257 PRELIMINARY STUDY OF THE MELTING LAYER IN THE TROPICS USING A POLARIMETRIC DOPPLER X-BAND RADAR

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1. INTRODUCTION

For the last five years, the University of Puerto Rico at Mayagüez in collaboration with the Colorado State University has been developing a network of three (3) Dual-Pol X-band Doppler radars that will provide coverage of the lower atmosphere for the Puerto Rico's west coast. The first node of the network, called TropiNet, has been in operation since early 2012, providing the first-ever observations of the lower atmosphere with a Dual-Pol radar in Puerto Rico. The radar generates various polarimetric products that have been used to analyze several weather events in the west coast as well as running specific experiments of interest to the scientific community. One of these experiments was the study of the occurrence of the melting layer in the Tropics.

For the Caribbean Tropic, there is no evidence in the literature of studies concerning the melting layer. Often, scientist had opted to neglect the presence of the melting layer in this region, since it might be too high in the atmosphere to affect radar measurements. But recent observations with the UPRM X-Band radar indicate that the melting layer can be low enough that its effects on radar measurements should be considered. This higher reflectivity measured by the radar results in excessive estimation of the accumulated water on the ground, a problem that has been observed before in the Puerto Rico's west coast with the use of long-range radars (i.e. NEXRAD). The over estimation creates discrepancies between the readings of the radar and other sensors deployed on the ground, making it more difficult for the scientists to create new precipitation models and properly calibrate the system. It is then of special interest, to study this layer in the tropics and analyze the effects that it might have on the measurements provided by weather radars. The attenuation caused by the melting layer at X-Band is equivalent to 10 km of rain that is present below it and it can cause severe limitations to the sensitivity of the sensor system (Bellon et al., 1997)

The use of a state-of-the-art agile polarimetric radar will serve as the main experimental tool, and the data collected will be used to analyze the effect of the melting layer on rain quantification over the Caribbean Island of Puerto Rico. It is the first time that an X-band Dual-Pol Doppler radar is installed on the Puerto Rico's west coast and the first time that multiple radar polarimetric products are analyzed to observe the melting layer in this tropical region. The main products that will be used to identify the melting layer are the corrected reflectivity ($Z_{H\_\text{corrected}}$), cross-polar correlation (ρ_{HV}), and the specific differential phase (K_{DP}). This is the first unit of three polarimetric radars that will form a network to densely monitor the west coast of the Island and at the same time will provide lower atmosphere data to complement the NWS long-range radar located over a 100 Km from the UPRM radar site.

Some of the characteristics of the melting layer, such as the height and width, are computed through algorithms developed in this work. For the purpose of this study, two different techniques to detect the melting layer were considered; vertical bidirectional sector scan technique and vertically pointing non-scanning technique. The features of the rain events where the melting layer was present were very different, from light to strong convective, and mixed.

Finally, with the statistical analysis and the characteristics of the melting layer, it is determined the necessity to incorporate algorithms to correct for attenuation or errors in the quantification of precipitation caused by the melting layer. The results will be mainly used in the improvement of the TropiNet Radar Network being deployed in the western coast of Puerto Rico, and could serve as well to the National

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Weather Service (NWS) Office in San Juan, Puerto Rico for forecasting purposes.

2. UPRM X-BAND RADAR

The main instrument used to accomplish our objectives is the first of three radars that will be deployed in western Puerto Rico to work as a network. This network focusing in the challenges of the dynamic weather in a tropical and mountainous region is known as Tropinet. The current operational radar which is located in Cornelia Hill at Cabo Rojo, PR is called the MRI-1 and is a state-of-the-art, low-power, short-range X-Band Doppler radar with linear dual-polarization. The radar has a 40 km radius coverage as shown in Figure 1.

