Pseudo RHI Software Developing for Dual-polarization Weather Radar CAPPI Observation Variables

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Abstract. RHI (range height indicator) is one type of operation and display for radar detection. Pseudo RHI is applying other observation data without RHI operation to generate RHI looks like echoes. Data processing method with interpolation and filter, computer display technology with coordinate transformation and pseudo color, and software development with Python for pseudo RHI are described in this paper. It is shown that this processing is useful for easily analysis and application of weather radar VCP (volume coverage pattern) observation data in vertical distributions of targets echoes for weather nowcast and severe weather warning.

1. Introduction
Weather radar is the most important tool for short-term weather forecasting (especially nowcasting), disaster weather warning, monitoring, tracking, and weather decision-making, operational command and operation effect assessment in weather modification operation, and hydrological management and aviation weather service support. The data observed by weather radar need to be shared across different application in different fields. However, there are great differences in the observation methods corresponding to the various radar data requirements. For radar operations, it is not possible to "traverse" all required observation modes one by one because of the rapid changes in precipitation targets.

VCP (volume coverage pattern) is standard observation mode recommended by WMO (World Meteorological Organization) in weather radar operation net. CAPPI (constant altitude plan position indicator) is usually as radar observation display mode which operating in VCP scanning. But some advances and benefits are obtained for using radar data by RHI, they are vertical structure clear echoes display, easy to be used by costumers and meteorologist, but there is no such kind of data in the radar data debase. So pseudo RHI is demanded to be developed for kindly using radar data.

In fact, the essence of the CAPPI observation mode is a combination of PPI (plan position indicator) with a reasonable configuration of different elevations, which calculated and translate the data scanned at each elevation angle into a plane at the desired height and display. Theoretically, the observation data of this method contain all the information of the observed volumes. In other words, pseudo RHI processing is Reasonable and effective.

2. Principle of Pseudo RHI
Pseudo RHI is a display mode for weather radar which operating on only CAPPI but without RHI. The structure of echoes represented weather system targets is clear in RHI observation. One replacement of this function is pseudo RHI.
So RHI and CAPPI is the basic of pseudo RHI.

2.1. RHI Operation
The RHI is a two-dimensional presentation indicating target range and height, and another hand, many characteristics of variables of target are presented as pseudo color in weather radar. In real time scan, the sweep originates in the lower left side of the scope, then moves across the scope, ends to the right. So the sweep lines are extended to the large areas of screen with elevation angle increasing.

RHI is basic observation mode in weather radar. But this kind of observation is replaced gradually by CAPPI for volume target data acquisition in weather radar nets near years.

2.2. CAPPI Operation
CAPPI displays a horizontal cross-section of the magnitude variables of echoes of targets at the selected altitude. These data are cut to certain height, calculated and placed on horizontal plane at that height from VCP scan. So CAPPI data means radar data are prepared ready on some constant height altitude planes.

The data are considered as complete and enough for the observation volume. So many others of observation or display modes are transformed or translated from CAPPI data. In fact this completeness is approximate only for fewer minutes to acquire weather system data in VCP scan. Some processing and display mode transformations must be done for good presentation of CAPPI data.

2.3. Pseudo RHI Principle
Pseudo RHI is RHI style echoes picture which employed the CAPPI data to generating some radial vertical profile section data for range-height indicator. So the scalar variables measured by weather radar can be converted as pseudo RHI by CAPPI data. The vector variables such as radial velocity (so call Doppler speed) not can be converted simply because they need vector operation support.

Reflectivity (represented by Z) and differential reflectivity (represented by Zdr) are scaler variables so they can be converted to pseudo RHI data from CAPPI one.

3. Software Development for Pseudo RHI
Pseudo RHI is a display mode for weather radar which operating on only CAPPI but without RHI. The vertical structure of echoes represented weather system targets is clear in RHI observation. For these benefits one replacement of this function is pseudo RHI.

Many complicated data format transformation, digital signal processing, pseudo color conversion, etc. for pseudo RHI are described in this chapter.

3.1. Data Reading from Files of CINRAD DP Weather Radar
CINRAD-DP weather radar means Chines new generation weather radar (looks like NEXRAD in the US), and had been updated as dual-polarization weather radar. The all data came from the observations of this kind of radar.

One routine is how to get the radar data in right sequence. The overall structure of the base data includes the condition of radar site, radar operation status, radar observation mode and parameter for scan, and large amount of differential format data of radar observation. According to the different weather conditions, the corresponding observation mode is used to obtain the radar data with different quantities and format. So the reading routine for radar data is complicated and controlled by some regulation.

According to the base data format for dual polarization weather radar, there are 19 kinds (or more in future) of radar moment data in one package file. Right reading these data is challenge. Analysis of the data format for file recorded by radar, the data structure can be drawn as up picture, (a) in fig. 1.

