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Boundary layer anomalies observed from radiometric observations during convective rain

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Abstract

In this study, anomalous observations in relative humidity at relative humidity profiles during heavy rain have been presented. Radiometric observations of relative humidity profiles show a significant fall at around 1 to 2 km height region during heavy rain events. An extensive investigation shows that the fall of relative humidity is strongly related to the characteristics of boundary layer temperature lapse rate profiles. However, these observations have only been reported during convective rain and are not very prominent in stratiform precipitation as the boundary layer dynamics does not play a significant role in those types of rain. The analysis also reveals the role of atmospheric pollutants as heating agents in the planetary boundary layer which can be crucial in causing such anomalies in atmospheric profiles.

1. Introduction

The boundary layer dynamics plays an important role in the evolution of convective rain, which constitute an important atmospheric phenomenon at tropical locations during the premonsoon and monsoon period [1,2]. It is expected that during such rain events, the whole atmospheric column must be saturated with water vapor parcels. However, the same is not true for many events at the present location. At first, this phenomenon was considered as a radiometric anomaly but after validation with other sources, it was found that the observations truly indicate a depletion in water vapor. Next, it was considered that an abnormally low relative humidity might be associated with high temperatures and consequently high latent heats before and during rain. This abnormally decreasing lapse rates might be responsible for this anomaly. It may be possible that the anomalies can be commonly caused by convective boundary layer dynamics coupled with atmospheric pollutants especially in urban regions.

2. Experimental Setup and Data

To investigate the anomalous features of intense convective rain, we study the radio environment over Kolkata (22.57ºN, 88.37ºE) using a multi frequency profiler radiometer (RPG-HATPRO) and a micro rain radar (MRR). It consists of two frequency bands, (22.24-31.4 GHz, 51.3-59 GHz) with 7 frequency channels in each band. The Ka band is used for humidity sensing while the V band is used for temperature sensing. It also has a rain sensor, GPS clock, pressure sensor, and a temperature sensor. Validation of atmospheric profiles is done from CALIPSO satellite observations. Micro rain radar operates, at 24.1 GHz in FMCW mode which senses DSD at different heights from the Doppler spectrum of the returned radar signal. Rain types can be classified into convective or stratiform based on radar reflectivity profiles [3,4]. Ground based rain information is retrieved from an impact type disdrometer which can sense drop sizes ranging from 0.3 to 5.5 mm. [5]

3. Results and Discussion

During intense convection, moisture laden winds are carried aloft which fills the entire atmospheric column leading to a possible saturation in vapour density during rain commencement. However, when relative humidity profiles from radiometric observation were observed, a dip is seen at 1-2 km height especially during heavy rain. An example has been depicted in Figure 1(a), where it is seen that a patch of low relative humidity is created at heights of 1-2 kms during rain. Initially, it was thought that radiometric profiles obtained during rain are faulty. For this reason, relative humidity and temperature profiles obtained from microwave radiometer have been validated with collocated passes of temperature and relative humidity profiles from CALIPSO observations during rain. The analysis showed that CALIPSO data also depicts similar anomalies during rain. Hence, it can be inferred that the observations are viable.

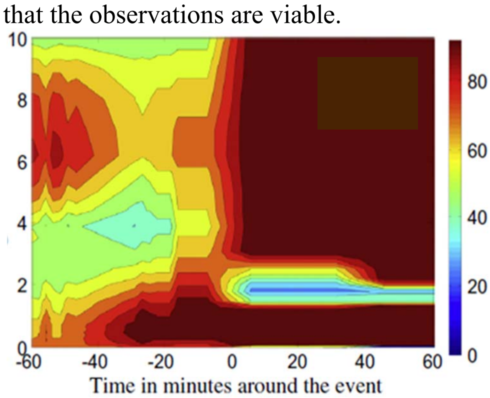

Figure 1. Parametric variation of relative humidty profiles during a convective day

This feature of relative humidity profile observation was followed by a study of the temperature profile. This has been shown in Figure 1(b). Analysing the ambient temperature profile it has been found that the ambient lapse rate significantly falls at around 1 to 2 km height both in raining and non-raining conditions, shown in Figure 2.

