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Melting layer characteristics at different climatic conditions in the Indian region: Ground based measurements and satellite observations

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ABSTRACT

Melting layer height, which is normally assumed to be the limits of rain region, is an important parameter to consider the performance of earth space communication link above 10 GHz. In this paper, the variation of melting layer observed by a vertically looking Micro Rain Radar (MRR) for 3 years has been presented for two different climatic locations in Indian tropical region — Shillong (25°34′ N, 91°53′ E, 1050 m) and Trivandrum (8°29′ N, 76°57′ E, 4 m). The analyses show that the variation is quite significant for different months in Shillong but not for Trivandrum. The height of melting layer shows a strong correlation with ground temperature of these locations. The results agree well with the long term Tropical Rainfall Measuring Mission (TRMM) measurements of melting layer indicating suitability of using TRMM data for such study. A comparison of MRR with the nearest Radiosonde measurement indicates that MRR can have potential application in the study of zero degree isotherm height in rainy conditions. Results also clearly indicate that the assumption of constant rain height is not a valid one for all tropical locations.

1. Introduction

Rain, hail, cloud and melting layer pose a serious threat to the earth–space link operating at frequency above 10 GHz (Crane, 1996; Ajayi, 1996; Ippolito 1986). In the absence of actual signal measurement in the earth space communication link, the attenuation prediction usually performed with the help of different meteorological parameters. For example, ITU-R Recommendation P. 618-7 (ITU-R, 2001) provides an easy way to calculate the attenuation for any earth–space link. Rain height is one of the important parameters for rain attenuation calculation in this model. ITU-R Recommendation P. 839-3 (ITU-R, 2005) provides a contour map of annual averaged zero degree isotherm height with 1.5° by 1.5° grid resolution for this purpose. However, these models are found to be inadequate for attenuation prediction in tropical region due to the different characteristics of rain and other hydrometeors (Ajayi and Barbaliscia, 1990; Green, 2004).

One of the assumptions made in the ITU-R model is of constant rain height, validity of which is questionable for tropical region (Ajayi and Barbaliscia, 1990; Green, 2004; Mondal and Sarkar, 2003). Rain height is the height up to which liquid rain exists. Usually it is derived from the 0 °C isotherm height. The ITU-R recommendation P. 452-14 (ITU-R, 2009) relates cumulative distribution of rain height to its mean value for interference calculations from various modes. However, in the context of the satellite communication modeling at high frequency bands, this ITU-R model has not been used.

The unsatisfactory result for ITU-R model in tropical region (Green, 2004), leads to re-examine the assumption of the constant rain height. With the Tropical Rainfall Measuring Mission (TRMM) satellite, more data about the melting layer in tropics have been available. The top of the melting layer usually coincides with the zero degree isotherm height (Glickman, 2000; Fabry and Zawadzki, 1995) and can be used to estimate the variability of rain height. Thurai and

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Iguchi (2000) and Thurai et al. (2003) show that there is a significant variation of melting layer height with the latitude. However, it also supported the fact that the annual average of zero degree isotherm is in expected range of ITU-R model (Thurai et al., 2003). Although, a more recent study shows that using a constant height leads to significant error in the attenuation calculation (Thurai et al., 2005) at these frequency bands. Seasonal variability of zero degree isotherm height for some tropical locations from local Radiosonde data are also reported (Mandeep, 2009; Mondal and Sarkar, 2003).

Although, TRMM provides a good amount of data, but its resolution is poor both spatially and temporally. Radiosonde measurements are only taken twice in a day. Thus, there is a need of continuous measurement of melting layer to estimate the actual variability of this layer. It can also provide an indication of validity of TRMM data for this region.

