A Comparative Study of ASOS and USCRN Temperature Measurements

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ABSTRACT

Temperature measurements from the U.S. Climate Reference Network (USCRN) instrument system were compared to the Automated Surface Observing System (ASOS) ambient air temperature measurements and were examined under different regimes of wind speed and solar radiation. Influences due to observing practice differences and the effects of siting differences were discussed.

This analysis indicated that the average difference between the ASOS and USCRN temperatures is on the order of 0.1°C. However, problems were noticed that were possibly related to the ASOS shield effectiveness, including a solar radiation warm effect under calm conditions and the dependence of ASOS minus USCRN temperature on wind speed.

The ASOS and USCRN time of observation difference was on the order of ~0.05°C, with a warmer ASOS daily $T_{\max}$ and a cooler ASOS daily $T_{\min}$. The local effect complicates the bias analysis because it depends not only on local heating/cooling, but it can be strongly modified by cloudiness, wind, and solar radiation.

1. Introduction

The primary instrument systems used in the history of the U.S. surface observing networks include the Cotton Region Shelter (CRS), housing the liquid-in-glass thermometer; the Maximum and Minimum Temperature System (MMTS); and the HO-xx hygrothermometer systems (including the HO-63, HO-83, and HO-1088). Data from the National Weather Service (NWS) stations that are analyzed in many studies (Robinson 1990; Quayle et al. 1991; Gall et al. 1992; Kessler et al. 1993; Easterling and Peterson 1995; Guttman and Baker 1996; McKee et al. 1997) have indicated that temperature differences among these different instrument systems can be significant.

Efforts have been undertaken at the National Climatic Data Center (NCDC) to evaluate data from the NWS observing instrument systems based on the U.S. Climate Reference Network (USCRN) measurements. The USCRN is a National Oceanic and Atmospheric Administration (NOAA)-sponsored network and research initiative. The first and foremost objective of the USCRN instrument suite is to provide benchmark-quality air temperature and precipitation measurements that are free of time-dependent biases. In this article, a comparative study of temperature measurements from ASOS and USCRN will be presented. The primary function of the ASOS is to generate the international Aviation Routine Weather Report (METAR)/Aviation Selected Special Weather Report (SPECI). Observations from the Automated Surface Observing System (ASOS) network are also used in meteorological and climatological research.

The temperature difference between ASOS and USCRN instruments ΔT is decomposed into the following terms:

$$\Delta T = \Delta T_{\text{instrument difference}} + \Delta T_{\text{local effect}} + \Delta T_{\text{shield effect}} + \Delta T_{\text{observing practice}}, \quad (1)$$

where T represents ambient air temperature, $\Delta T_{\text{instrument difference}}$ is the difference between the two

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systems that is inherent in the temperature sensors and the associated data-acquisition systems, $\Delta T_{\text{local effect}}$ is the temperature difference contributed by differences in surface characteristics surrounding the two instruments, $\Delta T_{\text{shield effect}}$ is the difference associated with the different radiation shield designs, and $\Delta T_{\text{observing practice}}$ refers to the temperature difference brought by different data observing practices or data processing methods.

Data from two locations, Sterling, Virginia, and Asheville, North Carolina, were used in this analysis. The Sterling test bed facility supports the intercomparison of NWS and USCRN sensors under the same environmental conditions. At Asheville, the ASOS station is located at the Asheville Regional Airport, about 2.4 km from the USCRN station, which is located at the North Carolina State Horticultural Crops Reservation Center. Daily and hourly data composed from 1-min measurements from the Sterling site were used to analyze $\Delta T_{\text{observing practice}}$ and $\Delta T_{\text{shield effect}}$. Based on that analysis, the role of $\Delta T_{\text{local effect}}$ in the temperature bias was assessed by analyzing the hourly operational data from the Asheville site.

2. Instrumentation systems

The two temperature measurement systems that were being compared in this study are the ASOS HO-1088 system and the USCRN system. Both instruments use platinum wire resistance temperature (PRT) sensors to measure ambient air temperature. Both systems are aspirated systems with fans located at the top of the radiation shields (Fig. 1). However, the USCRN system has three independent measurements of temperature for redundancy, while the ASOS HO-1088 system has a single measurement of temperature. Differences in the radiation shield design between the two systems are significant. The ASOS shield is a single cylinder and open at the bottom, whereas the USCRN shield is comprised of three concentric cylinders with an air gap between each pair and a circular plate at the inlet. The USCRN shield configuration maximizes airflow to the temperature sensor and minimizes longwave infrared radiation affecting the measurement at night.

