5.7 A COMPARATIVE STUDY OF ASOS AND CRN TEMPERATURE MEASUREMENTS

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1. INTRODUCTION

Surface air temperature is one of the basic climate system variables identified by the National Research Council as relevant to the detection, attribution, and direct societal impacts of climate change. A temperature measurement bias can arise directly from the bias that is inherent in the temperature sensor itself and the associated data-acquisition system, and particularly from the ineffectiveness of radiation shield. The temperature difference between any two different instrument systems, ΔT, can be decomposed into the following terms:

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

Where T represents ambient air temperature, $\Delta T_{\text{instrument bias}}$ is the sensor and data acquisition system related bias, $\Delta T_{\text{shield effect}}$ is the bias associated with different radiation shield design, $\Delta T_{\text{local effect}}$ is the temperature difference contributed by differences in surface characteristics surrounding the two instruments, and $\Delta T_{\text{observing practice}}$ refers to the temperature difference brought by different data observing practices or data processing methods. The U.S. Climate Reference Network (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 free of time-dependent biases.* In this study, temperature measurements from USCRN were compared to the Automated Surface Observing System (ASOS) 1088 system in different regimes of wind speed (W) and solar radiation (S). Instrument bias and shield effect were qualtified. The influences of observing practice difference and of siting differences are also discussed.

2. INSTRUMENTS AND DATA

Both ASOS and CRN instruments ues aspirated Platinum-wire Resistance Temperature (PRT) sensors, which are installed at 1.5-m above the ground, to measure ambient air temperature,. There are some differences between the systems , including (a) the ASOS 1088 system has a single independent measurement of temperature whereas the USCRN system has three independent measurements of temperature; (b) the ASOS shield is a single cylinder that opens at the bottom, whereas the USCRN shield is comprised of three concentric cylinders, with an air gap between each one, and a circular plate at the inlet. This design maximizes air flow to the temperature sensor and minimizes longwave infrared radiation that can affect the nighttime measurements; and (c) the ASOS system contains a chilled mirror system for measuring dew point temperature, which may greatly reduce air speed past the PRT sensor (Hubbard et al. 2001).

Data from two locations, Sterling, VA and Asheville, NC, were used in this analysis. The Sterling, VA 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 1.5-mile from the CRN station located at the North Carolina State Horticultural Crops Reservation Center. One-minute data from the period January-May 2003 at Sterling 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 of November 2002 to June 2003 from the Asheville site.

3. OBSERVING PRACTICE INFLUENCE

Table 1 summarizes the major differences in reporting T, daily T_{max} and T_{min} between the two systems, which essentially arise from the differences in the timing of the observing In short, ASOS observed hourly temperature about 5-10 minutes ahead of the CRN; daily T_{max} and T_{min} were determined from five-minute running averages in ASOS but from discrete five-minute averages in CRN.

Characteristic	ASOS	CRN
Sample interval	10 seconds	2 seconds
Calculation	Running five-minute averages calculated at each minute	Discrete five-minute averages calculated at the end of each five-minute period
Hourly T	Five-minute average between 46-50-minute or 50-54-minute depending on the station	Five-minute average of 55-59-minute
Daily T_{max} and T_{min}	Determined from 24 x 60 running five-minute averages	Determined from 24 x 12 discrete five-minute averages

Table 1. ASOS and CRN Temperature reporting characteristics

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One-minute data from the Sterling, VA facility were used to derive the temperatures by both the ASOS and CRN observing methods and thus to assess the role of $\Delta T_{observing\ practice}$ in ΔT.

Figure 1 shows percentage distributions of the difference (ASOS minus CRN) in daily T_{max} (top) and T_{min} (bottom). For T_{max}, 73% of samples had a near-zero difference. The mean difference calculated from all samples was 0.03^{o} C (with standard deviation of 0.04^{o} C). For T_{min}, about 55% cases had a near-zero difference and the mean difference was -0.06^{o} C (with standard deviation of 0.08^{o} C).

