Modifications to the PID

During the DYNAMO field campaign several misclassifications of the Particle ID (PID) program occurred routinely. Also the input field ρ_{hv} was improved. Therefore the membership functions and weights were modified and a new category was introduced to improve the output of the algorithm. The changes are described briefly below and fall into the following categories:

1. Spurious graupel classifications
2. Bright band signatures
   a) Low reflectivity (Z)
   b) Temperature threshold
3. Improved ρ_{hv} data
4. Receiver saturation

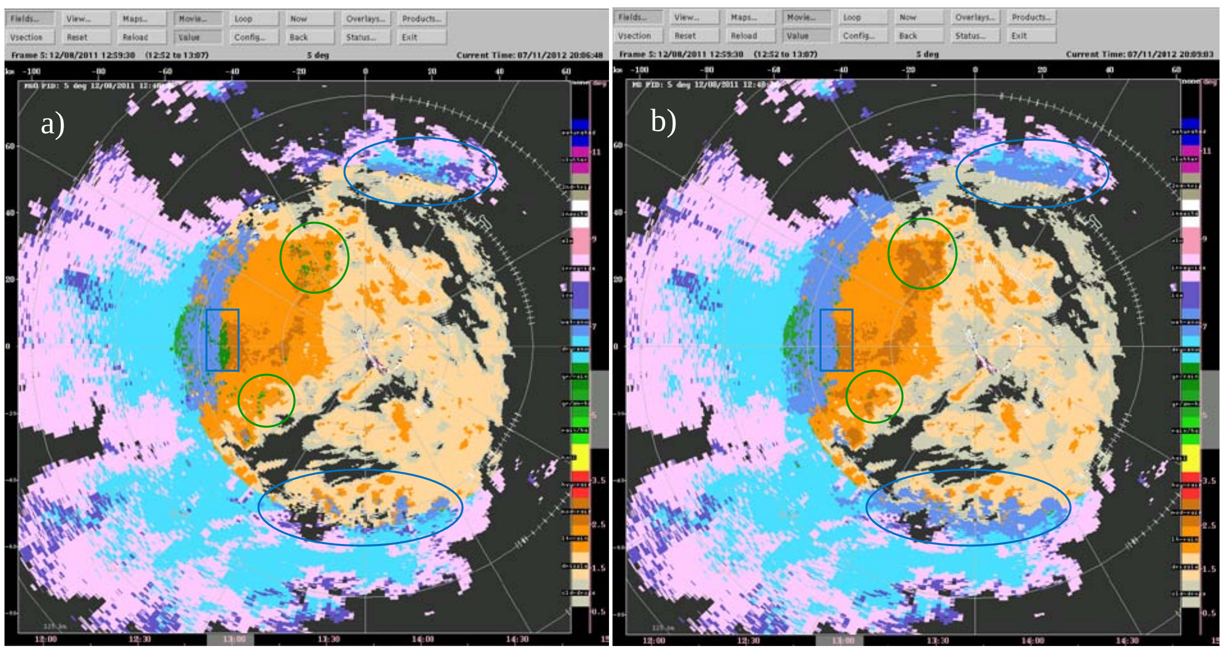

Figure 1. The PID results from October 8, 2011 at 1248 UTC at an elevation angle of 3.5 degrees. Shown are a) the previous version PID results set and b) the modified PID results. Both were run on the final QC data.

Figure 1 shows the PID results on 8 December, 2011 using a) the previous version used during DYNAMO and using b) the modified version, both run on the same QC'ed data set and using the same soundings. The green ovals in Figure 1 highlight the reduction in spurious graupel classifications, while the blue ovals and rectangle highlight the improvement in the brightband classification.

The PPI plots of reflectivity (Z), differential reflectivity (Z_{dr}), co-polar correlation coefficient (ρ_{hv}), and linear depolarization ratio (LDR) used in the PID results shown in Figure 1 are presented in Figure 2. We will refer to these figures in the following write up.

