4.5

NEW COOPERATIVE OBSERVER NETWORKS AND INSTRUMENTATION DATA QUALITY AN UPDATE

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1. INTRODUCTION

In the past few years, the advent of new cooperative volunteer networks such as the Citizen Weather Observer Program (CWOP) (http://www.cwop.net) has raised the issue of whether the instrumentation in these networks is of high enough quality to be used for nowcasting, forecast models, and climate monitoring purposes. For the most part, these networks consist of "backyard" or personal weather stations (PWS). These weather stations are typically designed to be affordable for the weather hobbyist and the data presentation is designed to be entertaining rather than utilitarian. Since the data from this network are made available to research and operational meteorologists in the National Oceanic and Atmospheric Administration (NOAA), understanding the performance of PWS relative to "official" NOAA weather station performance is necessary to effectively utilizing the data from these stations in day to day operations. These stations' data are captured by NOAA's Global Systems Division Meteorological Assimilation Data Ingest System (MADIS). This same system also captures data from the Automated Surface Observing System (ASOS) and other operational networks for input to Numerical Weather Prediction Models. This study compares the Davis Instruments passively shielded weather station to a NOAA Cooperative Observer Network (COOP) passively shielded Maximum-Minimum Temperature System (MMTS).

Davis Instruments was approached a few years ago with the prospect of providing free equipment in exchange for comparison data. For the purpose of the MMTS (Figure 2) comparison, the following Davis Instruments radiation product was used:

- Vantage Pro Temperature/Humidity Station, Product Number: 6380 (passive shield), Figure 1

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The Davis Instruments system and the MMTS system used their own temperature sensors, display and datalogging devices.

FIG. 1. Vantage Pro Temperature/Humidity Station with Anemometer

FIG. 2. MMTS – Photo from the Illinois State Climatologist Office

2. INSTRUMENTATION SITING

The comparison was done at the COOP site 2 miles southwest of downtown Sparta, Michigan, (43°8'34" N; 85°42'57" W; elevation 870 feet, 265 m) which is just north of Grand Rapids in the western part of the state. All radiation shields were installed at the same height above the ground as the COOP MMTS shield (5 feet, 1.5 m). The shields are spaced apart, so they do not shade or aspirate each other's environment. The grass is regularly mowed. A Davis Instruments anemometer was installed at this same height to measure the affects of wind speed on radiation shield effectiveness. A Davis Instruments Solar Radiation (insolation) sensor was also installed at the site to determine the daytime sky conditions, and therefore those effects on the radiation shields. Figure 3 shows the test bed with the Davis passive shield in the foreground right. The MMTS shield is on the left.

FIG. 3. Photograph of Test Location looking toward the southeast.

Figure 4 below is another view of the instrumentation siting configuration with the Davis passive shield to the left. The MMTS shield is in the center. The other shields were for an unrelated test.

In this latest study, data are presented over the period from October 5, 2006 to March 31, 2007. Intermittent suspect readings had been earlier observed by the NOAA COOP observer. In fact, the COOP observer later reported that the data cable from the MMTS shield to the display and datalogger unit had apparently been cut by utility service personnel and then poorly patched together using electrical tape and a sandwich bag. The cable has since been properly spliced and weather-proofed. This should prevent future temporary failures of this type. This problem connection was fixed prior to the beginning of the data presented in this study. Since then, two more MMTS systems have been added to the eastern and western edge of the test site (not shown). Unlike the "primary" or first MMTS reference, these shields are not as close in proximity to the Davis shield. Their purpose is to help discern whether large differences are due to failure of the primary MMTS or actual "true" atmospheric observations.

This study compared the MMTS to the Davis Instruments passive shield because it was believed that NOAA would be more likely to accept an installation where the radiation shield is separated from the rain collector. The most widely used weather station that Davis Instruments manufactures has a rain collector that is installed above the radiation shield.

There are two accuracy standards used to compare the two systems in this study. The less stringent standard uses the temperature sensing accuracy requirement for the measurement of "Surface Weather Observations and Reports",

±1.1°F (±0.6°C) (Office of the Federal Coordinator for Meteorological Services (OFCM) and Supporting Research, 2005). For a stricter comparison, this study also uses ±0.5°F (±0.3°C), which is the stated accuracy specification of the MMTS temperature sensor (National Weather Service Engineering Division, 1997). This study treats this tighter tolerance as the benchmark for climate monitoring purposes.

FIG. 4. Photograph of Test Location looking toward the northeast.

3. RESULTS AND DISCUSSION

3.1 *Daily Extrema*

The daily maximum and minimum temperatures for the Davis Instruments station and the MMTS were recorded. Both systems used local midnight as the start of each calendar day.

Figure 5 shows a scatter-plot of the daily maximum temperature readings. The line represents the MMTS readings and the dots the Davis readings. If the Davis shield readings were identical to the MMTS readings, they would fall exactly on the line. Dots below the line indicate the Davis shield read cooler than the MMTS; dots above the line indicate where the Davis shield read warmer than the MMTS. As Figure 5 indicates, a majority of the Davis readings fell within a few degrees of those of the MMTS.

