METER

ATMOS 41 COMPARISON TESTING AND SENSOR-TO-SENSOR VARIABILITY DATA

Climate parameters such as precipitation, air temperature, and wind speed can change considerably across short distances in the natural environment. However, most weather observations either sacrifice spatial resolution for scientific accuracy or research-grade accuracy for spatial resolution. The ATMOS 41 represents an optimization of both. It was carefully engineered to maximize accuracy at a price point that allows for spatially distributed observations. Additionally, because many researchers need to avoid frequent maintenance and long setup times, the ATMOS 41 was designed to reduce complexity and withstand long-term deployment in harsh environments. To eliminate breakage, it contains no moving parts, and it only requires recalibration every two years. Since all 14 measurements are combined in a single unit, it can be deployed quickly and with almost no effort. Its only requirement is to be mounted and leveled on top of a pole with an unobstructed view of the sky.

METER released the ATMOS 41 in January 2017 after extensive development and testing with partnerships across the world, in Africa, Europe, and the US. We performed comparison testing with high-quality, research-grade non-METER sensors and conducted time-series testing for sensor-to-sensor variability. Below are the results.

PRECIPITATION

The ATMOS 41 employs the latest technology to improve upon traditional measurement approaches. A key innovation on the ATMOS 41 is the drop-counting rain gauge technology. It uses gold-plated electrodes to detect and count discrete drops from a nozzle precisely engineered to produce a highly repeatable drop size. This no-moving-parts technology is less susceptible to mechanical failure than traditional tipping-spoon gauges. Three tipping-spoon rain gauges (Texas Electronics and ECRN-100) were deployed at our Forks, WA USA precipitation testbed (rainiest location in lower 48 US states) alongside three ATMOS 41 sensor suites. All sensors were deployed within 2 m of each other spatially at 2 m height above ground surface. Over four months of data from the winter and spring of 2018 are shown in Figure 1. Interestingly, the three tipping-spoon gauges represent the highest and two lowest accumulated rainfall totals, with all three ATMOS 41s measuring accumulated rainfall totals between the tipping-spoon gauges. Although the scatter in the tipping-spoon gauges makes drawing solid conclusions difficult, all three ATMOS 41 units agree within 3% of the average of the tipping-spoon measurements.

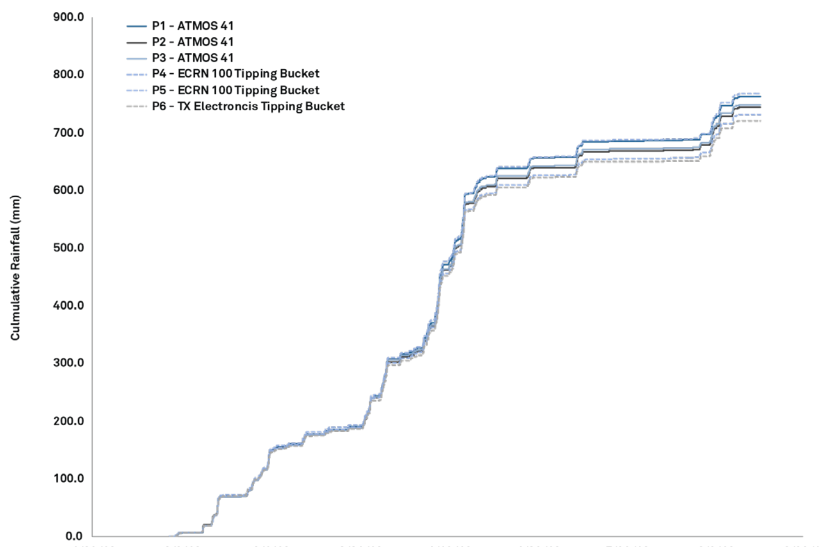

Figure 1 Precipitation comparison

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SOLAR RADIATION

The solar radiation comparisons were made on the rooftop testbed at METER's Pullman campus. A Kipp & Zonen CMP3 was co-located with an ATMOS 41 for about a month in the fall of 2017. Readings were averaged over a 15-minute period, and the data show good agreement based on the 1:1 plot (Figure 2). A linear regression shows a 3% underestimation by the ATMOS 41 pyranometer.

