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Realtime data filtering models for air temperature measurements

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[1] Air temperature measurement biases caused by solar radiation and ambient wind speed are well-known. However, realtime air temperature filtering models are essential for generating homogeneous climate data by transforming one air temperature measurement system into another, and correcting in-situ air temperature biases especially for non-aspirated radiation shield systems. This study investigated the air temperature biases caused in the commonly used radiation shields in the United States, including the ASOS, MMTS, Gill, CRS, ASP-ES, and NON-ASP-ES shields along with corresponding temperature sensors. The realtime air temperature filtering models developed for each air temperature system are capable of removing the solar radiation and ambient wind speed effects on air temperature measurements taken over comparable vegetation surfaces at any weather station or experimental site. *INDEX TERMS:* 1694 Global Change: Instruments and techniques; 3394 Meteorology and Atmospheric Dynamics: Instruments and techniques

1. Introduction

[2] The Cotton Region Shelters (CRS) with liquid-in-glass thermometers have been used for more than one century in collecting air temperature records. Beginning in the 1980s, the Maximum-Minimum Temperature systems (MMTS) in a plastic shelter replaced the CRS shield. Subsequently, a Gill shield with an HMP35C/45C sensor (provided by Campbell Scientific, Inc.) was widely used in new automated weather stations in the 1980s [*Hubbard et al.*, 1983] and thermometer shelters of yet another design [*Guttman and Baker*, 1996] were introduced in Automated Surface Observing System (ASOS) network in 1990s. In addition, a few other radiation shields have emerged in recent years such as aspirated and non-aspirated radiation shields from various manufacturers. Across the board, the biases of air temperature measurements taken by any combination of temperature sensor and radiation shield are mainly influenced by the solar radiation and air speed inside the radiation shields [*Lin*, 1999; *Hubbard et al.*, 2001]. Therefore, it is necessary to develop realtime data filtering models for more accurate representation of air temperature measurements for the climatological temperature studies. Such models can transfer the air temperature readings among different shield-temperature sensor combinations. Unlike the adjustment procedures developed by *Karl et al.* [1986] and *Karl et al.* [1989] for the time of observation bias, as well as the correction techniques developed by *Quayle et al.* [1991] and *Peterson and Easterling* [1994], our intent is to develop realtime air temperature data filtering models to remove the air temperature biases encountered when the different combinations of shield and temperature sensor are employed. The biases can transfer in either realtime fashion or on the historical data wherever solar radiation and the ambient wind speed are available at the station or research site.

2. Experiments and Model Development

[3] The experiments were conducted from April 2000 through August 2000 at the University of Nebraska's Horticulture Experimental Site (40°83′ N, 96°67′W, elevation 383 m). The site has flat terrain and the surface was mowed grass; there were no physical obstructions within 25 m of the sensors Figure 1. The experiments consisted of dual temperature systems for ASOS, MMTS, and Gill shield (with HMP45C sensor), as well as one aspirated (ASP-ES) and one non-aspirated (NON-ES) shield from Eastern Scientific Inc. (with HMP45C), and one CRS (with HMP45C). We chose to use a highly accurate R. M. Young 43347 temperature probe (±0.1°C accuracy) combined with an aspirated radiation shield (model 43408-L, R. M. Young Inc.) for reference air temperature measurements because both temperature sensor (1000 ohms PRT) and the aspirated shield (3 to 7 m s^{-1} air flow rate) have superior performance (radiation error <0.2°C under 1100 W m^{-2} irradiance). The solar radiation and ambient wind speed were also measured and the sampling frequency including temperature sensors was 0.1 Hz with 5 minute averaged outputs. The installation height of all temperature sensors, a solar radiation sensor (model LI-200S, LI-COR, Inc.), and a ambient wind speed sensor (model 014A, Met-One instruments) was at 1.5 meters.