Figure 6 shows a scatter-plot of the daily minimum temperature readings in the same manner as shown in Figure 5. Figure 6 indicates a majority of the Davis readings fell within a few degrees of those of the MMTS, but have a slight warm bias. Table 1 lists the statistical measures of correlation between the MMTS and the Davis sensor for daily highs and lows. Although the MMTS is used as the reference in this study, it is known that there are differences when comparing the MMTS to other "official" NOAA systems such as the US Climate Reference Network (USCRN) (Sun et al., 2005).

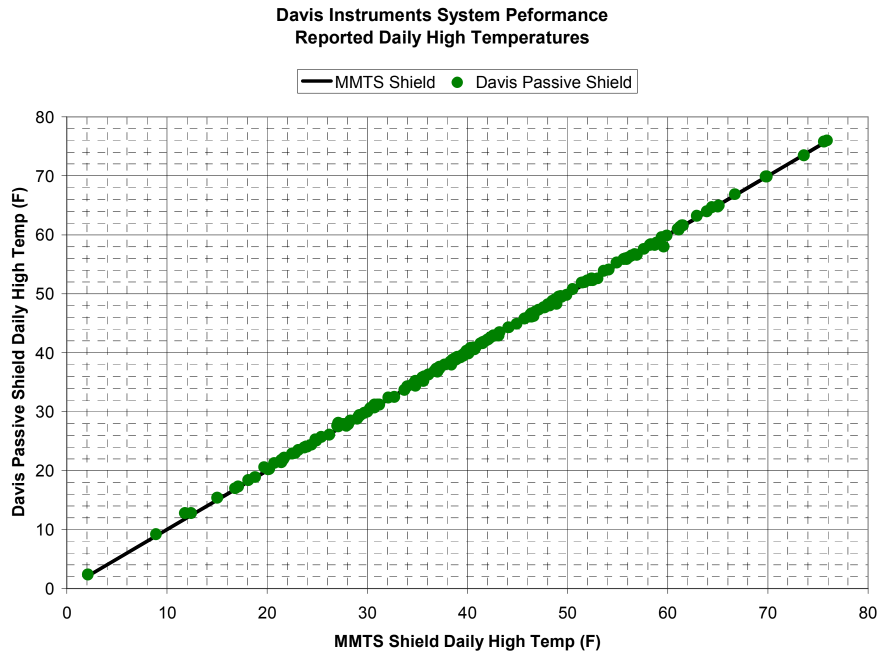

FIG. 5. Davis Instruments system performance for daily maximum temperature readings as compared to those of the MMTS

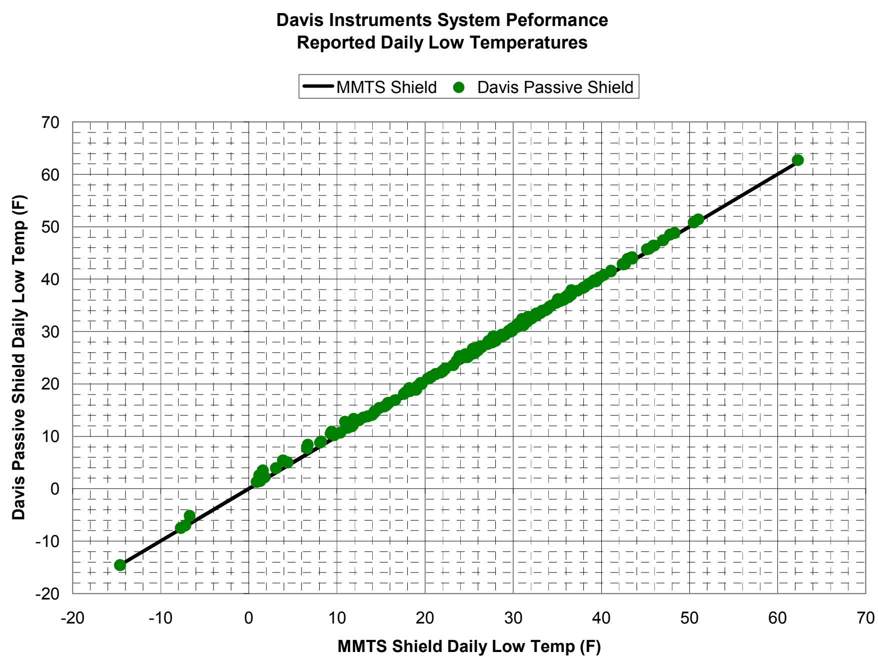

FIG. 6. Davis Instruments system performance for daily minimum temperature readings as compared to those of the MMTS

Difference Statistics	Daily Highs	Daily Lows
Maximum Difference	+1.0°F (+0.6°C)	+1.9°F (+1.1°C)
Average Difference	+0.1°F (+0.1°C)	+0.6°F (+0.3°C)
Minimum Difference	−1.6°F (−0.9°F)	−0.1°F (−0.1°C)
Standard Deviation	0.3°F (0.2°C)	0.3°F (0.2°C)
95% Confidence (2σ)	0.5°F (0.3°C)	0.7°F (0.4°C)
Correlation Coefficient	0.9997	0.9993

TABLE 1. Davis radiation shield daily extrema differences statistics. Reference: MMTS

Overall, the daily lows had a greater average difference than the daily highs as referenced to the MMTS. The magnitude of the greatest positive differences was greater for the daily lows than those for the daily highs. Conversely, the magnitude of the greatest minimum differences was greatest for the daily highs. Assuming the MMTS read the "perfect" temperature, this indicates at the 95% confidence level, the Davis Instruments station is twice as good as required. The overall average difference of both daily high and low temperatures also falls well within the "Weather Forecasting" requirement.

