CROSS-VALIDATION OF GRIDDED PRECIPITATION DATASETS AND A REGIONAL CLIMATE SIMULATION FOR THE INTERIOR WESTERN UNITED STATES

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ABSTRACT

This study compares orographic precipitation estimates in the interior western United States (IWUS) from four gauge-driven gridded datasets, a radar-based dataset, and a 10-year, 4 km convection-permitting simulation aided by gauge measurements. Gauge-driven gridded precipitation estimates disagree in areas where gauges are sparse, especially at higher elevations. The radar-based dataset underestimates the winter precipitation in IWUS because of blockage and lack of low-level radar coverage in complex terrain. The model simulation compares well against gauge measurements for winter precipitation. Comparison between model and gauge-driven datasets suggests their differences are related to elevation, gauge density and wind speed. The substantial disagreement between model and the gridded datasets over some mountains may motivate the re-evaluation of some gauge records and the installation of new gauges in regions marked by large discrepancies between modeled and gauge-driven precipitation estimates. (KEYWORDS: gridded precipitation, climate, DAYMET, SNOTEL, climate simulation)

INTRODUCTION

The Interior Western United States (IWUS) is mostly arid, but home to the headwaters of several major river systems (Woodhouse, 2004). Quantitative precipitation estimation (QPE) is important but challenging in mountainous IWUS (e.g. Rasmussen et al. 2012). The SNOw TELemetry (SNOTEL) network is one of the most important gauge networks (Serreze et al. 1999) in this region. However, the SNOTEL network only provides point measurements of precipitation, and the gauge density is low compared to that in highly populated or agricultural regions. Several different techniques have been developed to provide more complete precipitation distribution maps, including “terrain-aware” interpolation techniques using gauge measurements as input (e.g. Daly et al., 1994), space-based and ground-based remote sensing retrievals (e.g. Lin and Mitchell, 2005), and numerical model simulations (Liu et al., 2016). But the relative performances of different techniques in QPE are not well understood, so a cross-validation of different precipitation datasets is necessary.

The “terrain-aware” interpolation techniques have been widely used to study the precipitation distribution over IWUS (e.g. Daly et al., 1994; Thornton et al., 1997). There are several gauge-driven gridded datasets, such as Precipitation-elevation Regressions on Independent Slopes Model (PRISM, Daly et al., 1994), Daymet (Thornton et al., 1997), North American Land Data Assimilation System Stage II (NLDAS II, Xia et al., 2012), and the Continental United States ensemble gridded datasets (CUSEG, Newman et al., 2016). These datasets are developed based on physically informed statistical relations between precipitation and terrain driven by gauge measurements, but use different methods. Previous studies suggest there are large uncertainties of gauge-driven gridded datasets in areas where gauges are sparse, especially over mountains (e.g. Daly et al., 2008; Gutmann et al., 2012).

Other than gauge-driven gridded datasets, remote sensing techniques have been developed used to study the precipitation climatology (e.g. Lin and Mitchell, 2005). Datasets developed using ground-based scanning weather radars, such as the National Centers for Environmental Prediction (NCEP) National Hourly Multi-sensor Precipitation Analysis Stage IV (NCEP IV) dataset (Lin and Mitchell, 2005), is quite suitable to study the precipitation distribution at high spatial resolution (4 km). However, weather radar network is not sufficiently dense in IWUS. In addition, ground-based radars are challenged to estimate surface precipitation over complex terrain, because of blockage by the first range of mountains, and inability to capture the low-level orographic precipitation growth zone (e.g. Lin and Hou, 2012; Smalley et al., 2014).

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Recently numerical weather prediction (NWP) models with high resolution (< 6 km) have been used to study the precipitation climatology over complex terrain. Ikeda et al. (2010) showed that Weather Research and Forecasting model (WRF) at a grid spacing smaller than 6 km well captures the seasonal snowfall in the Colorado Rockies; the difference between the model output and SNOTEL is within 20%. Liu et al. (2011) pointed out that this performance is highly sensitive to the choice of cloud microphysics parameterization. Due to the good performance in simulating orographic precipitation over complex terrain, high-resolution WRF simulations have been used to assess changes of orographic precipitation in a changing global climate (e.g. Liu et al. 2016). Gridded precipitation datasets developed using different techniques have been widely used for various purposes due to their completeness (Lundquist et al., 2015), but their accuracy is not well known. This study aims to cross-validate high-resolution precipitation datasets currently available in the IWUS and a 10-years continuous convection-permitting WRF simulation at 4 km horizontal resolution. The model output is compared with gauge data (SNOTEL), a radar-based dataset (NCEP IV) and four gauge-driven gridded datasets (PRISM, Daymet, NLDAS II, CUSEG).

