Attenuation Correction for Melting Ice at C-Band and Verification from S-Band Profiler Radar Measurements

Adubi Tunde[1], Sounak Kumar Biswas[1&2], V. Chandrasekar[1], Robert Cifelli[2], and Ivan Arias Hernandez[1]
(1) Colorado State University, Fort Collins, Colorado. (2) NOAA Physical Sciences Laboratory, Boulder, Colorado.

ABSTRACT

The decrease in power of the EM wave by scattering or absorption upon encountering hydrometeors in the propagation path is known as attenuation. Weather radars at C-Band can suffer from attenuation in severe convective storm. Therefore it is necessary to correct for attenuation in order to get accurate measurements. This work proposes a methodology to estimate the attenuation suffered by radar beams caused by the presence of melting ice in the propagation path. Melting ice could be a combination of snow, graupel, wet hail, and heavy rain in the mix-phase region developed during the riming process in a convective precipitation systems. Simultaneous observations from the C-Band ARMOR Radar and the NOAA Physical Science Laboratory (PSL) S-Band Profiler are used to measure and correct attenuation in melting Ice during a convective event over Huntsville, Alabama on December 11, 2021. Attenuation correction due to melting ice is challenging due to the variability in the size distribution and composition of melting ice [1]. First, rain attenuation correction based on differential phase measurements was performed on the C-Band observations. Upon comparison of vertical profiles of reflectivity to profiler observations, it was determined that rain attenuation correction alone is insufficient in accounting for the enhanced attenuation caused by melting ice hydrometeors. Consequently, profiles of Z, Z_{dr} and co-polar correlation coefficient were examined for signatures of melting ice. This was further cross validated with hydrometeor classification algorithm. Attenuation correction coefficient for melting ice is computed separately following a methodology proposed by [2]. Next, a piecewise attenuation correction algorithm is implemented to correct regions of rain and melting ice separately.

INSTRUMENTS

Fig. 1a: A map showing the deployment location of the ground instruments in Alabama used in this study. The C-Band ARMOR radar is located at the Huntsville airport, while the S-Band profiler radar is deployed by NOAA at the Courtland (CTD) site. The yellow line represents a common azimuth of 272° and a distance of 52.57 km.

Parameters	C-Band Radar	S-Band Radar
Frequency (GHz)	5.625	2.875
Scan Strategy	PPI and RHI scans	Vertically pointing scan
Antenna beamwidth (deg.)	1	2.5
Temporal resolution (min)	5	1
Range resolution (m)	153	60

Fig. 1b shows the S-band profiler radar. Fig. 1c shows the C-Band ARMOR radar. Table 1 on the right side presents some important technical specifications and operating parameters of both instruments. Table 2 below shows the precise deployment locations of the instruments.

Site	Latitude	Longitude	Elevation (MSL)
ARMOR	34.6403° N	86.7756° W	186 m
CTD	34.6600 ° N	87.3500° W	187 m