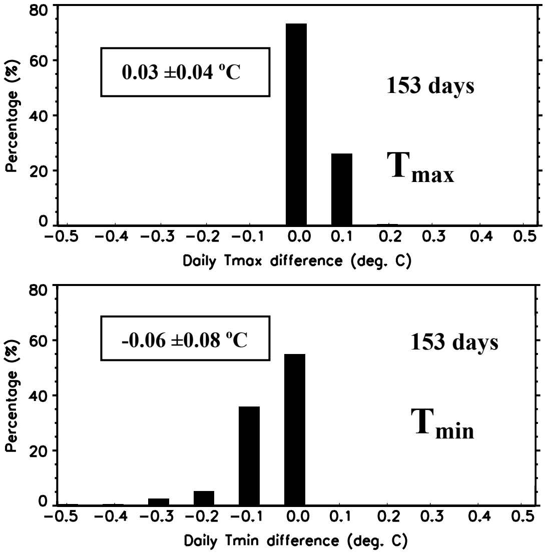

Figure 1. Percentage distribution of differences between ASOS and CRN observations of daily T_{max} (upper plot) and T_{min} (bottom plot) based on calculation using one-minute CRN data at Sterling. Mean difference and its standard deviation are shown inside the plots.

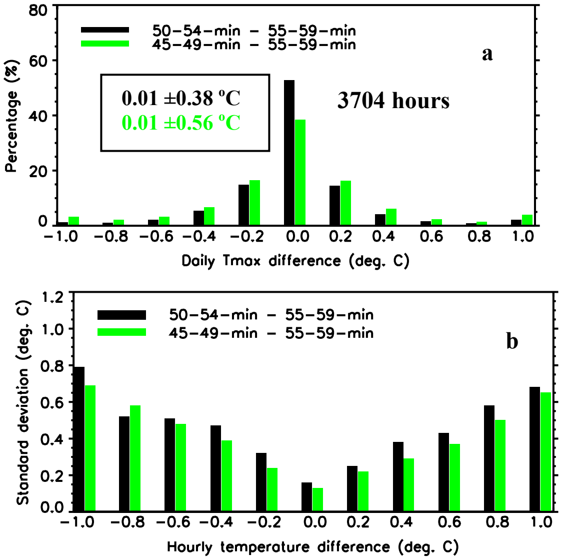

Figure 2. (a) Percentage distribution of differences between ASOS and CRN observations of hourly temperature calculated using one-minute data. CRN data from minutes 55-59 were compared to ASOS data from minutes 55-59 (HR_{crn}) (the dark bars) and minutes of 45-49 (HR^2_{asos}) minus HR_{crn}, (the light bars) (b) the standard deviation of the hourly temperature difference.

Figure 2 shows percentage distributions of hourly temperature difference (ASOS minus CRN) and the corresponding hourly temperature standard deviation. The mean differences for both HR^2_{asos} minus HR_{crn} and HR^1_{asos} minus HR_{crn} are only 0.01 ^{o} C. Regarding the difference of HR^2_{asos} minus HR_{crn}, 38% of the cases show values of near-zero corresponding to a standard deviation of 0.15^{o} C and 71% of the cases show values within ±0.3^{o} C corresponding to a standard deviation of 0.25^{o} C. Regarding the difference of HR^1_{asos} minus HR_{crn}, 53% of the cases haf near-zero values, corresponding to a standard deviation of 0.16^{o} C., and 82% of the cases had values within ±0.3^{o} C, corresponding to a standard deviation of about 0.29^{o} C.

This analysis indicated that an observing practice difference between ASOS and CRN resulted in a temperature difference. The standard deviation of 0.3^{o} C obtained from this section was next applied to filter the hourly data from the Asheville site (Section 4). In this way, the data points used for the $\Delta T_{local\ effect}$ analysis were without large intra-hourly variability and therefore were less affected by observing practice differences.

4. ANALYSIS FOR STERLING, VA

The one-minute data from both ASOS and CRN datasets were averaged into discrete five-minute averages, used in this analysis. The ΔTs and standard deviations calculated from these five-minute averages for nighttime, daytime, and all-the-day were -0.02^{o} C, -0.12^{o} C, and -0.06^{o} C, respectively. These numbers indicated that the ASOS showed a disagreement with CRN of about one tenth of a degree Celsius with standard deviation of 0.3^{o} C.

