# Determination of the Melting Layer from Meteorological Radar Data in Malaysia

Nor Hisham Haji Khamis[1], Omer Abdel Razag Sharif[2], Zakaria Hanzaz[1], Ameruddin Baharom[1]
[1]Radar Laboratory,
Faculty of Electrical Engineering
Universiti Teknologi Malaysia
81310UTM Skudai
[2] Electric and Electronics Department
Industrial Research and Consultancy Centre (IRCC), Sudan
[1]E-mail: zakahom@yahoo.com

**ABSTRACT**: A developed algorithm based on the vertical profile of radar reflectivity, has been applied to determine the boundaries of the melting layer and its thickness. The average values of the melting layer heights are compared with ITU-R recommendations and other obtained results in tropical regions at 500m resolution range. The results obtained showed lower values for heights of the melting layer.

**KEY WORDS**: Meteorological Radar Data; Melting Layer, Bright-Band Heights.

# 1 INTRODUCTION

Satellite links, particularly those operating at frequencies above 10GHz, are often degraded by the hydrometers such as rain, hail, cloud and melting layer [1], which can cause several problems, such as signal fading, depolarization and co-channel interference due to scattering. In particular, tropical regions have posed extra difficulties in predicting attenuation due to the lack of understanding of tropical precipitation and climate such as rainfall intensity and rainfall heights [2]. To explore this precipitation, direct measurements approach had been used, but due to the cost and time to collect statistically meaningful data and the difficulty to extrapolate the results to other sites, indirect measurement approaches are proposed.

The radar, which is one of the instruments that is used to evaluate precipitation and climate, is well suited because of its inherent spatial resolution. The enhancement in radar reflectivity, which is the ability of radar target to return energy, caused by melting snowflakes below the 0°C isotherm is known as the "bright-band". This is due to changes in size, fall speed and phase during the melting process. If unrecognized, the bright-band can lead to significant overestimation of precipitation reaching the ground, sometimes by as much as a factor of 5 [3].

# 2 RADAR SPECIFICATIONS AND DATA DISCRIPTION

The meteorological radar data was taken from Kluang Radar Station, which belongs to the Meteorological Department of Malaysia. This system utilizes the 3D RAPIC system that was developed by the Australian Meteorological Bureau. The specification of the Kluang Radar Station is shown in Table 1[4]. The duration of the meteorological data is 116 days covers the period from 2$^{nd}$ January to 18$^{th}$ July 1998, using two modes of scans which are plan position indicator (PPI) and range height indicator (RHI). For PPI scan there are 15 volumetric elevation angles, 0.5°, 1.2°, 1.9°, 2.7°, 3.5°, 4.6°, 6.0°, 7.5°, 9.2°, 11.0°, 13.0°, 16.0°, 20.0°, 25.0°, and 32.0°, all of which are used to build the vertical reflectivity profile (VRP). However, the radar image of each of these angles is recorded through the full RHI's scan range (360°). These scans have been made every thirty minutes during the first eight days (2$^{nd}$ –9$^{th}$ January 1998) and every ten minutes for the rest intervals, with a resolution range 500m. These data contains 285,231 encoded radar images (1.26 GB on disk) in the encoded text format.

Table 1: Radar Specifications

| Meteorological Radar MR 781 S<br>Kajicuaca, Kluang<br>With RAPIC Transmitter EH663 v.8.00 | |
|---|---|
| Station ID | 3 |
| Station Position | Latitude: 2.02°, Longitude: 103.320°,<br>Height: 88.1m above MSL |
| Reflector | 12 Feet parabolic (3.66m) |
| Frequency | 2800 MHz |
| Polarization | Vertical |
| Gain | 38 dB |
| Coverage | Elevation: -2° to +90°, Azimuth: 360° |
| Beam width | 2.0° |
| Pulse duration | 2.2µs |
| PRF | 278 pps |
| Peak power | 389 kW |
| STC range | 230 km |