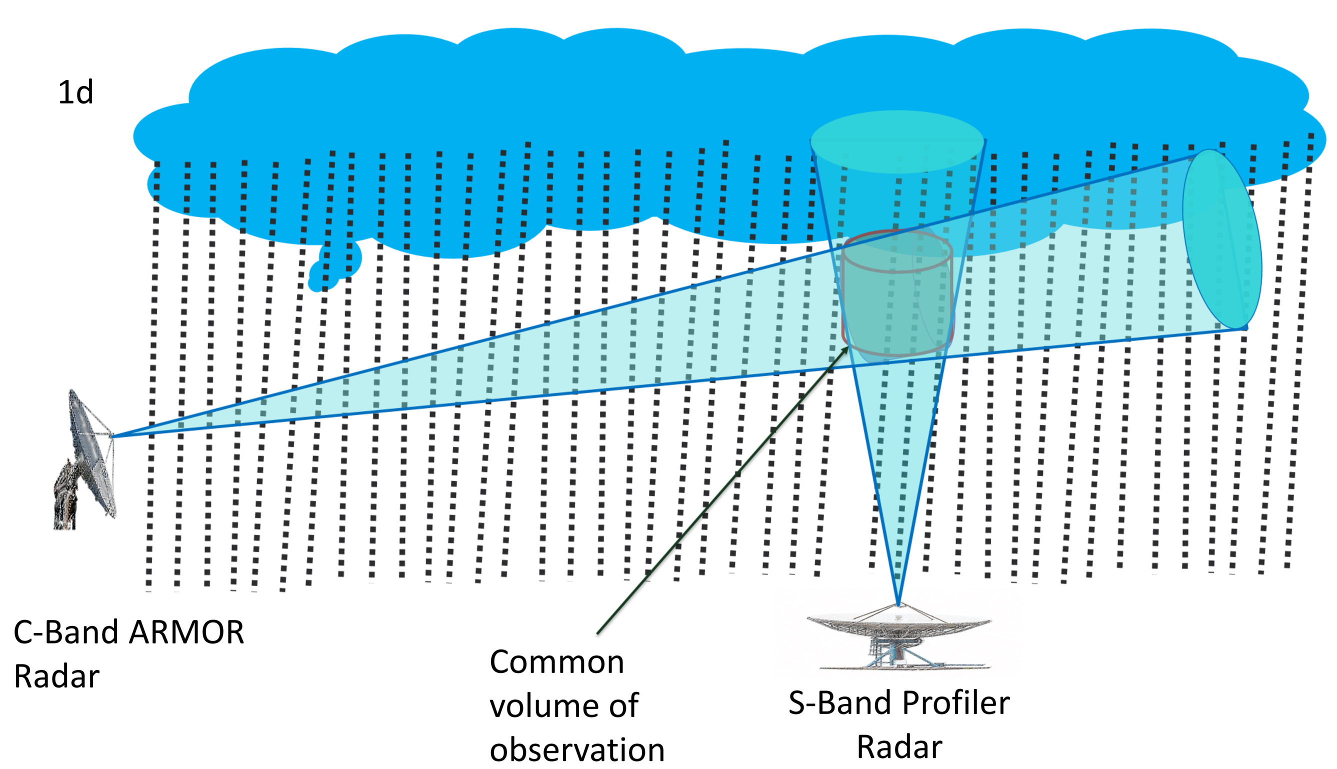


Fig. 1d is an illustration of the common volume of observation at the intersection of the C-Band ARMOR radar horizontal beam with the S-Band profiler radar vertical beam.

METHODS

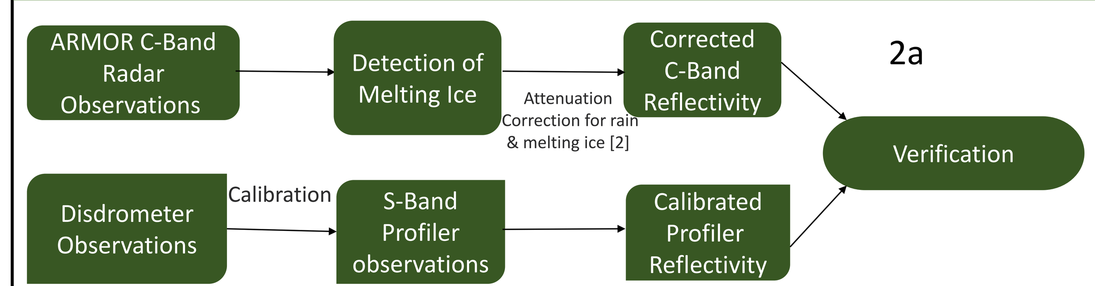
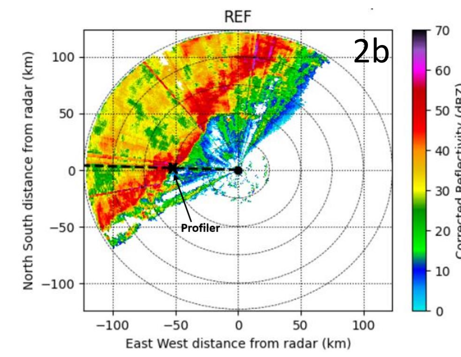
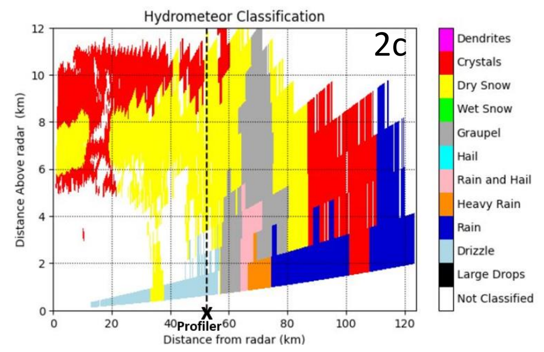