Indian Space Research Organization (ISRO) is currently planning to launch a Ka band beacon transmitter onboard to a geostationary satellite to study the rain attenuation at Ka band over Indian region. For this purpose, different meteorological parameters have been measured continuously at various locations for the past 3 years. This paper analyzes the melting layer variation for two tropical locations in India — Trivandrum (08°29′ N, 76°57′ E, 4 m) and Shillong (25°34′ N, 91°53′ E, 1050 m) from 3 years of measurement using a Micro Rain Radar (MRR). The results have been compared with available long term TRMM and Radiosonde data. Finally, some characteristics of melting layer over India are presented.

2. Data analysis

2.1. Data

2.1.1. Micro Rain Radar data

The data have been obtained using vertically looking MRR for 3 years (2005–2007) at Shillong (25°34′ N, 91°53′ E, 1050 m) and Trivandrum (08°29′ N, 76°57′ E, 4 m). Shillong is a hilly station on Himalaya, situated in the north-east of India, with heavy rain fall throughout the year. On the other hand, Trivandrum is a costal area situated in the southern part of India with substantial rainfall. The choices of the locations are due to different weather conditions at these two places.

The MRR is a FM-CW (Frequency Modulated Continuous Wave) Doppler radar which operates at 24.1 GHz. The time resolution is set to be 30 s and height resolution is fixed at 200 m to cover up to 6 km in 30 steps. The MRR software provides the 30 s average data of drop size distribution, radar reflectivity, rain rate, liquid water content and fall velocity profile. The rain rate and radar reflectivity profile has been used in the present study. The retrieval of Doppler spectra and different micro physical parameters are described in details by different researchers (Atlas et al., 1973; Strauch, 1976; Peters et al., 2002; Cha et al., 2007; Das et al., 2010, etc.) and thus not repeated here.

2.1.2. Radiosonde data

Local Radiosonde data of five years (1996–2003) are collected from the India Meteorological Department (IMD). The Radiosonde is located very near to the MRR site at Trivandrum. However, in the case of Shillong, nearest Radiosonde station is situated at a distance of 60 km at Gauahati. The Radiosonde launches two times in a day at 0000 GMT and 1200 GMT. As it measures different meteorological parameters including temperature, pressure, humidity, etc. at different heights, it can thus provide reliable information regarding freezing level height.

2.1.3. Satellite data

Precipitation radar (PR) onboard on Tropical Rainfall Measuring Mission (TRMM) satellite provides three-dimensional maps of rain. The measurements provide different parameters including rain intensity and distribution of the rain, rain type, storm depth and the height of melting layer. The PR has a vertical resolution on 250 m and horizontal resolution of 4.3 km. It covers the tropical region from 30°S to 30°N. In this study, the data of 12 years (1998–2009) has been used. The data product 3A-25 gives the monthly mean value of the different parameters in 5 × 5 degree grid and is used in this study.

2.2. Melting layer (bright band) detection

In radar data, melting layer is usually identified by the presence of "bright band" structure in radar reflectivity. Bright band is the enhanced reflectivity in the vertical profile due to the presence of melting snow, which has a different dielectric constant (Fabry and Zawadzki, 1995; Russchenberg and Lingthart, 1996). In Fig. 1, a rain event occurring on 15 July 2006 at Shillong is presented. The presence of melting

