DETERMINING WSR-88D PRECIPITATION ALGORITHM PERFORMANCE USING THE STAGE III PRECIPITATION PROCESSING SYSTEM

Gregory J. Story, HAS Forecaster
West Gulf River Forecast Center
Fort Worth, Texas

ABSTRACT

Over the past few years, the precipitation estimates from the network of National Weather Service (NWS) Weather Surveillance Radars - 1988 Doppler (WSR-88D) have become widely used. Not only are these precipitation estimates used for the flash flood warning program at NWS Weather Forecast Offices (WFO), but these estimates are also a primary input for river flood forecasts for many NWS River Forecast Centers (RFC). The program in which RFCs assimilate the WSR-88D precipitation estimates into the river forecast system is called the Stage III Precipitation Processing System (PPS). It is the responsibility of the Hydrometeorological Analysis and Support (HAS) Forecasters to quality control all sources of precipitation data, including the WSR-88D estimates. Unfortunately, the precipitation estimates from the WSR-88Ds may be in considerable error. They are dependent upon either atmospheric conditions, or the performance of the radar systems (calibration, precipitation algorithm settings), or both. The HAS forecaster must determine, in real time, if a particular radar is correctly estimating, overestimating, or underestimating precipitation, and make adjustments within the Stage III program so the proper amount of precipitation is inserted into the river forecast models.

1. Introduction

This paper will briefly discuss some of the reasons why the WSR-88D does not always estimate precipitation accurately and explain how some HAS forecasters use the Stage III PPS to determine the accuracy of radar precipitation estimates. Cases will be shown from the Stage II/III program where radar overestimation or underestimation occurred with an explanation on how these estimates were adjusted using a computed bias factor. Finally, it will be discussed how this information is shared with the WFOs.

2. Background Information on the WSR-88D Precipitation Algorithm

The precipitation algorithm in the radar product generator (RPG) is a complex algorithm. With all the factors involved in radar sampling and performance, it is understandable why radar precipitation estimates are often in error. The precipitation algorithm contains 46 adaptable parameters which control how it performs (Fulton et al. 1998). The algorithm itself consists of five main scientific processing components and two external support functions. These five components are actually "subalgorithms," while the support functions execute independently of the main algorithm. The five scientific subalgorithms are: 1) preprocessing, 2) rainfall rate, 3) rainfall accumulation, 4) rainfall adjustment, and 5) precipitation products. The two external support functions are precipitation detection and rain gauge data acquisition (ROC 1999).

The five major processing steps of the precipitation algorithm execute in sequence as long as the first support function, the precipitation detection function, determine rain is occurring anywhere within 230 km (124 nm) of the radar. Once light or significant precipitation is detected, the first subalgorithm is executed. The base reflectivity data goes through a preprocessing stage which includes a quality control step, corrections for beam blockage using a terrain-based hybrid scan (O'Bannon 1997), a check for anomalous propagation (AP), and bi-scan maximization. Next, the base reflectivity data is assigned a rainfall rate using a conversion known as a Z/R relationship. Within this precipitation rate subalgorithm, more quality control is executed (a time continuity test and a correction for hail) and correction is made for range degradation. Next, precipitation accumulations are determined. This is an interpolation of scan to scan accumulation while simultaneously running clock hour accumulations. The precipitation adjustment subalgorithm is not currently being used and neither is the rain gauge acquisition support function. Finally, precipitation products are generated. The products are updated each volume scan (ROC 1999). Of most importance to this paper is the product known as the Hourly Digital Precipitation Array (DPA). The DPAs contain 1-hour estimates of rainfall on a polar stereographic projection known as the Hydrologic Rainfall Analysis Project (HRAP) grid. These DPAs are one of two main inputs to the Stage II/III PPS, a tool used in the RFCs, which will be discussed later.

The WSR-88D precipitation algorithm is not without deficiencies and limitations which all operational radars experience when attempting to estimate rainfall. Many of these limitations have been well documented (Wilson and Brandes 1979 and Hunter 1996). These factors make accurate radar precipitation estimates difficult to achieve. Below are a partial list and a brief description of some of the limitations and how they affect precipitation estimates.

