7B.3 THE AP CLUTTER MITIGATION SCHEME FOR THE WSR-88D

Cathy Kessinger, Scott Ellis, Joseph Van Andel and Jaimi Yee
National Center for Atmospheric Research
P.O. Box 3000
Boulder, CO 80305

1. Introduction

Atmospheric conditions favorable for refraction of the radar beam can produce additional ground clutter return, called anomalously propagated (AP) ground clutter return. The AP clutter return is a serious data quality problem for the National Weather Service (NWS) national radar network, comprised of Weather Surveillance Radars–1988 Doppler (WSR-88D), because it causes erroneous radar-derived rainfall estimates within the Precipitation Pre-processing Subsystem (PPS; Fulton et al. 1998; O'Bannon 1998; O'Bannon and Ling, 2003), other algorithmic errors and errors in interpretation. Currently, the WSR-88D quality control system removes AP clutter through the manual application of ground clutter filters.

The AP Clutter Mitigation Scheme (Ellis et al. 2003; Kessinger et al. 2002) is initially being implemented within the WSR-88D Open Radar Product Generator (ORPG; Saffle et al. 2001) and finally within the Open Radar Data Acquisition (ORDA; Elvander et al. 2001) and has the goal of automating clutter-filtering processes. The first WSR-88D implementation of the AP Clutter Mitigation Scheme occurred in September 2002 with the deployment of the AP clutter detection algorithm (APDA) during Build 2 of the ORPG. The APDA output can be viewed on the Clutter Filter Control Panel of the ORPG. The AP Clutter Mitigation Scheme consists of four parts: the Radar Echo Classifier (REC) of which the APDA is one part, the Reflectivity Compensation scheme (Z-Comp), the augmentation of the clutter bypass map, and the specification and control of the clutter filters.

This paper discusses the REC and the Z-Comp algorithms as deployed on the NCAR S-Pol radar (Keeler et al. 2000) during real-time operations of the International H_20 Program 2002 (IHOP_2002) field program and on the Denver WSR-88D during a snow storm. Results of the newest REC algorithm, the sea clutter detection algorithm (SCDA), are shown as it was deployed on the United Arab Emirates (UAE) Doppler radars.

Corresponding author address: Cathy Kessinger, NCAR, P.O. Box 3000, Boulder, CO 80307; email: kessinge@ucar.edu

2. Radar Echo Classifier

The radar echo classifier (REC) is an expert system that uses "fuzzy-logic", data fusion techniques (Kosko, 1992) to estimate the type of scatterer measured by a single polarization radar. The REC is described in detail in Kessinger, et al. (2003). Currently, four algorithms have been designed and tested: the AP detection algorithm (APDA) detects regions of AP ground clutter return, the precipitation detection algorithm (PDA) defines convective and stratiform precipitation regions, the sea clutter detection algorithm (SCDA) defines regions of clutter caused by the radar beam interacting with the sea surface, and the insect clear air detection algorithm (ICADA) defines return from insects in the boundary layer.

The APDA, PDA and ICADA were developed using data from several WSR-88D and the S-Pol radar (Kessinger et al. 1999). The SCDA was developed, tested and deployed on the United Arab Emirates (UAE) Doppler radars. Real-time deployment of the REC has been accomplished on the S-Pol at various field experiments since June 2000.

3. Reflectivity Compensation Scheme

The Reflectivity Compensation scheme (Z-Comp) uses a Gaussian approximation for the precipitation spectra and a simulated WSR-88D clutter filter to estimate the correction to offset the clutter-filter-induced (negative) bias in the reflectivity. Details of the algorithm design and implementation are in Ellis (2001). The Z-Comp method has been tested quantitatively using WSR-88D time-series data (aka Archive 1) collected at the Memphis (KNQA) WSR-88D and has been run operationally on the S-Pol radar since 2001.

Within the AP Clutter Mitigation Scheme, output from the REC APDA and the PDA determine where the Z-Comp scheme is applied such that only regions of precipitation are compensated. This prevents undesired compensation of reflectivity values within ground clutter return.

