79 USING DUAL-POLARIZATION RADAR AND CROWDSOURCED MPING REPORTS TO INVESTIGATE HYDROMETEOR REFREEZING

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1. INTRODUCTION

A unique and persistent signature in polarimetric radar observables is seen during winter storms producing ice pellets. The signature, indicative of hydrometeor refreezing, is notably characterized by an enhancement in Z_{DR} and K_{DP}, and a reduction in ρ_{hv} within a region of decreasing Z_H beneath the melting layer "brightband" (Kumjian et al. 2013). An example of the signature in Z_H, Z_{DR}, and ρ_{hv} is shown in Fig. 1.

This polarimetric signature of hydrometeor refreezing is investigated using WSR-88D radar data, crowd sourced Meteorological Phenomena Identification Near the Ground (mPING; Elmore et al. 2014; www.nssl.noaa.gov/projects/ping) precipitation reports, and Rapid Refresh (RAP) thermodynamic profiles. Coincident with the refreezing signature events are numerous crowdsourced precipitation reports of ice pellets received at the surface. The evolution of the signature is investigated in transitional events from ice pellets to freezing rain as indicated by mPING reports. The variability of the signature is also examined for a mixed precipitation type event when both ice pellets and snow are reported simultaneously.

2. ANALYSIS METHODS

Polarimetric radar data are presented in the form of a time series of quasi-vertical profiles (QVPs) where a single QVP is the azimuthal mean of a PPI (Kumjian et al. 2013; Ryzhkov et al. 2015). Although this technique is typically employed at higher elevation angles, the 2.4° elevation angle is chosen to better capture low levels (<1 km; see Fig. 2). The first eight range gates in WSR-88D radar data are censored. For instance, the lowest ~700 m are censored at the 19.5° elevation angle, whereas only the lowest ~100 m are censored at the 2.4° elevation angle.

Crowdsourced precipitation reports from the mPING project within a 100 x 100 km^2 grid space centered on the radar are selected to represent precipitation types associated with QVP signatures. Fig. 2 shows the plan position indicator (PPI) of Z_{DR} at 2.4° elevation from the Wakefield, VA radar (KENX) with an overlay of precipitation report type and location over a period of 48 hours. Although the grid size is an arbitrary selection, it adequately captures the distribution of representative precipitation reports during each event.

Precipitation reports are abbreviated and symbolized as follows: HAIL (magenta squares) are hail, RA (green circles) are rain, NONE (brown squares) are reports of no precipitation, FZDZ (blue diamonds) are freezing drizzle, RA/SN (blue asterisks) are rain/snow mixtures, FZRA (blue circles) are freezing rain, RA/IP (cyan circles with blue outline) are rain/ice pellet mixtures, IP (cyan circles) are ice pellets, IP/SN (cyan asterisks) are ice pellet/snow mixtures, and SN (black asterisks) are snow reports. Reports are not modified or checked for accuracy; however, reports of HAIL within a prolonged period of IP reports and the presence of polarimetric refreezing are assumed to be IP incorrectly identified by users.

Thermodynamic profiles of temperature and relative humidity are obtained from hourly RAP model output. Stull (2011) provides an equation for computing wet bulb temperature (T_w) from values of T and RH. Resulting contours of T_w overlaid on QVPs are referred to as isopsychrotherms. Following conventions in the AMS glossary for lines of constant temperature (isotherm) and dewpoint temperature (isodrosotherm), it is derived from the Greek terms *Isos* (meaning "equal"), *psukhros* (meaning "cold"), and *thermē* (meaning "heat").

3. PRECIPITATION TRANSITION EVENTS

Examination of the evolution of QVPs during winter precipitation type transition events from IP to FZRA reveals a descent of the polarimetric signature of refreezing in time (see Fig. 3). The signature appears to intersect the ground at the time that mPING reports indicate a changeover. Most easily identifiable in Z_{DR}, the enhancement associated with refreezing descends nearly linearly in time.

