FINAL PROJECT REPORT

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Partnership to Integrate Hydrometeorological Data and New WSR-88D Algorithms into the Interactive Forecast Production System for the Eastern Sierra Nevada Region

submitted by
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Section 1: Summary of Project Objectives

The objectives of this project were to develop procedures for simultaneous analysis and intercomparision of specialized WSR-88D radar product gridded data fields, hydromet measurements, and quantitative precipitation Interactive Forecast Preparation System (IFPS) products, to improve precipitation analysis and forecasting in the Reno WSFO forecast region.

Analysis and prediction of precipitation amounts is problematic in mountainous regions. Research by faculty at the Desert Research Institute (DRI, a branch of the University of Nevada system) using data from the high altitude WSR-88D near Reno (KRGX) have resulted in improvements to the precipitation processing scheme (Huggins *et al*., 2002), and the improved methods were incorporated into this COMET project. A radar product that includes direct comparisons between surface hydromet data and the radar-derived quantitative precipitation estimate (QPE) tabulated values at the measurement sites is now automatically transmitted to the Reno WSFO, and these combination products are being evaluated next to the IFPS precipitation products from the California Nevada River Forecast Center (CNRFC).

The original objectives of the project also included the incorporation of precipitation climatology grids from the PRISM dataset (available from the Oregon Climate Service) in QPE fields, but the CNRFC began to use PRISM data to prepare QPE as well as quantitative precipitation forecast (QPF) products in late 2003. We are utilizing the CNRFC netCDF format IFPS data grids, which scale the surface measurements with PRISM spatial distributions of precipitation. These IFPS grids along with the gridded radar and point comparison datasets have advanced the capabilities of the Reno WSFO for precipitation forecasting.

Section 2: Project Accomplishments/Findings

2.1 VPR-enhanced WSR-88D QPE Product

A radar precipitation processing scheme that has been shown to provide more accurate QPE than standard methods (Huggins *et al*., 2002) is now operationally implemented for utilization in the Reno WSFO forecast process, and the improved product allows direct comparisons between the radar-derived QPE values, surface hydromesonet observations and a new IFPS precipitation product from the CNRFC.

The DRI procedure applies WSR-88D data from the Reno, Nevada (KRGX) system that are operationally transmitted to DRI using both the Unidata LDM 6 and the Base Data Distribution System (BDDS). Level II data archiving, software design and algorithm processing are accomplished at DRI. The WSR-88D Algorithm Testing and Display System (WATADS) is also installed on the DRI computer system to allow review of the reflectivity patterns in storms, but WATADS cannot run the highly modified precipitation algorithm that DRI has developed.

Intercomparisons of the DRI VPR-based radar algorithm against gauge measurements have shown the method to accurate estimates of accumulated precipitation (Figure 1). The primary DRI software includes a program named **profprecip** that uses Vertical Profiles of Reflectivity (VPR) signatures based on composite analyses of radar and gauge data from multiple seasons to construct a spatially consistent vertical gradient in radar-detected precipitation intensity for defined topographic regions within the radar scan area (Joss and Lee, 1995; Seo *et al*., 2000; Huggins *et al*., 2002). The VPR were also used to determine reflectivity-precipitation rate (Z-R) equations that were derived from a special set of precipitation gauge verification sites. Another program called **mapprecip** runs the same algorithm for all range bins within the radar scan area and produces two-dimensional maps of precipitation accumulation.

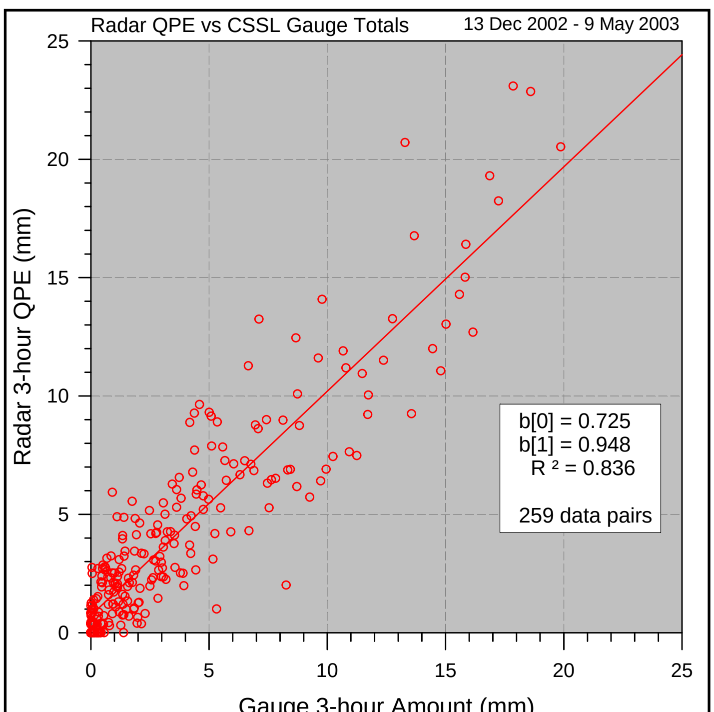


Figure 1. 3-hour QPE derived from the VPR-based radar method versus gauge totals for the Central Sierra Snow Laboratory site.

A number of auxiliary programs have been developed to construct VPR over variable range, azimuth and time intervals (**vprofile**), to analyze ground clutter returns (**mapclutter**), and to edit both the WSR-88D hybrid scan and occultation files (**nuhybrid** and **nuocc**). In addition to radar processing and analysis programs, another set of programs has been developed to access and analyze precipitation data. Hydromet data from the Reno NWSFO hydromet computer are transferred once an hour to DRI and to the computer running the precipitation algorithm.

Multiple case studies have shown the accuracy of this method for estimating precipitation accumulation in the region (Huggins *et al*., 2002). Figure 2(a) and Figure 2(b) present a comparison of the standard WSR-88D precipitation algorithm for a winter storm event and the corresponding DRI radar algorithm using VPR corrections.

