A Comparison of the U.S. Climate Reference Network Precipitation Data to the Parameter-Elevation Regressions on Independent Slopes Model (PRISM)

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ABSTRACT: Since drought and excessive rainfall can have significant socioeconomic impacts, it is important to have accurate high-resolution gridded datasets that can help improve analysis and forecasting of these conditions. One such widely used dataset is the Parameter-Elevation Regressions on Independent Slopes Model (PRISM). PRISM uses a digital elevation model (DEM) to obtain gridded elevation analyses and then uses a regression analysis along with approximately 15 000 surface precipitation measurements to produce a 4-km resolution daily precipitation product over the conterminous United States. The U.S. Climate Reference Network (USCRN) consists of 114 stations that take highly accurate meteorological measurements across all regions of the United States. A comparison between the USCRN and PRISM was performed using data from 2006 to 2018. There were good comparisons between the two datasets across nearly all seasons and regions; most mean daily differences were <1 mm, with most absolute daily differences ~5 mm. The most general characteristics were for a net dry bias in the PRISM data in the Southwest and a net moist bias in the southern United States. Verifying the PRISM dataset provides us with confidence it can be used with estimates of evapotranspiration, high-resolution gridded soil properties, and vegetation datasets to produce a daily gridded soil moisture product for operational use in the analyses and prediction of drought and excessive soil moisture conditions.

KEYWORDS: Drought; Precipitation; Soil moisture; Water budget/balance; Surface observations

1. Introduction

USCRN stations use highly accurate instruments to measure air temperature, surface temperature, solar radiation, relative humidity, precipitation, wind, soil temperature, and soil moisture (Diamond et al. 2013). In the present study, we compared the USCRN precipitation dataset to the Parameter-Elevation Regressions on Independent Slopes Model (PRISM) analyses (Daly et al. 1994, 2000, 2002, 2008). The PRISM analyses incorporate many different sets of measurements to produce a 4-km resolution daily precipitation product over the conterminous United States. Because the USCRN measurements are highly accurate, they can be used to verify the PRISM analyses. Although stations from this network were included in the PRISM analyses between May and September and after 2017, the USCRN could independently verify the PRISM analyses outside of these times. Also, the results show no significant differences in biases when the USCRN stations were included, which is not surprising given the large amount of additional data assimilated into PRISM. Having a consistent gridded precipitation product is important moving forward to the development of a national water model. Since regions of drought and excessive rainfall can have important socioeconomic impacts, having these more accurate datasets will improve the analysis and prediction of these extreme conditions, thereby helping mitigate adverse effects to the public and private communities.

Due to the highly accurate nature of the measurements, the USCRN precipitation data are used as "ground truth." An additional advantage of using USCRN is that it spans the entire conterminous United States and encompasses all dominant climate regions, and the data are available with the same temporal resolution (i.e., daily) as the PRISM dataset. Also, both the USCRN and PRISM datasets are available as far back as 2006, allowing for multiyear comparisons at individual stations and throughout different climate regions during different seasons. Using the USCRN dataset allows for the identification of regional and/or seasonal biases in the PRISM dataset, allowing for the gridded precipitation product to be a surrogate for the USCRN precipitation.

Once the accuracy of the PRISM dataset has been verified, it can be used as an input parameter into a soil moisture model. Along with gridded estimates of evapotranspiration (ET) from, for example, the Atmosphere–Land Exchange Inverse (ALEXI) model (e.g., Anderson et al. 2007), and high-resolution soil and vegetation analyses, a daily soil moisture product can be developed for operational use in the analyses and prediction of drought and excessive soil moisture conditions.

2. Datasets and methods

a. USCRN stations

The USCRN network precipitation measurements are highly accurate and are made using three Geonor T-200B cells measuring at 5-min intervals. The 5-min measurements at each cell are then used to derive the hourly precipitation values. Each station is also surrounded by a double-fence wind shield to improve collection accuracy. These wind shields have been shown to be effective even for solid precipitation in windy conditions (Rasmussen et al. 2012). The USCRN data are quality controlled and are available on a daily/subdaily time frame from the

