BALTRAD dual polarization hydrometeor classifier

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Abstract

A hydrometeor classifier (HMC) using dual polarization C-band data has been developed with partial funding from the EU financed project BALTRAD (Baltic Sea Region Programme 2007-2013).

Prior to the development of the HMC a number of investigations were undertaken to determine the sensitivity of the dual polarization parameters to, amongst others, the orange peel radomes used at the Danish Meteorological Institute (DMI). A number of data quality software tools to monitor the temporal variability of the parameters are now in operation, including a dedicated radar scan at 90 deg. elevation.

The classification scheme is based on fuzzy logic and the membership functions are represented by 1 dimensional Beta functions.

In the current version, the algorithm can undertake the so-called level 1 and level 2 classifications. In the level 1 classification a radar echo is classified into one of four simple classes: precipitation, clutter, clean air echoes, and electrical signals from external emitters. Similarly, in the case of level 2 classification a radar echo is classified into one of 12 classes; ground clutter, sea clutter, external emitters, clean air echoes, drizzle, light rain, moderate rain, heavy rain, violent rain, light snow, moderate to heavy snow and hail/rain mixture. In the level 2 classification the melting layer heights from the numerical weather prediction model are used to aid the classification. Melting layer determination algorithm using the dualpol parameters alone has also been developed as part of the HMC. This algorithm is under going evaluations before its use in the HMC scheme.

One of the by product of the HMC algorithm as been that it can be used to remove the non-meteorological echoes in, amongst others, the original radar reflectivity product, Z_{HH}. This product has been much appreciated by the DMI's end users, such as the operational meteorologists, and, not surprisingly, it was the first 'HMC' product to be put into operational use.

In the future, further improvements to the algorithm are planned such as fine tuning the membership functions for hail. As hail is observed in very small regions occupying few pixels, it has been a challenge to extract these cells in the radar data whilst ensuring they are not contaminated by other hydrometeor classes.

The algorithm has now been incorporated into the BALTRAD tool kit and is available to the potential users including the HMC computer source code. At the ERAD conference the details of the HMC will be provided including examples of its performance.

1. Introduction

DMI operates five weather radars, two of which, at Virring in central Jutland (56.024 °N, 10.025 °E) and on the island of Bornholm (55.113 °N, 14.999 °E) have dual polarization capabilities. These radars measure in addition to the four parameters measured by the traditional Doppler radars; uncorrected reflectivity (U), corrected reflectivity (Z_{HH}), radial doppler velocity (V), spectral width (W), also the differential reflectivity (Z_{DR}), differential phase shift (Φ_{DP}), specific differential phase (K_{DP}), co-polar correlation coefficient (r_{HV}) and linear depolarization ratio (LDR). These latter five so-called dual polarization parameters (Z_{DR}, Φ_{DP}, K_{DP}, r_{HV}, LDR) are sensitive to the properties of the returned echo such as its shape, size and orientation, its physical state and hydrometeor class (Bringi and Chandrasekar, 2001). In particular, Z_{DR} is sensitive to the shape of the hydrometeors and typically have values ~0.0 dB for small rain drops of size <0.3 mm and increases in value for larger drop size. It thus has the potential to discriminate between light and heavy precipitation. Similarly, r_{HV}, is useful for discriminating between precipitation and non-meteorological echoes. It is also sensitive to the physical state of the hydrometeors such as solid/liquid phase and is thus useful for detecting the melting layer. K_{DP} is sensitive to isotropic/anisotropic precipitation regions and is important for estimating rain attenuation corrections for Z_{HH} and Z_{DR}. Finally, LDR is also sensitive to the shape and orientation and dielectric constant of the precipitation particles so that wet non spherical particles results in large LDR whilst drizzle and dry ice particles are associated with low LDR (Bringi and Chandrasekar, 2001).