Fig. 2a. Flowchart illustrating the work-flow of attenuation correction of the C-Band radar, and verification from the S-Band profiler measurements. Fig 2b and Fig. 2c are the reflectivity and Hydrometeor classification [3] results at 12:03 UTC during the storm.





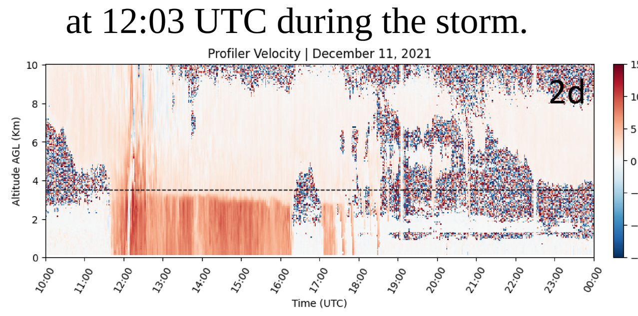


Fig. 2d. Shows the Doppler velocity with strong vertical updrafts of the storm. Positive velocity motion of about 10m/s is observed between 12:00 UTC to 16:30 UTC below the ML.

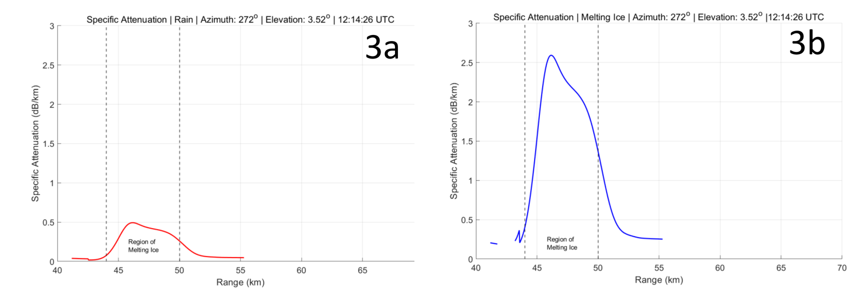
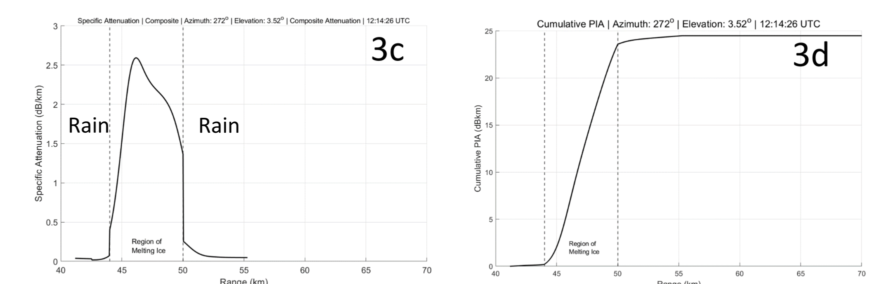


Fig. 3a and 3b represents the specific attenuation due to rain and melting ice coefficients respectively. Fig. 3c is the composite specific attenuation in the rain and melting ice region at 12:14 UTC. The path integrated attenuation (PIA) is shown in fig. 3d.



