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PRECIPITATION ALGORITHM IMPROVEMENTS IN THE EASTERN SIERRA

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Introduction

The National Weather Service Forecast Office (NWSFO) in Reno, NV, has been working this past year on a joint research project with the Desert Research Institute (DRI) through the newly formed Cooperative Institute for Atmospheric Sciences and Terrestrial Applications (CIASTA). The research is related to two of the more important forecast problems in the intermountain West - flash flood forecasting and quantitative precipitation estimates. The project was a natural evolution of earlier research efforts by DRI and the Reno NWSFO in establishing a hydrometeorological network through a COMET project, and is closely tied to two COMET research projects aimed to: 1) objectively analyze the data from the hydromet network using the Local Analysis and Prediction System, and 2) examine the utility of convective parameters for fire weather forecasts.

Both problems relate to analysis and interpretation of data from the Reno WSR-88D radar, located approximately 20 miles northeast of the city of Reno on a mountain top at 8500 feet MSL. This site was commissioned in June 1995 as the first NWS redundant system. A radar located at a high elevation has some unique problems regarding precipitation estimation in complex terrain. First, the lowest scan (0.5 degree) is well above the underlying terrain in a large percentage of the radar coverage (valleys in western Nevada are typically around 4000 feet MSL). Second, summer convection in the West frequently has high cloud bases. Algorithms relating base reflectivity to precipitation work well with radars on flat terrain and poorly in the mountainous West in situations where rain and hail falling from high-based thunderstorms evaporates before reaching the surface (Vasiloff and Adams 1997).

The problem in winter storms is almost the opposite. Precipitation is highly dependent on orography with the precipitation developing over the windward slopes of mountain ranges, and generally becoming most intense within the orographic feeder cloud closest to the mountain barrier. The Reno WSR-88D, even at its lowest scan, often samples above the bulk of the precipitating cloud. In addition, the reflectivity-precipitation rate algorithms, developed for rain events, have been found to be inappropriate for winter mountain storms where the radar frequently samples the ice cloud above the freezing level. Experience has shown that the current algorithms underestimate precipitation amounts during wintertime stratiform events (Haro 1995).

The main goals of this work are to improve the WSR-88D precipitation algorithms in the West by:

1) optimizing the Z-R relationship;
2) optimizing the hybrid scan and occultation files for the Reno radar; and
3) working on an improvement to the Z-R relationship for the winter, i.e., working with a Z-S relationship.

This Technical Attachment describes the current work on the NWS-DRI project to improve the WSR-88D precipitation algorithms, and discusses the future of the project.

Background on the WSR-88D Precipitation Algorithm

The WSR-88D Precipitation Processing Subsystem (PPS) has been fairly well documented (e.g., FMH-11; WSR-88D OSF Interactive Training Module Volume 1; and O'Bannon, 1998), and is only a portion of the radar's precipitation products. This section presents a brief description of the PPS.

The PPS begins after the thresholds have been met in the precipitation detection function. The PPS is divided into four parts: 1) preprocessing; 2) rate, 3) accumulation, and 4) adjustment. The work which DRI has been involved in to date has involved parts 1 and 2.

In the first step, preprocessing, the base data are quality controlled to correct problems due to radar beam blockage, spurious noise, reflectivity outliers, and ground returns. In the precipitation algorithm, only the first four tilts of the base data are used. For example, beam blockage information is found in the radar's Occultation File, which adjusts reflectivity by a factor for regions of partial beam blockage. Ground returns involve a tilt test, which can vary between values of 25-75 percent. The current value at KRGX is 75 percent. The last step in preprocessing tries to correct for the changes in beam height with range, involving the creation of a hybrid scan. All of these factors are applied to the base data and are input to the calculation of the precipitation rate.

