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AUTOMATIC DETECTION OF THE MELTING LAYER WITH A POLARIMETRIC PROTOTYPE OF THE WSR-88D RADAR

Scott E. Giangrande*, Alexander V. Ryzhkov, and John Krause,
Cooperative Institute for Mesoscale Meteorological Studies (CIMMS),
University of Oklahoma, Norman, Oklahoma

1. Introduction

A fuzzy logic approach has been adopted for operational implementation of hydrometeor classification with the polarimetric prototype of the WSR-88D (herein, KOUN). The Joint Polarization Experiment (JPOLE) validated the performance of this approach for discrimination of nonmeteorological echoes and detection of hail (Ryzhkov et al. 2005). The membership functions for several classes such as light rain and dry aggregate snow are significantly overlapped because of small polarimetric contrasts between these media. Therefore, identification of the melting layer is a necessary component for successful implementation of the fuzzy logic scheme. In addition to the benefits for operational hydrometeor classification, melting layer identification may be used to establish distances at which radar rainfall estimates become contaminated by melting hydrometeors. Freezing level detection is also important for evaluating regions of possible aircraft icing.

This paper examines a technique for automatic melting layer detection recently employed on the KOUN radar. Several studies have examined freezing level and/or bright band detection for conventional radar platforms (e.g., Gourley and Calvert 2003) and using polarimetric signatures (e.g., Brandes and Ikeda 2004). These techniques provide promising results when comparing radar estimated freezing level heights to available sounding data or model temperature output. However, the transition from rain to snow may extend to heights well below the 0°C isotherm. The presented detection procedure has been tailored for use in a real-time operational environment with the specific goal of improving hydrometeor classification and radar rainfall estimation techniques that benefit from accurate estimates of the bottom and top of the melting layer.

*Corresponding author address: Scott E Giangrande, CIMMS/NSSL, 1313 Halley Circle, Norman, OK, 73069; email: Scott.Giangrande@noaa.gov

2. Description of the Method

The automatic melting layer detection procedure capitalizes on radial dependencies of radar reflectivity factor Z, differential reflectivity Z_{DR}, and cross-correlation coefficient ρ_{HV} to estimate the boundaries of the melting layer. It is well known that the melting layer is characterized by a drop in ρ_{HV} associated with Z and Z_{DR} peaks. These signatures do not often coincide in height. Commonly, the maximum of Z is observed at a higher altitude than the maximum of Z_{DR} and minimum of ρ_{HV}. Among these variables, the ρ_{HV} signature has the most useful discriminative power for melting hydrometeors.

The procedure starts with identification along individual radials of range gate locations where ρ_{HV} falls between 0.9 and 0.97. If maximum values of Z between 30 and 47 dBZ and Z_{DR} exceeding 0.8 dB are observed in close proximity to these gates, these gates are flagged if below 6 km. The set of gates serves as the basis for determining the boundaries of the melting layer. Height contours bounding a majority of these gates (the required number of gates is a definable parameter) are calculated using a running 20-degree azimuthal window.

Data for the detection routine is collected at antenna elevation angles between 4 and 10 degrees for which polarimetric signatures of the melting layer are pronounced. The use of these elevation angles provides high resolution detection while maintaining modest radar coverage for observing melting hydrometeors. Information from the higher elevation angles (those with best resolution) has been weighted for more accurate results. A simple fuzzy-logic ground clutter and hail detection filter is applied to minimize spurious detections associated with these media.

In addition to the use of multiple elevation angles to improve detection, the procedure retains detection information from previous volume scans to alleviate sparse data intervals (time and space). For some events, it is possible that no pronounced melting layer signatures exist. Model output or user-defined values may be utilized operationally to supplement the detection procedure or

