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Some Concerns when Using Data from the Cooperative Weather Station Networks: A Nebraska Case Study

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NOTES AND CORRESPONDENCE

Some Concerns when Using Data from the Cooperative Weather Station Networks: A Nebraska Case Study

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ABSTRACT

In this study, daily temperature and precipitation amounts that are observed by the Cooperative Observer Program (COOP) were compared among geographically close stations. Hourly observations from nearby Automatic Weather Data Network (AWDN) stations were utilized to resolve the discrepancies between the observations during the same period. The statistics of maximum differences in temperature and precipitation between COOP stations were summarized. In addition, the quantitative measures of the deviations between COOP and AWDN stations were expressed by root-mean-square error, mean absolute error, and an index of agreement. The results indicated that significant discrepancies exist among the daily observations between some paired stations because of varying observation times, observation error, sensor error, and differences in microclimate exposure. The purpose of this note is to bring attention to the problem and offer guidance on the use of daily observations in the comparison and creation of weather maps. In addition, this study demonstrates approaches for identifying the sources of the discrepancies in daily temperature and precipitation observations. The findings will be useful in the quality assurance (QA) procedures of climate data.

1. Introduction

The Cooperative Observer Program (COOP) was formally established in 1890 to provide observational climatological data. More than 11 000 volunteers make daily observations of maximum and minimum temperature, snowfall, and 24-h precipitation totals in a variety of physical environments using federally furnished instruments. The Cooperative Network has been recognized as the most authoritative source of information on U.S. climate trends for temperature and precipitation. Also, the data support meteorological forecasts, warnings, and other public service programs. In addition, the data can be used in agricultural planning and assessment, engineering, environmental impact assessment, utilities planning, and so on. These data play a critical role in efforts to recognize and evaluate the extent of human impact on climate from local to global scales (Hubbard et al. 1982; NWS 2003; more information available online at the High Plains Regional Climate Center http://hprcc.unl.edu). There are about 320 COOP stations across Nebraska.

Decision makers and planners often require daily maps of temperature or precipitation, in which interpolation and comparison among COOP stations' data are involved. The COOP stations are operated by different observers. Because there are a few observing schedules that an observer may choose, the daily observation times vary from one station to another, as well as from year to year (Table 1), leading to site-to-site variability that is often associated with the human observers. In addition, meteorological phenomena, such as cold air pooling, "inversion poking," heat bursts, variations in snowfall and snow cover, microclimatic effects produced by local topography and land cover, and so on, can strongly influence the climate signals in a small region (Shafer et al. 2000; Fiebrich and Crawford 2001; Gustavsson et al. 1998). Furthermore, errors that are caused by observers or sensors will lead to inaccurate data. The objective of this study is to investigate the

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TABLE 1. Daily observation times for temperature and precipitation at selected COOP stations; *T* denotes temperature; *P* denotes precipitation. Numbers are observation time in hours after midnight (m).

	1991		1992		1993		1994		1995		1996		1997		1998		1999	
Station	*T*	*P*	*T*	*P*	*T*	*P*	*T*	*P*	*T*	*P*	*T*	*P*	*T*	*P*	*T*	*P*	*T*	*P*
Agate 3 E	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17
Ainsworth	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18	18
Albion	7	7	7	7	7	7	17	7	17	7	17	7	17	7	17	7	17	7
Curtis 3 NNE	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Anselmo 2 SE	18	m	7	m	7	7	7	7	7	7	7	7	7	7	7	7	7	7
Arthur	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
Atkinson	18	18	18	18	17	8	17	8	17	8	17	8	17	8	17	8	18	7
Auburn 5 ESE	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
Hartington	18	7	18	7	18	7	18	7	18	7	18	7	18	7	18	7	18	7
Imperial	18	18	18	18	18	18	18	18	18	18	7	7	7	7	7	7	7	7

variability of daily measurements of the COOP stations that is caused either by different observation times or by other factors in daily observing, and to identify the sources leading to the false variability of observations.

2. Methods

Geographically close observation points generally experience similar climate and, except for differences in microclimate exposure, should produce similar climatic records during the same time period. Thus, pairwise comparisons between geographically close COOP stations will reveal any discrepancies in observations that are caused by different observation times and other factors. Also, the instrument shelters, which are not operated by human observers and collect hourly measurements, serve as a reference for the nearby COOP stations. The Automated Weather Data Network (AWDN) operated by the High Plains Regional Climate Center (HPRCC) measures hourly data for air temperature and humidity, soil temperature, wind speed and direction, solar radiation, and precipitation (http://hprcc.unl.edu). The hourly data can be used to provide estimates of observation for morning or evening observation hours. In addition to hourly data, AWDN stations also collect daily observations at 2400 (midnight) LST. Therefore, AWDN stations provide the higher temporal resolution that is needed to interpret the differences of observations from geographically close COOP stations.

