J3.16 Comparison of Reflectivity and Precipitation Fields Estimated by Two Radar Systems

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1. Introduction

Remotely sensed observations of the earth atmosphere provide high-resolution coverage and often times information needs to be extracted from different sensors of the same (or different) type covering the same domain. Satellites and ground-based radars provide rainfall estimates covering large areas. Although the WSR-88D radar system is superior to rain gauge networks in capturing the space-time distribution of heavy rainfall, many problems need to be resolved in rain rate estimation from these radars. In addition, the NEXRAD coverage at low levels remains very limited, e.g. Maddox et al. (2002), especially in the West, mainly because of topography. Effective weather warning requires the integration of information from many sources, including input from multiple radars (Stumpf et al., 2002). Other benefits from integration of input from multiple radars include: AP and clutter mitigation, improvement of radar wind fields, coverage in case* of failure of one system, and coverage over the "cone of silence" of one system.

During the summer of 1998 the national Center for Atmospheric Research's S-band, dual-polarization radar (S-Pol) was deployed in east-central Florida during a special field experiment (PRECIP98) to evaluate the potential of polarimetric radar to estimate rainfall in a subtropical environment. The PRECIP98 experiment coincided with a field component of the National Aeronautics and Space Administration's Tropical Rainfall Measuring Mission dubbed the Texas and Florida Underflights Experiment (TEFLUN-B).

During PRECIP98, S-Pol was placed 26 km south-southwest of the operational Weather Surveillance Radar-1988 Doppler (WSR-88D) at Melbourne, Florida (KMLB); see Fig. 1. Measurement resolution was 1° x 1 km for KMLB and 1° x 0.15 km for S-Pol. The 1 km data for KMLB is subdivided into four data gates with 0.25 km spacing, and the measured 1 km radar reflectivity value is assigned to all four gates. Measurement resolution is approximately 5 minutes for KMLB and less than 2 minutes for S-Pol. The S-Pol reflectivity measurements were corrected for attenuation by atmospheric gases (oxygen and water vapor) and for rainfall attenuation using the differential phase measurements. Rainfall estimates were made with the default NEXRAD Z-R relation ($Z = 300 R^{1.4}$) for both radars. Because the interest here is primarily on radar-to-radar comparison, no attempt was made to partition the rainfall into

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convective and stratiform or to optimize the Z-R relation. Accumulations were made on polar grids (1° x .25 km for KMLB and 1° x 0.15 for S-Pol) using measurements from the .5° antenna elevation.

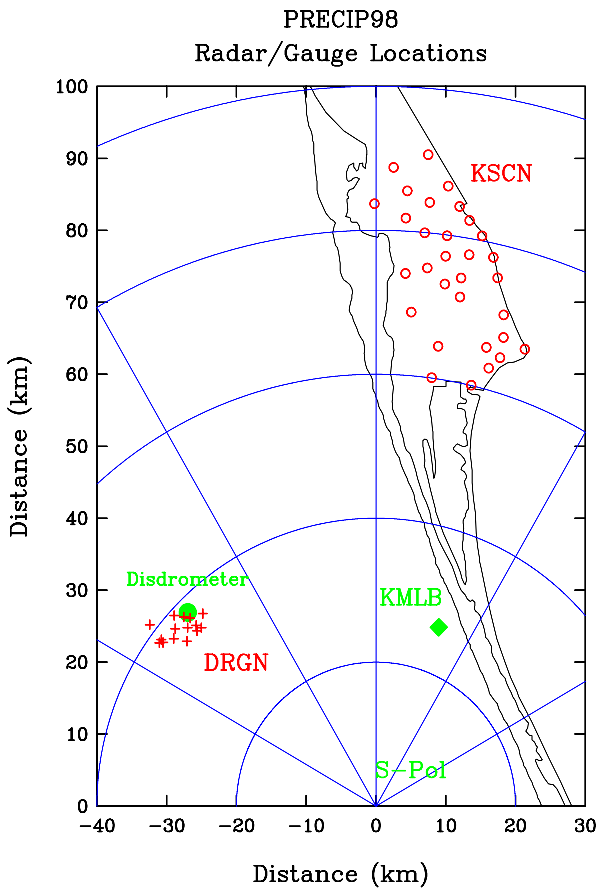

Figure 1

Location of the two radars (S-Pol and KMLB) and two rain gauge networks (DRGN and KSCN) and the disdrometer used in the field experiment