4. Radar Systems

The WSR-88D are 10 cm wavelength radars with single polarization. The S-Pol radar is a 10 cm wavelength, dual polarization radar. The S-Pol uses a four-pole

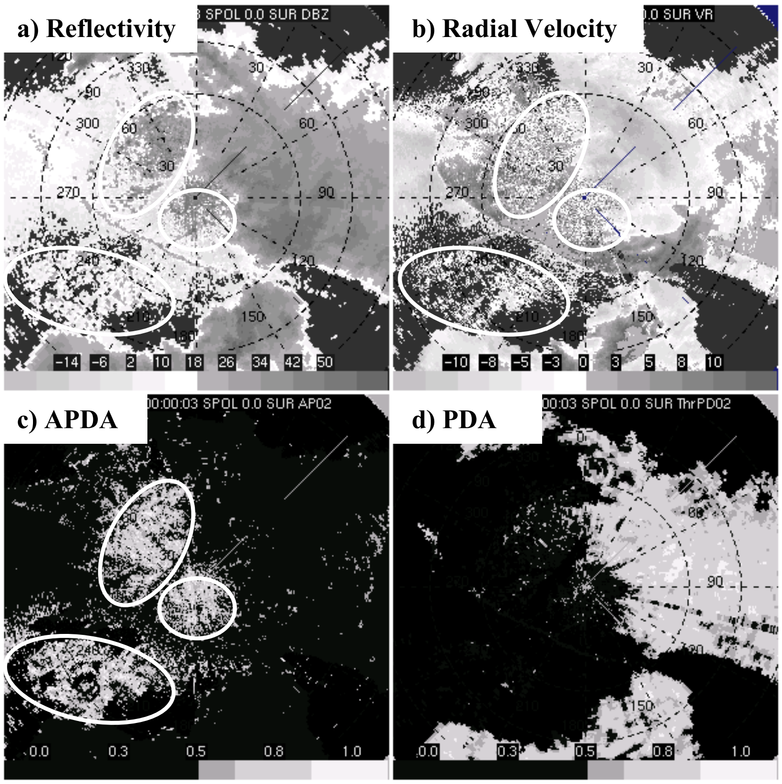

Figure 1. S-Pol data are shown from the IHOP_2002 field program on 16 June 2002 at 00 UTC. Fields shown include a) reflectivity (dBZ), b) radial velocity (m s^{-1}), c) REC output from the APDA thresholded at 0.5 interest, and d) REC output from the PDA thresholded at 0.5 interest. Three regions of AP ground clutter are encircled. The 0 degree elevation angle is shown with range rings at 30 km intervals.

elliptical, high pass ground clutter filter with passband edges of $\pm$0.5 m s^{-1}. The WSR-88D clutter filter for low suppression has passband edges of $\pm$1.2 m s^{-1} and for medium suppression has passband edges of $\pm$1.6 m s^{-1}. Because of its comparatively narrow width, the S-Pol ground clutter filter removes less data from the power spectra when compared to a WSR-88D.

The UAE radars are 5 cm radars from the Enterprise Electronics Corporation (EEC), Inc. They have a single polarization.

5. REC Results from IHOP_2002

Results from the REC APDA and the PDA algorithms are shown for one case from IHOP_2002 (Fig. 1). The S-Pol data were collected on 16 June 2002 at 00 UTC. Figure 1 shows the reflectivity and radial velocity fields within several large convective cells, a gust front and contamination from AP clutter (enclosed in the white circles) caused by passage of the gust front over the radar. Thresholded output from the APDA and the PDA are shown in Fig. 1c and 1d. The APDA detects the regions of clutter quite well. The PDA detects the regions containing both convective and stratiform precipitation with good performance.