- <u>Radar reflectivity calibration.</u> Precipitation estimates can experience significant error if the value of returned power (reflectivity) from a rainfall target is too large or too small. An in-depth study on this issue has been done by Chrisman and Chrisman (1999). The WSR-88D calibrates reflectivity every volume scan using internally generated test signals. These calibration checks should maintain an accuracy of 1 dB which translates to an accuracy of 17% in rainfall rates when the default Z/R relationship ($Z=300R^{1.4}$) is employed. Several factors may cause the estimated reflectivity, Z, from targets of known strength to change over time. One factor is hardware problems which can cause significant changes in absolute calibration. Absolute calibration needs to be maintained, since a change in Z of plus (or minus) 4 dBZ will result in doubling (or halving) the estimated rainfall rate R when the default Z/R relationship is used. Since radar reflectivity calibration is such a critical tool in improving precipitation estimates, the WSR-88D Radar Operations Center (ROC) has developed absolute calibration procedures which should ensure that reflectivity data is within +/- 1 dBZ.
- <u>Proper use of adaptable parameters.</u> As mentioned earlier, several adaptable parameters have a bearing on the precipitation algorithm. Two such adaptable parameters are the Z/R relationship and the maximum precipitation rate (MXPRA). The default Z/R relationship in the WSR-88D is the Convective $Z=300R^{1.4}$, and the default MXPRA was established at 53 dBZ which equates to a maximum rainfall rate of 103.8 mm/hr (4.09 in/hr). This

value was established to eliminate the effects of hail contamination on rainfall estimates, but on occasion, rainfall rates of greater than 103.8 mm/hr were observed. Extreme rainfall rates have been shown to occur when a deep warm cloud layer exists and warm rain processes prevail. These conditions are most prevalent in tropical rainfall regimes where larger drop size diameters exist (Baeck and Smith 1998). To compensate for this, radar operators have had the option of using a second Z/R relationship between reflectivity and rainfall rate. This Z/R relationship is called the Rosenfeld tropical Z/R ($Z=250R^{1.2}$). When the tropical Z/R relationship is employed, significantly more rainfall is estimated for reflectivities higher than 35 dBZ (Vieux and Bedient 1998). For example, at 40 dBZ, the default Z/R relationship yields a rainfall rate of 23 mm/hr (0.93 in/hr), while the tropical Z/R yields a rainfall rate almost twice as much of 46 mm/hr (1.83 in/hr). In addition to considering a change in Z/R relationship, radar operators may change the MXPRA parameter so a higher rainfall rate will be used in the accumulation function of the precipitation algorithm. In tropical storms, maximum precipitation rates of up to 152.4 mm/hr (6.00 in/hr) are possible. In general, changes in the Z/R relationship have been shown to be extremely important in radar precipitation estimation while changes in MXPRA have far less impact.

Three additional Z/R relationships have been approved for use by the ROC. They are the Marshall-Palmer relationship ($Z=200R^{1.6}$), and two cool season stratiform relationships (East $Z=200R^{2.0}$ and West $Z=75R^{2.0}$).

- Hail contamination, bright band, snow, and sub-cloud evaporation. The presence of frozen or wet frozen precipitation can cause significantly enhanced reflectivity values (Wilson and Brandes 1979). As hail stones which are present in strong convection grow in size, the stones become coated with water. These stones reflect high amounts of power back to the radar which can be significantly higher than the power returned from precipitation present within the storm. This results in an overestimation of the precipitation reaching the ground. Similarly, when ice crystals fall through the freezing level, their outer surfaces begin to melt. These water-coated ice crystals produce abnormally high reflectivities. This leads to bright band enhancement and an overestimation of the precipitation occurs.

  Snow flakes are sampled fairly well by radar, but improper Z/R relationships can lead to an underestimation of the snowfall by the WSR-88D. Research is in progress to develop a snow accumulation algorithm (SAA) using a more representative Z/R (Z/S) relationship (most likely the East or West cool season stratiform Z/R relationship) to improve the water equivalent snowfall estimates. Vasiloff (2001) and Barker et al. (2000) provide assessments of the SAA.