Where, the up-left picture means differential PPI in VCP, the up-right, the range sweep in one PPI, the down-right, the azimuth angle sweep in on PPI, and the others, the data structure of one time of radar observation.
Comparision of data length of range sweep, radial status of PPI azimuth angle sweep, and cut number of VCP scan, three nested loops can be established, shown in down picture (b) in fig. 1. The radar data reading routine can be programed by the pseudo flow chart.

![Data Format of CINRAD-DP](image1)

(a) Data format of CINRAD-DP

![Data reading orders](image2)

(b) Data reading orders

**Figure 1.** The data reading process from files which made by CINRAD DP radar

### 3.2. Pseudo RHI Radial Data Selection in Low Elevation PPI of VCP

After reading the file recorded by CINRAD-DP radar, the data of one VCP scan are ready for processing. Because of the weather system is always developing in the atmospheric boundary layer (from ground surface to up-air layer), the echoes from low elevation PPI scan is very important to find
the weather system. The PPI scan of low elevation, such as the first elevation, is selected for seeking the radial (azimuth) of pseudo RHI.

The data are withdrawn and displayed in polar coordinate as shown in left chart (a) in fig. 2. Nothing is processing but pseudo color displaying in this step for the data are polar coordinate array. A cut line is drawn and can be drag to any azimuth for selecting echoes in this chart. If it is made sure, the radial of pseudo RHI is confirmed.

![Figure 2. Pseudo RHI Principle](image)

This cut line is indicated as data coordinate in up-right chart (b) and down-middle chart (c) in fig. 1. The section determined by the height axis (Z) and the data coordinate axis is pseudo RHI cut off section.

The second step is developing a routine to pick up the data for pseudo RHI. The data address for this radial section can be calculated by using the initial azimuth and azimuth offset angle (cut line offset angle to north) of the PPI on each elevation angle. The addressing data can be read out to reconstitute an array of pseudo RHI section. This is still polar data which array of polar coordinates of elevation and slope range. The result is shown in down-right chart in fig. 1. For processing data with right angle coordinate, a coordinate transformation must be employed.

### 3.3. Coordinate Transformation and Data Save Format

The third step is coordinate transformation. Assume that the slope range of target is \( r \), and the elevation of target is \( \varphi \), then its horizontal range \( X \) and height \( Z \) can be calculated by equation (1).

\[
\begin{align*}
X &= \text{round}\left( r \cos \varphi \right) \\
Z &= \text{round}\left( r \sin \varphi \right)
\end{align*}
\]

![Figure 3. Coordinate transformation and data reorganization](image)
Where round is the rounding operator, \( r \) is counting with range resolution, and \( \varphi \) is discrete elevation. Considering the effect of beamwidth \( \theta \) of radar wave beam the elevation angle \( \varphi \) is spread from centre (the old \( \varphi \)) to side edge \( \pm 0.50 \).

The process is shown in fig. 3. The position of target is located at somewhere, such as left chart (a) in fig. 3. Although its coordinate values presented by tow coordinate are difference its position is in same place (not only the polar coordinate, middle (b) in fig. 3, but also right angle coordinate, right (c) in fig. 3).

For the reason of rounding, the distribution of target is not uniform in the array of right angle coordinate. That means some blind spots (no data point) will appear. So fill blind spots processing need to be accomplished.

Another problem is the observation variables are suddenly change because the elevation observed target is discrete. Analysis and application of this kind of echoes map are not convenient. Some smooth technologies are asked to improve the display products.

3.4. Signal Processing for Pseudo RHI

The digital signal processing for pseudo RHI is interpolation and filtering. This is 2D processing, vertical along Z direction, and horizontal along X direction, such as shown in fig. 4. The cubic spline data interpolation and ideal data interpolation (zero padding and low pass filtering) are tried and the first kind of technology is selected. Moving average filter, median filter, and Daubechies 2 wavelet filter, etc. are evaluated. As smooth result, these three kinds of methods are effective.

Note that the filter processing is put after the coordinate transformation because the angle variable in polar coordinate are in the direction of bending and do not meet to the two typical scales, vertical and horizontal in the weather system.

Figure 4. Data storage in right angle coordinate

Figure 5. Earth curvature compensation

3.5. Earth Curvature Compensation for Pseudo RHI

Since the earth is sphere, the radar ray with horizontal in radar site, it meet far target in a higher altitude, such as shown in fig. 5. These relationships can be obtained according to the principles of geometric relations and approximations, they are \( H = H' + \Delta H \), \( AB \approx AT = R \), \( CT \approx BT = H' \), \( (\Delta H + r_o)^2 = r_o^2 + R^2 \), and \( \Delta H \approx R^2 (2r_o)^{-1} \).
Where, $H$ is real height of target, $H'$ is measured height by radar, $\Delta H$ is height of earth curvature compensation, $r_e$ is earth radius, and $R$ is slope range for radar.