3. Site characteristics

The NWS test facility at Sterling provides surface and upper-air testing services for the qualification of new NWS field equipments and to validate proposed modifications to deployed equipment and sensor data processing algorithms. At present the USCRN is conducting a temperature intercomparison with the ASOS system. The ASOS and the USCRN temperature systems at the Sterling site were installed on a uniform grass-covered surface and are located about 90 m apart. The surface characteristics surrounding them are expected to be similar.

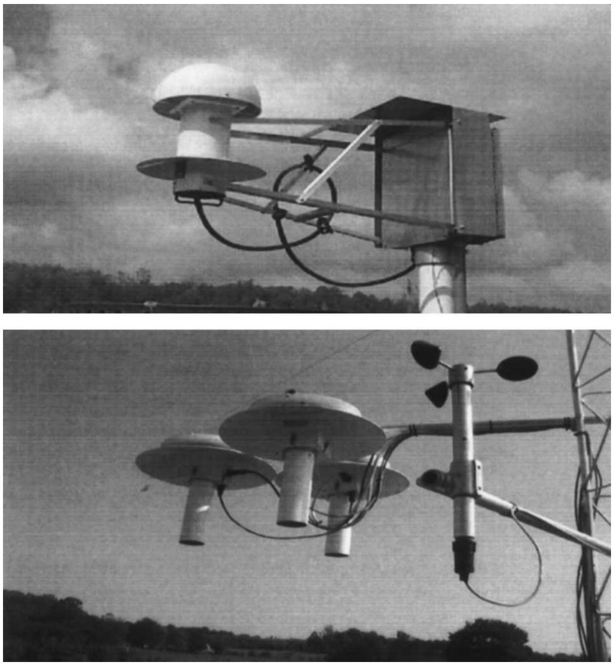

FIG. 1. (top) ASOS HO-1088 and (bottom) USCRN temperature measurement systems.

Asheville is located in the mountains of the western North Carolina. The USCRN station at the Horticultural Crops Reservation Center (with an elevation of 660 m) is about 16 km to the south of the city and 2.4 km from the ASOS station. There are no heating sources close to the USCRN site. The ASOS station is located at the airport with an elevation of 642 m. About 18–30 m west of the ASOS station, a 2500-m airport runway above the terrain by 2.5 m runs along the north-to-south direction. About 30–90 m to the north and east there are airport parking lots that are 4 m lower than the terrain. Heating from the surrounding parking lots and runway can affect the ASOS temperature measurements.

4. Data and preprocessing

The 1-min data from the Sterling site cover the period of January–May 2003. It includes ambient air temperature (T) from both ASOS and USCRN, and wind speed (U) at 1.5 m and downward solar radiation (SR) from USCRN. Data from the period of 1 November 2002 to June 2003 are used for the analysis of the Asheville site.

Before conducting the temperature comparison, several data preprocessing procedures were applied to the ASOS and USCRN datasets. In this study, the median value of the three independent USCRN T measurements was used if the differences among them were

TABLE 1. ASOS and USCRN temperature reporting characteristics.

Characteristic	ASOS	USCRN
Sample interval(s)	10	2
Calculation	Running 5-min averages calculated at each minute	Discrete 5-min averages calculated at the end of each 5-min period
Hourly report	5-min average between 45–49 and 55–59 min, depending on individual stations	5-min average of 55–59 min
Daily T_{max} and T_{min}	Determined from 24 × 60 running 5-min averages	Determined from 24 × 12 discrete 5-min averages

≤0.3°C. If one sensor differed from either of the other two by more than 0.3°C, the mean value of the other two sensors was used. A missing value was assigned if all three sensors differed from each other by more than 0.3°C. The 0.3°C difference used by USCRN was a value that was chosen to take into consideration the true natural variability in the atmosphere versus a malfunctioning temperature sensor. All 5-min-averaged ΔT greater than three standard deviations calculated from the 5-min ΔT time series were excluded in the bias analysis.

5. Effects of observing practice differences

a. Observing and reporting practices

At the USCRN observing system T, U, and SR are sampled at 1.5 m every 2 s at the end of every nonoverlapping 5 min; averages are calculated from the 150 two-second samples. Hourly means and standard deviations are then computed from 12 five-minute averages. Hourly T_{max} and T_{min} are determined from 12 five-minute averages at an hour. The hourly values, along with the last 5-min temperature of the hour (55–59 min, denoted as HR_{59}), and hourly T_{max} and T_{min} and times of their occurrence, are stored in the datalogger and are transmitted to the NCDC archive.