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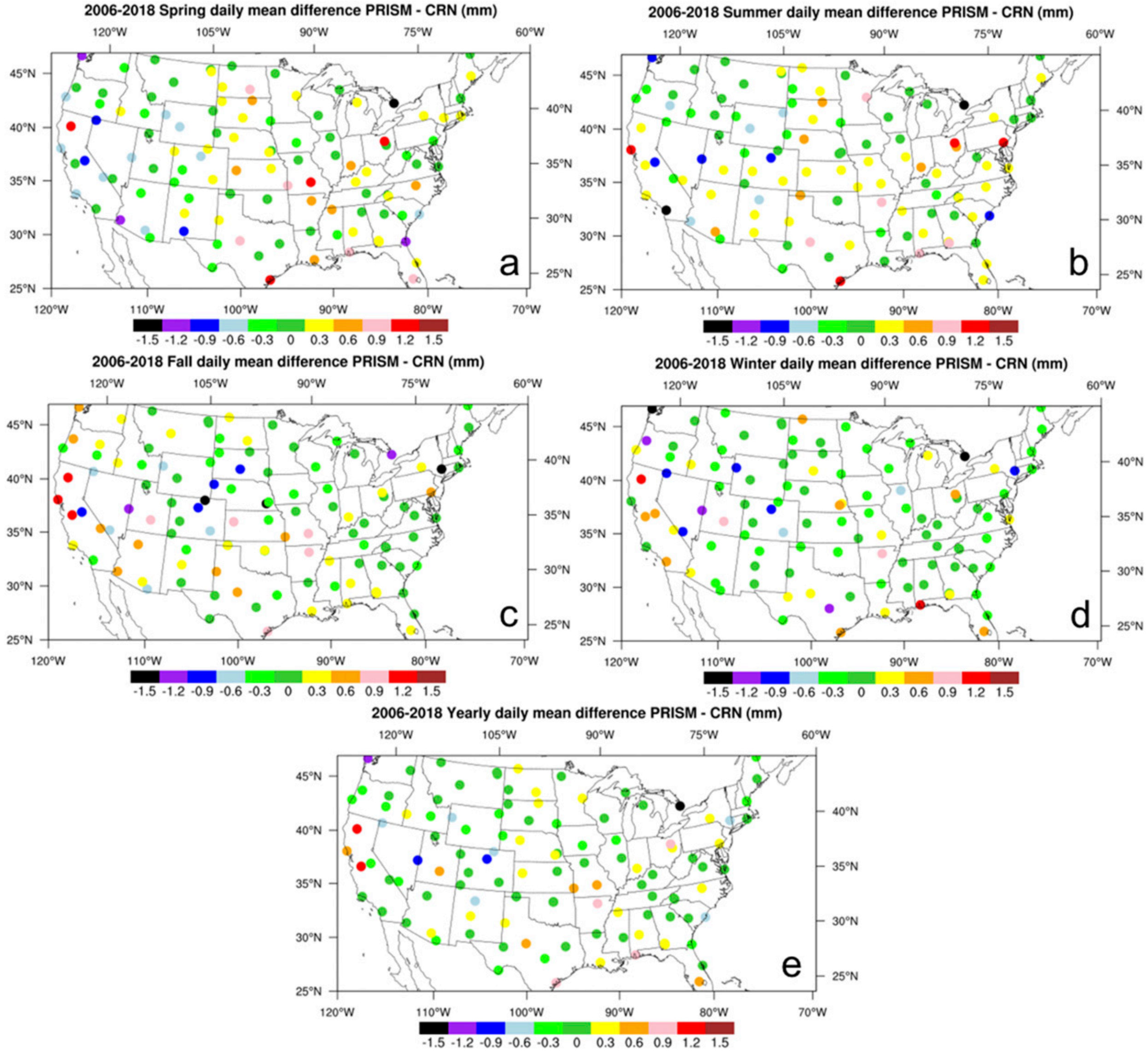

FIG. 1. 2006–18 (a) winter (December–February), (b) spring (March–May), (c) summer (June–August), (d) fall (September–November), and (e) full year mean daily precipitation differences (PRISM − CRN) between the nearest 4-km PRISM grid boxes and USCRN stations. The colored dots indicate the mean precipitation difference.

National Center for Environmental Information (NCEI). Since the data are available already quality controlled, the only modification of the data was to reformat the precipitation data to span a 1200–1200 UTC window to match the daily data window used by the PRISM dataset. For the present study, the 13-yr period of 2006–18 was used in the comparisons.

The USCRN datasets were officially commissioned in 2004, and installation of the stations was completed in 2008. The stations were meant for long-term measurements of 50 years or more to monitor changes in climate in pristine environments, and the stations are calibrated annually to ensure representativeness of the observations. Since installation, several studies have been conducted comparing USCRN stations to other networks. For example, Hubbard et al. (2004) conducted 1-yr side-by-side comparisons of the USCRN network to evaluate temperatures from a maximum–minimum temperature system (MMTS) and found a slight cool bias in the MMTS data. Leeper et al. (2015) compared the USCRN to the U.S. Cooperative Observer Program (COOP) network and found that the COOP stations had a small warm bias in daytime maximum temperatures and a cool bias in daily minimum temperatures. Leeper et al. (2015) also found that the COOP stations recorded less precipitation than the USCRN stations due to lack of shielding of the precipitation gauges. Leeper et al. (2017) used the USCRN to evaluate the North American Regional Reanalysis (NARR) dataset during the 2011–13 drought, finding the NARR was able to capture many aspects of the drought, such as the timing, duration

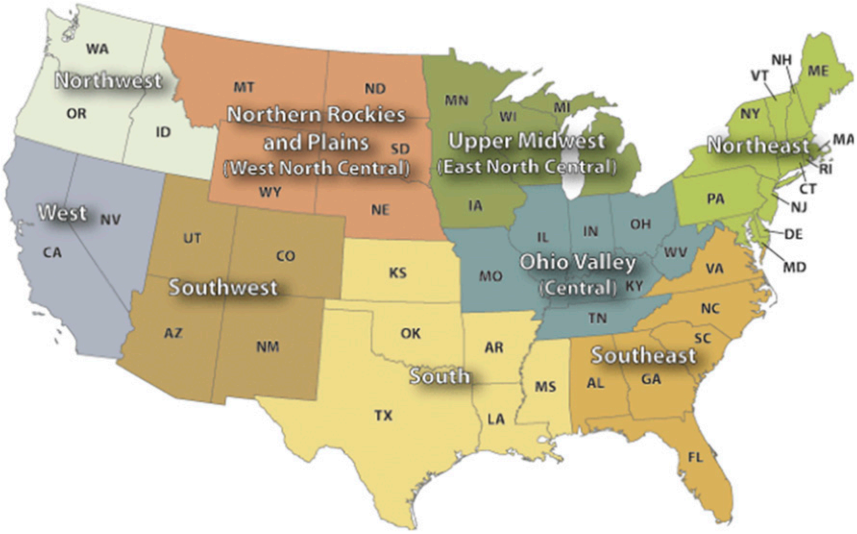

FIG. 2. Nine climate regions used in this study. Image courtesy of the National Centers for Environmental Information.

and spatial extent. Sun et al. (2005) compared the USCRN to the Automated Surface Observing System (ASOS) and found differences in temperature between the two networks of only ~0.1°C.