The monotonic descent of the refreezing signature in time prompts an investigation into its ability to forecast an IP to FZRA precipitation changeover event. Fig. 4 depicts a simple method employed at 0000 UTC 4 January 2015 at Albany, NY for forecasting the changeover. A linear extrapolation through the enhancement of Z_{DR} associated with refreezing in QVPs prior to 0000 UTC (Fig. 4; solid black line) and forward

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in time (Fig. 4; dashed black line) reveals an intersection with the ground at approximately 0200 UTC. Precipitation reports confirm the changeover occurs at this time.

This simple forecasting technique is compared to model-derived precipitation type forecasts to assess the potential advantages over existing forecasting techniques for a changeover event. A simple proxy for precipitation type from model output is used to provide the basis for a model-derived changeover time. Schuur et al. (2012) devise a simple algorithm to identify precipitation types from T_w profiles. SN is identified for profiles with $T_w < 0°C$ throughout the entire depth of the profile. RA is identified for profiles with T_w crossing 0°C once at a level greater than 1 km above the surface. Profiles with surface $T_w < 3°C$ that have a single layer of $T_w > 0°C$ may be classified as IP if $T_{w\_max} < 2°C$ and $T_{w\_min} < -5°C$, and as FZRA if $T_{w\_max} > 2°C$ and $T_{w\_min} \geq -5°C$. Hourly T_w profiles from 1900 UTC 3 January to 0400 UTC 4 January 2015 at Albany are plotted in Fig. 5. Precipitation types are identified using the simple algorithm and color coded in accordance with mPING report colors (i.e. SN is black, IP is cyan, FZRA is blue, and RA is green). Solid profiles are hourly analyses through 0000 UTC and dashed lines are hourly forecasts from the 0000 UTC cycle of the RAP. Ice pellets are identified at 0000 UTC, whereas FZRA is forecasted at 0100 UTC. The transition from IP to FZRA is thus forecasted to occur within the hour, whereas the transition actually occurs at approximately 0200 UTC. A lead time of two hours is insufficient in this case to accurately predict the transition time from model-derived precipitation type. The simple linear extrapolation of the refreezing signature from QVPs, however, shows more skill in providing an accurate transition time.

4. MIXED PRECIPITATION EVENTS

The variability of the refreezing signature is examined during an event which produced a mix of both ice pellets and snow. QVPs from the Oklahoma City, OK radar (KTLX) and associated mPING reports are plotted in Fig. 6. A time period with continuous reports of IP and significantly fewer reports of other precipitation types from 1937-2039 UTC (Fig. 6; black and cyan dashed rectangles) is chosen to characterize the polarimetric signature of refreezing. QVPs during this time are averaged to form a single profile representative of IP precipitation reports and plotted as a cyan line in Fig. 7.

Two time periods from 1743-1928 UTC (Fig. 6; black rectangles) are chosen to represent the polarimetric signature when IP, SN, and IP/SN are submitted simultaneously within the domain (not shown). Values from 1852-1906 UTC are neglected from the analysis due to a lack of IP and IP/SN precipitation reports. A spatial view of mPING reports indicates an even distribution of IP, SN, and IP/SN, not a precipitation transition line within the domain. QVPs from the two sets of time periods are averaged together to form a single representative profiles of an IP/SN mixture and plotted as a black line in Fig. 7.

The two precipitation type profiles in Fig. 7 are nearly identical at and above the melting layer. Beneath the melting layer the profiles remain similar in Z_{DR} and ρ_{hv}. The polarimetric signature of refreezing in both cases is evident in the enhancement in Z_{DR} within a region of decreasing Z_H and reduced ρ_{hv}. A remarkable difference in the QVPs exists in Z_H near the refreezing level. When IP is the dominant precipitation time, an enhancement of Z_H is located above the enhancement in Z_{DR} associated with refreezing. However, when reports are more evenly mixed among IP, IP/SN, and SN, there is instead a pronounced decrease in Z_H. The profiles differ by 14.5 dBZ where the Z_{DR} enhancement begins (just below 1 km). A maximum difference of 22 dBZ occurs just above the Z_{DR} maxima. At the height of the Z_{DR} maxima there is a relative maximum in Z_H for the IP QVP and a relative minimum for the mixed precipitation QVP. Differences between the two profiles near the refreezing level indicate potentially significant differences in the underlying microphysics that produce the refreezing signature when additional precipitation types are reported.

