Quasi-vertical profiles (QVP) and column vertical profiles (CVP) methodologies for processing and displaying data from polarimetric weather radars

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Novel methodologies for processing and displaying data obtained from polarimetric weather radars are introduced. They represent the data in a height vs time format and are instrumental for monitoring the evolution of the vertical structure of the storms with high quality and fine vertical resolution. These new techniques exhibit numerous advantages compared to the traditional ways for radar information representation which are discussed in the paper.

Предлагаются новые методы обработки и представления данных, получаемых поляризационными метеорологическими радарами. Поляризационные данные отображаются в формате время – высота, что позволяет отслеживать эволюцию вертикальной структуры облака с высокой точностью и вертикальным разрешением. В докладе обсуждаются преимущества подобной обработки и отображения радарной информации по сравнению с традиционными методами.

The routine ways of displaying weather radar information include the plan position indicator (PPI), range-height indicator (RHI), and constant altitude plan position indicator (CAPPI) modes of presentation. The CAPPI display product is widely accepted on the existing network of polarimetric Doppler radars (ДМРЛ-С) in the Russian Federation [1,2,3]. Although the Cartesian 3D CAPPI or RHI products are convenient for model applications, they may not adequately represent the general structure of the storm or its evolution with appropriate vertical resolution.

An alternative methodology for presenting polarimetric radar data called “quasi-vertical profiles” (QVP) was recently introduced by Ryzhkov et al. [4]. It involves azimuthal averaging of the polarimetric variables at high antenna elevation (typically between 10 and 30°), and presenting the QVP profiles in a height-versus-time format. The use of high elevations minimizes the effects of beam broadening and horizontal inhomogeneity. Azimuthal averaging reduces the statistical errors of the estimates without compromising temporal resolution and assigns their average vertical profiles to a conical volume with a vertical axis (Fig. 1). The benefits of the QVP technique include an ability to monitor temporal evolution of the microphysical processes governing precipitation production with high vertical resolution and to compare polarimetric data with observations made by vertically pointing remote sensors, such as wind profilers, lidars, radiometers, cloud radars, and radars operating on spaceborne and airborne platforms.

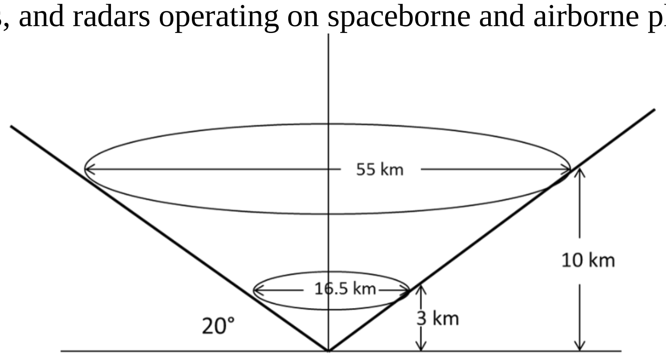

Fig. 1. Conical volume representing azimuthally averaged quasi-vertical profiles of radar variables.

An example of the composite QVP of the radar reflectivity factor Z, differential reflectivity Z_{DR}, cross-correlation coefficient ρ_{hv}, total differential phase Φ_{DP}, and specific differential phase K_{DP} in a cold-season frontal stratiform cloud observed by the S-band WSR-88D is presented in Fig. 2. The melting layer is clearly marked by enhanced Z, Z_{DR}, and Φ_{DP} as well as reduced ρ_{hv} at the height of about 2 km. Notable is clear delineation of the melting layer in Z_{DR}, ρ_{hv}, and K_{DP} during the interval between 0 and 4 UTC in which the traditional "bright band" in Z is absent. This underlines the benefit of using polarimetric measurements for identification of the melting layer. Very strong maximum of Φ_{DP} indicates the backscatter differential phase δ in the melting layer which can be as high as 100° at S band [5].

Another distinctive feature, a dendritic growth layer (DGL), is centered at the height of about 5 km at the temperatures between -10° and -15° and is manifested by high Z_{DR}, low ρ_{hv}, and strong vertical gradient of Z. The highest values of Z_{DR} are observed during the "shallow" phase of the storm with warmer cloud tops whereas the highest K_{DP} occurs during the period of much taller cloud with colder cloud tops. Essentially, Z_{DR} and K_{DP} in the DGL are anti-correlated and depend on the temperature at the top of the cloud. Monitoring DGL using the QVP product is very important for short-term precipitation forecast because the bulk of precipitation (rain or snow) is formed in the DGL and the appearance of the K_{DP} enhancement in the DGL means the enhancement in the surface precipitation 40 – 60 min later.