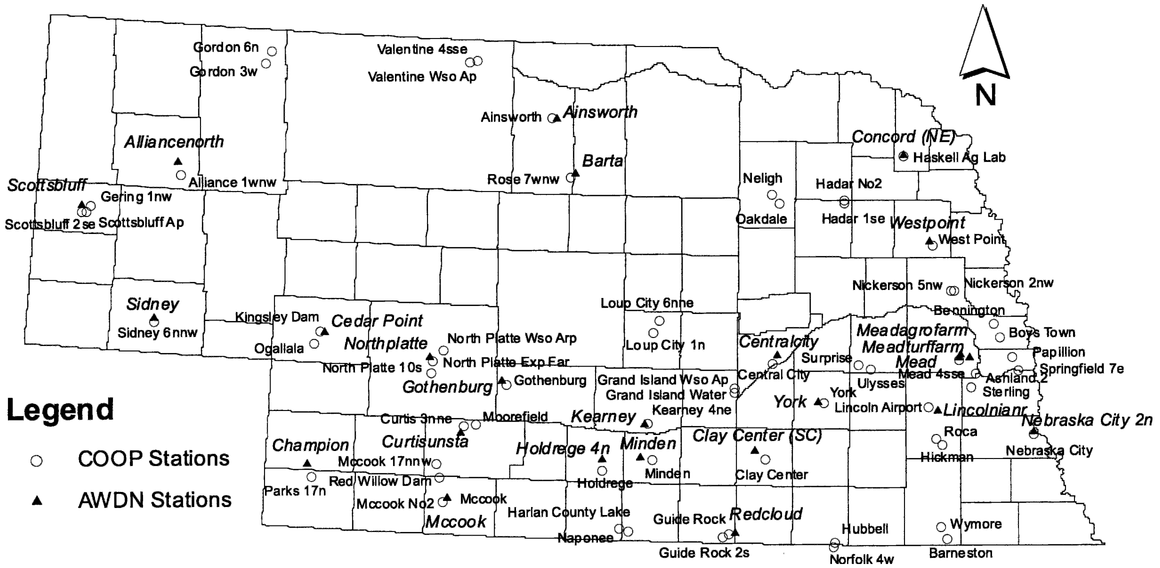

FIG. 1. Distribution of paired COOP stations, and AWDN and COOP stations in Nebraska, which were used in this study. Open circles denote the COOP stations. Solid triangles denote the AWDN stations. The name labels for the AWDN stations are in italics and bigger font.

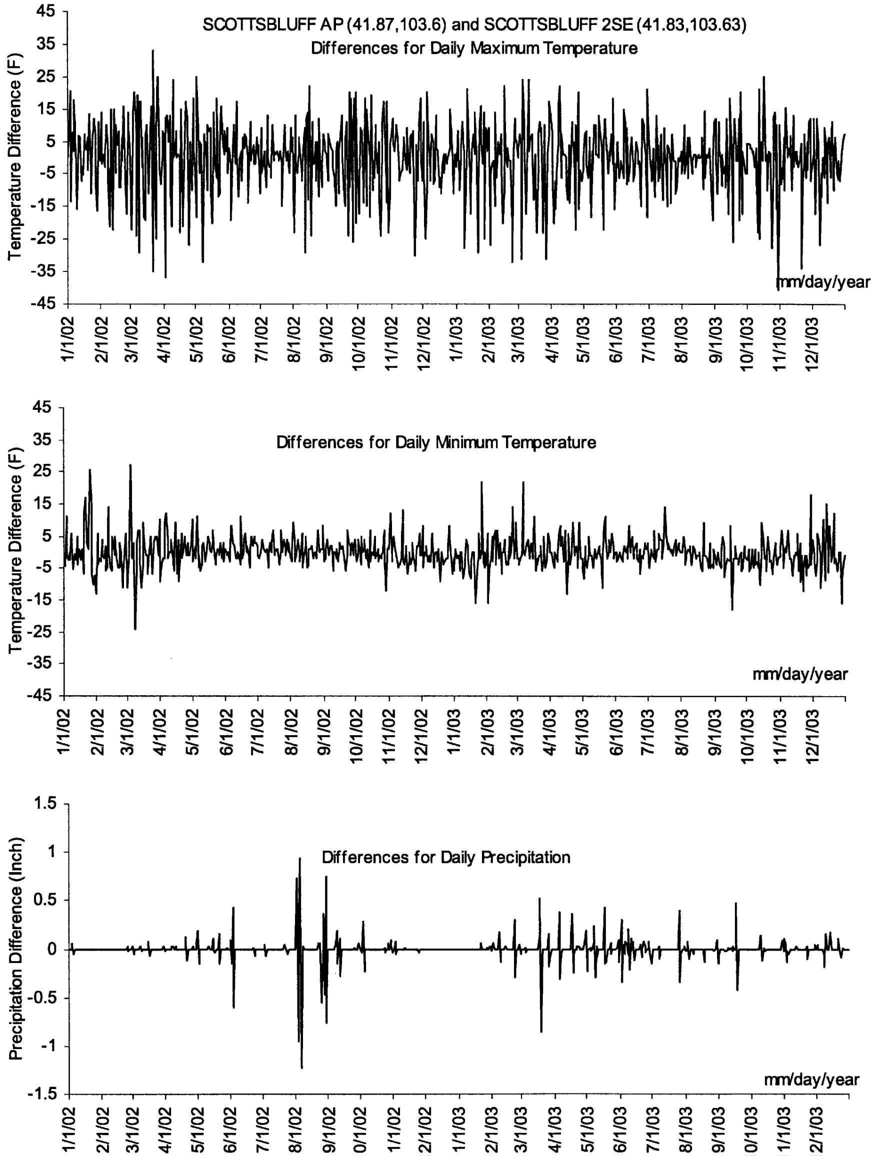

FIG. 2. Comparisons of daily maximum and minimum temperature and precipitation between Scottsbluff AP (41.87°N, 103.6°W) and Scottsbluff 2 SE (41.83°N, 103.63°W).