Table 2 provides a breakdown of the frequency of daily extrema observations with difference readings. As shown, nearly all of the differences fell within the "Weather Forecasting" accuracy requirements. A significant minority of daily lows were within twice this specification. The Davis passive shield performed well, and performance was better more often for recording daily highs.

Frequency of Differences – Weather Forecasting Standards ±1.1°F (±0.6°C)	Daily Highs	Daily Lows
Differences >+3.3°F (+1.8°C)	0.0%	0.0%
Differences >+2.2°F (+1.2°C) & <=+3.3°F (+1.8°C)	0.0%	0.0%
Differences >+1.1°F (+0.6°C) & <=+2.2°F (+1.2°C)	0.0%	8.5%
Differences <=+1.1°F (+0.6°C) & >=−1.1°F (−0.6°C)	99.4%	91.5%
Differences <−1.1°F (−0.6°C) & >=−2.2°F (−1.2°C)	0.6%	0.0%
Differences <−2.2°F (−1.2°C) & >=−3.3°F (−1.8°C)	0.0%	0.0%
Differences <−3.3°F (−1.8°C)	0.0%	0.0%

TABLE 2. Frequency of Davis radiation shield synoptic daily extrema differences. Reference: MMTS

Frequency of Differences - Climate Monitoring Standards ±0.5°F (±0.3°C)		
	Daily Highs	**Daily Lows**
Differences >+1.5°F (+0.8°C)	0.0%	1.7%
Differences >+1.0°F (+0.6°C) & <=+1.5°F (+0.8°C)	0.0%	9.0%
Differences >+0.5°F (+0.3°C) & <=+1.0°F (+0.6°C)	2.8%	30.5%
Differences <=+0.5°F (+0.3°C) & >=−0.5°F (−0.3°C)	96.0%	58.8%
Differences <−0.5°F (−0.3°C) & >=−1.0°F (−0.6°C)	0.6%	0.0%
Differences <−1.0°F (−0.6°C) & >=−1.5°F (−0.8°C)	0.0%	0.0%
Differences <−1.5°F (−0.8°C)	0.6%	0.0%

TABLE 3. Frequency of Davis radiation shield climate daily extrema differences. Reference: MMTS

Table 3 provides a similar breakdown as Table 2, but with the accuracy requirements for climate based monitoring needs. Table 1 indicates at the 95% confidence level, the Davis Instruments station was just outside the MMTS sensor requirements. When subjected to the higher accuracy requirement, the Davis shields performed within specifications much less often than with the OFCM requirements for reporting daily lows. Nearly all of the time, the shields still performed within specifications for recording daily highs. A significant minority of daily low readings were a multiple of two to three times warmer than this standard.

3.2 *Hourly Readings*

Hourly temperatures for the Davis Instruments station and the MMTS station were also recorded. Both the Davis station and the MMTS display recorded values at each hour boundary. The Davis station used a sampling interval of 10 to 12 seconds, while the MMTS display captured readings every 2 seconds.

Figure 7 shows a scatter-plot of the hourly temperature readings for the Davis passive shield. As in Figures 4 & 5, the line represents the MMTS readings and the dots, the Davis shield readings. If the Davis shield readings were identical to the MMTS readings, they would fall exactly on the line. Dots below the line indicate the Davis shield read cooler than the MMTS, dots above the line indicate where the Davis shield read warmer than the MMTS shield. Figure 7 indicates many of the Davis passive shield readings fell within a few degrees of those of the MMTS.