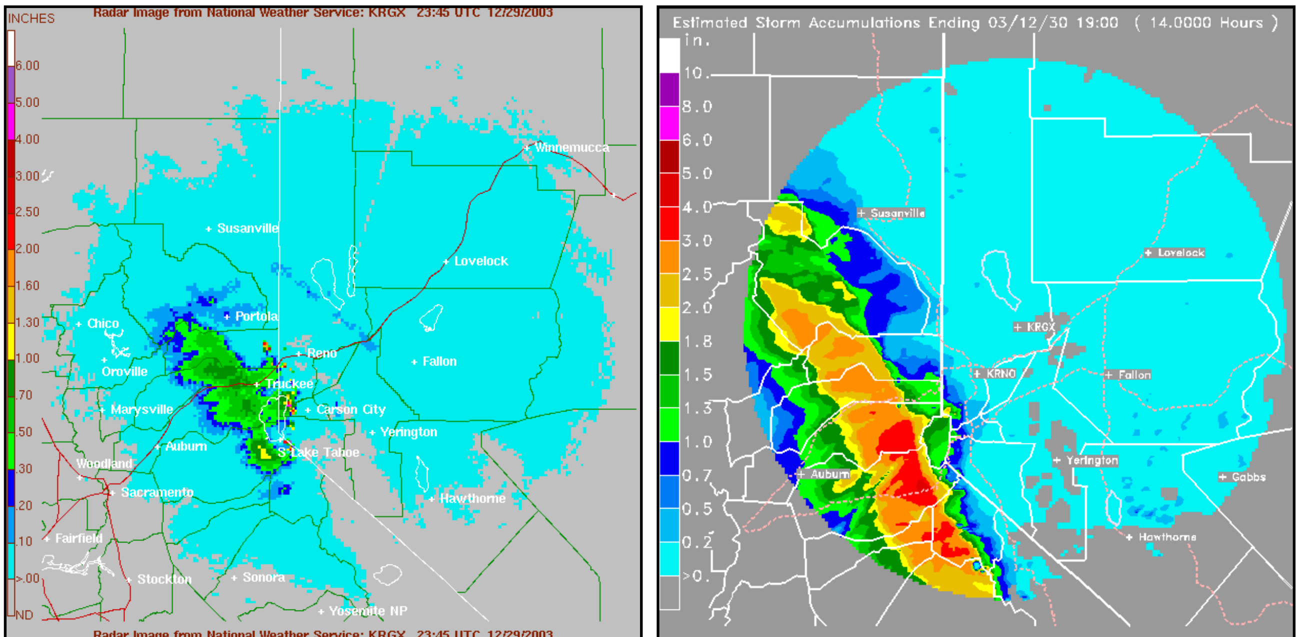


Figure 2. (a) Standard WSR-88D and (b) VPR-enhanced QPE displays for a 14-hour period on 29 Dec 2003. Note scales are different.

The NWS algorithm identified the orographic enhancement in the region immediately upwind of Tahoe, but failed to predict this same pattern at the longer ranges from the radar. Peak accumulations were generally in the range of 0.7-1.0 inch. This compares to QPE in similar areas of the DRI product that exceeded 2.5 inches. The VPR correction also extended the orographic enhancement along the entire upwind region of the Sierra Nevada within the KRGX coverage area. Gauge data from the region of maximum orographic enhancement suggest the radar-derived values are approximately 0.3-0.5 inch too high, but they still provide a more accurate QPE and a better spatial representation of the precipitation than the standard algorithm.

Dozens of surface measurement sites in the Eastern Sierra Nevada are available for QPE verification. A database for these observations has been created and is updated each hour with any new data. A processing program called **querydb** is used to determine 1-hour, 3-hour and storm total precipitation amounts for comparison with radar QPE. Both the radar and gauge precipitation programs can be run in real time or in a post-analysis mode. The operational products include tabular precipitation measurements for 33 mesonet sites (NWS, ALERT, RAWS and other), and the combined radar QPE graphics and hydromet data comparisons are available for 1-hour loops, and 3-hour totals, and storm totals at the following web addresses:

http://www.wrh.noaa.gov/rev/digital/1hour.php
http://www.wrh.noaa.gov/rev/digital/threehour.php
http://www.wrh.noaa.gov/rev/digital/stormtotal.php

2.2 Utilization with CNRFC IFPS Grid Files

These enhanced radar datasets are being transmitted in near real-time to the Reno WSFO where they are used by the NWS forecasters to evaluate the consistency between short-term QPE and the various QPF information sources. Gridded precipitation analysis and forecast grids are now being created by the CNRFC, by combining surface measurements from points shown in Figure 3 (including Reno-Tahoe area hydromesonet data collected by the Reno WSFO and sent via FTP to CNRFC) and Oregon Climate Service PRISM precipitation monthly 4-km precipitation climatology datasets. The CNRFC creates 6-hour accumulated QPE grids from these data, and also produces 72-hour QPF grids in a similar format by incorporating model output and analysis. The procedure for scaling the gridded QPF values according to PRISM spatial patterns is shown in Figure 4.

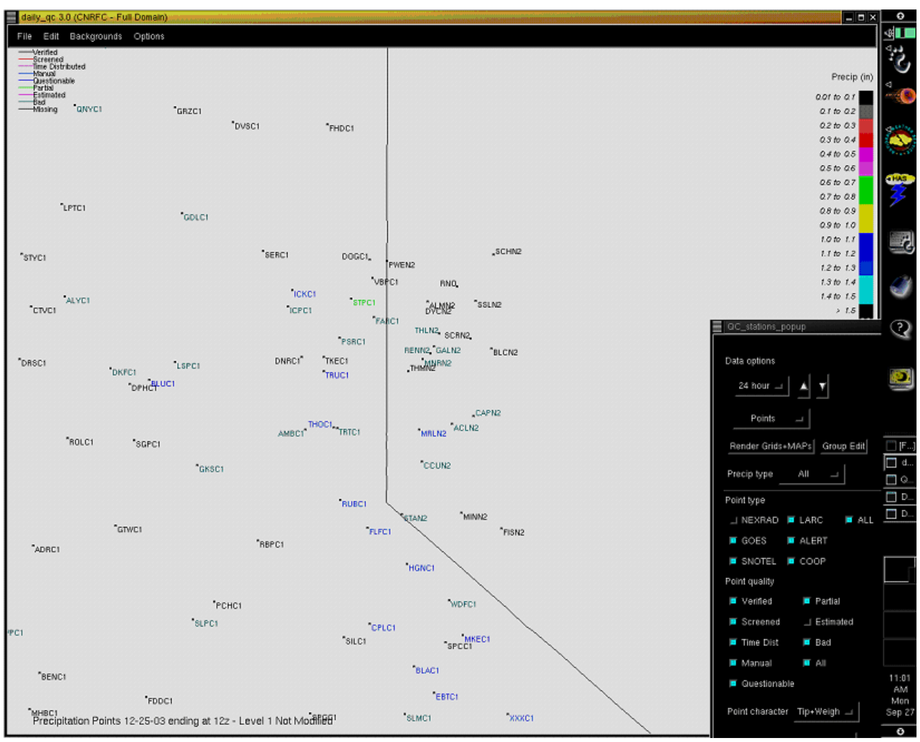
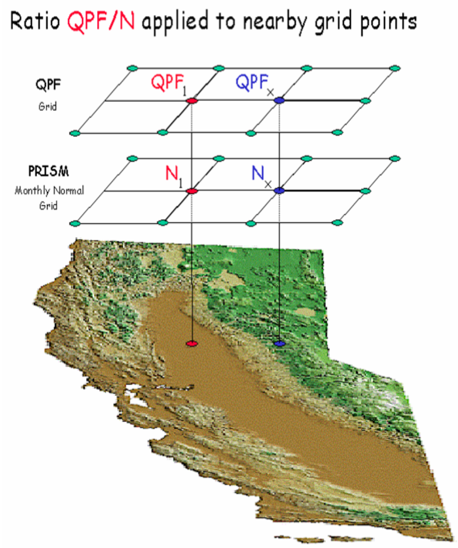