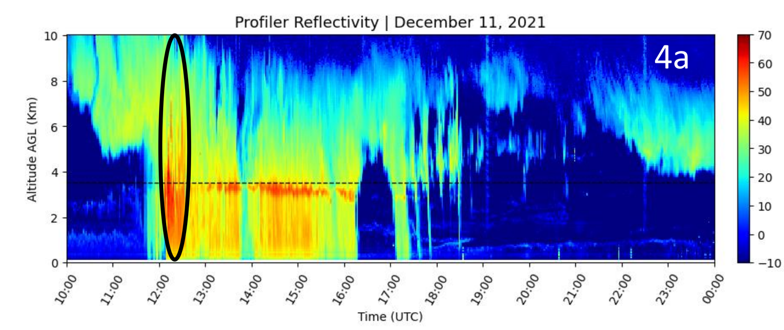


Fig. 4a is the profiler reflectivity showing storm formation around 11:00 UTC and squall lines passing at about 12:03 UTC, on December 11, 2021. The black dotted lines represents the melting layer (ML) around 3.75 km while the black oval is the squall lines between 12:03 UTC to 12:30 UTC. This was followed by a Stratiform event around 16:30 UTC.

$A_r = \alpha_r k_{dp}$ and $A_{mi} = \alpha_{mi} k_{dp}$ denote the relationship of specific differential phase and specific attenuation due to rain and melting ice. Kdp is estimated using [4].
The cumulative PIA from composite specific attenuation is given below.

$$PIA = 2\alpha_r \int_0^{r0} k_{dp}(s)ds + 2\alpha_{mi} \int_{r0}^{r1} k_{dp}(s)ds + 2\alpha_r \int_{r1}^{r2} k_{dp}(s)ds$$

RESULTS

➢ Case study at 12:03 UTC, before the squall line passed over the profiler location.

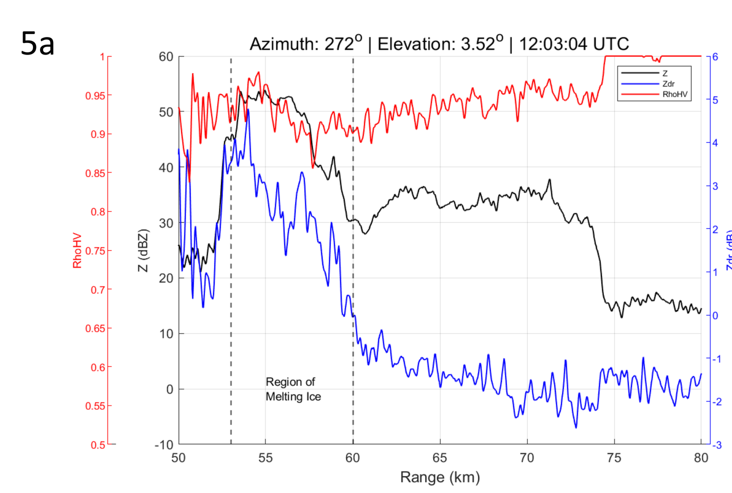
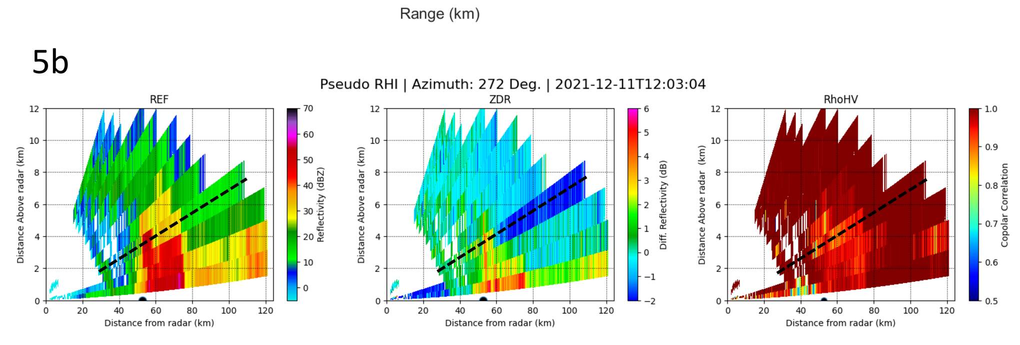