ASOS sensors sample temperature 6 times a minute to create a 1-min average. METAR reports are generated once an hour between 45 and 55 min past the hour. Once a METAR report is generated, the local observer is permitted to edit or augment the automated observation for up to 5 min. Until the METAR data are transmitted, all automated parameters are updated once each minute. The ASOS hourly temperatures are, thus, represented by the 5-min running averages between 45–49 and 55–59 min. For example, the Asheville ASOS METAR data, reported at hh:54, means that the 5-min-averaged temperature was calculated from the period of 50–54 min. In this work, the ASOS hourly temperatures averaged from 45–49 min and 50–54 min (denoted as HR_{49} and HR_{54}, respectively), are chosen to compare HR_{59} for the analysis of hourly $\Delta T_{\text{observing practice}}$ (see next section).

Table 1 summarizes the major temperature-reporting differences between the ASOS and USCRN systems, which essentially arise from the difference in observation times. One-minute datasets from the Sterling facility allow for the creation of ASOS and USCRN reports of these temperature characteristics and, thus, the opportunity to assess the role of $\Delta T_{\text{observing practice}}$ in ΔT.

b. Estimates of $\Delta T_{observing\ practice}$

Percentage distributions of the differences (between the ways in which ASOS and USCRN report temperature) in daily T_{max} and T_{min} are shown in Fig. 2. Mean differences for both T_{max} and T_{min} are about 0.05°C. With the exception of the near-zero difference, the differences are positive for T_{max} and negative for T_{min}.

Figure 3 demonstrates the percentage distributions of hourly temperature differences (from day and night cases) and the corresponding hourly temperature standard deviations that are calculated from 12 five-minute averages. The differences between HR_{49} and $HR_{59,}$ are near zero 38% of the time when the hourly standard deviation is 0.15°C, and are within ±0.3°C 71% of the time when the hourly standard deviation is 0.25°C. Likewise, we found the percentages of cases for the difference between HR_{54} and HR_{59} to be much higher. These numbers, along with Fig. 3b, clearly indicate that a smaller hourly $\Delta T_{\text{observing practice}}$ corresponds to a smaller hourly temperature standard deviation, and vise versa.

The percentage of cases whose differences are within ±0.3°C is smaller for nighttime than for daytime (by about 6%), which may suggest that the intrahourly temperature fluctuated more strongly during nighttime hours than daytime hours.

Respectively, Figs. 2 and 3 were based on daily and hourly data composed from 1-min USCRN measurements. Similar statistics from the 1-min ASOS data (not shown) indicate that the ASOS and USCRN observing practice differences can result in temperature differences. The hourly temperature standard deviations of 0.30°C for nighttime and 0.27°C for daytime (obtained from this section) were used to filter the hourly data from the Asheville site. With this adjustment, the data used for the $\Delta T_{\text{local effect}}$ analysis (section 7) are believed to be without large intrahourly variability and to be observing practice differences removed.

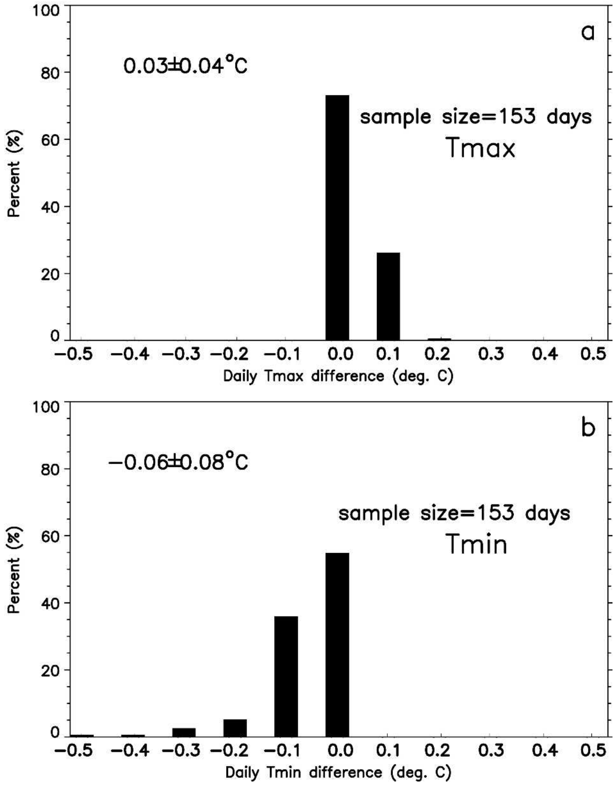

FIG. 2. Percentage distributions of daily (a) $T_{\max}$ and (b) $T_{\min}$ differences between the ways ASOS and USCRN report temperature. The sample size, mean difference, and standard deviation are shown on the plots. These plots are based on 1-min USCRN data from the Sterling site.