Additional advantage of the QVP product is an ability to monitor the quality of polarimetric radar variables and absolute calibration of Z_{DR} in particular. Using the measurements of Z_{DR} in dry aggregated snow just above the melting layer, one can ensure the accuracy of the Z_{DR} estimation within 0.1 – 0.2 dB.

The quasi-vertical profiles (QVP) methodology rapidly gains popularity among researchers and operational meteorologists across the world. Certain limitations of the QVP technique are also recognized. The QVP profiles represented in a height vs time format are radar-centric and utilize the data from a single high elevation tilt only. If the area of interest is quite far away from the radar, then the QVP does not provide appropriate information in this particular area.

A novel product which represents radar information in a vertical column centered on the area of interest – a Column Vertical Profiles or CVP was recently introduced. Similar to QVP, the CVP implies representation of the polarimetric radar data in a height vs time format which allows to capture the evolution of the microphysical processes in a vertical column of the atmosphere and to do precipitation nowcasting. The CVP also capitalizes on azimuthal averaging of the radar variables to reduce the standard errors in their estimates although such averaging is not as aggressive as in QVP.

The CVP principle is illustrated in Fig. 3. As opposed to QVP, all available elevation tilts are utilized instead of just one. For a column centered at the distance of 30 km from the radar with a radial extension of 20 km and azimuthal extension of 20° (Fig. 3a), the radar variables at any given elevation are averaged in azimuth (over 20°) and stuck vertically to produce continuous vertical profiles of each radar variable (Fig. 3b). Then the vertical profiles from the successive scans are represented in a height vs time format. As a result, vertical profiles of polarimetric radar variables are generated in a column with much smaller horizontal dimension at an arbitrary location.