From above it is clear that all the dual polarization parameters contain some information that is useful for radar echo discrimination. In most of the cases the range of values of the radar parameters, for the different hydrometeor classes, are overlapping. Thus how to combine the information in these parameters into useful operational products has been a challenge. A number of methods using neural networks, Boolan decision trees, statistical methods using probabilities and fuzzy logic have been tried (Bringi and Chandrasekar, 2001). However, in the last 10 – 15 years the method based on the fuzzy logic technique has become the preferred choice as it is well suited for combining the information from the overlapping hydrometeor classes from the different radar parameters. There are several articles in the literature describing various aspects of fuzzy logic hydrometeor classification (Bringi and Chandrasekar, 2001, Zrnic et. al., 2001, Schuur et. al., 2003, Lim et. al., 2005).

2. Data quality issues

As stated above fuzzy logic techniques are used for hydrometeor classification because they can deal with the overlapping classes from the different radar parameters. However, for reliable hydrometeor classification it is very important to have good quality radar observations. In particular, previous studies have concluded that Z_{DR} has to be accurate to within 0.1 – 0.2 dB, Φ_{DP} within 1º or better, r_{HV} greater than 0.98 in light to moderate rain (Sugier et. al., 2006). If these conditions are not met then all the products derived using the dual polarization parameters will be affected by noise so that the distinction between rain and wet snow, for example, will be difficult. Apart from requiring radar observation to be of very high quality, previous studies have also shown that, unlike the radar parameters from the traditional Doppler radars, the dual polarization radar parameters from the C-band radars that DMI operates are very sensitive to the radar hardware such as the radome, thermal noise in the receiver etc. (Sugier et. al., 2006). To ascertain the sensitivity of the dual polarization parameters to these radar hardware issues a number of investigations were undertaken at DMI. As a way of example, fig. 1 shows the sensitivity of the differential reflectivity parameter to the radome at Bornholm. Our investigations have shown that the maximum of Z_{DR} values are directly correlated with the positions of the bolts used to join the eight panels of the orange peel radome. Also note that Z_{DR} varies by as much as ± 0.2 dB which is, given what is stated above, barely tolerable. However, knowing the sensitivity of Z_{DR} to the physical properties of the radar radomes at Bornholm and Virring is important so that techniques can be developed to mitigate this effect.

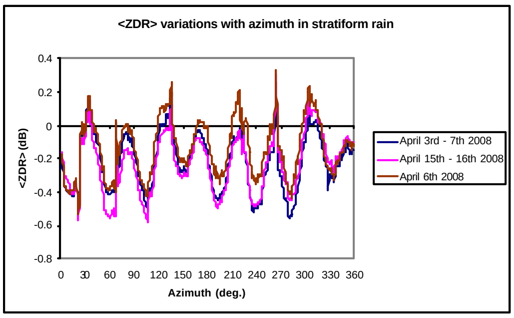

Fig. 1 Shows the variation of the Z_{DR} *parameter to the radome at the Bornholm radar.*

In addition to analysing the effects of radar radomes on the dual polarization parameters, a number of other monitoring indicators have been developed which measure the quality of the radar parameters. In particular, the monitoring indicators that were computed are the following; (i) Z_{DR} in light rain between 20 dBZ – 22 dBZ at close range, (ii) Φ_{DP} offsets using the first 5 consecutive gates containing precipitation, and (iii) upper 75% quantile r_{HV} in rain, and (iv) special radar scans at 90º elevation is performed to estimate the potential biases in Z_{DR}. (Sugier et. al., 2006, Boumahmoud et. al, 2010). The above parameters are computed daily to ascertain their temporal variability so that realistic temporal corrections can be applied to the data. As a way of examples, figures 2 and 3 shows the diurnal variations of r_{HV} in rain and Z_{DR} biases from the 90º elevation scan, from the radars at Bornholm and Virring, respectively. As can be seen from fig. 2 the variation of r_{HV} from the two radars meets the quality requirements i.e., r_{HV} greater than 0.98 in light to moderate rain. However, this is not the case for the Z_{DR} biases from the 90º elevation scan. For the latter, from theoretical considerations, the values of Z_{DR} in rain for the 90º elevation scan should be ~ 0.0 dB (Sugier et. al., 2006). However, from the figures it can be seen that whilst Z_{DR} parameter of the Bornholm radar meets this quality requirement, this is not the case for the radar at Virring. The latter shows biases of ~ -5.5 dB which is very large given that Z_{DR} should generally lie in the range ~ 0 dB - 8.0 dB in precipitation. Nevertheless, knowing these biases is very important so that corrective techniques can be developed and implemented.