b. PRISM dataset

The PRISM analyses address the effects of elevation and the scales of orography on the distribution of precipitation, particularly over complex terrain. PRISM uses a digital elevation model (DEM) to obtain gridded elevation analyses, then uses a DEM elevation-precipitation regression to produce a 4-km resolution daily precipitation product over the conterminous United States. It also takes into account prevailing weather patterns and precipitation sources. Many precipitation datasets are used in the creation of the final PRISM gridded dataset. These precipitation datasets include the Community Collaborative Rain, Hail and Snow (CoCoRaHS) network, the COOP and Weather Bureau Army Navy (WBAN) stations, USDA NRCS Snowpack Telemetry (SNOTEL), snow courses, USDA Forest Service and Bureau of Land Management Remote Automatic Weather Stations (RAWS), California Data Exchange Center (CDEC) stations, Bureau of Reclamation Agrimet stations, Environment and Climate Change Canada stations, Reynolds Creek Experimental Watershed stations, H. J. Andrews Experimental Forest stations, Department of Water Resources stations, USDA Forest Service stations, U.S. Geological Survey (USGS) stations, and various other local networks (Daly et al. 2008). The total number of precipitation stations included in the analyses is approximately 15 000. In addition to the station data, data from the National Weather Service's Advanced Hydrometeorological Prediction System (AHPS) 4-km gridded radar product are used to improve the analysis.

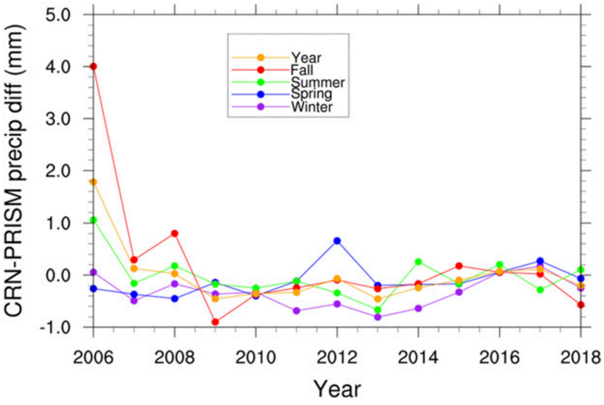

FIG. 3. Mean daily precipitation difference (PRISM minus CRN) as a function of year and season (colored curves) for the Northwest climate region.

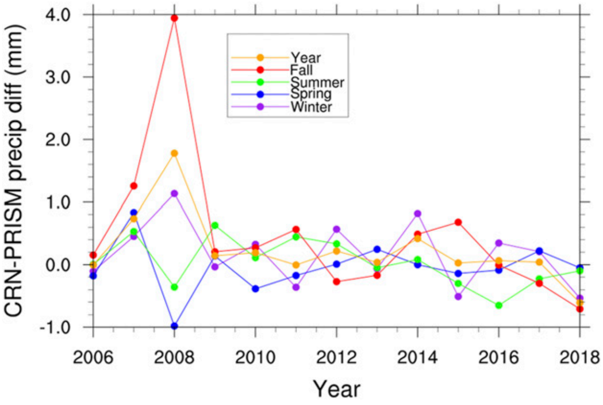

FIG. 4. Mean daily precipitation difference (PRISM minus CRN) as a function of year and season (colored curves) for the West climate region.

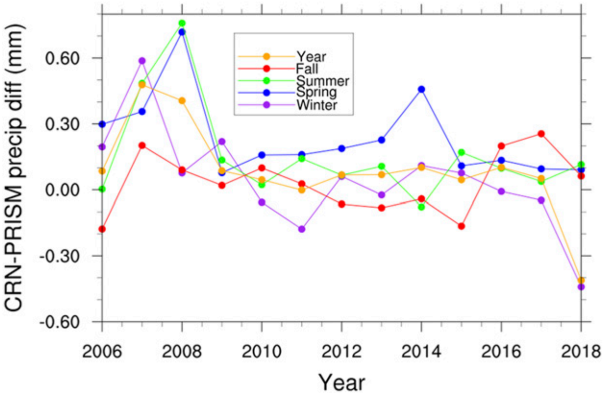

FIG. 5. Mean daily precipitation difference (PRISM minus CRN) as a function of year and season (colored curves) for the West North Central climate region.

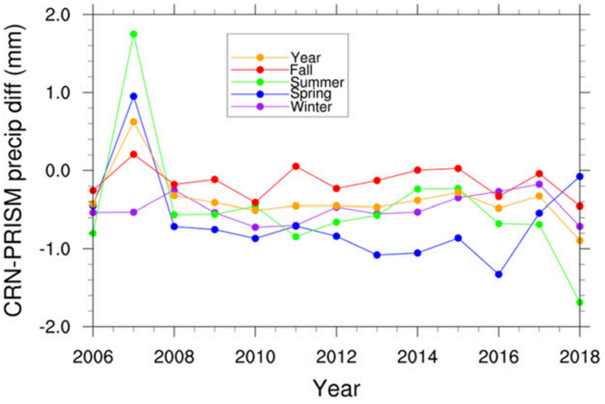

FIG. 7. Mean daily precipitation difference (PRISM minus CRN) as a function of year and season (colored curves) for the Upper Midwest climate region.

Correlations between the PRISM climatology and station precipitation are computed, and a weighting factor is applied to the final product.

Since the development of the product, several studies have used the PRISM precipitation analyses and compared them to various other networks, particularly over most complex terrain regions of the United States. For example, Widmann and Bretherton (2000) used the PRISM analyses to develop a new gridcell product to validate the NCEP reanalysis precipitation fields. Hunter and Meentemeyer (2005) used the PRISM precipitation climatology to produce a 2-km precipitation product to compare with station data in California over a 24-yr period. Guentchev et al. (2010) used the PRISM analyses along with two other gridded precipitation datasets to examine heterogeneity in precipitation fields over the Upper Colorado River basin. Lee et al. (2014), in a study using PRISM to downscale temperatures to complex terrain in the Virginia Blue Ridge Mountains, noted a warm bias in PRISM when comparing it with observations from within the region. McEvoy et al. (2014) compared the independent Nevada Climate-Ecohydrological Assessment Network (NevCAN) stations to four gridded data products (GDPs), including PRISM at 4 km, and found that having a GDP at higher resolution did not necessarily improve the comparisons. Daly et al. (2017) found good agreement between PRISM and a network of rain gauges in the Coweeta basin in North Carolina. Gowan et al. (2018) used the PRISM dataset to validate the prediction of precipitation from several high-resolution convection permitting numerical models over the western United States.

