Diurnal observation of the deep convective precipitation system and the associated gravity wave signatures using 206.5 MHz VHF radar over the central Himalayas

Aditya Jaiswal*(1), Manish Naja(1), Samaresh Bhattacharjee(1)
(1) Aryabhatta Research Institute of Observational Sciences, Nainital., India, 263001, https://www.aries.res.in

Abstract

With the aim to explore the dynamical behavior of the lower atmosphere during precipitation in monsoon season over Himalayan region, diurnal observation with ARIES Stratosphere Troposphere radar were conducted from September 23 to 24 , 2020. Development and evolution of the precipitation system was studied through the derived high resolution wind profiles from radar as well as from radar backscattered power and spectral width. A burst of gravity wave of 8 -10 minutes in period was detected before the precipitation in the mid-troposphere. Similarly gravity waves signatures of 25 minute period were detected among the updraft and downdraft couplet in the upper troposphere and lower stratosphere region during convective precipitation. Overall depletion of turbulent echo power is detected and significant reduction of about 6 dB in radar SNR in noticed around tropopause height during convection. Significant enhancement of horizontal momentum flux noticed during convection period at all height levels.

1 Introduction

Mountainous regions modulates the dynamics of the lower and middle atmosphere due to their complex orography. The induced vertical ascents by the mountains ranges causes variances in temperature and moisture assisting the development of mesoscale flows, convective cells and gravity waves. Deep convection is the primary mechanism for enhancing the upper tropospheric and lower stratospheric humidity levels which affect the climate by modifying the radiative budget at these altitudes. Gravity waves generated in the lower atmosphere propagate up to middle and upper atmosphere and transport momentum and mass flux, hence driving general circulation[2]. Earlier studies also demonstrated the crucial role of gravity waves in initiation and enhancement of convection in upper troposphere and lower stratosphere facilitating troposphere stratosphere exchange[4,6,7].

Radio waves in the VHF band have the unique capability to give backscatter of comparable strength from Bragg scale irregularities arising from temperature and humidity fluctuations as well as Rayleigh scatter from precipitation particles. Hence VHF radars are indispensable tool to investigate the dynamical and weather phenomenon in the lower atmosphere by providing three dimensional structure of wind profiles at high temporal and vertical resolutions. In this context, a Stratosphere –Troposphere Radar operating at 206.5 MHz has been set up in Aryabhatta Research Institute of Observational Sciences at the high altitude subtropical site of Nainital (29.4 N, 79.5 E; 1793 m amsl) located in the Himalayan foothills. The radar has the capability to retrieve vertical profile of winds up to upper troposphere and lower stratosphere. It bridges the data gap of the continuous and systematic wind profiling system over northern India, particularly over complex terrains of Himalayas.

In this communication, a case study of diurnal observations with ST radar conducted in monsoon season from September 23 to 24 in 2020 involving a mesoscale precipitating system along with its different dynamical features involving signatures of gravity waves in the middle and upper troposphere has been presented. Subsequent sections discusses the methodology, dataset and the experiment details in brief followed by detailed discussion on salient results.

2 System Description and Experiment Details

ARIES ST radar (ASTRAD) system consists of total of 588 Yagi-Uda antenna element divided in 12 hexagonal clusters of each having 49 elements and arranged as quasi circular equilateral triangular aperture array on the rooftop. Equal number of Transmitter and Receiver Modules (TRM) are attached to each antenna elements hanging from the ceiling. Peak power aperture product of the radar is 1 x10^8 Wm^2. Detailed discussion about the radar system and basic signal processing of the radar data can be referenced in the earlier communications[3].