# 3 METHODOLOGY

To trace the signature of the melting layer, many procedures have been developed. These scenarios include sorting out, filtering, decoding the meteorological data and building the vertical profile of radar reflectivity. From the plotted curve the melting layer is traced during the occurrences of the stratiform events. The classification of the rain event is evaluated according to the minimum amount of the rain rate that the radar can sense and is confirmed by using the widely accepted empirical relationship of the radar reflectivity factor Z, and rainfall rate **R** that is given by $\mathbf{Z = a\ R^b}$ $mm^6/m^3$, (**R** in mmn/hr) where the most common values for ***a*** and ***b*** are 200 and 1.6, respectively. These are also the values used by the radar operator of the Malaysian Meteorological Department of Malaysia [4]. Then the average threshold of the reflectivity for the expected rain event is setup to 17 dBZ, which coincides with the threshold that is used for event classification for the TRMM radar data by applying the routine algorithm 2A23 [5]. To extract the heights of the melting layer from the detected signature, an algorithm that is based on the obtained vertical profile of reflectivity has been developed. This algorithm is based on that the height of the melting layer ($BB_H$) can be given by determining the height of the maximum reflectivity in the vertical profile cure, which is a unique value. Also the height of the zero degree Celsius isotherm ($h_0$) and the rain height are evaluated by determining the height of the transition points from the ice region to the area of melting process and from this area to the rain region, respectively. By taking the advantage of the noticeable enhancement in radar reflectivity during the transition between the ice-melting and rain-melting regions, a minimum slope technique is used to trace the transition points and then to determine its corresponding height. The thickness of the melting layer ($BB_{th}$) is evaluated by calculating the difference between the 0°C isotherm height ($h_0$) and the rain height ($h_R$).

# 4 RESULTS AND DISCUSSION

### 4.1 Heights and Thickness of the Melting Layer

Figure 1 shows samples of the vertical profiles of radar reflectivity that have been built by using the available meteorological radar data. These profiles will be used to determine the boundaries of the melting layer and its thickness.

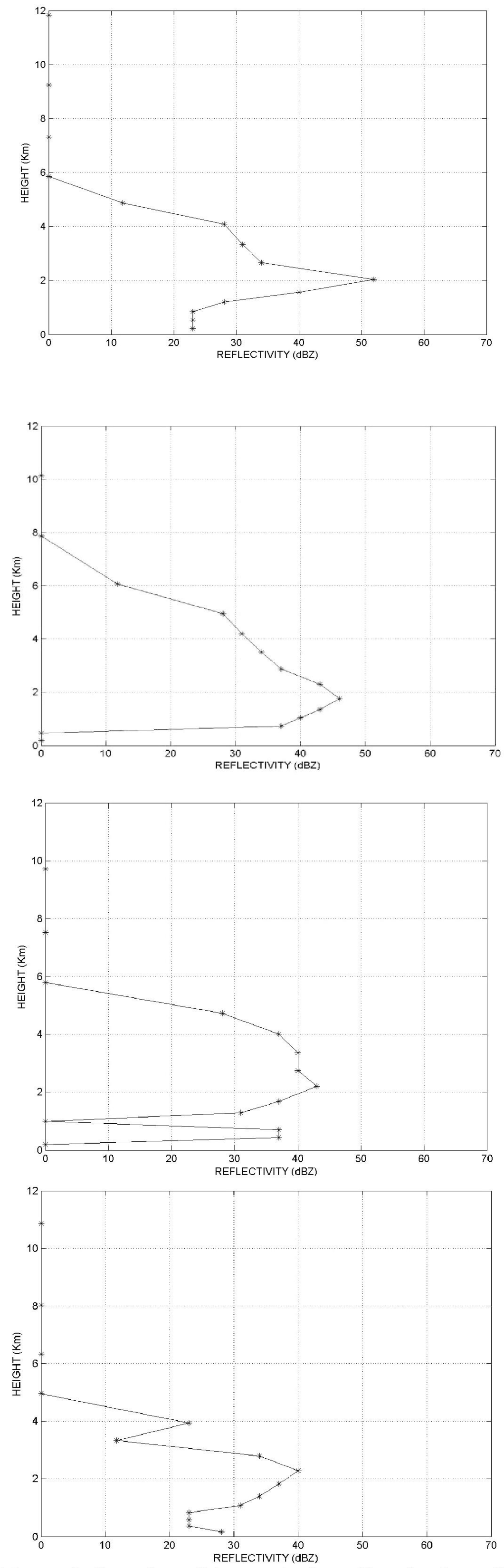
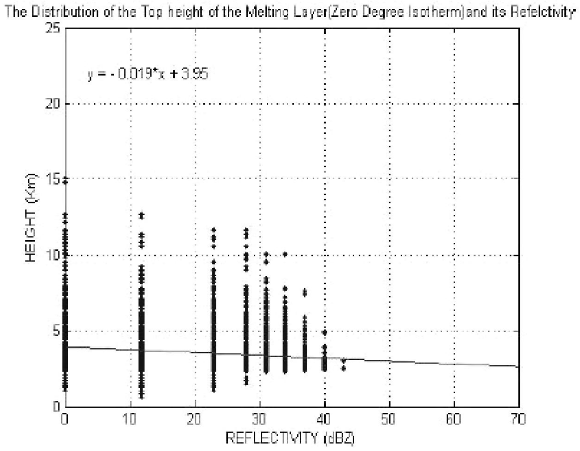
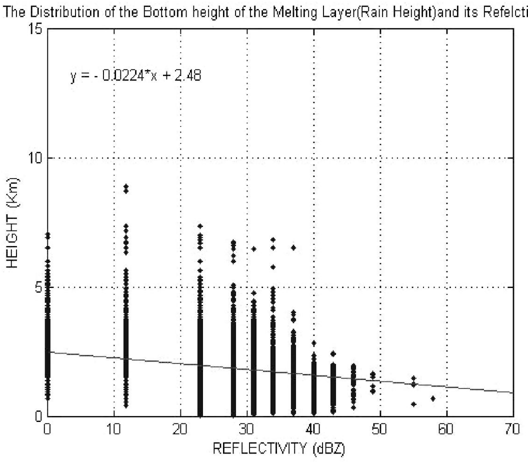