3. Results

a. Comparison by season

To compare the PRISM network to the USCRN network, first the PRISM 4-km grid was used to find the nearest grid point to a given USCRN station. Then, only the days for which precipitation was recorded either at a USCRN station or at the nearest PRISM grid point were used to compute the daily difference between the two. These differences were then used to compute the means at each station location. Data across all

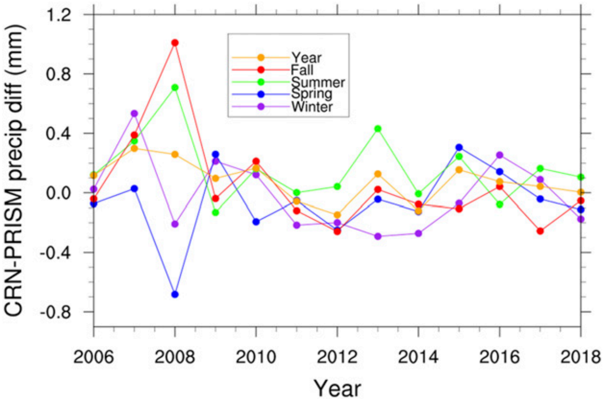

FIG. 6. Mean daily precipitation difference (PRISM minus CRN) as a function of year and season (colored curves) for the Southwest climate region.

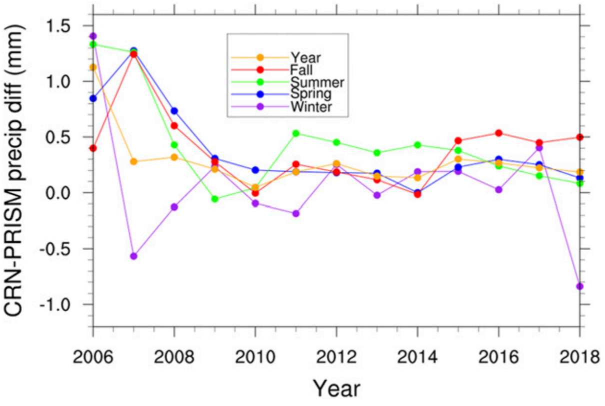

FIG. 8. Mean daily precipitation difference (PRISM minus CRN) as a function of year and season (colored curves) for the South climate region.

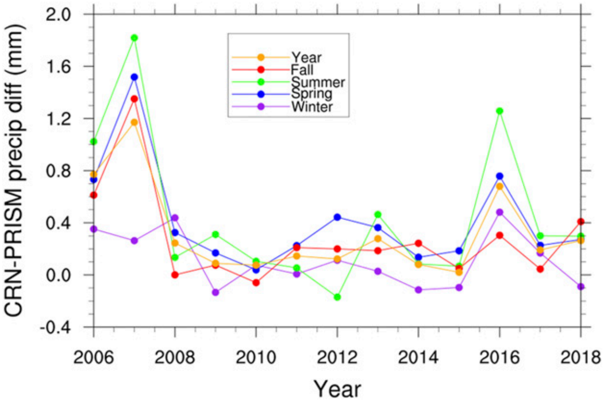

FIG. 9. Mean daily precipitation difference (PRISM minus CRN) as a function of year and season (colored curves) for the Ohio Valley climate region.

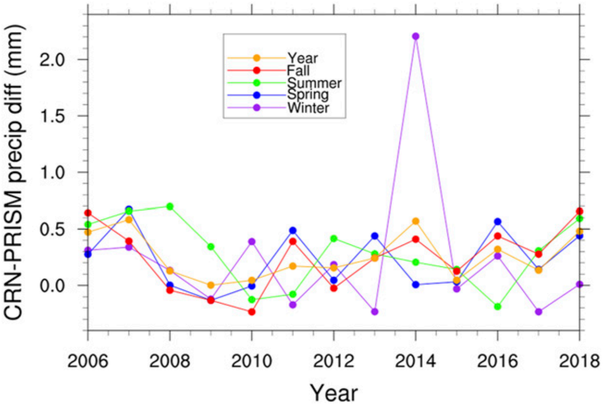

FIG. 10. Mean daily precipitation difference (PRISM minus CRN) as a function of year and season (colored curves) for the Southeast climate region.

13 years were used in the computations. First the statistics were split up by season, then by region.

The daily mean differences (PRISM − USCRN) across the continental United States for winter (1 December–28 February) are shown in Fig. 1a. The mean differences are generally small (from −0.3 to 0.3 mm) over much of the United States. Areas with the highest differences occur along the Gulf Coast and along the more complex terrain in the western United States with mean differences of ~1 mm. Over the Gulf Coast, there is a wet bias in the PRISM compared to the USCRN. We also note a dry bias over the higher terrain in the western United States and along the Northwest coast, and a wet bias in California. In the spring (1 March–31 May), the mean daily differences between PRISM and USCRN are generally larger at most stations than in the winter (Fig. 1b). During these months, there is a wet bias in PRISM that runs from the Louisiana/Arkansas region northwestward into the central and northern plains, and a dry bias over the Southwest. In the summer (1 June–31 August), the wet bias in PRISM expands from just east of the Rockies eastward to the Southeast northward into the Great Lakes region with the dry bias remaining over the Southwest. (Fig. 1c). In the fall (1 September–30 November) the mean daily differences show less of a regional pattern (Fig. 1d). There is a somewhat dry PRISM bias over the Colorado into Nebraska area and slightly wet bias over the South. Averaging over the full year, we see generally smaller biases over most stations (Fig. 1e).