On September 23 radar was operated continuously for 23 hours from 0700 IST till 0600 IST on September 24. Observations were carried out with reduced aperture of 7 internal clusters to increase the lower height coverage of far field region enabling first range bin from 375m above ground level. Effective beam width of the reduced aperture is 4.2^o. Pulse width of 1μs was transmitted coded with coded with baud width of 0.25 μs achieving the fine vertical resolution of 37.5 m. Data was sampled at pulse repetition frequency of 5 KHz with height coverage up to 20 km. For estimation of wind vector Doppler beam swinging method was used by transmitting radar beam in sequentially off-zenith 15^0 North, South, Zenith , East and West. Dwell time of each beam was 13 seconds. Using the capability of VHF radars to make the distinction between 'clear air ' and precipitation echo, care has been taken to avoid the contamination of radar signals with rain in the lower troposphere.

3 Range Time Intensity Variation of Radar SNR, Spectral Width and Vertical Wind Velocity

Figure 1 shows the variation of SNR and spectral width in Zenith direction and vertical component of wind vector. SNR is the indicator of the backscattered radar power arising out of strong region of turbulence and static stability. Several coherent structures of strong radar echoes can be observed below 5 km can be attributed to the arising due to strong turbulent regions within local boundary layer and elevated cumulus and stratocumulus clouds. These coherent structures are modulated during period of convection from 16:45 IST till the end of precipitation around 21:50 IST with few echo tops can be seen reaching up to 10 km. VHF radars tend to give strong backscatter from the sharp discontinuities in radio refractive index caused by the layers of static stability around tropopause which can be seen in the figure in the height region from 15 to 20 km . During convection a significant depletion in the radar SNR can be seen indicating weakening of the tropopause layer due to deep convection. Figure 2 shows the time averaged vertical profiles of SNR during convection and pre-convection period. Reduction in SNR of 6dB can be seen around tropopause at 16.5 km. SNR variation resumes to normal during nocturnal time period after precipitation is over after 22:00 IST.

Spectral Width, which is the indicator of the strength of turbulence shows significant enhancement in with values reaching above 2 m/s . Enhancement is larger in lower troposphere, but can be seen throughout the middle and upper troposphere signifying convection as the mechanism of turbulence generation up to upper troposphere.

Vertical Wind plot has been rescaled to within 0.5 m/s to show the updraft and downdraft couplet patterns in the Upper Troposphere and Lower Stratosphere(UTLS) region as well as in the lower troposphere. During precipitation period maximum downdrafts of 7.5 m/s and maximum updrafts of up to 4.5 m/s were detected.

Bottom plot shows the diurnal variation in horizontal wind speed along with the wind vector plotted at the height interval of 375 m and time interval of about 80 minutes for clarity. Existence of directional wind shear indicates the instability in the lower atmosphere within 5 km can be seen for most part of the observation period. Wind speed increased from 5m/s to 20 m/s in the lower atmosphere and from 30 m/s to 60 m/s in the middle and upper troposphere during precipitation period. Wind direction can also be seen to change from south-westerly to north-westerly in the mid and upper troposphere during precipitation period indicating instability in the higher altitude which correlates well with the increased spectral width and updrafts downdrafts couplets during that period in the region.