  Sub-cloud evaporation below the radar beam will cause overestimation. This occurs when the rain falls into a dry sub-cloud layer, and is most likely to occur in locations where clouds frequently have very high bases. While the rainfall estimate in the cloud may be relatively accurate, the estimate will be too high if little or no rainfall reaches the ground. An example of this is virga or dry microbursts.

- Range degradation. At far ranges, rainfall rates may be reduced due to signal degradation from partial beam filling. While the capability exists for range correction, it is currently not implemented on the WSR-88D. Two other range degradation problems are more significant compared to partial beam filling. Certain rainfall types, such as stratiform rains, show strong vertical reflectivity gradients. The stratiform gradient is positive until you get past the "bright band" then it decreases sharply. Orographic rain events also have sharp vertical reflectivity gradients (as can certain rainfall events associated with distinct meteorological lifting surfaces). A rainfall event with a sharp vertical reflectivity gradient will show fairly strong range degradation. The reflectivity values decrease so rapidly with height that the radar will underestimate more as the radar beam increases in altitude. In rainfall events with these sharp gradients, the beam height becomes the largest single contribu tor to radar rainfall underestimations. Lastly, in stratiform rain events and with rains from low-topped convection, a rainfall underestimation occurs due to the radar beam overshooting the precipitation at far ranges (a problem of lack of detection).
- Anomalous propagation (AP) and clutter suppression. The WSR-88D displays reflectivity returns at locations assuming the beam is refracting normal to a standard atmosphere. At times, severe deviations from the standard atmosphere occur in layers with large vertical gradients of temperature and/or water vapor. When these deviations occur, superrefraction of the radar beam can result and inaccurate calculations of actual beam height are made. These changes in refraction usually occur in the lower troposphere and can lead to persistent and quasistationary returns of high reflectivity either from ducting of the radar beam or from the beam coming in contact with the ground. This AP can lead to extreme precipitation accumulation estimates from false echoes. The WSR-88D does employ default clutter suppression using notch width and bypass maps and allows the radar operator to define further clutter suppression regions to eliminate AP (Chrisman et al. 1995). This capability depends upon the radar operator's ability to recognize the AP and react quickly to it.

  The existing precipitation tilt test algorithm further attempts to account for AP and is most effective when the AP occurs in the absence of reflectivities from actual rainfall. This algorithm rejects the lowest tilt (0.5°) if areal echo coverage of the tilt just above it (1.5°) is reduced by an amount greater than that expected from meteorological targets (Fulton et al. 1998). Unfortunately, occasional improper or excessive use of clutter suppression may cause real meteorological echoes to be unnecessarily removed and rainfall to be underestimated. This occurs most frequently when real rainfall targets are embedded within areas of AP, which is common behind a line of strong thunderstorms. For hydrologic applications, further data quality control is necessary external to the WSR-88D. This quality control is performed within the Stage III PPS at RFCs.

- Beam blockage. This is a major problem where radars are situated near mountains, which has been unavoidable in many western U.S. locations. For radials with a blockage of no more than 60% in the vertical and 2° or less in azimuth, reflectivities are increased by 1 to 4 dBZ in the range bins beyond the obstacle depending on the percentage of the blockage. Many sites have beam blockages of more than 60% and more than 2° in azimuth and no corrections are applied in these cases. Instead, the WSR-88D employs a terrain-based hybrid scan (O'Bannon 1997), so radials which experience beam blockages of more than 60% and more than 2° in azimuth use the next higher elevation slice for the PPS for that radial (up to a maximum elevation to the 3.4° slice). As stated earlier, if a higher elevation slice is employed, range degradation is more likely which leads to the underestimation of the precipitation. As a result, an underestimation of precipitation is common from radars located near mountains. The problem has been mitigated at some sites by installing radars on a peak as was done near Grand Junction, Colorado. However, in this situation the lowest elevation slices are so high above valleys that near-surface precipitation is not detected, which leads to the underestimation of rainfall from clouds of low vertical extent.