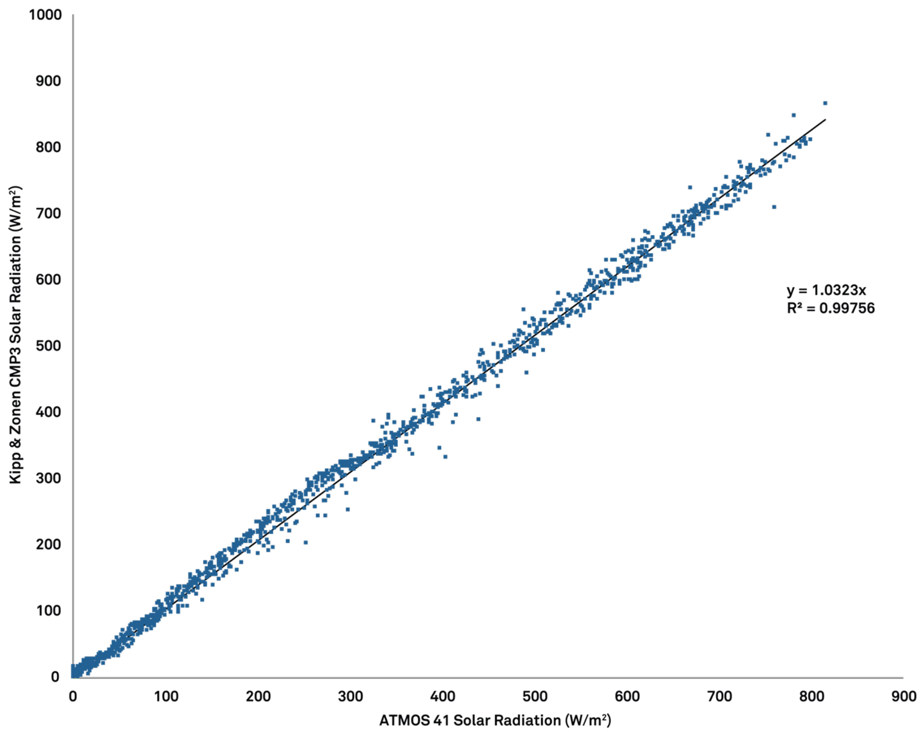


Figure 2 Solar radiation comparison

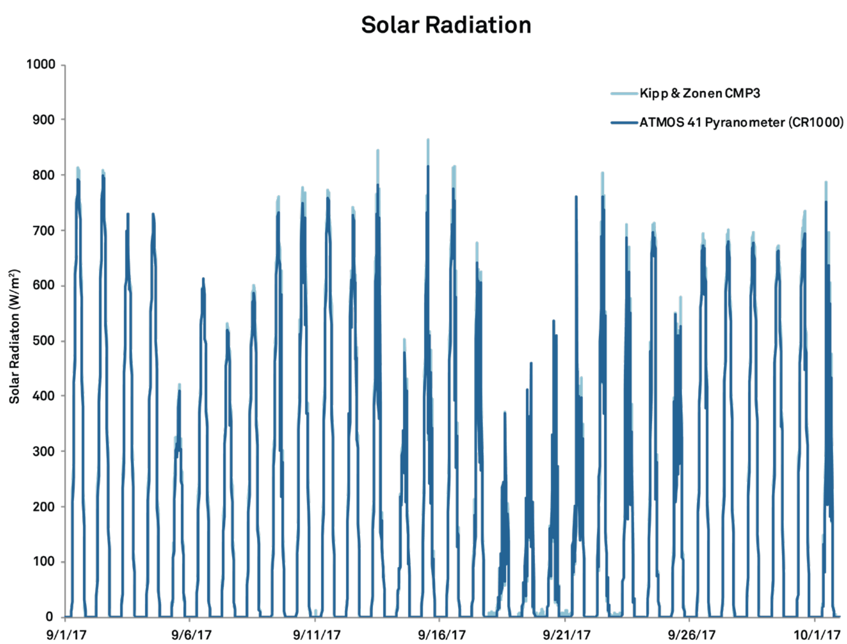
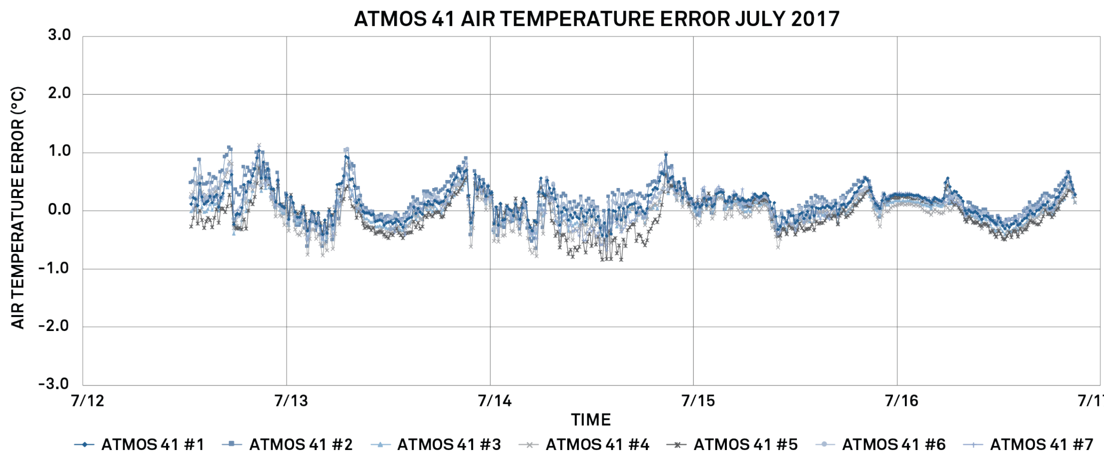


