Long Term Variation of Rain Drop Size Distribution in Relation to Aerosol and Cloud Parameters at a Tropical Location

Gargi Rakshit* (1), and Animesh Maitra(2)
(1), (2) Institute of Radio Physics and Electronics, University of Calcutta,
92, Acharya Prafulla Chandra Road, Kolkata-700009, India

Abstract

The present study provides an overview on the long term variation of rain drop size distribution parameters which are related to aerosol environment and ambient temperature controlling the evaporation of rain drops. The investigation has been done using both space borne and ground based measurements over Kolkata (22.57° N, 88.37° E), an urban tropical location near the land ocean boundary. The mass weighted mean drop diameter (D_m), which is the ratio of fourth to third moment of rain drop diameter, is seen to have varied over the period of 15 years (2004-2018) as observed from the disdrometer measurements during the pre-monsoon and monsoon period over Kolkata. D_m has a definite decreasing trend for convective rain during both the pre-monsoon and monsoon period. However, for stratiform rain, though D_m has decreased during monsoon period, it has shown an increasing trend in pre-monsoon month. Maritime contribution to this changing D_m has also been evaluated using HYSPLIT model. The variation of D_m has also been related to the rate of evaporation obtained from Global Land Evaporation Amsterdam Model (GLEAM) data. The data of aerosol optical depth and cloud effective radius obtained from Moderate Resolution Imaging Spectroradiometer (MODIS) over Kolkata have also been analyzed to understand the long term trend in D_m.

1 Introduction

Rain microphysics is mostly determined by raindrop size distribution (DSD) the knowledge of which is necessary for understanding the precipitation process and associated phenomena. The propagation of terrestrial and earth space radio signal operating above 10 GHz depends on the DSD features which are essential for propagation modeling [1]. The assessment of soil erosion process and surface runoff phenomenon depends on the estimation of drop size distribution [2]. Further, DSD has also a significant role in determination of quantitative precipitation estimation algorithms [3]. Bringi et al. (2003) showed DSD characteristics in different climatic regions such as equatorial, tropical, subtropical, continental and oceanic regions [4]. Distinctive differences in DSD parameters among stratiform, convective, and mixed type precipitations have been reported by previous researchers [5]. It may be noted that over the years industrialization has impacted different climatic processes on both local and global scale. In this connection the change of aerosol environment has played a significant role as it influences earth's radiation budget by absorbing and scattering solar radiation, and as a result impacts atmospheric hydrological cycle [6-7]. Though a fairly extensive investigation has been performed on the influence of aerosols on precipitation and cloud microphysics, however the uncertainty of the extent of the role of aerosol in precipitation process still exists [7]. Investigation on precipitation on long term and short term basis has been done by several researchers [7-8]. However DSD features as a climatic parameter in association with aerosol environment and cloud microphysics on a long term basis are inadequately investigated due to lack of long term DSD data. In the present study, DSD characteristics during pre-monsoon and monsoon period obtained from disdrometer data for 15 years (2004-2018) at the location of Kolkata have been studied. The results are examined in the light of changing aerosol environment, evaporation rate and cloud microphysics.

2 Site Meteorology, Data and Methodology

The present location Kolkata is situated near the land-ocean boundary of the north-east coast of Bay of Bengal. Kolkata is a highly polluted metropolitan city with heavy traffic load and industrial belts. Atmospheric processes over Kolkata are significantly influenced by pollution and prevailing aerosol environment as reported previously [9]. Kolkata experiences frequent convective events during the pre-monsoon months (March-May). Convective phenomena also occur during the monsoon period (June-September). In the present investigation pre-monsoon and monsoon seasons have been considered separately for the analysis of DSD data and associated climatic parameters.

For the present investigation, drop size distributions are obtained from an impact type Joss–Waldvogel disdrometer (Distromet RD-80) operated at the Institute of Radio Physics and Electronics, University of Calcutta, Kolkata. 20 size bins of rain drops ranging from 0.3 to 5.5 mm are obtained from disdrometer at a non-uniform interval. For the present study long term DSD data during 2004-2018 are considered, with a data gap in the year 2008.