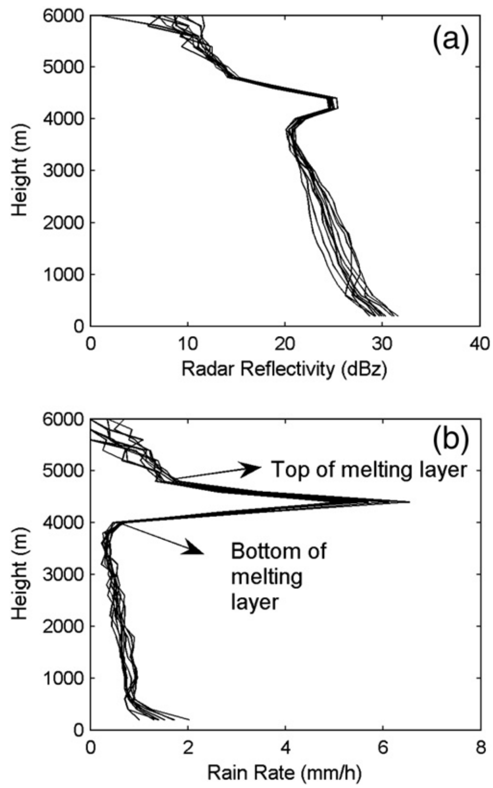

Fig. 1. Vertical profile of (a) radar reflectivity and (b) rain rate observed on 15 July 2006 at 22:49:30-22:54:30 UTC at Shillong. The peak in rain rate profile is more prominent than that in the radar reflectivity.

layer is clearly visible as enhancement around 4400 m height in both profiles. It can be seen clearly that the vertical profile of rain rate is sharper than the radar reflectivity profile. This fact is supported by many researchers (Peters et al., 2002; Das et al., 2010; Cha et al., 2007) that the rain rate profile is more sensitive to the bright band detection than the reflectivity profile in case of MRR. Hence, the rain rate profile with MRR data is used to identify the bright band in the present study. The peak rain rate is assumed to indicate the bright band height. The top of bright band is assumed where maximum negative gradient in rain rate is observed (Klaassen, 1988). Similarly, maximum positive gradient of rain rate gives the bottom of the melting layer. Thickness is calculated from the top and bottom layer information.

Bright band is a characteristic signature of stratiform rain. However, a clear bright band is not formed in all stratiform cases. It is found that for Shillong, 27% of total rain time shows clear bright band whereas for Trivandrum 21% cases shows the formation of bright band. To avoid false peak detection and erroneous data in the automatic detection scheme a few precautionary measures have been taken. It is first confirmed that the rain rate profile is continuous and only one peak is there, as double peak can occur in convective–stratiform transition case. To avoid a false peak, data are also discarded in which bright band peak does not lie in the vicinity of zero degree isotherm height as melting layer top usually coincides with zero degree isotherm. The average height of zero degree isotherm is taken from the available Radiosonde data.

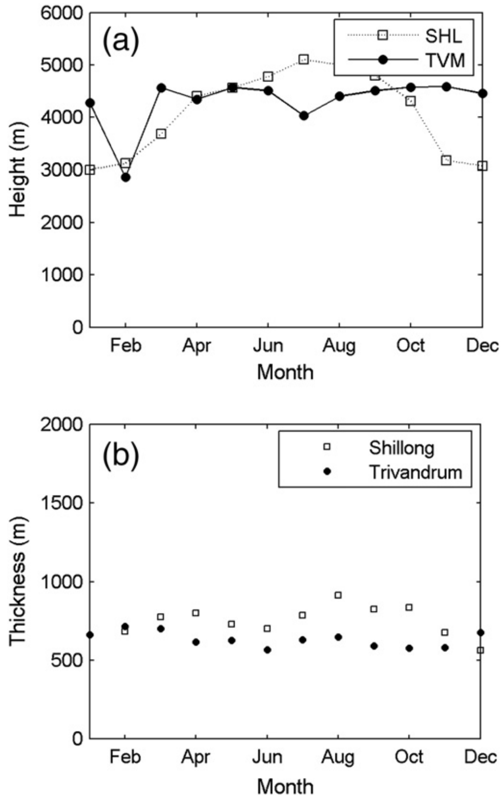

Fig. 2. Monthly mean (a) melting layer height and (b) thickness variation for Shillong and Trivandrum.

3. Results

3.1. Monthly Variation

Fig. 2 shows the variation of average melting layer for different months for Shillong and Trivandrum. It can be seen that the melting layer height variation is prominent for Shillong whereas for Trivandrum it is not significant except in February. The layer height is normally high during the monsoon months (July–Sept.) and low during winter months (Nov.–Feb.) in Shillong.