- <u>Attenuation.</u> The radar corrects for gaseous attenuation of the microwave radar signal, leaving wet radome and intervening precipitation as the principal attenuators of energy to and from the target. While both are considered to be small for S-band (10 cm wavelength), Ryzhkov and Zrnic (1995) show results indicating that attenuation may have a greater impact on rainfall estimates than previously thought (there is currently no accounting for attenuation by a wet radome or intervening rainfall). Since it may have an impact, this could be a reason why underestimation of rainfall often occurs during extremely heavy rain events.
- <u>Polarization.</u> The WSR-88D is single, a horizontal linear polarized radar. While that is not necessarily a deficiency, dual polarization radar measurements of a specific differential phase at two orthogonal polarizations (horizontal and vertical) have shown skill in improving rainfall estimates compared to single polarization radars using Z/R relationships (Zrnic and Ryzhkov 1999). Additional hydrometeor microphysical information can be inferred with the addition of vertical polarization measurements to obtain differential reflectivity as an aid in determining hydrometeor size and type (rain, sleet, hail, or snow) which, in turn, would lead to improved precipitation estimation.

3. Stage II/III PPS Precipitation Estimate Adjustments

The main purpose of the Stage II/III Precipitation Processing System (PPS) is to take the raw Hourly Digital Precipitation (DPA) arrays from the WSR-88Ds in an RFC's area of responsibility and perform additional quality control. The additional quality control features in the Stage III PPS attempt to achieve the best radar-based precipitation estimates possible for inclusion into the National Weather Service River Forecast System (NWSRFS) for the purpose of river streamflow prediction. Here is a brief overview of the three stages of the PPS:

- <u>Stage I.</u> The first stage of the PPS is the ingesting of the radar precipitation data. The DPA is a digital precipitation estimate generated by a radar at the top of each hour which has a size resolution of 4 by 4 kilometers and a high data resolution of 256 levels. The only quality control which the DPA goes through is the quality control features associated with the WSR-88D precipitation algorithm itself (Story 1996).
- <u>Stage II.</u> The second stage of the PPS is the calculation and application of a bias adjustment factor which increases or decreases the raw radar precipitation estimates. This bias adjustment procedure is described in the next section. If a bias adjustment factor calculated for one or more radars does not appear to be representative, the HAS forecaster may manually adjust this bias.

In addition, a Gauge-Only field is derived, and the hourly rain gauge observations are quality controlled at this stage. If any gauge reading appears incorrect, they are edited by the HAS forecaster and Stage II is rerun. This may cause a change in the bias adjustment factor and gauge-only fields for one or more radars. The end result of Stage II is an adjusted radar precipitation estimate for each WSR-88D defined in the Stage III program.

- Stage III. Stage III is where the multisensor analysis is determined. The Stage II adjusted radar field is combined with the derived gauge-only to arrive at the final multisensor field. Then this is mosaicked together with the multisensor fields of the other radar sites to obtain the final Stage III main display. The HAS forecaster has other quality control options within the Stage III program, such as the removal of AP. For a more detailed discussion of Stage III precipitation processing at the West Gulf River Forecast Center, see Story (1997).

3.1 Stage II Bias Adjustment

While there are five Stage II algorithms, one primary quality control algorithm allows RFC HAS forecasters to make deterministic judgements about the performance of area radars. This is the Stage II bias adjustment factor. The purpose of the bias adjustment factor is to increase or decrease the raw radar precipitation estimates based upon rain gauge data to compensate for the radar precipitation estimation deficiencies mentioned earlier. This bias estimation is calculated for each radar every hour using available hourly rain gauge data. Unfortunately, a dense rainfall network does not exist under every radar umbrella. For some radars, fewer than 10 hourly rain gauges report, and for these radars a bias adjustment is likely inaccurate. But under radar umbrellas which have dense rain gauge networks of more than 100 hourly gauges, accurate bias adjustment factors may be achieved.