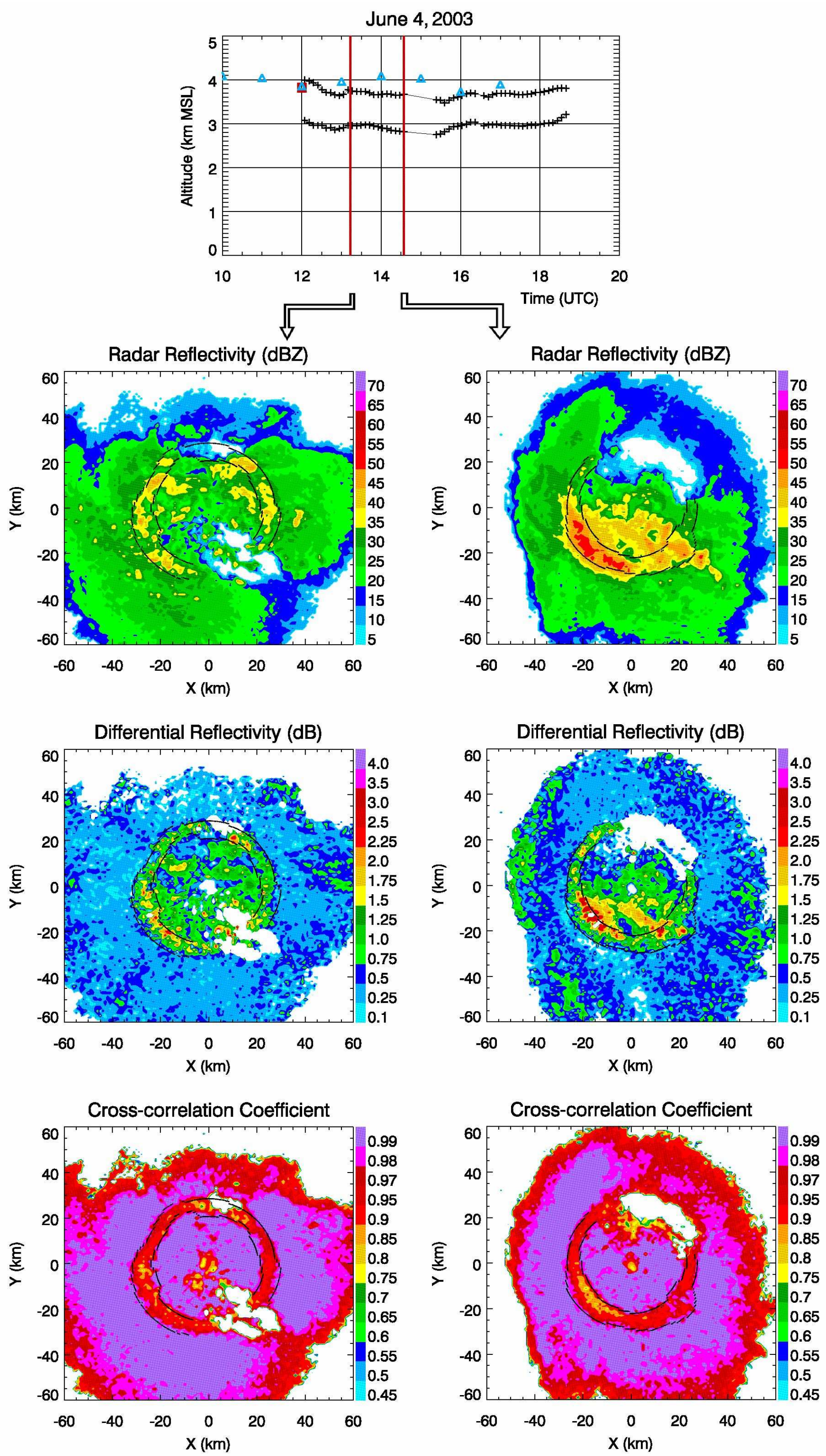

Figure 1: (Top) Mean melting layer top and bottom detections as a function of time for the 4 June 2003 event. Triangles indicate RUC model anaylsis output freezing level heights for the KOUN location. Red square indicates the local NWS OUN sounding freezing level height. (Bottom) Select KOUN PPI images (times denoted with red lines) with overlaid melting layer detections.

until sufficient radar measurements can be accumulated. Since this procedure is run in real-time, such considerations are necessary for smooth transition of melting layer detections into other polarimetric radar products (e.g., hydrometeor classification and rainfall estimation).

3. Detection of Melting Layer

Melting layer signatures are regularly found in both cold and warm season events. Prominent signatures are often observed in trailing stratiform regions behind squall lines. Figures 1 and 2 present the results of automated melting layer detection for several events observed by the KOUN radar.

Figure 1 illustrates detections for several hours of a convective squall line passing through central Oklahoma on 4 June 2003. The lone upper panel in Figure 1 displays a time series of azimuthal-mean top and bottom melting layer detections (when available), with cross-hairs indicating radar detection updates times. For comparison, freezing level heights from hourly Rapid Update Cycle (RUC) model analysis output (interpolated to the KOUN location) are included on the plot (blue triangles). The freezing level designation from the Norman, OK (OUN) 12Z NWS sounding is also displayed (red square).

Mean melting layer top heights compare favorably with available model output and sounding freezing level values, typically to within a few hundred meters. Since the detection method is keying on polarimetric characteristics of melting hydrometeors, it is expected that the melting layer top detection may slightly undercut the freezing level. The height of the mean melting layer bottom ranges from 0.5 km to 1.2 km below the melting layer top with azimuth. Temperatures associated with bottom height detections for this event are centered at 5°C based on sounding and RUC model output (not shown).