In this study, daily observations of COOP stations were compared among geographically close COOP and AWDN stations. Twenty-four pairs of geographically close COOP stations and 28 pairs of geographically close AWDN and COOP stations with a distance less than 10 km were selected to conduct the pairwise comparisons (Fig. 1). Because the period of record for these selected stations varied, the analyses used data from the station pairs when data were available at both sites. The comparison periods for the paired stations ranged from 1919–2002 to 2001–02. The maximum differences in daily maximum temperature, minimum temperature, average temperature, and precipitation between the paired COOP stations were summarized.

To quantitatively express the discrepancies between the paired COOP and AWDN stations, root-mean-square error (rmse), mean absolute error (MAE), and an index of agreement (*D*) were calculated. These indices have been used as performance measures for comparing model predictions and observations (Janssen and Heuberger 1995). In this study, the observations from AWDN stations were considered as observations, while the observations from COOP stations were considered as predictions. The equations used to calculate these indices are as follows:

TABLE 2. Daily observations during 14 Feb 1991–31 Mar 1991 from Curtisunsta (40.63°N, 100.5°W, AWDN, midnight observation) and Curtis 3 NNE (40.67°N, 100.43°W, COOP, morning observation) with a distance of 4.75 km from each other.

Month	Day	Yr	$T_{\max}$ (AWDN) (°F)	$T_{\min}$ (AWDN) (°F)	Precipitation (AWDN) (in.)	$T_{\max}$ (COOP) (°F)	$T_{\min}$ (COOP) (°F)	Precipitation (COOP) (in.)
2	14	1991	35.697	15.206	0	58	27	0
2	15	1991	34.315	5.18	0	32	5	0
2	16	1991	68.018	19.418	0	33	4	0
2	17	1991	51.692	31.348	0.26	70	22	0
2	18	1991	33.762	24.854	0	51	25	0.28
2	19	1991	46.67	20.066	0	33	20	0
2	20	1991	66.956	30.038	0	48	20	0
2	21	1991	64.13	27.554	0	69	26	0
2	22	1991	53.06	24.368	0	64	24	0
2	23	1991	50.594	23.738	0	52	22	0
2	24	1991	31.419	8.24	0.18	51	17	0
2	25	1991	42.445	−0.58	0	31	−1	0.20
2	26	1991	43.779	23.522	0	42	0	0
2	27	1991	53.222	16.826	0	43	10	0
2	28	1991	65.336	22.334	0	51	19	0
3	1	1991	49.226	17.258	0	65	20	0
3	2	1991	26.312	13.82	0	43	14	0
3	3	1991	63.734	15.494	0	28	14	0
3	4	1991	70.988	32.796	0	66	16	0
3	5	1991	67.442	30.182	0	73	37	0
3	6	1991	45.464	21.272	0	67	25	0
3	7	1991	46.166	14.828	0	46	16	0
3	8	1991	51.692	24.566	0	49	19	0
3	9	1991	61.322	16.52	0	55	16	0
3	10	1991	72.806	30.182	0	61	28	0
3	11	1991	74.498	29.426	0	72	27	0
3	12	1991	46.454	31.833	0.06	74	29	0
3	13	1991	41.185	19.922	0	36	30	0.07
3	14	1991	43.005	17.186	0.01	42	14	0
3	15	1991	33.073	25.682	0.05	43	21	0
3	16	1991	34.039	29.156	0.25	34	26	0.05
3	17	1991	46.886	30.038	0	34	29	0.24
3	18	1991	59.468	22.604	0.04	48	23	0
3	19	1991	60.62	20.498	0.04	62	23	0
3	20	1991	66.794	37.845	0	61	21	0.03
3	21	1991	66.146	30.659	0.07	68	27	0
3	22	1991	44.906	37.915	0.02	66	27	0.05
3	23	1991	61.466	31.005	0	44	34	0.01
3	24	1991	72.464	27.428	0	64	31	0
3	25	1991	77.45	32.106	0	72	31	0
3	26	1991	76.802	39.511	0.27	78	34	0
3	27	1991	48.308	24.368	0.08	77	24	0.24
3	28	1991	58.19	27.482	0	47	24	0.1
3	29	1991	34.453	24.638	0.04	59	26	0
3	30	1991	58.028	24.422	0	35	15	0.02
3	31	1991	68.45	27.284	0	58	24	0

$$\mathrm{rmse} = \sqrt{\frac{\sum_{i=1}^{N} (P_i - O_i)^2}{N}}, \qquad (1)$$

$$\mathrm{MAE} = \frac{\sum_{i=1}^{N} |P_i - O_i|}{N}, \qquad (2)$$

$$D = 1 - \frac{\sum_{i=1}^{N} (P_i - O_i)^2}{\sum_{i=1}^{N} (|P_i'| + |O_i'|)^2}, \qquad (3)$$

where P_i denotes the observations from COOP stations at time i, O_i is the observations from AWDN stations, $\overline{O}$ is the mean of AWDN observations, $P_i' = P_i - \overline{O}$, and $O_i' = O_i - \overline{O}$.