4.1 *Ambient Wind Speed Effect*

Next $\Delta T_{shield\ effect}$ was investigated in terms of the individual influences of W, S and infrared radiation (IR). The W-ΔT relationships for nighttime and daytime are described in Figure 3. Under calm conditions (W≤1.5 m s^{-1}), with the increase in W from 0.25 m s^{-1}to 1.25 m s^{-1}, the ΔT goes was negative: in the range of 0.20^{o} C to -0.1^{o} C for nighttime and -0.06^{o} C to -0.11^{o} C for daytime. Under windy conditions (W>1.5 m s^{-1}), with the increase in W, the cooling bias was linearly reduced. ΔT was close to zero when W reached 4.5 m s^{-1} or higher for both nighttime and daytime. The close-to-zero value associated with W of 4.5 m s^{-1} or higher at nighttime tended to indicate that the instrument bias inherent in the ASOS system, represented by the term $\Delta T_{instrument\ bias}$ in Eq. 1, was negligible. A daytime warm bias of 0.11^{o} C, however, was noticed when W reached 6.25 m s^{-1}. The mechanism for this phenomenon was unclear. The strong ambient wind may have interfered with the airflow generated by the ASOS's aspirated fan, due to its shield geometry, and consequently reduced the airflow efficiency within the shield, leading to a warm solar bias.

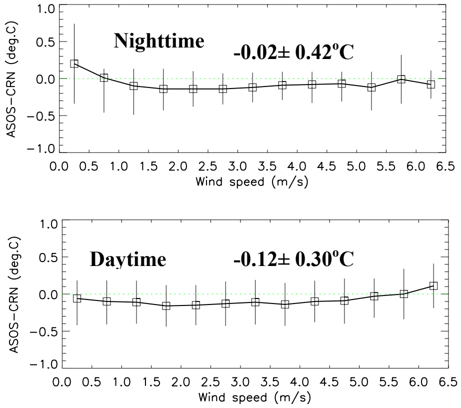

Figure 3. Relationship between ambient wind speed (W) and air temperature difference (Tasos-Tcrn, ΔT) at Sterling, VA. The vertical lines represent values of one ΔT standard deviation. Mean differences and standard deviations are indicated on the plots.

For an unaspirated shield system, temperature biases caused by S and/or IR are expected to be reduced with the increase in W (Lin et al. 2001). However, the temperature bias of the aspirated ASOS system also depended on W (Figure 4), which suggests that there may have been a ventilation drawback in the ASOS system. Even though ASOS is an aspired instrumentation, the large chilled mirror system can block the airflow entering from the outside and may reduce the speed as suggested by Hubbard et al. (2001).

4.2 *Global Solar Radiation Effect*

Functional relationships between ΔT and S were found to be present under all categories of weak wind conditions, including W of less than 1 m s^{-1}, 1-1.5 m s^{-1}, and 1.5-2 m s^{-1}, respectively (Figure 4): With the increase in S, ΔT shifted to a positive direction from a negative value. The S-ΔT relationship shown in Figure 4 can be described by a simple linear regression equation $\Delta T = a + b \times S$, where a is the regression constant and b is the slope. Corresponding to the three categories of weak wind regimes (Figure 4), values of a were -0.108, -0.157, and -0.206, respectively, and values of b were 1.26 $\times 10^{-4}$, 1.89 $\times 10^{-4}$, and1.17 $\times 10^{-4}$, respectively. The variances explained by the regression slopes were all statistically significant at the 0.05 level. The average solar radiation warm bias calculated from $\Delta T = b \times S$ under calm conditions (W≤ 1.5 m s^{-1}) was about 0.03° C. The bias could reach 0.12° C with one standard deviation of 0.37° C when S reaches 600 Wm^{-2}, however this condition represented only 7.8% of cases.

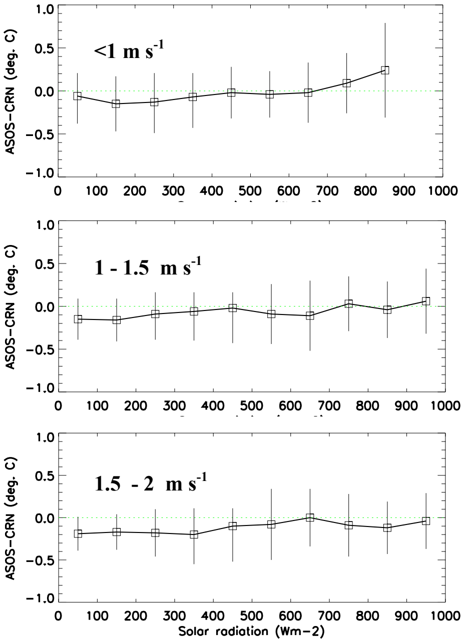

Figure 4. Same as Figure 3 except for the relationship between solar radiation (S) and air temperature difference (Tasos-Tcrn, ΔT).