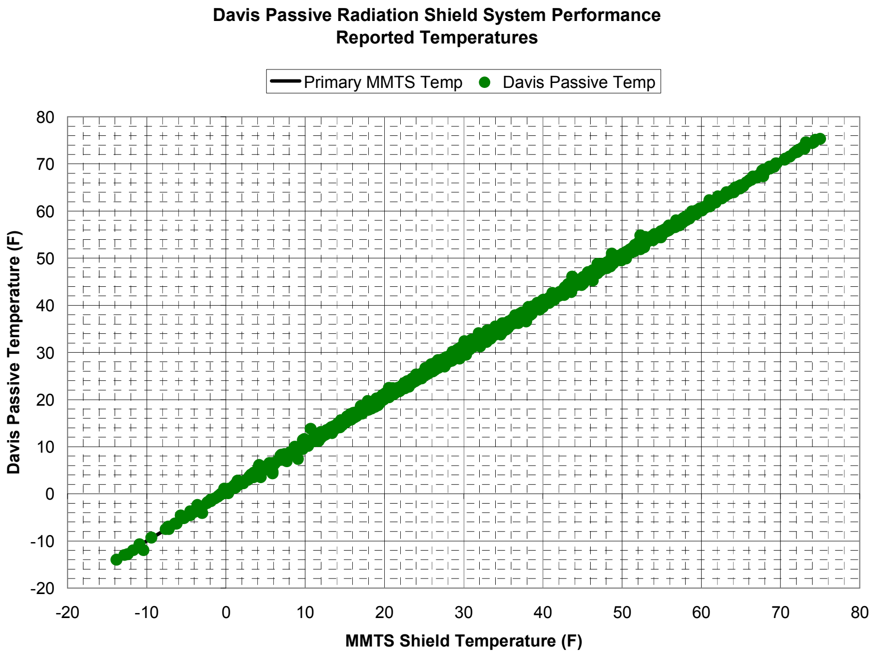

FIG. 7. Davis Instruments passive radiation shield system performance for hourly temperature readings as compared to those of the MMTS

Difference Statistics	
Maximum Difference	+3.1°F (+1.7°C)
Average Difference	+0.4°F (+0.2°C)
Minimum Difference	−1.7°F (−0.9°C)
Standard Deviation	0.3°F (0.2°C)
95% Confidence (2σ)	0.6°F (0.3°C)
Correlation Coefficient	0.9996

TABLE 4. Davis radiation shield hourly difference statistics. Reference: MMTS

Table 4 lists the statistical measures of correlation between the MMTS hourly readings and the Davis hourly readings. These indicate that at the 95% confidence level, as with the daily extrema, the Davis Instruments station is twice as good as required. The overall average also falls well within the Weather Forecasting requirement. Table 5 provides a breakdown of the frequency of hourly observations with difference readings. As shown, nearly all of the differences fell within the Weather Forecasting accuracy requirements.

Table 6 provides a similar breakdown as Table 2, but with the accuracy requirements for climate observations. When subjected to these requirements, the Davis shields performed within specifications a majority of the time. A significant minority fell within two times warmer than this specification. Table 4 indicates at the 95% confidence level, the Davis Instruments station was just outside the MMTS sensor requirements.

Frequency of Differences – Weather Forecasting Standards ±1.1°F (±0.6°C)	
Differences >+3.3°F (+1.8°C)	0.0%
Differences >+2.2°F (+1.2°C) & <=+3.3°F (+1.8°C)	0.1%
Differences >+1.1°F (+0.6°C) & <=+2.2°F (+1.2°C)	1.4%
Differences <=+1.1°F (+0.6°C) & >=−1.1°F (−0.6°C)	98.4%
Differences <−1.1°F (−0.6°C) & >=−2.2°F (−1.2°C)	0.1%
Differences <−2.2°F (−1.2°C) & >=−3.3°F (−1.8°C)	0.0%
Differences <−3.3°F (−1.8°C)	0.0%

TABLE 5. Frequency of Davis radiation shield synoptic hourly differences. Reference: MMTS

Frequency of Differences - Climate Monitoring Standards ±0.5°F (±0.3°C)	
Differences >+1.5°F (+0.8°C)	0.4%
Differences >+1.0°F (+0.6°C) & <=+1.5°F (+0.8°C)	1.6%
Differences >+0.5°F (+0.3°C) & <=+1.0°F (+0.6°C)	16.7%
Differences <=+0.5°F (+0.3°C) & >=−0.5°F (−0.3°C)	80.8%
Differences <−0.5°F (−0.3°C) & >=−1.0°F (−0.6°C)	0.3%
Differences <−1.0°F (−0.6°C) & >=−1.5°F (−0.8°C)	0.1%
Differences <−1.5°F (−0.8°C)	0.1%

TABLE 6. Frequency of Davis radiation shield climate hourly differences. Reference: MMTS

3.3 *Largest Differences – Example # 1*

Figure 8 shows a plot of the hourly temperatures of the Davis and reference MMTS system during a night that represents the greatest differences between the two stations. Hourly average wind speed is also plotted for reference. The greatest maximum difference in the dataset of 3.1°F (1.7°C) occurs at 1:00 local time. The greatest minimum difference of 1.7°F (0.9°C) occurs at 5:00. Other significant maximum differences of 1.9°F (1.0°C) occur at 4:00 and 9:00 as well. When observing the wind speed during these times, the wind appears to be relatively calm. So, wind speed does not explain these differences.

Figure 9 shows the same dataset with hourly average insolation in place of wind speed. As shown, insolation appears to play no part in explaining the differences between the shields.