Figure 3 Time-series of Kipp & Zonen CMP3 and ATMOS 41 pyranometer data

AIR TEMPERATURE

The ATMOS 41 uses a micro thermistor in the anemometer opening and corrects for effects of solar radiation and wind using a basic energy balance approach. Solar radiation and wind speed are combined to adjust air temperature measurement for solar heating and convective cooling instead of the common louvered radiation shield. This method was optimized and verified at METER's Pullman campus using an micro thermistor sensor housed in an Apogee TS-100 aspirated radiation shield as the air temperature standard. The verification results show a 95% confidence interval of +/- 0.6°C for the ATMOS 41 air temperature measurement (Figure 4), which is significantly better than the error expected for a typical sensor housed in a non-aspirated shield. More information on the air temperature correction can be found in our webinar "Stop Hiding Behind a Shield".



(All units are °C)	ATMOS 41 #1	ATMOS 41 #2	ATMOS 41 #3	ATMOS 41 #4	ATMOS 41 #5	ATMOS 41 #6	ATMOS 41 #7
Bias ->	0.13	0.17	0.00	-0.03	-0.05	0.13	0.08
95% confidence interval	0.52	0.61	0.46	0.62	0.60	0.49	0.57

Figure 4 Time-series of ATMOS 41 temperature correction model verification

RELATIVE HUMIDITY

The improved air temperature is used to accurately correct relative humidity. All METER relative humidity sensors are individually calibrated and verified at three humidity levels against a dew point hygrometer standard. Figure 5 shows data consistency between sensors. One to 16 sensors are calibrated at a time, and are held to a pass/fail criterion of 2% relative humidity at all three humidity levels. Data show excellent consistency between sensors which are typically calibrated to within 1% of the actual humidity.