Figure 3. Surface measurement sites used by CNRFC in creating gridded QPE.



$$QPF_x = N_x \left[\frac{\frac{QPF_1}{N_1}\left(\frac{1}{d_1^2}\right) + \frac{QPF_2}{N_2}\left(\frac{1}{d_2^2}\right) + \frac{QPF_3}{N_3}\left(\frac{1}{d_3^2}\right) + \frac{QPF_4}{N_4}\left(\frac{1}{d_4^2}\right) + \frac{QPF_5}{N_5}\left(\frac{1}{d_5^2}\right) + \cdots}{\frac{1}{d_1^2} + \frac{1}{d_2^2} + \frac{1}{d_3^2} + \frac{1}{d_4^2} + \frac{1}{d_5^2} + \cdots} \right]$$

Figure 4. Schematic diagram and equation showing the method by which CNRFC uses the ratio of point-specific QPF to the PRISM gridded monthly normal (N) precipitation to calculate the QPF field for the model grid based on inverse squared distance weighting from several surrounding points (each at distance d from analysis point). (Source: Alan Haynes, CNRFC)

In order to allow direct analysis of the CNRFC IFPS product with the DRI VPR radar products, Sam Keck (DRI) installed the NWS Graphical Forecast Editor (GFE) software on a DRI computer. The program, "runGFE" reads netCDF format files and allows display and query of data values. Several winter storm events with greater that one inch of accumulated precipitation were selected for study, and Alan Haynes of the CNRFC generated netCDF files for those events. Serena Chew, a graduate student supported by this COMET project with a partial assistantship at the Desert Research Institute, developed a program that composites data into 6-hourly accumulation files and graphics (see example in Figure 5) to match the time frequency of QPE products from CNRFC. For each event, the CNRFC netCDF files are compared to the 6-hourly radar products. Case studies are described below.

2.3 Product Intercomparisons

2.3.1 Case of 7 December 2003

QPF products were compared with radar-derived precipitation patterns and gauge measurements for 6-hour accumulation periods. Figure 6 shows the radar QPE data from DRI and the CNRFC QPF products for the same 6-hour accumulation periods, ending at 06 UTC on 7 December 2003. Precipitation maxima over the Sierra Nevada in both products were indicated in the range 1.2-1.6 inches. Measurements made at gauges located in these areas of maxima (for example, see text boxes for BCYC and HLLC in Figure 6b, near Lake Tahoe) had similar values (1.2-1.3 inches). In Figure 7, the area of precipitation moved southward along the Sierra Nevada. Measurements from the same gauge locations in the central Sierra Nevada showed close correspondence to the QPE and QPF trends, with accumulation values of less than 0.6 inches in that six-hour period.

Note that the color scheme differs between the two types of products, and the circle overlays are used in these graphics to facilitate matching the same geographic areas in each map, indicating that low values of precipitation correspond to a range of colors. Magnitudes up to 0.2 inch are shown as cyan or light blue in the radar product, but range from light violet through blue to cyan in the QPF product. Auto-scaling of color assignments for parameter value ranges can cause difficulty in quick pattern recognition and evaluation that are needed for operational forecasting.

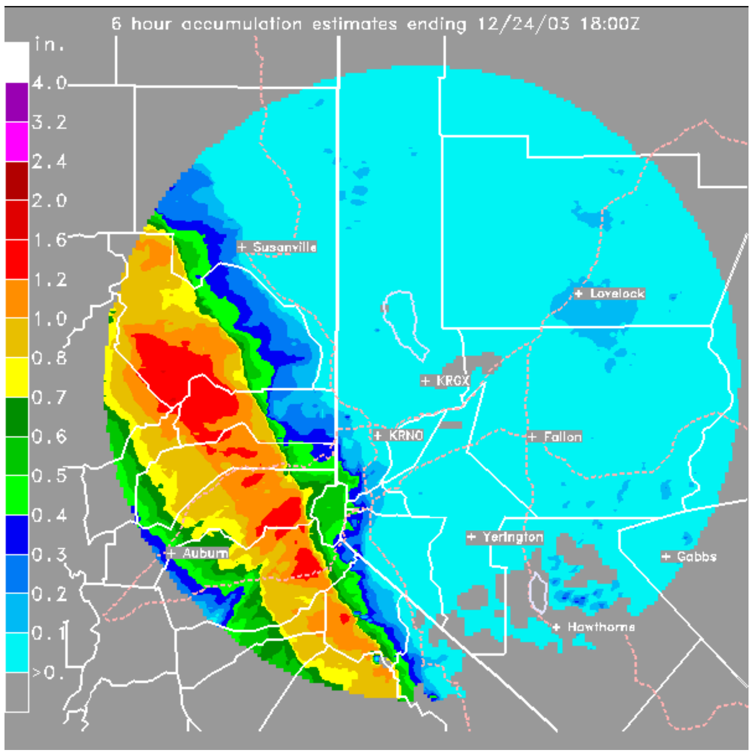


Figure 5. Graphical version of the radar-derived accumulated precipitation product (units of inches) for the 6-hour period ending 18 UTC on 24 December 2003.

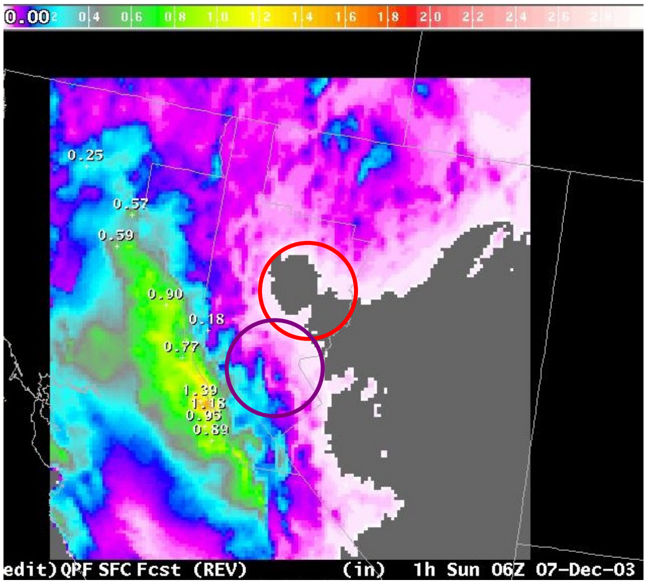


Figure 6a. CNRFC 6-hour QPF (inches) for the the period ending 06 UTC 07 Dec 2003. White numerals indicate point values sampled in GFE. State outlines shown in light gray.

