Characteristics of orographic precipitation by using Doppler radar and Disdrometer

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Abstract

The characteristics of convective and stratiform precipitation over the high-altitude tropical station, Mahabaleshwar (17.92 °N, 73.85°E; 1438 m above sea level) has been studied in the present paper by using multi-frequency radars and disdrometer measurements. The station, receiving an average annual rainfall of 5000 mm represents one of the important points of heavy precipitation belt of Western Ghat orographic region of Indian sub-continent. It has been found that the region experiences a shallow convection with the cloud top height merely exceeding 6 km. The dropsize of diameter 1-2 mm contributes more in the span of rain rate range of 2-4 mm/hr compared to other rain rate classes. Correspondingly, drops of larger diameter dominate the convective rain with respect to the stratiform one.

Introduction

According to [1], precipitations can be clearly distinguished into two different types, stratiform and convective. Association of rainfall with stratiform or convective clouds is important in observational, modeling and remote sensing studies as the microphysical process affects the (i) kinematics fields via differing vertical profiles of latent heating and (ii) radar rainfall estimation via differing of raindrop size distribution. The classification of different rain types are thus of practical importance, since the vertical structure of rainfall is directly associated with the origin of cloud and the cloud microphysics, thus, experimental observations of rain structure provides an excellent opportunity to study the growth of cloud droplets under various conditions.

Several studies could be found in the open literature from all over the world related to the variation of raindrop size distribution from storm to storm, within the storm and from one season to the other [2][3][4]. India, being a tropical country, receives much rainfall in two different types of monsoon circulation, South-West Monsoon (SWM) and North-East monsoon (NEM), however, the effect of SWM is more than the NEM over India along with their variation of raindrop size distribution [5].

The present paper studies the characteristic features of convective and stratiform rainfall as analyzed from the several in-situ measurements over the High-Altitude station Mahabaleshwar situated at the south-western part of Indian sub-continent that. The importance of the paper lies in the fact that for the first time a study has been made and the result portrays the characteristics of raindrop size distribution as observed by multi-frequency radar and ground based disdrometer over a high altitude tropical station.

Data

The region under consideration is Mahabaleshwar, a hill station located at the Western Ghat mountain range of Southern Peninsular India. The High Altitude Cloud Physics Laboratory, a high altitude station of Indian Institute of Tropical Meteorology, Pune, is situated at Mahabaleshwar, at a height of 1,438 m above the sea level. The region receives an annual rainfall of more than 5000 mm on an average. Various meteorological instruments are currently operating at this location to study the cloud physics and rainfall characteristics, among which the data obtained from X-band dual polarized Doppler weather radar, Micro Rain Radar and Disdrometer have been used for the present study

X-band Doppler Weather Radar is one of the important instruments that have been used for the vertical reflectivity analysis over the present site. The radar is situated at a place known as Mandhardevi (18.51°N, 73.85°E), which is around 26 km (aerial distance) away from the observational

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site over Mahabaleshwar. It operates at a frequency of 9.523 GHz and scans at an elevation angle ranging from 0° - 90°. The beam width of the radar is 1° whereas the range gate is 50 m.

Micro rain radar (MRR), which is vertical pointing radar, is a Frequency Modulated Continuous Wave (FM-CW) Doppler radar at 24.1 GHz. It can measure rain characteristics up to 9 km with a time resolution of 10 seconds and height resolution of 300 m. It gives drop size distribution, radar reflectivity, rain rate, liquid water content and fall velocity profile. The radar reflectivity profile has been used in the present study. The retrieval of Doppler spectra and different microphysical parameters are well documented in various literatures [6]. The basic parameter it measures is the fall velocity of hydrometeors, specifically the rain drops as this particular frequency is more sensitive to rain drops than any other hydrometeor.

The Joss and Waldvogel [7] (disdrometer (RD-80) (hereafter JWD) is used to measure high-resolution (1-minute) raindrop size distribution (DSD) at Mahabaleshwar. It can measure the raindrops in the range of 0.3–5.1 mm with 20 classes. The instrument uses the momentum of raindrops for estimation of its size since the relation between these two parameters is well defined (Gunn and Kinzer, 1949). The rain-rate (R) is estimated from the disdrometer data by employing the following standard formula

$$R = \frac{\Pi}{6} \times \frac{3.6}{10^3} \times \frac{1}{F \times t} \sum_{i=1}^{20} (n_i \times D_i^{\,3}) \qquad (3)$$

where n_i is the number of drops measured in drop size class i during time interval t, D_i is the average diameter of drops in class i, F is the size of sensitive surface of the sensor of disdrometer ($0.005 m^2$) and t is the time interval (60 sec).