The data for Aerosol optical depth (AOD) and cloud effective radius (CER) over Kolkata are obtained from monthly MODIS dataset at a spatial resolution of 1ºx1º, during the period of 2004-2018. AOD at 0.55 μm is considered for the present study [8]. 5-day back trajectory analysis of wind arriving at 2000 m above the ground level over Kolkata for different seasons are drawn by using TrajStat (Trajectory Statistics), which is a geographic information system-based software. In TrajStat, the trajectory calculation function appears from Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT). Global Land Evaporation Amsterdam Model (GLEAM) data are utilized for obtaining evaporation rate (E_r) for the present location. It is a process-based semi-empirical model used to estimate land evaporation and its separate components on a monthly basis with a resolution of 0.25ºx0.25º [10].

3 Results

3.1 Variation of DSD parameter over Kolkata

To investigate the long term variability of DSD parameter, mass weighted mean drop diameter (D_m) over Kolkata have been estimated for pre-monsoon and monsoon period for the time span 2004 to 2018.

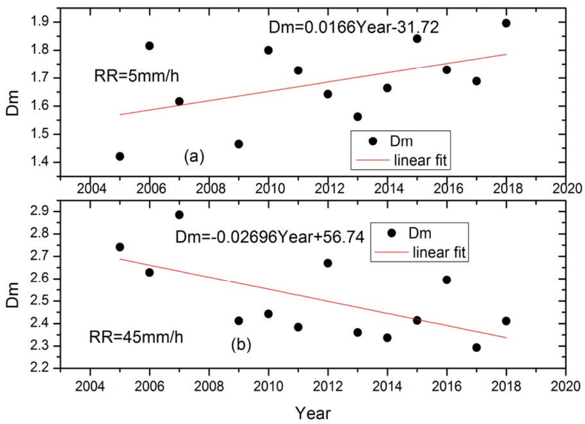

Figure 1.D_m values in different years with linearly fitted lines are shown during pre-monsoon at rain rates: (a) 5 mm/h, (b) 45 mm/h.

A power law relation between D_m and rain rate (RR) has been formulated and the coefficients (a and b) of the relation, $D_m = aRR^b$, for a particular year during monsoon and pre-monsoon period have been estimated seperately. Now, the variation of D_m at different rain rates has been observed by varying the RR value. It is seen that for pre-monsoon D_m has increased over the years for lower rain rates (RR<15mm/h) and a decreasing trend of D_m has been noticed for higher rain rates (RR >15mm/h). Figure 1 shows D_m variation during pre-monsoon at rain rates 5 mm/h and 45 mm/h where an increasing (slope 0.0166) and a decreasing (slope -0.02696) trend are respectively noticed. But for the monsoon season a decreasing trend of D_m for all rain rate regimes have been observed. Figure 2 shows variation of D_m for rain rates 5 and 45 mm/h as representative cases of lower and higher rain rates respectively. To investigate the role of associated atmospheric parameters in this long term DSD trend, AOD, CER and E_r data during this period have been examined.

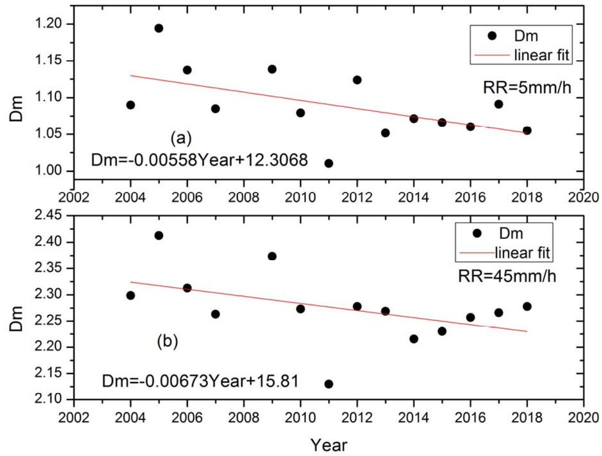

Figure 2.D_m values in different years with linearly fitted lines are shown during monsoon at rain rates: (a) 5 mm/h, (b) 45 mm/h.