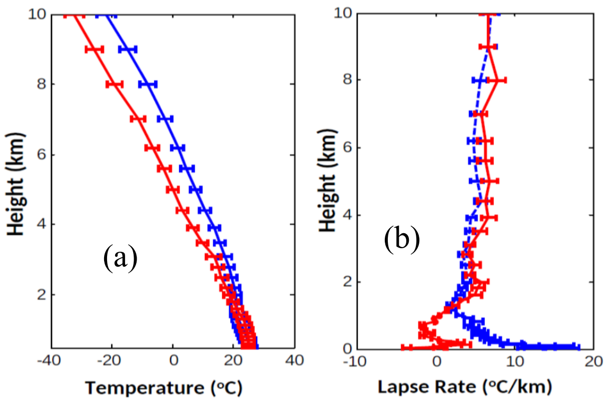

Figure 2. Parametric variation (a)temperature, and (b)lapse rate profiles during and before rain

Due to this fall of lapse rate, normal convection at that particular height may diminish. As a consequence to this fact, more number of moist air parcels is accumulated at that height just before rain events and the high concentration of moist air reaches to saturation. This may influence the condensation of vapour to liquid water, which releases latent heat.

Hence, latent heat profiles have been calculated and shown in Figure 3(a). This increase in latent heat only points to the conversion of excess vapour to liquid at that height. Hence the liquid profiles shown by MRR have been studied; shown in Figure 3(b). MRR too shows a high LWC at that height. That the latent heat contributes to ambient heating at this height region which in turn may cause a fall of lapse rate thereby fading the normal convection by catalyzing an enhancement in condensation of vapour to liquid in a cyclic manner. Thus the amount of vapour decreases at this height resulting into a decrease in relative humidity during rain.

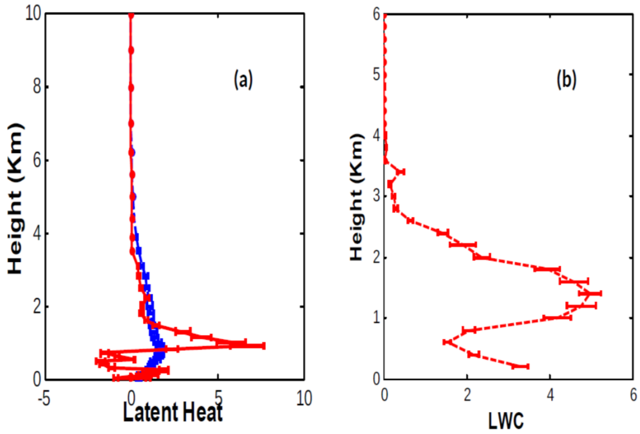

Figure 3 Variation of (a)latent heat, (b)liquid water content during rain.

Now, it has to be checked whether these anomalies can also occur in stratiform rain. To investigate this anomaly, a group of stratiform rain events with minimal intensities are recorded and the atmospheric profiles are plotted in Figure 4. From the figure, it is seen that stratiform rain doesnot show such clear instances of low relative humidity and lapse rates. The difference are seen because such type of rain is not generated by intense updrafts of moisture which can move to boundary layer height and accumulate to release huge amount of latent heat as in convective rain cases.

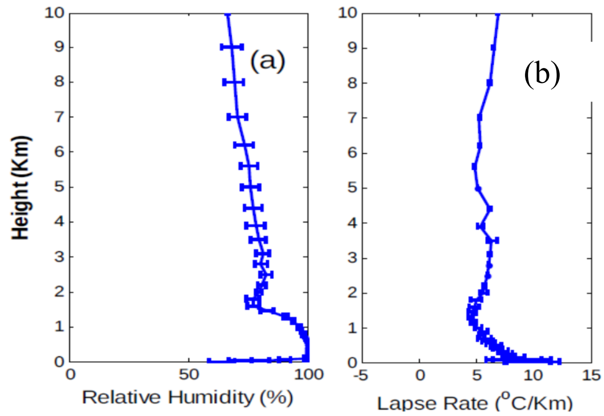

Figure. 4 Parametric variation (a)relative humidity, and (b)lapse rate profiles during stratiform rain