TABLE 3. Statistics of maximum differences in daily high, low, and average temperatures and precipitation for the paired COOP stations; N/A means the observation is not measured at the station.

Paired stations	Distance (km)	Max $T_{\max}$ (°F)	Max $T_{\min}$ (°F)	Max T_{ave} (°F)	Max precipitation (in.)
Papillion Springfield 7 E	9.83	21.42	11.70	10.72	3.07
Kingsley Dam Ogallala	9.82	44.00	40.00	27.00	3.29
Gordon 3 W Gordon 6 N	9.78	18.00	19.00	10.50	1.77
North Platte 10 S North Platte EXP FAR	7.78	9.00	11.00	6.50	0.82
Gering 1 NW Scottsbluff AP	7.3	41.85	23.50	25.40	1.78
Scottsbluff AP Scottsbluff 2 SE	5.09	41.00	27.00	26.50	1.78
Guide Rock Guide Rock 2 S	4.8	9.39	5.96	4.70	3.02
Grand Island Water Grand Island WSO AP	3.33	18.36	20.18	13.97	1.69
Gering 1 NW Scottsbluff 2 SE	3.3	18.20	22.00	10.00	1.25
Hadar 1 SE Hadar NO 2	2.22	3.97	14.08	6.81	2.03
McCook McCook NO 2	0	4.83	1.94	2.48	1.65
Valentine 4 SSE Valentine WSO AP	4.22	43.00	41.00	25.50	2.00
Bennington Boys Town	9.82	N/A	N/A	N/A	4.06
Loup City 1 N Loup City 6 NNE	9.82	N/A	N/A	N/A	3.57
Ashland 2 Sterling	9.24	N/A	N/A	N/A	4.30
McCook 17 NNW Red Willow Dam	9.25	N/A	N/A	N/A	3.08
Surprise Ulysses	9.02	N/A	N/A	N/A	6.10
Barneston Wymore	8.87	N/A	N/A	N/A	5.88
Curtis 3 NNE Moorefield	8.5	N/A	N/A	N/A	4.30
Neligh Oakdale	8.3	N/A	N/A	N/A	4.90
Harlan County Lake Naponee	6.06	N/A	N/A	N/A	2.52
Hicakman Roca	5.38	N/A	N/A	N/A	7.00
Hubbell Norfolk 4 W	2.38	N/A	N/A	N/A	6.61
Nickerson 2 NW Nickerson 5 NW	1.66	N/A	N/A	N/A	7.29

3. Results and discussion

Figure 2 shows the differences for the daily maximum temperature, minimum temperature, and precipitation between COOP stations of Scottsbluff AP and Scottsbluff 2 SE during 1 January 2002–31 December 2003. The locations of the two stations have a 0.04° difference in latitude and a 0.03° difference in longitude, which is a separation distance of about 5 km. As indicated, the differences can be significant. For instance, the largest difference of maximum temperature reached 40°F, or 22°C, on 30 October 2003.

Table 2 lists the daily observations during 14 February 1991–31 March 1991 from a paired AWDN and COOP station, Curtisunsta and Curtis 3 NNE. As can be seen, the observations of the two stations are signifi-

TABLE 4. Rmse, MAE, and D between the paired COOP and AWDN stations; $T_{\max}$ denotes the daily maximum temperature, $T_{\min}$ is the minimum temperature, T_{ave} is the average temperature, and precip is the observed precipitation.