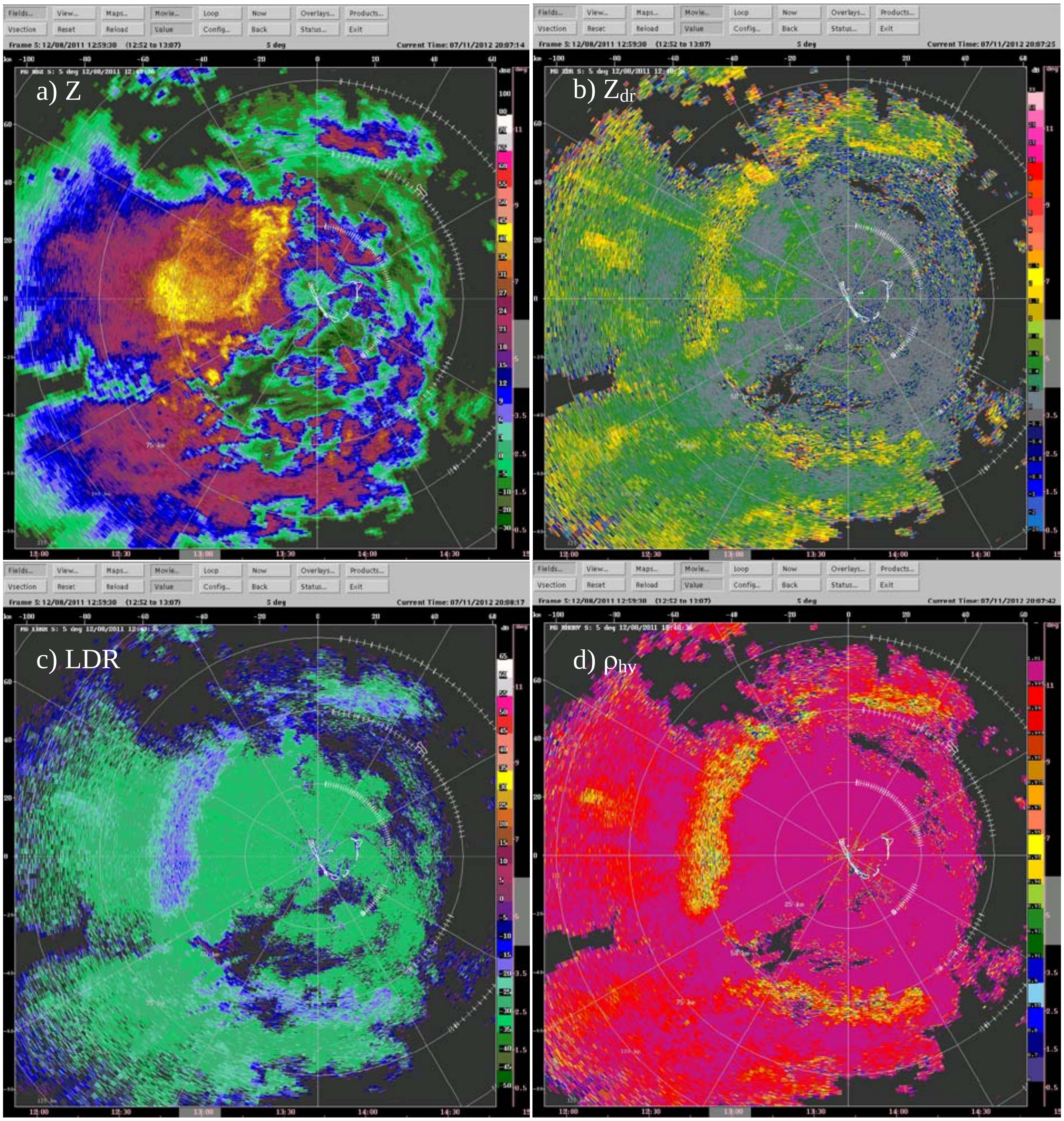

Figure 2. PPI plots of a) reflectivity (dBZ), b) Z_{dr} (dB), c) LDR (dB), and d) ρ_{hv}. The data were collected December 8, 2011 at 1248 UTC at an elevation angle of 5 degrees.

1. Spurious Graupel Classifications

Small regions and/or speckling of spurious graupel identifications appeared during DYNAMO from the real-time version of PID. While graupel (and lightning) can occur in the DYNAMO region, graupel was misclassified well below the melting level, which is an unlikely occurrence in the hot and humid environment. The graupel identified was often speckly and discontinuous.