b. Comparison by region

To determine any regional biases in the mean daily precipitation differences the statistics are averaged over nine different climate regions as shown in Fig. 2. Over the Northwest region (Fig. 3), mean precipitation differences are relatively small across all years and all seasons, with a slightly net dry bias in the PRISM data. The largest wet bias occurred during the fall in 2006 and the largest wet bias occurred during the fall of 2009. In the West, there was generally a very small wet bias in the PRISM data (Fig. 4), likely due to those stations in California that were consistently wet offsetting stations in Nevada that were consistently dry. The largest biases occurred in 2008, where fall was very wet, and spring was dry. In most years and most seasons, like in the Northwest, the mean differences were less than 1 mm. In the West North Central region, the differences were smaller, with generally a net wet bias across the seasons and years (Fig. 5). Like in the West, the largest wet biases were in 2008; however, they occurred during the spring and summer instead of the fall, which exhibited only a small wet bias. Overall, 2018 had the largest dry biases during the winter season. In the Southwest, the mean differences were small (from ~−0.4 to 0.4 mm). The year 2008 also had the largest differences with a wet summer and fall, and dry winter and spring, leading to only a small net wet bias for the year (Fig. 6). In the Upper Midwest there was a larger net PRISM dry bias across all seasons and all years (Fig. 7) with the exception of 2007 that featured a wet bias across all seasons, the summer being the wettest. In this region the yearly mean dry bias was ~0.5 mm across the years. In the South, the largest variability in the precipitation differences occurred from 2006 to 2008, and the biases were wet with the exception of winter in 2007 and 2008 (Fig. 8). From 2009 to 2017 most seasons

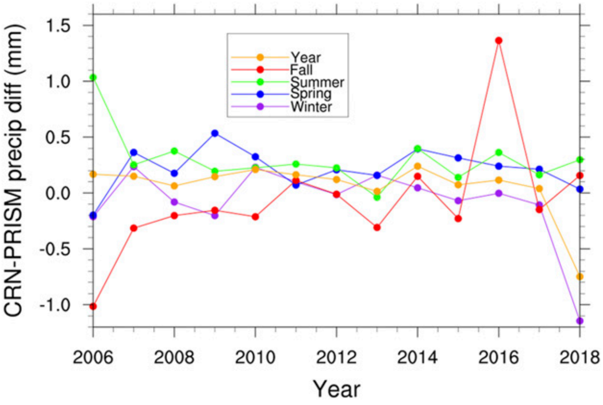

FIG. 11. Mean daily precipitation difference (PRISM minus CRN) as a function of year and season (colored curves) for the Northeast climate region.

TABLE 1. Mean bias (differences) in daily precipitation, in millimeters (PRISM minus USCRN), as a function of region and season over the 13-yr period 2006–18.

Climate region	Winter	Spring	Summer	Fall	Year
Northwest	−0.34	−0.11	−0.38	0.28	−0.05
West	0.23	−0.04	0.05	0.57	0.20
West North Central	0.08	0.25	0.16	0.03	0.13
Southwest	−0.00	−0.06	0.17	0.07	0.04
Upper Midwest	−0.47	−0.69	−0.38	−0.12	−0.41
South	0.14	0.39	0.46	0.34	0.34
Ohio Valley	0.13	0.43	0.45	0.27	0.32
Southeast	0.25	0.21	0.27	0.21	0.23
Northeast	0.01	0.23	0.30	−0.08	0.11

TABLE 2. The root-mean-square error (RMSE; mm) between PRISM and USCRN as a function of region and season over the 13-yr period 2006–18.

Climate region	Winter	Spring	Summer	Fall	Year
Northwest	2.96	1.87	1.66	2.98	2.77
West	2.58	1.50	1.90	2.77	2.67
West North Central	2.15	2.39	1.74	1.35	2.20
Southwest	1.70	1.65	1.97	1.89	2.02
Upper Midwest	2.43	3.37	3.43	1.79	3.00
South	3.81	4.27	4.66	4.06	4.57
Ohio Valley	3.42	3.97	4.24	3.23	3.95
Southeast	4.86	4.45	5.19	4.73	4.98
Northeast	4.19	3.93	4.24	3.03	4.11

featured a small net wet bias, with a dry bias during the winter. In the Ohio Valley region both 2007 and 2016 had exceptionally wet biases in the PRISM analyses (Fig. 9). Other years had only small wet biases over most seasons. Over the Southeast the general pattern was for most seasons and years to have a small wet bias (Fig. 10). The exception was 2007, which featured a very wet winter. The remaining months of that year were only slightly wet in the PRISM data, leading to a yearly net wet bias of ~0.7 mm. Finally, in the Northeast, again we found a small wet bias in most months and years, except for fall which occasionally had a dry bias (Fig. 11). The exception was in 2016, where fall had a large wet bias and 2018 where winter had a larger dry bias. A summary of the statistics is shown in Table 1.

In addition to analyzing the mean differences in precipitation between the USCRN and PRISM, it is instructive to look at root-mean-square error (RMSE) associated with those means. As in Table 1, the RMSEs are categorized by region and season and are shown in Table 2. In the Northwest, the RMSEs in the daily precipitation differences are larger in the fall and winter, and smaller in the spring and summer. This seasonal pattern is also seen in the West, with RMSE values similar to the Northwest. In the West North Central region, the seasonal pattern is shifted, where there is higher variability in the daily precipitation differences during the winter and spring, and less variability during the summer and fall. In the Southwest regions there is not much change in the RMSE values across the seasons with values comparable to the less variable seasons of the Northwest, West, and West North Central regions. In the upper Midwest, the spring and summer show higher values than during the fall and winter. In the South and Ohio Valley the change in RMSEs are more muted compared to the upper Midwest, but still show a weak seasonal dependence like in the upper Midwest with more variability during spring and summer and less in the fall and winter. In the Southeast, there is not much difference in the RMSEs across the seasons. In the Northeast, the variability is similar from winter through summer and variability declines in the fall. In generally, variability in the daily mean precipitation differences are largest in the South, Ohio Valley, Southeast, and Northeast regions and smaller in the Northwest, West, West North Central, and Southwest regions.