The second step involves calculation of a precipitation rate. The main inputs to this part involve the quality-controlled base data, and the hybrid scan. A Z-R relationship is then applied to the data, followed by two quality control steps: 1) a time continuity step and 2) a range correction. The latter corrects for underestimation of precipitation rates at long ranges due to signal degradation and partial beam filling.

The third step is a summation of the calculated precipitation, and the fourth step adjusts the rate using rain gage data for bias corrections. Currently, only the first three steps are being performed in the forecast office.

Methodology

Radar analysis to date has been with Level II archive tapes acquired from NCDC. The primary analysis tool has been the WSR-88D Algorithm and Testing Display System

(WATADS). In addition, several programs were acquired which extract data over precipitation gages from Level II tapes, create vertical profiles of reflectivity, and unpack binary files such as the Hybrid Scan File and the Occultation File. WATADS produces 1-hour, 3-hour, and storm total precipitation using the current WSR-88D PPS algorithm, and allows for testing the effects of changing various adaptable parameters.

One of the first tasks was the identification of precipitation gage sites to use as ground truth for comparison with radar precipitation estimates. About 100 potential sites were selected from a variety of weather instrument networks. This work was completed under a COMET Cooperative Project (Reinhardt and Cairns 1995). The mesonet data are collected in real time in the forecast office and sent hourly to the Western Region Climate Center at DRI for archiving. These data are also available to the forecasters for use in real-time forecasting.

Analyses

The initial focus in the analysis was on three storms from 1996; 27 May, 25 June and 26 June. These storms produced both stratiform and convective rainfall. The cases were analyzed with the default settings of the PPS, and subsequently with numerous changes to the adaptable parameters including a range correction to precipitation rate. One of the most recent changes was to run the algorithm with a substantially modified Hybrid Scan and Occultation File. The initial results with the Reno KRGX Hybrid Scan file showed a marked underestimate of precipitation inside 50 km range, particularly in stratiform precipitation. Often a discontinuity in the precipitation pattern could be noted at each point where the Hybrid Scan called for a change in the tilt to be used by the precipitation algorithm. In the original Hybrid Scan the fourth tilt was used from 0-19 km range, the third tilt from 20-28 km, the second tilt from 29-49 km, and the first tilt at 50 km and beyond (except for a few areas of beam blockage between azimuths of 199° and 232°, where the second tilt was used). Originally designed to ensure that data at about the same level were used in the algorithm, at high altitude radar sites this Hybrid Scan forces the use of data from regions that are too high to detect precipitation from shallow stratiform cloud systems.

To correct this problem, the Reno Hybrid Scan was modified. The Hybrid Scan (acquired with WATADS) was first unpacked and made into an ASCII text file. The ASCII version of the Hybrid Scan was modified so that the first elevation tilt was used at all ranges 10 km and beyond. The second tilt was used from 1-9 km range. The ground clutter Region to the southwest of the radar was left unmodified. Once the edits were made, the ASCII file was again packed into a binary format and substituted for the original Hybrid Scan.

An analysis of the reflectivity patterns in the three case studies also determined that the original Occultation File, which adjusts reflectivity factor for regions of partial beam blockage, was producing an inadequate adjustment (+ 1 dBZ) in one Region centered at an azimuth of about 223°, at ranges beyond 59 km. In a manner similar to modifying the Hybrid Scan, the Occultation File was edited to include an adjustment from +1 to +4 dBZ in the blockage Region between 219° and 226°. This change improved the comparison of radar precipitation estimates to gage measurements in the blocked area.

Examples of storm total precipitation for the three cases, produced with the original and the modified files, showed a dramatic improvement in the radar precipitation estimates inside 50 km range with the modified Hybrid Scan. Table 1 compares data from 10 gage sites for the storm on 25 June 1996. The fourth column in Table 1 shows the results of using the modified Hybrid Scan and a range correction. The range correction, in units of dBR (10logR), applied to all ranges beyond 24, was:

$$\text{Corrected dBR} = -13.5 + \text{dBR} + 9.7\log D,$$

where R is the precipitation rate in mm/hr and D is range in km.