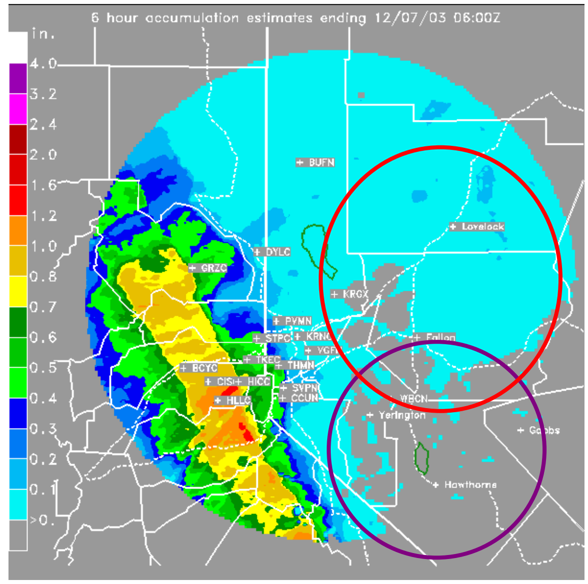


Figure 6b. Radar-derived 6-hour accumulated precipitation (inches) at 06 UTC 7 Dec 2003. Gray/white text indicates gauge sites. State and county outlines are white.

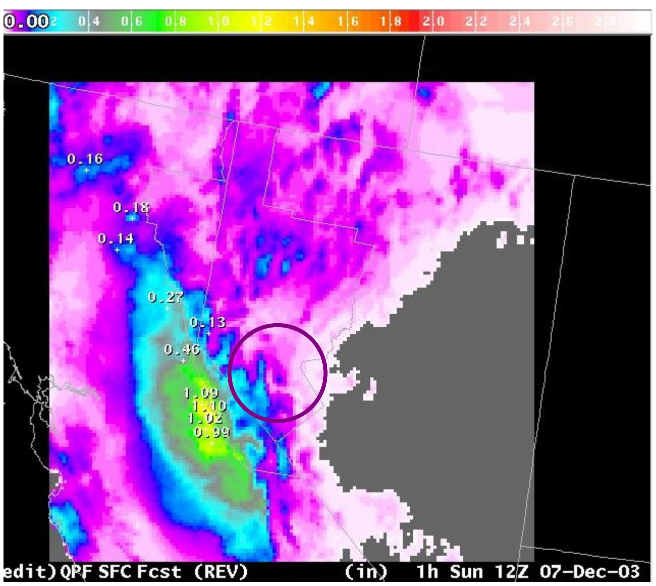


Figure 7a. CNRFC 6-hour QPF product for the the period ending 12 UTC 7 Dec 2003.

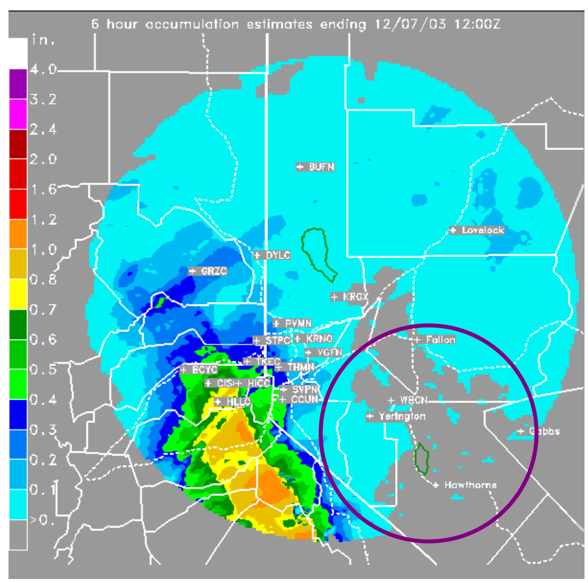


Figure 7b. Radar-derived 6-hour accumulated precipitation ending 12UTC 7 Dec 2003.

2.3.2 Case of 14 December 2004

The precipitation band structure and precipitation magnitudes are in very good agreement between Figures 8a and 8b for the morning of 14 December 2003. Precipitation gauge accumulations at locations BCYC and HLLC (Figure 7b) were 0.23-0.38 inches, while the radar-derived QPE was approximately 0.3-0.5 inches within that area. The radar QPE and CNRFC

QPF agreed on domain maximum accumulations above 2.0 inches for this period. In the following 6-hour period some differences became apparent. While radar QPE accumulations indicated in the northwest portion of the radar data domain were still greater than one inch (compare Figure 9a and 9b areas shown in small black rectangles), the accumulations were estimated to be lower in the southern extent of the mountain region in the radar product, while the CNRFC QPF predicted a more equal spatial distribution along the mountain chain. The precipitation amounts indicated in both the radar QPE and the CNRFC QPF for the central region (near Lake Tahoe) were 0.6-0.8 inches, which compare quite closely with precipitation gauge observations (0.70-0.84 inches).

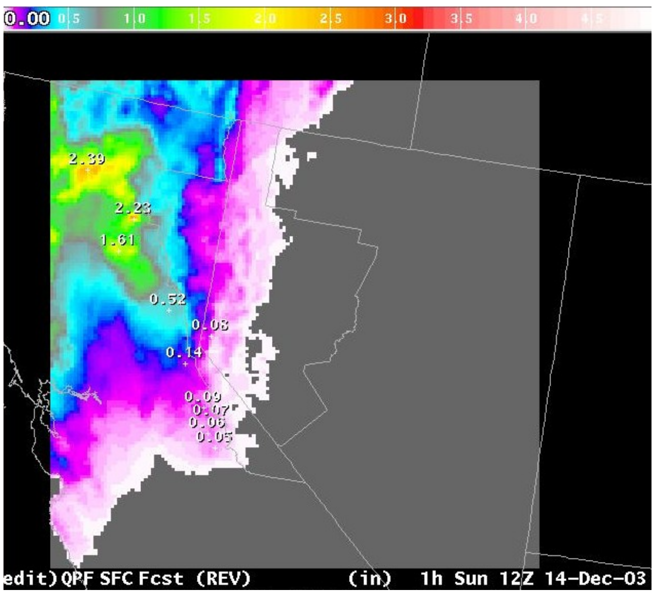


Figure 8a. CNRFC 6-hour QPF product for the the period ending 12 UTC 14 Dec 2003. White text values are sampled from the grid using GFE.

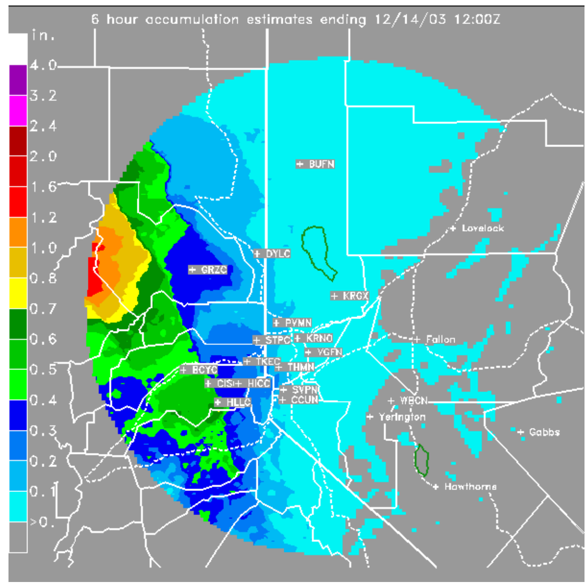


Figure 8b. Radar-derived 6-hour accumula-ted precipitation at 12 UTC 14 Dec are point States and forecast region outlines in white.