No meaningful relationship was found between ΔT and S with W greater than 3 m s^{-1}. With W greater than 4.5 m s^{-1}, ΔT was close to zero under most solar conditions, except with S values in the range of 800-900 W m^{-2}, where negative values from -0.1 to -0.2° C were shown. The cause for this anomalous cooling was unclear. It may be related to a strong IR cooling effect which occurred at the time when S values were 800-900 W m^{-2}.

The ASOS solar warming bias, though small in magnitude, was noticed under weak wind conditions, suggesting that the solar insulation of the ASOS shield is less effective than the CRN shield. This may be because the ASOS shield has only a single cylinder in contrast to the three-concentric cylinder configuration inside the CRN shield. This shield design difference may also be responsible for the ASOS IR cooling bias discussed in the next section.

4.3 *Infrared Radiation Effect*

Unlike S effect, IR effect can work day and night. The IR thermal effect under calm conditions generally is stronger than under windy conditions as a stronger convective heat exchange occurs under windy conditions. IR effect is therefore discussed on a diurnal cycle and for calm and windy conditions respectively. Figure 5 shows the diurnal variability of ΔT for calm (W ≤1.5 m s^{-1}, top) and windy conditions (W >1.5 m s^{-1}, bottom).

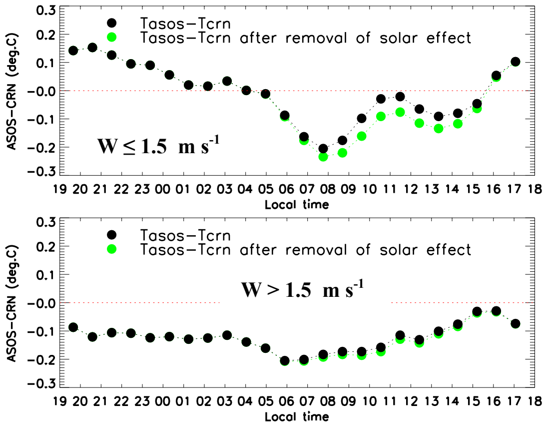

Figure 5. Diurnal variations of air temperature difference (T_{asos}-T_{crn}, ΔT, dark dot) and the difference after the removal of solar effect (light dots) based on the Sterling data, for calm conditions (W≤1.5 m $s^{-1,}$ top) and windy condition (W>1.5 m s^{-1}, bottom).

Two types of biases are depicted in Figure 5; ΔT caused primarily by a combination of solar and IR effect (dark dots) and ΔT after the removal of solar effect (light dots) based on ΔT= bX S (see Section 3.2). The latter actually represent the IR inducing bias. It appears to indicate from Figure 5 that (1) under windy conditions, the ASOS shield had an IR-cooling bias (of about -0.13^o C with one standard deviation of 0.28^o C) and (2) in contrast, under calm conditions, the ASOS shield IR-related ΔT showed a strong diurnal variability.

It was unclear about the mechanism for the diurnal variability under calm conditions, but a thermal lag between the sensor and shield noticed by Tanner et al. (1996) could have been responsible for this time-dependent IR-related bias. Given the small magnitude in the diurnal variability of IR bias under calm conditions (ranging from -0.2^o C in the early morning to 0.1^o C in the early night), a slight difference in siting characteristics between the ASOS and CRN instruments (though it is not expected) may also have been the cause or one of the causes for the diurnal cycle of IR bias.

5. EFFECTS OF SITING DIFFERENCE AT THE ASHEVILLE SITE

At the Asheville site, the official ASOS hourly temperature is represented by the average of minutes 46-50 of the hour whereas the average of minutes 55-59 represents the corresponding CRN hourly temperature. As discussed in Section 3, due to the existence of the intra-hourly temperature variability, this reporting practice difference could affect the accurate quantification of temperature biases. The standard deviations for the one-minute observations from Section 3 could next be used as the threshold values 0.3^o C for nighttime and 0.27^o C for daytime, corresponding to a $\Delta T_{\text{observing practice}}$ of 0.3^o C.