The reason for different meting layer characteristics is due to the effect of local climatology and latitudinal dependence. The greater seasonal variation for Shillong occurs mainly because of the higher latitude, as compared with the Trivandrum. The monthly average temperature of these locations shown in subplots of Fig. 3 supports the fact. Shillong has greater monthly variation of temperature, but the proximity of Trivandrum to the equator limits the monthly temperature variation. As height of melting layer depends upon the zero degree isotherm height, melting layer in Shillong shows greater variability than at the Trivandrum.

The monsoon months (June–Sept.) show significantly greater melting layer height than the other months for Shillong, indicating that an average value of melting layer height is not a good representative value for the whole year. Trivandrum, however, experiences a much less annual variation in melting layer height for which an average value can be considered to be a representative one. Also, the melting layer thickness shows some variation at Shillong but not significant change at Trivandrum throughout the year as shown in Fig. 2 (b).

3.2. Comparison among TRMM observations, Radiosonde and ground measurements

The 3A-25 data product gives monthly average bright band height in 5×5 degree grid. Mean monthly bright band height of 12 years data of respective grid has been computed to compare with the ground measurements. The bright band observed by TRMM and MRR are in good agreement as shown in Fig. 3. It should be noted that the TRMM provide bright band height average over 5×5 degree grid and satellite foot prints are not always present. The MRR observations show similar nature with long term 12 year average of TRMM observation. The discrepancy between MRR and TRMM observations is primarily in April and May, when the rain occurrence is comparatively less than the monsoon months. This also supports the fact that the MRR can provide good means to study the melting layer in continuous fashion.

Average zero degree isotherm height calculated from the 5 years of Radiosonde data compared with the MRR measurement to understand the relationship between melting layer height and zero degree isotherms. It is to be noted that the zero degree isotherm height is not directly measurable with MRR, but can be estimated from melting layer top height since zero degree isotherm normally coincides with it.

It is observed that the zero degree isotherms always lie above the bright band height observed by TRMM and MRR as shown in Fig. 4. This is because the melting starts from zero degree isotherm level and reflectivity peak occurs where the mixing of ice and water is optimum. It can be clearly seen that

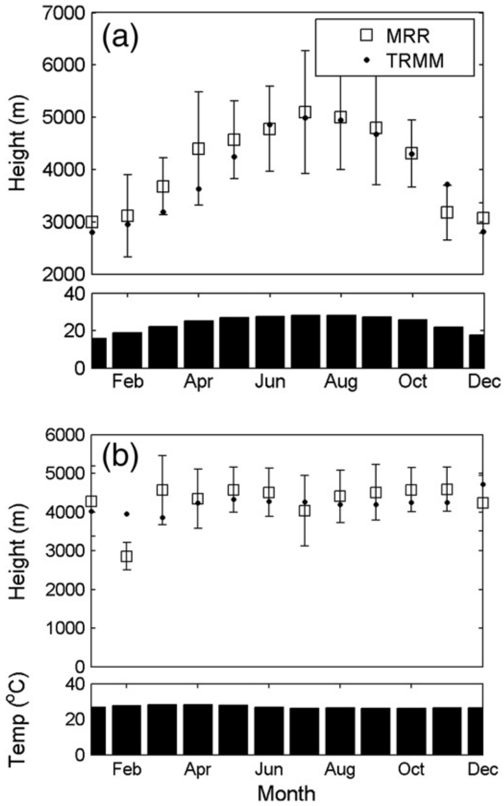

Fig. 3. Comparison of monthly mean melting layer height measured by MRR (2005–2007) and long term TRMM observation (1998–2009) at (a) Shillong and (b) Trivandrum. Lower subplots show the monthly mean temperatures at respective locations. The vertical bar indicates the standard deviation values of MRR data.