2. Comparison of Total Rainfall Accumulations

For comparison, storm total accumulations for all data bins within 1 km of the gauge site were averaged. Computed parameters are bias factors, defined as the sum of gauge observations divided by the sum of the radar estimates at gauges reporting rain, and the correlation coefficient (ρ) between radar-estimated and gauge-observed rainfall accumulations. For the ten rainfall events considered (table 1), the bias factor for the S-Pol radar (default relation) varied from 0.92 (a small overestimate) on 22 September to 1.69 (a large underestimate) on 21 August. The overall bias for the ten storms was 1.21. Bias factors for KMLB (default relation) varied from a low of 1.12 (22 September) to a high of 2.17 (21 August). The overall bias for KMLB was 1.43. This suggests a calibration difference in the order of 1.0 dB, but part of the difference could relate to the difference in sampling intervals (see Fig.2 of Wilson and Brandes, 1979). Correlation coefficients between radar-estimated and gauge-observed amounts are generally high. The overall correlation coefficient is a little higher for S-Pol, possibly due to higher spatial and temporal resolutions of the measurements. Lower correlations with the KMLB radar on 4 and 21 September are thought to be due to missing measurements during periods of heavy rain. A similar study conducted using the S-Pol radar in Kansas found high correlation between the rainfall estimates of the two systems.

3. Comparison of Instantaneous Rain Rates

Comparison of storm total accumulations indicates that both systems underestimate rainfall, compared to rain gauge, with S-Pol estimates being consistently higher than those of KMLB. Comparison of instantaneous rainfall estimates from the two systems is a lot more involved. Because of the difference in scanning strategy, the radar records of the two systems were searched scan by scan to identify the situations where the two systems has full scans, at the lowest elevation angle, that are nearly simultaneous (within less than 20 seconds). Only a few scans from each storm match the above criterion. Simultaneous rainfall estimates have to be compared at the exact same areas also. The finest resolution can be attained is to compare the estimates over the KMLB bins (1° x 1 km). The method applied for these computations is explained in the following section.

3.1 Calculation of S-Pol Estimates Over KMLB Bins

It is a common practice to compute radar rainfall estimates for Cartesian grids, or area of any shape, by taking an average of the values of the radar bins whose centers fall within the grid or area. All radar bins have the same weight regardless of how much of the radar bin area falls within the grid. This approach can introduce significant errors in several situations. For example, it is possible that just over 50% of the radar bin area falls within a particular grid and the simple interpolation scheme will assume that 100% of the area falls within the grid. Conversely, if just less than 50% of a radar bin falls in a grid, its contribution will be ignored altogether. Actually this is the approach used in comparing total accumulations as described in section 2.1. The fact that adjacent radar bins along a ray do not have exactly the same area is always ignored in this approach. In reality, the difference in area between radially adjacent 1 km radar bins at 10 km distance from the radar is 20%; the difference drops to 5% at 40 km distance from the radar. It can be argued that there are many uncertainties associated with radar rainfall estimates that make these concerns look trivial, for instance: beam power distribution, side lobes, and three-dimensional averaging within the radar bin. We think precise radar rainfall interpolation for hydrologic application is more than an exercise in geometry and is warranted for many reasons. It can be easily shown that for certain situations, precise interpolation can make significant differences in estimated rainfall which, in turn, might lead to larger differences in estimated runoff (e.g. *Winchell et al.*, 1997, *Sharif et al.*, 2002). Since radar measurement values projected on the ground have truncated triangular shapes, it is better to perform precise interpolation based on this shape, especially since precise interpolation in not very complex and does not require significant computational effort.