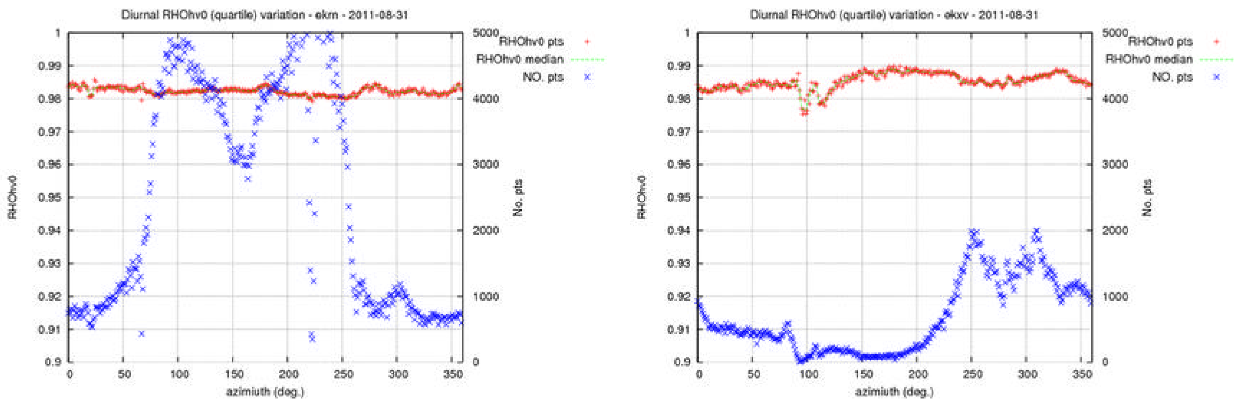

Fig. 2 The diurnal variations of r_{HV} (colour red) as a function of azimuth in rain from 31st August 2011 for Bornholm and Virring radars, left and right diagrams respectively. The curves in blue are the corresponding number of r_{HV} points that met the diagnostic criteria.

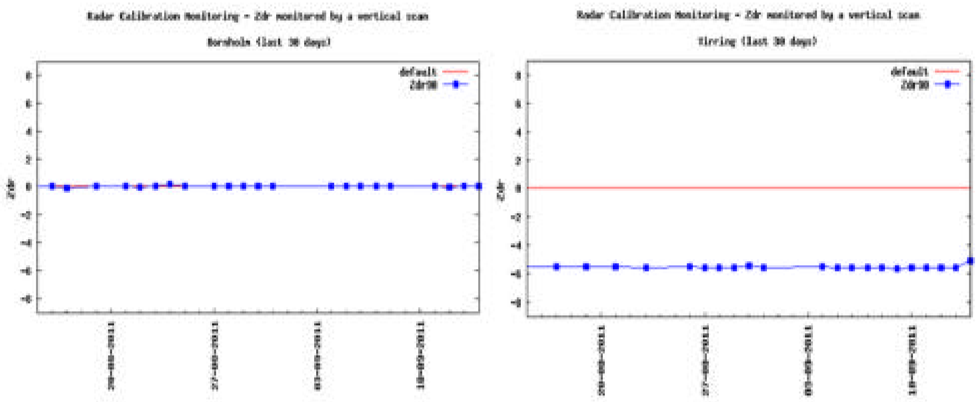

Fig. 3 the diurnal biases in the Z_{DR} parameter for the Bornholm and Virring radars, computed using the radar scan at 90º elevation.

