USE OF RADAR FOR SPATIAL SNOW MAPPING: IMPLICATIONS FOR WATER SUPPLY FORECASTS

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ABSTRACT

Water supply forecasts in the West rely largely on data from over 700 SNOw TELemetry (SNOTEL) sites in the Western United States. Forecast methodology is based on 30-yr regression periods using SNOTEL and measured run-off. However, SNOTEL data represent point values and are rarely sufficiently clustered to depict the true 3-dimensional spatial distribution of snowfall. Furthermore, many headwaters basins do not have SNOTEL sites. Thus the lack of observations can result in large uncertainties in the forecasts. This paper presents a case study from a gap-filling radar project that targeted the San Juan Mountains in Southwest Colorado. For the Animas River Basin the additional radar observed a 10-fold increase in the snow water equivalent compared to surrounding NEXRAD radars. In addition the radar depicted the spatial distribution of precipitation. While the location of the radar was not optimal, radar quantitative precipitation estimates were very similar to SNOTEL precipitation amounts at most SNOTEL locations. (KEYWORDS: radar, SNOTEL, snowpack assessment, runoff forecasting, San Juan Mountains)

INTRODUCTION

Water supply forecasts in the West largely rely on data from over 700 SNOw TELemetry (SNOTEL) sites in the Western United States with 110 in Colorado (Fig. 1). Forecast methodology is based on 30-yr regression periods using SNOTEL and measured run-off (Garen, 1992). Close examination reveals the low density of SNOTELS in the San Juan Mountains. In fact, many headwater basins do not have SNOTEL sites.

While east of the Rocky Mountains weather radar can used extensively for flood warnings and hydrologic forecasting, NEXRAD coverage in the West is sparse. As a result the western River Forecast Centers use only gauge data in their hourly QPE analyses. A map of radar quality index for Colorado is shown in figure 2 and indicates that the west slopes have very little radar coverage. Effective radar coverage depends on the beam height above the ground, as well as the beam height relative to the height of the 0 C (melting) level. Thus, the RQI can change over time as the melting level changes. The radar's beam width relative to storm depth is an additional factor in the RQI.

The National Severe Storms Laboratory's mission includes improvement in quantitative precipitation estimates (QPE) for the Nation. High-quality QPE requires a multi-radar multi-sensor approach (e.g., Vasiloff et al. 2007). In February 2011 NSSL conducted a gap-filling radar field experiment to sample snow storms in southwest Colorado mountains. The goal was to demonstrate the potential benefit of an additional radar for various winter weather impacts. These include hydrologic forecasting applications, airport operations, emergency management, highway and aviation safety and avalanche control. The NSSL X-band polarized Doppler weather radar (NOXP) was deployed at the Durango – La Plata County Airport. Two real-time reporting snow gauges were installed between the airport and the foothills to the north. The radar captured a significant snow storm on February 19th – 21st with as much as 12" reported at high elevations. This paper documents the spatial measurements by the radar and discusses implications for improved water supply forecasts based on existing tools and prospects for new water supply forecast methods.

