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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

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, 2, 3]. Stratiform and convective rain are the two broad types of precipitation. As the convective rain involves strong vertical velocity, formation of melting layer is not possible in this type of rain [4]. On the other hand stratiform rain is associated with weak vertical velocities, and hence formation of melting layer can be sustained in this rain type. Stratiform rain is thus identified with the help of a bright band structure from the radar observations due to melting of ice crystals. Melting layer appears bright because of the enhanced reflectivity caused on account of the change in dielectric constant of water coated ice crystals [5]. Identification of melting layer is necessary because this layer helps in determining signal attenuation caused a higher frequencies [6, 7]. The layer helps in identifying the rain height and in classifying solid and liquid precipitation.

Experimental observations of the propagation effects on Ku band in the earth space link revealed the effects of melting layer in both co-polar and cross polar attenuation on rain events and that depolarization of signals is more dominant due the melting layer [8] over Kolkata. [4] reported the effect of different climatic conditions on melting layer height from measurements at Shilong and Trivandrum in India. There lies an extensive studies that deal with the detection algorithm of melting layer through radar observations, attenuation due to the melting layer which has been reported earlier [9]. However, long term studies of melting layer features and 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 [10, 11]. Kolkata receives an average rainfall of nearly ~1500 mm, of which around 80% of rainfall occurs between June and September comprising the monsoon season [12]. 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). The present study deals with the following aspects of melting layers and associated atmospheric features,

- Presentation of diurnal variation of melting layer height and boundary layer height.
- Seasonal variation of melting layer width for the period 2009-2019.
- Long term trend of melting layer height for the period 2009-2019 and its consequence.
- Long term trend of atmospheric instability expressed in terms of Convective Available Potential Energy (CAPE) with respect to melting layer features.

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). MRR is a frequency modulated continuous wave radar (FM-CW) which operates at 24.1 GHz at the rooftop of the Institute of Radio Physics and Electronics, University of Calcutta. It yields vertical profiles of rain parameters such as drop size distribution (DSD), liquid water content and rain rate at 30sec temporal resolution from 200 m to 6 k m above the ground. 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, 13]. 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 2009-2019. Radiosonde observations are made twice a day, at around 00 and 12 GMT (0530 and 1730 IST).

3. Results and Discussions

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. Diurnal variation of melting layer height is shown by the box and whisker plot in Figure 2.

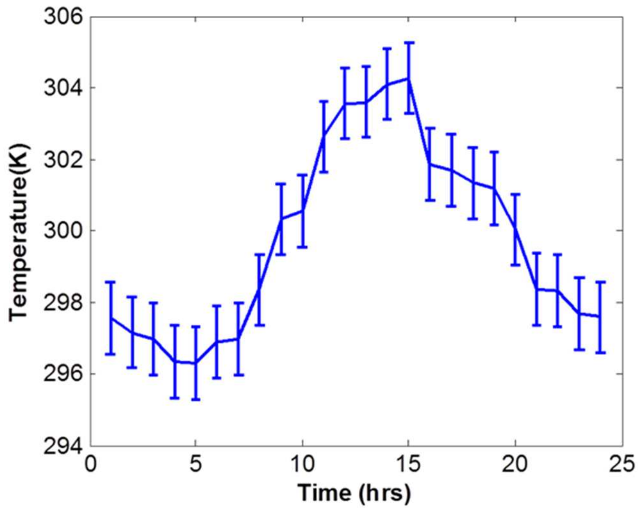

Figure1. Diurnal Variation of Temperature

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. In Figure 2, melting layer height has a mean (median) value of 4.7(4.9), 4.82(4.98), 4.90(5) and 4.75(4.8) during night and early morning hours (20.00H-0.00H and 0.00H-5.00H), before noon time (5.00H-12.00H), noon and afternoon (12.00H-17.00 H) and in the evening (17.00H-20.00H) respectively. Melting layer height is higher when surface temperature is also higher during 6.00H-11.00H and 11.00H-17.00H. While during night and evening hours melting layer height is relatively lower. [14] reported that in warmer seasons melting layer forms at higher heights. Surface temperature increases when it receives maximum solar radiation which is during the noon and afternoon hours, melting layer height also elevates and consequently when surface temperature cools down the melting layer height decreases. This variability of melting layer height can also get affected by the atmospheric boundary layer height.

