METER

ATMOS 41

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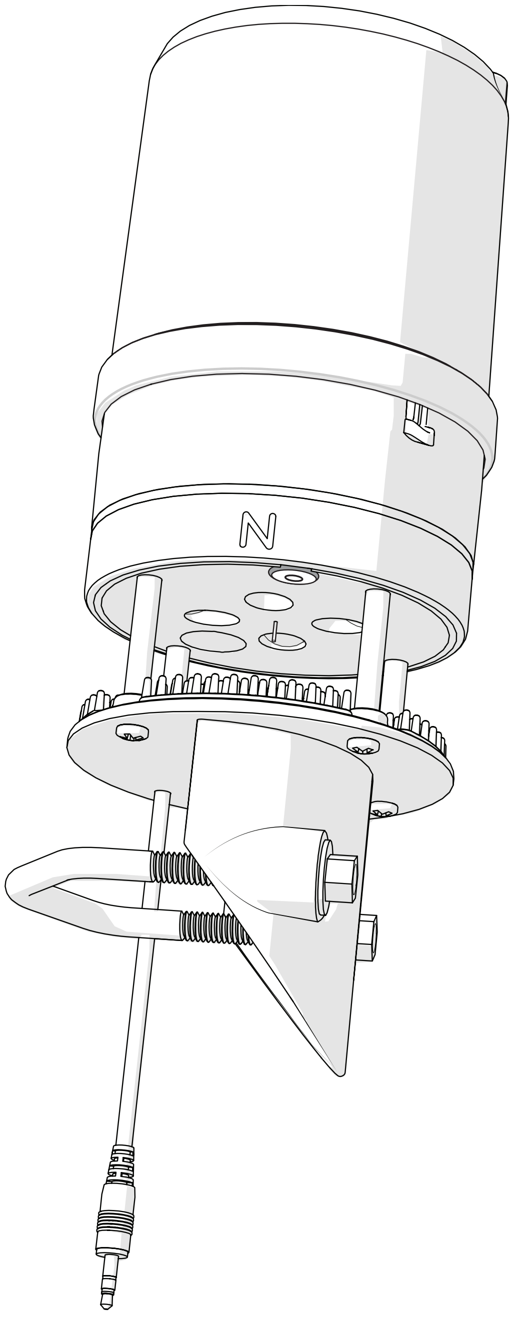
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1. INTRODUCTION

Thank you for choosing the ATMOS 41 All-in-One Weather Station from METER Group.

The ATMOS 41 All-in-One Weather Station is designed for continuous monitoring of environmental variables, including all standard weather measurements (Section 3).
The ATMOS 41 measures the following:

- Solar radiation
- Precipitation
- Precipitation maximum intensity
- Air temperature
- Barometric pressure
- Vapor pressure
- Relative humidity
- Wind speed
- Wind direction
- Maximum wind gust
- Lightning strikes
- Lightning distance
- Tilt

WEATHER STATIONS REIMAGINED

All sensors are integrated into a single, small form-factor unit, requiring minimal installation effort. A robust, no moving parts design that prevents errors because of wear or fouling make the weather station ideal for long-term, remote installations.

Applications of the ATMOS 41 are listed below:

- Weather monitoring
- Microenvironment monitoring
- Spatially-distributed environmental monitoring
- Crop weather monitoring
- Fire danger monitoring
- Weather networks

Additional advantages include its low-power design that supports battery-operated data loggers, and the SDI-12 three-wire interface. A tilt sensor warns the user of out-of-level condition, and no configurations are necessary.

2. OPERATION

Please read all instructions before operating the ATMOS 41 to ensure it performs to its full potential.

⚠ PRECAUTIONS

METER sensors are built to the highest standards, but misuse, improper protection, or improper installation may damage the sensor and possibly void the manufacturer's warranty. Before integrating ATMOS 41 or other METER sensors into a system, make sure to follow the recommended installation instructions and have the proper protections in place to safeguard sensors from damage.