5. SUMMARY

A repeatable observation of the evolution of a polarimetric signature of refreezing during ice pellet to freezing rain changeover events is evaluated in association with mPING precipitation reports and RAP model output. Quasi-Vertical Profiles of operational S-band polarimetric radars at a 2.4° elevation angle reveal a descent of the refreezing layer in time leading up to a precipitation type transition. The time at which the RFL appears to intersect the ground indicates the approximate time when reports transition from IP to FZRA. This descent is nearly linear in time and allows for an accurate short-term forecast for the changeover time to be made. This forecasting method is done by making a linear extrapolation of the Z_{DR} enhancement associated with the RFL to the ground. This simple forecasting technique shows greater skill with forecasting a transition event than a model-derived forecast of precipitation type.

Differences are observed in the signature when snow is mixed with ice pellets. An increase in Z_H located above the enhancement in Z_{DR} associated with refreezing is present with IP reports. This enhancement in Z_H is not present when reports of SN and IP are simultaneously submitted. Future work will investigate the microphysical differences between these two profiles.

6. REFERENCES

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Stull, R., 2011: Wet-Bulb Temperature from Relative Humidity and Air Temperature. *Journal of Applied Meteorology and Climatology*, **50**,2267-2269.

7. FIGURES

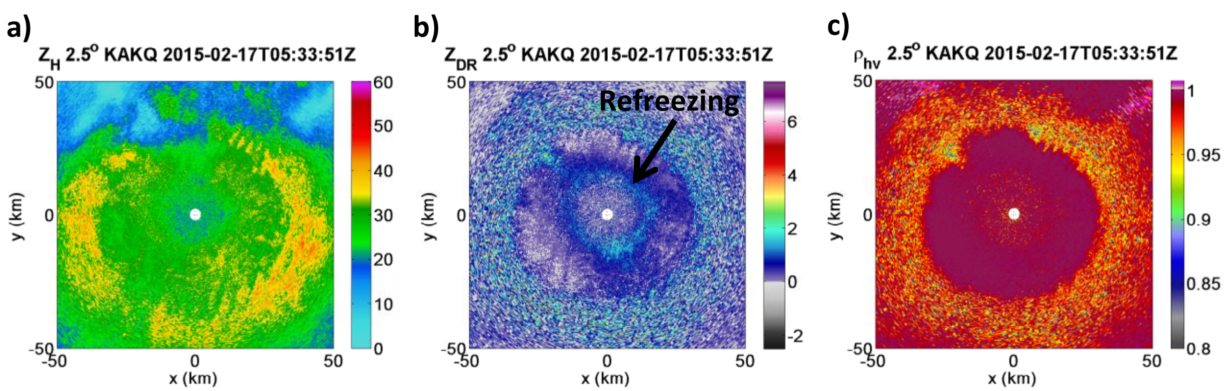

Fig. 1: Example refreezing signature in PPIs of the polarimetric radar variables (a) Z_H, (b) Z_{DR}, and (c) ρ_{hv} at 2.5° elevation collected at 0533 UTC 17 February 2015 by the S-band KAKQ radar. Refreezing is indicated by the black arrow in (b). Colorbars adapted from traditional AWIPS color schemes.