The bias calculation is rather simple as it is the ratio of the sum of all positive rain gauge data over the radar umbrella from the previous x number of hours to the sum of all non-zero DPA rainfall data at the same gauge locations over the same spatio-temporal window of sampling. The size of the temporal window, x, is specified by the adaptable parameter "mem-span" (in hours). If you set "mem-span" to 1, you are using radar-gauge pairs only from the current hour. If you set it to 720, you are using radar-gauge pairs from the most recent 30 days. The optimal choice for "mem-span" depends largely on the gauge network density under a radar umbrella. Qualitatively speaking, the denser the rain gauge network is, the smaller "mem-span" should be to capture the temporal variability of the bias (to allow for the variability of radar precipitation estimates). At West Gulf RFC, HAS forecasters have set "mem-span" to a small number of hours for the radars with more than 100 hourly reporting gauges under their um brella while setting "mem-span" to up to one year under radar umbrellas who have fewer than 10 gauges under it. In the latter case where the number of gauges is small the program calculates a climatological radar bias where non-zero radar-gauge pairs do not frequently occur.

Other adaptable parameters influence the bias estimation. A detailed description of all Stage II adaptable parameters can be found in the Stage II Users Guide (NWS/OHD/HL 1997). One adaptable parameter is the minimum number of valid radar-gauge pairs needed to initiate a bias calculation (called "nmin"). This prevents a bias calculation based on too small a number of radar-gauge pairs. Another adaptable parameter specifies the maximum range (in kilometers) from a radar site for pairing rain gauge data with collocated radar rainfall data (called "rng_max"). If this is set at a value of less than 230 km, this adaptable parameter prevents rain gauges at greater distances from being used in the bias calculation where radar precipitation estimates are less reliable due to range degradation.

Under radar umbrellas which have a large number of hourly rain gauges available, the calculated Stage II bias adjustment factor *is a good indicator as to whether a radar is overestimating or underestimating*. The larger the number of rain gauges located under a radar umbrella, the better chance the program has of obtaining non-zero radar/rain gauge pairs. Simply, a bias estimate of 1.00 means that the Stage II program has accepted the radar estimates as correct. If the bias estimate is calculated above 1.00, it means that the radar is underestimating compared to its associated gauges. If the bias estimate is calculated below 1.00, it means the radar is overestimating. As an example, if the computed bias adjustment factor is 1.50, it means the radar-rain gauge pairs show a radar trend of underestimation, and the precipitation estimates on the final Stage II analysis are raised by 50% over the entire radar umbrella. Conversely, if the calculated bias estimate is 0.50, overestimation is implied, and the precipitation estimates across that radar umbrella are lowered by 50%.

3.2 Stage II Quality Control

Since the final Stage III precipitation estimates are based in part upon the bias adjustment factor, the HAS forecasters running the Stage III program *must* quality control the gauge-radar pairs which are used in calculating the bias. Known differences are associated with comparing point rain gauge and volume-averaged radar data (Fulton et al. 1998). While rain gauge data are often referred to as "ground truth," these data also have known deficiencies. Some of these deficiencies include 1) mismatch of radar and gauge clocks, 2) rain gauge undercatch associated with intermittent power outages during thunderstorms, 3) undercatch due to or extreme rain rates (primarily a problem with tipping bucket gauges) and high winds around the gauge orifice, 4) bad gauge reports due to hardware malfunctions or communications problems, and 5) errors in gauge latitude-longitude locations. While these deficiencies exist, WGRFC HAS forecasters have found from their quality control efforts that most rain gauge data received are of acceptable quality and can be used (with some caution) to make deterministic judgements about radar performance during most events.

4. How HAS Forecasters Determine Radar Precipitation Estimate Inaccuracies

The RFC HAS forecasters have several tools to assist them in determining the performance of any one radar. While much of this determination is done using the Stage III PPS, other tools are used. One tool is the WSR-88D products available on the Advanced Weather Interacting Processing System (AWIPS). One clue to radar precipitation estimate inaccuracies is to compare the precipitation products from all the radars which are sampling the same area of rainfall (within 230 km of each other). If the radars are all estimating about the same amount of precipitation over the same time period for the same general location, it is logical to conclude that the radars are estimating correctly. But HAS forecasters must be careful with this conclusion, though, as the sampling radars may be overestimating or underestimating because of the same meteorological phenomena (i.e., hail contamination in a thunderstorm). By contrast, if two or more radars are sampling the same part of a storm and the estimates do *not* agree, it is safe to conclude one (or more) of the radars are performing inaccurately. The problem HAS forecasters face is to determine which radar estimate is wrong and why. Sometimes a HAS forecaster's experience can lead to a conclusion about which radar is incorrect based on past knowledge of a particular radar's performance. The HAS function at WGRFC has been comparing 24-hour rain gauge data to radar precipitation estimates for five years. The performance of individual radars is determined and shared with other RFC personnel. After a period of time, conclusions about radar performance can be drawn. As an example, if one radar site is estimating higher than its neighboring radars and it has been shown through previous rain gauge/radar comparisons that this radar has overestimated, the HAS forecaster can conclude the radar with the lower estimate is closer to the observed.