DATASETS

The model simulation is conducted using WRF version 3.7.1. The Climate Forecast System Reanalysis (CFSR; Saha et al. 2010) is used to provide the initial and lateral boundary conditions. The unnested model domain has 420 × 410 grid points at 4 km horizontal resolution, and 51 vertical levels, with a high layer density close to the ground. The simulation runs from October 2001 to February 2012, and the output from March 2002 to February 2012 is used to study the precipitation patterns in the IWUS. SNOTEL measurement is used to evaluate the modelled results. The four gauge-driven gridded datasets used in this study are PRISM, Daymet, NLDAS II, and CUSEG. CUSEG is a 100-member ensemble precipitation dataset using probabilistic interpolation (Newman et al. 2016). The radar-based dataset (NCEP IV) uses merged surface radar and rain gauge products to produce hourly precipitation at 4 km resolution (Lin and Mitchell, 2005). Information of the datasets used in this study is shown in Table 1.

Table 1. Information about WRF and the precipitation datasets used in this study.

	Spatial Resolution	Temporal Resolution	Duration	Type	Reference
SNOTEL	single points	daily	1979-present	gauge	Serreze et al. (1999)
PRISM	4 km	monthly	1981-present	gauge and statistical model	Daly et al. (1994)
Daymet	1 km	daily	1980-2015	gauge and statistical model	Thornton et al. (1997)
NLDAS II	0.125º (~12 km)	hourly	1979-present	gauge, ground-based radar and statistical model	Xia et al. (2012)
CUSEG	0.125º (~12 km)	daily	1980-2012	gauge and statistical model	Newman et al. (2015)
NCEP IV	4 km	hourly	2002-present	ground-based radar and gauge	Lin and Mitchell (2005)
WRF	4 km	hourly	2002.3-2012.2	numerical model	

RESULTS

Figure 1 shows the maximum absolute bias between any two of PRISM, Daymet, NLDAS II and the 100 CUSEG datasets (103 datasets in total, giving a total of 5253 pairs) at any grid point in the study domain. Bilinear interpolation is used to project different datasets onto a common 4 km grid. The difference between different datasets generally is larger over the mountains than the plains in all seasons, maybe not in a relative sense, but certainly in an absolute sense (Figure 1). This likely is due to different statistical relations between precipitation and terrain used for the different datasets. In areas with lots of SNOTEL sites (e.g. the Front range in Colorado), the difference between the datasets is relatively small. The differences between gridded datasets are relatively small in summer (0-150 mm) and relatively large in winter and spring (0-250 mm) (DJF and MAM), which is the wettest period over the mountains.