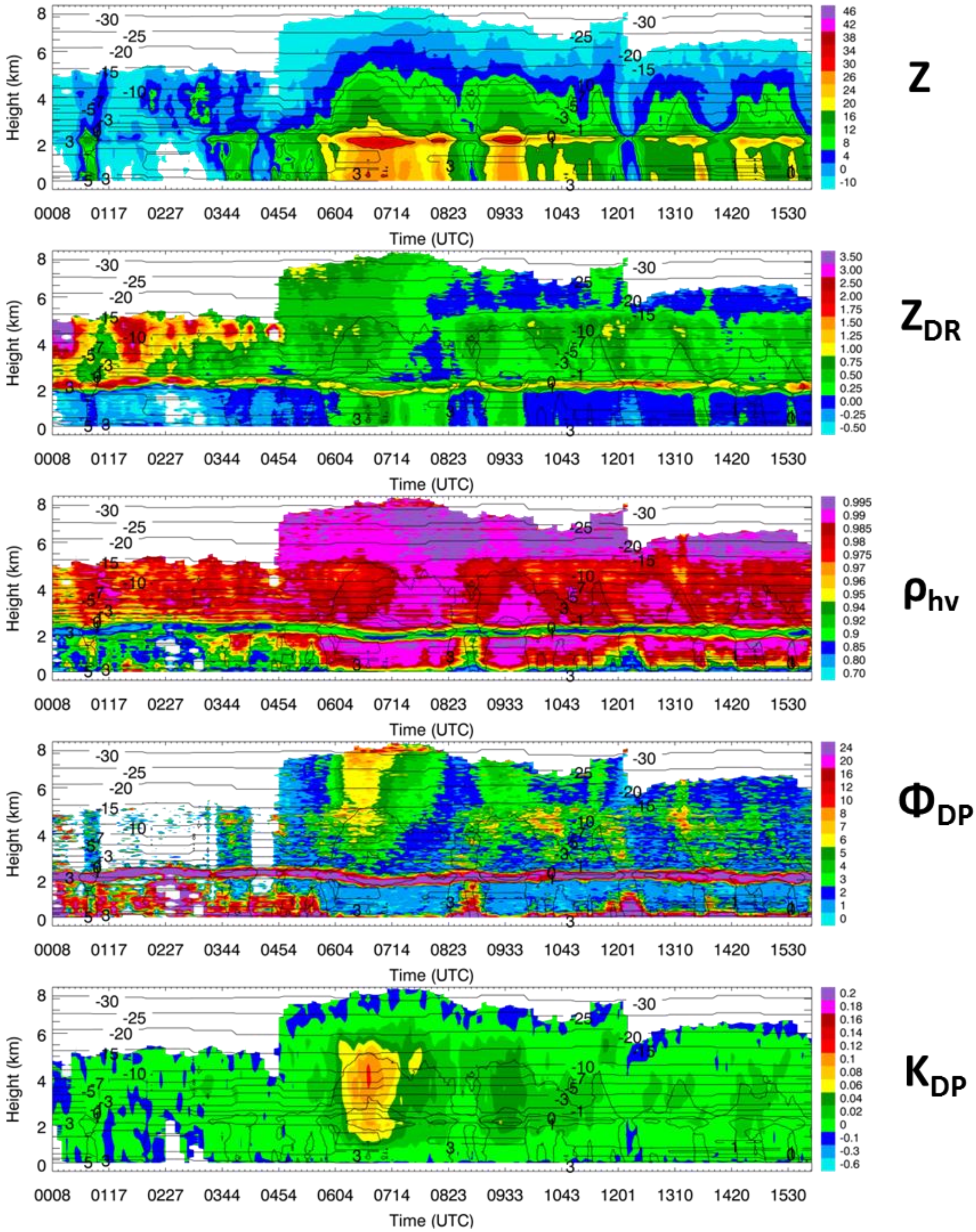

Fig. 2. Quasi-vertical profiles of *Z*, Z_{DR}, ρ_{hv}, Φ_{DP}, and K_{DP} retrieved from the KFFC WSR-88D radar data collected at antenna elevation 9.9° on 2 February 2014. Contours of HRRR model wet-bulb temperature (°C) are overlaid in each plot. Also, *Z* is contoured at 10, 20, 30, and 40 dBZ. From Griffin et al. [5].

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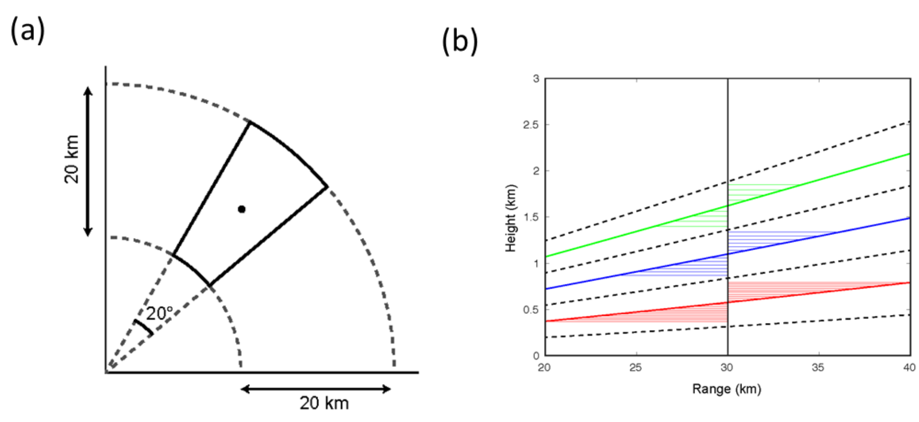

Fig. 3. Illustration of the CVP concept.

An example of the CVP product generated from the KVNX WSR-88D radar data for the case of mesoscale convective system observed during the Midlatitude Continental Convective Clouds Experiment (MC3E) on 20 May 2011 is shown in Fig. 4 (panels (a) – (d)). Horizontal size of the vertical column is 20 km x 20° (shown at the top of the plot). A research aircraft flew through the storm and the CVP column followed the aircraft track (shown by black line). It is important to contrast the CVP product with a 4D-grid WSR-88D product suggested by Homeyer [6], and Homeyer and Kumjian [7] in a column following aircraft for the same storm (panel (e) [8]). The latter has horizontal and vertical resolution of 2 km and 1 km respectively. It is obvious that the CVP product has better vertical resolution (at the expense of degraded horizontal resolution) compared to the 4D-grid product.