2.1 INSTALLATION

Follow the steps listed in Table 1 to set up the ATMOS 41 and start collecting data.

Table 1 Installation

Tools Needed	**Wrench** 13 mm (1/2 in) **Secure mounting location** **Mount** meteorological stand pole in concrete tripod Diameter 31.8–50.8 mm, 1.25–2.0 in **NOTE: Smaller mounts are compatible if washers are added to the V-bolt (not included). Standard pipe sizes that are compatible are 1.00-, 1.25-, and 1.50-in diameter pipes. Square tubing with a width of 1.25 to 2.00 in or T-posts can also work as mounting options.**
Preparation	**Consider the Surroundings** Avoid obstructions. Ensure that site selection is far from wind obstruction. Make sure surrounding objects will not shade the solar radiation sensor. **Conduct System Check** Verify all sensors read within expected ranges (Section 3). **Adjust Pole Height** Many installations require the ATMOS 41 to be mounted 2 m above ground, but this can be adjusted based on the specific application.

Table 1 Installation (continued)

Mounting	**Install on Mounting Pole** The ATMOS 41 is fitted with a V-bolt, allowing it to be mounted on top of most posts, poles, tripods, etc. **Mount Toward True North** The ATMOS 41 must be oriented correctly by hand for accurate wind direction measurements. An **N** engraved on the side of the instrument should be oriented to point true north (not magnetic north). **Level the System** Use the bubble level underneath the ATMOS 41 or a ProCheck display to level the weather station. The angle of the mounting pole may need to be adjusted or shims added to the ATMOS 41 pole interface to achieve level. The ATMOS 41 must be within approximately ±2 degrees of dead level (0, 0) in both the X and Y directions to accurately measure rainfall and solar radiation. **Secure the System** Use a wrench to tighten the bolts, securing the ATMOS 41 flat and tight against the top of the stand.
Connecting	**Plug Sensor into Data Acquisition System** Connect the 3.5-mm stereo plug connector into ZENTRA or EM60 series data loggers. Configure the data logger to read the ATMOS 41 using ZENTRA Utility software (Section 2.2.1). Improperly protected cables can lead to severed cables or disconnected sensors. **NOTE: Cabling issues can be caused by many factors such as rodent damage, driving over sensor cables, tripping over cables, not leaving enough cable slack during installation, or poor sensor wiring connections.** **Relieve Cable Strain**—Relieve strain on the connections and prevent loose cabling from being inadvertently snagged by gathering and securing the cables between the ATMOS 41 and the data acquisition device to the mounting mast in one or more places. **Prevent Rodent Damage**—Install cables in conduit or plastic cladding when near the ground to avoid rodent damage. **Secure Excess Cable**—Tie excess cable to the data logger mast to ensure cable weight does not cause sensor to unplug. **Verify** Use the `SCAN` function in the software to show a list of ATMOS 41 readings. Verify that these readings are within expected ranges. **Non-METER Data Loggers** To connect to a non-METER data logger, refer to the ATMOS 41 Integrator Guide.

NOTE: ATMOS 41 will not work with legacy Decagon data loggers (Em50 Series and Em5B) because the ATMOS 41 outputs contain too many parameters.

2.2 CONNECTING

The ATMOS 41 All-in-One Weather Station works most efficiently with ZENTRA or EM60 data loggers. This system will not work with legacy data loggers (Decagon Em5, Em5B, Em50, Em50R, Em50G) because the ATMOS 41 has too many output parameters (previously limited to three). The sensor can also be used with other data loggers, such as those from Campbell Scientific, Inc. For extensive directions on how to integrate the sensor into third-party loggers, refer to the ATMOS 41 Integrator Guide.

The ATMOS 41 sensor requires excitation voltages in the range of 3.6 to 15.0 VDC and operates at 2.8 to 5.5-VDC level for data communication. The ATMOS 41 communicates using the SDI-12 communication protocol and should be compatible with any SDI-12 compatible data acquisition device capable of the ATMOS 41 excitation range. See the ATMOS 41 Integrator Guide for details on interfacing with data acquisition systems.