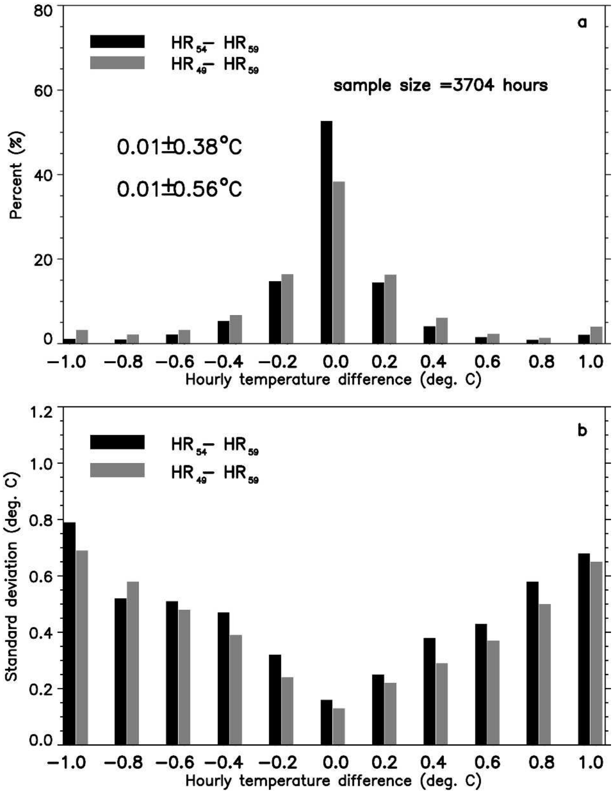

FIG. 3. (a) Same as Fig. 2, but for the difference of hourly temperature represented by 5-min averages. Two sets of differences of 50–54 min (HR_{54}) minus 55–59 min (HR_{59}), and 45–49 min (HR_{49}) minus HR_{59} are shown. HR_{54} (HR_{49}) and HR_{59} mimic the ways in which standard ASOS and USCRN report hourly temperature; (b) the hourly temperature standard deviations are calculated from 12 five-minute averages.

6. Analysis for Sterling, Virginia

Because the standard ASOS hourly temperatures are 5-min averages, the 1-min ASOS and USCRN test bed datasets were averaged into nonoverlapping 5-min averages for the analysis. The ΔT calculated from these 5-min averages for nighttime, daytime, and all of the day are −0.02°, −0.12°, and −0.06°C, respectively. Next, $\Delta T_{\text{shield effect}}$ is examined in terms of the individual influences of U, SR, and IR.

a. Ambient wind speed effect

The relationships between U and ΔT for nighttime and daytime are displayed in Fig. 4. Under calm conditions ($U \leq 1.5$ m s^{-1}), with the increase in U, ΔT was negative from 0.20° to −0.1°C for nighttime and from −0.06° to −0.11°C for daytime. Under windy conditions ($U > 1.5$ m s^{-1}), with the increase in U, the cooling bias was linearly reduced. When U reached 4.5 m s^{-1} or higher for both nighttime and daytime ΔT was close to zero. To estimate the term $\Delta T_{\text{instrument difference}}$ in Eq. (1), the near-zero value associated with U that was 4.5 m s^{-1} or higher at nighttime was used and suggests that $\Delta T_{\text{instrument difference}}$ was negligible. A daytime ΔT of 0.11°C, however, is evidenced when U reached 6.25 m s^{-1} (Fig. 4b). The mechanism for this phenomenon was unclear, but we hypothesize that the strong ambient wind might have interfered with the airflow that was generated by the ASOS's aspirated fan and, consequently, reduced the airflow efficiency within the shield. This would explain the warm solar bias that was observed.

To better isolate the U effect from other possible effects, data points of ΔT from the daytime case (Fig. 4b) were stratified based on the estimated SR (0–200, 200–400, 400–600, 600–800 W m^{-2}; see Fig. 5). The relationships between U and ΔT are quite similar under the different categories of SR; all are similar to the one shown in Fig. 4b. For an unaspirated shield system, temperature biases that are caused by SR and/or IR are expected to be reduced with the increase in U (Lin et al. 2001a). However, ΔT in Figs. 4 and 5 also depends on U (Figs. 4 and 5). This suggests that there may be inadequate ventilation in the ASOS system. Even though

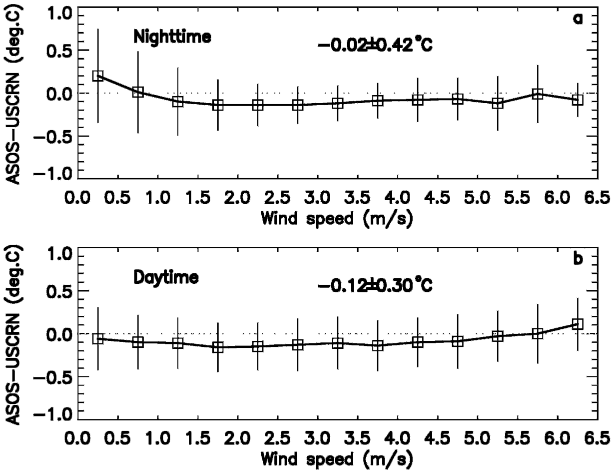

FIG. 4. Relationship between ambient wind speed (U) and ambient temperature difference ($T_{\mathrm{asos}} - T_{\mathrm{uscrn}}$, ΔT) for (a) nighttime and (b) daytime at the Sterling site. Vertical lines represent values of one ΔT standard deviation. Mean differences and standard deviations are indicated on the plots.