[4] All experimental data except the ASOS temperature record were collected using two CR10 dataloggers (Campbell Scientific Inc). An RS-232 communication protocol was developed for directly interrogating the ASOS. The MMTS temperature measurements were automatically recorded using a full bridge circuit by the CR10 datalogger, rather than conventional visual observation of an LCD display. The signal conditioning circuitry for the thermistor in

Figure 1. From upper right, the array of air temperature systems used (ASOS, ASP-ES, RMY, MMTS, Gill, NON-ES, and CRS shields) at the experimental field. The bottom shows all air temperature radiation shields individually with labels A, B, C, D, E, F, and G depicting the ASOS, ASP-ES, NON-ASP-ES, Gill, MMTS, CRS, and R. M. Young aspirated radiation shields.

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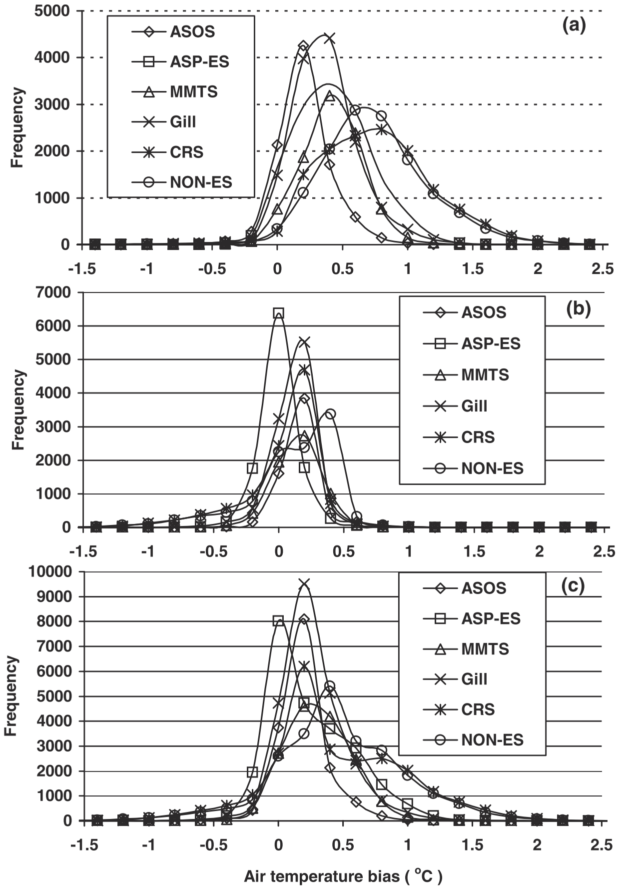

Figure 2. Statistical distributions of (a) daytime air temperature biases, (b) nighttime air temperature biases, and (c) overall air temperature biases for all air temperature systems in the measurements.

the MMTS was calibrated to an accuracy (±0.2°C) better than the original MMTS readout (12-bit ADC and microprocessor-based). All sensors involved in the study were newly acquired from manufacturers.

[5] In order to increase the robustness of our analysis, the realtime air temperature, solar radiation, and ambient wind speed data from June 2000 were used to derive the data filtering models while separate data from July 2000 were used to validate the models. The solar radiation (up to 1152 W m^{-2} and highest solar elevation occurs during June and July), ambient wind speed (up to 10.5 m s^{-1}, monthly mean was 2.6 m s^{-1} at 1.5 meters), and ground surface characteristics [typical grass surface, solar reflectivity (about 0.24)] are typical of growing season conditions and data for the dormant vegetative period or periods of snowfall are not yet available. The term air temperature bias for each conventional system (ASOS, ASP-ES, MMTS, Gill, CRS, and NON-ES) in this article is defined as the difference relative to the R. M. Young aspirated sensor system.