The standard ATMOS 41 comes with a 3.5-mm stereo plug connector (Figure 1) to facilitate easy connection with METER loggers. ATMOS 41 sensors may be ordered with stripped and tinned (pigtail) lead wires for use with screw terminals when connecting to some third-party loggers (Section 2.2.2).

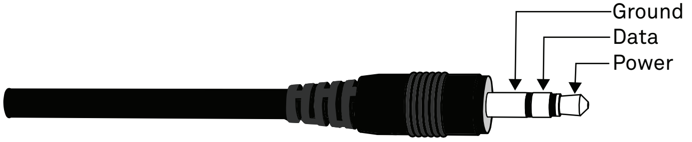


Figure 1 3.5-mm stereo plug connector wiring

The ATMOS 41 comes standard with a 5-m cable. It may be purchased with custom cable lengths for an additional fee (on a per-meter basis). METER has successfully tested digital communication on cable lengths up to 1,000 m (3,200 ft). This option eliminates the need for splicing the cable (a possible failure point). However, the maximum recommended length is 75 m.

2.2.1 CONNECT TO METER DATA LOGGER

The ATMOS 41 works seamlessly with ZENTRA or EM60 data loggers. Check the METER downloads webpage (metergroup.com/downloads) for the most recent data logger firmware. Logger configuration may be done using either ZENTRA Utility (desktop and mobile application) or ZENTRA Cloud (web-based application for cell-enabled ZENTRA data loggers).

NOTE: This system will not work with legacy data loggers (Decagon Em5, Em5B, Em50, Em50R, Em50G).

1. Plug the 3.5-mm stereo plug connector into one of the sensor ports on the logger.
2. Once the ATMOS 41 has been connected to a ZENTRA or EM60 data logger, using the appropriate software application, configure the chosen logger port for the ATMOS 41.
3. Set the measurement interval.

NOTE: The ATMOS 41 draws more current than most other METER sensors because it makes frequent wind speed and precipitation measurements. As a result, plugging multiple ATMOS 41 stations into a single ZENTRA or EM60 data logger may have significant impact on battery life. At times or in regions with plentiful sunshine, the solar panel should provide ample charge and this should not be an issue. During the winter or periods of extended heavy clouds, the solar panel may not provide enough charging current to keep the system running with multiple ATMOS 41 units. METER recommends using only one ATMOS 41 per ZENTRA or EM60 data logger.

2.2.2 CONNECT TO A NON-METER LOGGER

The ATMOS 41 can be used with non-METER (third party) data loggers. Refer to the third-party logger manual for details on logger communications, power supply, and ground ports. The ATMOS 41 can be ordered with stripped and tinned (pigtail) connecting wires for use with screw terminals. Connect the ATMOS 41 wires to the data logger as illustrated in Figure 2 and Figure 3, with the power supply wire (brown) connected to the excitation, the digital out wire (orange) to a digital input, and the bare ground wire to ground. The ATMOS 41 Integrator Guide gives detailed instructions on connecting the weather station to non-METER loggers.

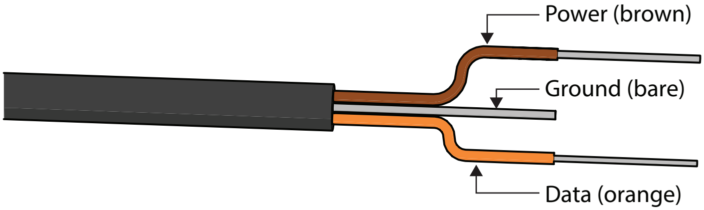


Figure 2 Pigtail wiring

NOTE: Some early ATMOS 41 units may have the older Decagon wiring scheme where the power supply is white, the digital out is red, and the bare wire is ground.