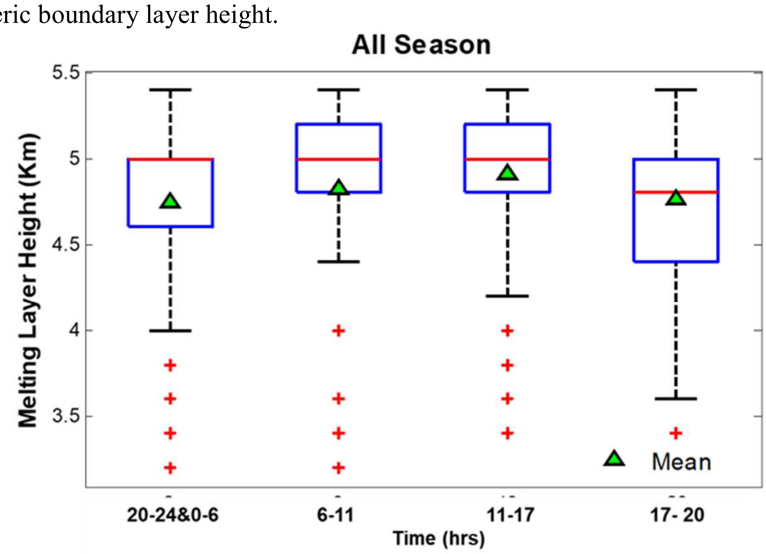

Figure 2. Box and Whisker plot of the Diurnal Variation of Melting Layer Height (Km) during 2009-2019.

Boundary Layer is a key component that controls the exchange of heat, moisture between the surface and the atmosphere and typically ranges from few 100 m to 2 km above the ground. Boundary layer height is strongly controlled by its strong diurnal cycle [15]. As depicted in Figure 3, boundary layer height has a mean (median) height of 377.5(357.82), 519(535.66), 633.2(592.33) and 392.9(358.25) during night and early morning hours (20.00H-0.00H & 0.00H-5.00H), before noon time (5.00H-12.00H), noon and afternoon (12.00H-17.00H) and in the evening (17.00H-20.00H) respectively. During daytime when the surface temperature is higher, boundary layer height expands to few kilometres, but during night when temperature is relatively lower, boundary layer height diminishes to few meters above the ground. This diurnal variability of boundary layer height is shown in Figure 3. It is seen that mean boundary layer height has maximum values during noon time i.e. 11.00H- 17.00H and lower values during night and evening hours.

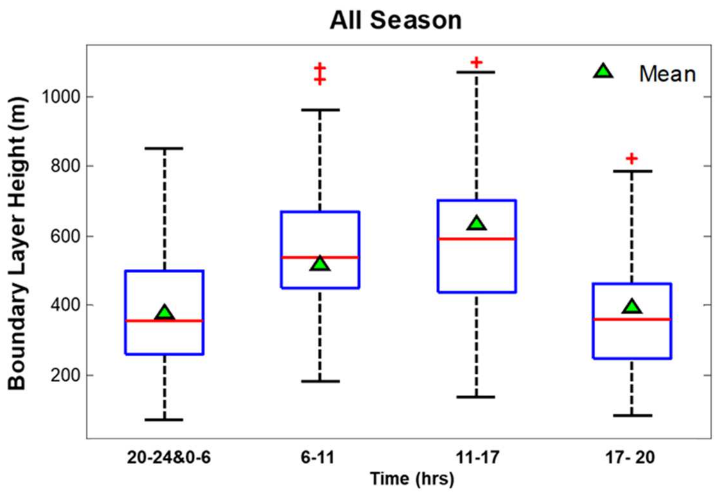

Figure 3. Box and Whisker plot of the Diurnal Variation of Boundary Layer Height (m) during 2009-2019.

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.

Melting layer width shows significant seasonal variation rather than diurnal variation. Hence seasonal variation of both melting layer width and height is observed and is shown in Table1. It is seen that mean melting layer height has maximum value during monsoon season and minimum during winter season which is as expected. On the other hand, the mean melting layer width is maximum values during monsoon. As reported earlier [16, 17] liquid water content is high during monsoon season than the other seasons. 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.

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**

Long term trend of melting layer height for the period 2009-2019 is analysed and shown in Figure 4. 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 [12] at the present location. This is in commensurate with the change in long term CAPE values.

