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On

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Lecture Note

on

Processing Doppler Radar Data for quality control and Mesoscale data assimilation

by

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Introduction:

Radar being an active sensor, the quality of generated product has a say right from radar transmission, signal reception processing till display. The main focus here is the product level quality processing for the basic radar products, so that the quality controlled data can be assimilated. Inspite of raw data feed, end users also demand derived by-products viz. Velocity Products (VVP), Precipitation Products (SRI, PAC) and reflectivity. Thus it becomes a necessity to quality control through algorithms and logics in minimizing the error estimates.

For VVP product generation, it is assumed uniform wind flow prevails and variability is minimum, which normally differs during rough weather. Thus instead of VAD derived winds the spatial extrapolation schema with velocity unfolding is applied in arriving out proper winds. Further the errors rising out of minimal available data are removed though SD and number of valid data sets settings. The settings are fine-tuned that over filtering doesn't happen at the same time not in considering noise as data.

For Precipitation products in spite of differences due to point measurement and volume sampling the ambiguity due to DSD & mixed precipitation leads to error. To attribute for these different coefficients are being used, the VPR is artificially fed through configuration settings, which can be fed on the go dynamically. Recent algorithms in the radar has the provision of deriving VPR automatically leading to better filling of beam-blocked regions as well as bright-band contamination minimization.

Radar Quality Pre Processing for Assimilation:

The average three-dimensional quality index fields for reflectivity, polarimetric parameters, and Doppler velocity can be easily transferred with the measurements and can be easily interpreted either by a non trained end user or an automated scheme that generates radar products.

For reflectivity measurements main factors leading to uncertainties are the increase in resolution with range, beam shielding from ground clutter, attenuation of the electromagnetic wave by hydrometeors, and inhomogeneous vertical profile of reflectivity. The quality of polarimetric parameters is quantified by determining range resolution, beam shielding, the amount of attenuation, homogeneous beam filling, discriminating rain from other hydrometeors, and applying a consistency check between Z_H, Z_{DR}, and K_{DP}.

Main factors quantifying the quality of Doppler velocity measurements are the spatial resolution, beam shielding, contamination from non- meteorological targets, and utilizing the standard deviation.

Use of radar reflectivity and radial velocity observed by Doppler weather radar (DWR) is immense in the field of modeling, flash flood warnings. The quality characterization in terms of Quality Index (QI) of radar reflectivity and radial velocity are presented for all the operational DWRs in India.

The quality of radar data from Doppler weather radar is very crucial for a variety of applications like numerical weather predictions (NWP), quantitative precipitation estimation, nowcasting etc. In the case of NWP on different time scales, the demand for automated and flexible quality correction of radar data has increased in the last few years (Friedrich et al., 2006).

QI is necessary to describe uncertainty in the radar data taking into account potential errors that can be quantified (Friedrich et al., 2006). The quality index is a measure of data quality and gives a more detailed quality characterization in the range 0 (bad data) to 1(excellent data) with values greater than 0.5 is assumed to be good in the case of reflectivity. In this scheme, the quantities that need to be determined are quality factors (xi), quality functions (f(xi)), quality indices (QIi), weights of the QI (Wi), and total quality index (Average QIi of individual factors).

$$\bar{Q} = \begin{cases} 0 \; for \; F_A = 0 \; or \; F_S \\ \frac{1}{AW}(W_R F_R + W_S F_S + W_A F_A + W_B W_B) \end{cases}$$

$$AW = W_R + W_S + W_A + W_B$$

$$QI_w = \sum_{i=1}^{n} (QI_i \bullet W_i) \qquad (1)$$

Here, QI_w in equation (1) is the total QI of the individual quality characterizations. 'i' is the factor and 'n' is the total number of factors considered. The factors considered are described below in brief.

For measurements taken at far distance, the radar beam expands in horizontal and vertical directions. As the distance from the radar increases then the basic assumption that the radar beam is filled by homogeneous meteorological targets is not valid. The accuracy decreases quadratically (range QI of Szturc et. al 2011), due to the quadratic increase in radar pulse volume with range.

The beam broadening formulation of the Friedrich et al. (2006) is used for the computation of quality index as follows.

$$F_r = \begin{cases} 0\, for\, 'r' \geq r_M \\ 1\, for\, 'r' \leq r_m \\ \dfrac{r_M - r}{r_M - r_m}\, for - r_m < r < r_M \end{cases} \quad (2)$$

Where Fr is quality index for beam broadening, r_m is the minimum range and r_M is the maximum range and 'r' being the distance between the radar centre and the target.