It was discovered the graupel misclassifications often occurred due to rain with slightly lower Z_{dr} values than the 2D rain membership functions indicated. This was combined with anomalously low KDP values. Although there is no verification data there was consensus that many of the graupel regions identified were in error.

The Z_{dr} membership functions for rain are dependent on reflectivity (dBZ), e.g. as Z increases the Z_{dr} also increases. To correct for the spurious graupel classifications the Z_{dr} rain membership functions lower bound was reduced by about 20%. This is illustrated in Figure 3 that shows the upper and lower bounds of the Z_{dr} rain membership value of 1.0 for the previous version (a) and modified (b) values. The membership values are 1.0 between the blue lines in Figure 1 and decrease to 0 above (below) the upper (lower) curves. This adjustment resulted in most of the rain with low Z_{dr} values being correctly classified while at the same time not, in general, eliminating reasonable graupel classifications.

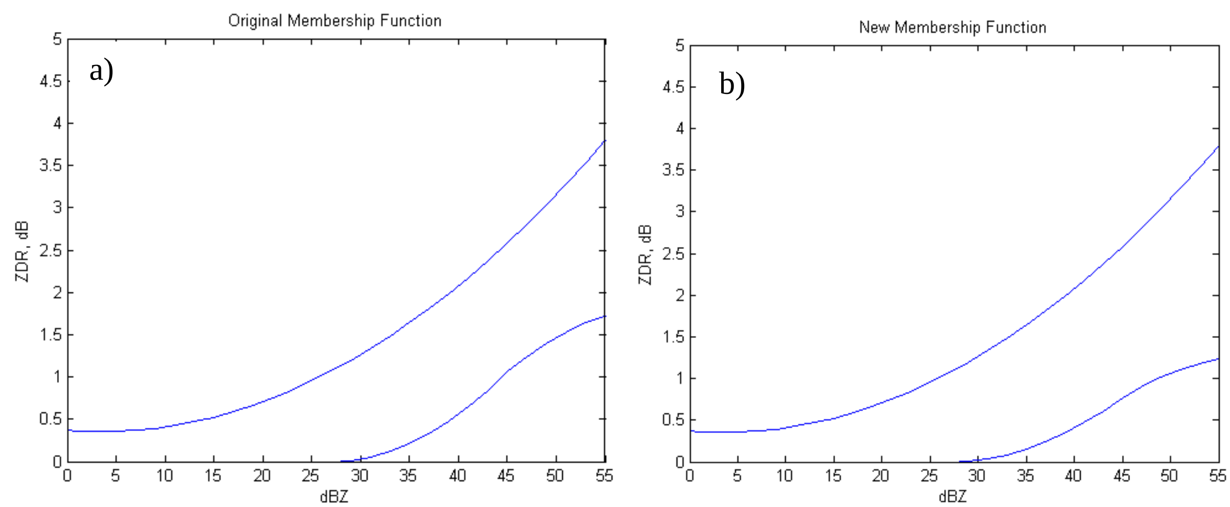

Figure 3. Plots of the 2D Z_{dr} membership functions for rain, plotted are a) the previous version membership function and b) the modified membership function.

Another cause of the spurious graupel classifications was the noisiness and range smoothing of KDP. Sometimes in moderate rain the KDP would be 0 or near 0 due to noise and/or the length of the filtering of Φ_{dp} required to compute KDP. The weight of the KDP was reduced by a factor of two in the modified version of PID. This allows the value of the KDP to continue to add to the classification, but reduces the impact of the KDP artifacts.

The results can be seen in Figure 1. In the previous PID version (Figure 1a) there are spurious graupel classifications embedded in the broad area of rain, which are noted by the green ovals. In the modified PID output most of the spurious graupel is removed and rain is correctly identified.

2. Bright band signatures

a) Low reflectivity (Z)

The wet snow category is the only category that identifies the melting layer. Wet snow, or aggregates, generally has a reflectivity value above 15 dBZ or so. However the dual-polarimetric mixed phase signature of the melting layer was sometimes apparent at much smaller values of Z. The reflectivity membership function for wet snow was modified to include values of Z as low as between 0 and 7 dBZ. In other words the membership function is 1 at 7 dBZ and decreases linearly with decreasing Z to 0 at 0 dBZ. A sketch of the new membership function is shown in Figure 4 with modified values in red. The previous version was 1 at 20 dBZ and decreased to 0 at 15 dBZ (black in Figure 4). The modified wet snow category should be thought of as wet (melting) snow or ice crystals.