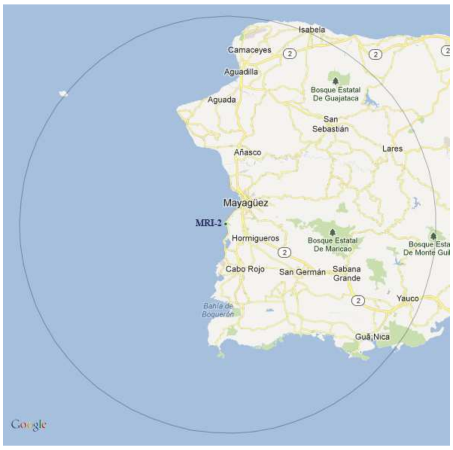

Figure 1 – TropiNet's MRI-1 radar coverage area.

The computer of the radar is connected to the Internet through a point-to-point wireless link from Cornelia Hill to the R&D Building in the UPRM Campus, where the main server is located. The transceiver uses a magnetron transmitter, fed to the antenna by a high isolation dual-channel duplexer. To ensure the maximum accuracy in estimating its frequency, phase, power and duration of the transmitted signal, a sample of the pulse is fed to the receiver through a dedicated coupling path.

The receiver has only one down-converting stage that is programmable and capable of tracking the magnetron's frequency across the entire bandwidth.

Figure 2 – First node of Tropinet network, MRI-1, during calibration at CSU CHILL site (on the back).

To assure the overall coherency of the system the receiver is phase-locked to the data acquisition system. The data acquisition system has an Automatic Frequency Control (AFC) based on a Numerically Controlled Oscillator (NCO).

The antenna is a 6 ft. dual-pol center fed reflector, as shown in Figure 2. The dish is covered with a radome to reduce the water/ice build-up and wind loading on the reflector, however, no ice accumulation is expected in the tropics. The connectors of the dual-pol scalar feeder are extended to the back of the reflector through two waveguide segments. Other important specifications of the radar are shown in the Table 1.1. (*Gálvez et al*., 2009).

TRANSMITTER	
Type	Magnetron
Center Frequency	9410 +/- 30 MHz
Peak Power Output	8.0 kW (per channel)
Average Power Output	12 W (per channel)
Pulse Width	660-1000 ns
Polarization	Dual Linear, H and V
Max. Duty Cycle	0.16%
ANTENNA	
Type	Dual-pol parabolic Reflector
Diameter	1.6m
3-dB Beam Width	1.4 deg
Gain	41 dB
Max. Scan Rate	60 deg/s
RECEIVER	
Type	Parallel, dual channel
Output	Linear I/Q
Dynamic Range	95 dB (BW = 1.0 MHz)
Noise Figure	5 dB

Table 1. Radar Specifications

3. MELTING LAYER EXPERIMENT

More than 50 rain events were analyzed during the 2012 rainy season as part of this experiment. From all the events recorded, only three showed characteristics that deserve special attention and therefore analyzed with detail. The three events that were considered show different characteristics, so a specific pattern to help identify the presence of the melting layer was not established.

The dataset obtained from the TropiNet X-band radar on July 31st, 2012 around 23:52:53 UTC, correspond to a dying thunderstorm that reached reflectivity values in the order of 50 dBZ. Then on August 24th, 2012 around 19:31:18 UTC, a light rain event that reached reflectivity values in the order of 30 dBZ was detected and finally on August 25th, 2012 around 04:08:17 UTC, a mixed rain event that reached reflectivity values in the order of 50 dBZ was also considered.

For the purpose of this study a vertical bidirectional sector scan technique was implemented. The vertical bidirectional sector scan technique consists of scanning the atmosphere horizontally at first, performing a PPI scan. From the PPI scan the operator or the algorithm, depending if the operation of the radar is automated or not, decides where to perform vertical scans depending on the reflectivity intensity of the clouds or any other characteristic that might hint the presence of a melting layer. Then the data is saved for further processing, and a Vertical Profile of Reflectivity (VPR) is created and filtered (*Matrosov* et al., 2007)

Other techniques, such as the vertically pointing no-scanning technique, were also considered but the processing procedure was more complicated and the time series data takes significantly more memory storage space in the computer hard drive.