3. Melting layer algorithm

One of the key parameters in developing the hydrometeor classifier is determining the height of melting layer (ML). For the latter, a melting layer determination algorithm has been developed based on the previous studies in the open literature using the dual polarization moments Z_{DR}, Z_{HH} and r_{HV} (Giangrande et. al., 2008). It has been found that this algorithm gives very favourable results when compared to the Numerical Weather Prediction (NWP) model at short lead times (1 – 2 hours). Unfortunately, a ML algorithm based solely on the dual polarization parameters, requires sufficiently full radar volumes and the use of higher elevation scans for reliable results. These conditions are difficult to meet in routine operations. To overcome this problem it has been necessary to supplement the ML heights determined using the radar data alone with those estimated using the wet bulb temperature profiles from the NWP model forecast. Fig. 4 shows an example of the output from the ML algorithm.

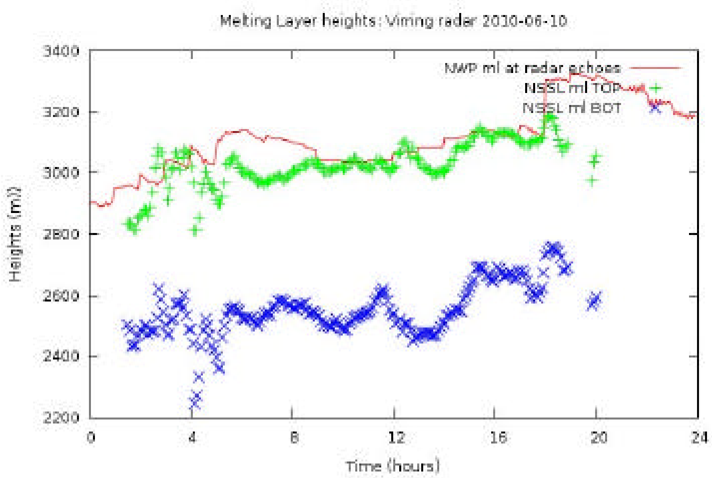

Fig. 4 shows the top (green) and bottom (blue) of the melting layer computed using the radar algorithm superimposed on the one computed by the local NWP forecast model(red).

4. Computation of specific differential phase (K_{DP})

The K_{DP} parameter is not available from the radar processing software provided by the radar manufacturer. It had to be thus estimated. K_{DP} is computed as follows (Boumahmoud et. al, 2010):

a. The differential phase shift offset, $\Phi_{DP}(0)$, is computed dynamically for each ray from the first 5 gates containing precipitation,
b. Φ_{DP} is then smoothed using a median filter with a window size of 6.5km,
c. K_{DP} is then estimated by fitting a straight line on the above window.

5. Rain attenuation correction

The parameters Z_{HH} and Z_{DR} were corrected for attenuation due to rain using the following relations:

$$Z_{HH\ new}(r) = Z_{HH\ (old)} + a\ .\ [\Phi_{DP}(r) - \Phi_{DP}(0)]$$
$$Z_{DR\ (new)}(r) = Z_{DR\ (old)} + ß\ .\ [\Phi_{DP}(r) - \Phi_{DP}(0)]$$

where the a and ß are constants and at C-band have the values 0.08 and 0.03, respectively (Gourley et al., 2007a).

6. Hydrometeor classifier

Pixel based hydrometeor classification is carried out using the fuzzy logic methodology (Bringi and Chandrasekar, 2001, Zrnic et. al., 2001, Schuur et. al., 2003, Lim et. al., 2005). In the current approach, a given pixel of hydrometeor class j has a score S_j given by the relation

$$S_j = \frac{\sum_i w_i \cdot P_i}{\sum_i w_i}$$

where P_i and W_i are the value of the parameter i, and the associated weight, for the class j. The radar parameters that have been used in the classifier are: Z_{HH}, Z_{DR}, K_{DP}, r_{HV}, plus the texture parameters associated with Z_{HH}, Z_{DR}, Φ_{DP} (Schuur et. al., 2003, Sugier et. al., 2006). In fuzzy logic the values of the P_i for the different hydrometeor classes are described by the membership functions (MF). In the current version the latter are expressed as Beta-functions with the 3 parameters: a, ß and g indicating the centre, half-width at inflection point and the slope of the curve (Lim et. al., 2005). As a way of example, fig. 5 shows the membership functions for the parameter Z_{HH} for the different classes of rain.