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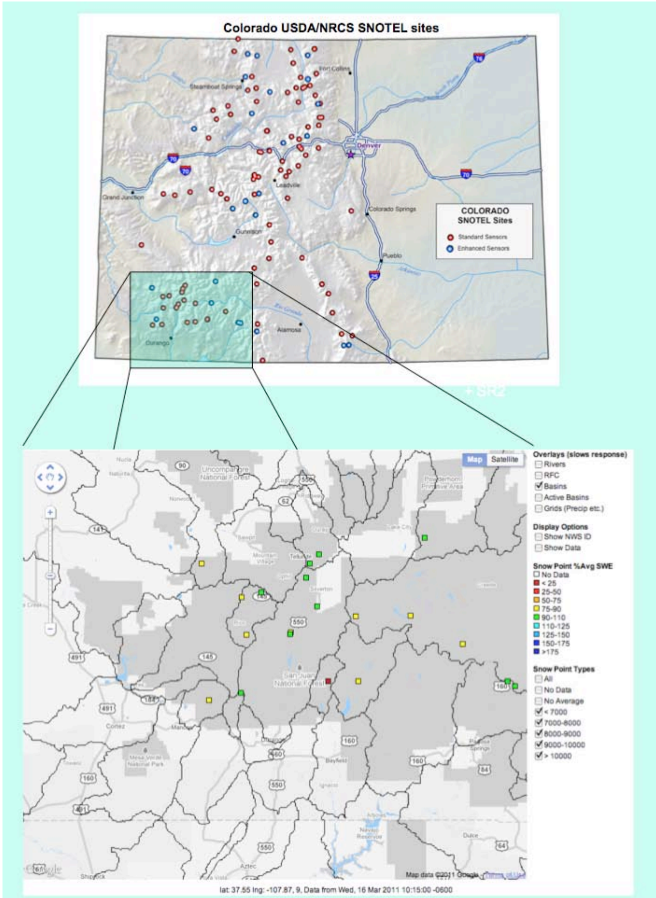

Figure 1. SNOTEL sites in Colorado. Colors represent SWE % of normal as of 16 March 2011.

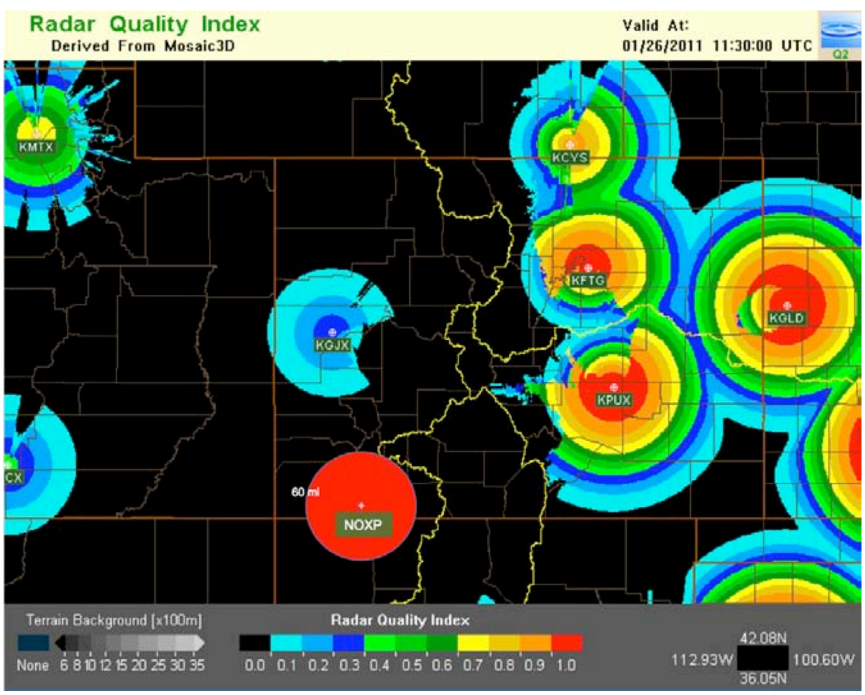

Figure 2. Radar Quality Index map for Colorado from NSSL's QPE verification System (http://nmq.ou.edu). Red indicates highest confidence in radar data and light blue indicates lowest confidence. The NOXP is hypothetical and is not actually integrated within the NMQ system. Boundaries of the four river forecast centers that intersect in central Colorado are outlines in yellow.

19-20 FEBRUARY 2011 STORM CASE STUDY

A significant winter storm moved through southwestern Colorado starting early February 19, 2011 and tapering off early February 21st. The bulk of snow fell on the first day with as much as 1.2" of snow water equivalent (SWE) precipitation falling in a 24 hour period north of Silverton, CO. Radar coverage degrades with increasing range (height above the earth) and the best coverage for the NOXP location was the south facing slopes of the San Juan Mountains. Radar precipitation estimates were calculated from the reflectivity fields using the standard reflectivity- snowfall relationship $Z=75S^2$ used by the NWS NEXRAD algorithm (Z is radar reflectivity factor and S is SWE precipitation rate). Precipitation began as rain at the lower elevations turning to all snow with the passage of a cold front.