To better quantify the differences between the PRISM and USCRN datasets, the mean absolute error (MAE) and normalized seasonal error (NSE) for a given period are shown in Tables 3 and 4 . Here,

$$\mathrm{MAE} = \frac{\sum_{i=0}^{n} |\mathrm{PRISM}_i - \mathrm{CRN}_i|}{n},$$

where n is the number of days in a season, i is the day, and

$$\mathrm{NSE} = \frac{\sum_{i=0}^{n} \mathrm{PRISM}_i - \mathrm{CRN}_i}{\mathrm{CRNSUM}},$$

where CRNSUM is the seasonal total CRN precipitation.

In the Northwest and West, the largest MAEs occur during the winter and fall, with smaller differences in the spring and summer. In the West North Central, the largest absolute differences are in the winter and spring, with a lower value in the summer and the lowest in the fall. In the Southwest, the largest values are in the summer; however, there is not much variability across seasons. In the Upper Midwest, South, and Ohio Valley regions, the largest MAEs occur during the spring and summer, with lower values in the winter and fall. In the Southeast the MAEs are fairly similar throughout the seasons, and in the Northeast the same is true from winter through summer, with lower values in the fall. Generally, across the

TABLE 3. Mean absolute error (MAE; mm) (PRISM minus USCRN) as a function of region and season over the 13-yr period 2006–18.

Climate region	Winter	Spring	Summer	Fall	Year
Northwest	6.58	4.24	3.57	6.96	5.90
West	5.62	3.14	3.80	5.91	5.39
West North Central	4.62	4.91	3.69	3.01	4.42
Southwest	3.87	3.77	4.33	4.16	4.27
Upper Midwest	5.42	7.55	7.48	3.86	6.21
South	8.28	9.16	9.83	8.65	9.34
Ohio Valley	7.75	8.98	9.25	7.18	8.5
Southeast	10.64	9.73	10.47	10.11	10.28
Northeast	8.94	8.56	9.12	7.03	8.69

TABLE 4. Normalized seasonal error (NSE; %) (PRISM minus USCRN) as a function of region and season over the 13-yr period 2006–18.

Climate region	Winter	Spring	Summer	Fall	Year
Northwest	−0.54	1.01	−4.00	6.10	1.36
West	2.19	−7.26	1.84	4.25	1.85
West North Central	1.55	6.44	7.11	1.29	3.29
Southwest	−0.58	−3.11	6.13	1.76	2.51
Upper Midwest	−10.50	−9.34	−8.70	−3.09	−6.79
South	2.11	5.03	6.52	6.14	5.03
Ohio Valley	2.62	8.15	13.18	4.49	5.95
Southeast	2.49	3.51	4.85	2.48	3.25
Northeast	−0.88	4.38	4.90	−4.47	2.14

United States, the lowest MAE values are in the western part of the country with highest values toward the east. The MAEs are found to be highest in regions with the largest amount of precipitation and lowest in regions with smaller amounts of precipitation. To further understand biases between PRISM and USCRN, the NSE values are shown in Table 4. Over the Northwest, the largest NSEs occur during the summer and fall, with a dry summer bias and wet fall bias in PRISM. In the West, spring has a relatively large dry bias with a wet bias during the fall. In the West North Central region, spring and summer have a wet bias, with lower NSE values during the winter and fall. In the Southwest, the highest NSE occurs over the summer months, with a wet PRISM bias. The upper Midwest has the highest NSE values overall, with PRISM having a dry bias. Over the south, spring through fall have the largest NSE values with a wet bias, and this is similar to the Ohio Valley, although this regions NSE magnitudes are larger. In the Southeast, the values do not show as much variability throughout the year as other regions. In the Northeast, there is a dry bias in the fall and winter and a wet bias in the spring and summer. In general, throughout the year, with the exception of the upper Midwest, there is a wet PRISM bias of around a few percent.