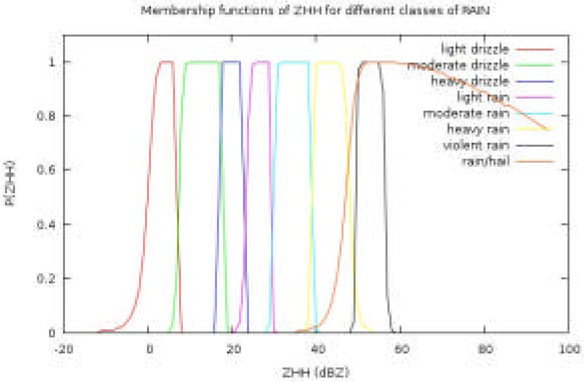

Fig. 5 Membership functions for Z_{HH} for different categories of rain.

Similar membership functions exits for other hydrometeor classes for Z_{HH} and for all the other parameters used in the classification.

In the current version of the algorithm the following 12 hydrometeor classes have been identified: (1) ground clutter, (2) sea clutter, (3) electrical signals from external emitters that interfere with our radars, (4) clean air echoes (CAE) such as from birds and insects, (5) drizzle, (6) light rain, (7) moderate rain, (8) heavy rain, (9) violent rain, (10) light snow, (11) moderate to heavy snow, (12) rain/hail mixture.

The current version of the algorithm does the so-called level 1 and level 2 classifications. In the level 1 classification a radar echo is classified into one of four simple classes: precipitation, clutter, clean air echoes, and external emitters. Figure 6 shows an example of the output.

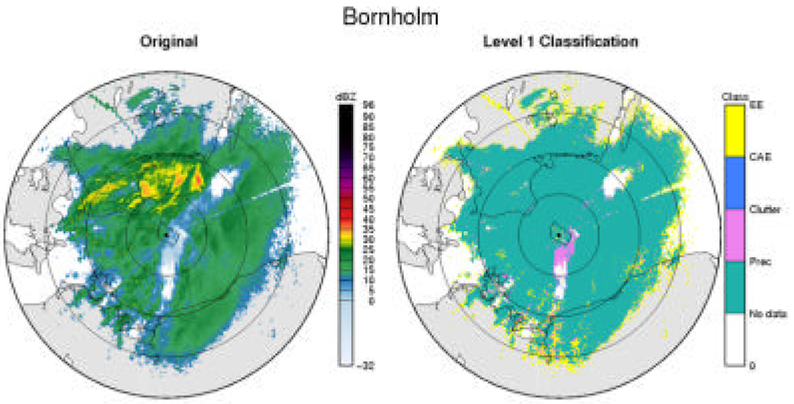

Fig. 6 shows radar image on the left (original) and its corresponding level 1 hydrometeor classification into four classes: external emitters (EE), clean air echoes (CAE), clutter and precipitation (prec), colour code: yellow, blue, purple and green, respectively.

In the level 2 classification, the echoes that are classified as precipitation in level 1 are further sub-classified into different precipitation classes mentioned above. In this case the heights of the melting layer computed by the local NWP model are used to strengthen the classification between the different classes of rain and snow. In the current version of the level-2 classification only the parameters Z_{HH}, $Z_{DR,}$ $K_{DP,}$ and r_{HV} are used. In particular, in this case score S_j is given by the relation

$$S_j = \frac{P^j{}_{Zhh} \cdot P^j{}_{height} \left[w_{Zdr} \cdot P_{Zdr}{}^j + w_{rhv} \cdot P^j{}_{rhv} + w_{Kdp} \cdot P^j{}_{Kdp} \right]}{w^j{}_{Zdr} + w^j{}_{rhv} + w^j{}_{Kdp}}$$

Fig. 7 shows an example of the level 2 classification. Note that the radar data used to illustrate the classifications results are the same in figures 6 and 7.