Paired stations	Distance (km)	Rmse				MAE				D index			
		$T_{\max}$	$T_{\min}$	T_{ave}	Precip	$T_{\max}$	$T_{\min}$	T_{ave}	Precip	$T_{\max}$	$T_{\min}$	T_{ave}	Precip
Champion (AWDN) Parks 17 N (COOP)	9.85	10.99	5.03	6.51	0.19	8.30	3.92	4.87	0.05	0.93	0.98	0.97	0.55
Alliance North (AWDN) Alliance 1 WNW (COOP)	9.48	10.79	5.31	6.75	0.18	8.17	3.60	5.09	0.06	0.94	0.98	0.97	0.46
North-Platte (AWDN) North Platte WSO (COOP)	9.48	1.81	3.14	1.99	0.11	1.27	2.25	1.47	0.03	1.00	0.99	1.00	0.89
Clay Center (SC) (AWDN) Clay Center (COOP)	8.75	9.45	5.21	6.02	0.35	7.06	3.71	4.48	0.11	0.95	0.98	0.98	0.51
Minden (AWDN) Minden (COOP)	8.74	8.81	4.94	5.75	0.28	6.35	3.29	4.22	0.08	0.96	0.98	0.98	0.55
Red-Cloud (AWDN) Guide Rock 2 S (COOP)	8.35	5.27	3.60	3.73	0.26	3.83	2.61	2.79	0.09	0.98	0.99	0.99	0.60
Holdrege 4-N (AWDN) Holdrege (COOP)	7.78	9.93	5.36	6.38	0.31	7.57	3.91	4.83	0.09	0.94	0.98	0.97	0.48
LincolnIANR (AWDN) Lincoln Airport (COOP)	7.08	1.46	3.51	1.91	0.13	0.99	2.60	1.40	0.04	1.00	0.99	1.00	0.93
Meadagfarm (AWDN) Mead 4 SSE (COOP)	7.06	9.48	5.77	6.32	0.27	7.18	4.03	4.77	0.09	0.95	0.98	0.98	0.58
Central-City (AWDN) Central City (COOP)	6.10	5.09	4.71	3.98	0.25	3.04	3.38	2.75	0.08	0.99	0.99	0.99	0.69
Scottsbluff (AWDN) Scottsbluff AP (COOP)	5.90	2.14	1.67	1.38	0.08	1.14	1.16	0.88	0.02	1.00	1.00	1.00	0.89
Scottsbluff (AWDN) Gering 1 NW (COOP)	5.56	10.54	4.64	6.19	0.17	8.23	3.43	4.82	0.05	0.93	0.98	0.97	0.46
McCook(AWDN) McCook (COOP)	4.76	10.23	4.68	6.13	0.25	7.78	3.42	4.61	0.08	0.94	0.98	0.97	0.48
Curtisunsta (AWDN) Curtis 3NNE (COOP)	4.75	10.03	5.18	6.10	0.23	7.39	3.47	4.58	0.07	0.94	0.98	0.98	0.54
Mead-Turf-Farm (AWDN) Mead 4 SSE (COOP)	4.52	9.33	5.23	6.01	0.28	7.00	3.56	4.49	0.09	0.95	0.98	0.98	0.59
Barta (AWDN) Rose 7 WNW (COOP)	4.15	10.43	4.43	6.25	0.17	7.88	3.17	4.70	0.06	0.94	0.99	0.98	0.59
North-Platte (AWDN) North-Platte EXP (COOP)	3.73	10.64	5.33	6.45	0.20	8.25	3.99	4.95	0.07	0.94	0.98	0.97	0.56
Red-Cloud (AWDN) Guide Rock (COOP)	3.58	5.90	3.90	4.12	0.27	4.31	2.80	3.09	0.09	0.98	0.99	0.99	0.61
Gothenburg (AWDN) Gothenburg (COOP)	3.36	5.01	3.30	3.18	0.18	3.08	2.26	2.00	0.04	0.99	0.99	0.99	0.66
York (AWDN) York (COOP)	3.36	9.50	5.47	6.11	0.26	7.23	4.07	4.60	0.09	0.95	0.98	0.98	0.60
Cedar Point (AWDN) Kingsley Dam (COOP)	3.34	9.98	4.70	5.97	0.16	7.32	3.27	4.47	0.04	0.94	0.98	0.97	0.83
West-Point (AWDN) West Point (COOP)	3.33	9.39	4.95	5.95	0.32	7.20	3.29	4.52	0.10	0.96	0.99	0.98	0.54
Ainsworth (AWDN) Ainsworth (COOP)	2.46	4.47	3.29	3.09	0.20	2.61	2.09	1.88	0.06	0.99	0.99	0.99	0.76
Mead (AWDN) Mead 4 SSE (COOP)	2.22	8.86	5.30	5.79	0.30	6.45	3.59	4.22	0.10	0.96	0.98	0.98	0.56
Nebraska City 2 N (AWDN) Nebraska City (COOP)	2.22	9.26	5.40	6.14	0.25	6.66	3.65	4.59	0.07	0.95	0.98	0.98	0.63
Sidney (AWDN) Sidney 6 NNW (COOP)	2.22	10.72	5.29	6.71	0.20	8.21	3.86	5.21	0.06	0.93	0.98	0.97	0.44
Kearney (AWDN) Kearney 4 NE (COOP)	1.68	9.77	4.92	6.26	0.27	7.38	3.15	4.71	0.08	0.95	0.98	0.98	0.57
Concord (NE) (AWDN) Haskell Ag Lab (COOP)	1.11	9.24	4.87	5.97	0.27	6.98	3.30	4.54	0.10	0.96	0.99	0.98	0.52