Figure 1: Samples of the vertical profile of radar reflectivity curve

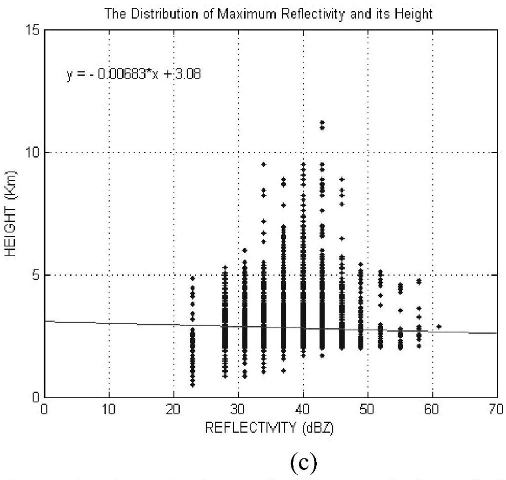
However, recordings of the radar images is handled to analyze the meteorological data and to determine the heights and thickness of the melting layer during the stratiform precipitation events. Figures 2, and 3 show the spread of bright band heights versus its reflectivity values and the distribution of these heights and thickness of the melting layer using 500m-resolution range (RR). These figures are built based on the collected data, which covers 39 days from 2nd March to 23rd April 1998.




(a)

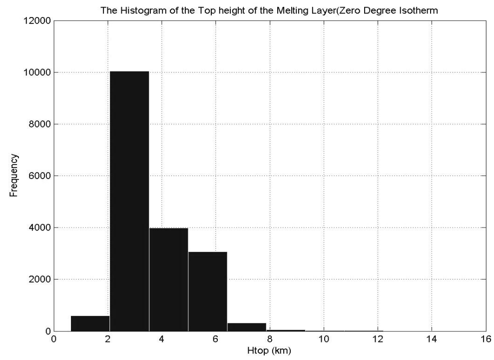



(b)

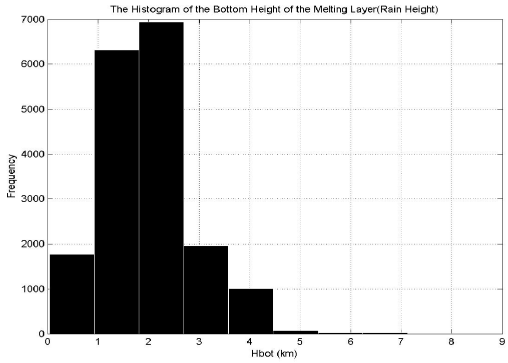



(c)

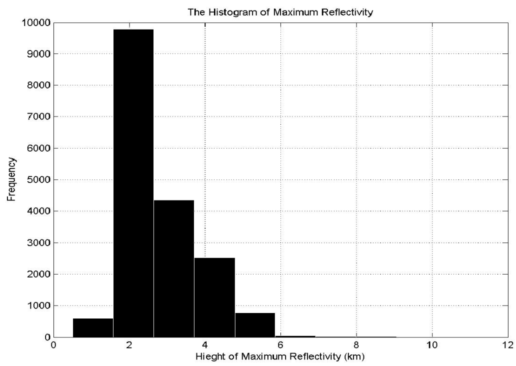
Figure 2: Spread Plots of the Boundaries of the Melting Layer using 500m Resolution Range: (a) $h_0$-dBZ, (b) $h_R$-dBZ, and (c) $BB_H$-dBZ



