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Accounting for Radar Beam Blockage Patterns in Radar-derived Precipitation Mosaics for River Forecast Centers

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1. Introduction

Since 1992, National Weather Service (NWS) River Forecast Centers (RFCs) have been using a program referred to as Stage III which creates gridded mosaics of hourly radar derived precipitation (Breidenbach et. al. 1998). In areas where two or more radars overlap, Stage III has optionally used the mean or maximum value when creating the RFC-wide precipitation mosaic. Up to this point, no information pertaining to areas whose estimates are compromised by beam blockage or range degradation has been used in deciding what value to assign to a given grid point in the mosaic. This problem has created a significant error in the Stage III estimates, especially in mountainous areas. A new algorithm has been developed which selects radar data with the lowest unobstructed coverage in the overlapping area when creating the RFC-wide rainfall mosaic.

2. WSR-88D Rainfall Algorithm

The precipitation estimation algorithm which runs within each Weather Surveillance Radar-1988 Doppler (WSR-88D) produces rainfall estimates out to a radius of 230 km (Fulton et. al. 1998). To account for beam blockage by terrain, a reflectivity hybrid scan generated each volume scan uses the lowest unobstructed tilt which clears the terrain by at least 500 ft as the main input into the rainfall algorithm (O'Bannon 1998). Most commonly, the first elevation angle (0.5°) is used in the hybrid scan beyond about 50 km. However, in some instances where high terrain occurs near the radar along some radials, the second elevation (1.5°) or higher may be used from the point of obstruction out to the outermost coverage range (230 km).

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3. Range Degradation

An analysis of radar derived rainfall estimates found a significant underestimation of precipitation by the radar at long ranges where the lowest radar tilt is likely to overshoot some precipitation echoes (Seo et. al. 1998). The range degradation problem is even more severe in the cool season which is dominated by stratiform type precipitation events. The range at which the radar overshoots the top of the precipitation echoes is still shorter for those azimuths where beam blockage of the lowest tilt angle necessitates the use of a higher elevation tilt angle in the hybrid scan.

There are other instances where the lowest tilt angle at a particular azimuth angle is used in the hybrid scan even though it is partially or totally obstructed by objects other than terrain. Precipitation estimates computed for ranges beyond these unaccounted blockages can be severely underestimated.

4. Determination Of Effective Radar Coverage For Precipitation Estimation

To determine areas which are climatologically beam blocked, an interactive technique has been developed to analyze the mean value and frequency of WSR-88D derived precipitation at each grid point over a several year period. Areas that are beam blocked or poorly observed due to the beam overshooting the precipitation have lower radar rainfall frequencies than those areas which are well sampled. The frequency of rainfall computed for the Blacksburg, Virginia radar is shown in figure 1. The wedge shaped area with lower rainfall frequency located to the north of the radar indicates where the radar beam is blocked at the lowest elevation angle due to intervening mountains. It is also apparent that the frequency of rainfall at long ranges is much less than at close and mid ranges.

A map showing which grid points are not well sampled can be created by assigning missing values to those grid points whose frequency or mean