If there are no neighboring radars, much more reliance is placed upon the rain gauge/radar comparisons to determine radar inaccuracies. The easiest way to accomplish this is through the Stage III PPS program. When using Stage III, the HAS forecaster has the option of zooming on an area of radar-based precipitation estimates and overlay the corresponding hourly rain gauge values. HAS forecasters may conclude a radar is incorrectly estimating if the rain gauges show significant differences between their readings and the radar estimates. When these comparisons are made for several hours and eventually over several meteorological events, a conclusion is drawn about a radar's performance based on these comparisons. Conclusions are logged for future reference.

Of course, as mentioned earlier, several factors can change (such as a change in an adaptable parameter) which affect a radar's ability to accurately estimate rainfall. As an example, at one time the rain gauge/radar comparisons for one radar showed the radar was overestimating significantly by roughly a factor of three. The radar base reflectivity was running 6 to 7 dBZ too high. After defective parts were replaced and path loss calibrations were performed, the radar began to correctly estimate. One of the responsibilities the HAS forecaster performs is to note when a change is made to a radar which ultimately affects its performance and its precipitation estimates. Quite often the HAS forecaster will call the appropriate radar focal point to see if any changes have been made to the radar system or if any algorithms were adjusted which may be affecting the precipitation estimates.

Another tool available to the HAS forecaster within the Stage III program is the Gauge Table. This table enables the user to easily see the contrast between a particular rain gauge measurement and the radar(s) estimation around that gauge. An example of a gauge table from the Stage III program is shown in Table 1. Information available on the gauge table includes the rain gauge ID, the rainfall measurement, the amount of rain for that gauge shown on the final Stage III display (mosaic), a list of the radar(s) which estimate rainfall over that gauge site, multisensor field precipitation information for each radar, and Stage I precipitation data. The piece of data which is most important to the HAS forecaster when comparing a rain gauge to the volumetric radar estimate near that gauge is the 'High' column of the Stage I precipitation data (the raw unbiased radar estimate). As an example, in Table 1 you will find the rain gauge SBMT2. This gauge measured 1.42 inches of rainfall for this hour and this was the value displayed on the final Stage III mosaic. The WSR-88Ds which produced rainfall estimates over this gauge include KHGX, KCRP, KGRK, and KEWX. The KHGX radar estimated a maximum of 0.72 inches of rainfall near this gauge, KCRP estimated 0.07 inches, KGRK estimated 1.08 inches, and KEWX estimated 1.14 inches. Based on this gauge reading, the radars underestimated the rainfall at this location. The next highest rainfall value for that hour, LGRT2, measured 1.22 inches. The radars which estimate precipitation over this gauge were the same four as for SBMT2. Again, KEWX and KGRK were very close on their estimates (1.28 inches and 1.24 inches, respectively). However, the KHGX radar estimated only 0.62 inches. So on the basis of these two gauges, the HAS forecaster concludes the KHGX radar is underestimating but the KEWX and KGRK radars are close enough to deem fairly reliable. The KCRP radar is suffering from range degradation problems as these gauges are close to 230 km from the radar site and are ignored in this example. It is dangerous to make hard and fast conclusions about a radar's performance based on just two gauges. But when the HAS forecaster watches the rain gauge/radar estimates on the gauge table for several consecutive hours (in addition to monitoring each radars' Stage II bias adjustment factors), they can get a good idea on how well the sampling radars are estimating. Table 1 will be examined further in the next section.