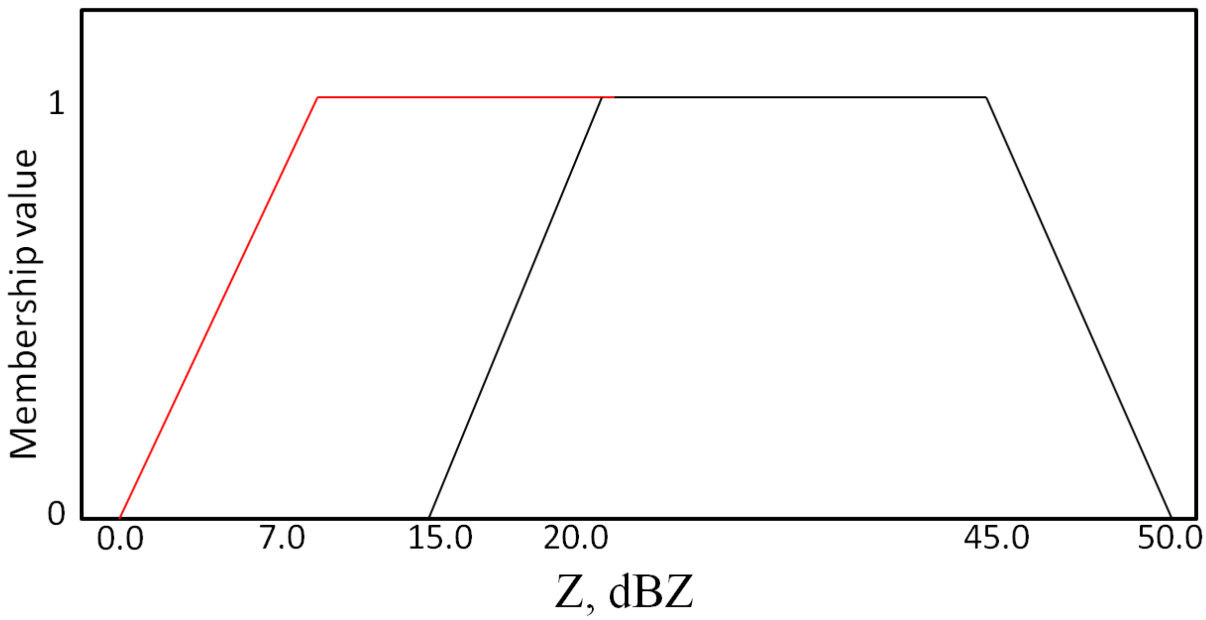

Figure 4. Sketch of modified (red) and previous version (black) Z membership functions for wet snow.

The results of the modified wet snow Z membership functions can be seen in Figure 1 and are highlighted by the blue ovals. Notice that the modified version of the PID wet snow (Figure 2b) and ice category is more continuous than the previous version (Figure 2a) in regions of small Z values (Figure 2b) that have clear brightband signatures in the Z_{dr}, ρ_{hv} and LDR (Figures 2b, 2c, and 2d).

b) Temperature threshold

The previous version of PID had a threshold applied to the wet snow category that prevented it from being classified at temperatures greater than $+5^o$ C. Sometimes during DYNAMO the brightband signature extended to heights below the $+5^o$ C level. The result would be a misclassification because the wet snow category was not possible. The threshold was changed to $+8^o$ C in the modified version of PID. This allowed the wet snow category to exist in the problem areas while not eliminating the possibility of any other particle types from being classified.

An example of the impact of the change can be seen in Figure 1 and is highlighted by the blue rectangle. In the previous version of PID there is a layer of melting graupel identified below (at shorter ranges) the wet snow classification due to the $+5^o$ C threshold (Figure 1a). The modified version of PID does not threshold the wet snow in this layer and it can be seen that the layer is now classified as wet snow (Figure 2b) and is consistent with the rest of the brightband.