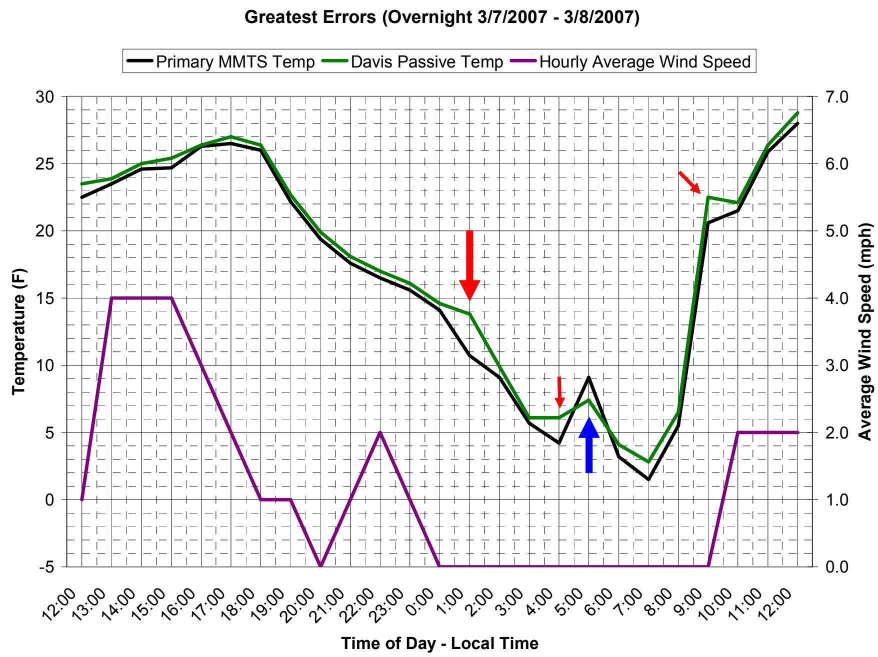

FIG. 8. System performance during the night of the greatest hourly reading maximum difference as compared to the MMTS for hourly temperature readings as compared to wind speed

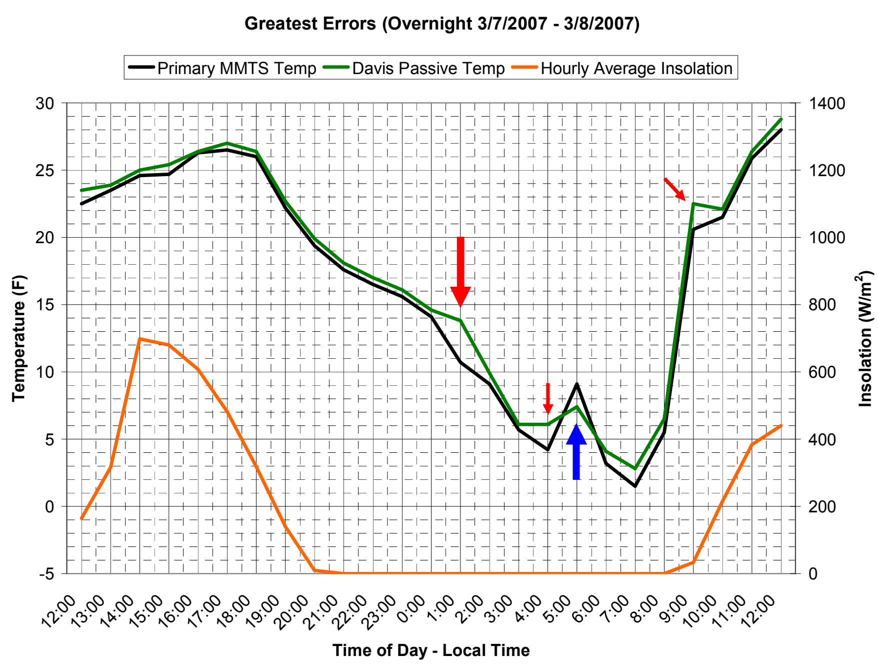

FIG. 9. System performance during the night of the greatest hourly reading maximum difference as compared to the MMTS for hourly temperature readings as compared to insolation

Figure 10 provides cloud cover and temperature data from the Grand Rapids Airport. The cloud cover does not change from the previous hour at any times noted as significant in their difference in readings. The Grand Rapids airport does not follow the Davis temperature closely enough to indicate that this provides anything meaningful. This is not entirely unexpected since the airport is 20 miles (32 km) away.

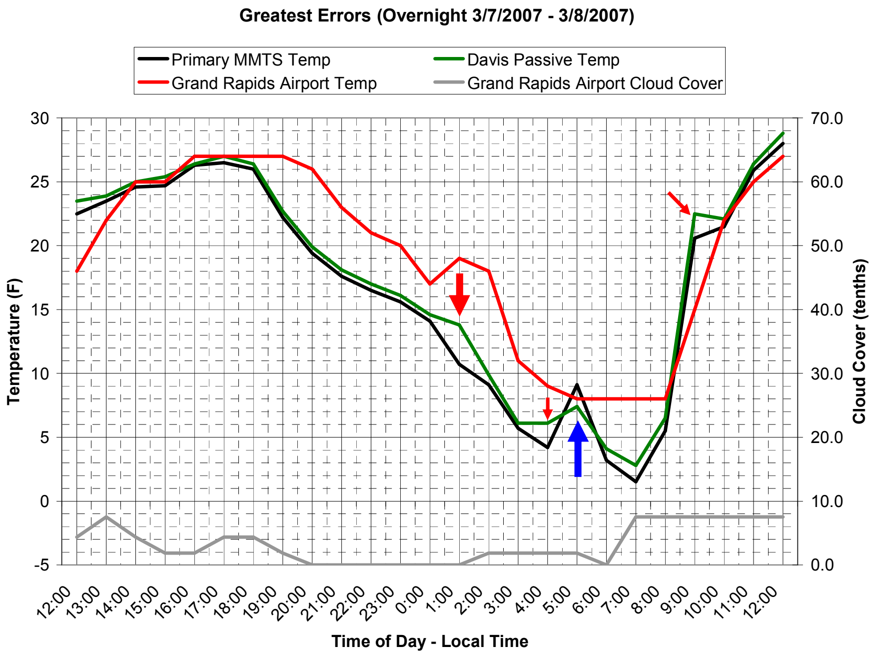

FIG. 10. System performance on day of greatest hourly reading maximum difference as compared to the MMTS for hourly temperature readings as compared to cloud cover and Grand Rapids airport temperature