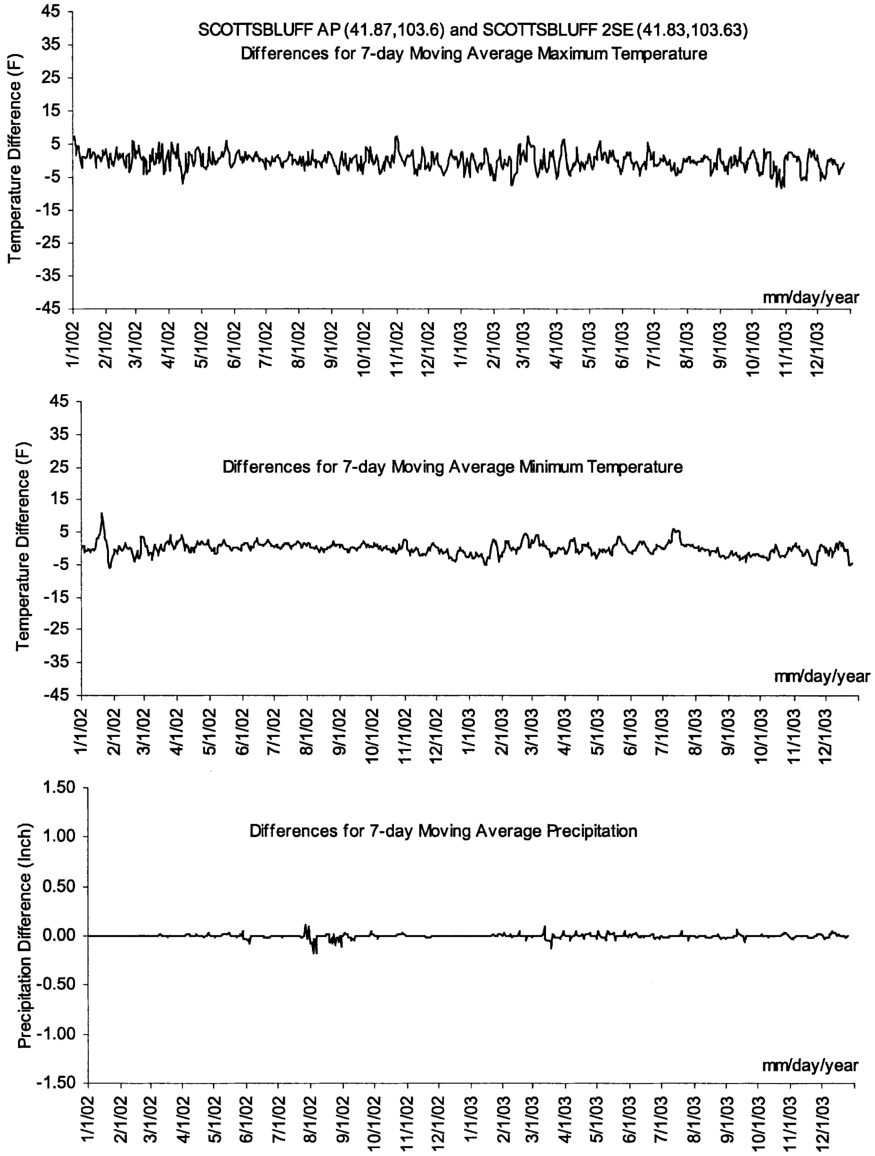

FIG. 3. Comparisons of 7-day moving averaged temperature and precipitation between Scottsbluff AP (41.87°N, 103.6°W) and Scottsbluff 2 SE (41.83°N, 103.63°W).

cantly different for the majority of the period. If the recorded date of the COOP station Curtis 3 NNE is displaced 1 day before its actual date, that is, starting on 13 February rather than 14 February, the data from the two sets would have matched better. As indicated in Table 1, the observation time of the COOP station Curtis 3 NNE is 0700 LST, referring to a morning observation, while the observation time of the AWDN station Curtisunsta is 2400 LST, referring to a midnight observation. According to the regulations, observations are supposedly labeled on the calendar date at the end of the 24-h observing period. This introduces a problem; that is, the different observation times cause the records of the two stations to have up to a 1-day lag, although the labels indicate that they were recorded on the same day.

Table 3 summarizes the statistics on the maximum differences of the daily maximum, minimum, and average temperatures and precipitation from all of the selected pairs of COOP stations. As shown, the largest daily differences are more than 40°F (22°C) for the maximum and minimum temperature, about 30°F (17°C) for average temperature, and more than 7 in. (178 mm) for precipitation. The differences in the observations are not related to the distances between the paired stations.