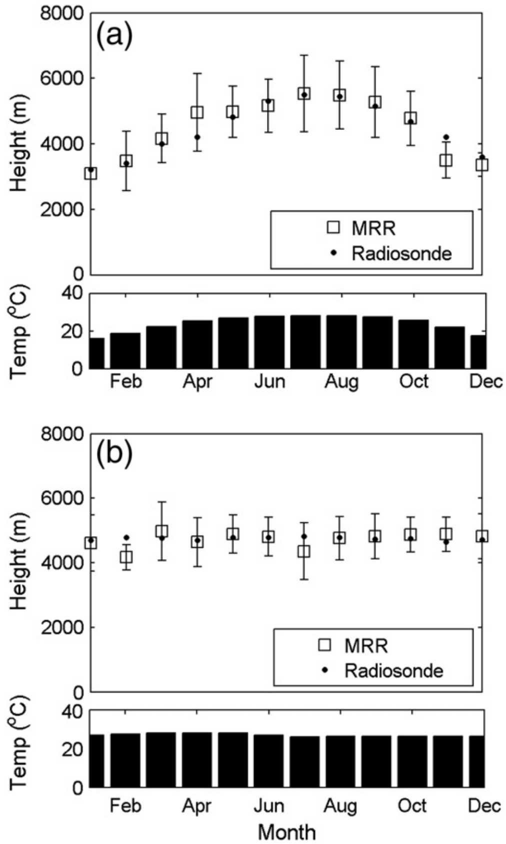

Fig. 4. Comparison of monthly mean melting layer top height measured by MRR (2005–2007) and long term Radiosonde observation (1994–1999) of zero degree isotherm height at (a) Shillong and (b) Trivandrum. Lower subplots show the monthly mean temperatures at respective locations. The vertical bar indicates the standard deviation values of MRR data.

the melting layer top and zero degree isotherm are closely related and, in fact, this is the reason for using the zero degree isotherm for rain height calculation. The melting layer top height matches well with the zero degree isotherm height for both the location indicating another effective method for monitoring the zero degree isotherm height in rainy conditions. This result is very interesting as Radiosondes are normally not available in rainy condition and MRR can have potential applications to study the zero degree isotherm in rainy weather.

3.3. *TRMM observations of melting layer characteristics over Indian region*

Melting layer characteristics over Indian region are shown in Fig. 5 using TRMM data. The figure also shows significant variation of melting layer in different months. It can be seen that the melting layer is significantly higher in monsoon months (June–September) in most of the places. The monthly variation is more prominent in higher latitudes. This results also points to the need of using variable melting layer height in melting layer models. The melting layer height is found to be decreasing with the higher latitude which is expected as the zero degree isotherm height decreases away from the equator (Thurai et al., 2003, 2005).

4. Conclusions

From the above results, it is evident that the constant rain height assumption is valid only for some tropical parts. However, it is inadequate to model for region like Shillong where monthly variability of melting layer is quite significant. This may be due to the fact that Shillong is located at higher latitude. The present results indicate the importance of acquiring of data from different tropical locations for proper modeling of earth–space propagation in the tropical region. It is also observed that the thickness of a melting layer is more or less uniform for both the locations with slight higher value in monsoon months. To model the attenuation due to melting layer, the seasonal variation of melting layer height should be considered and requires local data from other locations. The comparison of melting layer height with long term TRMM observation indicates the validity of the ground-based measurement. It also shows that the TRMM 5×5 degree grid data can well represent the average melting layer characteristics and can be a good source of melting layer information where local data gathering is not sufficient.