Figure 11 compares the Davis shield to the two other newly installed MMTS shields. At the 1:00 reading, the Davis shield differs quite a bit from the primary MMTS reference, but the “third” reference actually tracks it well. The “second” reference tracks the first. At the 9:00 reading, the Davis reading falls between the readings of the second and third MMTS. At the other noted times of difference, all three MMTS track each other well. In cases of large differences between the Davis and the MMTS, if all three MMTS track, then the difference probably represents actual performance differences between the Davis shield and the MMTS. In cases where the second or third MMTS track the Davis shield, then the differences seen when comparing it to the first may represent micro-climatic effects or anomalies in one of the MMTS readings.

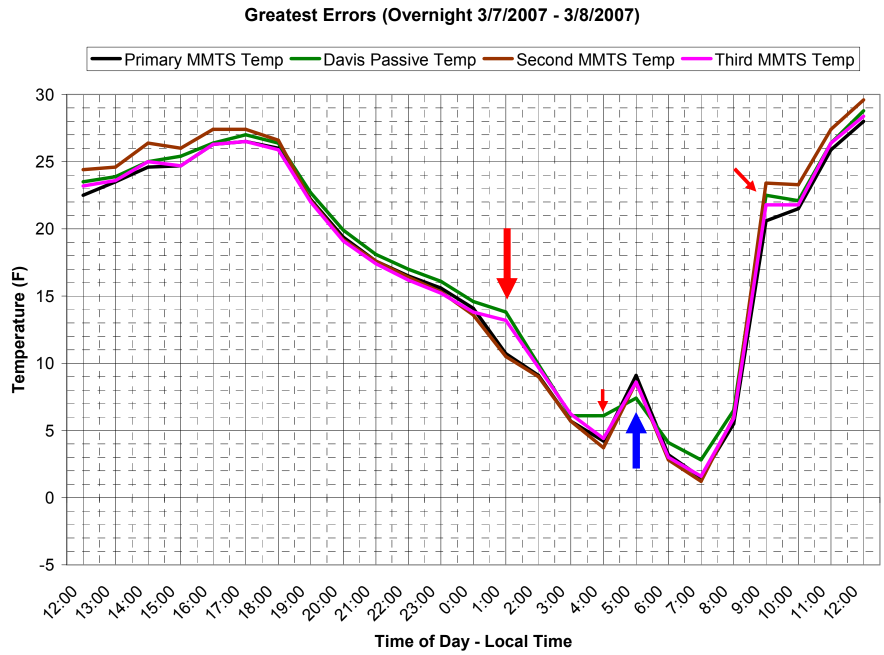

FIG. 11. System performance on day of greatest hourly reading maximum difference as compared to all three MMTS shields for hourly temperature readings

3.4 *Largest Differences – Example # 2*

Figures 12, 13 and 14 compare the Davis shield to all three MMTS shields with wind speed, insolation, and cloud cover, respectively, on a day that illustrates another example of large differences between the Davis and primary MMTS hourly data. As in the previous example, the differences are negligible when compared to one of the other MMTS shields. None of the three elements of wind speed, insolation, nor cloud cover explain the differences between the Davis shields and the MMTS shields. Note the readings at 09:00. The Davis shield agrees with the second MMTS shield much more closely than it does with the other two. At 7:00, all three shields agree, yet the Davis shield shows a significant difference. Since the thermodynamic characteristics of the shields do not change, these variations in agreement among the MMTS shields must represent small-scale differences in the atmospheric signal or anomalous sensor readings, not shield performance.