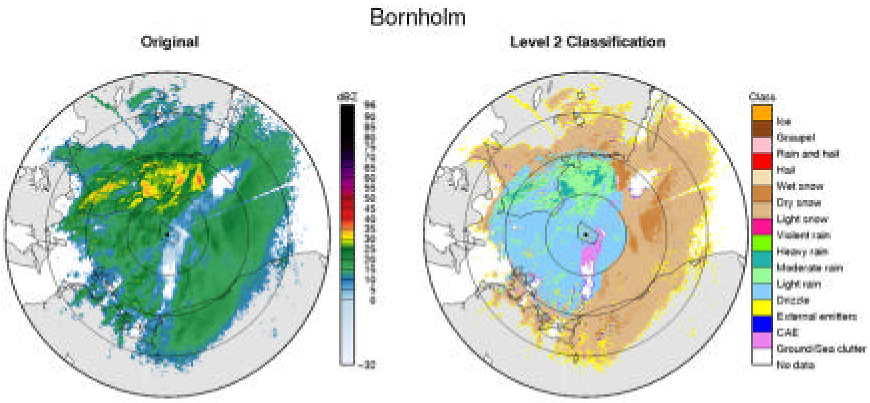

Figure 7 shows radar image on the left (original) and its corresponding level 2 hydrometeor classifications into eleven classes.

In addition to the above level 1 and 2 classifications, the algorithm can make use of the above classification output to remove the non-meteorological echoes in the original radar reflectivity product, Z_{HH}, shown on the left in each of the figures 6 and 7. This is illustrated in figure 8 below. Concerning the latter product, it was the first product that was requested for routine operational use by the DMI end users, namely its meteorologists.

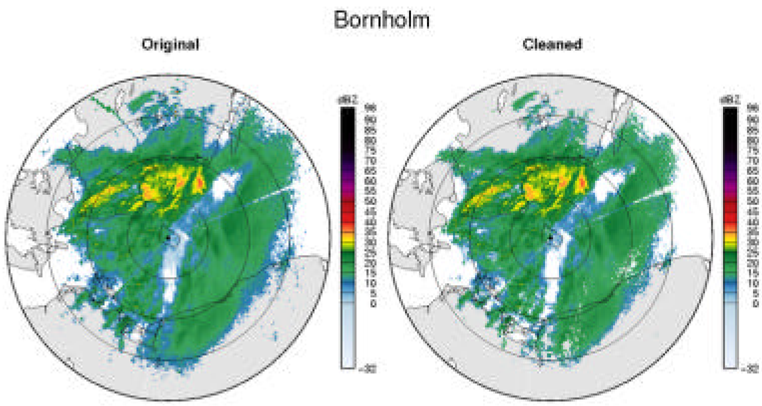

Figure 8 shows the original radar product on the left and corresponding "cleaned" version on the right which has non-meteorological echoes removed.

7. Summary and future plans

Hydrometeor classifier using the fuzzy logic method has been developed. The classifier make use of the dualpol parameters Z_{HH}, Z_{DR}, K_{DP}, r_{HV}, plus the texture parameters associated with Z_{HH}, Z_{DR}, Φ_{DP} and the melting layer heights computed using the local NWP model forecasts. The latter are update every hour. In the current version of the algorithm, a radar echo can be classified into one of 12 classes. The subsequent versions of the algorithm will also include the following classes: hail, grapules, ice and rain/snow mixture.

Finally, the hydrometeor dassifier described above has been developed with partial funding by the EU BALTRAD project which requires the software is made available according to open source principles (Michelson et. al, 2010). The software is thus available to the interested users. The Gnu Lesser general Public License policy shall apply.

Acknowledgment

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