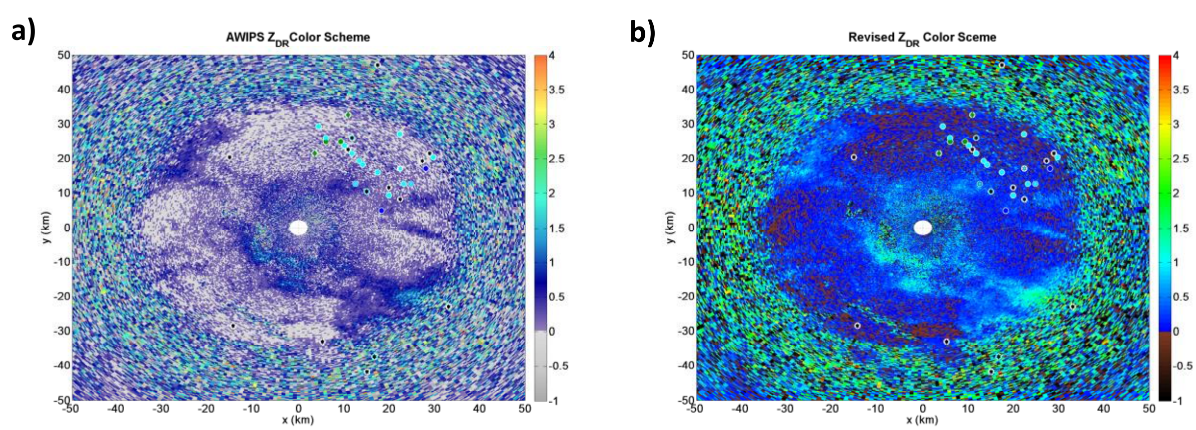

Fig. 2 : PPIs of Z_{DR} with (a) AWIPS color scheme and (b) a revised color scheme at 2.46° elevation collected at 0001 UTC 4 January 2015 by the S-band KENX radar. Overlaid mPING precipitation reports from 3-4 January 2015 indicate location and precipitation type where black stars are SN, cyan stars with black outline are IP/SN, cyan circles

are IP, cyan circles with blue outline are RA/IP, blue circles are FZRA, green diamonds are DZ, and green circles are RA.