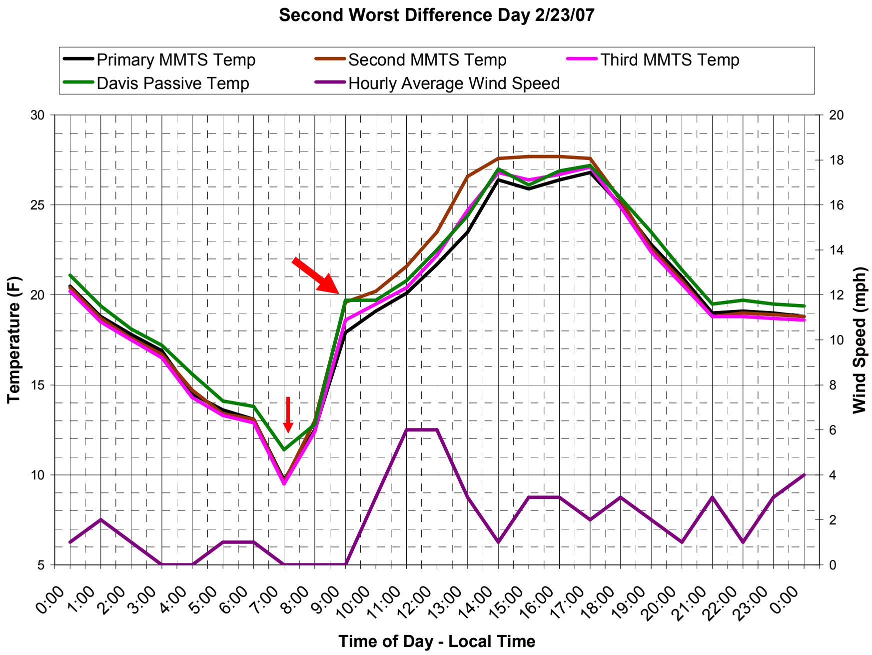

FIG. 12. System performance on another day of great hourly reading maximum difference as compared to all three MMTS shields for hourly temperature readings as compared to wind speed

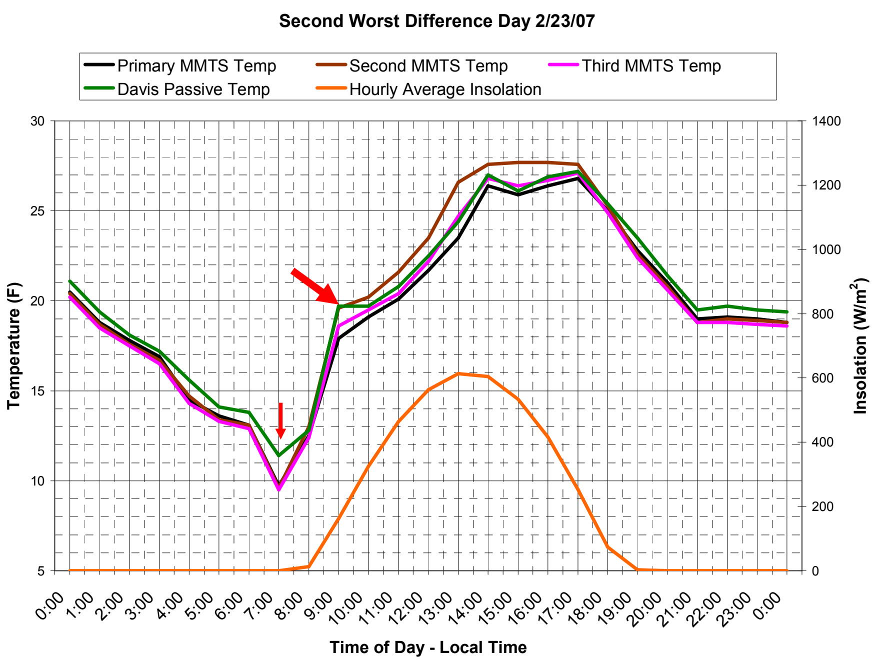

FIG. 13. System performance on another day of great hourly reading maximum difference as compared to all three MMTS shields for hourly temperature readings as compared to wind speed

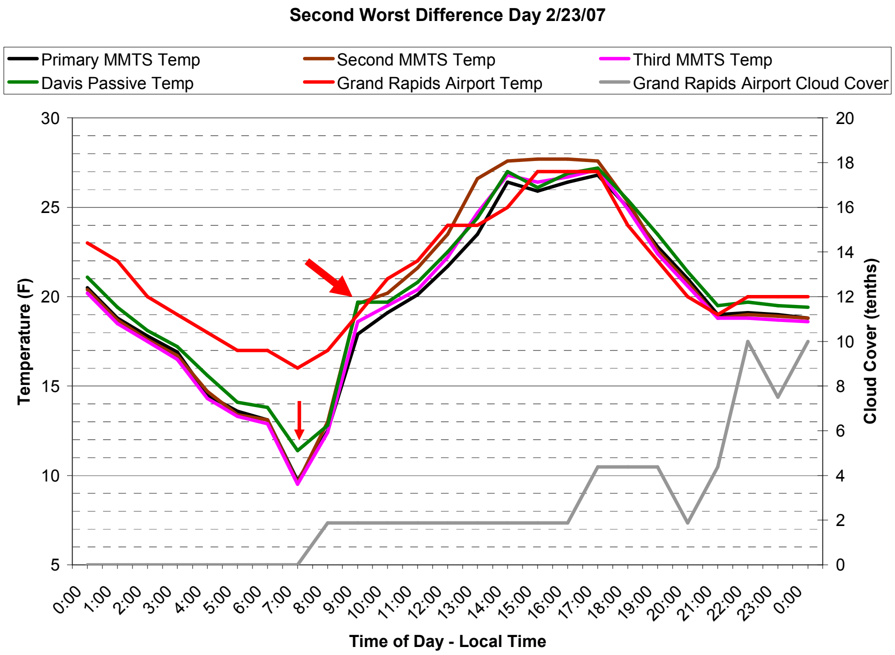

FIG. 14. System performance on another day of great hourly reading maximum difference as compared to all three MMTS shields for hourly temperature readings as compared to insolation

3.5 *Daily Extrema Results as Compared to Hourly Results*

Table 7 combines the data from Tables 1 and 4 for a side-by-side comparison. Except for the maximum differences, the data are nearly identical. The daily maximum difference is considerably better than the hourly maximum difference.