3. Improved ρ_{hv} data

The ρ_{hv} field was improved by utilizing the noise subtracted power. In the non-noise corrected version of ρ_{hv}, there is a bias for data with SNR values below roughly 10 dB. Figure 5 shows the non-noise corrected version of ρ_{hv} (a) compared to the noise corrected version (b) of ρ_{hv}. Figure 5b is the same as Figure 1d, but repeated here for convenience. The improvement is dramatic in the regions of low SNR near the edges of the echo and above the bright band. The noise correction has no noticeable impact on the strong bright band signature.

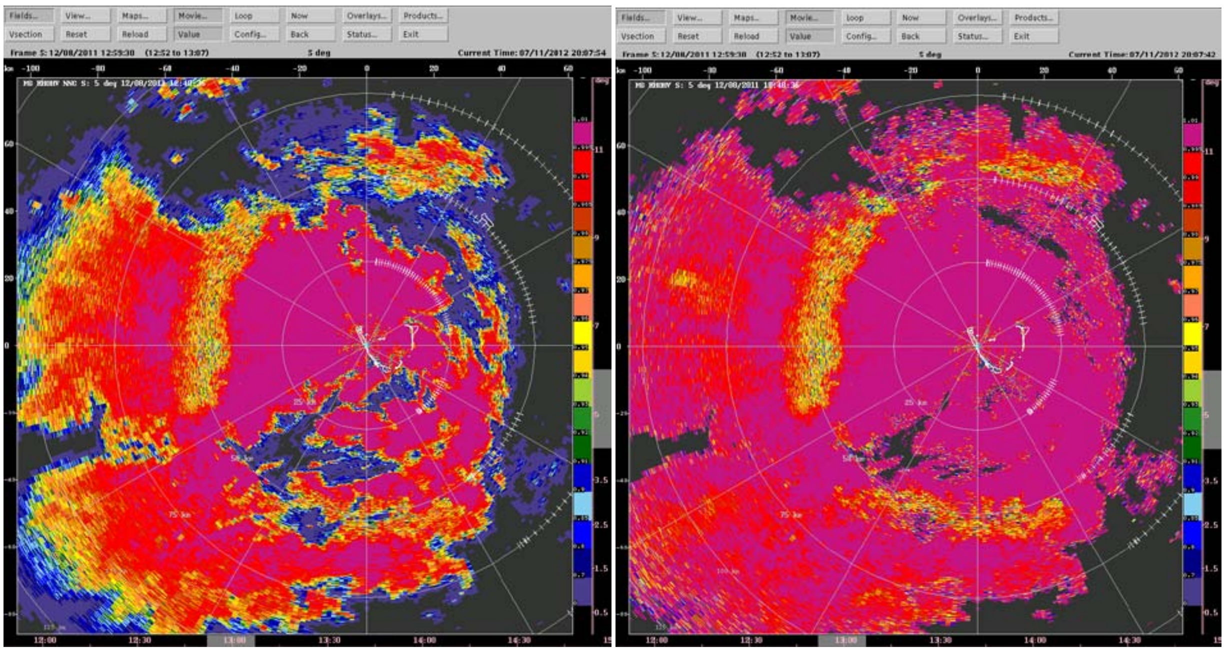

Figure 5. PPI plots of ρ_{hv} for a) non-noise corrected and b) noise corrected data.

The improved ρ_{hv} allowed for changes in the membership functions because the ρ_{hv} values are higher in snow and light drizzle in low SNR situations. For example the rain membership functions for the corrected ρ_{hv} were shifted towards one to account for the higher mean values in rain. The change in rain membership functions is illustrated in Figure 6, with the new values plotted in red and the previous values in black. The membership functions for the other categories were adjusted accordingly so there are no gaps in the membership function values.

The difference in PID results from this modification (not shown) is a small improvement in the separation between pure rain or pure ice from mixed phase because of the increased ρ_{hv} in the pure cases.