Using the MRI-1, the atmosphere was then vertically scanned. This allowed us to have a vertical cross section, to be displayed in a RHI showing the polarimetric products selected for this study.

The main products used to identify the melting layer were the *corrected reflectivity* ($Z_H^{corrected}$), the *differential phase* ($Ø_{DP}$) defined as

$$\phi_{dp} = \phi_{hh} - \phi_{vv} \qquad (1)$$

and the *specific differential phase* (K_{DP}) (*Rinehart*, 2010) defined as.

$$K_{dp} = \frac{\phi_{dp(r_i)} - \phi_{dp(r_j)}}{2(r_i - r_i)} \qquad (2)$$

Other radar products can be used to identify characteristics of the melting layer and some conditions that are needed for the melting layer to be formed, such as the mean Doppler *velocity* (v) and the *differential reflectivity* ($Z_{DR}^{corrected}$). After the data is corrected and filtered, the PPI and/or the RHI scan showing the melting layer is displayed for each polarimetric product. The presence of the melting layer is also validated with data obtained from radiosondes and the cross-polarization correlation (ρ_{HV}) product from the radar itself.

4. RESULTS

The melting layer was observed three times during the period of this study. The average top height of the melting layer was found to be 4,614 m with an average thickness of 208 m.

Fifty rain events were analyzed in this study, and only three showed the presence of the melting layer. In July 31st, 2012, a strong convective rain event occurred in the west coast of Puerto Rico and within the coverage area of the MRI-1. An RHI scan of the corrected reflectivity (Z_H) as well as the co-polar correlation factor was recorded at 248.9˚ in azimuth.

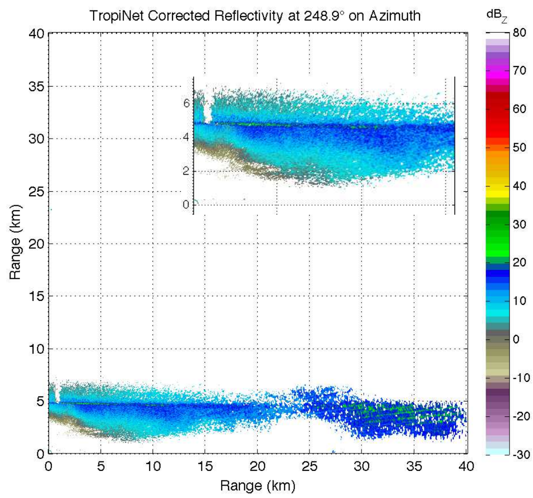

Figure 3 - Z_H for strong convective rain event showing the presence of the melting layer. Close up also shown. .

Figure 3 and 4 show the corrected reflectivity and the cross-polar correlation for this event. A close up to easily visualize the melting layer is integrated in each of the figures. The height of the melting layer for this event was calculated as 4,683 m.

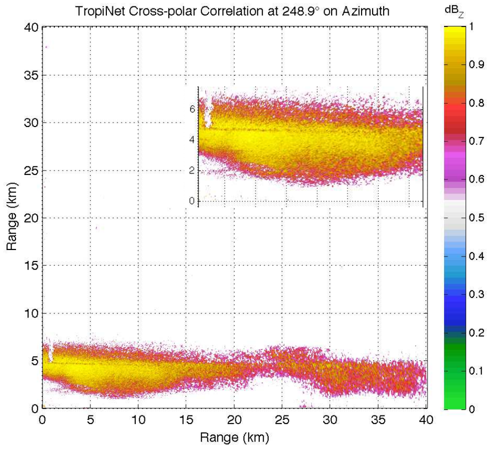

Figure 4 Cross-polarization correlation for strong convective rain event showing the presence of the melting layer. A close-up of the first 15 km is shown on the inset.

A second light rain event was also recorded in August 24th, 2012 and it also showed the presence of the melting layer. In this particular case the height was calculated at 4,653 meters with a width of 209 m. For this case, Figures 5 and 6 show the presence of the melting layer. A Range Height Indicator (RHI) scan from the corrected reflectivity shows an increased Z_H and the co-polar correlation with a drop to 0.9 are both evidence of the melting layer presence.