[6] Development of the realtime data filtering models for air temperature measurements is based on the mechanism of both solar radiation and ambient wind speed effects on the accuracy of air temperature measurements. The goal of the model is to predict the air temperature biases by using readily available climate data (solar radiation and wind speed) at the weather station or specific research site. The approach taken was to use nonlinear regression methods with two input parameters: solar radiation and ambient wind speed. The fraction of solar radiation loading inside the temperature radiation shields is a parabolic function of solar time [*Lin*, 1999; *Hubbard et al.*, 2001], whereas the air temperature radiation errors increase linearly with the increase of solar radiation impinging on the air temperature sensor inside the shield [*Fritschen and Gay*, 1979]. The relationship of wind speed inside to wind speed outside the shield is to a good approximation-a linear function [*Lin et al.*, 2001], whereas, the air temperature error caused by wind speed is an exponential function [*Fritschen and Gay*, 1979; *Lin et al.*, 2001]. The model for air temperature bias (Y) is, therefore, defined as follows,

$$Y = \alpha + \beta \cdot e^{(\gamma \cdot WS)} + \delta \left(\frac{SR}{1000}\right)^2 + \epsilon \left(\frac{SR}{1000}\right),$$

where the α, β, γ, δ, and ϵ represents coefficients to be determined by the nonlinear regression for each specific air temperature system, WS the ambient wind speed, and SR the ambient solar radiation.

3. Results and Discussion

[7] Figure 2 shows the frequency distribution of air temperature biases calculated from data in June 2000. In general, both daytime and nighttime air temperature biases illustrated positive average biases for all radiation shields; however, the daytime air temperature biases and standard deviations were quite large compared to the nighttime air temperature biases due to the solar radiation effects. The aspirated radiation shields, especially the ASOS shield, had a decreased bias range because its solid walls block most of the solar radiation and the aspiration keeps the sensor and shield in thermal equilibrium with the air. From the overall distribution of air temperature biases (Figure 2c), both ASOS and ASP-ES produced smaller average biases while the non-aspirated radiation shields resulted in larger standard deviation of biases especially for the CRS and NON-ES shields Table 1. The three-sigma biases suggest that true accuracy for each temperature system in the field varies beyond the manufacturer's specifications, which implies that it is necessary to build the realtime data filtering models for filtering air temperature biases caused by solar radiation and ambient wind speed (Table 1).

[8] The simulation results shown in Figure 3 illustrate the response surface for the air temperature filtering model for two systems used by the National Weather Service: non-aspirated MMTS and aspirated ASOS. Due to space limitations the other response surfaces are not shown, but can be easily constructed from the coefficients in Table 2. All non-aspirated systems (MMTS, Gill, CRS, and NON-ES) show that the air temperature biases increased exponentially with the decrease of ambient wind speed and parabolical cross sections in the direction of solar

Table 1. Summary of Average Air Temperature Biases, Standard Deviation of Bias (σ), and Three-Sigma Biases (±3σ Plus Mean Bias) for Each Temperature System

Performance	ASOS	ASP-ES	MMTS	Gill	CRS	NON-ES
Average bias (°C)	0.09	0.15	0.21	0.16	0.34	0.37
Standard deviation (σ)	0.22	0.33	0.25	0.26	0.53	0.51
3σ (low bound)	−0.57	−0.84	−0.54	−0.62	−1.25	−1.16
−3σ (up bound)	+0.75	+1.14	+0.96	+0.94	+1.93	+1.90