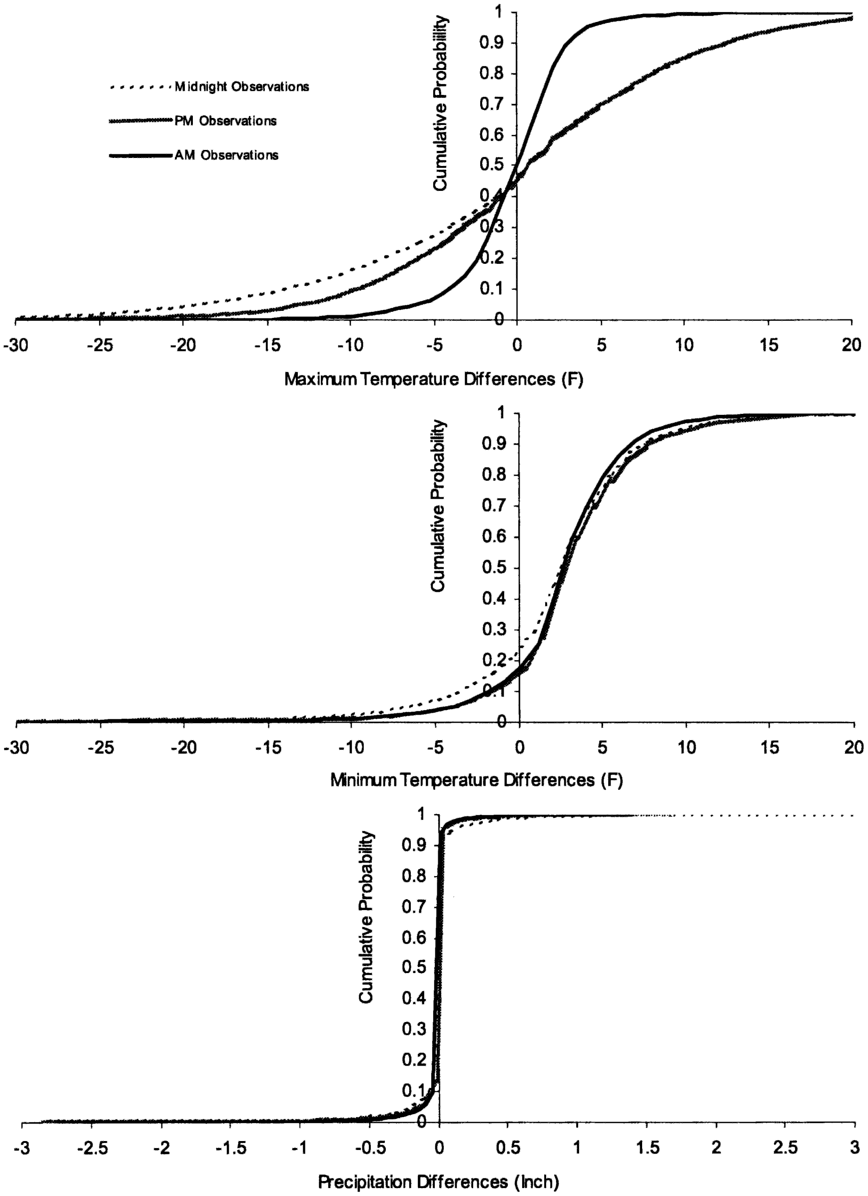

FIG. 4. Cumulative probabilities of differences between the Sidney (AWDN) and Sidney 6 NNE (COOP) stations for $T_{\max}$, $T_{\min}$, and precipitation when using AWDN morning, evening, and midnight observations.

Table 4 summarizes the values of rmse, MAE, and *D* measures on the daily maximum, minimum, and average temperatures and precipitation from the paired AWDN and COOP stations. The *D* values indicate that the three temperature observations agree very well between the paired stations because all of the values are close to or equal to 1. For precipitation, half of the measures are between 0.5 and 0.6, indicating that the precipitation observations between the paired COOP stations do not agree well. According to the *D* values, it seems that the daily temperature observations are consistent between the paired AWDN and COOP stations. In addition, the study reports rmse and MAE because *D* is a dimensionless measure that provides relative assessment of the differences, while rmse and MAE are able to quantify the differences in terms of the units of the variable (Legates and McCabe 1999).

As illustrated in Table 4, the rmse for two-thirds of the 28 paired stations is greater than 9°F (5°C) for the maximum temperature ($T_{\max}$), three-quarters of the pairs have rmse $>$ 4°F day^{-1} (2°C) for the minimum ($T_{\min}$) and average temperatures (T_{ave}),

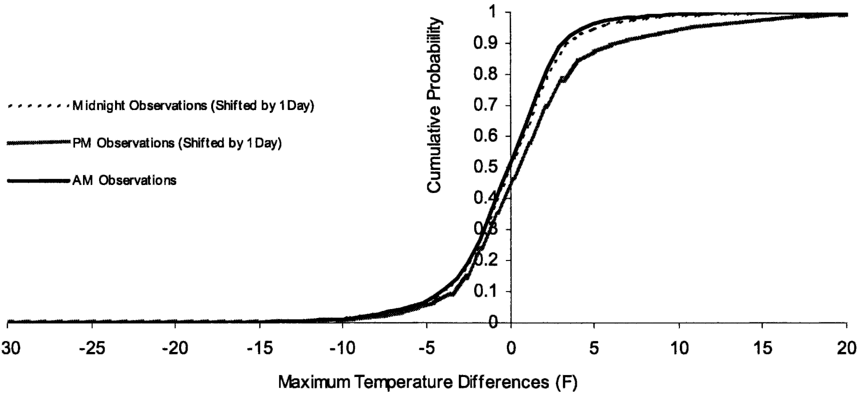

FIG. 5. Cumulative probabilities of differences between the Sidney (AWDN) and Sidney 6 NNE (COOP) stations for $T_{\max}$, when AWDN evening and midnight observations are shifted by 1 day.

and 19 out of 28 pairs have rmse > 0.2 in. day^{-1} (5 mm) for precipitation (precip). Compared with rmse, the MAE measures are lower, with 7°F day^{-1} (4°C) for the high temperature, 3°F day^{-1} (1.7°C) for the low and average temperatures, and 0.1 in. day^{-1} (3 mm) for precipitation for two-thirds of the paired stations.

Based on the pairwise comparison results presented above, it is clear that large discrepancies exist among the daily data for some of the paired COOP stations, and paired COOP and AWDN stations. If these discrepancies are caused by different observation times, users of the data should be cautious when daily observations from COOP stations are used in mapping or comparison. To decrease these discrepancies, a moving average procedure was applied to the temperature and precipitation. The size of the moving average window can be chosen based on the purpose of the user. Figure 3 demonstrates the differences between the stations at Scottsbluff AP and Scottsbluff 2 SE after a 7-day moving average was applied to the original temperature and precipitation records. As can be seen, the significant discrepancies drop dramatically compared with Fig. 2.