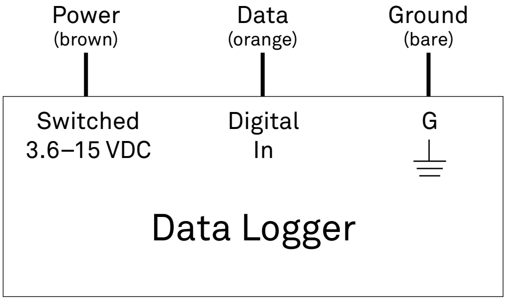


Figure 3 Wiring diagram

NOTE: The acceptable range of excitation voltages is from 3.6 to 15.0 VDC. To read the ATMOS 41 with Campbell Scientific data loggers, power the sensors off a 12 V port.

If the ATMOS 41 has a standard 3.5-mm stereo plug connector and will be connected to a non-METER data logger, please use one of the following two options when connecting to a non-METER data logger.

Option 1

1. Clip off the plug on the sensor cable.
2. Strip and tin the wires.
3. Wire it directly into the data logger.

This option has the advantage of creating a direct connection with no chance of the sensor becoming unplugged. However, it then cannot be easily used in the future with a METER readout unit or data logger.

Option 2

Obtain an adapter cable from METER.

The adapter cable has a connector for the female stereo plug connector on one end and three wires (or pigtail adapter) for connection to a data logger on the other end. The stripped and tinned adapter cable wires have the same termination as in Figure 3; the brown wire is excitation, the orange is output, and the bare wire is ground.

NOTE: Secure the 3.5-mm stereo plug connector to the pigtail adapter connections to ensure the sensor does not become disconnected during use.

3. SYSTEM

This section describes the ATMOS 41 All-in-One Weather Station system.

3.1 SPECIFICATIONS

MEASUREMENT SPECIFICATIONS

Solar Radiation	
Range:	0–1750 W/m^2
Resolution:	1 W/m^2
Accuracy:	±5% of measurement typical
Precipitation	
Range:	0–400 mm/h
Resolution:	0.017 mm
Accuracy:	±5% of measurement from 0 to 50 mm/h
Vapor Pressure	
Range:	0–47 kPa
Resolution:	0.01 kPa
Accuracy:	Varies with temperature and humidity, ±0.2 kPa typical below 40 °C
Relative Humidity	
Range:	0–100%
Resolution:	0.1%
Accuracy:	Varies with temperature and humidity, ±3% RH typical
Air Temperature	
Range:	−50 to 60 °C
Resolution:	0.1 °C
Accuracy:	±0.6 °C
Humidity Sensor Temperature	
Range:	−40 to 50 °C
Resolution:	0.1 °C
Accuracy:	±1.0 °C

Barometric Pressure	
Range:	50–110 kPa
Resolution:	0.01 kPa
Accuracy:	±0.1 kPa
Horizontal Wind Speed	
Range:	0–30 m/s
Resolution:	0.01 m/s
Accuracy:	The greater of 0.3 m/s or 3% of measurement
Wind Gust	
Range:	0–30 m/s
Resolution:	0.01 m/s
Accuracy:	The greater of 0.3 m/s or 3% of measurement
Wind Direction	
Range:	0°–359°
Resolution:	1°
Accuracy:	±5°
Tilt	
Range:	−90° to 90°
Resolution:	0.1°
Accuracy:	±1°
Lightning Strike Count	
Range:	0–65,535 strikes
Resolution:	1 strike
Accuracy:	Variable with distance, >25% detection at <10 km typical
Lightning Average Distance	
Range:	0–40 km
Resolution:	3 km
Accuracy:	Variable

PHYSICAL CHARACTERISTICS

Dimensions	
Diameter	10 cm (3.94 in)
Height	34 cm (13.39 in), includes rain gauge filter
Cable Length	
5 m (standard)	
75 m (maximum custom cable length for additional cost)	
NOTE: Contact Customer Support if a nonstandard cable length is needed.	
Connector Types	
3.5-mm stereo plug connector or stripped and tinned wires	

