Temporal Evolution of the boundary layer height using dual-pol C band Radar Observations in the Core Monsoon Zone

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Abstract

Polarimetric Doppler weather radars (DWRs) are conventionally used for quantitative estimation of precipitation and the microphysical features of precipitating clouds. However, the Bragg scatter signatures can be identified at the top of the convective boundary layer (CBL) as the low value of differential reflectivity (Z_{DR}). This work intends to assess the feasibility of the utilization of the operational dual polarization observations to monitor the evolution of the CBL height. A conjoint of quasi vertical profiles of polarimetric variables (Z_{DR}, Correlation coefficient, ρ_{HV}) along with basic products (Radar Reflectivity factor, Z and Spectral Width, W) has been utilized for eliminating the inconsistencies associated with the CBL height estimation. Therefore, a methodology has been proposed along with a case study about the temporal evolution of the CBL height using a dual pol C band radar facility operational at Atmospheric Research Testbed near Bhopal in the Core monsoon Zone. The results are further investigated with respect to the GPS radiosonde and reanalysis datasets.

1. Introduction

Information about the depth and evolution of the convective boundary layer (CBL) is crucial, considering their influence on the turbulent exchange of heat, momentum and moisture between the surface and the free troposphere. It also influences the extent of vertical mixing, dispersion of pollutants, initiation and development of cloud formations due to the dominance of convective processes during daytime. The underlying surface and the environment have a critical role to play in the growth of the planetary boundary layer, thus demanding a good and systematically consistent observational network to comprehend its complexity. However, the direct observations of the boundary layer height and its evolution at fine spatiotemporal resolution are limited. The conventional estimation by radiosonde is limited by temporal resolution, while the observations by the profiling instruments (wind profiler radars, lidars, sodars) are scantily distributed over the globe.

At the top of the CBL, there is frequent mixing of the turbulent airmass into the free troposphere, causing refractivity index fluctuations. These fluctuations occurring at the scale of half of radar wavelength can be detected by the radar as the backscattered echo. In the Plan position indicator (PPI) scans of DWRs, these are detected as circles of enhanced radar reflectivity [1, 2]. However, the polarimetric radars can provide the more distinct identification of Bragg scatter from contaminations like biota, precipitation and ground clutter. Considering, Bragg scattering to be isotropic, Z_{DR} close to 0 dB is expected[3]. Utilising the detection of minima in the Quasi vertical profile (QVP) of Z_{DR}, the temporal evolution of CBL have been studied using the S-band WSR – 88D radar in the USA[4]. The QVP is recent technique, to obtain the time height cross section of any radar product by azimuthally averaging of higher elevation radar scans with conversion of range into height[5,6].

However, these studies were carried at the lower elevation angles(~4.5°), which covers a larger averaging area and may lead to spatial discontinuities in the Z_{DR} profiles obscuring the minima of Z_{DR} in the CBL. Furthermore, the Z_{DR} minima is also possible in the free troposphere in the absence of other potential scatterers making the identification of CBL ambiguous.

Therefore, the objective of the present study to improve the method for the detection of CBL by incorporating more variables. We have utilized the routine observation of the dual polarization C band Doppler weather Radar facility at Atmospheric Research Testbed – Central India (ART-CI), in Silkheda (23.57°N, 77.24°E; 563m amsl) near Bhopal. The next subsections in this paper discusses the dataset used, detailed methodology along with a case study showing the temporal evolution of the CBL.

2. Methodology

2.1 Description of datasets used

The dual-pol C band DWR at ART-CI operates at the central frequency of 5.625 GHz having the peak transmitting power of 250 kW having the fine beam width of ~1°. The radar employs the PPI scans at (0.5, 1, 1.5, 2.5, 3.5, 5, 7, 9, 11, 15, 20, 30, 45, 60-degree elevations). Time period of each scan is ~6 minutes. The radar dataset during the routine observation on July 6, 2023 has been used for the present case study. Additionally, the co-located observations of temperature, dew point and relative humidity from GPS radiosonde (1100 hours UTC) have also been utilised to verify the CBL height obtained by the radar. ERA5 derived product of planetary boundary layer height has also been used for the comparison.

2.2 Estimation of CBL height using GPS radiosonde and Radar

Boundary layer height using the radiosonde has been estimated by taking the altitude of maximu gradient of refractivity (N) which contains both the water vapour as well as the temperature.

$$N = (n-1) \times 10^6 = 77.6\frac{p}{T} + 3.73 \times 10^5 \frac{e}{T^2}, \qquad (1)$$

Where, p is the atmospheric pressure (in hPa), T is the temperature (K) and e is the water vapour mixing ration (g/kg).

For the CBL height estimation using radar, it was noticed that the gradient of differential reflectivity is a better representation of evolution of CBL height. Furthermore, it is widely known that the strength of turbulence in the mixing layer decrease with altitude in the boundary layer. Hence, a quantity σ has been calculated defined as the ratio of gradient of differential reflectivity to the square of spectral width. The local maxima in the σ up to 3 km above ground level has been selected as the CBL height. Specifically, following steps were followed, first quality controlling the data from the contaminants [4]:

1. QVPs of Radar reflectivity factor (Z), Differential reflectivity (ZDR), correlation coefficient (ρ_{HV}), spectral width (W) have been calculated at an elevation angle of ~11° giving a better representation of local atmospheric conditions.
2. All the data points with Z>0 and ρ_{HV} >0.8 are removed (uniform precipitation).
3. QVP profiles with ZDR<2dB throughout the entire height range are also removed (light precipitation).
4. Smoothing over the data is 3 points in time domain, 5 points in the height domain to minimize the spatial inconsistencies the data.
5. Local maxima in the σ ratio (up to 3 km above ground level) has been selected as CBL height.

