Long Term Melting Layer Features related to Atmospheric Instabilities at a tropical location

Pallabi Saha* (1), and Animesh Maitra(1)
(1) Institute of Radio Physics and Electronics, University of Calcutta,
92, Acharya Prafulla Chandra Road, Kolkata 700009, India: mail.pallabisaha@gmail.com*;
animesh.maitra@gmail.com

Abstract

The present study is concerned on the melting layer height and width variations and its relation to atmospheric feature such as boundary layer height and atmospheric instability expressed in terms of Convective Available Potential Energy (CAPE) over a tropical location, Kolkata, India.

1. Introduction

Studies on melting layer and its features have been of interest as it helps in rain and hydrometeor classification algorithms. Formation of rain which has a crucial part in earth's climate change takes place in this layer. Transition of ice crystals to rain drops occurs within the melting located just below the 0°C isotherm level [1]. Extensive studies dealing with the detection of melting layer through radar observations and attenuation due to the melting layer have been reported earlier [2, 3, 4]. However, long term studies of melting layer features and their relations to various atmospheric parameters are limited, particularly over a tropical location like Kolkata. Owing to its location, Kolkata experiences a combinational rainfall pattern from both continental and maritime wind inflow which makes it even more interesting to carry out rain related studies [5, 6].

2. Data and Methodology

The present study employs long term radar observations from Micro Rain Radar (MRR) and reanalysis data from ERA-5. Melting Layer height is determined from the enhanced reflectivity observed in the vertical profile of the radar reflectivity from Micro Rain Radar (MRR) operating at 24.1 GHz at the Institute of Radio Physics and Electronics, University of Calcutta during the period 2009-2019. Based on the presence of melting layer in the rain/radar reflectivity profile of MRR, a rain event is classified as stratiform rain whereas absence of the melting layer characterizes convective rain [1, 10]. Convective Available Potential Energy (CAPE) values are procured from Radiosonde measurements from the University of Wyoming (website http://www.uwyo.edu) over Kolkata, India during the period 2005-2019.

3. Results

The two most important features in stratiform rain that characterizes melting layer are its height and width. Study of these features is important because this layer is the major source of precipitation. The time slots are divided with the help of the diurnal variation of temperature as shown in Figure 1.

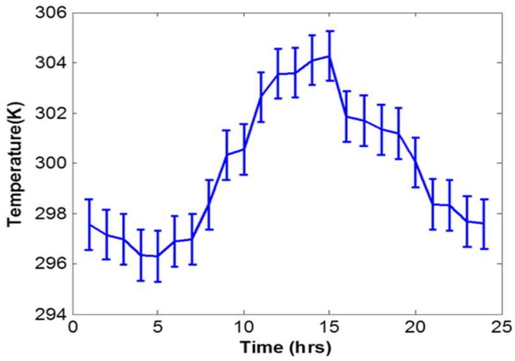

Figure 1. Diurnal Variation of Temperature

The four time slots include night and early morning hours which stretches from 20.00H -6.00H, noon time extending from 6.00H – 11.00H, afternoon hours spreads from 11.00H- 17.00H and finally the evening hours extends from 17.00H- 20.00H. Diurnal variation of melting layer height is shown in Figure2.

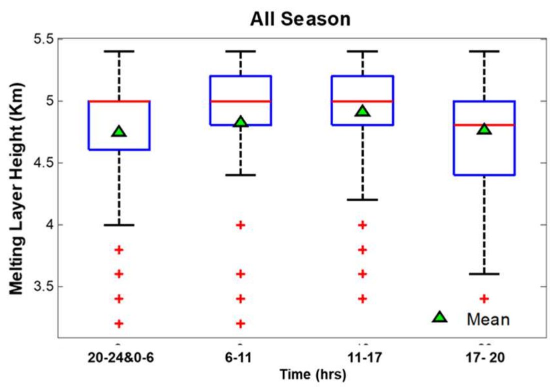

Figure 2. Box and Whisker plot of the diurnal variation of Melting Layer Height (Km) during 2009-2019.

Surface temperature increases when it receives maximum solar radiation which is during the noon and afternoon hours (6.00H -11.00H and 11.00H-17.00H), melting layer height also elevates, and consequently when surface temperature cools down the melting layer height decreases. [7, 8] reported that in warmer seasons melting layer forms at higher heights. This variability of melting layer height can also get affected by the atmospheric boundary layer height [9,15]. As boundary layer is situated below the melting layer, the diurnal variation of boundary layer may directly influence the diurnal variation of the melting layer height. During daytime, when surface temperature is highest, boundary layer expands which pushes the melting layer simultaneously and during the night time the reverse phenomenon happens as shown in Figure3.