ELECTRICAL AND TIMING CHARACTERISTICS

Supply Voltage (VCC to GND)	
Minimum	3.6 VDC continuous
Typical	NA
Maximum	15.0 VDC continuous
Digital Input Voltage (logic high)	
Minimum	2.8 V
Typical	3.0 V
Maximum	5.5 V
Digital Input Voltage (logic low)	
Minimum	–0.3 V
Typical	0.0 V
Maximum	0.8 V
Digital Output Voltage (logic high)	
Minimum	NA
Typical	3.6 V
Maximum	NA

Power Line Slew Rate	
Minimum	1.0 V/ms
Typical	NA
Maximum	NA
Current Drain (during measurement)	
Minimum	0.2 mA
Typical	8.0 mA
Maximum	33.0 mA
Current Drain (while asleep)	
Minimum	0.2 mA
Typical	0.3 mA
Maximum	0.4 mA
Operating Temperature Range	
Minimum	−50 °C
Typical	NA
Maximum	60 °C
Power Up Time (SDI Ready)—`aRx!` Commands	
Minimum	NA
Typical	10 s
Maximum	NA
Power Up Time (SDI Ready)—Other Commands	
Minimum	NA
Typical	800 ms
Maximum	NA
Measurement Duration	
Minimum	NA
Typical	110 ms
Maximum	3,000 ms

COMPLIANCE

Manufactured under ISO 9001:2015
EM ISO/IEC 17050:2010 (CE Mark)

3.2 PYRANOMETER

Solar radiation is measured by a pyranometer that is integrated into the lip of the rain gauge funnel at the top of the ATMOS 41. Designed, manufactured, and calibrated by experts at Apogee Instruments, the miniature pyranometer uses a silicon-cell sensor to measure the total incoming (direct and diffuse) solar radiation. A carefully developed cosine-correcting head ensures accurate readings regardless of sun angle, while the painstakingly researched optical filter material balances cost and performance to ensure the silicon-cell provides good accuracy regardless of temperature or sensor age. Silicon-cell sensors have excellent response time to changing radiation conditions and acceptable sensitivity across the solar spectrum (Figure 4), which make them perfect for use on the ATMOS 41.

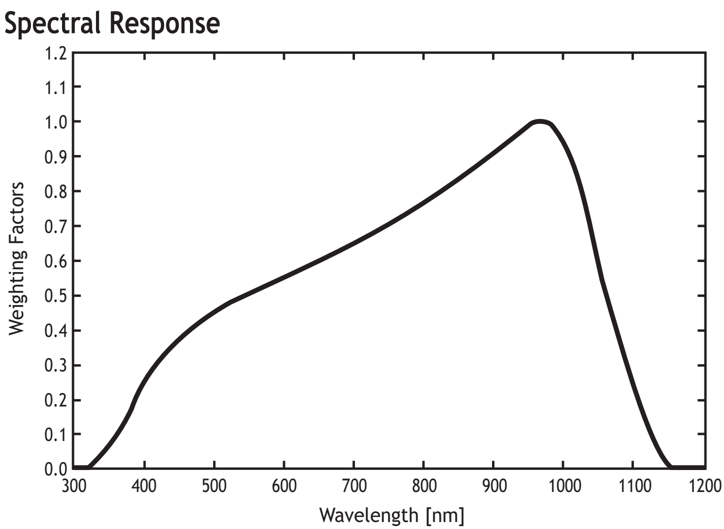


Figure 4 Spectral response estimate of Apogee silicon-cell pyranometers

Spectral response was estimated by multiplying the spectral response of the photodiode, diffuser, and adhesive. Spectral response measurements of diffuser and adhesive were made with a spectrometer, and spectral response data for the photodiode were obtained from the manufacturer.

Leveling the ATMOS 41 is particularly important for accurate solar radiation measurements. Out of level, the pyranometer will overestimate some portions of the day while underestimating others. Ensure accurate solar radiation measurements by carefully leveling the ATMOS 41 at installation. Bird droppings and other soiling of the domed sensor surface will cause serious errors in pyranometer measurements. Check the sensor regularly to make sure it is clean and check data often to identify possible problems. Isopropyl (rubbing) alcohol and a Q-tip work well for cleaning the sensor area. Microfiber bags work well, too. Do NOT use an abrasive cloth on the sensor surface, as it will scratch.