Lower panels in Figure 1 present detection results overlaid on corresponding 6.5° elevation angle KOUN polarimetric radar measurements for two volumes (scan time denoted with red lines on the upper panel). The individual detections match regions with lower values of correlation coefficient consistent with the melting layer, as well as the more traditional regions of heightened reflectivity values. It is noted that the while the bright band is apparent in the correlation coefficient field, it is not always visible using only reflectivity factor. The azimuthal variability of the melting layer contours is also noteworthy. Relative azimuthal differences in the contours can exceed several hundred meters. Such differences may explain discrepancies between mean azimuthal top contour heights and freezing level heights from observations, and may be attributed to the location of convective cells or horizontal temperature variations.

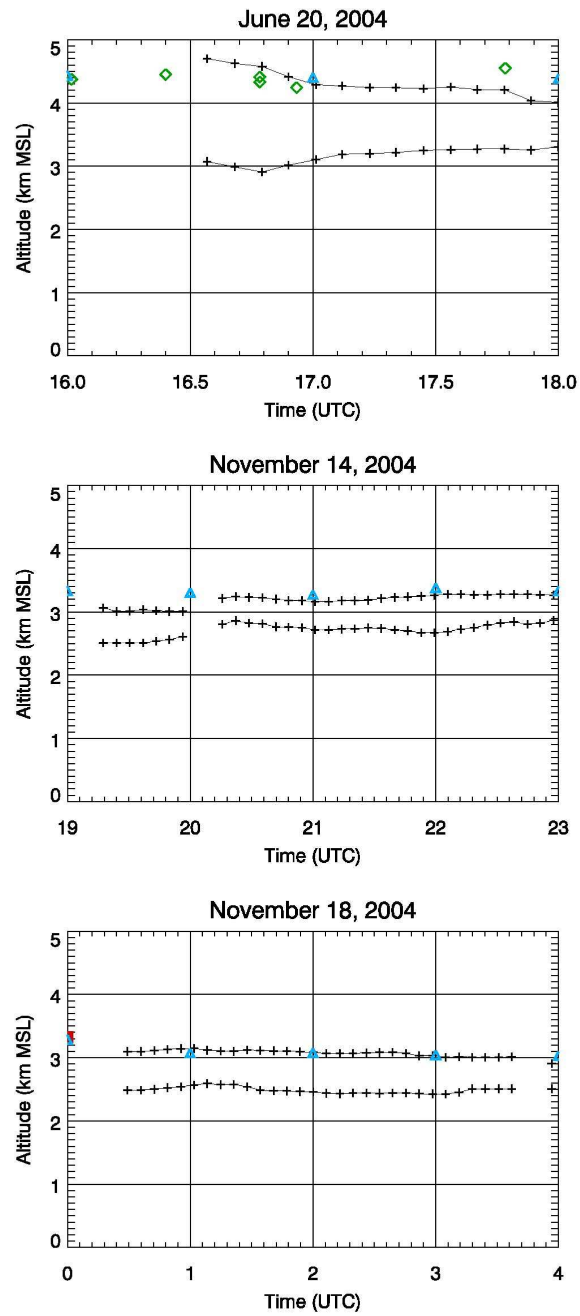

Figure 2: Mean melting layer detection results for select KOUN events as in the upper panel of Figure 1.

Figure 2 presents melting layer detections for three events on 20 June 2004, 14 Nov 2004, and 18 Nov 2004 (as in the upper panel of Figure 1). In addition to RUC model output, the 20 June 2004 event displays freezing level height from environmental and updraft soundings (green diamonds) from the TELEX field campaign (Rust et al. 2004). In all events, sounding and model output freezing level heights show agreement with melting layer detections. As with the 4 June 2003 event, the 20 June event experiences heightened azimuthal variability of the melting layer, which may account for some discrepancy between the detection results and observations. Both November events show good agreement between melting layer top and the RUC freezing level heights.

4. Interpreting Melting Layer Detection

Melting layer detection is performed at intermediate elevation angles, which maximize available polarimetric signatures at modest resolution. Operational hydrometeor classification and radar rainfall estimation is most applicable for severe weather and forecasting operations at grazing angles, which maximize radar coverage and are closest to the ground. Thus, projecting detection results performed at these higher elevations to the lowest elevation angles for use in such applications is a priority.