These standard deviations were used to calculate two sets of ΔTs listed in Table 2. Obviously, the ΔT calculated from data with a larger intra-hourly variability (the first row in Table 2) showed a much larger value and standard deviation (for nighttime) than that calculated from data with a smaller intra-hourly standard deviation (the second row in Table 2). The results appeared to indicate that the standard deviation threshold values obtained from the Sterling site were applicable to the Asheville site, though the climate conditions between them were not the same. In the 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.

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

Table 2. Influence of different observing practice (described at Table 1) on hourly temperature difference (T_{asos} –T_{crn}, ΔT) at the Asheville site. The threshold values of five-minute temperature standard deviations, 0.3^{o}C for nighttime and 0.27^o C for daytime obtained from the Sterling site, were used to classify the hourly data.

The $\Delta T_{\text{local effect}}$ at Asheville was calculated by subtracting $\Delta T_{\text{shield effect}}$ obtained from the Sterling site from the ΔT (the second row of Table 2). The mean value of $\Delta T_{\text{local effect}}$ averaged from both nighttime and daytime cases was 0.25^o C with a standard deviation of 0.43^o C. This value was much larger than the $\Delta T_{\text{shield effect}}$ (about 0.1^o C, see Section 3). The warm $\Delta T_{\text{local effect,}}$ shown in both nighttime and daytime at Asheville, may have been caused by the heat produced by the airport runway and parking lots near the ASOS site. The daytime $\Delta T_{\text{local effect}}$ increased with the amount of solar radiation, indicating solar heating on airport runways and parking lots might have enhanced the local heating at the ASOS site. Additionally, the $\Delta T_{\text{local effect}}$ associated with the northerly (the prevailing wind) was found to be warmer by 0.20^o C than the southerly.

Cloudiness is another important factor in regulating $\Delta T_{\text{local effect}}$ (Guttman and Baker, 1996) through cloud-emitted downward IR. For this study, sky conditions were classified into two categories. Category 1 includes “clear”, “few”, and “scatter”, and Category 2 includes “broken” and “overcast”. During nighttime, $\Delta T_{\text{local effect}}$ of Category 1 was 0.26±0.54^o C against 0.16±0.32^o C of Category 2. During daytime, $\Delta T_{\text{local effect}}$ of Category 1 was 0.35±0.39^o C against 0.22±0.29^o C of Category 2. These numbers indicated that $\Delta T_{\text{local effect}}$ changed with cloud types and 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. A similar relationship was found for daytime but with a less statistical significance.

6. CONCLUSION

This analysis indicated that there was a slight difference between the ASOS and CRN temperature with the former being about 0.1^{o} C cooler than the latter. However, problems which appeared to be related to the ASOS shield efficiency were noticed, namely, a systematic IR cooling bias (noticed under windy conditions), a solar radiation warm bias under calm conditions, and a drawback in air flow efficiency inside the shield. In addition, several other phenomena which may also be related to the ASOS shield design were noticed, including a strong diurnal cycle of IR-related bias under calm conditions and a warm bias under daytime strong wind conditions. Rigorous instrument experiments, however, are needed to physically understand them.

Different observing practices between two instrument systems could introduce artificial biases, $\Delta T_{\text{observing practice.}}$ ASOS differs from CRN essentially in observation times (Table 1), which leads to a warm bias in daily T_{max} and a cooling bias in daily T_{min} (though only in the magnitude of ~0.05^{o} C) and 20% - 30% of cases with biases beyond $\pm 0.3^{o}$ C. Caution is therefore needed in comparing two instrument systems if their observing practices or data processing methods are different.

At the Asheville site, the effect of siting difference between the ASOS and CRN led to a $\Delta T_{\text{local effect}}$ of about 0.25^{o} C, much larger than the $\Delta T_{\text{shield effect}}$ (about -0.1^{o} C). This local warming effect, 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. Siting effect can vary with different locations and regions as well. This term, undoubtedly, needs to be taken into account in the bias analysis if two instruments of interest are separated by a significant distance.

7. REFERENCES

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