3.2 AOD variation over Kolkata

AOD is the estimation of the extinction of solar radiation by prevailing dust, pollutant particle and haze. The presence of these particles absorb and scatter solar radiation. High AOD value (>0.4) corresponds to very hazy condition. Figure 3 shows the mean variation of AOD during pre-monsoon and monsoon period over Kolkata obtained from MODIS. Kolkata experiences an increasing trend of AOD from 2004-2018 for both pre-monsoon and monsoon period. The rate of increase of AOD over Kolkata is higher during pre-monsoon (slope: 0.022) compared to that of monsoon (slope: 0.005).

3.3 Change of evaporation rate over Kolkata

A variation of evaporation rate has also been observed over Kolkata. Figure 4 shows the mean E_r along with the standard deviation values over Kolkata during the pre-monsoon and monsoon season for the time period 2004-2018. It is observed that during the pre-monsoon period evaporation rate shows an increasing trend with a slope of 0.68 (Figure 4(a)) for the considered time period. E_r during the monsoon months shows slight increasing trend with a slope of 0.019 (Figure 4(b)).

3.4 Variation of CER over Kolkata

To investigate the variation of cloud microphysics in relation to the aerosol environment, CER behaviour is also shown. CER is the weighted mean values of cloud droplet size distribution determining the radiative properties of liquid water clouds. Monthly mean values of CER obtained from MODIS are observed to have an increasing trend during pre-monsoon and monsoon period of slope 0.049 and 0.061 respectively (Figure 5).

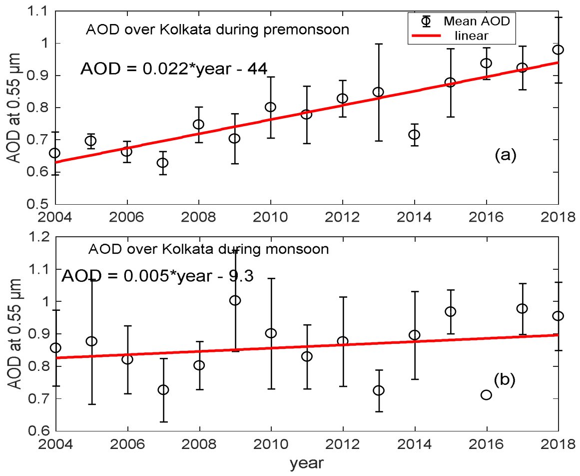

Figure 3. Mean AOD at 0.55 µm over Kolkata during 2004-2018 the: (a) Pre-monsoon, and (b) Monsoon season.

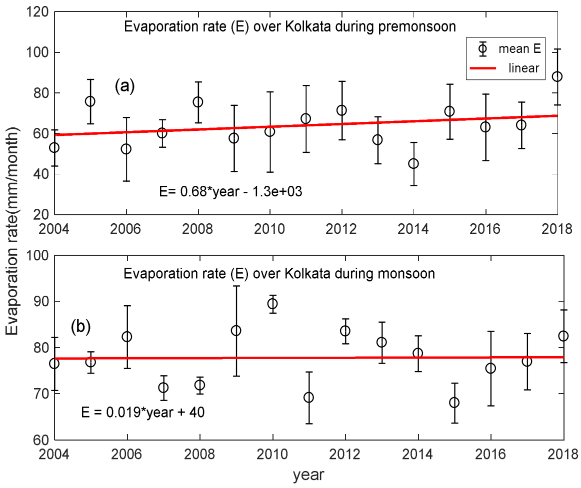

Figure 4. Mean evaporation rate (mm/month) over Kolkata during 2004-2018 for: (a) Pre-monsoon, and (b) Monsoon season.