In order to determine areas contaminated by blockage, partial beam blockage values (PBB) are computed. The PBB is defined as a ratio of blocked beam cross section area to the cross sectional area if the beam is not blocked. Equation (3) shows the formulation used for partial beam blockage formulation of Bech et.al (2003, 2007).

$$PBB = \frac{y\sqrt{a^2 - y^2} + a^2 \arcsin\left(\dfrac{y}{a}\right) + \dfrac{\pi a^2}{2}}{\pi a^2} \quad (3)$$

Where 'a' is the radar beam cross section at the given distance from radar, y is the difference between the height of the terrain and the height of the radar beam centre. The partial blockage takes place when $-a < y < a$, and varies from 0 to 1. Digital elevation model (DEM) of Global Land One-km Base Elevation Project (GLOBE), NOAA is used to compute the percentage of blockage. The DWR data is also processed at 1 km resolution (default 0.5 km) to bring it at par with the resolution of DEM.

The attenuation of electromagnetic energy by hydrometeors due to both absorption and scattering is observed in the case of C band DWR. The attenuation and the rain rate are related by a power law relation of the form given below:

$$A = 2\int_{r_1}^{r_2} aR^b dr$$

Where the prefactor 'a' and the exponent 'b' have been derived using an assumed drop size distribution and temperature. The values for the particular frequency and temperature of 18^0 are considered (Raghavan 2003). The rainfall (R) is computed using the Z-R relation of the form ($Z=aR^b$). Here the Marshall-Palmer coefficients are used for obtaining the rainfall.

In this study, we have computed the negligible amount of attenuation seen by S-band radar. The radar reflectivity is classified into convection and stratiform type (Steiner et al., 1995) and the weights are assigned accordingly. The reflectivity threshold considered here for the classification of a convective cell is 38 dBz.

The quality indicators are harmonized by scaling each factor values linearly between 0 and 1 and finally average QI is computed. The quality maps of individual indices and a composite one for each radar reflectivity and the radial velocity are generated. The averaged QI is computed on the basis of fixed weights for each factor as given in table 1.

Table 1: Weights used for the generation of QI map of reflectivity and Velocity

S.No.	Parameter	Weights
1	Beam Widening	1.0
2	Ground Clutter	1.0
3	Attenuation	0.6 (Stratiform Rain) 1.0 (Convective Rain)

4	Non Meteorological Echoes	1.0
5	Standard Deviation of Radial Velocity	1.0

The QI maps are generated for the effects of beam broadening, beam shielding, attenuation of radar reflectivity due to rain and bright band. For all the radars, the amount of blockage is computed using the 1 km DEM data. The quality indices are presented here are only for the lowest elevation scans and hence the bright band effect was not seen for any of the cases and hence the averaged QI is the combined effect due to the above mentioned errors.

The DWR can measure the component of the velocity of targets toward or away from the radar. This component is called radial velocity. To derive the QI of radial velocity two specific parameters are used, one is the standard deviation of radial velocity and the other is the identification of non meteorological echoes. The spectrum width along with Nyquist velocity is used for the estimation of standard deviation of radial velocity. The QI of non meteorological echoes, the QI of standard deviation of radial velocity, the QI for the effect of beam broadening and beam shielding QI are combined to obtain the average quality index for the radial velocity for a radar range of 100. The weights to compute the overall average QI is set to 1.0. All the radars discussed above are operating in the dual pulse repetition frequency (PRF) mode (600/450Hz) with PRF ratio of 3:4.

The quality characterization of radar reflectivity described here is based on various factors like broadening of the radar beam, attenuation of radar signal due to rain and blockage of the radar signal due to clutter. The blockage of the radar signal is computed using the digital elevation model of 1 km resolution (GLOBE, NOAA). The attenuation of the radar signal is computed for all the cases examined in this study (both S and C band). The averaged quality index of reflectivity is computed for all the factors mentioned above for all the radars. The QI of reflectivity is above 0.5 in all regions except in the regions of blockage, high attenuation due to rain and beam broadening.

The quality characterization of the radial velocity is computed based on factors like blockage, beam broadening, standard deviation of the radial velocity and echoes from non – meteorological targets. The QI of the radial velocity is good and above 0.7 except for the clutter region and the region affected by non-meteorological echoes. The range of radial velocity considered is around 100 km and therefore the influence of the beam broadening is not significant. Equal weights are assigned for each factor mentioned above to maintain uniformity in the computation of QI radial velocity and reflectivity.

In addition, to the above mentioned quality characteristics a generalized quality map has been generated using the static sources of errors like beam blockage and the beam broadening. These static maps will help the detection of low QI region in advance. This shall help in the pre-processing of radar observations quickly, since the regions of low QI can be masked without any investigation. The information in the form of QI will serve as valuable tool in the data pre-processing step and allow only good quality data into the data assimilation system which prepares the initial condition for the NWP model. This will enhance the use of DWR data in the NWP system and create positive impact in the accuracy of the numerical forecast.

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