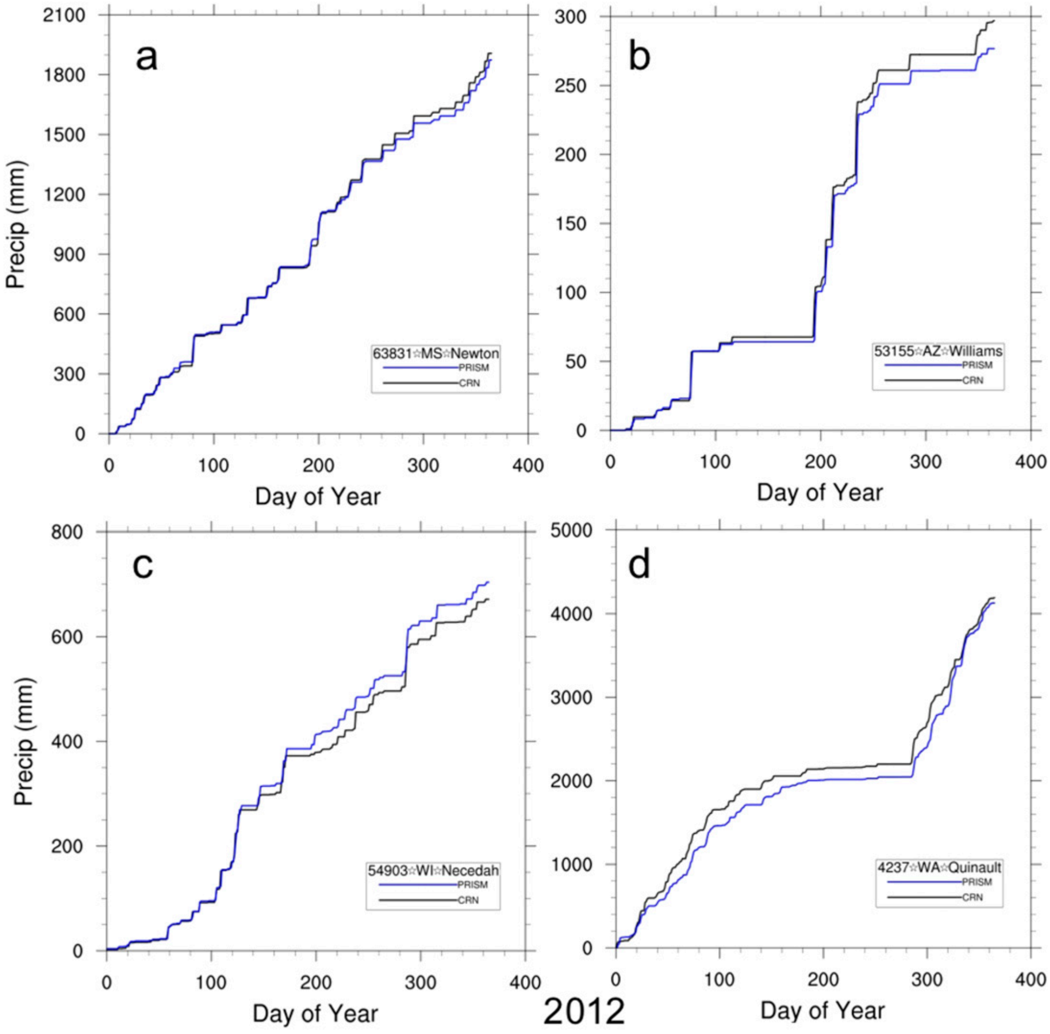

FIG. 12. Accumulated daily precipitation from the CRN (black) and PRISM (blue) for the year 2012 for (a) Newton, MS; (b) Williams, AZ; (c) Necedah, WI; and (d) Quinault, WA.

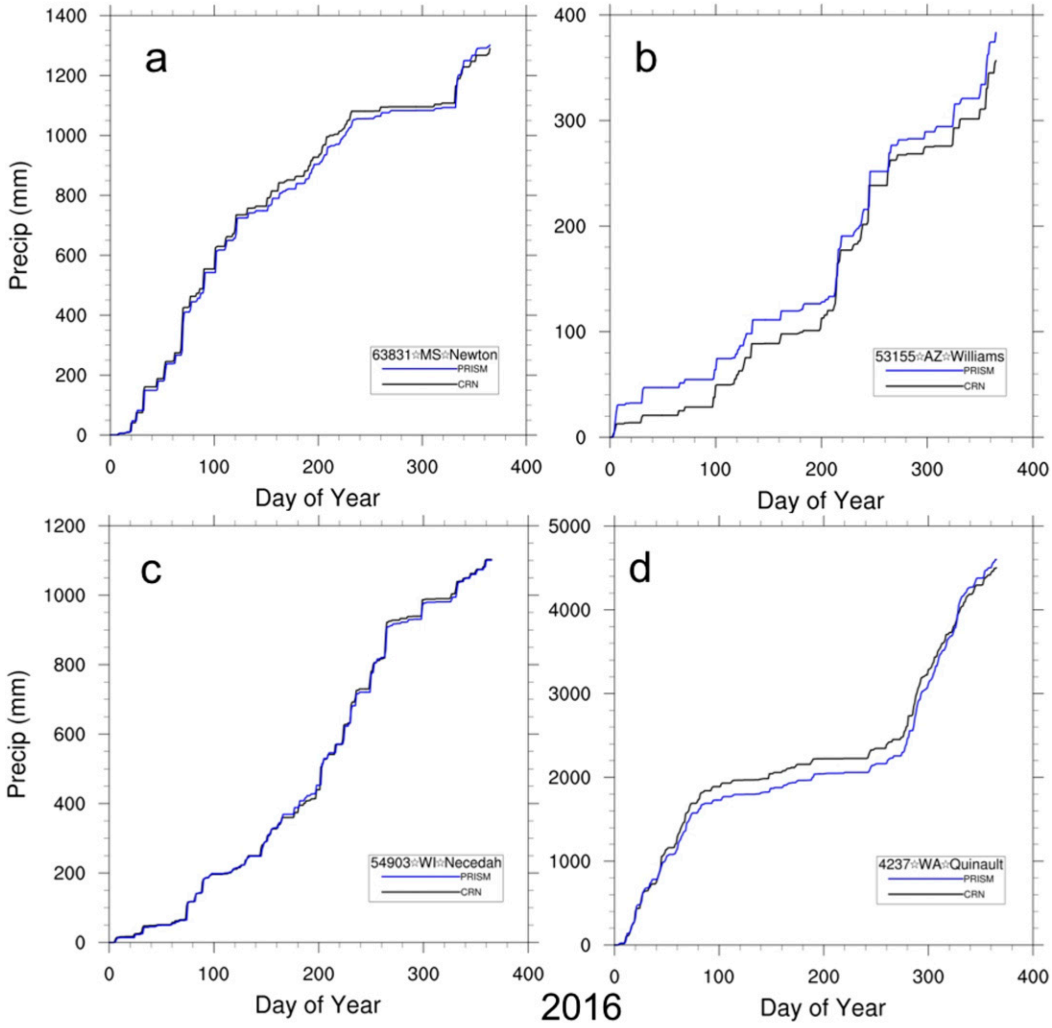

FIG. 13. Accumulated daily precipitation from the CRN (black) and PRISM (blue) for the year 2016 for (a) Newton, MS; (b) Williams, AZ; (c) Necedah, WI; and (d) Quinault, WA.