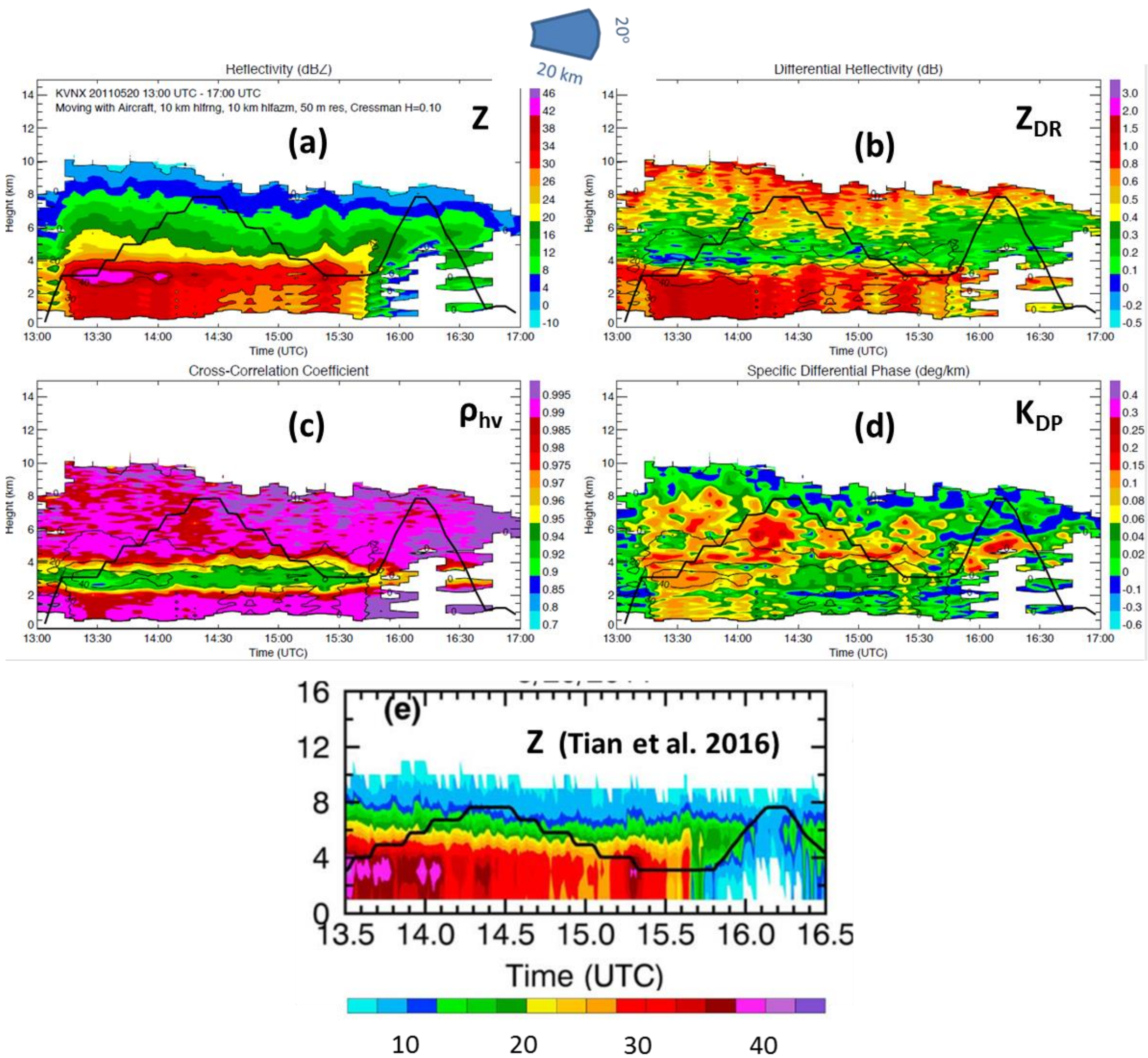

Fig. 4. Vertical profiles of radar variables in a vertical column following the aircraft represented in a height vs time format for the MCS on 20 May 2011. Panels (a) – (d): Z, Z_{DR}, ρ_{hv}, and K_{DP} estimated from the WSR-88D data using the CVP methodology. Panel (e): 4D-grid Z product from WSR-88D [8]. Aircraft height vs time is depicted with black line.

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