Fig. 5a Shows the measurements of reflectivity (Z), differential reflectivity (Z_{dr}), and copolar correlation coefficient (ρ_{hv}) signatures in the melting ice region between 53-60 km at 12:03 UTC. In this mix phased region, the C-band radar observables of Z and Z_{DR} had the highest values of about 53 dBZ and 4.5 dB respectively with a gradual decline in ρhv. After this phase, a steady increase of about 0.99 in ρhv is measured followed by a corresponding negative Z_{dr} of -2 dB, a characteristic that could be of attenuation due to melting ice [2].



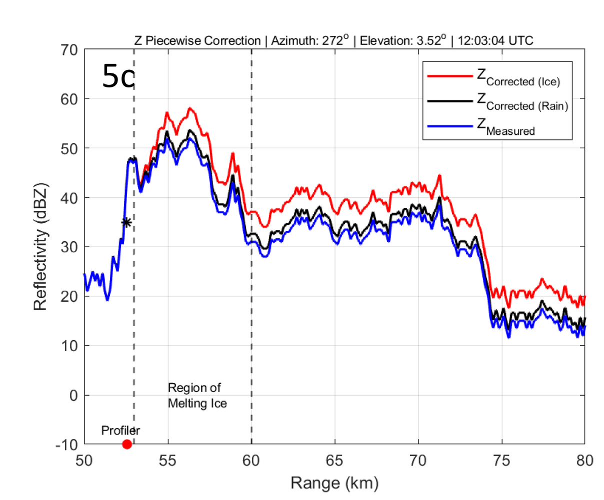


Fig. 5b Range Height Indicator (RHI) scans from the C-band radar for Z (dBZ), Z_{dr} (dB) and ρ_{hv}. The black dotted lines indicates the radar beams at 3.5° elevation corresponding to the signatures in fig. 5a. Fig. 5c Shows comparison of measured Z, rain corrected Z and melting ice corrected Z, and verification from the profiler radar measurements at 12:03 UTC.

➢ Case study at 12:08 UTC, When the squall line passed over the profiler location.

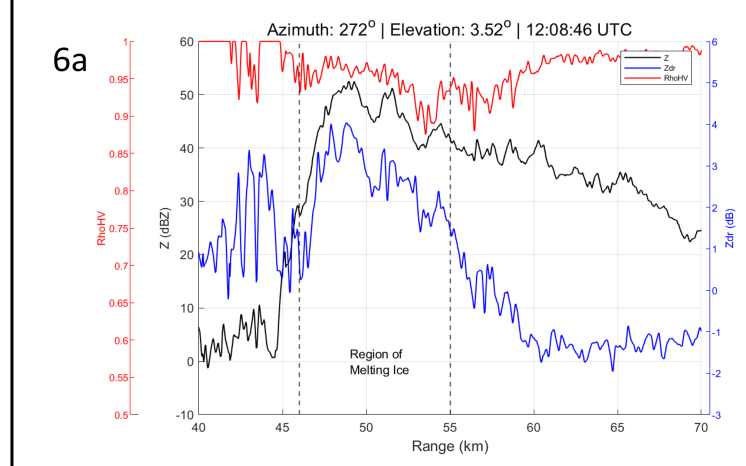
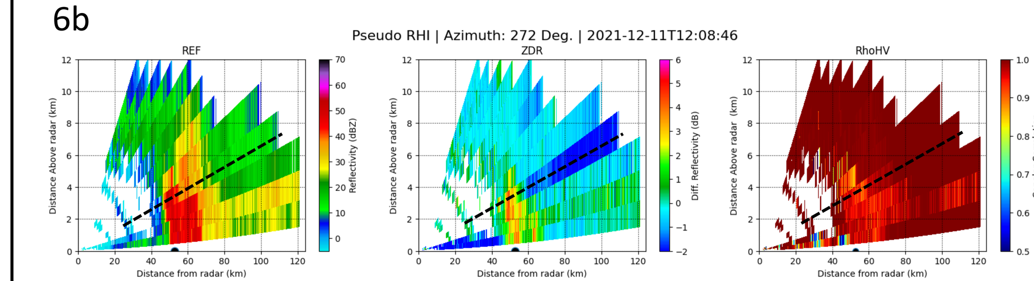