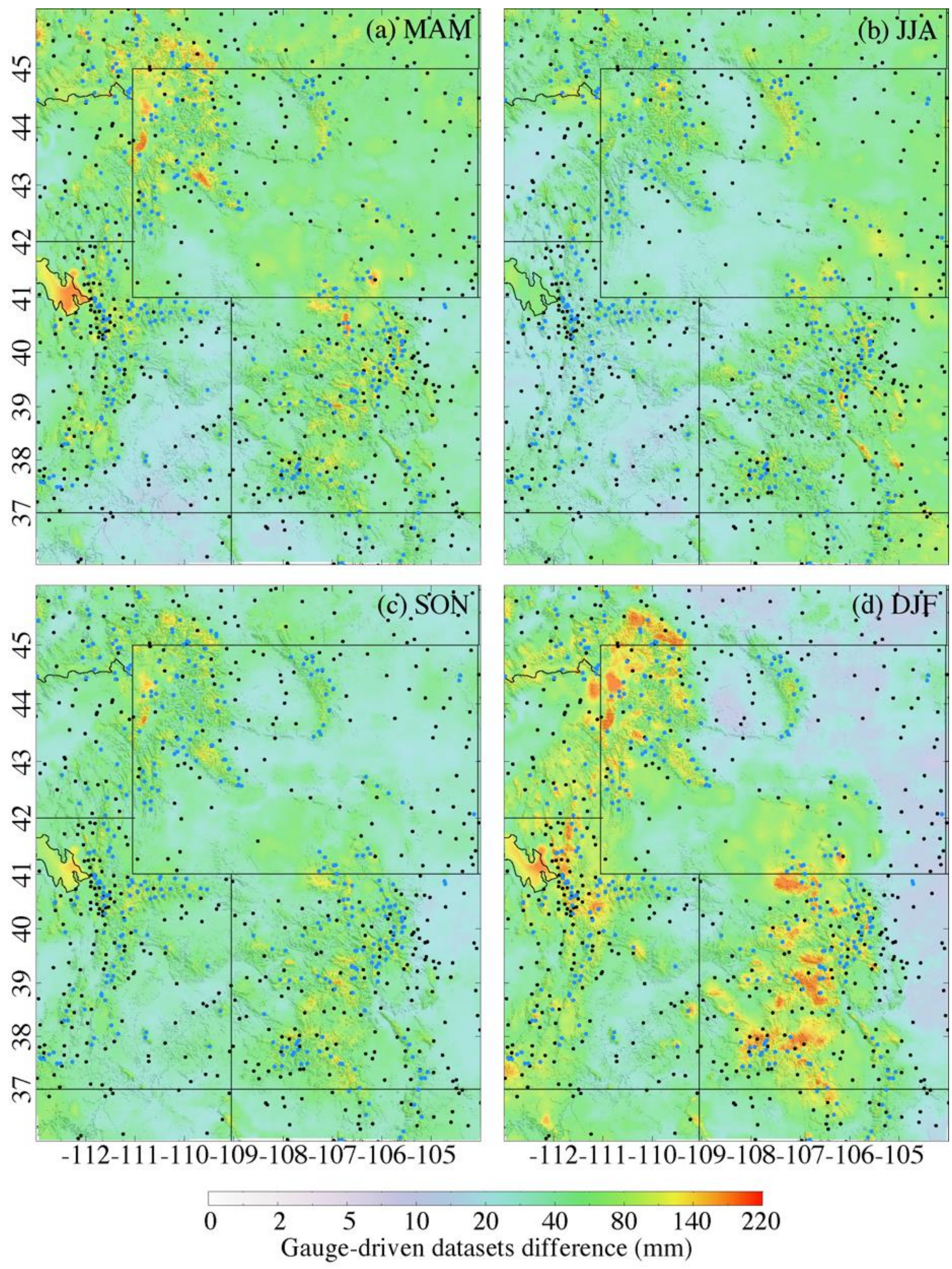

Figure 1. Seasonal precipitation estimation uncertainty evident from gauge-driven gridded datasets in spring (MAM), summer (JJA), fall (SON) and winter (DJF). The uncertainty is defined as the maximum absolute difference between any two of PRISM, Daymet, NLDAS II and the 100 CUSEG datasets (103 in total) for each grid box. The blue (black) dots indicate the locations of SNOTEL (other) gauges.

The relative performances of the four gauge-driven gridded datasets are evaluated by comparing a gauge-driven gridded datasets (PRISM, Daymet, NLDAS II or CUSEG) against the mean of them (not shown). The results indicate PRISM has the least RMSB of summer precipitation against the mean (11.41 mm), and Daymet has the least RMSB of winter precipitation against the mean (24.52 mm). NLDAS II estimates 13.52 mm more summer precipitation and 12.85 mm less winter precipitation compared to the mean, while CUSEG estimates 8.92 mm less summer precipitation and 18.48 mm more winter precipitation compared to the mean. A comparison between NCEP IV and the four gauge-driven datasets (not shown) suggest NCEP IV compares well against other datasets in the vicinity of radars, but grossly underestimates winter precipitation over the mountains, probably because of blockage by the first range of mountains, and inability to capture the low-level orographic precipitation growth zone (Lin and Hou, 2012; Smalley et al., 2014).

The WRF output has been evaluated in detail using SNOTEL measurements (not shown). The results indicate WRF captures the characteristics of winter precipitation very well. Given these possible data-related uncertainties in the gauge-driven gridded datasets, we can assume WRF to be the reference to evaluate gridded observational datasets. A further comparison between WRF and gauge-driven datasets (not shown) indicate the standard deviations of wintertime precipitation bias (again assuming WRF to be the truth), estimated by all gauge-based gridded datasets, increase with terrain height, suggesting that these observational datasets have larger uncertainties at higher elevations, consistent with Figure 1. In addition, the correlation coefficient between any of the gauge-driven gridded datasets and WRF decreases with decreasing gauge density, as in some high-elevation places, indicating uncertainties in the statistical interpolation techniques.

The algorithms behind the gauge-driven gridded datasets lack detailed physical processes. We find that the gauge-driven gridded datasets slightly overestimate precipitation when the surface wind is weaker than 16 m s^{-1}, and underestimate precipitation in winds exceeding 24 m s^{-1}. So, in mountain areas where strong winds are common, all gauge-driven gridded dataset may underestimate the wintertime precipitation.

CONCLUSIONS

This study compares the precipitation estimates in the IWUS by four gauge-driven gridded datasets (PRISM, Daymet, NLDAS II and CUSEG), a radar-based dataset (NCEP IV), and a 10-year, 4-km resolution, convection-permitting WRF simulation aided by gauge measurements. The results are helpful to understand the relative performances of different precipitation datasets in the IWUS. The main findings are as follows:

- Cross-validation of WRF, PRISM, Daymet, NLDAS II, CUSEG and NCEP IV suggests that uncertainties of the gauge-driven gridded datasets are larger over mountains in winter. Among the four gauge-driven gridded datasets, NLDAS II estimates the least winter precipitation and the most summer precipitation, CUSEG estimates the most winter precipitation and the least summer precipitation in the IWUS. PRISM and Daymet are more consistent with WRF than NLDAS II and CUSEG. NCEP IV compares well against other datasets in the vicinity of radars, but grossly underestimates winter precipitation over the mountains.

- Comparison between WRF and the gridded gauge-driven datasets indicates the bias standard deviation between WRF and gauge-driven datasets is larger at higher elevations; WRF and gauge-driven datasets are better correlated in areas with denser gauges; Compared to WRF, gauge-driven datasets tend to overestimate the precipitation in areas with relatively weak prevailing wind, and tend to underestimate the precipitation in areas with strong prevailing wind speed.

- Cross-validation of different precipitation datasets can be helpful to inform where gauges are too sparsely distributed, and to indicate which SNOTEL sites may be questionable. Due to the good performance in estimating wintertime precipitation, WRF can be useful to study the precipitation distribution in IWUS and its future changes.

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