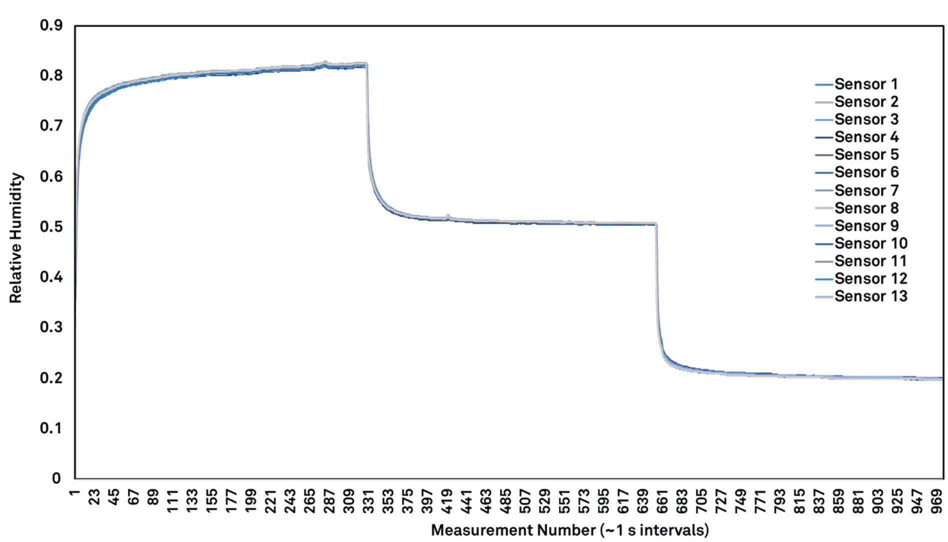


Figure 5 Relative Humidity sensor-to-sensor testing

Data collected in the field use the integrated relative humidity and temperature sensor to calculate vapor pressure (kPa). Figure 6 shows sensor performance in the field over an eight-day period and gives an idea of what to expect in terms of consistency between vapor pressure measurements.

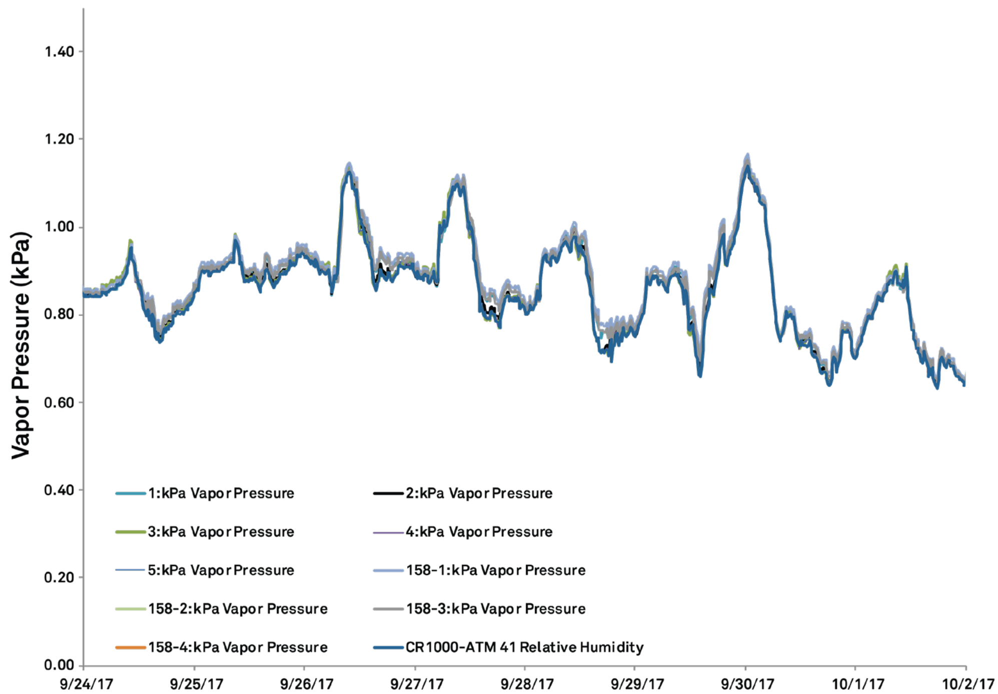


Figure 6 Vapor pressure field data

WIND SPEED AND DIRECTION

The ATMOS 41 wind speed and direction were tested by a third party ISO 17025 certified lab. Wind speed is measured by an ultrasonic anemometer with no moving parts as opposed to a cup anemometer. Wind direction is also measured by ultrasonic anemometers since there are two sonic transducers located at 90 degrees apart. The engraved N on the unit must be pointed toward True North to record accurate wind direction. Data are shown in Figure 7 (wind speed) and Table 1 (wind direction).