This is typical earth curvature compensation for radar detection. For the differential horizontal distance, the compensated height ($\Delta H$) is difference and can be calculated.

3.6. Pseudo Color Display

Weather radar is imaging radar. Detection variables observed by weather radar are scalar or vector and their values can be presented by positive or negative. Echoes in the screen means these variables are displayed on screen by some color with pseudo color technology. By this technology, the echoes presented variables look clear and easier to be analysed and applied.

4. Product of Pseudo RHI

The data from CAPPI can be transformed or translated to other formats for differential display modes and obtain the effects such as other kinds of observation modes. Pseudo RHI is only one try in extending data applications observed by weather radar.

By routines design, code writing, and execution debug, the software for pseudo RHI has been developed in python compile platform. Under a few test with data recorded by CINRAD-DP radar, some advantages of data application can be obtained. The first is extension of only several line to continuous areas, that is met the distribution of weather system. The second is the vertical structures of echoes can be see clear, such as strength echo cores and reflectivity layers. And the third, the echoes look like more really.

Some pictures of the software products are shown below in fig. 6. The up-left picture (a) is the first processing result for extending current elevation to beamwidth range, the up-right picture (b) is the linear interpolation one, the down-left (c) is $5 \times 5$ median filter, and down-right (d) is wavelet filter.

![Figure 6. Echoes display for pseudo RHI of reflectivity (Z)](image)

Echoes display for pseudo RHI of difference reflectivity (Zdr) are given in fig. 7 and the up is the first processing, the middle is the linear interpolation and moving smooth, and down is cubic spline interpolation (appeared some distortion). In fig.6 and fig.7, earth curvature compensation has been operated, so the attitude rises in far distant.

5. Conclusion

Pseudo RHI is a kind of method extending applications of weather radar data. It is impossible to see and understand the echoes map by identifying a few rays of a certain orientation from the CAPPI data to show them directly. If extending the angle to range of the beamwidth, the results are the most realistic, but many discontinuous area gaps are unacceptable. The dataless gap for linear interpolation or cubic spline interpolation will visually feel much more natural. If some kind of smooth filter is used,
such as moving average filtering, median filtering, or Daubechies 4 wavelet filtering, the results are very similar to the real RHI. However, it is important to note that the determination of filter parameters is important, and if not set properly, the excessive smooth can make the echoes map is severely distorted.

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7. References
[1] Figueras i Ventura J, F Honoré, and P Tabary 2013 X-band polarimetric weather radar observations of a hailstorm J. Atmos. Oceanic Technol. D 12 00243
[2] Snyder, J.C., A.V. Ryzhkov, M.R. Kumjian, A.P. Khain, and J. Picca 2015 A ZDR column detection algorithm to examine convective storm updrafts Wea. Forecasting WAF-D-15-0068.1
[3] Thomas J. Ganger, Mitretek Systems, Falls Church, VA; and M. J. Istok, D. J. Smalley, B. Klein, and S. Smith 2003 WSR-88D Products and standard data structures 19th Conference on IIPS https://ams.confex.com/ams/annual2003.techprogram/program_139.htm
[4] Picca, J. and A. Ryzhkov 2012 A dual-wavelength polarimetric analysis of the 16 May 2010 Oklahoma city extreme hailstorm Mon. Wea. Rev. 10.1175/MWR-D-11-00112.1
[5] The Common Operations and Development Environment (CODE) for the WSR-88D Open RPG CODE B18_0r1_11: April 2018 Includes ORPG Build 18_0r1_11
[6] Shaik Allabakash, Sanghun Lim and Bong-Joo Jang 2019 Melting layer detection and characterization based on range height indicator–quasi vertical profiles Remote Sens. 10.3390/rs11232848
[7] Heistermann, M., S. Collis, M.J. Dixon, S. Giangrande, J.J. Helmus, B. Kelley, J. Koistinen, D.B. Michelson, M. Peura, T. Pfaff, and D.B. Wolff 2015 The emergence of open-source software for the weather radar community Bull. Amer. Meteor. Soc. 10.1175/BAMS-D-13-00240.1
[8] Andrea Antonini, Samantha Melani, Manuela Corongiu, Stefano Romanelli, Alessandro Mazza, Alberto Ortolani and Bernardo Gozzini 2017 On the implementation of a regional X-band weather radar network Atmosphere 10.3390/atmos8020025
[9] Dixon, M., and G. Wiener 1993 TITAN: Thunderstorm Identification, Tracking, Analysis, and Nowcasting—A Radar-based Methodology J. Atmos. Oceanic Technol. 10.1175/1520-0426(1993)010

Figure 7. Echoes display for pseudo RHI of difference reflectivity (Zdr)