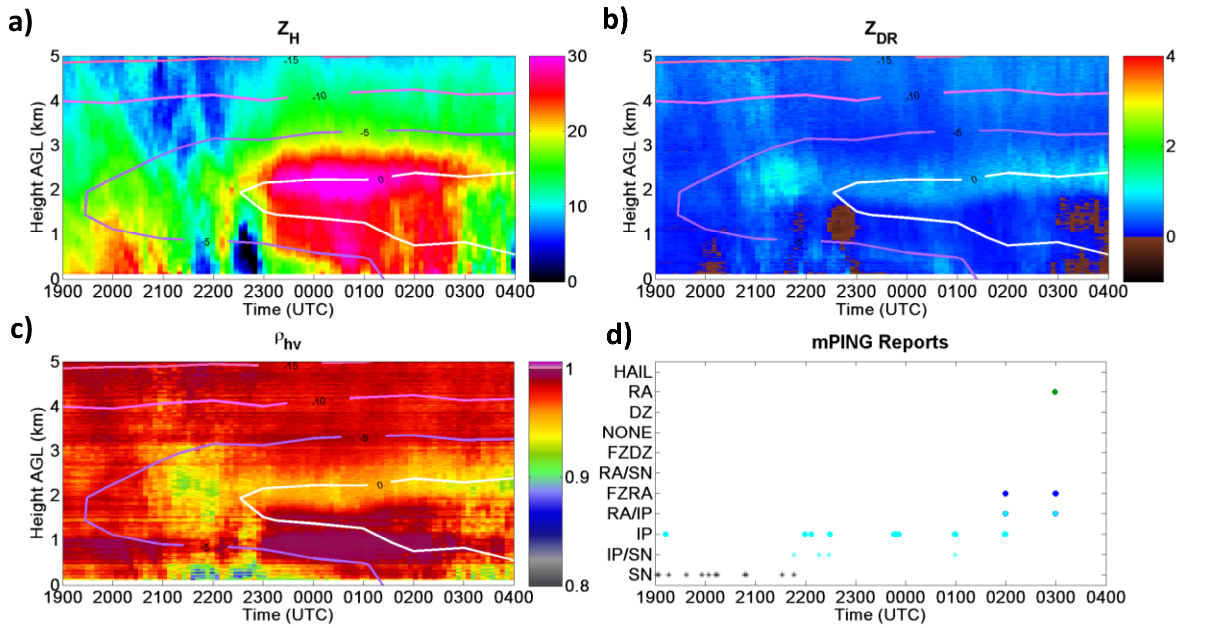

Fig. 3: QVPs of (a) Z_H, (b) Z_{DR}, and (c) ρ_{hv} at 2.4° elevation collected on 3-4 January 2015 by the S-band KENX radar with (d) accompanying mPING reports. Labeled contours indicate isopsychrotherms in °C derived from hourly RAP analyses.

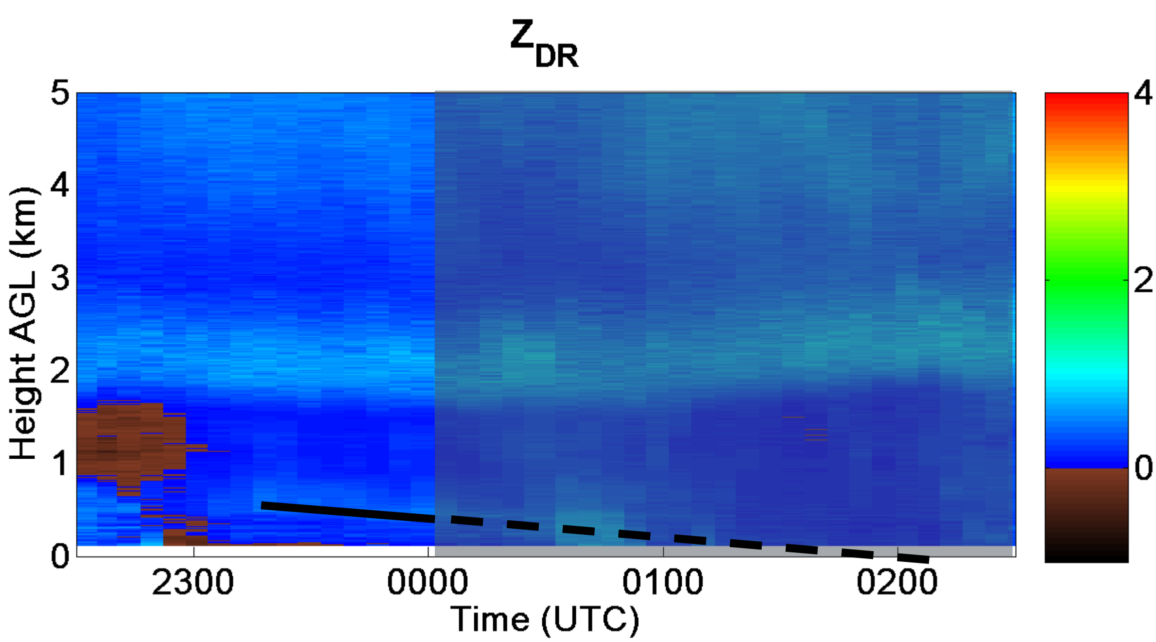

Fig. 4: Schematic of linear extrapolation to approximate precipitation changeover time. Dashed line indicates projection of Z_{DR} enhancement prior to 0000 UTC forward in time through greyed out QVPs. Intersection of the line with the ground at approximately 0200 UTC indicates the forecasted precipitation transition time from IP to FZRA.