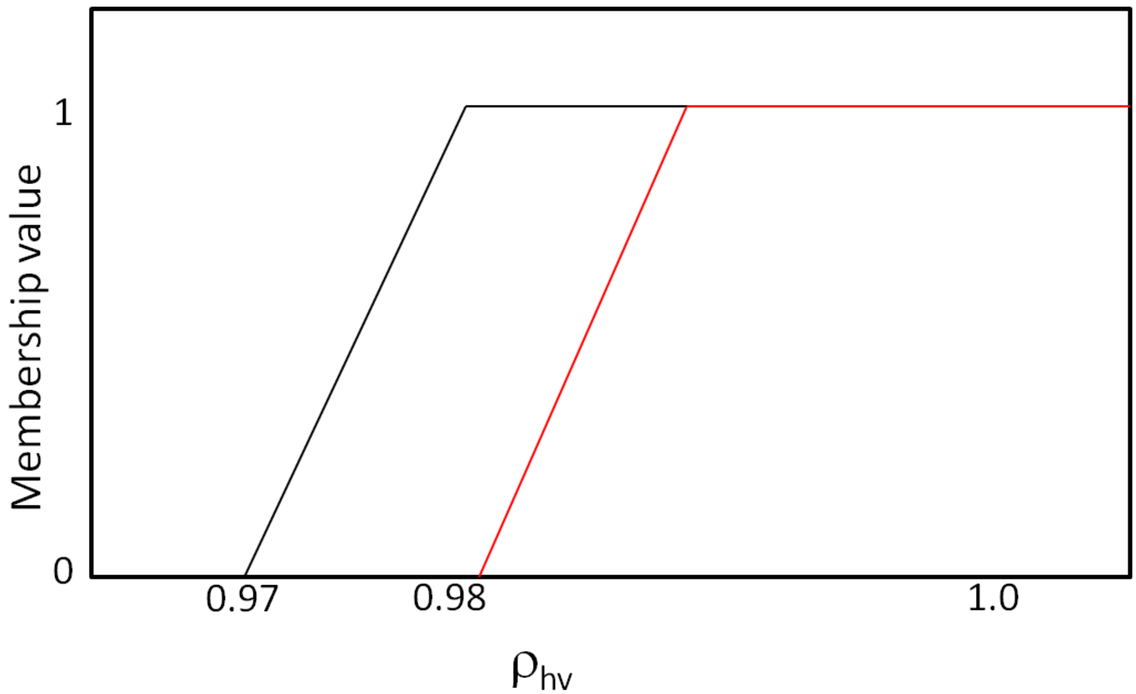

Figure 6. Sketch of previous (black) and modified (red) ρ_{hv} membership functions for rain.

4. Receiver Saturation

Often during DYNAMO strong convective cells with heavy rain occurred at short ranges to S-PolKa (e.g. < 10 km). In these cases, the power received may be outside of the dynamic range of the receivers, i.e. the receivers are saturated. When the receivers saturate the measured signal is constant for changing levels of actual received power. In this case the measurements are not valid and will cause errors in the PID and rain rate estimations. For example the Z is too low, and the Z_{dr} is simply the offset of the saturation levels of the horizontal (H) and vertical (V) receivers. The previous version of PID did not account for receiver saturation and this often resulted in erroneous classifications, typically of graupel and hail instead of rain. This is because the Z is high in order to saturate the receivers, and the Z_{dr} is low because the offset of the H and V receivers is small. An example of this is illustrated in Figure 7 which shows PPI plots of a) Z, b) Z_{dr}, c) PID from the previous version and d) the modified PID results. The black oval in Figure 7 indicates the region of receiver saturation resulting from strong rain echoes close to the radar. This is a heavy rain storm with Z values in excess of 45 dBZ, but the Z_{dr} values are close to 0 dB near the radar due to the receiver saturation. In valid radar data this combination Z and Z_{dr} is a strong indicator of graupel and hail and accordingly the previous version of PID identifies graupel/small hail in this region (green in Figure 7c). This is a misclassification due to the receiver saturation. The modified version of the PID indicates receiver saturation as a separate classification indicated by dark blue in Figure 7d. It can be seen that all of the erroneous graupel classifications from the previous version are now identified as saturation. Further, there are regions that the previous version of PID classified as rain that were in fact saturated. These areas are also important to identify, because in regions just above the saturation level there is a transition between valid Z_{dr} measurements and the receiver offset value with the Z_{dr} bias increasing with increasing power. In these regions the Z_{dr} is biased, but not enough to trigger a hail classification. Even though the Z_{dr} bias may not be obvious here, it will have a large impact on rain rate determined from Z and Z_{dr}. Therefore the rain rate estimates in regions of receiver saturation should be carefully considered. Options in saturated regions include but are not limited to: Ignoring the rainfall estimates, using on Z-R (this would result in an underestimate), using KDP only rainfall estimate.