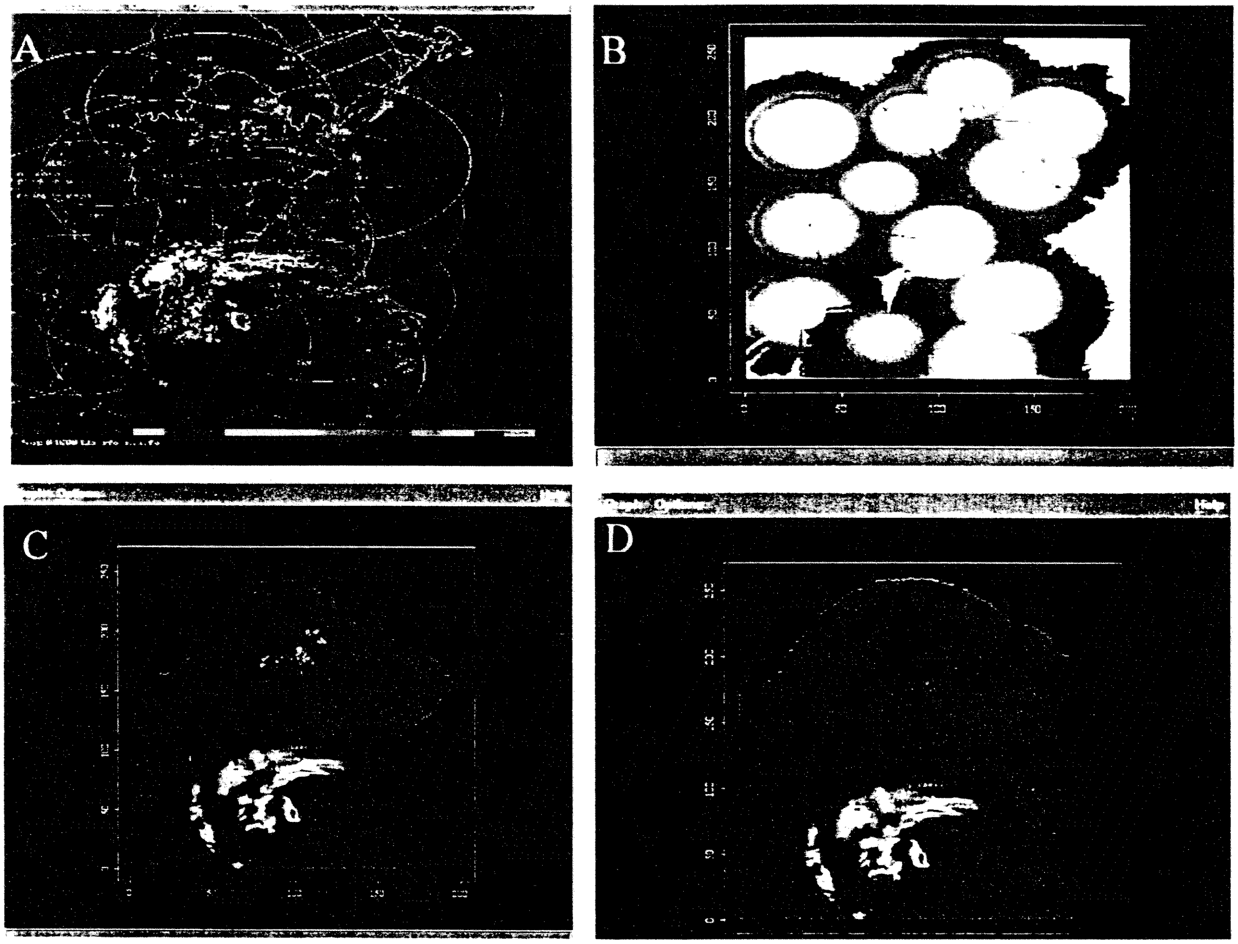

Figure 4 a) Stage III hourly derived precipitation mosaic for Mid Atlantic RFC, Sept 6^{th} ,1996, 12:00 GMT using mean value in overlapping areas. b) Height of coverage array. Light areas indicate coverage at lower elevations. Darker areas indicate coverage at higher elevations above sea level. White areas indicate no radar coverage available. c) Radar derived precipitation mosaic using lowest unobstructed tilt. Black areas indicate no radar coverage available. d) Multi-sensor hourly precipitation mosaic.

The height (above sea level) associated with each pixel in the radar mosaic is shown in figure 4b. Note that in areas where one radar did not have coverage at a low elevation due to a blockage close to the radar site, data from a neighboring radar was used to fill in the missing areas where ever possible. This resulted in the height of coverage being much higher in the blocked areas.

Once the gridded radar-derived rainfall mosaic has been constructed, it is merged with all available rain gage observations to create a gridded multi-sensor analysis. The multi-sensor analysis is accomplished by determining weighting factors for rain gage and radar observations which are located near each grid point. The weights are determined through a single optimal estimation technique (Seo 1997). The resulting analysis places a large weight on gage observations for grid points that are located very near a gage while heavily favoring the radar derived precipitation field at grid points that are not located near a gage.

The technique of choosing the lowest unobstructed data in the overlapping area still leaves some grid points that are not covered by any radar in the rainfall mosaic. An example of missing areas in the radar mosaic is shown in figure 4 c. The optimal estimation technique can be adapted to fill in the missing areas by a relative weighting of nearby raingage and radar estimates. Figure 4 d illustrates how the missing areas shown in figure 4 c are filled using the optimal estimation technique.

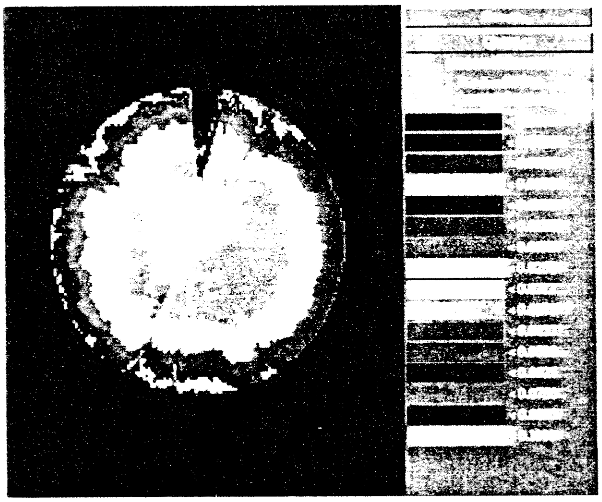

Figure 1 Frequency of rainfall for Blacksburg, Virginia radar site

accumulation is less than a user specified threshold. The effective radar coverage as defined by applying
a threshold to the precipitation climatology for the Blacksburg Radar is shown in figure 2. The blockage area located to north of the radar matches those areas where higher tilts are used in the reflectivity hybrid scan