The range correction was based on vertical profiles of dBZ created for this case, and the assumption that the profile changed very little below the lowest sampling level of the radar. In this case of stratiform rainfall and a very moist subcloud layer, the assumption seemed to be valid, but would likely not be in more typical summer convective weather. It was found that this particular correction was not appropriate for the other two cases, and that unique range corrections were needed for each case due to disparate vertical reflectivity profiles.

Table 1. Comparison of storm total precipitation amounts (inches) at 10 gage sites for 25 June 1996.

Gage ID	Old Hybrid Scan	New Hybrid Scan	New + Range Correction	Gage Total
ALMN	0.03	0.09	0.20	0.23
DYCN	0.02	0.14	0.20	0.20
HDVN	0.04	0.19	0.24	0.24
HUFN	0.03	0.13	0.17	0.22
PVEN	0.03	0.05	0.14	0.12
SSLN	0.05	0.16	0.24	0.17
SCRN	0.03	0.14	0.23	0.20
KRNO	0.02	0.18	0.25	0.22
PVMN	0.03	0.05	0.08	0.20
DSSP	0.00	0.05	0.07	0.16
Totals	0.28	1.17	1.82	1.96

For all cases, there were 106 paired values of precipitation from gages and the radar algorithm. The gage average precipitation was 0.21 inches, compared to the results from the radar algorithm using the original Hybrid Scan and no range correction, which was 0.07 inches. The results from the modified Hybrid Scan and range corrections produced an average of 0.18 inches. Figures 1 and 2 show the storm total precipitation product for the 27 May and 26 June cases, respectively.

Discussion

These results were produced using the standard Z-R relationship, $Z = 300R^{1.6}$, in all algorithm trials. A separate study which pairs specific precipitation periods with the radar data from the lowest tilt (and directly over the gage) is being used to develop new Z-R relationships. This study is in progress, but preliminary results indicate that the appropriate Z-R will be markedly different from the standard relationship. For example, from the data available in these three cases, a subset of data from those precipitation gages 1000 to 1500 m below the lowest beam tilt were extracted. All precipitation periods from 18-90 minutes in duration were matched with radar reflectivity factor data in the range bin directly over each gage. An optimum Z-R was computed by forcing the radar precipitation rate to match the gage rate at each period. The technique is described by Super and Holroyd (1996). Eleven different gage sites were identified which had 65 separate precipitation periods and 490 corresponding radar values. The optimized Z-R returned from this sample was $Z = 72.2\ R^{2.15}$. The marked difference between this and the standard Z-R is very likely the result of how the cloud is sampled by the high-altitude Reno radar. The precipitation particle size distributions, often sampled well above cloud base in stratiform situations near Reno, would be expected to be very different from the size distributions near the surface, from which the standard Z-R was derived. In general, much weaker reflectivity factors in the high altitude situation are being paired with precipitation rates at the surface, leading to a quite different Z-R than is currently being used.

Future Work

Work will continue this year on the project with an emphasis on the winter precipitation. DRI has proposed some simple changes to the Z-R coefficient and exponent to match those proposed by Super and Holroyd (1996). In addition, it has been proposed that the Reno NWSFO be a test site for future snow algorithms.