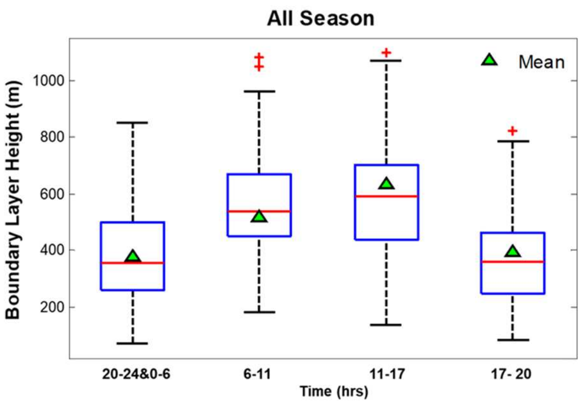

Figure 3. Box and Whisker plot of the diurnal variation of Boundary Layer Height (m) during 2009-2019.

Melting layer width shows significant seasonal variation rather than diurnal variation. The mean melting layer width has maximum value during monsoon compared to other seasons shown in Table1, which might be due to high liquid water content during monsoon which is in line with earlier findings [10, 11].

Table1. Seasonal Variation of Melting Layer Height (Km) and Width (m)

Season	Mean Melting Layer Height (Km)	Mean Melting Layer Width (m)
Pre-Monsoon	**4.419**	**735.48**
Monsoon	**5.052**	**870.20**
Post-Monsoon	**4.610**	**850.90**
Winter	**4.20**	**833.33**

So, high liquid water content might be the reason for high melting layer width during monsoon season. Despite the fact that pre-monsoon season experiences higher temperature than monsoon, the melting layer height is still lower. This may be because, during pre-monsoon season, stratiform rain occurs mainly during the evening and night hours.

Long term trend of melting layer height for the period 2009-2019 is analyzed and shown in Figure4. A decreasing trend of melting layer height is observed over the period 2009-2019. Earlier observations showed a control of CAPE on melting layer height [1,2] at the present location. This is in commensurate with the change in long term CAPE values.

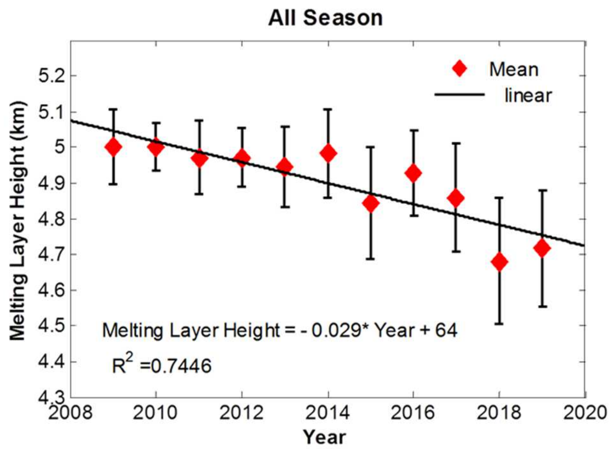

Figure 4. Long term MRR observation of mean Melting Layer Height (Km) variation for the years 2009-2019.

This prompted us to investigate the long term CAPE variation further. Figure5, represents the long term trend of CAPE values for the period 2005-2019 and exhibits a decreasing trend of CAPE values.

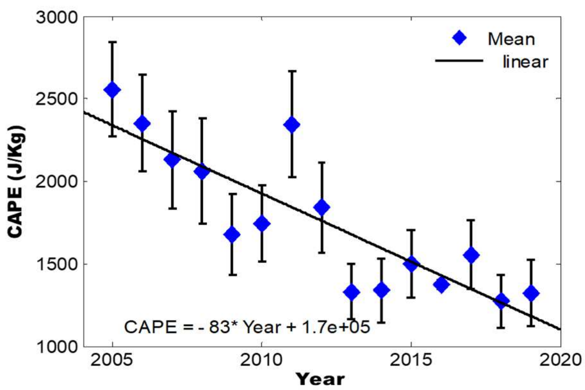

Figure 5. Long Term variation of CAPE values for the years 2005-2019 as observed from radiosonde measurements.

High values of CAPE are usually analogous to convective precipitation whereas stratiform rains are linked to low values of CAPE [13, 14, 15]. Hence, this decrease in CAPE values over the years can indicate decreased convective activities and increased stratiform precipitation.

4. Summary and Conclusion

The present study investigates the diurnal variations of melting layer height, boundary layer height and seasonal variations of melting layer width for the period of 2009-2019, and the possible causes for this variation over Kolkata, a tropical location near the land sea boundary. The study also focuses on the long term trend of melting layer height and the resulting consequences. This study utilizes measurements obtained from MRR and radiosonde measurements for a period of almost 11 years i.e. 2009-2019. The major outcomes of this work are:1) Melting layer height shows a diurnal variation which is influenced by a strong diurnal variation of boundary layer height. 2) Melting layer width exhibits seasonal variation with monsoon season having the maximum width compared to the other seasons. 3) A long term decreasing trend of melting layer height is observed for the period 2009-2019. 4) Atmospheric instability in terms of CAPE also shows a decreasing trend which can be an indicative of increased stratiform rain events.