3. Results and Discussion

Figure 1 shows the maximum gradient in the square of refractivity (~1.6km) chosen as the height of the CBL. Figure 2 represents the temporal variation of ZDR, Correlation coefficients, Radar Reflectivity factor (dBZ) and spectral width. It can be noticed that the low value region of ZDR shows growth with the daytime (0000 hours UTC to 1300 hours UTC) although the ambiguities in detecting the minima remains. Precipitation observed during time period during 1500 hours UTC to 2100 hours UTC represented by the high values of Z, ρ_{HV} and ZDR~0. The precipitation data has been ignored for analysis as mentioned in the above section.

Radar derived estimates of the CBL height has been demonstrated in the Figure 3. The gradient of ZDR maximise around CBL top while spectral width minimized around CBL top giving rise to the layer of maxima in the

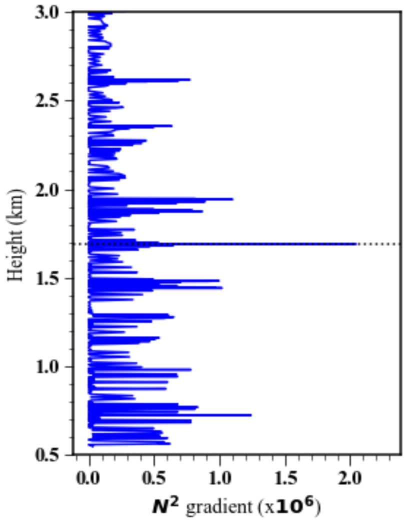

Figure 1. Vertical variation of the refractivity derived using GPS radiosonde observation on July 6, 2023. The dashed line shows the CBL height

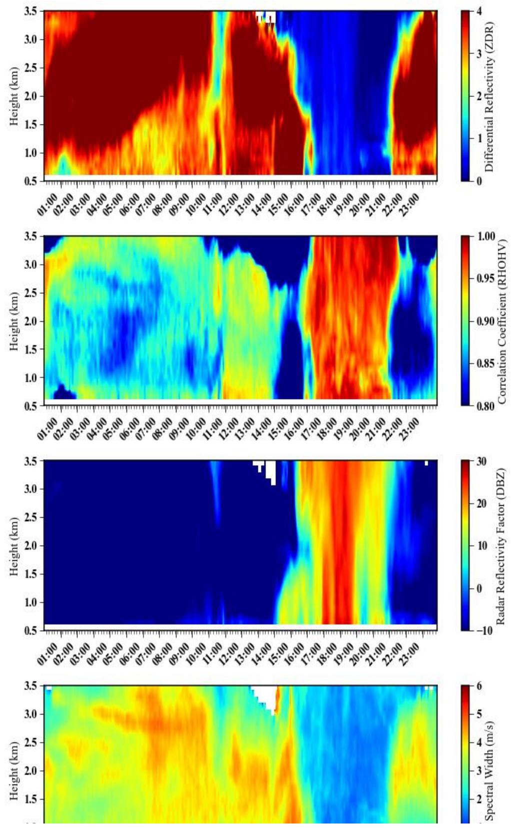

Figure 2 (top to bottom) Height time cross section of quasi vertical profiles of differential reflectivity (ZDR), Correlation coefficient, Radar reflectivity factor and spectral widths on 6th July, 2023.

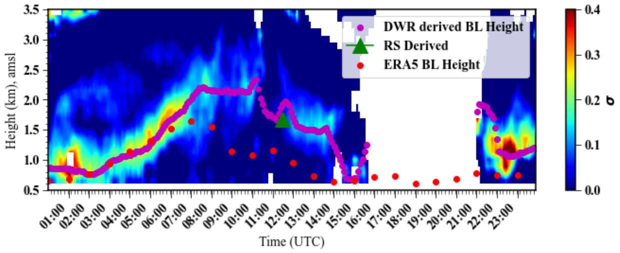

Figure 2. Temporal variation of σ ratio along with the radar estimated DWR height (magenta circles). Radiosonde derived CBL height is represented by the green triangle. ERA5 derived boundary layer product for the site are represented with red circles.

σ ratio. As can be seen from the figure, that the evolution of maxima in the σ ratio is similar to the CBL evolution during daytime. The layer starts growing due to surface heating along with the sunrise ~0100 hours UTC from ~0.87 km amsl and deepens to its maxima of 2.35 km around late afternoon (~1000 hours UTC). It can also be visualized by the strong turbulent mixing in the afternoon as shown by the spectral width variation in the Figure 2. The CBL gradually declines with sunset leaving a residual layer. The CBL height derived by the GPS radiosonde is also in close proximity to the radar derived CBL height. PBL height product obtained from the ERA5 reanalysis around the radar site also shows one to one correspondence to the radar derived CBL till late morning. Although, it is unable to capture the full deepening of the CBL from noon onwards but it shows the characteristic evolution of the CBL as manifested by the radar derived CBL.

4. Conclusions

In this study a methodology has been proposed for the detection and monitoring of convective boundary layer depth utilizing the dual polarized Doppler weather radars. Utilisation of the quasi vertical profiles of the differential reflectivity at the higher elevation angles provides a sharp detection of the Bragg scatter at the top of the CBL utilizing differential reflectivity and the spectral width.

The growth pattern of the elevated layers of gradients of differential reflectivity was observed to be akin to the expected behavior of the CBL evolution during daytime. Numerous reporting during previous studies have indicated the importance of monitoring of the CBL evolution and behavior for convective initiation, air quality forecasts and forest fires.

Potential usefulness of this method will provide the way for utilizing the existing nationwide network of the Doppler weather radars to monitor the boundary layer height at good spatiotemporal resolution. It will further be useful for obtaining the climatologies of the CBL height and understatnding their pattern at various geographical locations.

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