ASOS is aspirated, the large chilled-mirror system can block the airflow entering from the outside and reduce the speed, as suggested by Hubbard et al. (2001).

The vertical arrows in Fig. 5 denote the U turning points, the "critical" wind speeds U_c, in which the U pattern that is transited from weak wind regimes to windy regimes depends on SR values. The fact that ΔT under $U < U_c$ was warmer than those associated with U slightly greater than U_c suggests that there tends to be a warm solar bias under weak wind conditions. This conjecture appears to be confirmed when the data points are stratified by U.

b. Global solar radiation effect

Functional relationships between SR and ΔT were found to be present under all of the categories of weak wind conditions, including a U of less than 1, 1–1.5, and 1.5–2 m s^{-1}, respectively (Fig. 6). With an increase in SR, ΔT shifted from negative to positive values. The SR and ΔT relationship (Fig. 6) can be approximated by a simple linear regression equation $\Delta T = a + b$*SR, where a is the regression constant and b is the slope. Corresponding to the above-mentioned three weak wind regimes, values of a are −0.108, −0.157, and −0.206, respectively, and values of b are 1.26×10^{-4}, 1.89×10^{-4}, and 1.17×10^{-4}, respectively. The regression slopes are all statistically significant from 0 at the 0.05 level. The average solar radiation–related ΔT that is calculated from the term b*SR under calm conditions ($U \leq 1.5$ m s^{-1}) was about 0.03°C. The ΔT could reach 0.12°C when SR reached 600 W m^{-2}. However, this condition represented only 7.8% of the cases.

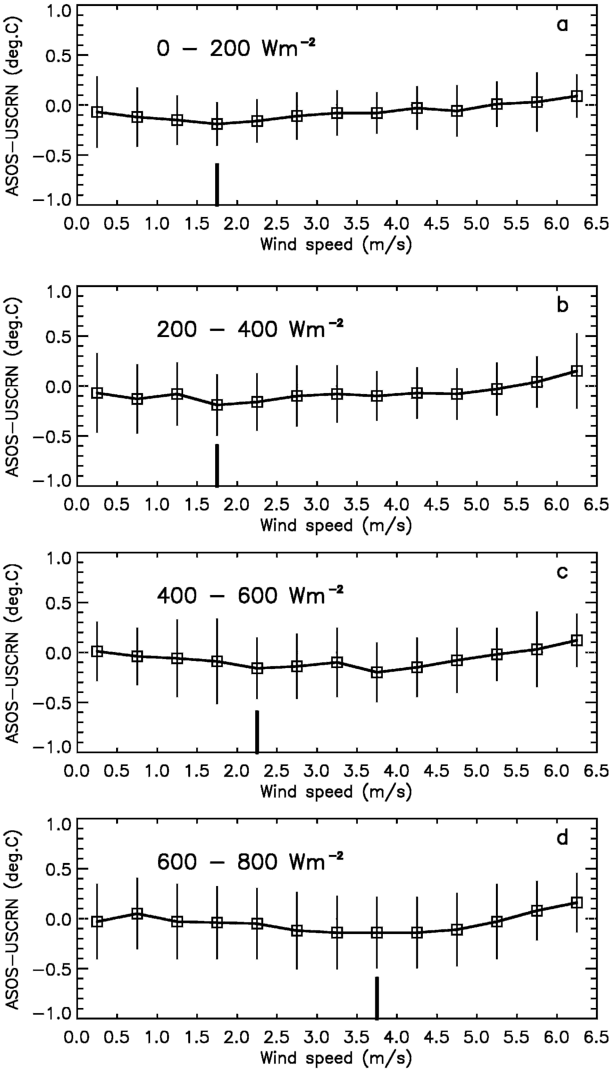

FIG. 5. Relationship between ΔT and U under different solar radiation regimes at the Sterling site under solar radiation regimes of (a) 0–200, (b) 200–400, (c) 400–600, and (d) 600–800 W m^{-2}. Vertical lines on the curves represent values of one ΔT standard deviation. Thick vertical lines pointing from the x axis denote the U turning points in which the U patterns transited from weak wind regimes to windy regimes depend on SR values. These "critical" wind speeds U_c were approximately 1.5–2.0, 2.0–2.5, and 3.0–3.5 m s^{-1}, corresponding to an SR of less than 400, 400–600, and 600–800 W m^{-2}, respectively.