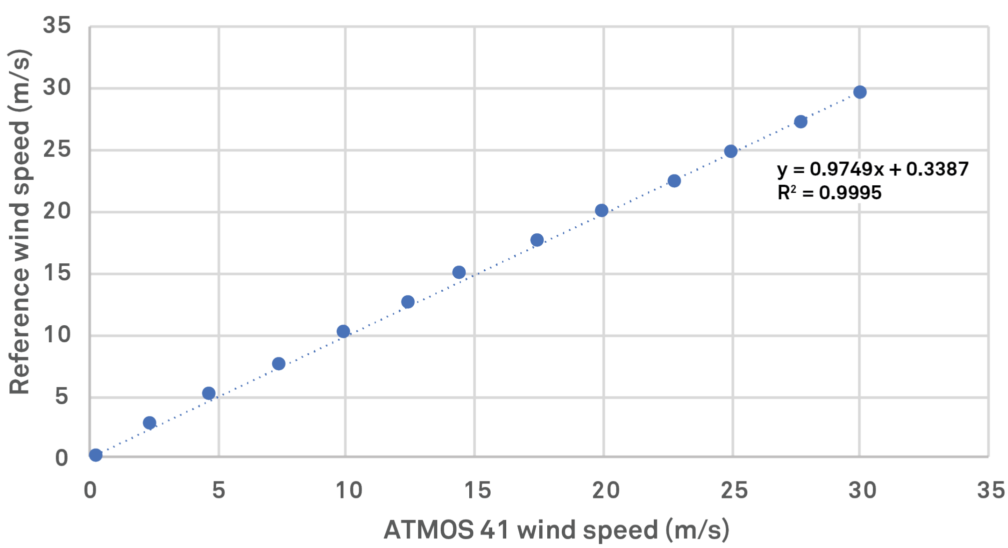


Figure 7 Wind speed data

Table 1 **Wind direction data, average of 3 data points**

REFERENCE WIND DIRECTION (°)	ATMOS 41 WIND DIRECTION (°)	DIRECTION DIFFERENCE (°)
2	1.89	-0.11
91	91.08	0.08
180	179.65	-0.35
270	270.23	0.23

BAROMETRIC PRESSURE

Each ATMOS 41 barometric pressure sensor is individually calibrated against a NIST-traceable pressure reference. The difference between the pressure reference and the pressure sensor must be within +/- 0.1 kPa. The difference is then stored on the sensor as an offset. Figure 8 shows the performance of seven ATMOS 41s at the METER testbed. Differences between the top and bottom pressure are around 0.2 kPa.