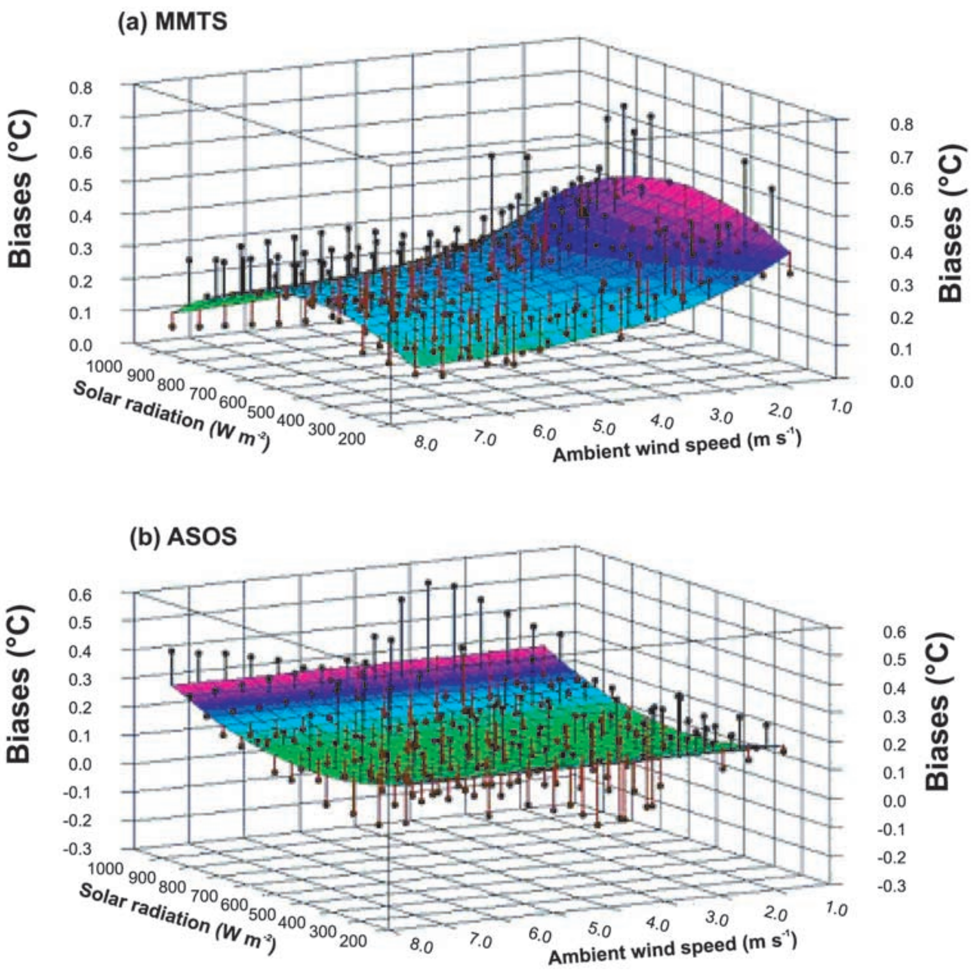

Figure 3. The distribution of air temperature biases, as a function of the ambient wind speed and solar radiation, measured by (a) the non-aspirated radiation shield-MMTS and (b) the aspirated radiation shield-ASOS.

radiation (Figure 3a and Table 2). Generally, temperature biases in the aspirated system were rather insensitive to both solar radiation and ambient wind speed (Figure 3b and Table 2) because the aspirated shields have constant ventilation rates and relatively solid wall construction. An interesting point supported by Figure 3a is that air temperature biases were larger for the solar radiation in the range from 500 to 800 W m^{-2} for all non-aspirated radiation shield systems, rather than the highest solar radiation (e.g., 1100 W m^{-2}). This finding suggests that the maximum solar radiation loading inside the shields occurs in either the middle morning or middle afternoon. This is because all non-aspirated radiation shields are composed of the solid top with multiple slanted plates (Figure 1), through which the solar radiation can directly pass or be reflected onto the temperature sensor surface. This raises one possibility that

Table 2. Model Coefficients and Air Temperature Biases Caused By Combinations of Low (L) and High (H) Ambient Wind Speed (*WS*) and Solar Radiation (*SR*) for Each Air Temperature System

Shields	Model Coefficients					Typical Values (°C)			
	α	β	γ	δ	ϵ	(L,L)	(L,H)	(H,L)	(H,H)
ASOS	0.297	−0.0001	−0.5	0.555	−0.599	0.30	0.17	0.30	0.17
ASP-ES	0.245	0.229	−0.62	−0.222	0.459	0.41	0.64	0.25	0.48
MMTS	0.015	0.357	−0.45	−0.758	0.866	0.30	0.51	0.04	0.25
GILL	0.014	0.431	−0.54	−0.821	0.862	0.34	0.51	0.03	0.20
CRS	0.267	0.641	−0.48	−0.666	1.11	0.75	1.21	0.30	0.76
NON-ES	0.298	0.706	−0.46	−0.463	1.069	0.86	1.42	0.34	0.90

