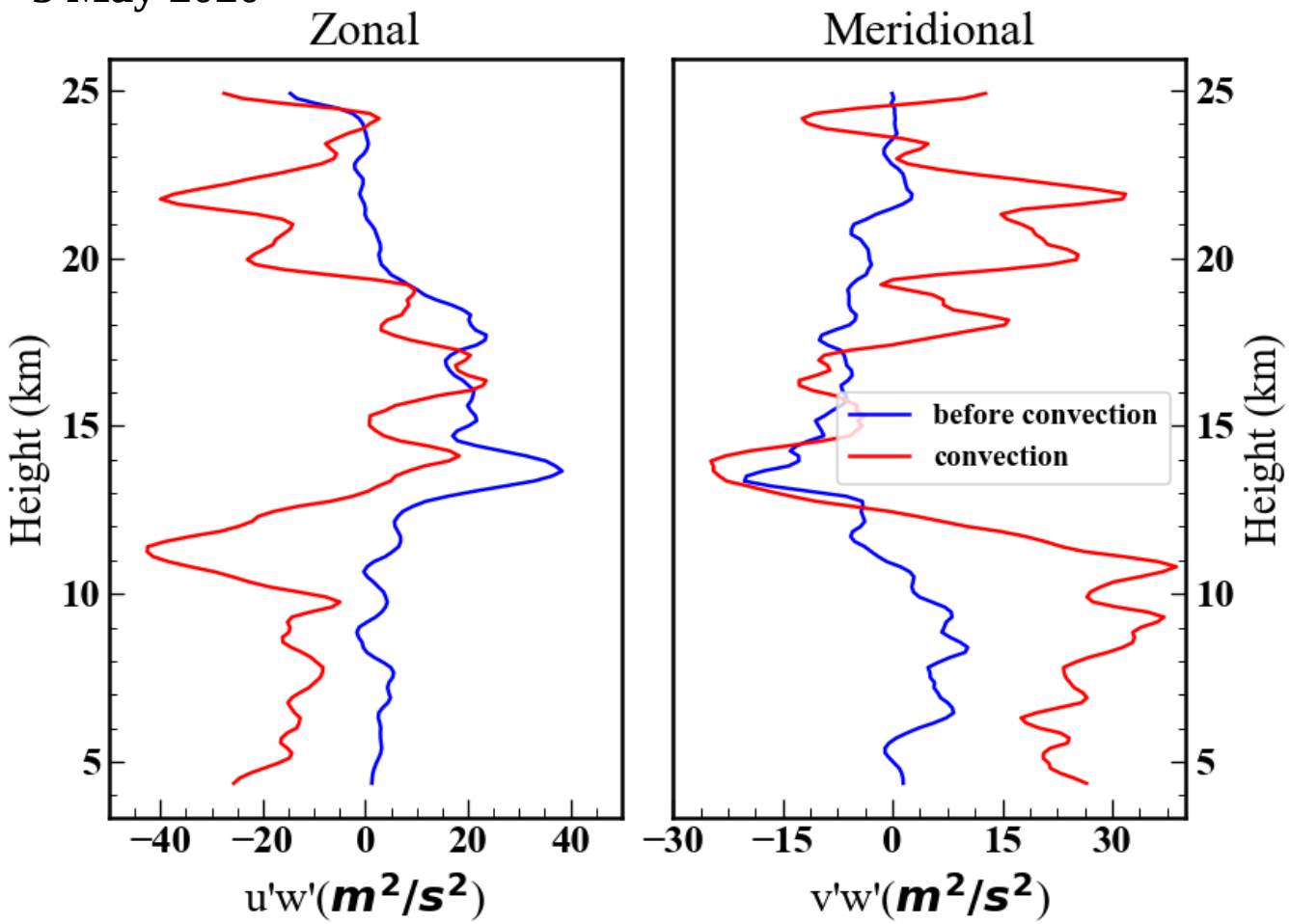
Meridional Component of momentum flux, $\overline{v'w'} = \frac{\overline{V_N'^2} - \overline{V_S'^2}}{2Sin\ 2\theta}$

Vincent and Reid, 1983

v'_E v'_W v'_N v'_S radial wind perturbations in the direction of beam

Momentum flux during deep convection

5 May 2020



u’ , v’ are radial wind velocity perturbations

- Up to 30 – 40 times enhancement in the momentum flux during intense convective activity.
- Change in the direction of flux have been observed from westward to eastward and vice – versa indicating the evidence of the presence of convectively generated gravity waves.

Summary

- We have presented a case study of intense deep convective system using VHF Radar over central Himalayan site.
- Weakening of stability of the UTLS region has been noticed during deep convection. This has led to the enhanced turbulent mixing between stratospheric and tropospheric airmasses.
- Penetrative convection also triggered the upward propagating internal gravity waves transferring as large as 40 times enhancement in the momentum flux in the UTLS during intense convection.
- Internal gravity wave also induced the downward transport of the stratospheric airmass into the troposphere. Significant increase has been observed in the ozone mixing ratio in the mid – upper troposphere.

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Thanks