6. REC Results from the United Arab Emirates

Results from the sea clutter detection algorithm (SCDA) are shown in Fig. 2 using data from the Al Dhafra radar on 27 May 2002 at 0346 UTC. Details of the fuzzy logic technique used in the SCDA will be presented at the conference; however, the vertical variation of the reflectivity field is a key indicator. The Al Dhafra radar is located within 25 km of the Arabian Sea and has frequent problems with sea clutter contamination. Atmospheric conditions conducive to anomalous propagation are common, especially during the summer months. The reflectivity field is shown in Fig. 2a before thresholding is applied with the SCDA while Fig. 2b shows the reflectivity field after thresholding is applied with the SCDA. The SCDA removes the strongest regions of sea clutter return but does leave some weaker clutter return near the edges of the main echo.

7. Z-Comp Results from Denver KFTG

To illustrate the Z-Comp algorithm, a snow case was selected using the Denver WSR-88D (KFTG) located to the east of Denver and approximately 60 km east of the Rocky Mountains. This case was selected from 18-19 March 2003 because of the stratiform nature of the reflectivity return and because of the storm's long duration. The negative bias induced by application of the ground clutter filters is most apparent in stratiform precipitation.

Figure 3 shows the reflectivity, radial velocity and the REC PDA output fields from 18 March 2003 at 2205 UTC. At this time, the most intense reflectivity is located over and north of KFTG. The winds are from the north and remain very steady during the nine hour

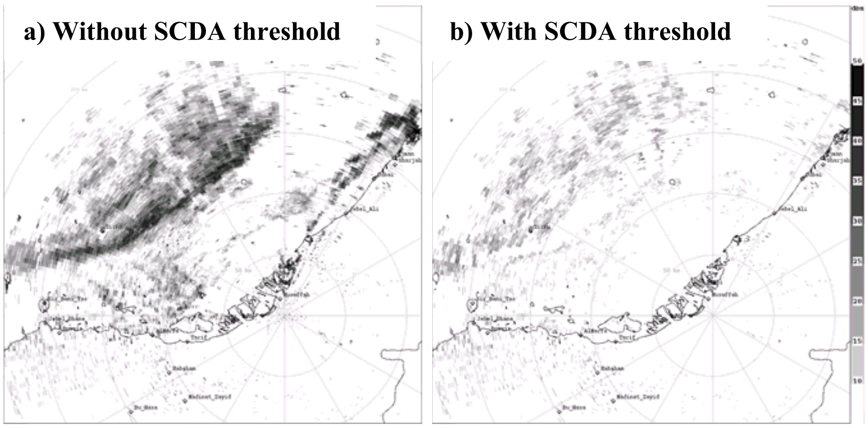

Figure 2. Reflectivity (dBZ) data are shown from the United Arab Emirates radar at Al Dhafra. The reflectivity fields are shown a) before the sea clutter detection algorithm (SCDA) is applied as a threshold to remove the contamination and b) after the SCDA is applied as a threshold.

period that is analyzed from 20 UTC on the 18th to 5 UTC on the 19th of March. The PDA performs well at detecting the snow regions.

To show the negative bias in the reflectivity field, a higher magnification of the reflectivity field is shown in Fig. 4a. Figure 4b shows the reflectivity field after application of the Z-Comp algorithm to correct the reflectivity bias while Fig. 4c shows the difference between the compensated and filtered reflectivity fields. Notice that the reflectivity difference is about 4 dB at maximum.

Using the snow accumulation algorithm described by Super and Holyrod (1997), and after applying the dielectric factor (Smith, 1984), the water equivalent snowfall rate (S) is calculated from

$$S = 0.089165 Z_e^{0.5}$$

where S is expressed as mm hr^{-1}, and Z_e is expressed as mm^6 m^{-3}. Integration of *S* over a specified time period gives the snowfall (water equivalent) accumulation. For this case, the snowfall accumulation is calculated over the 9 hour period mentioned above. Snow accumulation is shown with the filtered reflectivity data as input (Fig. 5a) and with the compensated reflectivity as input (Fig. 5b). Notice how the Z-Comp correction allows a more continuous region of snow accumulation to be derived without the negative bias induced by the clutter filter. The maximum difference in water equivalent snow accumulation is about 4 mm within 30 km of KFTG within small regions to the east and west of the radar location (where the radial velocity was near zero), with maximum differences of about 2 mm in regions farther to the west-northwest. Near the radar, the approximate change in snowfall accumulation is from about 6 mm to 10 mm, a significant.