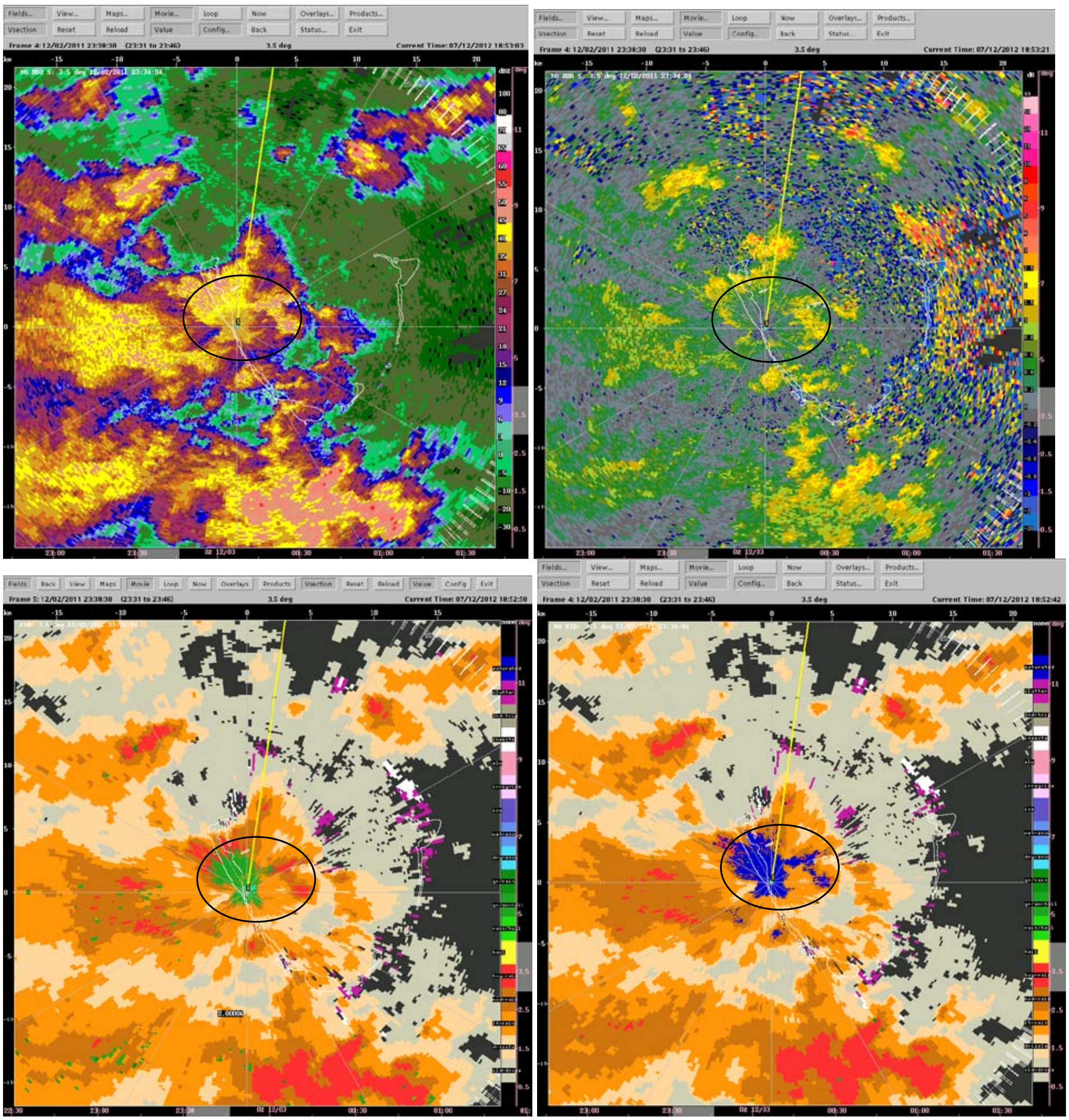

Figure 7. PPI plots of a) Z, b) Zdr, c) previous version PID results and d) modified PID results.