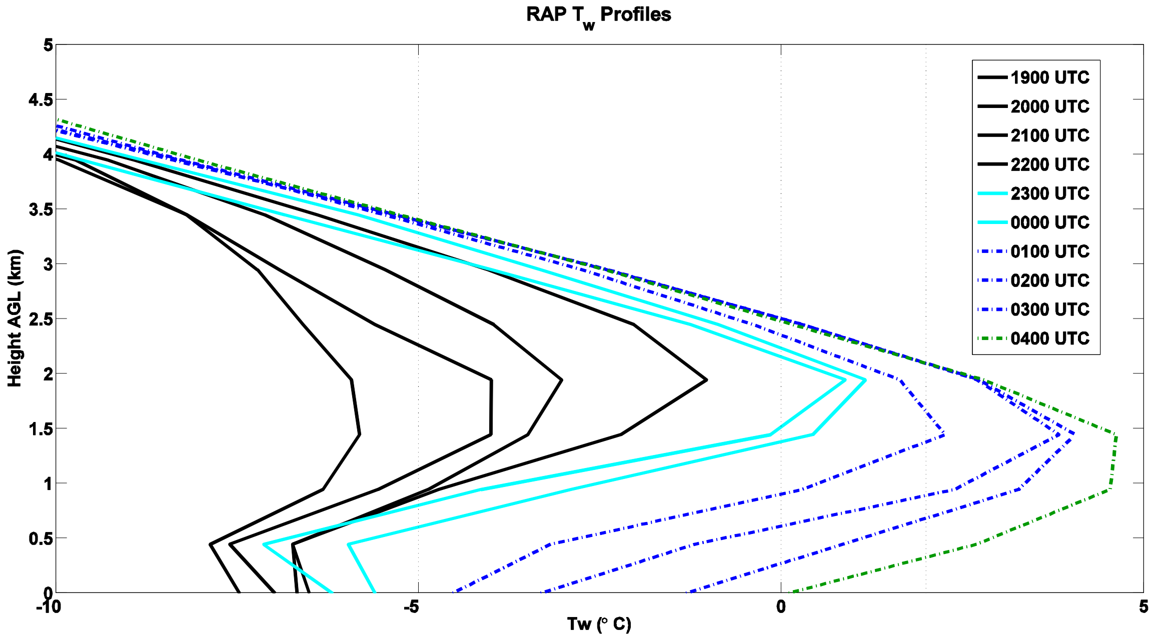

Fig. 5: RAP-derived wet bulb temperatures from 3-4 January 2015. Solid contours are hourly analyses. Dashed contours are hourly forecasts from the 0000 UTC cycle. Precipitation types are indicated by color where SN is black, IP is cyan, FZRA is blue, and RA is green. The precipitation transition from IP to FZRA is forecasted to occur prior to 0100 UTC.