This is the first time that the Z-Comp algorithm has been applied to winter precipitation conditions and shows that the technique is applicable to warm and cold season precipitation.

8. ORPG and ORDA Implementations

The Enhanced Preprocessing Subsystem (EPRE; O'Bannon and Ling, 2003) will be implemented within

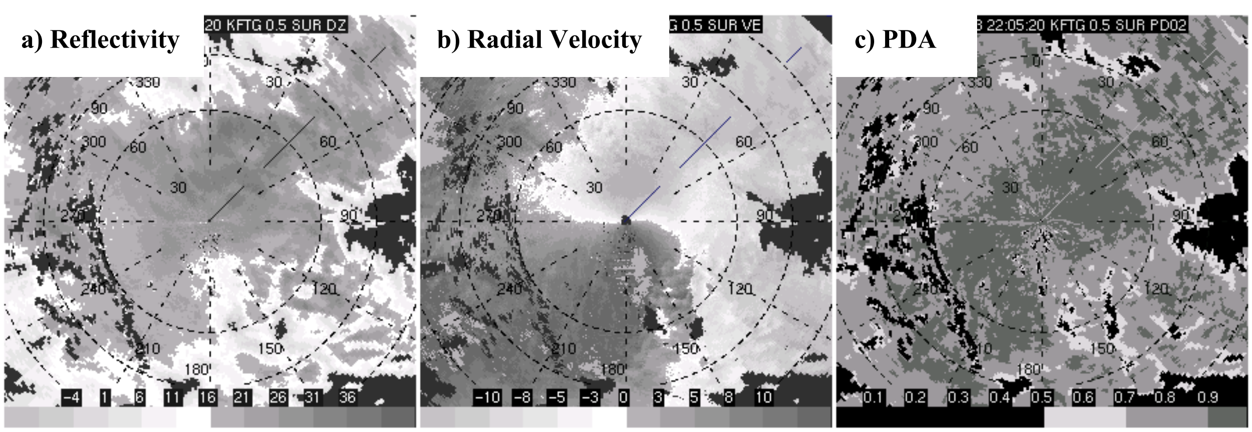

Figure 3. Data are shown from the Denver WSR-88D (KFTG) on 18 March 2003 at 2205 UTC. Fields shown are the a) filtered reflectivity (dBZ), b) the radial velocity (m s^{-1}) and c) output from the precipitation detection algorithm (PDA) thresholded at 0.5 interest. The 0.5 degree elevation angle is shown with range rings at 30 km intervals.