In order to compare instantaneous rainfall rate for S-Pol and KMLB, we precisely compute the fraction of each S-Pol bin that falls over a given 1° x 1 km KMLB bin. The computations were performed precisely e.g. if 15 S-Pol bins fall partly or entirely within a KMLB bin, we precisely compute the portion of each S-Pol bin that falls inside the KMLB bin such that if we add the contributions from all 15 bins, they will equal to the area of the KMLB bin exactly. The S-Pol estimated rainfall rate aver the KMLB bin is computed by multiplying each S-Pol bin rainfall rate by the fraction of its area falling within the KMLB bin, adding them together and then dividing by the area of the KMLB bin. This interpolation scheme allows us to compare the two radar estimates bin by bin.

3.2 Comparison of Instantaneous Rain Rates

The domain for comparison of the instantaneous rates is a 200 x 200 km square. The midpoint between the two radars is approximately at the center of the square. Around each radar, rainfall estimates over a 10 x 10 km square are discarded because estimates within area may be severely affected by ground clutter. After applying the interpolation algorithm to the S-Pol estimates we obtain two co centric radar maps with different rainfall rate estimates and identical shapes.

Rainfall detection by the two radars is compared using a binary classification to form a simple pattern data. If we assign a value of 1 when rainfall is detected by either radar and a value of 0 when no rain is detected, the result will be a set of four possible states for each KMLB bin i.e. S_0K_0, S_0K_1, S_1K_0, S_1K_1, where S_0K_0 represent a bin where the rain rate detected by both radars is below a certain threshold *T*, S_1K_1 for a bin when the two radars detect rain rate higher than *T*, etc; S and K refer to the S-Pol and KMLB radars, respectively. Since storms cover only a small fraction of the 200 x 200 km domain, the S_0K_0, bins were not used in the comparison; otherwise the result of the comparison will be dominated by S_0K_0, and therefore will mask all the cases of mismatch between the two radars. The comparison is performed by the Detection Matching Measure *m*, which is defined by:

$$m = \frac{\sum S_1 K_1}{\sum S_1 K_1 + \sum S_1 K_0 + \sum S_0 K_1}$$

If there is a perfect match between the two radar maps, the last two terms in the denominator will disappear. Time series of the values of *m* for 150 of the instantaneous rainfall snapshots are plotted in Figure 2. The left hand panel shows the time series as the threshold *T* is increased for 0 to 10 mm/hr. Different colors represent different values of *T*. Average values for all series are plotted in the right hand panel using the same color code of the left side panel. For a threshold of 0 mm/hr, the value of *m* is about 0.7. If we relax the value of *T* a little, *m* will be significantly higher. The relationship between *m* and *T* is shown in the right side panel of Figure 2. For rain rates above 5 mm/hr, the match between the two maps, in terms of rain detection, is almost perfect. The time series plot highlights the events dominated by very light rain. Those events have low values of m. The time series pattern does not change much with increasing the value of *T*. Averaging of S-Pol data over KMLB bins may be responsible for the differences at very small values of the rain rate in addition to the fact that S-band radar estimate for very light rain are not always reliable.

Rain rate estimates of the two radars were compared bin by bin and when all bins are plotted together and linear regression is performed, it reveals that S-Pol estimates are 1.12 times KMLB estimates. The relationship holds for all magnitudes of rain rate, i.e. if the comparison is done for rain rate values at a certain range, e.g. greater than 15 mm/hr, the regression result is virtually the same. Linear regression on bin reflectivity values reveals that S-Pol values are higher than those of KMLB by about 0.94 dB, which is comparable to the 1.0 dB found when comparing storm average values on larger areas.

Rainfall accumulations for seven storms were compared after computing S-Pol accumulations over KMLB bins. This is different from the comparison in section 2.1, which is a comparison over regions of intense precipitation. Results from this comparison are similar to the results of instantaneous rain rate comparisons. Results of the regression reveals that S-Pol estimates are about 1.1 times KMLB estimates and the difference in dB is around 0.81. The average value of the measure *m*, when the threshold (*T*) value is taken as 0, is more than 0.9, which is much larger than the average value for the case of instantaneous rain rates. It worth noting that a similar radar-to-radar comparison study between S-Pol and two WSR-88D radars revealed high correlation between rain rate estimates of the two systems.