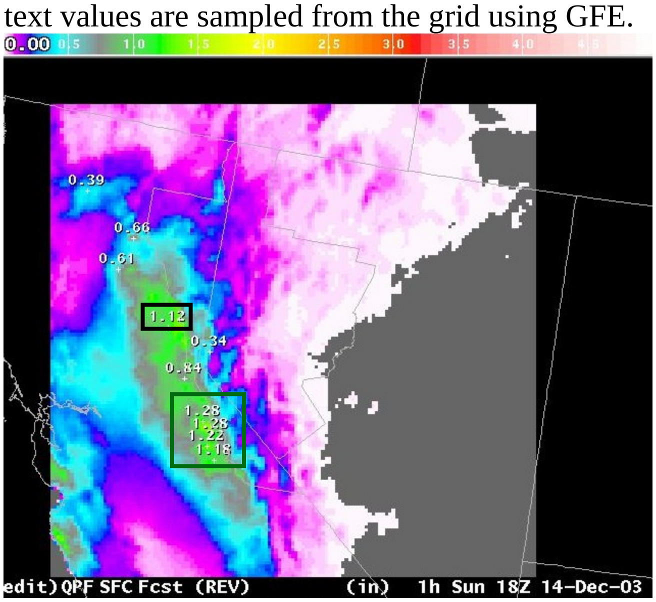


Figure 9a. CNRFC 6-hour QPF product for the the period ending 18 UTC 14 Dec 2003.

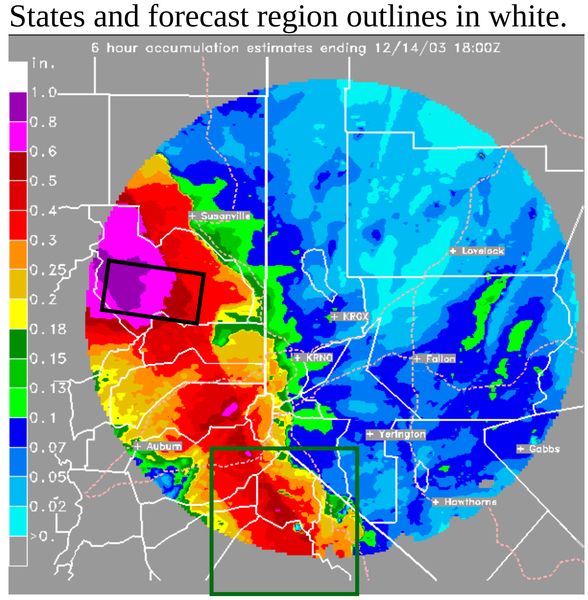


Figure 9b. Radar-derived 6-hour accumula-ted precipitation at 18 UTC 14 Dec 2003.

2.3.3 Case of 24-25 December 2003

This case demonstrates relatively good correspondence between the CNRFC QPF and the radar-derived QPE for the magnitudes of 6-hour accumulations of precipitation. A sequence of figures demonstrates the temporal evolution of precipitation accumulations as the storm moves through the Sierra Nevada. Figures 10-13 show the progression of intense precipitation zones beginning in the northern Sierra and moving southward. For the 6-hour period ending at 18 UTC on 24 December, radar-estimated QPF (Figure 10b) was in the range 1.2-1.6 inches; similar to points sampled from the QPF (Figure 10a) in the northern Sierra, but the heavy precipitation zone had not reached the Lake Tahoe region in the QPF product. Precipitation gauges near Lake Tahoe measured accumulations of 0.7-1.1 inches that corresponded to the radar QPE.

The QPF product for the following 6-hour period (Figures 11a and 11b) indicated heavy accumulations to occur to the southwest and south of Lake Tahoe, nearly matching the magnitude of radar QPE in that area. Although no precipitation gauge sites are located this far south, measurements at MNRN (site location not shown, but is immediately west of Lake Tahoe in Figure 11b) were 1.0 for the six-hour period, similar to the QPE and QPF products. The zone of maximum precipitation continues to shift southward in Figures 12a and 12b with similar magnitude. Accumulation amounts west of Lake Tahoe dropped to half of the previous 6-hour period, and this was verified by gauge observations. A later time period in Figure 13 indicates precipitation distribution evolving to a more orographic character as is typical for these storm systems, with more mesoscale variability in accumulation amounts. Figure 13a and 13 b show agreement in both magnitude and distribution patterns between the CNRFC QPF and the radar-derived QPE. Maximum accumulations measured west of Lake Tahoe were lower (0.35 inches), and may be associated with the scattered precipitation distribution often observed for post-frontal orographic convection.

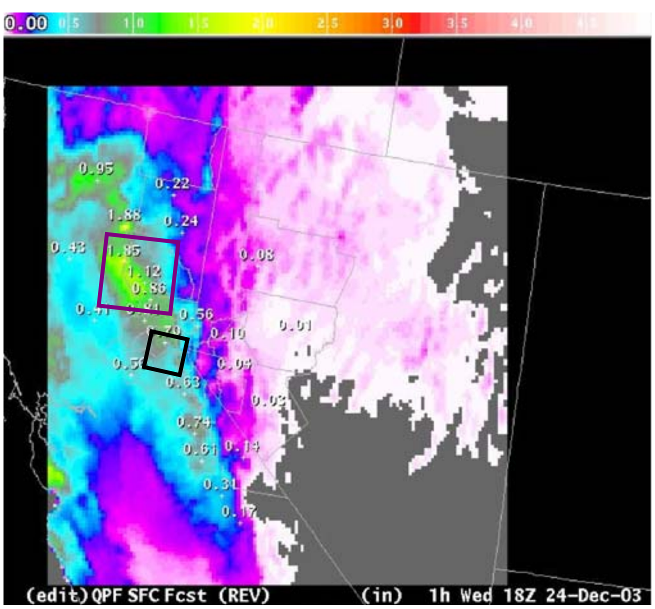


Figure 10a. CNRFC 6-hour QPF product for the the period ending 18 UTC 24 Dec 2003.