Radar SWE maps are shown in figure 3 for the 24 hour period ending 0800 LT on 20 February. NSSL's National Mosaic and QPE system (http://nmq.ou.edu) was used to process the radar data and provide SWE fields using merged regional NEXRADs without the mobile radar and with the mobile radar (Fig. 3). SNOTEL data are overlaid using the same color scale. Selected basins are outlined with the Animas River Basin in blue.

Additional data from the mobile radar resulted in a 10-fold increase in SWE for the Animas River Basin, from under 3,400 acre-feet to nearly 35,000 acre-feet. Radar totals match SNOTEL readings to varying degrees along the Animas Basin with the radar less than SNOTEL in the north and visa versa in the south. Note that the average basin SWE amounts for each basin are identical illustrating that the right answer can result from the wrong reasons. Efforts are ongoing to calibrate the radar estimates with SNOTEL data. Reasons for underestimation in the north of the basin and overestimation in the south are being explored and may be related to radar beam coverage issues and variable snow levels. Hourly stratification by altitude of rain vs. snow for smaller sub-basins will be performed.

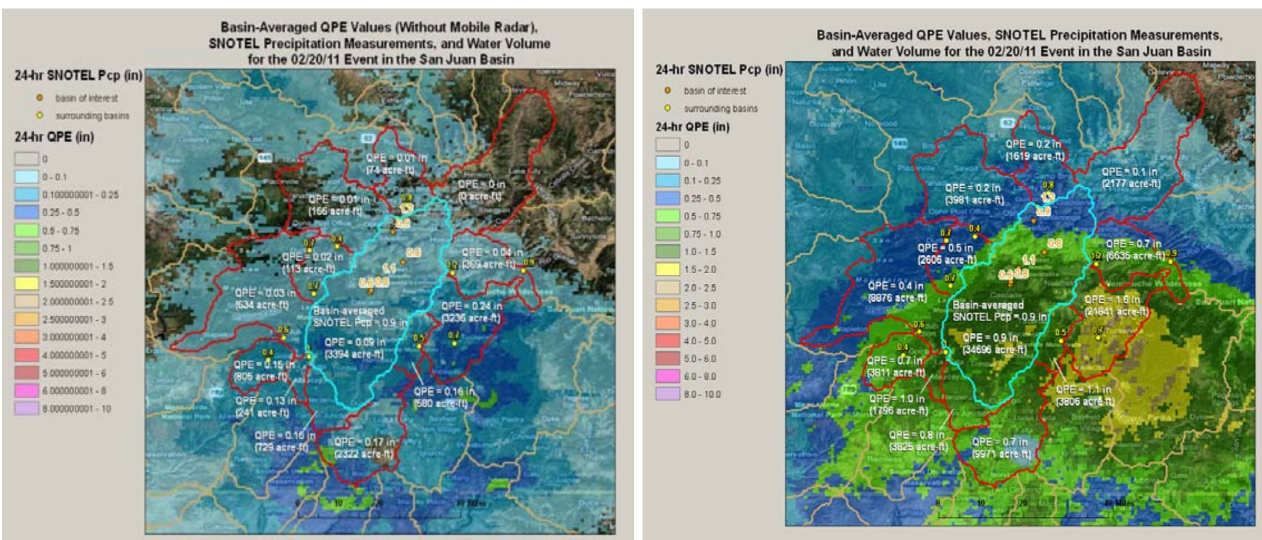

Figure 3. SWE images for the 24 hr period ending 0800 local time on 20 February 2011. Merged NEXRAD QPE without the mobile radar is at the left. Merged NEXRAD QPE including the mobile radar is at the right. The SNOTEL color scale is the same as for the radar QPE. The Animas River Basin is outlined in blue.