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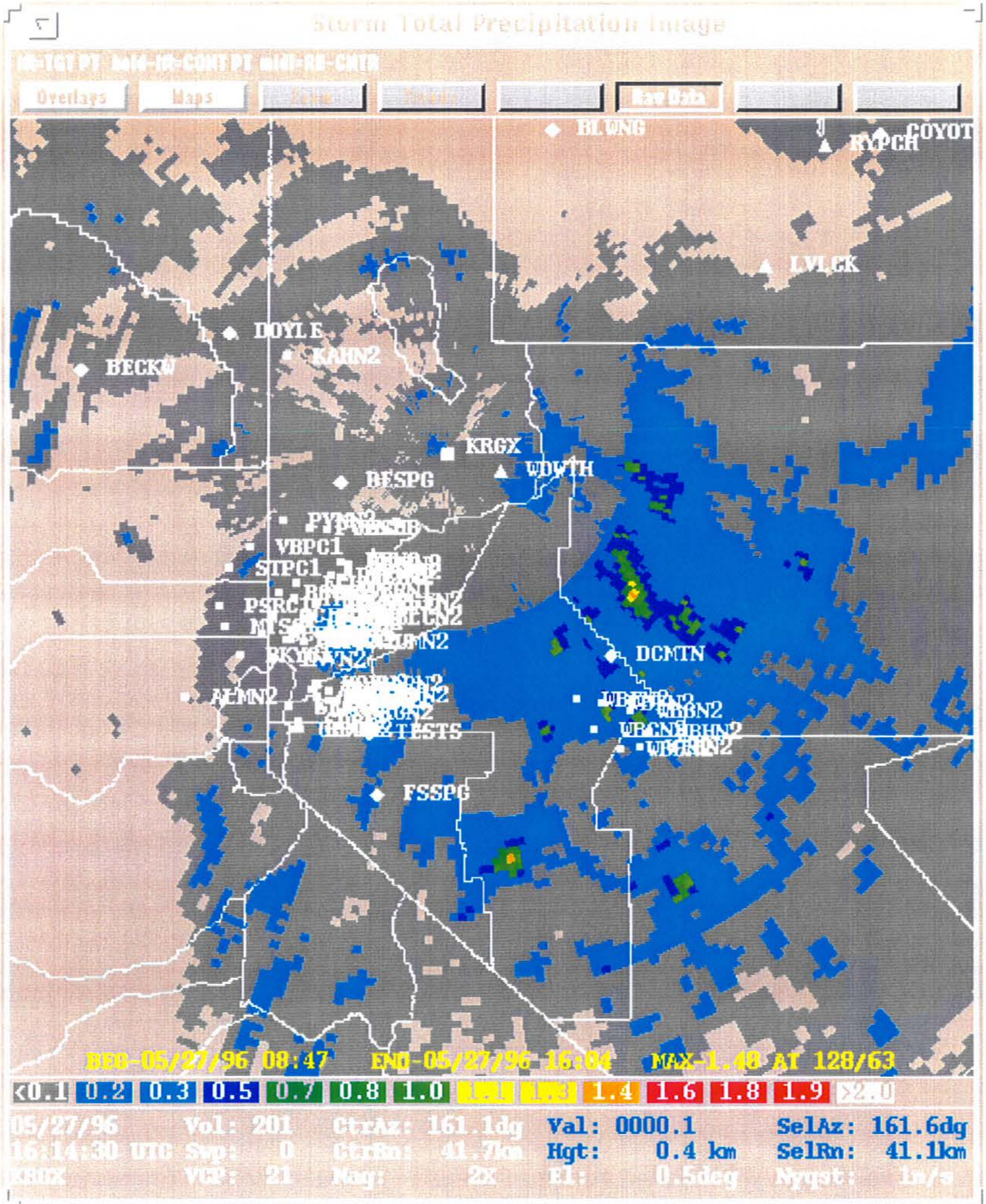

Figure 1a. The KRGX WSR-88D storm total precipitation product from 0847 - 1604 UTC 27 May 1996 using a) default settings and b) DRI adjustments (see text).