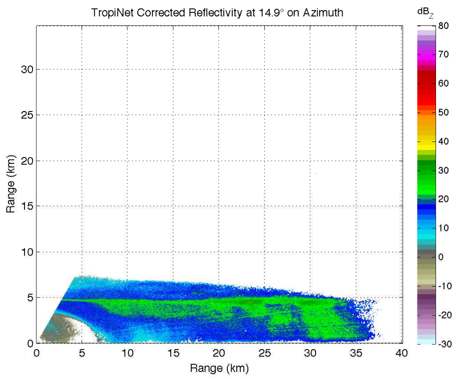

Figure 5 – Corrected reflectivity for light rain event showing the presence of the melting layer.

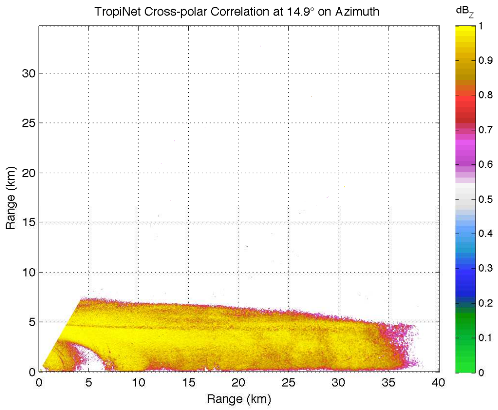

Figure 6 – Cross-polar correlation for light rain event showing the presence of the melting layer.

A third event that showed the presence of the melting layer was a mixed moderate rain recorded in August 25th 2012. The melting layer was noticed around 04:08:17 UTC.

Figure 7 shows a reflectivity RHI scan of the rain event taken at 75.0° in azimuth with a close-up of the same scan where the melting layer can be better appreciated within the range of 0-10 km. It is intriguing how in this event in the first few kilometers the melting layer is visible and then over a 20 km range, when the convective rain is present, it disappears. In this particular scan, the melting layer height was calculated as 4,572m.

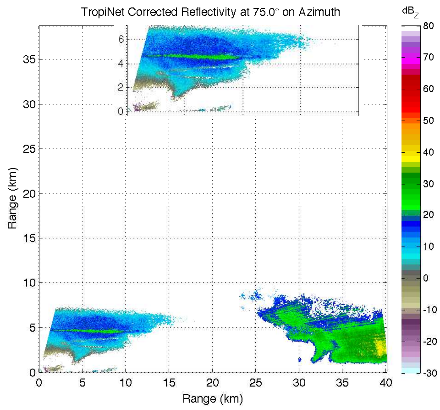

Figure 7 – Corrected reflectivity for mixed rain event showing the presence of the melting layer.

5. CONCLUSIONS

This study has confirmed that the melting layer is present in the Caribbean Tropic, specifically on the western coast of Puerto Rico. The melting layer was only found in three of the fifty rain events studied. Compared with the statistics presented in (*Jaiswal*, 2010), the occurrence of the melting layer in the western coast of Puerto Rico is low. The features of the three rain events were different; light, strong convective, and mixed, which did not showed any particular pattern to conclude that the melting layer will be present depending on the type of precipitation.

In the case of western Puerto Rico, the height of the melting layer will not be in the TropiNet radar's regular beam path and any effects can be neglected. Even at 4.5˚ of elevation the radar beam does not reach the bottom height of the melting layer. To make the TropiNet MRI-1 radar reach the bottom height of the melting layer at 40 km of range, it has to be operated between 6 and 7 degrees on elevation.

In the case of the (long-range) NEXRAD radar which is located approximately 100 km east from the MRI-1, any effects can also be neglected for the Western Puerto Rico case, but its measurements could be affected by the melting layer, as presented in this study, for ranges beyond approximately 155 km.

6. ACKNOWLEGEMENT

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7. REFERENCES

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