No meaningful relationship between SR and ΔT was found when U was greater than 3 m s^{-1}. The solar radiation–related warm ΔT, which was found under weak wind conditions, although small in magnitude, suggests that the solar insulation of the ASOS shield is less effective than that of the USCRN shield. This may be because the ASOS shield has only a single cylinder, in contrast to the three concentric cylinder configurations inside the USCRN shield.

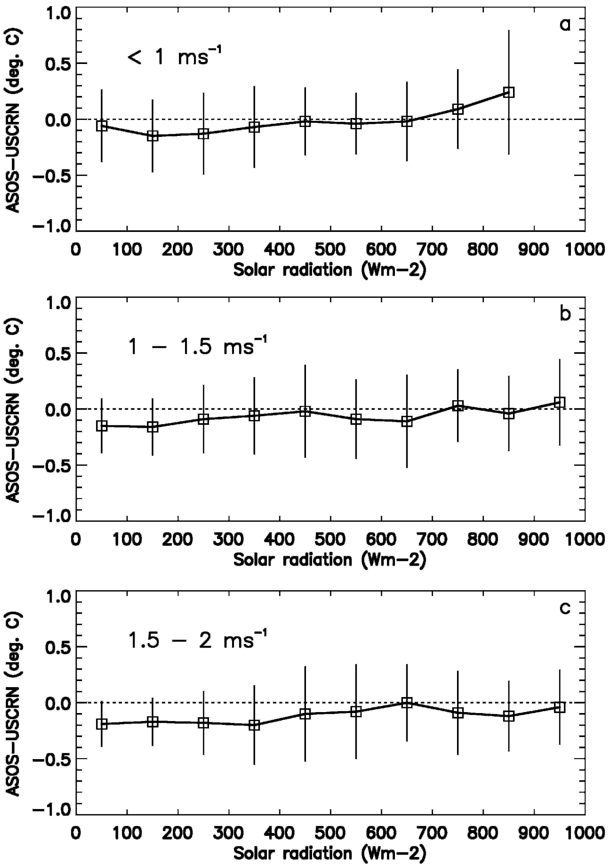

FIG. 6. Same as Fig. 5, except for relationships between ΔT and SR under wind regimes of (a) <1, (b) 1–1.5, and (c) 1.5–2.0 m s^{-1}.

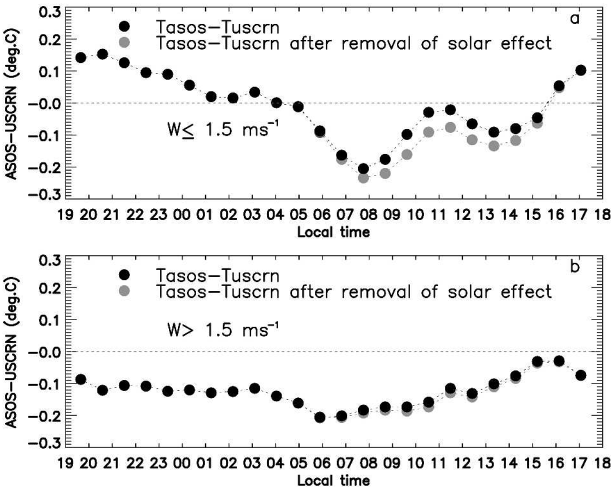

FIG. 7. Diurnal variations of ΔT (dark dots) and ΔT after the removal of solar effect (gray dots) based on the Sterling data, for (a) calm ($U \leq 1.5$ m s^{-1}) and (b) windy ($U > 1.5$ m s^{-1}) conditions.

c. *Infrared radiation effect*

The IR thermal effect under calm conditions generally is stronger than that under windy conditions because a stronger convective heat exchange occurs under windy conditions. The IR effect is, therefore, expected to differ on the diurnal cycle and is based whether calm and windy conditions exist.

Two types of ΔT are depicted in Fig. 7—the ΔT that is related primarily to a combination of solar and IR effects (dark dots), and the ΔT after the removal of the solar effect (green dots), calculated from $\Delta T = b$*SR. The latter ΔT is supposed to represent the IR-inducing difference. Under windy conditions, there was an IR-related cooling ΔT of about -0.13°C, and, in contrast, under calm conditions, the IR-related ΔT showed a diurnal variability (Figs. 7a and 7b).

The mechanism for the diurnal variability was unclear, but a thermal lag between the sensor and shield that is noticed by Tanner et al. (1996) could have been responsible for this time-dependent IR-related ΔT. Given the magnitude in the diurnal variability of IR-related ΔT (ranging from -0.2°C in the early morning to 0.1°C in the early evening), a slight difference in siting characteristics between the ASOS and USCRN instruments (though it is not expected at the Sterling site) might also have been the cause, or one of the causes, for the diurnal cycle of the IR-related ΔT.