Geometric projection of melting layer results, however, will not satisfy operational quality needs because of a beam broadening effect. This effect is illustrated in Figure 3 which displays a polarimetric RHI from KOUN during an event with prominent melting layer signatures. While melting layer location at higher elevation angles (close to the radar) is stable, melting layer signatures are observed at much lower heights at lower elevation angles. Relative differences can be significant, with melting layer signatures first encountered a kilometer lower to the ground at grazing angles. Cursory modeling efforts using intrinsic profiles of radar variables obtained at close distances (not largely affected by beam broadening) also produce similar relative differences (not shown).

Figure 4 provides a practical example of the beam broadening issue with projections of melting layer results on the 4 June 2003 event to the 0.5° elevation angle assuming a standard mean beam height to slant range relation. The purple melting layer detection points (bottom only) on the image reflect direct geometric projection of the melting layer detection. The black contour reflects the results of the detection procedure projected adjusted using the following relation matched for RHI data

$$H^{\star} = H + 0.6 \ln(\frac{\phi}{4.5}), \qquad (1)$$

where H is the melting layer detection height for the current azimuth, and ϕ is the elevation angle to project this height to (in degrees). Results suggest that similar relations are required for more accurate interpretation of melting layer detections at grazing angles.

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References

Brandes, E. A. and K. Ikeda, 2004: Freezing-level estimation with polarimetric radar. *J. Appl. Meteor.*, **43**, 1541–1553.

Gourley, J. J. and C. M. Calvert, 2003: Automated detection of the bright band using WSR-88D data. *Wea. Forecasting*, **18**, 585–598.

Rust, W. D., D. R. MacGorman, T. Schuur, E. Bruning, J. Straka, B. Rison, T. Hamlin, P. Krehbiel, C. Ziegler, T. Mansel, M. Biggerstaff, K. Eack, and B. Beasley, 2004: Overview of the 2003 and 2004 field program phases of the thunderstorm electrification and lightning experiment (TELEX). *22nd Conf. on Severe Local Storms*, Amer. Meteor. Soc., Hyannis, MA.

Ryzhkov, A. V., T. Schuur, D. W. Burgess, P. L. Heinselman, S. E. Giangrande, and D. S. Zrnic, 2005: The joint polarization experiment: polarimetric rainfall measurements and hydrometeor classification. *Bull. Amer. Meteor. Soc.*, **86**, 809–824.