The present study indicates that the long term changes in melting layer features can be related to varying atmospheric dynamics over a location near the land-sea boundary.

5. Acknowledgements

This work was supported in part by the Government of West Bengal, Ministry of Higher Education through the award of Swami Vivekananda Fellowship to one of the authors (P.S.).

6. References

1. F. Fabry and I. Zawadzki, “Long-term radar observations of the melting layer of precipitation and their interpretation”, *Journal of the atmospheric sciences*, **52**, 7, April 1995, pp. 838-851,1995 doi: https://doi.org/10.1175/15200469(1995)052<0838:LTROOT>2.0.CO;2

2. S. Jana, G. Rakshit and A. Maitra. "Aliasing effect due to convective rain in Doppler spectrum observed by micro rain radar at a tropical location." *Advances in Space Research* **62**, no. 9, November 2018, pp: 2443-2453. doi: https://doi.org/10.1016/j.asr.2018.07.010

3. S. Das, A. Maitra and A. K. Shukla, "Melting layer characteristics at different climatic conditions in the Indian region: Ground based measurements an d satellite observations." *Atmospheric research*, **101**, no. 1-2 July 2011, pp:78-83,

4. S. E. Giangrande, J. M. Krause and A. V. Ryzhkov, "Automatic designation of the melting layer with a polarimetric prototype of the WSR-88D radar." *Journal of Applied Meteorology and Climatology*, **47**, no. 5 May 2008 pp: 1354-1364.
doi: https://doi.org/10.1175/2007JAMC1634.1

5. G. Rakshit, S. Jana and A. Maitra. "Multitechnique observations on the impacts of declining air pollution on the atmospheric convective processes during COVID-19 pandemic at a tropical metropolis." *IEEE Geoscience and Remote Sensing Letters* **19**, January 2021 pp: 1-5. doi: 10.1109/LGRS.2021.3049887

6. G. Rakshit, S. Jana and A. Maitra. "Long-Term Impact of Continental and Maritime Airflow on Aerosol Environment and Rain Microstructure Near Land–Sea Boundary." *IEEE Geoscience and Remote Sensing Letters* **19**, March 2022 pp: 1-5. doi: 10.1109/LGRS.2022.3158980

7. W. Klaassen, "Radar observations and simulation of the melting layer of precipitation." *Journal of Atmospheric Sciences*, **45**, 24, December 1988 pp: 3741-3753.

8. R.E. Stewart, E. Ronald, J. D. Marwitz, J. C. Pace and R. E. Carbone, "Characteristics through the melting layer of stratiform clouds.", *Journal of Atmospheric Sciences*, **41**, 22, November 1984, pp. 3227-3237, doi: https://doi.org/10.1175/15200469(1984)041<3227:CTTMLO>2.0.CO;2

9. J. I. Song, S. S. Yum, S. H. Park, K. H. Kim, K. J. Park and S. W. Joo. "Climatology of melting layer heights estimated from cloud radar observations at various locations." *Journal of Geophysical Research: Atmospheres*, **126**, no. 17 August 2021. doi: https://doi.org/10.1029/2021JD034816.

10. G. Rakshit, L. Quibus, D. V. Janvier, A. Maitra and L. Luini. "Non-rainy attenuation over earth-space paths at tropical and temperate sites using meteorological data and nwp products." *IEEE Access*, **9**, July 2021 pp: 101311-101320. doi: 10.1109/ACCESS.2021.3096380

11. A. Maitra, U. Saha and A. Adhikari. "Solar control on the cloud liquid water content and integrated water vapor associated with monsoon rainfall over India." *Journal of Atmospheric and Solar-Terrestrial Physics*, **121**, December 2014 pp: 157-167.
doi: https://doi.org/10.1016/j.jastp.2014.06.010

12. P. Saha, G. Rakshit and A. Maitra, "Dependence of rain drop size distribution parameters on atmospheric instability over a tropical location near the land-sea boundary." *Radio Science*, **57**, no. 3, March 2022 pp: 1-13. doi: 10.1029/2021RS007374

13. Houze Jr, Robert A. "Observed structure of mesoscale convective systems and implications for large scale heating." *Quarterly Journal of the Royal Meteorological Society,* **115**, no. 487, April 1989 pp: 425-461. doi: https://doi.org/10.1002/qj.49711548702

14. V. N. 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**, no. 2, January 2003 pp: 354 - 365.

15. S. Das, A. K. Shukla and A. Maitra. "Investigation of vertical profile of rain microstructure at Ahmedabad in Indian tropical region." *Advances in Space Research*, **45**, no. 10, May 2010 pp: 1235-1243. doi: https://doi.org/10.1016/j.asr.2010.01.001