4 Discussions

From the above mentioned results, it may be mentioned that significant increasing rate of AOD during pre-monsoon over Kolkata resulted into increase in evaporation rate. Aerosol loading causes not only significant changes in cloud microphysical properties and thus resulting in smaller rain drops, but also warming of the atmosphere, which can increase the evaporation of the falling rain drop. It may be noted that DSD is modified by evaporation over the rain height [11]. Evaporation results in greater decrement of smaller drops than larger drops causing an increase of mean drop diameter. During pre-monsoon, due to significant increase in evaporation rate, smaller drops, which are dominant for lower rain rates, evaporates rapidly resulting in an increase of D_m value. For higher rain rates (*RR*> 15 mm/h) during pre-monsoon, larger drops break up and simultaneously evaporate resulting in a decreasing trend of D_m values. On the other hand, Kolkata experiences a decreasing trend of D_m values for all rain rate regimes during monsoon.

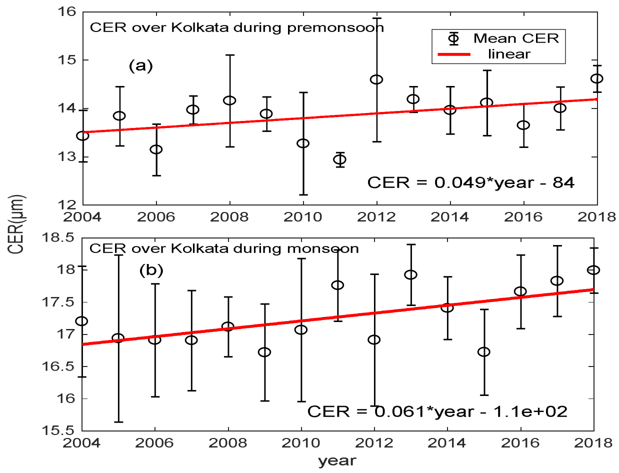

Figure 5. Mean CER (µm) over Kolkata during 2004-2018 for: (a) Pre-monsoon, and (b) Monsoon season.

The decrease of D_m for higher rain rates indicates that break-up processes dominate over the coalescence causing redistribution of drop diameters with higher number of smaller drops. The decreasing trend of D_m for low rain rates during monsoon is rather small, which is in commensurate with the low decreasing gradient of evaporation rate as shown in Figure 4. Further positive correlation between AOD and CER shows anti-Twomey effect prevailing over Kolkata, similar to the findings of Yuan et al., (2008) [12].

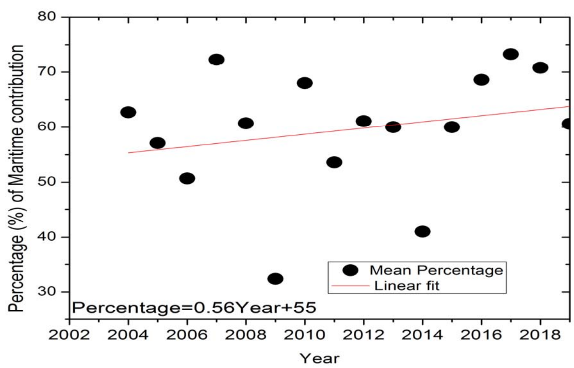

Figure 6. Maritime Percentage during pre-monsoon over Kolkata

Increasing AOD is expected to reduce the cloud effective radius, but the increase in CER with AOD suggests that other mechanisms over urban polluted locations affect cloud properties and as a consequence compensate the aerosol effect on cloud. The maritime contribution in total precipitation during pre-monsoon has been obtained by back trajectory cluster analysis. Kolkata being located near the land ocean boundary the maritime contribution has shown an increasing trend during pre-monsoon for the period of study (Figure 6). On the other hand monsoon is mainly dominated by maritime activities. The warm humid environment may favour the increase of CER at the present location [12].

5 Conclusions

Long term observations on rain microstructure using space borne and ground based observations over a tropical metropolitan city Kolkata in association with the change of cloud microphysics, and aerosol environment have been investigated. A distinctive variation of D_m in pre-monsoon and monsoon period during the period of 2004 to 2018 has been observed. The increasing trend in D_m values at lower rain rates during pre-monsoon period is due to increased evaporation rate over Kolkata. The decreasing trend of D_m on a long term basis during monsoon is possibly linked to the aerosol environment and subsequent cloud formation at the present location. An increasing trend of AOD with CER is seen to have prevailed over Kolkata disobeying the hypothesis formulated by Twomey (1977) [13] which is also reported by other researchers. The study presents a long term data on DSD variation from a tropical location which is valuable in understanding the microphysical features of precipitation and associated atmospheric processes.

