# 2.3 REALTIME FILTERING TECHNIQUES OF AIR TEMPERATURE DATA IN WEATHER STATIONS

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## 1. INTRODUCTION

Air temperature is considered one of the most important variables in efforts to recognize and evaluated the extent of human impacts on climate from local to global scales. The instrumented climate records holds information on the spatial distribution and secular trends in temperature over many areas of the world (Karl et al. 1989). However, the inhomogeneities in the air temperature records in weather stations may mask the signal of climate changes (Hubbard and Lin, 2002; Hubbard et al., 2001; Lin et al., 2001a; and Lin et al. 2001b). For example, with the advances in temperature sensors and instrumentation, the air temperature monitoring system has been significantly upgraded from the Cotton Region Shelter (CRS) with liquid-in-glass thermometers to the automated measurement system such as the MMTS shield with a thermistor, Gill shield with an HMP35AC or HMP45AC, and ASOS aspirated shield with a precision resistance thermometer (PRT) inside.

This paper explores air temperature data filtering techniques in weather stations based on the statistical modeling and field comparison during both summer time and winter time in Lincoln, Nebraska.

## 2. MEASUREMENTS AND DATA MODELING

The experimental measurements in the filed were conducted from April 2000 to March 2001 at the University of Nebraska's Horticulture Experiment Site ($40^{o}83'$ N, 96o67' W , elevation 383m). The ground surface experienced from typical mowed grass during summer time to the full snow covered surface during winter time. The experiment consists of dual temperature monitoring system for ASOS, MMTS, and Gill shield (with HMP45AC sensor), as well as one aspirated (ASP-EP) and one non-aspirated shields from the Eastern Scientific Inc. (with HMP45AC), and once CRS with (HMP45AC) (Fig. 1).

A highly accurate R. M. Y. 43347 temperature probe (± $0.1^{o}$C) combined with a R. M. Young aspirated radiation shield (radiation error < $0.2^{o}$C under 1100 W $m^{-2}$ irradiance) was selected as a reference air temperature measurement. All temperature sensors as well as solar radiation and wind speed were measured by CR10 dataloggers (Campbell Scientific. Inc.) at the height of 1.5 meters. It should be noted that the MMTS system was monitored by a full bridge circuit connected to the CR10 datalogger instead of the MMTS manual read-out. The ASOS system was directly connected into a PC via an RS232 cable.

**Fig. 1.** Instrumentation illustration. From upper left, 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.

All measurement sampling rates were 10 seconds with 5 minute average outputs. The term air temperature bias for each conventional system (ASOS, ASP-ES, MMTS, Gill, CRS, and NON-ES) in this paper is defined as the difference relative to the R. M. Young aspirated sensor system. The data filtering of air temperature is based on the mechanism of solar radiation, ambient wind speed, and ground surface solar reflectivity effects on the accuracy of air temperature measurements. The approach taken was to use nonlinear regression

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methods with two input variables (Hubbard and Lin 2002). The model for air temperature bias (*Y*) is following (Hubbard and Lin, 2002),

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

where the α, β, 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. PRELIMINARY RESULTS AND DISCUSSION

A typical air temperature bias during winter time when snow covered is shown in Fig.2. The air temperature bias is a worst case scenario due to low ambient wind speed, high solar radiation, and high ground surface reflectivity. Apparently, during daytime the non-aspirated radiation shields with temperature sensors have relatively large biases, which reach 4.5 to 5°C for the NON-ES and CRS systems, 2 to 3 °C for Gill shield system, and over 1°C for both the ASOS and ASP-ES. From Fig. 1, the aspirated shield systems have smaller biases (maximum about 1.0°C). However, during nighttime the air temperature biases (Fig.2. bottom panel) are quite close to the zero except for the fixed biases inherent in the sensor and data acquisition system (e.g., coefficient α). Since the α is a fixed constant during certain period of sensor's operation it could be removed by adjustment of sensor itself. However, the changes of air temperature biases are associated with the ambient wind speed and solar radiation and filtering models must be applied to remove such biases.

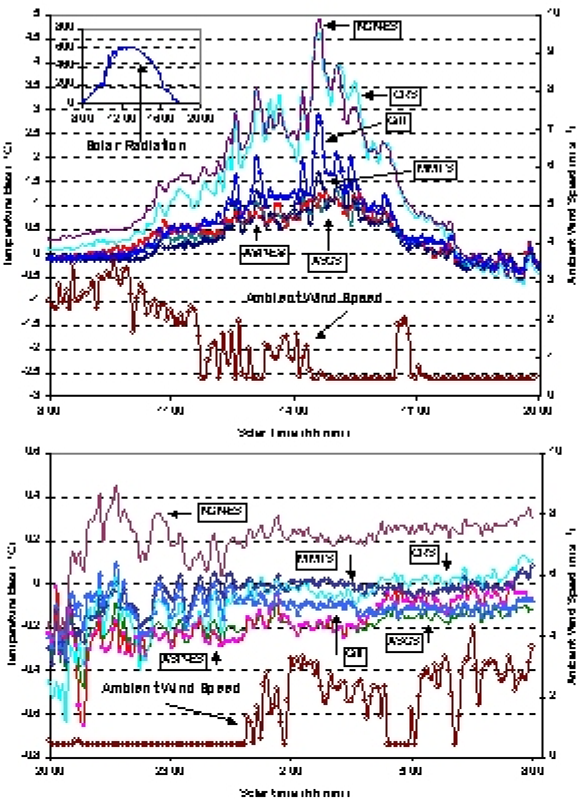


**Fig. 2**. typical air temperature biases on February 22, 2001 at the site. The ground surface had 3 inches snow cover.

The simulation results shown in Fig. 3. Illustrate the response surface for the air temperature filtering model for the Gill radiation shield with HMP45AC sensor.