The measurements of zero degree isotherm from Radiosonde data and of melting layer top height with MRR are in

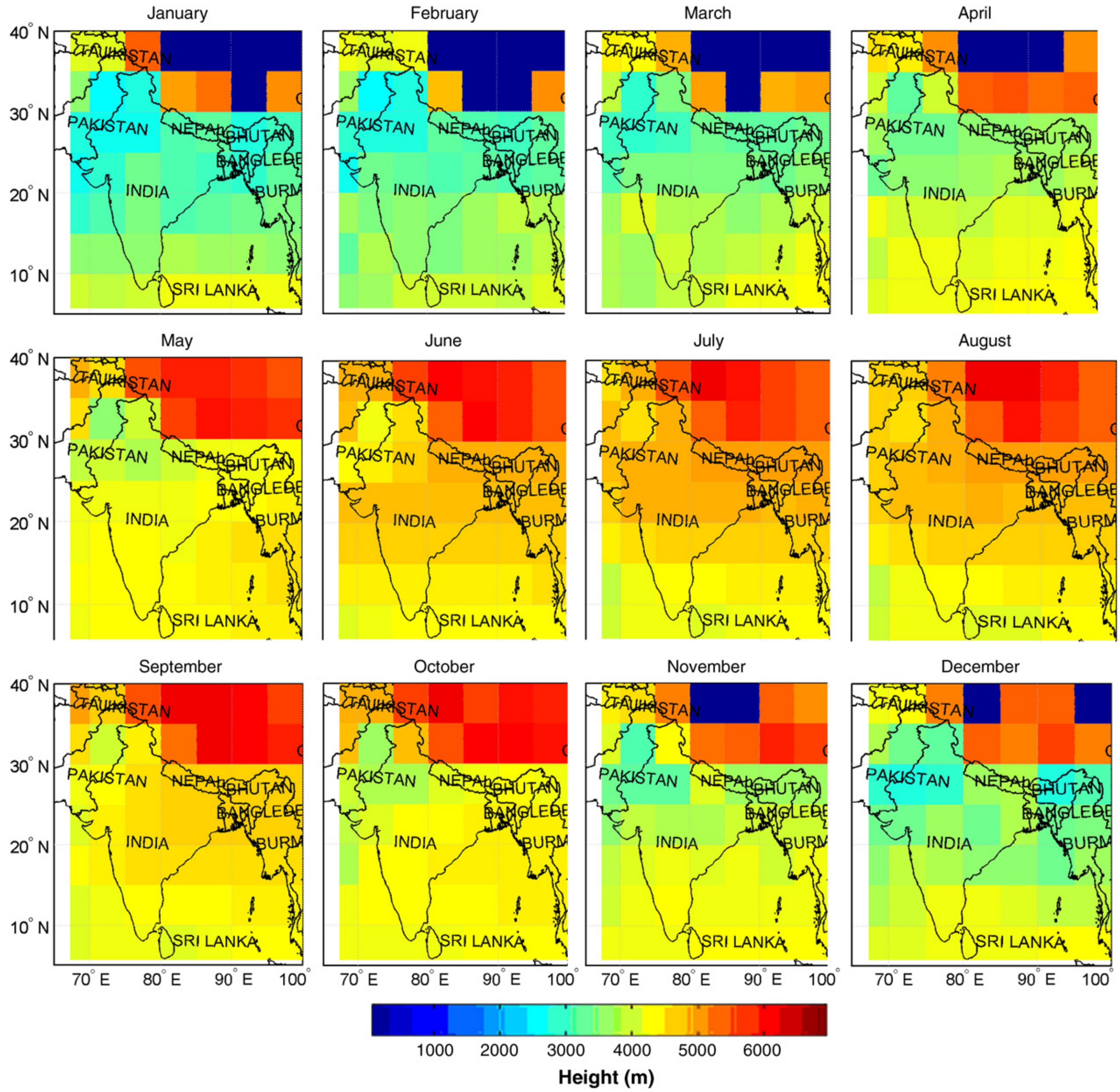

Fig. 5. Monthly mean variation of melting layer over Indian region observed by TRMM.

good agreement. This indicates possibility of using MRR to monitor the zero degree isotherm height in rainy condition when Radiosonde measurements are restrictive.

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