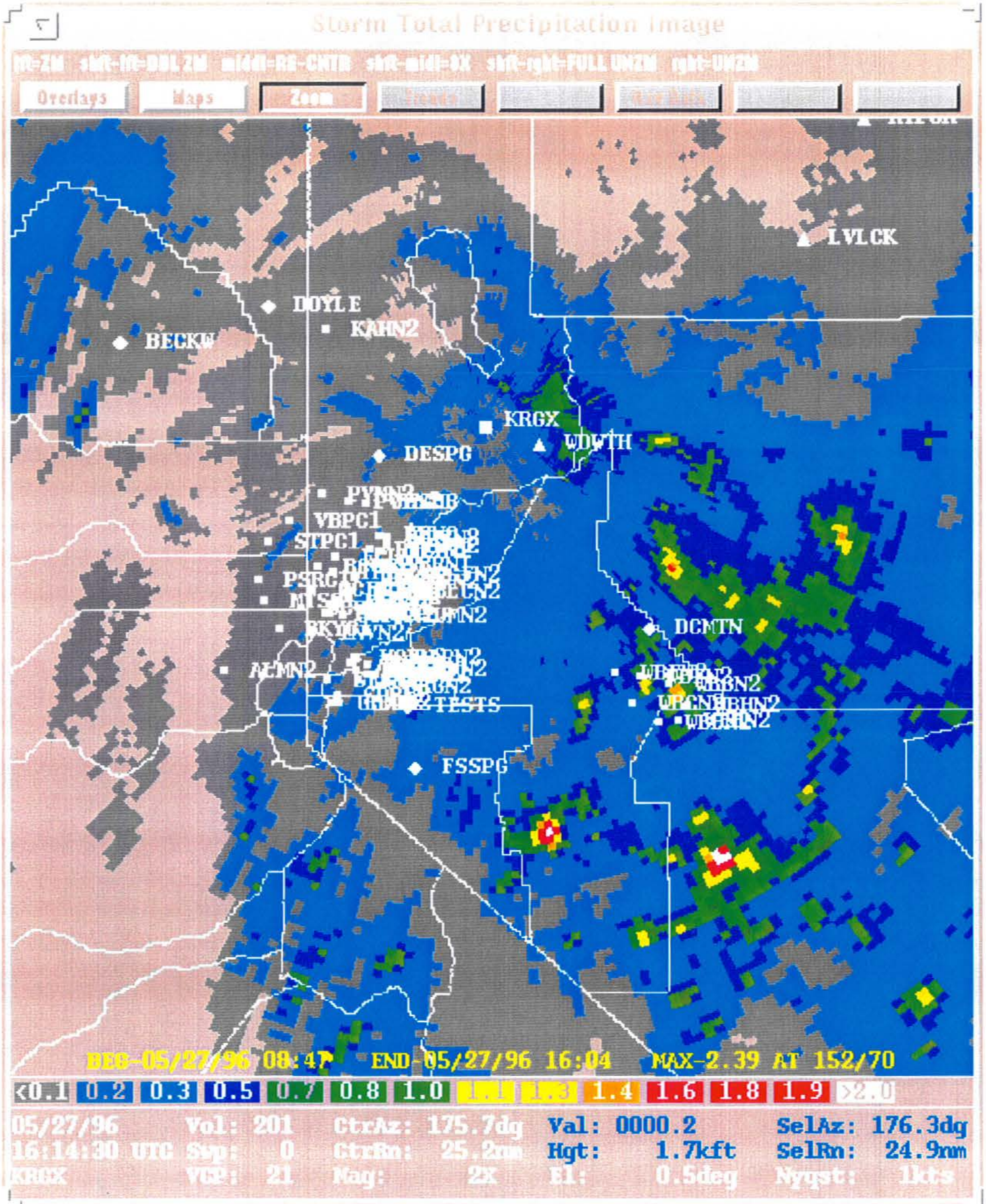

Figure 1b. The KRGX WSR-88D storm total precipitation product from 0847 - 1604 UTC 27 May 1996 using a) default settings and b) DRI adjustments (see text).