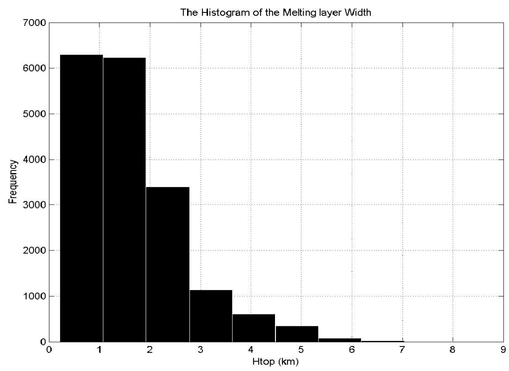

(a)




(b)




(c)




(d)

Figure 3: Histograms of the Melting Layer Boundaries using 500m Resolution Range: (a) Histogram of $h_0$, (b) Histogram of $h_R$, (c) Histogram of $BB_H$, and (d) Histogram of $BB_{th}$

The results showed a wide distribution for all the heights of the melting layer as indicated by their spread plots and histograms, especially the rain height

($h_R$) and the thickness ($BB_{th}$) of the bright band, which their minimum and maximum values vary from 0.04363 km to 8.893 km and from 0.2205 km to 8.745 km, respectively. This occurrence can be generalized to the range of the reflectivity values that are covered by the rain and the 0°C isotherm heights which are varied from 0 dBZ to 58 dBZ and from 0 dBZ to 43 dBZ, respectively.

Furthermore, this wide variability in the reflectivity distribution for the bright band heights, including the height of the bright band itself (from 23 dBZ to 61 dBZ), can be interpreted as there are many vertical profile structures of the bright band (Figure 1) due to the existence of many degrees or levels of the stratiform rain intensity, especially when the full RHI range is utilized during the tracing of the bright band signature, this might also be due to the EL Nino event during 1998 which is one of the strongest events that have been recorded [1].

However, the regression best-fit lines for the different heights show an independency between the average height value and its corresponding reflectivity. This can be extracted by examining the slope of the regression best-fit line for the different height-reflectivity curves.

To investigate the agreement between the results that obtained by utilizing the Kluang meteorological radar data with that obtained previously by other models in tropics, a comparison between the ITU-R models in [6] and [7], the results that have been obtained from the precipitation radar on-board the TRMM (Tropical Rainfall Measuring Mission) satellite [1], and the characteristics of the melting layer in Singapore which were obtained by using S-band polarization-diversity Doppler radar [2]; have been made.

The results gave an acceptable correlation with the ITU-R recommendations and a good one with the results that were obtained from the TRMM and specification of the melting layer in Singapore as shown in Table 2.

Table 2: Comparison between the Melting Layer Heights Values in Tropics

| | Melting layer Height ($BB_H$ km) | 0°C Isotherm Height ($h_0$ km) | Rain Height ($h_R$ km) |
|---|---|---|---|
| ITU-R P.839-3 | 5.36 | * | 5.0 |
| Singapore [8] | 4.73 | 4.55 | 4.31 |
| TRMM-PR [5] | 4.5 | 4.2 | 3.9 |
| Kluang (500m RR) | 3.961 | 2.952 | 1.976 |

The trends of the melting layer heights and thickness should be combined with the properties of the measurement precipitations, such as snowflake sizes and shapes, temperature profile, and vertical air velocity, beside the type of the used radar, and the duration of the measurement.

# 5 CONCLUSION

One hundred and sixteen days of observations from the Kluang radar station, which belongs to the Meteorological Department of Malaysia and utilizes the 3D RAPIC system, have been analyzed to obtain the melting layer heights and thickness after tracing its signature during the straiform precipitations events using a resolution range of 500m. The bright band heights and thickness were compared with ITU-R Recommendations P.839, the results that have been obtained from the precipitation radar on-board the TRMM (Tropical Rainfall Measuring Mission) satellite [1], and the characteristics of the melting layer in Singapore which were obtained by using S-band polarization-diversity Doppler radar [2]. The results give an acceptable correlation with the ITU-R recommendations and a good one with the results that are obtained from the TRMM and specification of the melting layer in Singapore.

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