6 Acknowledgements

This work has been supported by the grants under the projects: (i) “Council of Scientific and Industrial Research (CSIR), HRDG (File No: 09/028(1040)/2018-EMR-I)”, (ii) “UGC Basic Science Research Faculty Fellowship” (No.F.18-1/2011(BSR)).

7 References

1. M. Marzuki, T. Kozu, T. Shimomai, W. L.Randeu, H. Hashiguchi, and Y. Shibagaki, "Diurnal variation of rain attenuation obtained from measurement of raindrop size distribution in equatorial Indonesia," *IEEE Transactions on Antennas and Propagation*, **57**, 4, April 2009, pp. 1191–1196.

2. M. Angulo-Martinez, and A. P. Barros, "Measurement uncertainty in rainfall kinetic energy and intensity relationships for soil erosion studies: An evaluation using PARSIVEL disdrometers in the Southern Appalanchian Mountains," *Geomorphology*, **228**, January 2015, pp. 28–40.

3. B.Chapon, G. Delrieu, M. Gosset, and B. Boudevillain, "Variability of raindrop size distribution and its effect on the Z–R relationship: A case study for intense Mediterranean rainfall," *Atmospheric Research*, **8** , 1, 2008, pp. 52–65.

4. V. Bringi, V. Chandrasekar, J. Hubbert, E.Gorgucci, W. L. Randeu, and M. Schoenhuber, "Raindrop size distribution in different climatic regimes from disdrometer and dual-polarized radar analysis," *Journal of the Atmospheric Sciences*, **60**, 2, January 2003, pp. 354–365.

5. A. Tokay, and D. A. Short, "Evidence from tropical raindrop spectra of the origin of rain from stratiform versus convective clouds," *Journal of Applied Meteorology*, **35**, 3, March 1996, pp. 355–371, .

6. R. J. Charlson, S. E. Schwartz, J. M. Hales, R. D. Cess, J. A. Coakley, J. E. Hansen, and D. J. Hofmann, Climate forcing by anthropogenic aerosols, Science, **255**, 5 January 1992, pp. 423–430.

7. W. K. Tao, J. P. Chen, Z. Li, C. Wang, and C. Zhang, "Impact of aerosols on convective clouds and precipitation," *Reviews of Geophysics*, **50**, 2, April 2012.

8. P. Dahutia, B. Pathak, and P. K. Bhuyan, "Vertical distribution of aerosols and clouds over north-eastern South Asia: Aerosol-cloud interactions," *Atmospheric Environment*, **215**, October 2019, pp. 116882.

9. S. Talukdar, S. Jana, and A. Maitra, "Dominance of pollutant aerosols over an urban region and its impact on boundary layer temperature profile," *Journal of Geophysical Research: Atmospheres*, **122**, 2, December 2017, pp. 1001-1014.

10. B. Martens, R. de Jeu, , N. Verhoest, H. Schuurmans, J. Kleijer, and D. Miralles, "Towards Estimating Land Evaporation at Field Scales Using GLEAM," *Remote Sensing*, **10**, 11, October 2018, pp. 1720, doi: 10.3390/rs10111720.

11. Z. Levin, G. Feingold, S. Tzivion, and A. Waldvogel, "The evolution of raindrop spectra: Comparisons between modeled and observed spectra along a mountain slope in Switzerland," *Journal of Applied Meteorology*, **30**,6, June 1991, pp. 893-900.

12. T. Yuan, Z. Li, R. Zhang, and J. Fan, "Increase of cloud droplet size with aerosol optical depth: An observation and modeling study," *Journal of Geophysical Research: Atmospheres*, **113,** D4, February 2008.

13. S. Twomey, "The influence of pollution on the shortwave albedo of clouds, *Journal of the atmospheric sciences*, **34**, July 1977, pp. 1149–1152.