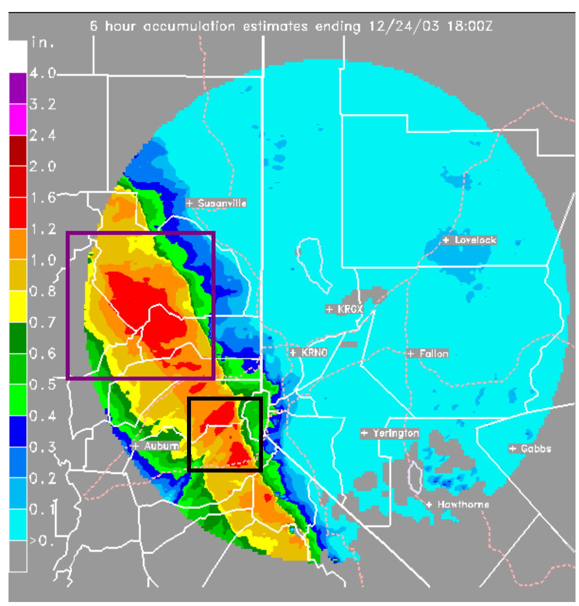


Figure 10b. Radar-derived 6-hour acumen-lasted precipitation at 18 UTC 24 Dec 2003.

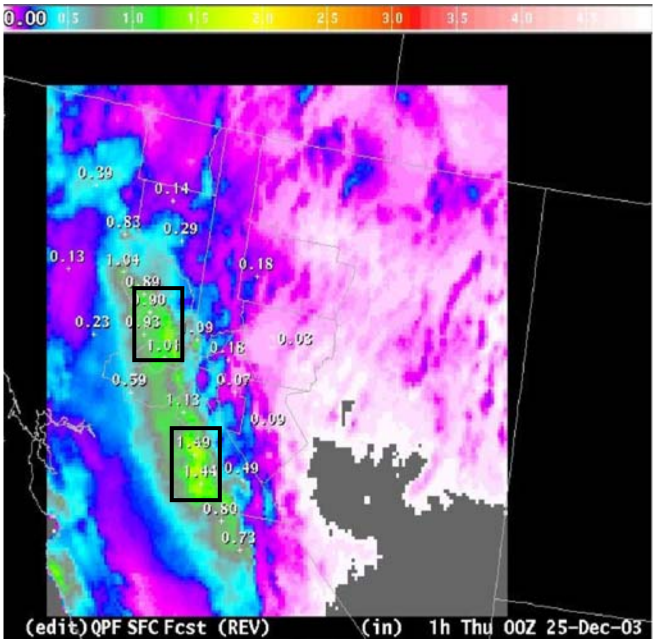


Figure 11a. CNRFC 6-hour QPF product for the the period ending 00 UTC 25 Dec 2003.

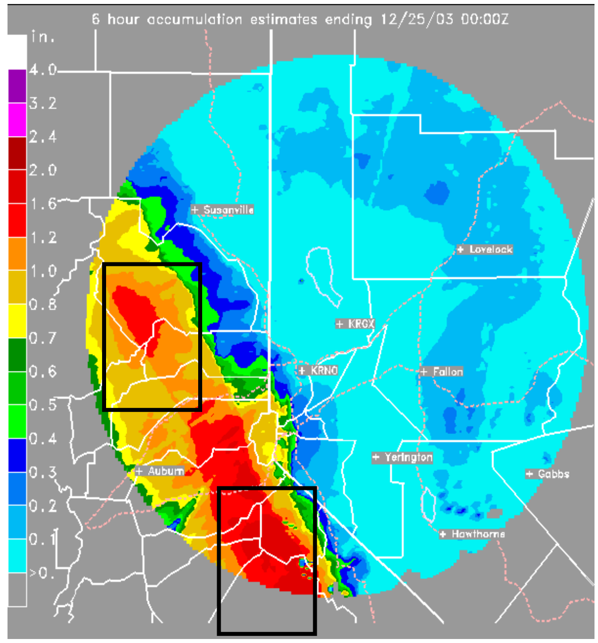


Figure 11b. Radar-derived 6-hour acumenlasted precipitation at 00 UTC 25 Dec 2003.

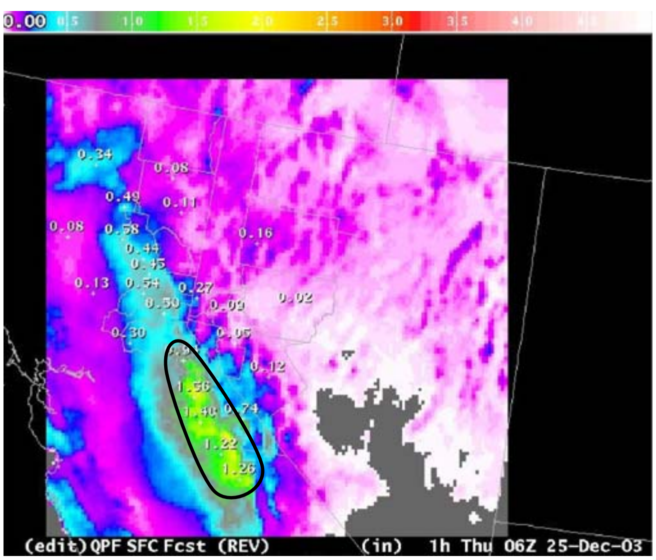


Figure12a. CNRFC 6-hour QPF product for the the period ending 06 UTC 25 Dec 2003.

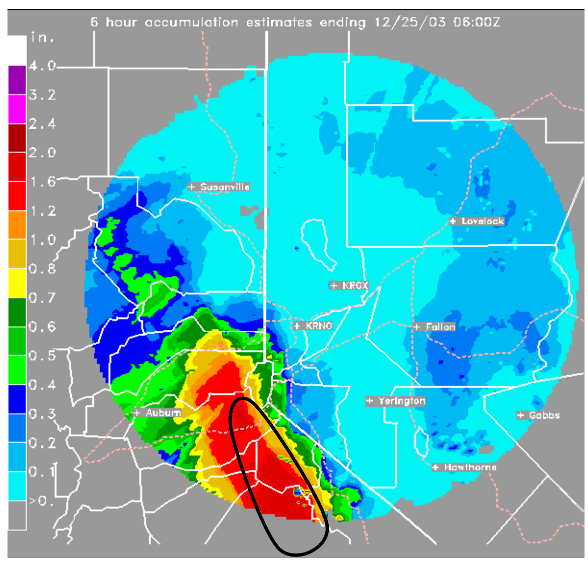
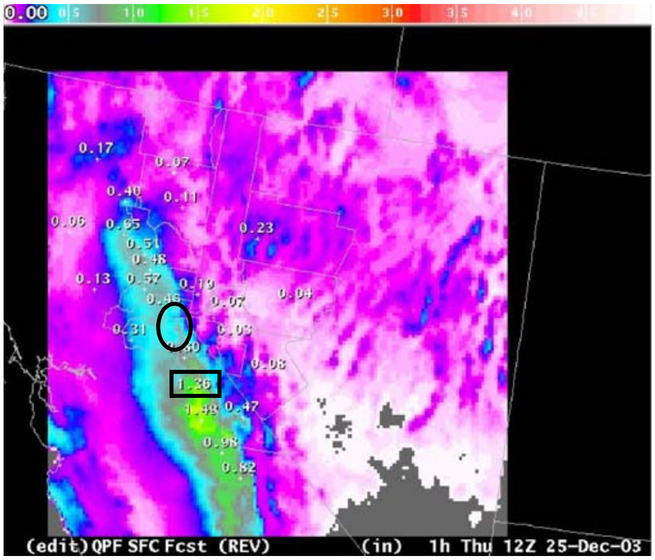


Figure 12b. Radar-derived 6-hour acumenlasted precipitation at 06 UTC 25 Dec 2003.