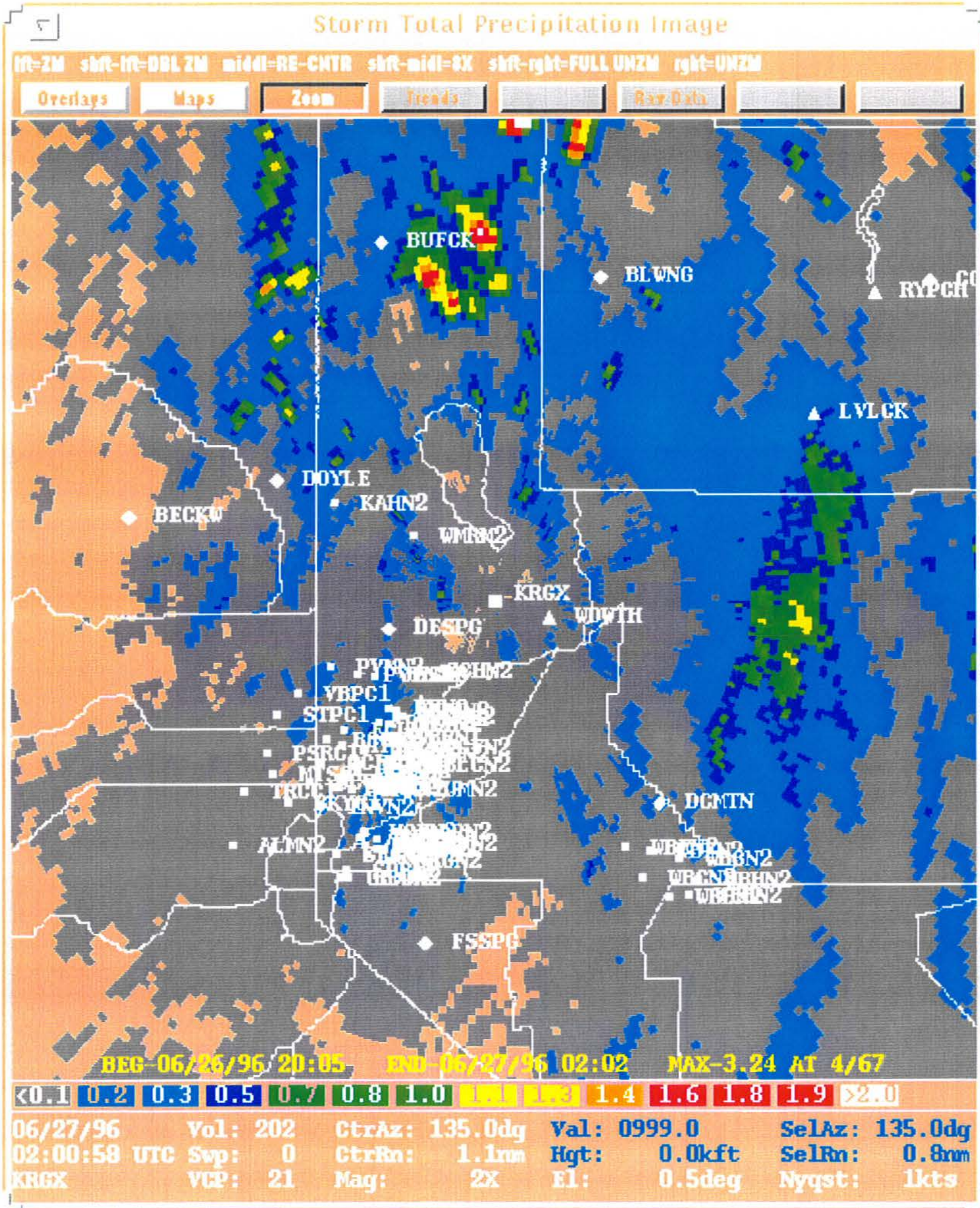

Figure 2a. As in Figure 1 except for the 26 June 1996 case.