Result :

Figure 1 represents the annual rainfall over Mahabaleshwar for the last 6 years under consideration. It is quite evident from the above figure that the average rainfall touches 5000 mm annually though in

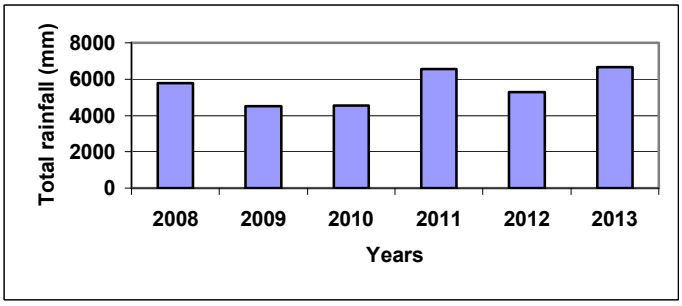

Fig. 1. Total annual rainfall over six consecutive years

some years it exceeds the specified value. In order to take into account these huge rainfall characteristics of the region under consideration, a case study for a heavy rain event on September 10, 2013 has been done over the mentioned region. Figure 2 represents the hourly variation of total

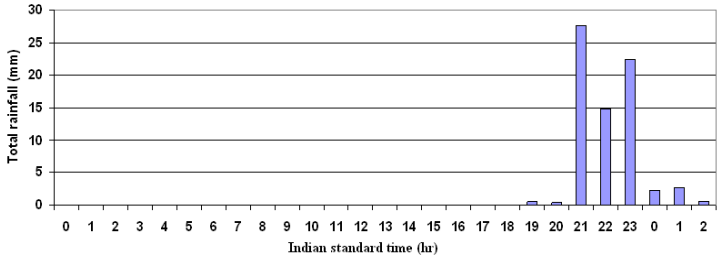

Fig 2. Hourly rainfall variation on September 10-11, 2013

precipitation over Mahabaleshwar on September 10-11, 2013. The figure portrays that the rainfall started from 19.00 hrs and it lasted upto 02.00 hrs. For the entire episodes, the rainfall accumulation has taken two peak values, one during 20.00-21.00 hrs with the total rainfall of 27.6 mm and the other during 22.00-23.00 hrs with the total rainfall of 22.4 mm. Figure 3 represents the variation of rain rate and raindrop size distribution w.r.t local time for the entire rain event starting from 15.00 – 02.00 hrs.

Figure 3(a) represents the variation of rain rate with time whereas Figure 3 (b) represents the variation of raindrop size distribution of the same rain event. It is quite visible from the above figure that the

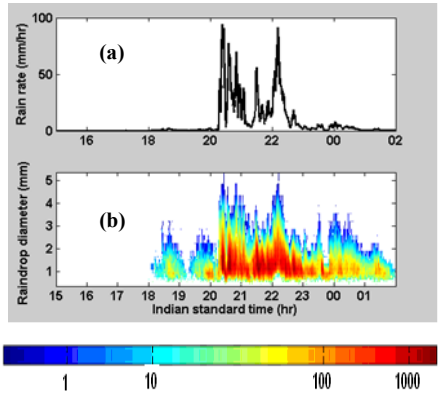

Fig. 3. Variation of (a) rain rate and (b) raindrop size distribution w.r.t time

rain rate shooted around 90 mm/hr twice for the entire event. Significantly, it is seen from Figure 3 (b) that the heavy concentrations of band of smaller drops are visible for the intense rain event during 20:10 – 23:00 hrs. Figure 4 represents the vertical profile of radar reflectivity as obtained from the

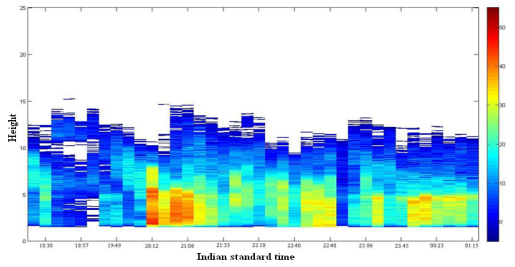

Fig. 4. Vertical profile of Radar reflectivity (dBz) obtained from X-band Radar

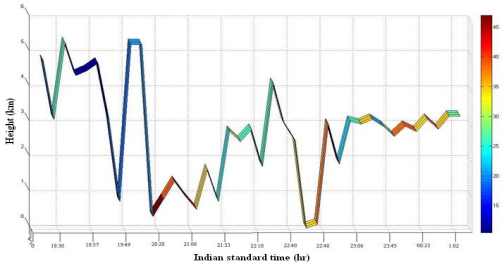

Fig. 5. Column-maximum highest reflectivity (dBz) from the vertical profile of Radar