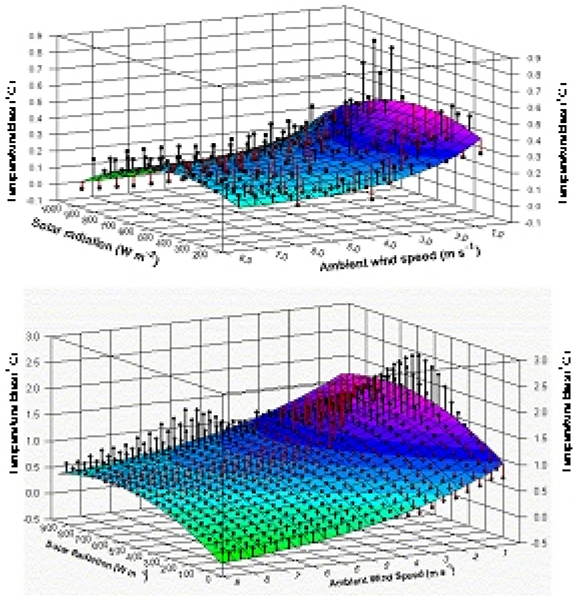
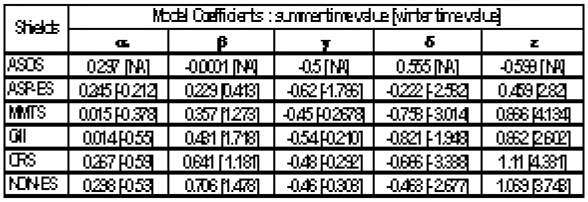


**Fig. 3.** The distribution of air temperature biases, as a function of the ambient wind speed and solar radiation measured by the Gill shield with an HMP45AC during summer time (top panel) and during winter time with snow covered (bottom panel).

All non-aspirated systems (MMTS, Gill, CRS, and NON-ES) show that air temperature biases exponentially increase with the decrease of ambient wind speed and give rise to parabolical cross sections in the direction of solar radiation. The air temperature biases under the snow covered ground are almost double compared to the grass cover during summer time because of the higher solar reflectivity (0.85 to 0.95). It is apparent that the combination of high solar radiation, low wind speed, and high solar reflectivity is a worst case, whereas the combination of low solar radiation, high ambient wind speed, and low surface solar reflectivity is the best case.

Table 1 presents all coefficients of the air temperature bias models. Due to the shortage of ASOS data during snow cover, there are no ASOS coefficients available. The ASOS coefficients may be similar to the ASP-ES because of the similar shape of shields with open bottom. For aspirated shields (e.g., ASOS and ASP-ES), the ambient wind speed is not critical because ventilation is provided independently. Constant ventilation inside the shields also decreases the solar radiation effects on air temperature bias. In the summer time simulation, we found both ASOS and ASP-ES have relative flat surface responses compared to Fig. 2. However, during snow cover, they suffer almost equal amount of incoming solar radiation from reflected ground surface. It is clear from Fig. 2 and Table 1 that the realtime air temperature filtering models are able to decrease average air temperature biases especially for the non-aspirated air temperature systems. The largest biases occur at the middle range of solar radiation from 500 to 800 W m$^{-2}$ instead of the highest solar radiation at noon. This is because of radiation shield design (Fig. 1). Some shields are composed of the solid top with multiple slanted plates (radiation pathway through the sides). Other shields have the open bottom but a solid piece that blocks reflected solar radiation near solar noon. Thus, if we employ these realtime data filtering models, we can reduce the solar radiation, ambient wind speed, and ground surface effects on air temperature measurements in practice.

**Table 1**. Model coefficients for air temperature bias in each air temperature system.



| Shields | Model Coefficients : summertime value [winter time value] | | | | |
|---|---|---|---|---|---|
| | α | β | γ | δ | ε |
| ASOS | 0.297 [NA] | -0.0001 [NA] | -0.5 [NA] | 0.555 [NA] | -0.599 [NA] |
| ASP-ES | 0.245 [-0.212] | 0.229 [0.413] | -0.62 [-1.786] | -0.222 [-2.582] | 0.459 [2.82] |
| MMTS | 0.015 [-0.378] | 0.357 [1.273] | -0.45 [-0.2678] | -0.758 [-3.014] | 0.866 [4.134] |
| Gill | 0.014 [-0.55] | 0.481 [1.718] | -0.54 [-0.210] | -0.821 [-1.948] | 0.862 [2.602] |
| CRS | 0.267 [-0.59] | 0.641 [1.181] | -0.48 [-0.292] | -0.686 [-3.388] | 1.11 [4.381] |
| NON-ES | 0.298 [-0.53] | 0.706 [1.478] | -0.46 [-0.308] | -0.463 [-2.677] | 1.069 [3.748] |

## 4. SUMMARY AND CONCLUSIONS

Air temperature comparisons revealed that the daytime air temperature biases typically increase when ambient wind speed decreases and increases when both solar radiation and solar reflectivity increase. Simulations of air temperature bias due to the solar radiation and ambient wind speed provide a means of removing air temperature biases when we employ the ambient wind speed and solar radiation data in weather stations. The models can be simply implemented for transforming one type of air temperature monitoring system to another among the ASOS, MMTS, Gill, CRS, ASP-ES, and NON-ASP-ES systems in the United States when the solar radiation and ambient wind speed are available at the weather station or experimental site. This is important to the goal of using homogeneous records to determine climate trend signals but, takes on additional importance if wind speed and global solar radiation are also changing.

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