The sources that cause the discrepancies among the observations can either be different times of observation or meteorological phenomena or errors made by observers or sensors. In this study we demonstrate how to distinguish the error that is caused by different observation times from other types of errors. The hourly data observed at AWDN stations were recalculated to obtain daily data time series to match COOP morning, evening, or midnight observation times. For instance, the AWDN Sidney's hourly data were recalculated as morning observations (0800 LST), evening observations (1800 LST), and midnight observations (2400 LST). The COOP station Sidney 6 NNW is located 2.22 km away the AMDN Sidney station, with an observation time of 0800 LST. The differences between Sidney 6 NNE (COOP) and Sidney (AWDN) stations for the $T_{\max}$, $T_{\min}$, and precipitation were computed when using the data produced by the three observation times, respectively. Cumulative probabilities of the differences for the $T_{\max}$, $T_{\min}$, and precipitation at the three observation times are shown in Fig. 4. The cumulative probability is the probability that a variable ($T_{\max}$, $T_{\min}$, or precipitation) takes a value less than or equal to a given amount. Therefore, based on the cumulative probability plot, one can find the probability of the difference between two stations' observations. As shown in Fig. 4, for $T_{\max}$ the differences between the COOP and AWDN morning observations are the least because the COOP station's observation time is also in the morning. Larger discrepancies exist between COOP and AWDN evening and midnight observations. This is most likely because of the significantly different times of observation. When the AWDN evening and midnight $T_{\max}$ observations are shifted by 1 day, those discrepancies are largely reduced between COOP and AWDN stations (Fig. 5). For $T_{\min}$ and precipitation, the observation times do not significantly influence the differences between the two stations. This approach will be useful in the quality assurance (QA) procedures, which have been developed and applied to climatic observations in different regions (Shafer et al. 2000; Hubbard et al. 2005).

Furthermore, the discrepancies between COOP Sidney 6 NNW and AWDN Sidney morning series (best fitted) were analyzed on the "upper and lower" threshold test (Hubbard 2001; Hubbard et al. 2005). Here it is assumed that the instruments used by the AWDN stations provide correct measurements of hourly time series. The standard deviation σ of the discrepancies between COOP and AWDN morning observations was obtained. Scatter diagrams of Sidney morning data and Sidney 6 NNE with an f value of 3, which indicates that

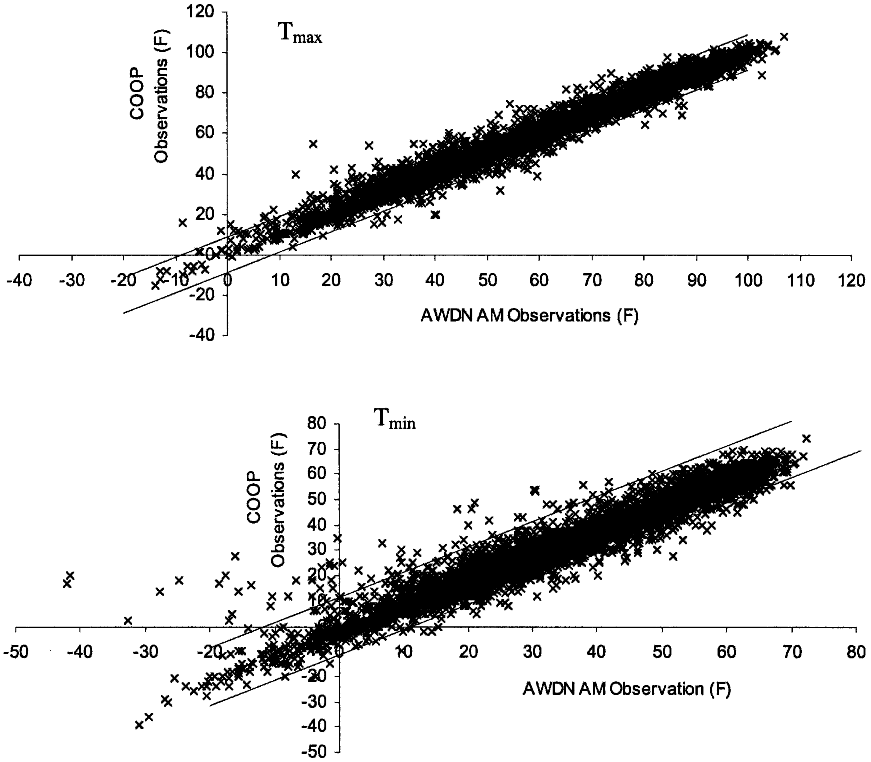

FIG. 6. Scatterplots between Sidney 6 NNE (COOP) and Sidney (AWDN) morning observations for T_{max} and T_{min} with 99.73% confidence intervals.

99.73% of the data should fall into the confidence intervals, were presented (Fig. 6). Therefore, the data pairs falling outside of the confidence intervals should be considered to have a significant difference. These data need to be noted as suspicious or potential outliers in the QA procedures. It should be further investigated whether the difference is caused by either location or by observation error.

4. Conclusions

Large discrepancies exist among the daily observations between geographically close COOP stations, as well as between geographically close AWDN and COOP stations. According to the statistics of the paired COOP stations, the largest differences are more than 40°F (22°C) for the daily maximum and minimum temperatures, 30°F (17°C) for the average temperature, and 7 in. (178 mm) for daily precipitation. For most of the paired AWDN and COOP stations, the rmse measures show about a 10°F (6°C) day^{-1} difference for the maximum temperature, 5°F (3°C) day^{-1} for the minimum and average temperatures, and 0.2 in. (5 mm) day^{-1} for the precipitation. The MAE measures are slightly lower. Results also show that a moving averaged temperature and precipitation will dramatically decrease the discrepancies.

In addition, the sources causing the discrepancies between COOP and AWDN observations can be either varying observation times or meteorological phenomena or the observer or sensor failure. The type of error sources can be determined by plotting cumulative probability and conducting an "upper and low" threshold test. These discrepancies should be noted when using both COOP and AWDN data simultaneously. This approach will be useful in the QA procedures of climate data.

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