One of the biggest challenges facing HAS forecasters is how to determine radar performance under radar umbrellas which have but a few hourly gauges reporting beneath them. This is especially the case for the radars located in mountainous terrain or in sparsely populated areas where often fewer than 10 hourly rain gauges exist. In this case no immediate conclusions can be drawn concerning radar performance. In doing post-analysis, several 24-hour cooperative observer rainfall reports are often available for comparative purposes. Conclusions can be drawn by comparing the 24-hour total precipitation product from the radar with the 24-hour rain gauges. An example of this is shown in Figure 1 from 24 August 1999. Stage III estimates from Hurricane Bret are shown with corresponding 24-hour rainfall reports overlayed. In the area where Stage III estimated 8 to 10 inches of rainfall, a rain gauge captured 4.49 inches. Although this rain gauge amount may be low due to local wind effects, it still suggested to the HAS forecaster that radar overestimation occurred.

The only other means of comparison in real time is from satellite-derived precipitation estimates. While the interactive flash flood analysis may not be available from the National Environmental Satellite Data Information Service (NESDIS) for the location in question, automated satellite-derived precipitation estimates are now available for the CONUS in real time over the Internet. Scofield (1999) has shown some success with an automated technique of estimate rainfall using GOES IR satellite imagery. While it is not wise to make hard conclusions about radar performance based on satellite-derived precipitation estimates, HAS forecasters can confirm radar performance if the precipitation estimates from both sources are close to being in agreement in a convective environment.

5. Two Case Studies

To illustrate how HAS forecasters determine radar estimation errors using the Stage III program, two case studies were selected. These cases show how the use of the Stage II bias adjustment factor calculation together with the gauge table can give a good indication of radar performance. The first case shows a radar which is underestimating, while the second shows examples of overestimation.

5.1 Underestimation case

Figure 2 shows the 4-panel precipitation estimates from Stage III for the Houston, TX, WSR-88D (KHGX) at 0800 UTC 19 March 1999. The image in the upper left corner of the display is the Stage I DPA, which is unbiased (note the Stage I bias is 1.00, which is constant). It is identical to the 1-hour precipitation estimates displayed on AWIPS. Below it in the lower left corner is the Stage II adjusted radar. This is the Stage I array with the precipitation estimates changed by the amount of the calculated Stage II bias, which in this case is 2.07. The precipitation estimates on the Stage II adjusted radar is roughly double the estimates from Stage I. The image in the upper right corner is a display of the rain gauge values plotted by themselves. In this example, several gauges measured more rainfall than the WSR-88D estimated. The image in the lower right corner shows the multisensor field which is the Stage II Adjusted Radar field and the Gauge Only field combined. The multisensor field is the Stage II Adjusted Radar Field, with the radar estimates replaced by the hourly reporting gauges. It is this multisensor precipitation field which is used in the calculation of mean areal precipitation (MAP) for the river basins under the KHGX radar umbrella. The computed Stage II bias adjustment factor is shown at the bottom of Figure 2. While this bias factor is based on the radar trends from several hours, the initial conclusion is the KHGX radar has underestimated the rainfall for this hour. Table 1, as mentioned in the previous section, further supports the argument that the KHGX radar underestimated this rainfall. The observed rainfall at gauges SBMT2 and LGRT2 are roughly doublethe rainfall estimates from the KHGX radar.

Later that morning at 1300 UTC 19 March 1999, the radar estimates on KHGX improved. Figure 3 shows the 4-panel display from Stage III. The gauges displayed on the Gauge Only field are very close to the locations which the radar estimated similar hourly rainfall rates. Table 2 shows the gauge table which corresponds to the Stage III display for this hour. While the KHGX radar underestimated the rainfall at gauges GHBT2 and WHAT2 somewhat, it overestimated the rainfall for gauge HBAT2 (and other gauges not shown). From these radar/rain gauge pairs, the program computed a Stage II bias of 1.00 (as seen on Figure 3) which leads the HAS forecaster to conclude the radar estimates were valid. With a bias of 1.00, no adjustment of the Stage I precipitation estimates were performed. While no adjustment was made to the precipitation estimates, the HAS forecaster removed the anomalous propagation from extreme southeast Texas and southwest Louisiana by manually editing the multisensor field.