7. Analysis for Asheville, North Carolina

At the Asheville site, the ASOS hourly temperature is represented by the average of minutes 50–54 of the hour, whereas the corresponding USCRN hourly temperature is represented by the average of minutes 55–59. As discussed in section 5, due to the existence of intrahourly temperature variability, the ASOS and USCRN reporting practice difference could affect the accurate quantification of temperature bias.

In Table 2, ΔT calculated from data with a larger intrahourly variability (the first row in Table 2) showed a much larger value and/or a larger ΔT standard deviation than that calculated from data with a smaller intrahourly standard deviation (the second row in Table 2). The hourly temperature standard deviation thresholds that are used to classify the Asheville hourly data listed in Table 2 were obtained from the Sterling site. The results appear to indicate that the standard deviation threshold values that are obtained from the Sterling site were applicable to the Asheville site, though the climate conditions between them were not the same. In the Asheville siting effect analysis, only the data points in the second row of Table 2 were used, which did not appear to be affected significantly by the observing practice difference.

TABLE 2. Influence of ASOS vs USCRN observing practice difference (described in Table 1) on hourly temperature difference ($T_{\rm asos} - T_{\rm uscrn}$, ΔT) at the Asheville site. The threshold values of hourly temperature standard deviations (0.3°C for nighttime and 0.27°C for daytime, obtained from the Sterling site) were used to classify the hourly data.

		Sample size	Mean difference	Std dev
ΔT with standard deviation *beyond* the thresholds	Nighttime	799	+0.67	0.96
	Daytime	1588	+0.14	0.51
	All day	2387	+0.32	0.74
ΔT with standard deviation *within* the thresholds	Nighttime	1939	+0.17	0.49
	Daytime	1238	+0.18	0.36
	All day	3177	+0.18	0.44

a. Comparison of wind speed between the ASOS and USCRN sites

In the Sterling analysis, the USCRN U data were used to assess the ASOS shield effectiveness. Similar results would be expected if ASOS U data were used because these two instruments were only 90 m away on a flat, uniform grassy surface. The situation at Asheville is different—the USCRN instrument has been operating about 2.4 km from the ASOS and the wind speeds may be different between these two sites. If so, the shield effectiveness analysis could be biased if U data from the USCRN site are used. Similar to the Asheville site, many sites that are considered to be "collocated" in the national observing networks may be separated by a distance of a couple of miles (Guttman and Baker 1996). Thus, the Asheville site may be used as a case study to understand the spatial variability of near-surface U.

USCRN U data were hourly values averaged from 12 five-minute averages. Standard ASOS hourly U data were represented by 2-min averages past the hour. For this comparison, the ASOS high-resolution sensor data with a 1-min resolution were used to estimate the hourly U data in the same way in which the USCRN hourly winds were calculated. The 1-min ASOS data are primarily intended for maintenance troubleshooting purposes and have not undergone final quality control checks (National Weather Service 1992). Before conducting the U comparison, some quality control procedures were applied to refine the 1-min dataset. Under a neutral near-surface atmosphere condition, the following formula [Eq. (2)] was used to convert the ASOS U from a height of 8 (at which height the Asheville ASOS U was measured) to 1.5 m:

$$U_2 = U_1\,[\ln(z_2 + z_0)/z_0]/[\ln(z_1 + z_0)/z_0], \tag{2}$$

where U_2 is the wind speed at z_2, U_1 is wind speed at z_1, and z_0 is the surface roughness length (assumed 0.02 m).

The ASOS wind speed (U_2) and USCRN wind speed were correlated (Fig. 8); the correlation coefficient reached 0.76 with a sample of 2951 h. However, on average, U at the ASOS site was higher than that of the USCRN site by 0.67 m s^{-1}. This might be because the ASOS site was more open in space and the trees about 100 m north of the USCRN instrument might reduce the USCRN wind speed. Given the large difference of U values, the ASOS U data (converted from a height of 8 to 1.5 m) were used in the following analysis.

b. Effects of siting difference

Because the data points of hourly ΔT with significant observing practice influence were already eliminated (Table 2), the ΔT that we analyze in this section is composed mainly of $\Delta T_{\rm shield\ effect}$ and $\Delta T_{\rm local\ effect}$. The $\Delta T_{\rm local\ effect}$ at Asheville was calculated by subtracting $\Delta T_{\rm shield\ effect}$ (which varied with U) obtained from the Sterling site (Fig. 4) from ΔT (the second row of Table 2). The mean value of $\Delta T_{\rm local\ effect}$ averaged from both nighttime and daytime cases was 0.25°C, with a standard deviation of 0.43°C. This value was much larger than that of $\Delta T_{\rm shield\ effect}$ (about 0.1°C, see section 6). The warm $\Delta T_{\rm local\ effect}$ shown in both the nighttime and daytime at Asheville most probably was caused by the heat produced by the airport runway and parking lots near the ASOS site. The daytime $\Delta T_{\rm local\ effect}$ also increased with the amount of solar radiation, indicating that solar heating on concrete constructions might have enhanced the local heating at the ASOS site. Additionally, the $\Delta T_{\rm local\ effect}$ associated with the northerly (prevailing) wind was found to be warmer by 0.20°C than that of the southerly wind.