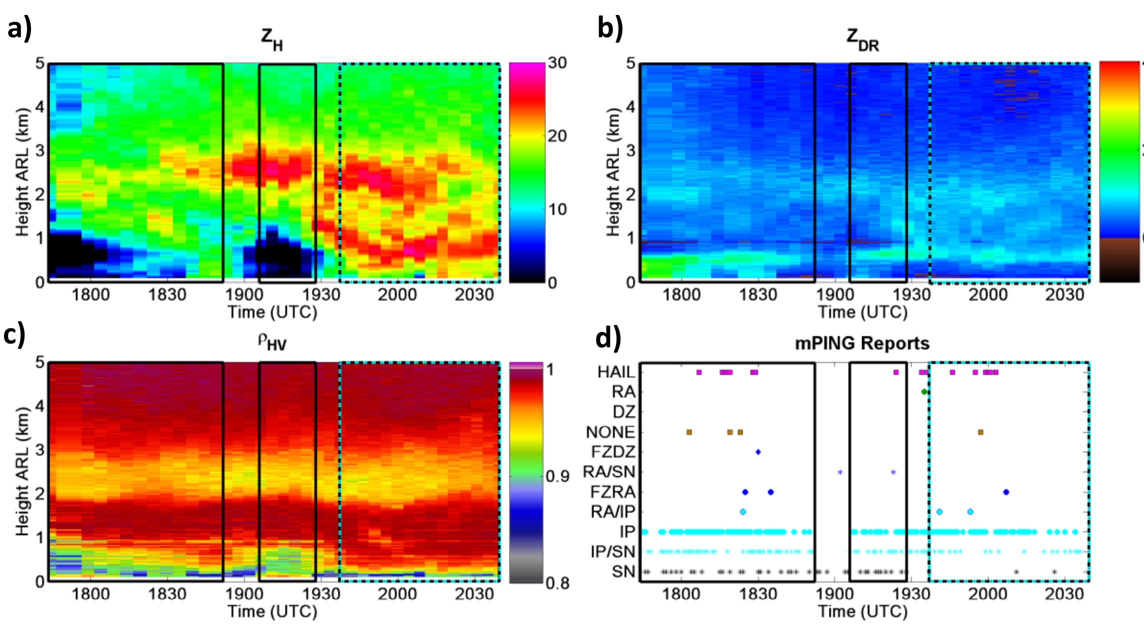

Fig. 6: QVPs of (a) Z_H, (b) Z_{DR}, and (c) ρ_{hv} at 2.4° elevation collected on 2 March 2014 by the S-band KTLX radar with (d) accompanying mPING reports. Solid black rectangle outlines indicate time periods of IP, IP/SN, and SN mixed precipitation reports. Dashed black and cyan rectangle outlines indicate a time period of mostly IP precipitation reports.

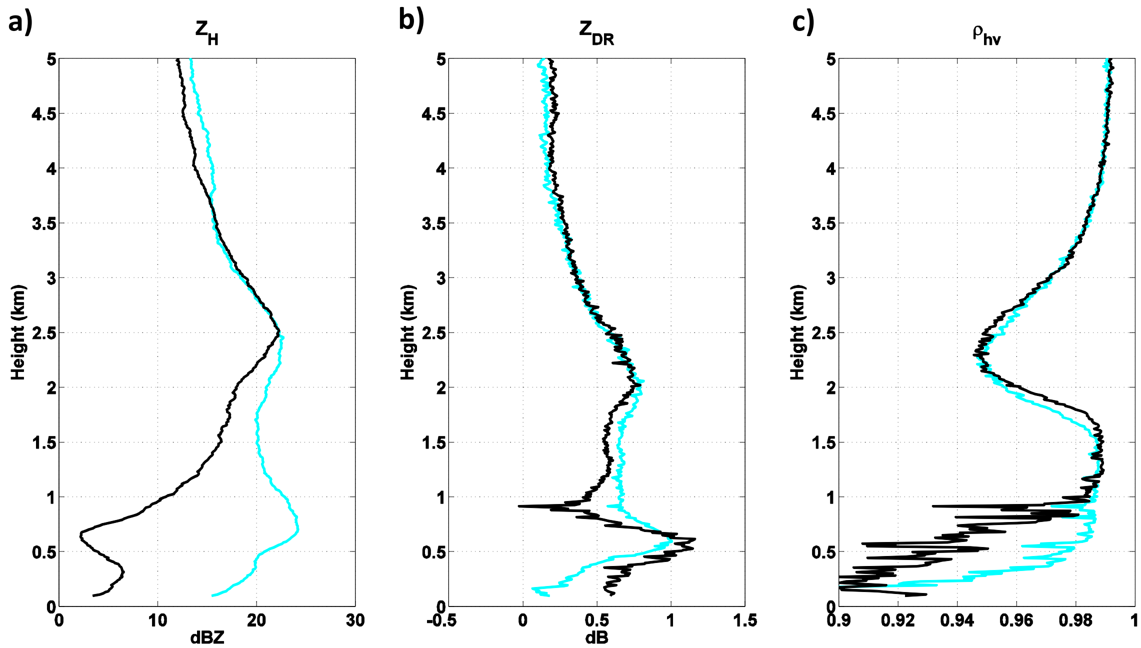

Fig. 7: Time-averaged QVPs of (a) Z_H, (b) Z_{DR}, and (c) ρ_{hv} from time periods indicated by rectangles in Fig. 5. Black QVP indicates time periods of IP, IP/SN, and SN mixed precipitation reports. Cyan QVP indicates a time period of mostly IP precipitation reports.