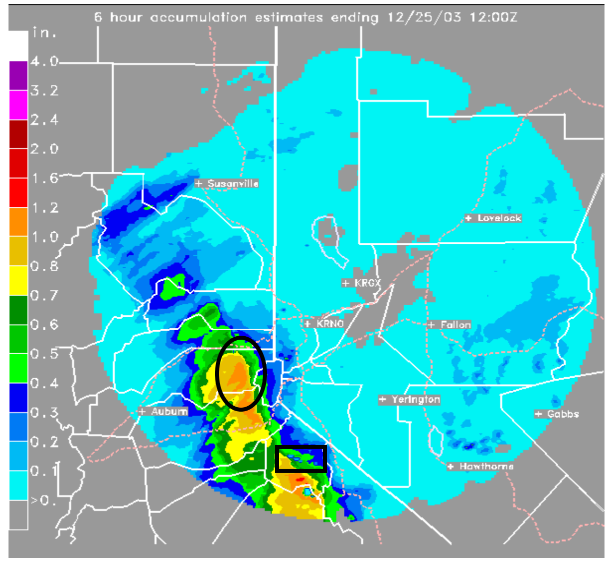


Figure13a. CNRFC 6-hour QPF product for the the period ending 12 UTC 25 Dec 2003.

Figure 13b. Radar-derived 6-hour acumen-lasted precipitation at 12 UTC 25 Dec 2003.

2.3.4 Case of 1-2 January 2004

A New Year's day snow event in 2004 presented a case in which the radar-derived QPE indicated more intense precipitation accumulations than predicted by the CNRFC QPF product. Some storms have a vertical structure (such as the level of freezing or the cloud layer microphysics) markedly different from the mean Vertical Profile of Reflectivity conditions used for the radar QPE method, which can cause over- or under-estimation of accumulations. This event demonstrates one of the worst such cases observed with this type of discrepancy. In Figure 14a, the black rectangle contains an area QPF 6-hour accumulations of approximately one inch, with somewhat larger values to the south, while the radar QPE values (Figure 14b) were > 2.4 inches within the northwest portion of the rectangle area. Measured accumulation was 0.72 inches at HLLC southwest of Lake Tahoe (Figure 14b), much more closely matching the QPF than the radar QPE magnitude. Figure 15a and 15b displayed a similar discrepancy in the magnitude of the precipitation, and the radar QPE continued to indicate that significant precipitation was further north than shown by the QPF pattern. Again, gauge measurements indicated that the radar QPE was an over-estimate. Case studies such as this are very valuable in refining both the radar estimation method and forecast process.

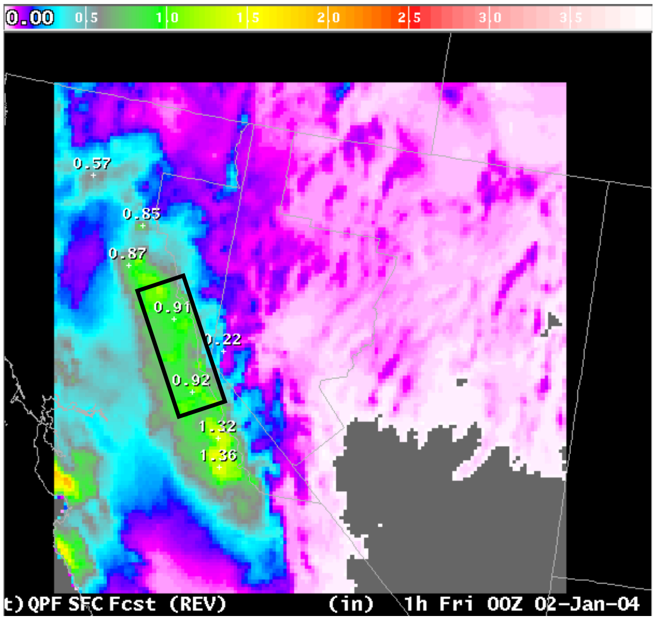


Figure14a. CNRFC 6-hour QPF product for the the period ending 00 UTC 1 Jan 2004.

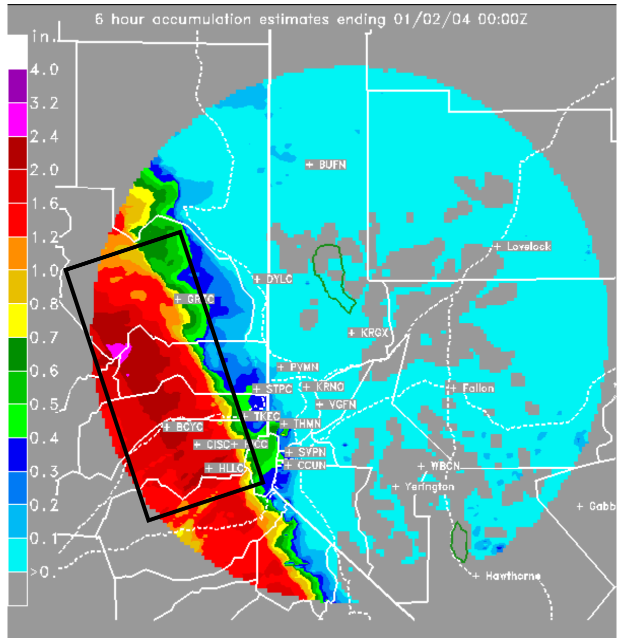


Figure 14b. Radar-derived 6-hour accumulated precipitation at 00 UTC 2 Jan 2004.

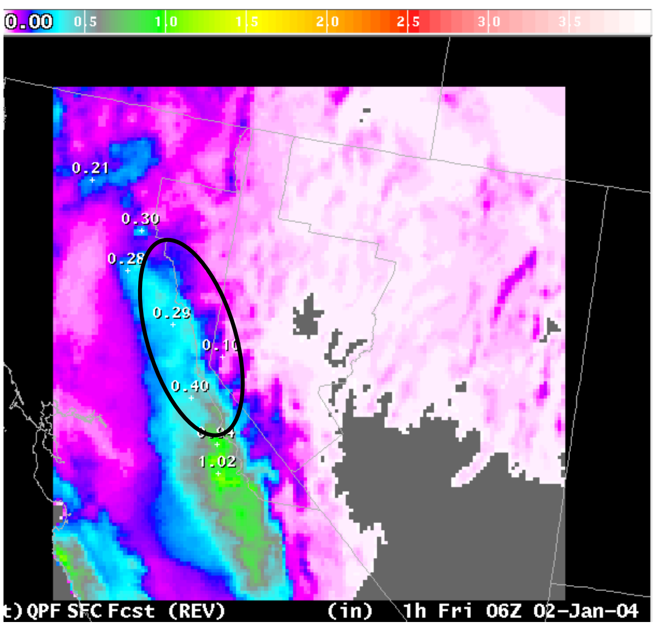


Figure15a. CNRFC 6-hour QPF product for the the period ending 06 UTC 2 Jan 2004.