Fig. 6a Shows the polarimetric measurements of reflectivity (Z), differential reflectivity (Z_{dr}), and copolar correlation coefficient (ρhv) signatures in the melting ice region between 46-55 km at 12:08 UTC. In this mix phased region, the C-band radar observables of Z and Z_{dr} had the highest values of about 52 dBZ and 4 dB respectively with a gradual decline in ρhv. Beyond the 55 km, a steady increase of about 0.98 in ρhv is measured followed by a corresponding negative Z_{dr} of -1.5 dB, a characteristic that could be of attenuation due to melting ice .



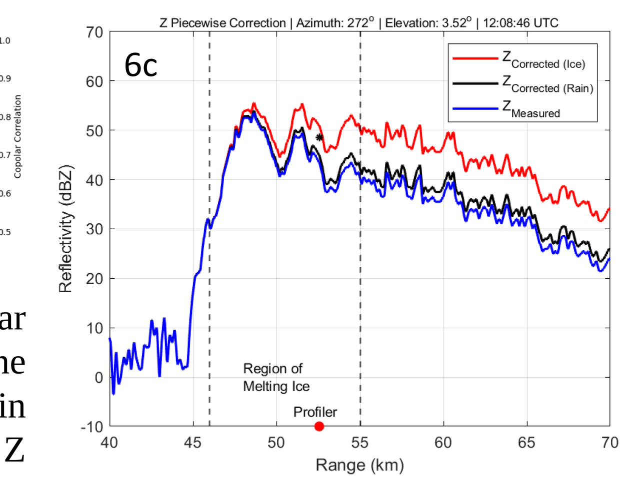


Fig. 6b Range Height Indicator (RHI) scans from the C-band radar for Z (dBZ), Z_{dr} (dB), and ρ_{hv}. The black dotted lines indicates the radar beams at 3.5° elevation corresponding to the signatures in fig. 6a. Fig. 6c Shows comparison of measured Z, rain corrected Z and melting ice corrected Z, and verification from the profiler radar measurements at 12:08 UTC.

➢ Case study at 12:14 UTC, After the squall line passed over the profiler location.

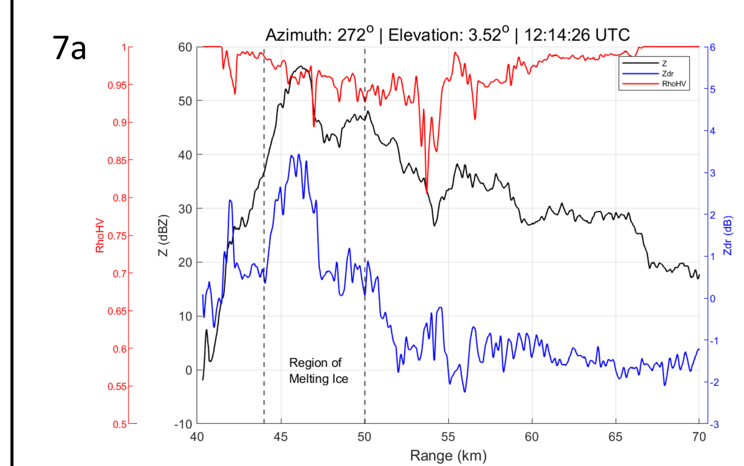
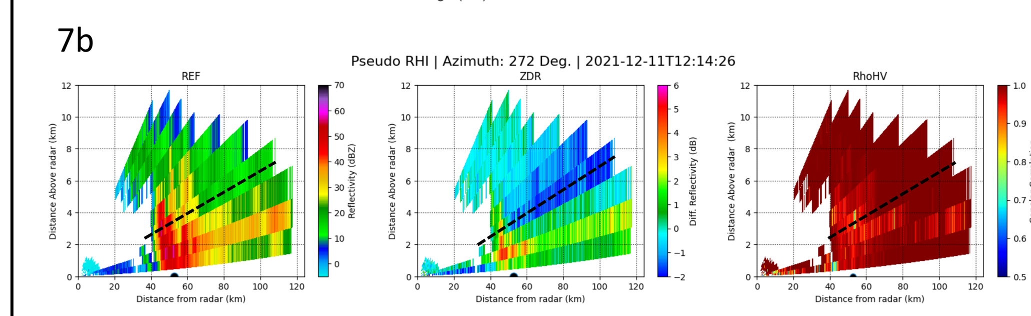