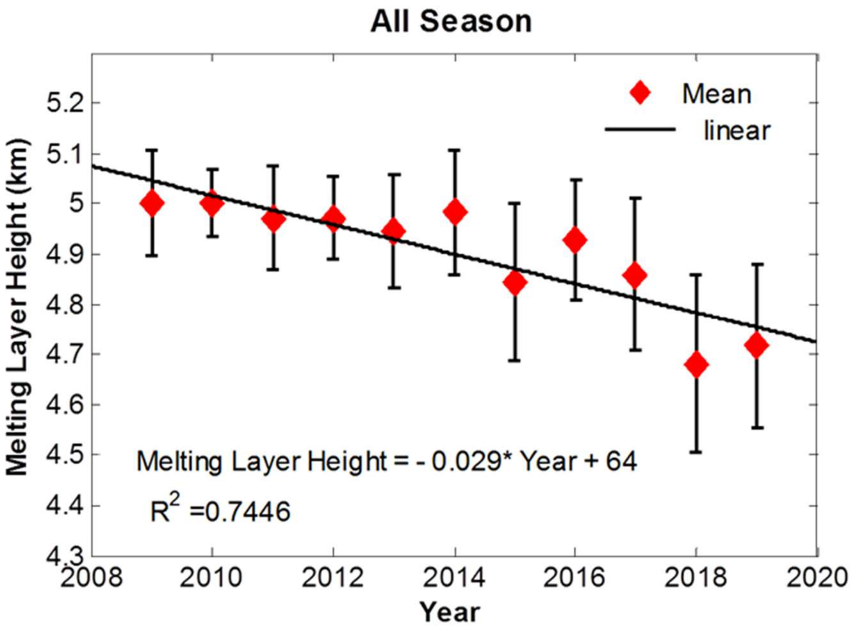

Figure 4. Long Term MRR observation of mean Melting Height (Km) variation for the years 2009-2019.

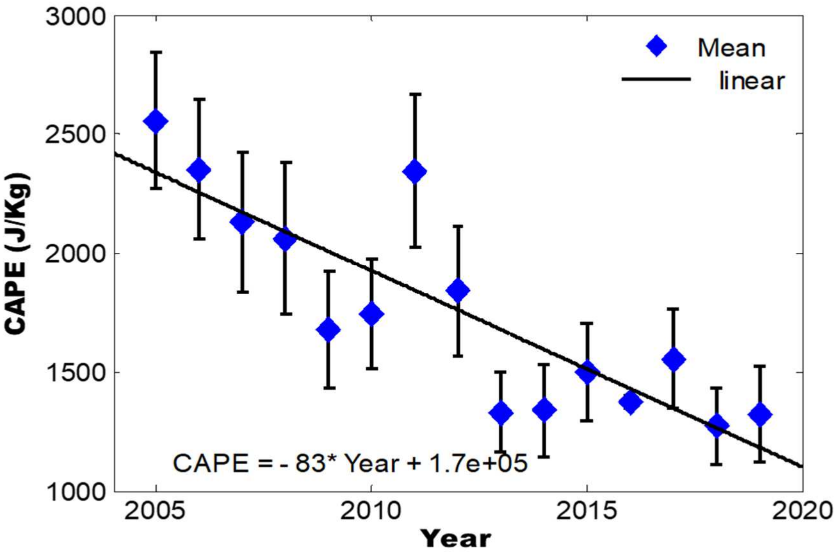

Figure 5. Long Term variation of CAPE values for the years 2005 - 2019 as observed from radiosonde measurements.

Figure 5, represents the long term trend of CAPE values for the period 2009-2019 and exhibits a decreasing trend of CAPE values. High values of CAPE are usually analogous to convective precipitation whereas stratiform rains are linked to low values of CAPE [18, 19]. Hence this decrease in CAPE values over the years can indicate decreased convective activities and increased stratiform precipitation.

4. Conclusion

The present study analysed 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,

- Melting layer height shows a diurnal variation which is influenced by a strong diurnal variation of boundary layer height.
- Melting layer width exhibits seasonal variation with monsoon season having the maximum width compared to the other seasons.
- A long term decreasing trend of melting layer height is observed for the period 2009-2019.
- 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.

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