The anomalies reported at 1-2 km height might be attributed to two primary reasons. The first reason might be the strong association with boundary layer dynamics [6,7]. It has been broadly discussed in previous studies, that the turbulences near the earth surface stabilize the temperature and wind speed within the mixed layer which is up to about 1.5 Km, [7]. Above this height wind speed abruptly increases as the effect of turbulence decreases above this height [6]. This increase in wind speed causes a rapid dispersion of buoyant particles from this region. This fact may allow the buoyant particles like water vapour rising from the surface due to convection, to make room up to around 1.5 km region and get accumulated there. This feature of the boundary layer structure may have a controlling effect to limit convection above this height [6,7,8]. This also may influence the fall of relative humidity at around this height region. Another strongly associated reason might be high concentration of heat absorbing atmospheric particles such as aerosols like black carbon or dust which absorb solar radiation and increase the ambient temperature to reduce the relative humidity. It also has been discussed in earlier articles that solar radiation absorbed by the aerosol above the boundary layer increases the atmospheric stability and can hinder convection [9,10]. It has also been found from LIDAR profiles of aerosol backscatter at 532 nm, that the coefficients have a high value at around 2 Km height region [11,12]. As a result, it is expected that bulk of the heat absorbing particles such as aerosols might lie within this height. A large concentration of atmospheric gases leads to a high heat absorption which again reduces the temperature lapse rates at those heights thereby increasing the temperature and reducing the relative humidity as obtained from present observations.

At the same time, it was also thought that this anomaly might be very prominent in urbanized regions owing to the presence of highly polluted planetary boundary structures compared to rural regions. Hence, aerosol extinction and average lapse rate values were recorded for several grid points according to forest cover map of the country. The average variation is shown in Figure 6. From the figure, it is evident that urban regions have much higher values of aerosol extinction at 532 nm at PBL height of 1-2 km compared to rural regions as a result of which, the lapse rate in those regions are also consistently lesser than the rural counterparts. Thus the dominant effect of planetary boundary layer on convection and the occurrence of anomalies during rain are expected to be relatively lesser in rural atmosphere than in the urban locations. However, the current hypothesis needs to be validated further from ground based rain observations from other locations which is beyond the scope of this study.

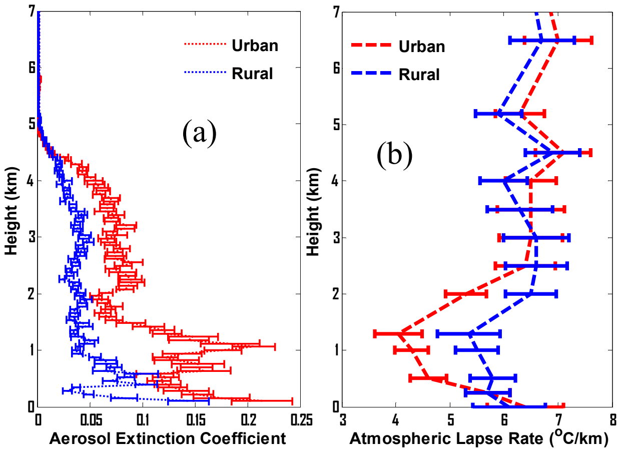

Figure. 5. Variation of aerosol extinction and atmospheric lapse rate for urban and rural regions

4. Conclusion

Microwave radiometric observations have depicted decreased lapse rates to be responsible for fall of relative humidity at 1-2 km height during rain. It has been realized that the association between the abrupt decrease in relative humidity aloft may bear a signature to the boundary layer height during rain. Again, relative humidity anomalies during intense rain are caused by high latent heat release which is not observed during stratiform cases. These anomalies may be caused by the combined effect of boundary layer dynamics during intense convection and due to presence of heat absorbing pollutants at the boundary layer height at urban locations.

5. Acknowledgements

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