Fig. 7a Shows the polarimetric measurements of reflectivity (Z), differential reflectivity (Z_{dr}), and copolar correlation coefficient (ρ_{hv}) signatures in the melting ice region between 44-50 km at 12:14 UTC. In this mix phased region, the C-band radar observables of Z and Z_{dr} had the highest values of about 56 dBZ and 3.5 dB respectively with a gradual decline in ρhv. Beyond this phase, a steady increase of about 0.99 in ρhv is observed followed by a corresponding negative Z_{dr} of -1.5 dB, a characteristic that could be of attenuation due to melting ice.



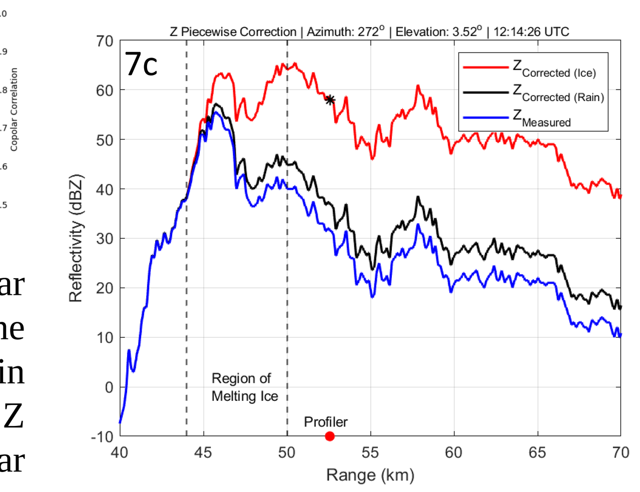


Fig. 7b Range Height Indicator (RHI) scans from the C-band radar for Z (dBZ), Z_{dr} (dB), and ρ_{hv}. The black dotted lines indicates the radar beams at 3.5° elevation corresponding to the signatures in fig. 7a. Fig. 7c Shows comparison of measured Z, rain corrected Z and melting ice corrected Z, and verification from the profiler radar measurements at 12:14 UTC.

SUMMARY

- ➢ The presence of melting ice hydrometeors during the convective event, analyzed in this study, show significant attenuation at the C-band radar measurements.
- ➢ Attenuation correction considering only rain model is not sufficient to account for the enhanced attenuation caused due to melting ice.
- ➢ Signatures of melting ice are detected using dual-pol measurements.
- ➢ Attenuation correction is performed using a piecewise correction methodology considering rain and melting ice.
- ➢ Comparisons of corrected reflectivity at C-Band with S-Band profiler radar measurements show good agreement.

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[2] I. A. Hernandez and V. Chandrasekar, "Attenuation of Melting Ice at C-band Frequencies , Observed Attenuation of Melting Ice at C-band Frequencies , Observed Using Dual Radar Observations During the RELAMPAGO Campaign," *JSTARS-2023-00168*
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[4] Wang, Yanting, and V. Chandrasekar. "Algorithm for estimation of the specific differential phase." Journal of Atmospheric and Oceanic Technology 26.12 (2009): 2565-2578.

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Colorado State University