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Atmospheric Measurement Techniques Discussions

Interactive comment on "More Science with Less: Evaluation of a 3D-Printed Weather Station" *by* Adam Theisen et al.

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Thank you for your review of our manuscript. Your comments were well received and will lead to a better paper in response. We will structure our responses as follows: each referee comment will have a number based on referee number and comment from their review. The authors response will be the number with a "R" next to it and changes in the manuscript will be the number with a "C".

3.1 - A more detailed analysis of the comparisons of the low-cost and reference weather stations is necessary in order to show the clear differences between the two instruments, as the study using only scatterplots and average differences appears too raw and limiting. A more detailed and quantitative approach through merit factors (such

as error, bias...) would be desirable.

3.1R - Authors agree. Additional processing has been applied to relative humidity, solar radiation and wind speeds. A correction for the temperature coefficient was applied to the relative humidity based on vendor documentation which improved the overall results. The solar radiation was measured in counts and a linear regression was performed to convert counts to W/m2. Given the differences in height of wind measurement heights, a logarithmic wind profile conversion was done based on Allen et al 1998.

Using these results, a more in-depth analysis has been performed to calculate standard error of means, root mean square error (RMSE), and also a linear regression including slope, intercept, and correlation. This information along with min/max values for each station are included on the plots. Statistics were also calculated for each month of the deployment and the RMSE and correlation coefficients were recorded in an additional table. Additionally, the performance of the temperature and relative humidity sensors were analyzed with increasing wind speeds to determine the effects the naturally aspirated wind shield would have on the measurements.

3.1C - Updated figures with more in depth statistics, summary table of RMSE and correlation coefficient, summary table of RMSE and correlation coefficient for temperature and relative humidity based on different wind speed thresholds, and additional discussion on results.

3.2. Can be low-cost measurements corrected in some way in order to reproduce reference observations?

3.2R - It would be relevant to run the sensors through calibrations before and after deployment to the field to better characterize the sensors, similar to the Oklahoma Mesonet practice. However this would also add additional expenses. Inaccuracies owing to drift would be harder to compensate for. It is also unknown how the drift rates differ between boards of the same sensor type. Further analysis of the performance of multiple boards of the same sensor would be necessary to better characterize them. As mentioned in 3.1R, the relative humidity, solar radiation, and wind speed measurements were corrected, which produced improved results.

3.2C - Where relevant, the result discussion was updated with the corrected data.

3.3. Are there some meteorological situations/events in which the low-cost station performs best?

3.3R - Through the added analysis, it was determined that the temperature sensors had improved performance with increasing wind speed, which is expected as the flow through the radiation shield would be more comparable to the Mesonet aspirated radiation shields. The relative humidity did not see the same improvement in performance which could be related to dust collection on the filter on the sensor. While the filter on the sensor was hydrophobic, the dust that collected on it may have not been. The relative humidity did perform better in drier conditions which is expected based on the reduce vendor stated accuracy for the lower to mid ranges of relative humidity.

Overall though, more data over repeated seasons would be necessary to determine which conditions/events the station performs best in.

3.3C - Manuscript results discussion was updated with some of this additional analysis.

3.4. It is not very clear how the UV data of the two stations were compared, as it stated in the paper that they do not measure the same radiative components.

3.4R - The UV sensor calculates the UV index by measuring visible and infrared light. This is stored as counts in the data files. It was determined that some other sensors did provide equations to calculate lux from which the W/m2 could be estimated, the sensor used in this study did not. Authors initially used the visible counts to compare with the downwelling global solar radiation but the errors reported would not be informative. To improve on the analysis, a linear regression was performed on the entire dataset and a slope/intercept was applied to the data to make the measurements comparable.

3.4C - Manuscript discussion on the radiation results, solar radiation plot, and statistics will be updated with the new results.

3.5. I think a table summarizing all the sensor differences/performances would be valuable to have a clear picture of the comparisons.

3.5R - Authors agree.

3.5C - Table 4 will be included with summary of RMSE and correlation coefficient for all measurements for each month and for the entire campaign. This is also relevant to updates made in Table 1 and Table 2 to better follow WMO guidelines on reporting range, resolution, accuracy, and more. Table 3 was added to give an overview of the specific measurement accuracy of the reference sensors used thus far in all comparisons with 3D-PAWS.

3.6. The comparison between the two rain gauges should be expanded: how the two instruments work on the basis of rain rate?

3.6R - Both rain gauges are tipping bucket gauges with the 3D printed rain gauge performing a tip for every 0.2 mm while the Mesonet bucket tips on 0.254 mm. The white Mesonet gauge is located 0.6 m off the ground and is surrounded by an alter shield to decrease the wind effects. The gray 3D weather station gauge was roughly 0.3 m off the ground and was not surrounded by an alter shield. The color of the gauges are noted as neither gauge has a heater and how the different gauges heat up following a solid precipitation event could impact the rain rates recorded.

3.6C - Manuscript will be updated to include this relevant information and expand on it.

Minor Comments

3.m1 - Do you have any idea about the duration of 3D-printed weather station and its sensors without any maintenance located, for example, in a remote area?

3.m1R - Based on our experience, the durability of the 3D printed parts varied. Printed parts used in the wiring of the station such as the nuts for tightening instruments in place, for example, would have a low life expectancy without proper maintenance. The durability of the wiring connectors was inconsistent due to minor imperfections caused by the printing process. These imperfections forced excessive filing of the wire connectors in order to securely fit wiring. Connectors that were excessively filled often wore down to the point where wiring had difficulty remaining in the connector itself. Nuts tended to lose grip over time causing the instruments to sag or rotate in their housing. Parts with constant friction, like the anemometer, would have lower expected life spans. Most of the parts that did not fall under these previous examples remained in very good condition at the conclusion of the deployment. Sensor longevity seemingly was related to whether the sensor could be impacted by the outside elements, namely moisture. The temperature, humidity, and pressure sensors housed in the radiation shield showed varying degrees of corrosion throughout the study, with the humidity sensor ultimately having to be removed. The rain gauge and wind sensors, which were more sheltered from the outside conditions, showed no evidence of degradation at the conclusion of the study. If we were to recreate this system again, the wiring connectors would be the main area of improvement sought as a lot of time was spent working on these connections. The fitting to secure the wind direction vane would be second as the results were not ideal as it kept coming loose and rotating from truth North orientation.

3.m1C - Manuscript section discussing the 3D printed components will be updated with some additional information.

3.m2 Line 64: the average difference of air temperature is 0.81, while the related scatterplot indicates 0.82

2.m2R - Thank you for noting this. The more in-depth analysis has produced some updated results and the manuscript will be updated accordingly.

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