The first term in parentheses is for the *WS* where L = 0.5 m s^{-1} and H = 6 m s^{-1}. The second term in parentheses is for *SR* where L = 0 W m^{-2} and H = 800 W m^{-2}. Thus, the (L, H) refers to the combination of 0.5 m s^{-1} *WS* and 800 W m^{-2} *SR*.

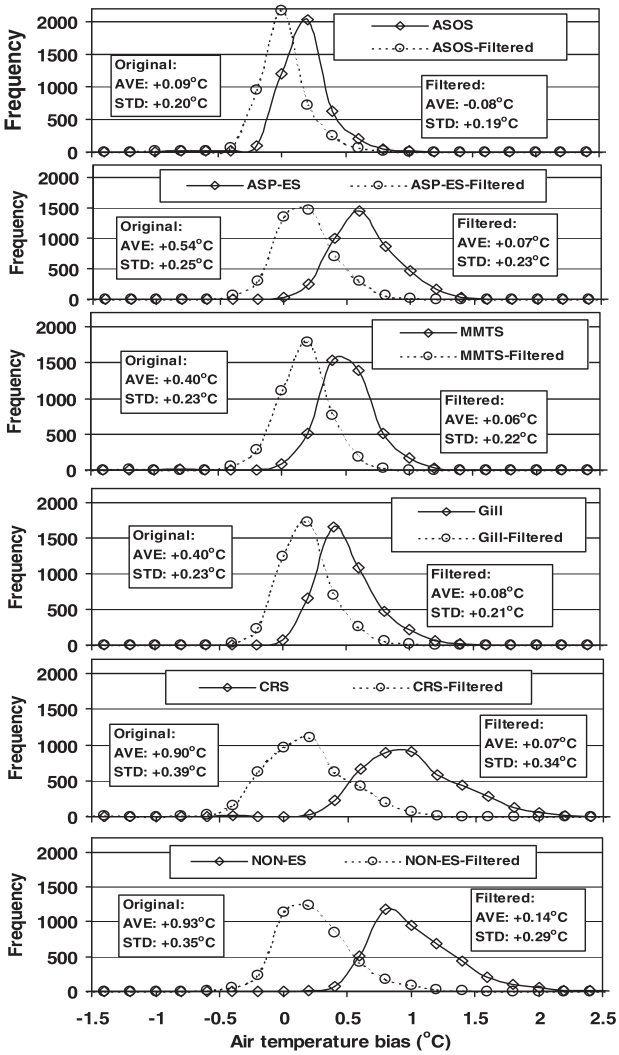

Figure 4. Validation of air temperature filtering models for the air temperature measurement systems of the ASOS, ASP-ES, MMTS, Gill, CRS, and NON-ES shields, respectively from the top to bottom.

maximum air temperature records have the greatest positive biases because the maximum usually occurs in the afternoon during the period when the air temperature is largest bias. Some comparative air temperature biases for four possible combinations of solar radiation and ambient wind speed are shown in Table 2. It is apparent that the combination of high solar radiation and low ambient wind speed is the worst case, whereas the combination of low solar radiation and high ambient wind speed is the best case.

[9] It is clear from Figure 4 that the realtime data filtering models improved both average air temperature bias and standard deviation bias so that the three-sigma bias (accuracy of each system) are greatly improved. The average air temperature biases were less than one tenth of a degree except for the NON-ES system (+0.14°C). Thus, if we employ these realtime data filtering models, we can reduce the solar radiation and ambient wind speed effects on air temperature measurements in practice. The models can be simply implemented for transforming one radiation shield system to any other especially for the relations among the ASOS weather station networks, automated weather station networks (Gill with HMP45C), and the stations using the MMTS shield with its thermistor sensor in the United States. This is what climatologists are seeking for both historical air temperature records and current climate research.