Cloudiness is another important factor in regulating $\Delta T_{\rm local\ effect}$ (Guttman and Baker 1996; McKee et al. 1997) through cloud-emitted downward IR. Sky conditions from ASOS observations were classified into two

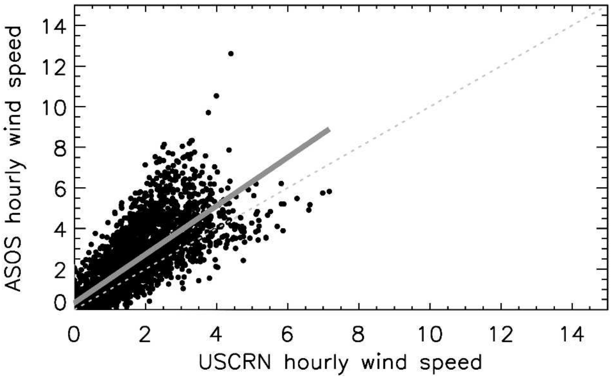

FIG. 8. USCRN vs ASOS hourly wind speeds (m s^{-1}) at the Asheville site. The ASOS 8-m wind speed was converted to the height of 1.5 m, where the USCRN wind speed was measured. The regression equation represented by the thick gray line is $U_{\rm asos} = 0.34 + 1.19\ U_{\rm uscrn}$; $R^2 = 0.57$.

categories. Category 1 included "clear," "few," and "scatter," and category 2 included "broken" and "overcast" conditions. During nighttime, $\Delta T_{\text{local effect}}$ of category 1 was 0.26°C, against 0.16°C of category 2. During daytime, $\Delta T_{\text{local effect}}$ of category 1 was 0.35°C, against 0.22°C of category 2. These numbers indicate that thick clouds with an extensive coverage more effectively dampened the effect of siting difference than thin and scatted clouds. During nighttime, with the decrease in cloud height, $\Delta T_{\text{local effect}}$ also decreased, suggesting that stronger downward IR from lower clouds effectively reduced horizontal temperature differences at the surface. Given the decadal- and longer-scale variability in cloudiness, including cloud amount and cloud type (Sun et al. 2001; Sun 2003), the long-term influence of cloudiness on $\Delta T_{\text{local effect}}$ could have been present if the two instruments were separated by a certain distance.

8. Conclusions

The test bed data from the Sterling site indicated that ambient air temperatures from the ASOS system deviated from those from the USCRN system by less than 0.1°C. Problems, however, were noticed that were possibly related to the ASOS shield efficiency, including a solar radiation warm effect under calm conditions and a wind speed–dependent ASOS minus USCRN temperature difference. In addition, several other phenomena were also noticed, including a diurnal cycle of IR-related ΔT under calm conditions, a systematic IR-related cooling of ΔT under windy conditions, and a warm ΔT under daytime strong wind conditions. Hypothesized causes for these problems were offered in the previous sections. Rigorous instrument experiments, for example, by Hubbard et al. (2001) and Lin et al. (2001a,b), however, are needed to physically understand these problems.

The ASOS and USCRN observing practice differences essentially are the differences in "observation time." These differences could lead to a warm ΔT in daily $T_{\max}$ and a cooling ΔT in daily $T_{\min}$ (~0.05°C). About 20%–30% of the hours had an hourly ΔT beyond ±0.3°C.

At the Asheville site, the ASOS and USCRN siting difference led to $\Delta T_{\text{local effect}}$ of about 0.25°C, which is larger than that of $\Delta T_{\text{shield effect}}$. This site-specific warming, believed to be caused by the heat from the airport runway and parking lots next to the ASOS site, was found to be strongly modulated by wind direction, solar radiation, and cloud type and height. As well, $\Delta T_{\text{local effect}}$ varies with different locations and regions (Guttman and Baker 1996). This term, however, needs to be taken into account in the bias analysis if the two instruments of interest are separated by a certain distance.

Results from this study are preliminary due to limited data samples. A better understanding of the ASOS and USCRN measurement systems can be achieved when data with longer records and from more sites are available.

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