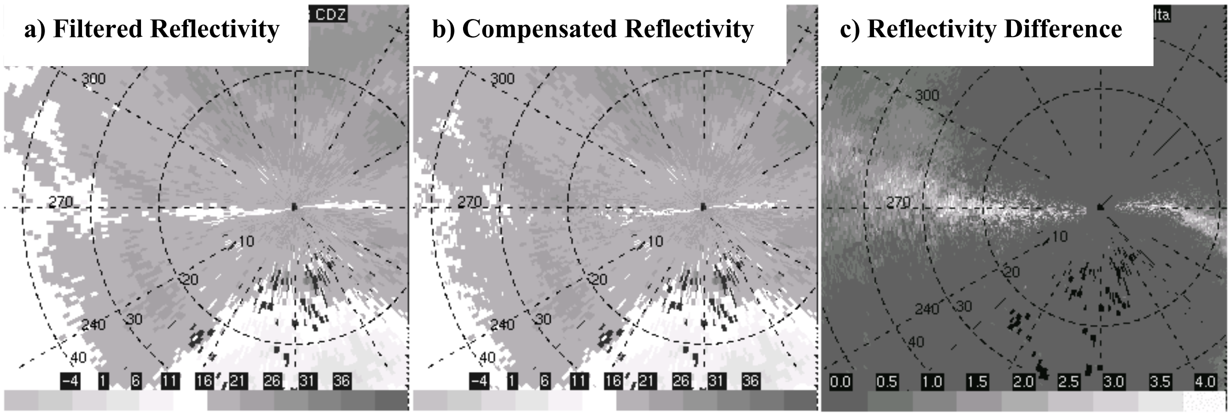

Figure 4. Data are shown from the Denver WSR-88D (KFTG) on 18 March 2003 at 2205 UTC. Fields shown are the a) filtered reflectivity (dBZ), b) the compensated reflectivity (dBZ) and c) the difference between the compensated reflectivity and the filtered reflectivity fields (dBZ). The 0.5 degree elevation angle is shown with range rings every 10 km.

ORPG Build 5 in spring 2004. The EPRE is an updated version of the PPS and will use the APDA to remove clutter contamination to improve precipitation estimates derived from the WSR-88D. The PDA and the Z-Comp algorithms are planned to be implemented in the ORPG Build 6 in the fall of 2004. Once implemented, the PDA and the Z-Comp output will be input into EPRE to further enhance precipitation estimates by correcting for the clutter filter bias in the reflectivity.

The last REC algorithm to be developed and eventually deployed within the ORPG will be the stratiform/ convective partition algorithm based on the Steiner et al. (1995) technique.

For ORDA, the AP Clutter Mitigation Scheme will be adapted to incorporate spectral domain processing techniques. The Sigmet Corporation's RVP8 digital signal processor will be the new processor for the WSR-88D and has also been installed on the S-Pol radar. The RVP8 allows various spectral processing techniques to be used for clutter filter removal that should lead to additional enhancements in radar data quality. Having RPV8 on both the S-Pol and the WSR-88D should expedite technique development and deployment.

9. Summary

An update on the AP Clutter Mitigation Scheme for the WSR-88D has been given. Recent results from the REC and the Z-Comp algorithms were shown.

10. Acknowledgements

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11. References

Refer to the following two references, for a complete list of references used.

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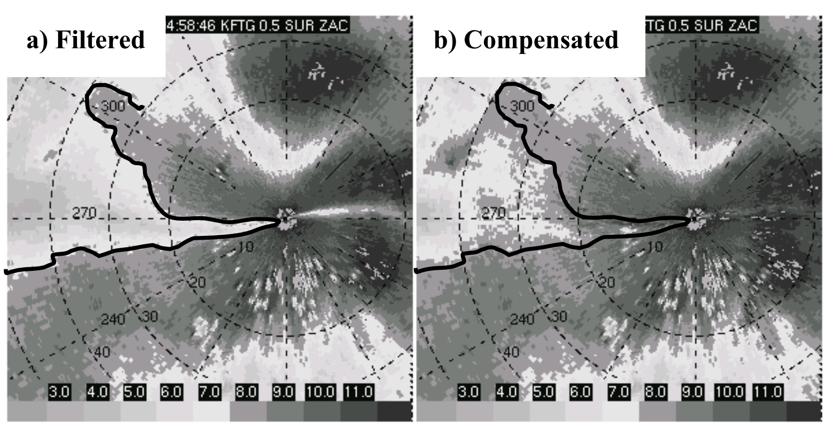

Figure 5. Snow accumulation (mm) is shown derived from data taken with the Denver WSR-88D (KFTG) on 18-19 March 2003. Nine hours of data are included from 20 UTC on the 18th to 5 UTC on the 19th of March. Fields shown are the a) snow accumulation using the filtered reflectivity (dBZ) and b) the snow accumulation as calculated using the compensated reflectivity. The bold line shows the 7.5 mm snow accumulation contour when the filtered reflectivity is used.