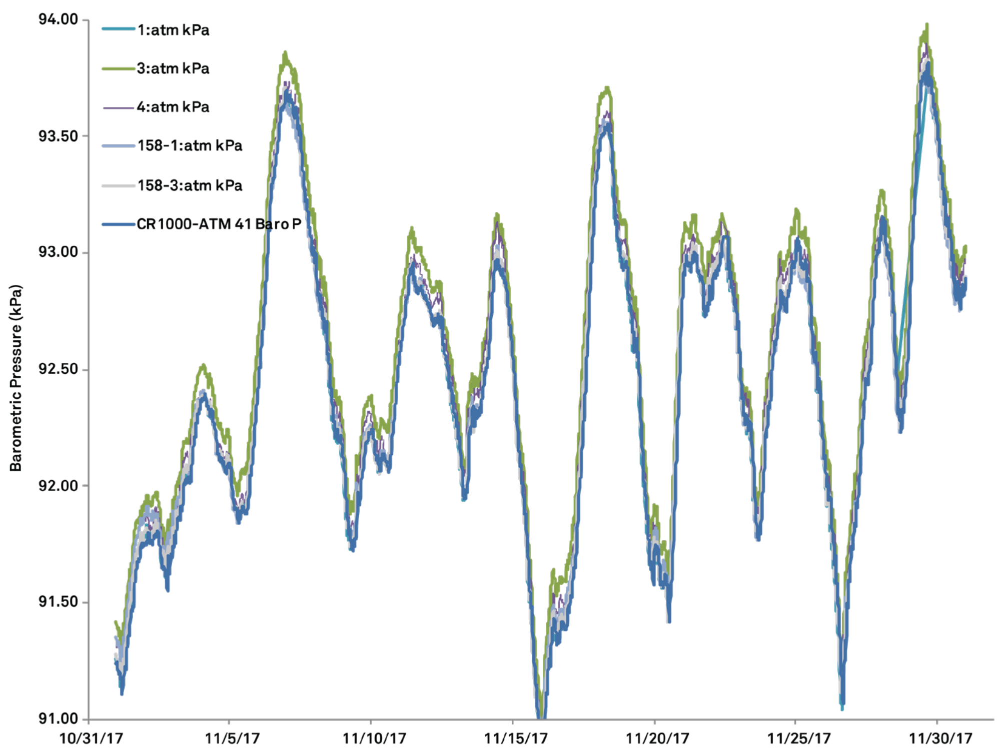


Figure 8 Barometric pressure sensor-to-sensor testing

TILT SENSOR

The ATMOS 41 also features a tilt sensor to alert when there's a problem with level. Tilt sensors are zeroed in the METER production calibration fixture using a bubble level as an indicator. Figure 9 shows the tilt sensor performance using seven ATMOS 41s in the testbed. The gray lines show an example of a sensor that was blown out of level and subsequently discovered and fixed. Each accelerometer showed relatively low noise and high repeatability. It is important to note that occasional episodes of higher noise are a result of high wind speeds and instability in the mounting apparatus and not problems in the sensor.

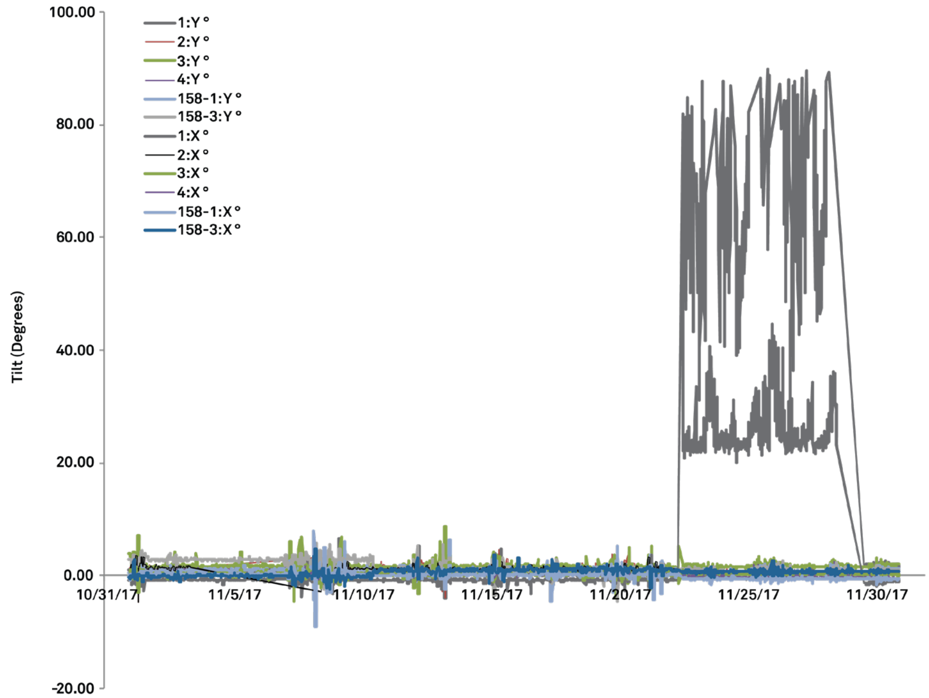


Figure 9 Tilt sensor performance. Data show variation in tilt measurement as well as a unit blown over during a holiday break.

SUMMARY

Data from independent sensor comparisons along with side-by-side observations show that the ATMOS 41 meets the goal of research-quality measurements in a simple, robust, and easy-to-maintain unit. Its unique design features such as a no-moving-parts anemometer and drop-counting rain gauge enable long-term, accurate measurements in a harsh environment, and because it's affordable, it can be relied upon to provide the critical spatially distributed data that will fill the gaps in meteorological measurements.