Difference Statistics		
	Daily	**Hourly**
Maximum Difference	+1.9°F (+1.1°C)	+3.1°F (+1.7°C)
Average Difference	+0.4°F (+0.2°C)	+0.4°F (+0.2°C)
Minimum Difference	−1.6°F (−0.9°C)	−1.7°F (−0.9°C)
Standard Deviation	0.4°F (0.2°C)	0.3°F (0.2°C)
95% Confidence (2σ)	0.8°F (0.4°C)	0.6°F (0.3°C)
Correlation Coefficient	0.9995	0.9996

TABLE 7. Davis radiation shield differences statistics summarized. Reference: MMTS

Frequency of Differences - Weather Forecasting Standards ±1.1°F (±0.6°C)	Daily	Hourly
Differences >+3.3°F (+1.8°C)	0.0%	0.0%
Differences >+2.2°F (+1.2°C) & <=+3.3°F (+1.8°C)	0.0%	0.1%
Differences >+1.1°F (+0.6°C) & <=+2.2°F (+1.2°C)	4.2%	1.4%
Differences <=+1.1°F (+0.6°C) & >=−1.1°F (−0.6°C)	95.5%	98.4%
Differences <−1.1°F (−0.6°C) & >=−2.2°F (−1.2°C)	0.3%	0.1%
Differences <−2.2°F (−1.2°C) & >=−3.3°F (−1.8°C)	0.0%	0.0%
Differences <−3.3°F (−1.8°C)	0.0%	0.0%

TABLE 8. Frequency of Davis radiation shield differences summarized. Reference: MMTS

Frequency of Differences - Climate Monitoring Standards ±0.5°F (±0.3°C)	Daily	Hourly
Differences >+1.5°F (+0.8°C)	0.8%	0.4%
Differences >+1.0°F (+0.6°C) & <=+1.5°F (+0.8°C)	4.5%	1.6%
Differences >+0.5°F (+0.3°C) & <=+1.0°F (+0.6°C)	16.7%	16.7%
Differences <=+0.5°F (+0.3°C) & >=−0.5°F (−0.3°C)	77.4%	80.8%
Differences <−0.5°F (−0.3°C) & >=−1.0°F (−0.6°C)	0.3%	0.3%
Differences <−1.0°F (−0.6°C) & >=−1.5°F (−0.8°C)	0.0%	0.1%
Differences <−1.5°F (−0.8°C)	0.3%	0.1%

TABLE 9. Frequency of Davis radiation shield differences summarized. Reference: MMTS

Table 8 summarizes the frequency of differences for synoptic standards and Table 9, for climate standards. When comparing the performance of the Davis shield when examined on a daily maximum and minimum basis against an examination of the hourly readings, the Davis shield performance is similar in both instances. The differences are more visible when using the more stringent “climate” standards. The hourly values meet these standards a bit more than the daily values do.

4. CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDY

4.1 *Conclusions*

The data results suggest that, if properly sited, the Davis Instruments weather stations perform well enough to meet the requirements of NOAA for surface observations, and therefore, in most cases, can be used for daily observations, forecast model input and forecast verification. Most of the time, the Davis Instruments station satisfied the requirements for climate monitoring purposes as well. Daytime performance is much better than nighttime performance. The Davis Instruments station was in better agreement reporting hourly observations than in reporting daily highs and lows. The hourly maximum difference is greater than the daily maximum difference, but the frequency of differences that are positive are smaller for the hourly data. This suggests that although the maximum difference is larger, it represents one of a small number of outliers in the data. These outliers or greater differences may be further explained by either micro-climatic variations across the test site or anomalies in the readings of the MMTS.

4.2 *Suggestions for Further Study*

As previously stated, two more MMTS systems have been added to give guidance whenever MMTS data is suspect. The Davis systems have also been upgraded to the equivalent Vantage Pro2 version to better represent current product and facilitate easier data collection. Any radiation shield design modifications will also be tested at this site.

Further studies could include other COOP sites where the ground cover is different from this Michigan location, and therefore, the infrared radiation properties of the ground would be vastly different. These types of climates would include those that receive different amounts of snowfall and snow cover during the year and arid areas that have sparser amounts of ground cover. Other test locations could include locations in the southern tier of the United States that receive higher levels of insolation. These studies might indicate whether Davis Instruments radiation shield performance varies significantly in environments with different solar and infrared radiation properties. Such studies will require other COOP observers to volunteer their sites, their recorded information, and to some extent, their time and effort, to setup and sustain a viable test.

The results presented here do not represent a final conclusion of the effectiveness of Davis Instruments radiation shields and how they compare to the MMTS shield. These results are presented to encourage similar evaluations by other interested parties.

Acknowledgments. Special thanks should be given to Andrew L. Schut for approaching Davis Instruments with the idea for the study, volunteering his Cooperative Observer site as well as his time and efforts in providing maintenance and data. Thanks to members of the Davis Instruments Engineering team in providing technical support and editorial review of this manuscript.

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