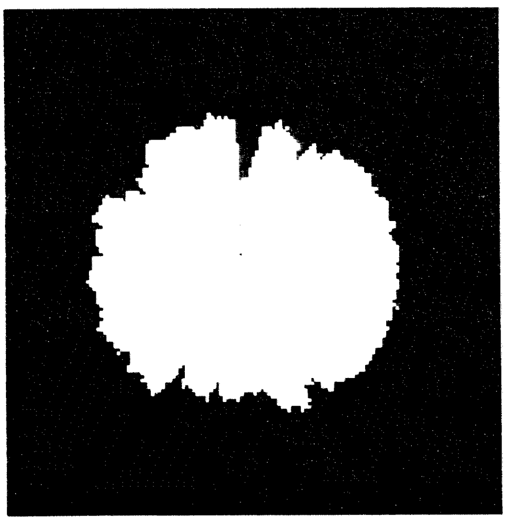

Figure 2 Effective radar coverage pattern for Blacksburg, Virginia. Black area indicates no or poor coverage. White area indicates good coverage.

Radar precipitation climatologies and blockage patterns for the Pittsburgh, Pennsylvania radar were defined for both cool and warm seasons (Figure 3a-d). Note that the cool season coverage area is much less than that of the warm season. Severe beam blockage problems occur at several different azimuths, most notably to the south and east in both seasons. It is interesting to note that none of the blocked radials were accounted for in the reflectivity hybrid scan, yet the blockage pattern is very clear in the radar derived rainfall climatologies. The explanation for these beam blockages is likely due to the existence of trees located very near the radar which are apparently tall enough to produce radar beam occultation. Beam occultations caused by trees, which tend to grow after the initial radar siting, are not accounted for in the hybrid scan which is based only on beam geometry and on terrain as defined in digital elevation model (DEM) data. This problem appears to be quite widespread, occurring even at relatively flat locations such as Dover, Delaware, Jackson, Mississippi, and Tallahassee, Florida.

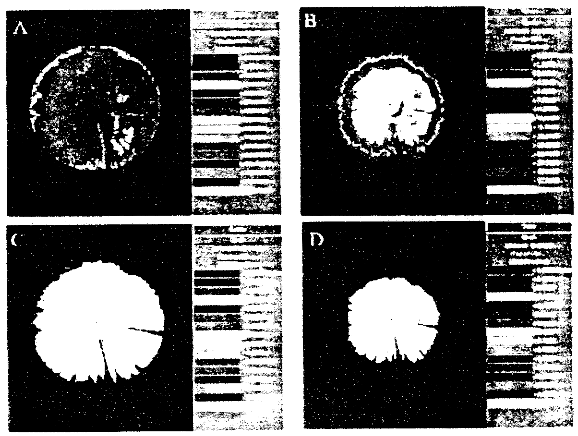

Figure 3 Pittsburgh, Pennsylvania: a) mean rainfall warm season; b) mean rainfall cool season; c) effective radar coverage warm season; d) effective radar coverage cool season.

4. RFC-Wide Multisensor Rainfall Mosaic

The new RFC- wide rainfall estimation algorithm first creates a mosaic of radar derived rainfall using data from the lowest available coverage from multiple overlapping radars. An example of the new multi-radar mosaic for the Mid-Atlantic River Forecast Center is shown in Figure 4c and compared with the default Stage III analysis shown in Figure 4a.

5. Future Work

Precipitation estimates obtained by using radar data taken from altitudes near or above the freezing level can contain significant errors. In fact, errors caused by bright band contamination and difference in the dielectric constant for ice verses water can be so severe that it is undesirable to use such estimates for hydrologic purposes. The height of coverage array which is a bi-product of the mosaicking technique can be used to screen out radar data that has been obtained above the freezing level. Planned future enhancements will compare the height of coverage array to a gridded analysis of the height of the zero degree isotherm. Any area where the height of coverage exceeds the freezing level will be marked as "missing" and the optimal estimation technique will be used to fill in those areas with nearby radar data and gage data obtained below the freezing level.

Another enhancement will include a clear air Anomalous Propagation (AP) detection algorithm which will compare satellite Infra Red (IR) brightness temperatures to the surface temperature. Areas where the IR brightness temperature is not significantly cooler than the surface temperature will be flagged as "clear". Any radar derived precipitation falling in a clear area will be flagged as AP and set to zero.

6. References

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