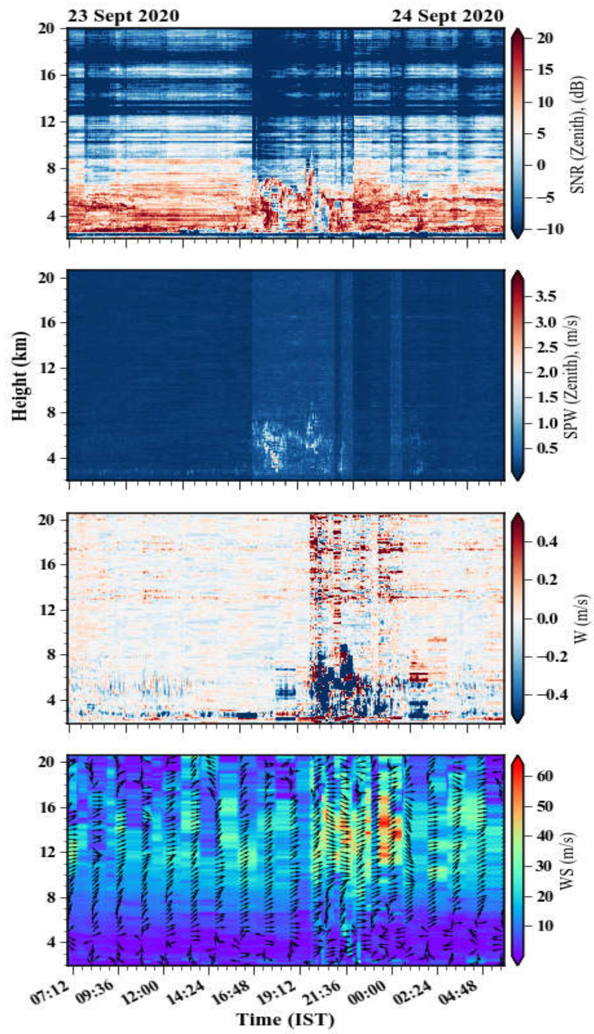

Figure 1.ASTRAD observations for the Zenith beam showing diurnal variation of (from the top) Signal to Noise Ratio in dB, spectral width, spw in m/s ,Vertical component of wind velcoity, W (m/s) and Horizontal wind velocity vector , WS (m/s).

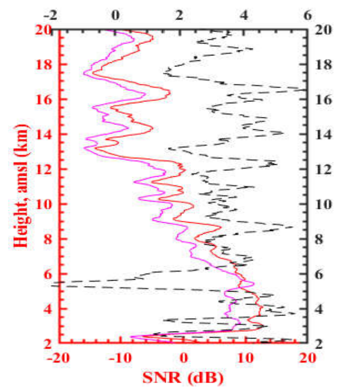

Figure 2.Time averaged vertical profile of SNR before convection (red), convection(magenta), difference between two (dashed)

4 Variation in Momentum flux

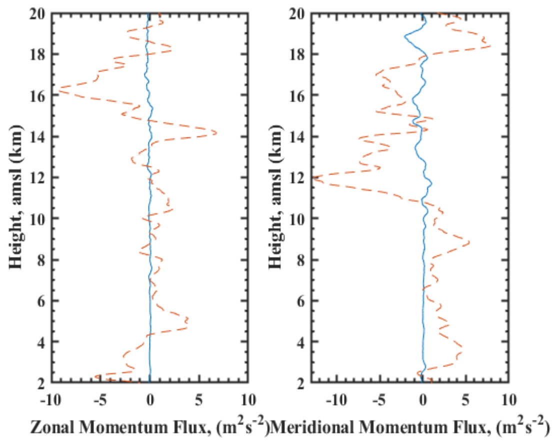

Figure 3.Time averaged vertical profile of zonal and meridional compont of momentum flux before convection (solid), convection(dashed).

Vertical profiles and zonal and meridional momentum fluxes are estimated using radial velocity fluctuations in the symmetric beams[1]. During quiet period the zonal momentum flux values are within +/- 0.5 m^2 s^{-2} and within +/- 1.0 m^2s^{-2} for meridional momentum flux with larger values in the UTLS regions. During convection, there is enhancement in momentum flux from 5 to 10 times from lower to upper troposphere. Meridional momentum flux has northward direction in the lower troposphere and reverses to the southward from 10 km, which is the top of the downdraft region where gravity waves are generated. Zonal momentum values also shifts abruptly from eastward to westward direction corresponding to the updraft and downdraft couplets detected in UTLS region.

5 Signature of Gravity Waves

On the observation of the alternate updraft and downdraft pattern in the lower troposphere before convection and in upper troposphere during convection, time series data of vertical velocities in these height regions are subjected to wavelet analysis. Morlet wavelet has been used for the analysis.

In the 5 - 8 km height region before convection, oscillations of about 8 - 10 minutes period are detected around 9:00 IST as shown in figure 5 which could be due to the topographic origin as they persisted throughout the observation.

Similarly figure 5 depicts that during convection a dominant oscillations of period about 25 min excited in the 15 to 20 km height region around 20:00 to 21:30 IST. This mode of oscillation could have been triggered by the pressure perturbations produced by the rising convective parcels obstructing the environmental mean horizontal flow[4,5].