The comparisons between the PRISM and USCRN datasets can be further demonstrated by evaluating individual stations for a given year. Figure 12 shows the total yearly accumulated precipitation for both USCRN and PRISM during 2012 at a station in the South, Southwest, upper Midwest, and Northwest. All four stations show very good agreement in the total accumulated precipitation, both throughout the whole year and for individual events. For the stations in the Southwest and upper Midwest, the small biases tend to increase during the year (wet and dry PRISM biases, respectively) whereas the stations in the Northwest showed an increase in dry bias before decreasing toward the end of the year. The same four stations are also shown in Fig. 13, for the year 2016. Again, we see an good agreement between the USCRN and PRISM datasets throughout the year and within individual events. During 2016, the stations in the South and in the Upper Midwest tracked nearly identically in the accumulated precipitation, whereas stations in the South had a larger wet bias, and the stations in the Northwest had an increase in dry bias that reversed and led to a net yearly moist bias. Although the majority of the USCRN stations compare well with the PRISM dataset, there are some outliers. For example, although individual events are captured in the PRISM analyses, at the Redding, California, site, the magnitude of precipitation events are sometimes overestimated as shown in Fig. 14. This site is situated in a region of localized terrain variability. As the PRISM model uses terrain slopes as a model estimator, this can lead to biases where the terrain is highly variable on the small scale.

4. Summary and outlook

Using data from 2006 to 2018, a comparison between the USCRN and PRISM was performed. The comparisons between the two datasets were very close across nearly all seasons and regions, with most mean daily differences less than 1 mm and MAE ~5 mm. The general patterns were for a net dry bias in the PRISM data in the upper Midwest and a net moist bias in the southern portion of the United States.

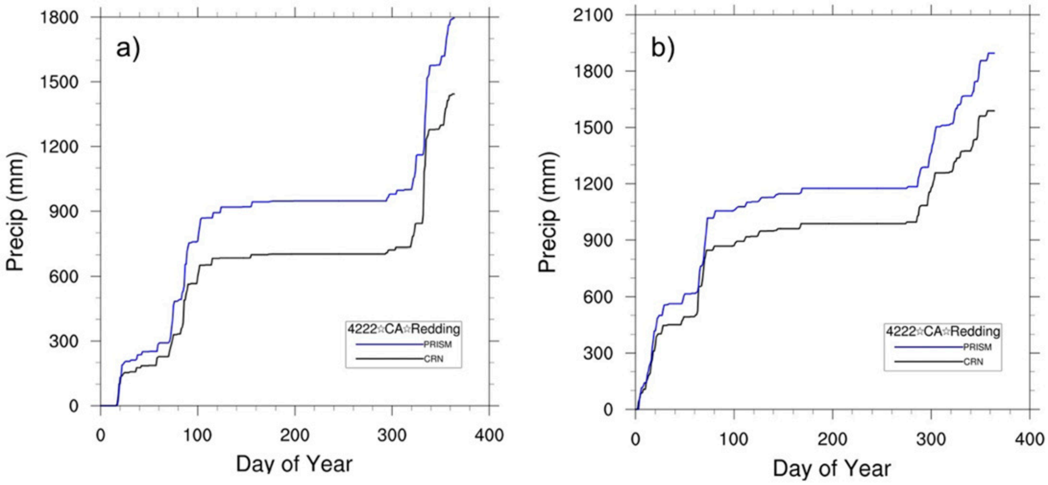

FIG. 14. Accumulated daily precipitation from the CRN (black) and PRISM (blue) for the year (a) 2012 and (b) 2016 for Redding, CA.

Also, differences were larger in the spring and summer, and smaller in the fall and winter, except for in the West/Northwest regions. It should be noted that the USCRN network was included in the PRISM analyses during the May through September period and after 2017. The results show no significant differences in biases when the USCRN stations were included, which is not surprising given the large amount of additional data that was assimilated into the PRISM analyses. In fact, the differences were actually larger when the USCRN stations were included during the warm season. When integrated over the course of a year, total precipitation accumulation from the PRISM dataset is in very close agreement with the USCRN stations at most locations (Fig. 12). The results in this study are consistent with previous studies comparing USCRN and PRISM datasets (Velpuri et al. 2016; Currier et al. 2017; Spangler et al. 2019). Many hydrological forecasts, including those available from, e.g., the Office of Water Prediction's National Water Model (NWM), are based on models coupled with observations. These forecasts are important for identifying and prediction areas of flood and/or drought conditions that can have important socioeconomic impacts.

Now that we have determined that the PRISM dataset is shown to be an adequate surrogate for USCRN precipitation, we can use the PRISM data to fill in the gaps between USCRN measurements to aid in the development of a 4-km daily gridded soil moisture product for the conterminous United States. The relationship of the soil moisture response to soil/vegetation and precipitation at each USCRN station can be used as a proxy at gridpoints that do not contain a USCRN station, but have the soil/vegetation categories representative of a USCRN station. PRISM daily precipitation along with ET from ALEXI (e.g., Anderson et al. 2007) can be used as forcing functions. We have shown that the errors in the PRISM dataset are relatively small compared to the observed USCRN data. To produce a daily gridded soil moisture product it would be instructive to see how the errors in PRISM compare to other components in the water budget (e.g., ET); however, we do not have ET data from the USCRN stations to compare the magnitude of the errors in this product. However, preliminary comparisons of measured USCRN soil moisture to a PRISM input/ALEXI output simple model shows promise. More analyses will be conducted going forward.

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