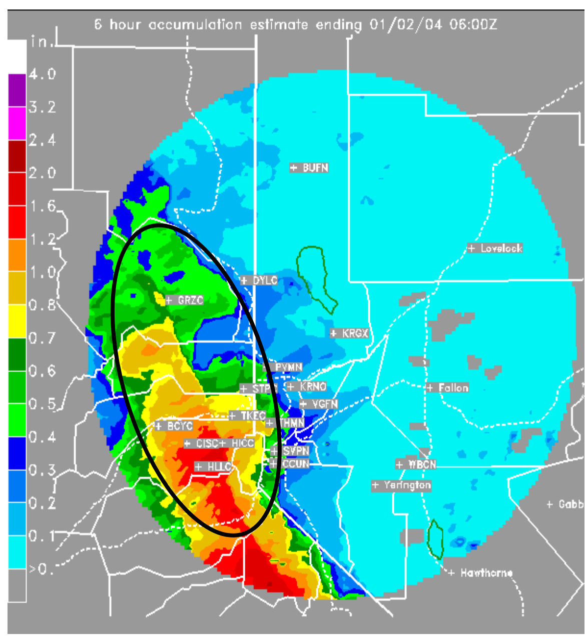


Figure 15b. Radar-derived 6-hour accumulated precipitation at 06 UTC 2 Jan 2004.

2.4 Summary

Side-by-side comparisons of CNRFC products accessed in the IFPS system and the DRI radar product graphics provide an excellent method of evaluating conditions where the CNRFC QPF produces spatially consistent precipitation fields and magnitudes similar to radar observations. The WSFO Reno staff can now make direct comparisons such as this for any storm during their operational forecast process, using the DRI graphics and observation-radar verification data for > 30 hydromesonet measurement sites. Limitations in this method of intercomparison between the CNRFC products and the radar products are that the color enhancement tables for the two products are different (and may vary due to auto-scaling), and there are differences in grid resolution, scale and map projection. In order to facilitate analysis of differences and similarities between the two products, Serena Chew developed a program that converts the radar DRI precipitation estimates from the WSR-88D radar into netCDF format. These radar-product netCDF files can be processed and viewed by IDL and now in GFE. This will allow the Reno WSFO to not only verify gridded precipitation forecasts from the RFC and the WSFO but also allow comparison of the precipitation estimates, derived at the RFC from point data, with the precipitation estimated from the improved DRI 88D algorithms.

Section 3: Benefits and Lessons Learned: Operational Partner Perspective

Collaboration on this project has benefited the WSFO IT staff. They are more aware of procedures for converting between various digital forecast formats, with application for converting any gridded product into IFPS format. The forecast staff has benefited from having precipitation forecast guidance in IFPS format, and being made more aware of improved radar precipitation estimates produced operationally by DRI using the Reno WSR-88D data.

The difficulty with producing the radar product in a readable netCDF format for IFPS was solved late in the project so direct comparisons within GFE of the various data was not done. The frame work is now in place for the Reno WSFO to do verification and comparison of all three data sources. This will allow more effective viewing, point sampling, differencing and temporal accumulation periods that use the CNRFC QPE and QPF with the radar-derived precipitation products together. One lesson learned regarding the creation of products for use in IFPS is to try to contact staff who are directly involved in the development of code for these IFPS products, to facilitate the process of determining required technical specifications for the file formats, file global attributes and processing protocol.

Section 4: Benefits and Lessons Learned: University Partner Perspective

This project has contributed to additional research discussions and other professional exchange between the partners. Research related to this project includes radar analysis of winter storm events in which DRI is conducting operational cloud seeding. The NWS IFPS products will contribute to forecasting and diagnosis of storm evolution. The graduate student working on the COMET project is also working with Arlen Huggins in the DRI cloud seeding program supported by the State of Nevada. In addition, she participated in a mountain meteorology field course in which she gathered data on snowfall measurement methods that generated additional knowledge of errors inherent in precipitation observations that are used in evaluation of radar products.

Section 5: Publications and Presentations prepared from this Project

Wetzel, M., A. Huggins, S. Chew, S. Keck, J. Fischer, B. Brong, D. Pike and C. Jordan, 2003: Merging hydrometeorological data for the National Digital Forecast Database. *Tenth Annual Workshop on Weather Prediction in the Intermountain West*, 6 Nov 2003, Reno, NV.

Chew, S., M. Wetzel, J. Fischer, A. Huggins, D. Pike, B. Brong and S. Keck, 2004: Integrating Observation Data and New Radar Algorithms into the National Weather Service Interactive Forecast Preparation System. To be presented at: *Eleventh Annual Workshop on Weather Prediction in the Intermountain West*, 4 Nov 2004, Reno, NV.

Section 6: Summary of University/Operational Partner Interactions and Roles

The collaboration on this project has enhanced the relationship between the operational staff at the Reno National Weather Service Forecast Office and the researchers at DRI. The roles of the university scientists (M. Wetzel, A. Huggins, S. Keck) included supervising the research of a graduate student assistant partially supported by this project (Serena Chew), holding project meetings and discussions with the NWS lead scientist (Reno SOO Jim Fischer), installing and testing the GFE software, and compiling project reports. The WSFO efforts involved several staff members (Jim Fischer, David Pike, Brian Brong, Chris Jordan) in activities related to project leadership, IT support related to the GFE, IFPS and AWIPS, facilitating contacts to the CNRFC, and scientific discussions. The interactions between operational forecasters and university scientists contributed to the understanding of local and regional forecast priorities in orographically-forced precipitation events. The team members from DRI and NWS greatly appreciate the help of Alan Haynes and others at CNRFC as well as staff at the NWS Western Region Headquarters in this effort.

Serena Chew, while working as a graduate student assistant on this COMET Partners Project, traveled with NWS staff members to CNRFC and attended a Heavy Precipitation Workshop at the University of California, Davis. Ms. Chew has also brought students from a University of Nevada meteorological dynamics class to the NWS office to become familiar with the forecast process of the NWS.

Communication between the partners has increased the participation of NWS Reno forecast staff in scientific seminars held at Desert Research Institute, and the UNR/DRI faculty and graduate students have participated in training sessions at the WSFO. The NWS Reno forecast staff has become more aware of ongoing research being done at DRI directly relating to the mission of the NWS. As an indirect result of communication during this project between

DRI and NWS, another COMET proposal was initiated to investigate high wind events and mesoscale modeling.

References

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