4. Work in Progress

Instantaneous reflectivity fields are being analyzed to determine the radar-to-radar influence factors such as radar orientation, bin size, and radar range on differences. Instantaneous and storm accumulated precipitation are also being compared at different spatial and temporal scales. Radar-rainfall estimates from both systems were also compared to rain gauge observations for Kennedy Space Center network (KSCN) at different spatial and temporal scales and the results are being analyzed. Issues such as accuracy of interpolation, grid size and shape, grid orientation, and distance from the radar will be examined. Moreover, the S-Pol has higher spatial and temporal resolutions than the KMLB. The effects of higher spatial and temporal resolution on radar-rain gauge comparisons are also being investigated.

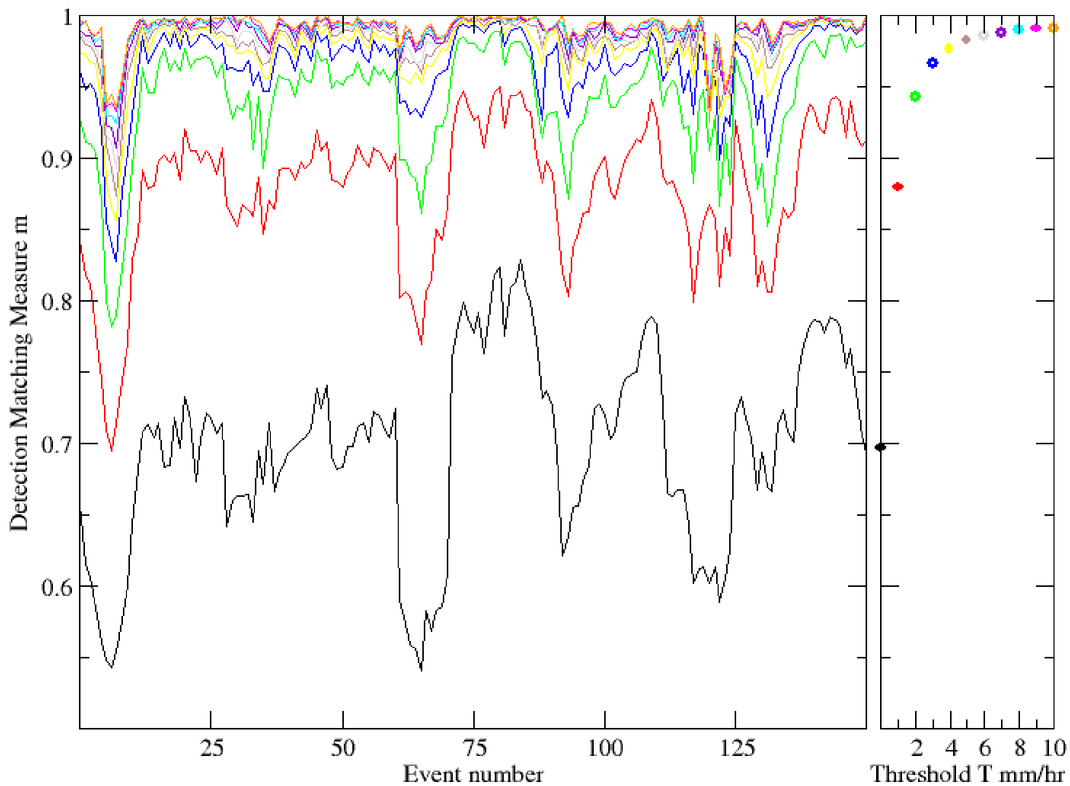

Figure 2

Time series of pattern matching measure *m* for different values of the threshold *T*. Average values of *m* for different values of *T* are shown on the right hand panel

5. Conclusion

The algorithm developed in this study can be instrumental in situations where reflectivity fields from two different radar systems are to be merged in real time. Ideas of merging data from different radar systems are being discussed both the research and operation communities. The study reveals that average correlation between the instantaneous rain rate estimates of the S-Pol and WSR-88D is of similar magnitude to the correlation in storm total accumulations. There is virtually a perfect match in rainfall detection between the two radars for rainfall rates greater than 4 mm/hr.

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