X-band radar. It is very much evident from the above figure that reflectivity as high as 45 dB reached around 6 km from the ground level during the span of heavy precipitation of 20.00 - 21:30 hrs. Correspondingly, in the span of precipitation during 23:00-00:30 hrs, higher reflectivity is confined in the altitude of 4.5 – 5 km. In order to make the findings more accurate, the time-series analysis of the column maximum highest reflectivity as obtained from the RHI scan of the radar is plotted in Figure 5. The figure gives a distinct variation of the characteristics reflectivity of radar during the two-time span. As noticed from the figure, that the radar reflectivity shows a rapid fluctuations of signal related to altitude variation from 0.5 – 4 km during the time interval of 20:15 - 22:40 hrs whereas such structure are absent in the later part of the event. Significantly, during 23:00 – 01:00 hrs, the highest reflectivity is confined around 3 km. Thus from the features of Convective and Stratiform precipitation,

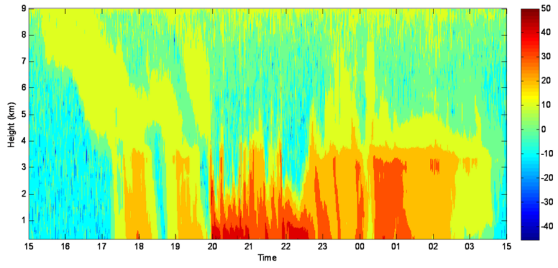

Fig.6. Vertical profile of reflectivity (dBz) from Microrain radar

it can be said that the rainfall during the period of 20:15 – 22:40 hrs is of convective in nature whereas the rainfall during the period of 23:00 – 01:00 is of stratiform type. In order to get the characteristics precipitation pattern of the convective and stratiform rain, the vertical looking Ka-band Micro Rain Radar has also been taken into consideration.

Figure 6 shows the vertical looking reflectivity profile as obtained from the Micro Rain Radar. The rapid fluctuations of highest reflectivity could be visible during the time span of 20:00 – 22.50 hrs whereas the steady reflectivity pattern is observed during the later hours i.e in the period from 00:30 – 01:30 hours. This again proves the strong convective signature during the initial hours whereas the stratiform signature in the later part. Figure 7 represents the variation of the number density of drops for the core convective and stratiform part. The domination of larger drops in the convective rain is

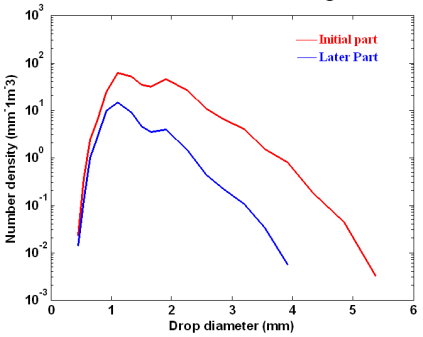

Figure 7. Number density of drops w.r.t drop diameter in case of convective and stratiform rain

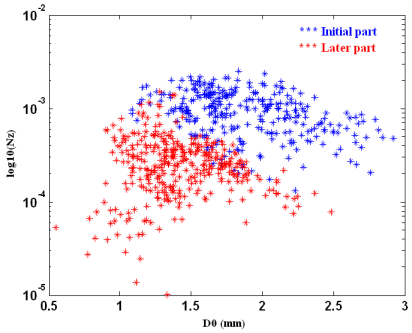

Figure 8. Relationship between median volume diameter (D_0) and intercept parameter log10(Nz) for convective and stratiform rain

quite visible from the mentioned figure. The distinctions between convective (noted by blue dots) and stratiform cores (noted by red dots) are also visible from the relationship between median volume diameter (D_0) and intercept parameter (Nz) as depicted in Figure 8.

Conclusion

The paper presents the characteristics features of convective and stratiform precipitation as observed over a High Altitude station in the Western ghat region of the Indian sub-continent. It has been found that the region experiences a heavy rainfall from shallow convective clouds with the cloud layer extending vertically upto 6 km. This is basically due to the fact that the huge cloud liquid water content present at the lower level of the region cannot go to the higher level due to weak updraft. These liquid water content interact with the Giant Cloud Condensation Nuclei (GCCN) and finally gives rise to heavy rainfall over the mentioned region [8]. Correspondingly, it has also been observed that the drops of larger diameter dominate the convective rain with respect to the stratiform one.

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