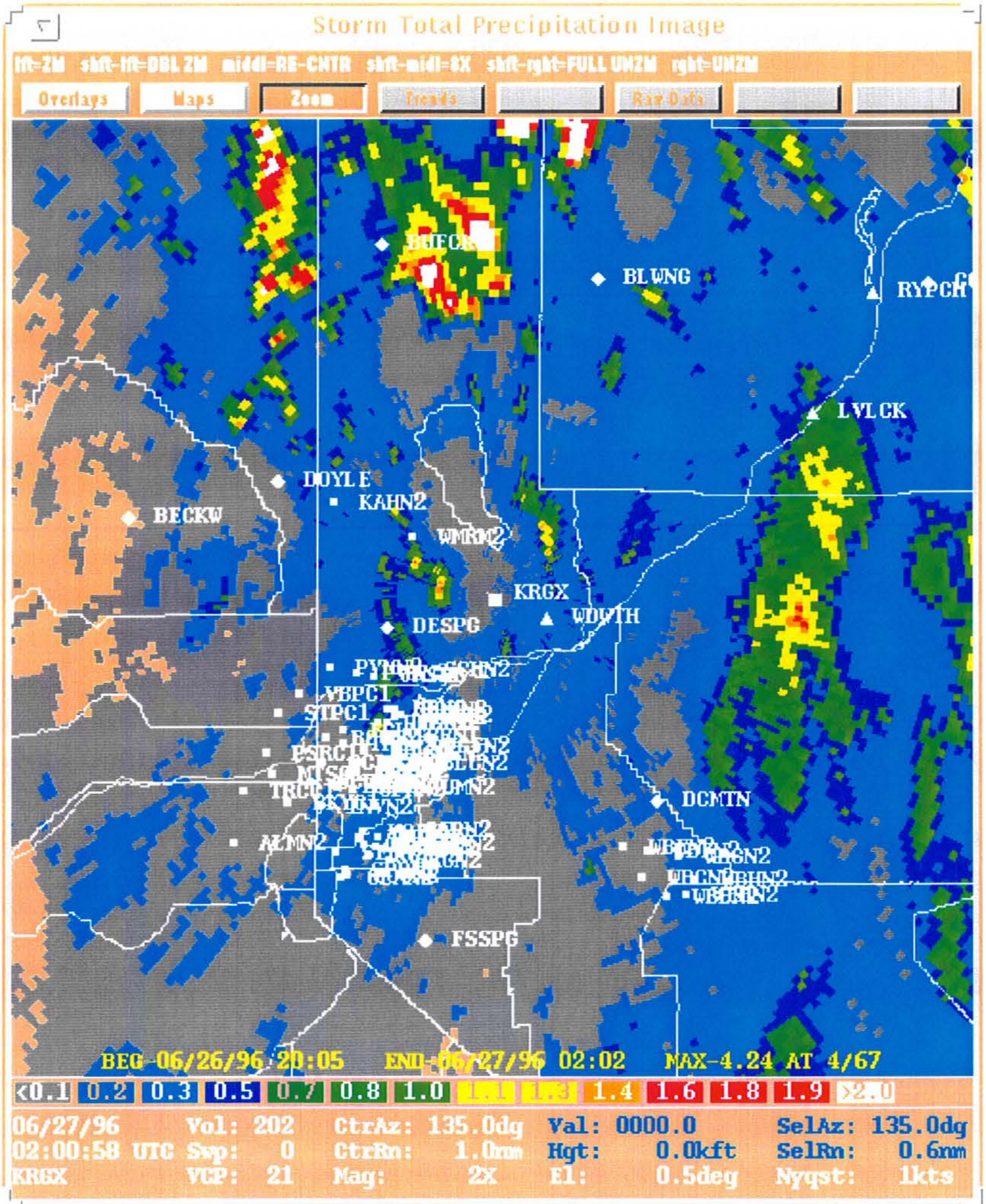

Figure 2b. As in Figure 1 except for the 26 June 1996 case.