Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2019-454-AC2, 2020

Atmospheric Measurement Techniques
Discussions

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

Adam Theisen et al.

atheisen@anl.gov

Received and published: 1 May 2020

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".

2.1 Introduction: in my opinion, the authors should provide a more detailed and comprehensive state of the art of the considered topic. Moreover, they should better emphasize the added-value of their study compared to the previous work.

2.1R - Authors agree. There has been limited peer reviewed articles on this topic.

This study will provide an argument for the expanded use of these low cost sensors in science and education. The results on the previous studies will be improved with the comparisons against additional commercial instrumentation, but also through improvements to the processing and analysis. Additional corrections to the wind speed, relative humidity, and solar radiation have been performed improving the overall results. This will also provide the first look at the performance of the UV radiation sensor and its ability to indirectly measure the global downwelling solar radiation.

2.1C - The introduction, station configuration, and results sections will be updated accordingly.

2.2 Station configuration: the authors must provide additional details about technical characteristics of each of the meteorological weather stations involved in this study, the commercial one (Mesonet) and the innovative one (3D-printed). More specifically, I suggest adding a table that list the following specifications: range of measure, resolution, update interval, time-constant and uncertainty (or accuracy). Please consider the following WMO manual as reference: World Meteorological Organization: Guide to Meteorological Instruments and Methods of Observation, 2008.

2.2R - Authors agree. This information has been compiled for both the 3D-printed sensor and the Mesonet sensors. Furthermore, an additional table was developed to compare the accuracy of the reference instrumentation across the previous comparison of the 3D-PAWS stations.

2.2C - Tables 1 and 2 have been updated to gather this information.

2.3 Deployment: According to Table 2, the traditional weather station includes sensors from different commercial companies (Vaisala, RM Young, Met One, Li-Cor). Why did the authors choose a reference meteorological station with these features and with this configuration? From a comparison with standards required by WMO (see Annex 1.E of WMO, 2008), emerges that those sensors are not an adequate and good benchmark to evaluate the performance of the proposed 3D-printed station. For example, according to WMO recommendations, temperature sensor should have an uncertainty of 0.2 K, which is considerable lower than the uncertainty of the RM Young 41342 RTD Probe (0.5 K). This consideration is easily extendable to other "reference" sensors involved in this study, which do not satisfy the WMO requirements. Probably, the authors chose the sensors listed in Table 2 as reference because their accuracy is comparable to that of 3D-printed instruments. However, I am quite skeptical about this approach. At first instance, it may be reasonable, but I think that an additional comparison with sensors that fulfill the WMO standard is necessary, in order to achieve results that are valuable from a "high-level" scientific perspective.

2.3R - This was a low-cost project and access to sensors that fulfill WMO standards while deployed in the field was not possible. The WMO guide does indicate that operational uncertainty conforming to these requirements will not be met in many instances and are only achievable with the "highest quality sensors and procedures". As such, there are a number of organizations that deploy high quality sensors and implement best practices as they relate to calibration and data quality that can serve as viable reference stations. Oklahoma Mesonet sensors undergo routine maintenance and are rotated out of the field on a regular schedule. Calibrations are performed before and after deployment to the field, leading to well-characterized systems. The Oklahoma Mesonet also has a robust data quality program and the data used from their station has been reviewed and properly quality controlled. These sensors were chosen as they were well-maintained sensors that were also accessible to the research team.

The 3D Printed weather station was donated to the Cooperative Institute of Mesoscale Meteorological Studies (CIMMS) Education and Outreach program and an additional study will not be possible without building a completely new system. Three of the four authors have also relocated to new positions and funding would need to be secured for another comparison study with sensors meeting WMO standards while deployed in the field.

2.3C - Additional discussion on why these sensors were chosen and how they compare

with other studies and the WMO guidelines will be added into the manuscript.

2.4 Moreover, I suggest adding a figure including a photo of Mesonet station facilities. For a reliable comparison, the sensors of the two stations should be installed at the same height above the ground level: as an example, the wind sensors operated at two very different heights (10 m for the Mesonet, 2 m for the 3D-printed station). The authors seem to be conscious of this limit (Lines 85-87), but in my opinion they should discuss this aspect in a more comprehensive manner and should better highlight the limits of their work.

2.4R - Authors agree on adding an additional plot of the Mesonet station. With respect to the wind speed comparisons, a logarithmic wind profile correction was applied to the Mesonet wind speed based on Allen et al 1998. This did bring the Mesonet wind speed values more in line with the 3D printed station for a majority of the deployment.

2.4C - Will add an addition plot of the Mesonet Facility. Authors will also further discuss the differences in the systems and the limits of the comparison.

2.5 Results: the measurements of the two meteorological stations have been compared only in terms of simple scatter plots. It is a very "rudimental", although useful, analysis. Therefore, I suggest to do more work in this sense: for example, it may be interesting evaluating the performance of the proposed stations as a function of the season and to investigate about the data accuracy in particular "extreme" weather conditions (e.g. strong winds, cold and/or heat waves, strong rainfall, fog, etc.).

2.5R - A more in-depth analysis has been done 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. This information was also calculated for each month of the deployment and the RMSE and correlation coefficients were recorded in an additional table. Additional processing has been applied to the relative humidity, solar radiation and wind speeds as well. The relative humidity was corrected using a temperature coefficient correction supplied by the vendor. 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.

The station was only deployed for 8 months, so more data would be needed to evaluate the performance of the station as a function of season and to further investigate data accuracy in extreme weather conditions. Interestingly, the precipitation gauge performed very well in the one heavier rain event that was encountered. The 3D printed gauge and Mesonet both recorded roughly 104 mm/hr precipitation rate.

2.5C - Authors will update figures with more in depth statistics, summary table of RMSE and correlation coefficient, and additional discussion on results.

2.6 Furthermore, for rainfall data, I suggest to perform a comparison not only in terms of daily accumulated rainfall but also in terms of rain rate.

2.6R- Data were processed for rain rate and will be included in the discussion and results accordingly.

2.6C - Rain rate results will be added to the results section.

2.7 Conclusions: please add an additional discussion about the limits of those preliminary results and about the future planning and evolution of this study.

2.7R - Authors will add additional discussion noting the differences between the systems and the limitations. The future and evolution of this study would have naturally been to extend it to different measurement types (soil moisture, spectral radiation, etc). Two of the authors have/will graduate from the University and the lead author has changed jobs and is now at Argonne National Lab in Chicago which will limit additional comparisons with the Oklahoma Mesonet. However, there still exists some opportunities to further advance this topic and potentially partner with other groups for future studies.

2.7C - Authors will add in addition discussions on the limits of the results and the natural evolution of this study.

Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2019-454, 2020.