5.2 Overestimation Case

Figure 4 shows the 4-panel precipitation estimates from Stage III for the KHGX radar at 2000 UTC 13 July 1999. The Stage I image shows scattered thunderstorms which produced hourly rainfall rates of up to 1.50 inches. Comparing the radar estimates to the gauge only field, only one rain gauge recorded rainfall in excess of 0.30 of an inch. At first glance it appears that the KHGX radar has overestimated and indeed their computed Stage II bias is 0.90. Figure 5 shows the single radar display for KLCH (Lake Charles, LA) radar for the same time. When comparing the KLCH and KHGX radars, both radars show the same spatial and temporal resolution of the rainfall over the Houston and Galveston areas (where the two radars both sample the same areas of precipitation). The estimates from the KLCH radar are considerably higher than those from KHGX with estimates of more than 3.00 inches. An initial analysis of Figure 5 would suggest severe overestimation of the radar estimates from KLCH and the corresponding computed Stage II bias was 0.63. Table 3 is the gauge table which corresponds to these Stage III displays. The rain gauge CBST2 received 1.33 inches for this hour. The KHGX radar estimated 1.52 inches, which does suggest the radar overestimated slightly (this gauge is out of the range of the KLCH radar). The next gauge shown is GLS, which received 0.28 inches. The KHGX radar estimated 0.68 inches and the KLCH radar estimated 1.28 inches. While this suggests both radars estimated high, the KLCH radar was overestimating more severely. The third gauge was IAH, which received 0.24 inches. The KHGX radar estimated 1.40 inches near this gauge and KLCH estimated 3.31 inches. Again, this suggests that both radars overestimated and, most important, the computed Stage II biases of 0.90 for KHGX and 0.63 for KLCH appear valid. Comparing Figures 4 and 5, the precipitation estimates have been reduced for both radars as shown on their Stage II adjusted radar fields. The estimates for both radars turned out looking very similar as did their corresponding multisensor fields.

6. Conclusions

Several factors mentioned in this paper often lead to unreliable radar precipitation estimations. The challenge for WSR-88D radar operators is to determine, in real time, when the radar is not correctly estimating the precipitation. Great attention needs to be given by radar operators to the meteorology of the day to know the optimum settings for the adaptable parameters, including the Z/R relationship, which would produce the most accurate rainfall accumulations.

While WFOs may have some rain gauge data to check the accuracy of the estimates or may have the time to check the estimates from a nearby radar, the HAS forecasters at the RFCs are in a unique position to assist radar operators in making this determination. While not foolproof, the tools in the Stage III PPS program allow HAS forecasters to make reliable conclusions as to radar precipitation algorithm performance, especially with radars which have adequate rain gauge networks underneath their umbrellas. It is the responsibility of the HAS forecasters at RFCs to make these determinations so the proper calculations of MAP are made to support river and flood forecast operations. The Stage II/III PPS allows the HAS forecaster to quickly set a preferred bias for any single WSR-88D whose precipitation estimates appear unrealistic.

Since both radar operators and HAS forecasters have a need for accurate radar-based precipitation estimates, it is recommended that more coordination take place between the Unit Control Position (UCP) WSR-88D operators and HAS forecasters. During precipitation events, UCP operators need to be aware of the algorithm settings in use by the radar and how those settings influences the precipitation estimates. In addition, HAS forecasters need to communicate to UCP operators what the computed Stage II bias adjustment factor is for their radar (for radars where reliable calculations are obtainable) and how their estimates compare with adjacent radars. One way the HAS forecasters can communicate these biases are through the Hydrometeorological Coordination Message (HCM), which are free text messages internal to the National Weather Service sent over AWIPS. These messages can alert the Weather Forecast Offices (WFOs) that a radar is not correctly estimating, and can also confirm the suspicions of a WFO that a ra dar is overestimating or underestimating. Either way, the goal of more accurate radar-based precipitation estimates can be achieved.

Acknowledgements. The author would like to thank Christopher Bovitz, for his assistance in getting this paper into its electronic format. The author also thanks Cynthia Ableman, Senior HAS Forecaster, West Gulf RFC, for her comments, critical review, and assistance with the graphics.

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