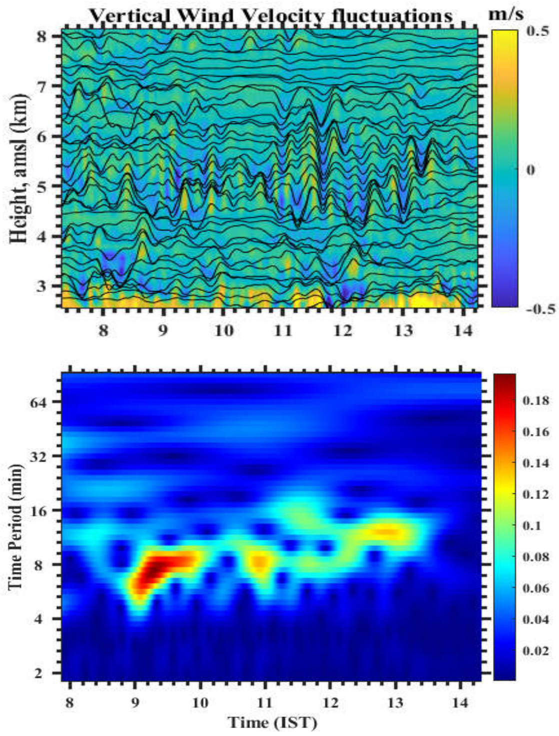

Figure 5. (Top) Time height variation of the vertical velocity fluctuations showing gravity wave pattern in the height region of 5 –8 km before convection period (bottom) Wavelet spectrum of peak vertical velocities in the same height region.

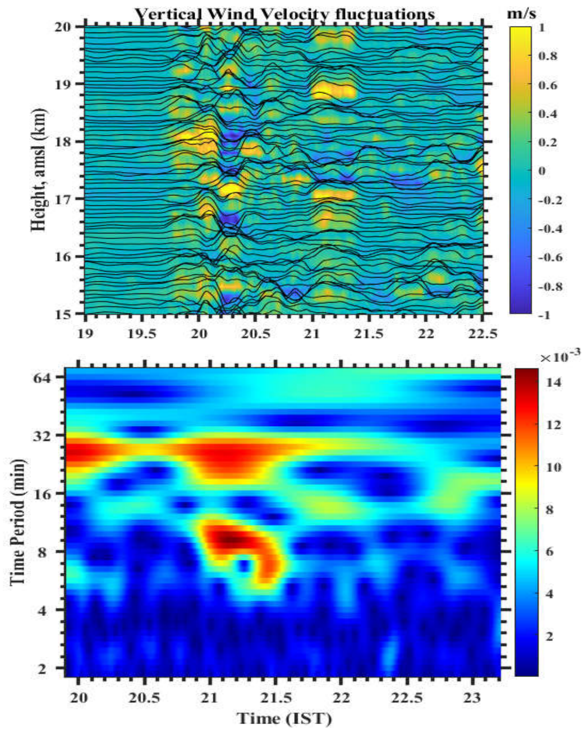

Figure 6. (Top) Time height variation of the vertical velocity fluctuations showing gravity wave pattern in the height region of 15 –20 km during convection period and Wavelet spectrum of peak vertical velocities in the same height region.

6 Conclusion

. Diurnal observations of high temporal and vertical resolution from ARIES ST Radar has been used to explore the dynamical variations in the lower atmosphere during the development of mesoscale convective system during monsoon season. Observations revealed the existence of instabilities in the lower atmosphere caused by the instabilities caused by directional wind shear and wind gusts in the lower atmosphere during the event. Deep convection triggered the gravity wave oscillations in the upper troposphere and lower stratosphere region which greatly enhanced the transfer of momentum flux in the upper troposphere regions weakening the stable tropopause layer revealed by the significant reduction in radar SNR during that period. The study is the beginning of attempts to probe the dynamical features and improve the understanding of mesoscale convective systems developing over Himalayan regions.

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