DISCUSSION

We have demonstrated that radar can provide spatial estimates of SWE. Future efforts include a demonstration project that "forces" SNODAS with quality radar QPE and provide enhanced spatial data sets to stakeholders and forecasters for improved decision making.

A limitation of current water supply forecasting methods is the inability to fully to measure mountain snowpack in the Western U.S. The Colorado Water Conservation Board monitors snowpack and provides various layers of snow-related information on their Weather Modification Decision Support System(http://flooddss.state.co.us/pages/WeatherModification.aspx). The system includes spatial data at 1 km resolution from the NOHRSC National Snow Analyses SNOw Data Assimilation System (Carroll et al. 2001) as well as point data from SNOTELs. Near the end of a run-off season many SNOTELs indicated little-to-no SWE, yet snowpack at higher elevations was still melting resulting in under-forecast flows. Figure 4 shows an example of this on 16 June 2011. Because of elevation differences, most SNOTELs showed near-zero SWE while SNODAS indicated snowpack SWE of 12-15”. Note the large difference between Wolf Creek Summit (19.0” SWE) and Upper San Juan (1.1” SWE) SNOTELs. The effect of not fully observing snowpack is noted in a Rio Grande Roundtable discussion of forecast uncertainties (Alamosa News, 16 June 2011): “The benefits of better observations and forecasts are tremendous. In the Rio Grande Basin, our Compact operations are based

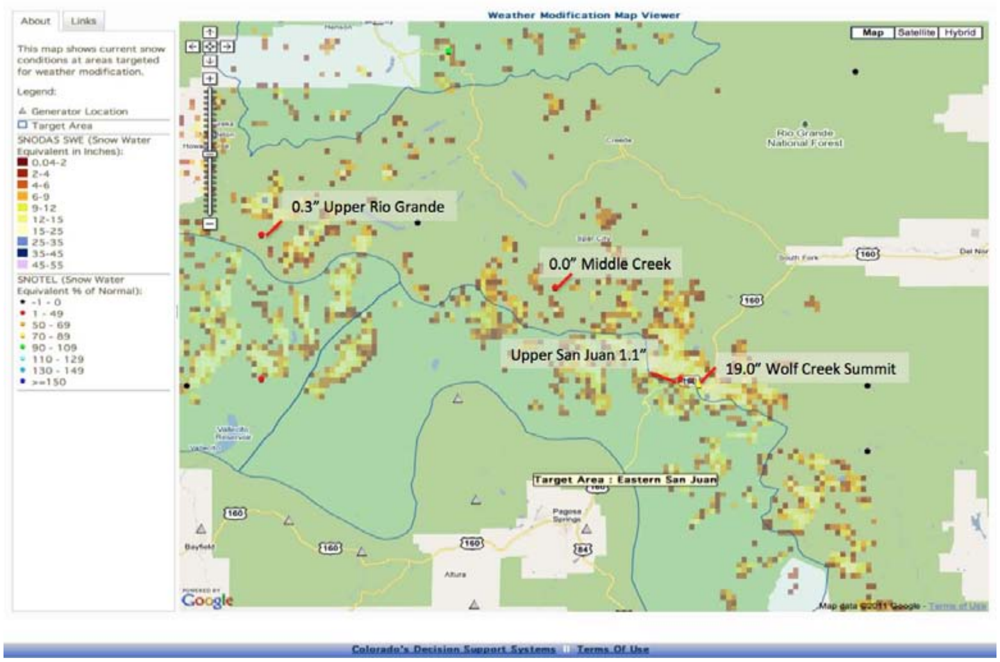

Figure 4. Image from the CWCB DSS showing SNOTEL and SNODAS data on 16 June 2011. SNOTEL colors indicate percent of average SWE.

exclusively on stream flow forecasts. Inaccurate stream flow forecasts can cause unnecessary curtailment of ditches, over- or under-delivery of Colorado’s compact obligations, and a disruption of the priority system.” (Craig Cotten, Division Engineer, CDWR, Division 3).

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