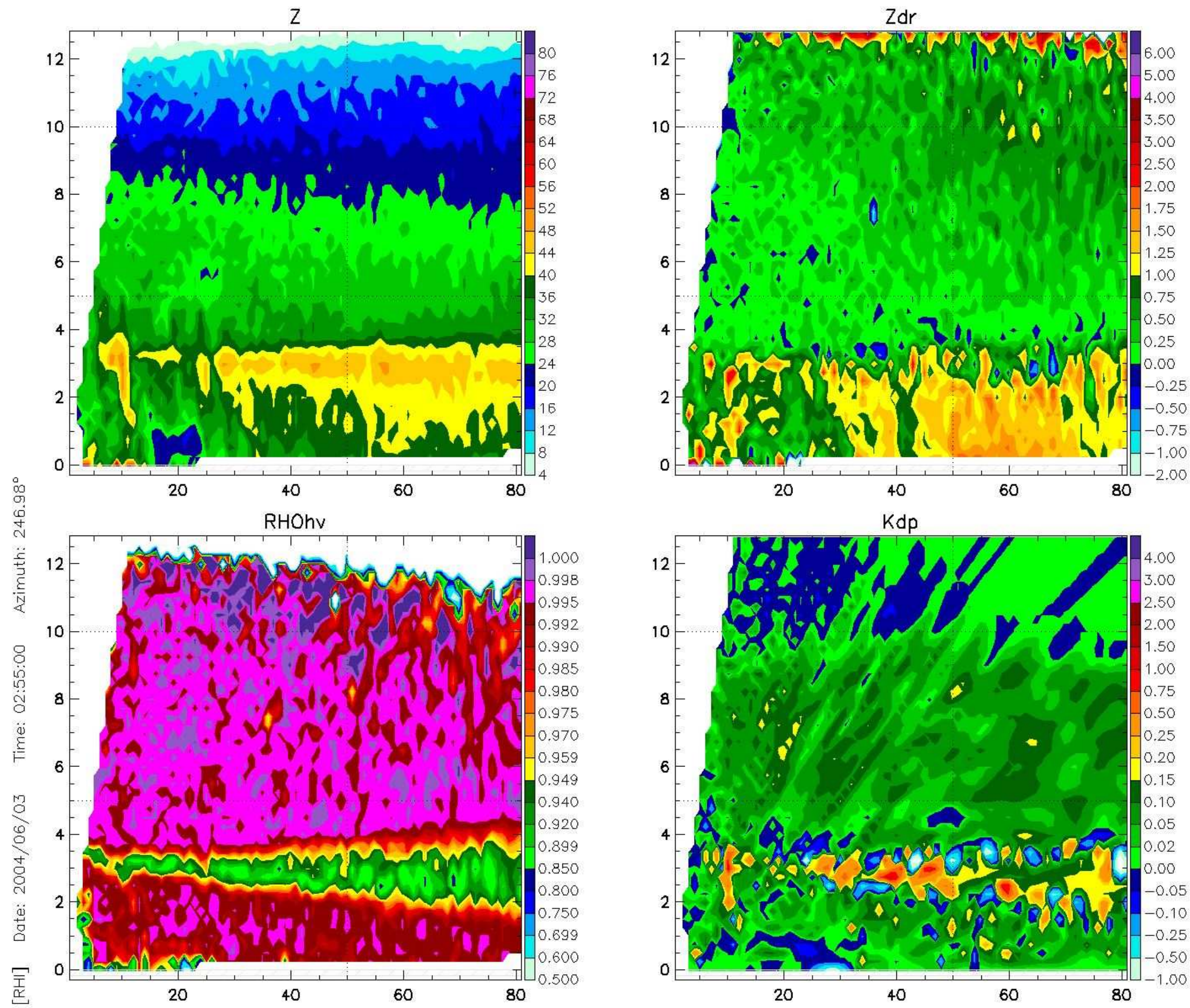

Figure 3: KOUN polarimetric RHI for a 3 June 2004 event which features a prominent melting layer signature and highlights beam broadening.

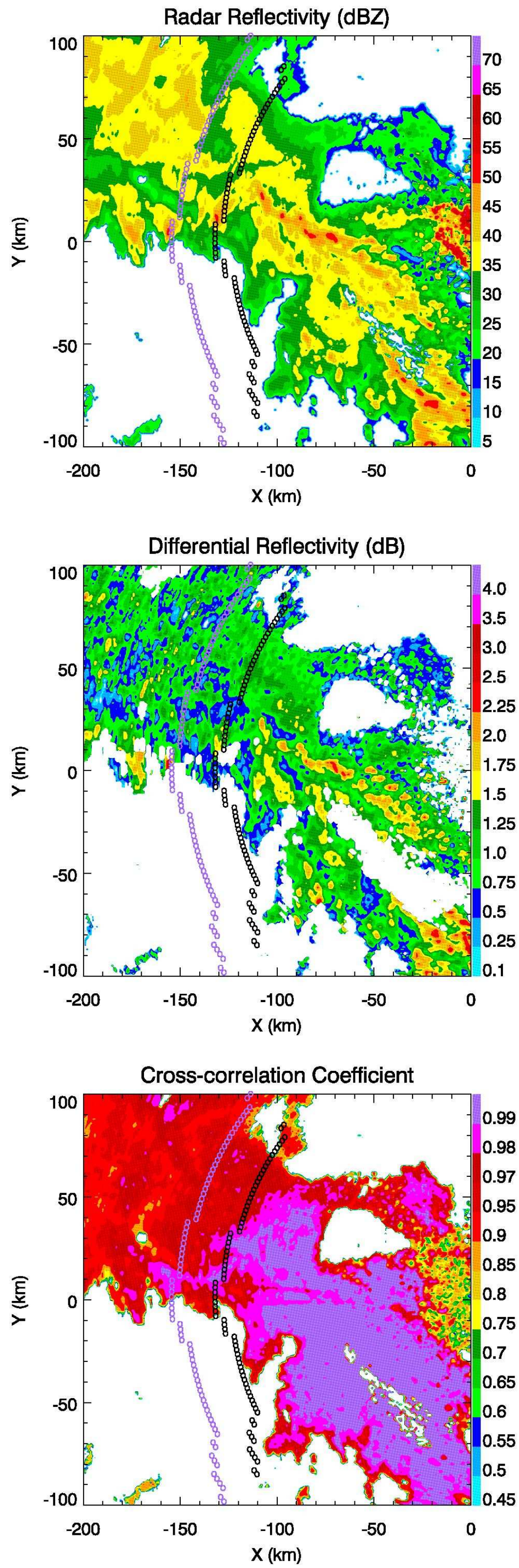

Figure 4: Results of direct(black) and modified(purple) projections of melting layer bottom detection heights to KOUN PPI fields at the 0.5 degree elevation angle.