4. Conclusions

[10] Without air temperature data filtering, both average air temperature bias and three-sigma bias for each temperature system are as large as a few tenths of a degree. The non-aspirated radiation shield systems, including the MMTS, Gill, CRS, and NON-ES systems, had a bias ranging from a half degree to nearly two degrees, whereas the aspirated radiation systems, the ASOS and ASP-ES systems, were much better. At other locations, biases could be larger in certain combinations of solar radiation and wind speed. The maximum air temperature bias occurred in the mid-morning and mid-afternoon for all non-aspirated radiation shield systems. This suggests that the maximum temperature records in weather stations have encountered or will encounter the maximum positive contamination by non-aspirated shield systems. However, the aspirated radiation shield systems performed relatively independently of both solar radiation and ambient wind speed.

[11] We have presented new air temperature data filtering models for the ASOS, MMTS, ASP-ES, Gill, CRS, and NON-ES temperature systems appropriate for the growing season. These realtime air temperature filtering models decreased the average air temperature bias and the standard deviation of bias. The models for each temperature system can be applied to generate homogeneous climate data by transforming data from one air temperature system into another when the solar radiation and ambient wind speed are available at the weather station or experimental site. It should be noted that the models do not eliminate calibration or sensor drift biases that may be inherent in the air temperature sensors either when derived from manufacturers or after long-term use without calibration. In addition, we expect our realtime air temperature filtering models will require new coefficients when the ground surface is not grass, e.g., fresh snow-covered ground surfaces.

[12] **Acknowledgments.** We acknowledge the National Weather Service and manufactures for providing systems for testing.

References

Fritschen, L. J., and L. W. Gay (Eds.), Environmental Instrumentation, 216 pp., Springer-Verlag, New York, 1979.

Guttman, N. B., and C. B. Baker, Exploratory analysis of the difference between temperature observations recorded by ASOS and conventional methods, *Bull. Amer. Meteor. Soc.*, *77*, 2865–2873, 1996.

Hubbard, K. G., N. J. Rosenberg, and D. C. Nielsen, Automated Weather Data Network for agriculture, *J. of Water Resources Planning and Mngmnt.*, *109*(3), 213–222, 1983.

Hubbard, K. G., X. Lin, and E. A. Walter-Shea, The effectiveness of the ASOS, MMTS, Gill, and CRS air temperature radiation shields, *J. Atmos. Oceanic Tech.*, *18*(6), 851–864, 2001.

Karl, T. R., C. N. Williams, P. J. Young, and W. M. Wendland, A model to estimate the time of observation bias associated with monthly mean maximum, minimum, and mean temperatures for the United States, *J. Climate Appl. Meteor.*, *25*, 145–160, 1986.

Karl, T. R., J. D. Tarpley, R. G. Quayle, H. F. Diaz, D. A. Robinson, and R. S. Bradley, The recent climate record: What it can and cannot tell us, *Reviews of Geophysics*, *27*, 405–430, 1989.

Lin, X., Microclimate inside the radiation shields. Ph.D. dissertation, 187 pp., University of Nebraska-Lincoln, 1999.

Lin, X., K. G. Hubbard, and G. E. Meyer, Air flow characteristics of commonly used temperature radiation shields, *J. Atmos. Oceanic Tech.*, *18*(3), 329–339, 2001.

Peterson, T. C., and D. R. Easterling, Creation of homogeneous composite climatological reference series, *International J. Climatology*, *14*, 671–679, 1994.

Quayle, R. G., D. R. Easterling, T. R. Karl, and P. Y. Hughes, Effects of recent thermometer changes in the cooperative station network, *Bull. Amer. Meteor. Soc.*, *72*, 1718–1723, 1991.

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