The pyranometer is factory calibrated and the sensor-specific calibration value can be found on the interior of the rain funnel. This factor has already been added into the ATMOS 41 so there is no need to do anything with it. In the event that this value is needed, it can be found by taking the funnel off the base and checking underneath. Follow the steps in Section 3.5 to remove the funnel.

When powered on, the ATMOS 41 measures the solar radiation once every 10 s and records the instantaneous values. When queried, the ATMOS 41 outputs the average of the instantaneous measurements since the last query.

3.3 ANEMOMETER

The space underneath the rain gauge is where the ATMOS 41 measures wind speed. Ultrasonic signals emitted from transducers at right angles to each other bounce off the porous sintered glass plate (Figure 5) and back up to the opposite sensor. The speed of sound is affected by the wind, and the wind speed is calculated by measuring differences in the time it takes for sound to travel back and forth between sensors (Section 3.11.1).

When powered on, the ATMOS 41 measures the wind speed and direction once every 10 s and records the instantaneous wind vector components. When queried, the ATMOS 41 outputs the average of the instantaneous measurements since the last query for wind speed and direction and the maximum instantaneous wind speed value for wind gust.

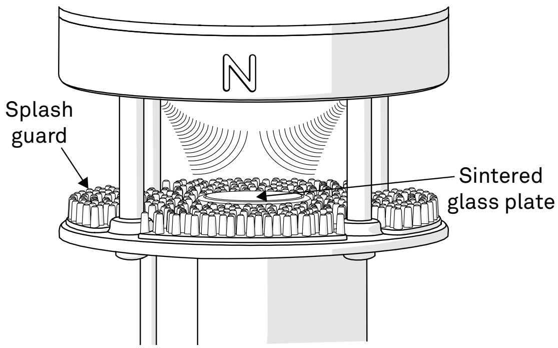


Figure 5 Anemometer

3.4 VAPOR PRESSURE/RELATIVE HUMIDITY SENSOR

The vapor pressure sensor (Figure 6) on the ATMOS 41 is located behind the circular Teflon™ screen in the same housing as the sonic transducers. The Teflon screen protects the sensor from liquid water and dust while allowing water vapor to freely pass to the sensor and equilibrate with air vapor pressure. The sensor measures relative humidity and temperature in addition to computing vapor pressure.

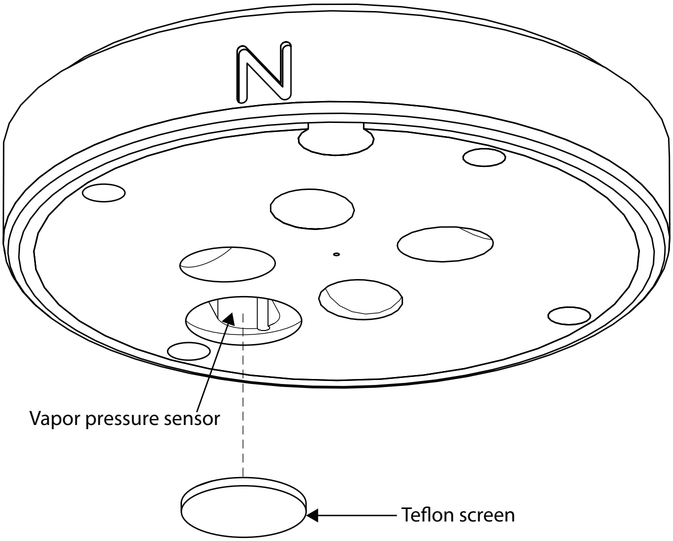


Figure 6 Vapor pressure sensor

If the relative humidity of the air is desired, it can be computed using Equation 1.

$$RH_{r,air} = \frac{e_a}{e_s(T_{air})}$$ **Equation 1**

where e_a is the vapor pressure of the air, from the ATMOS 41, and $e_s(T_{air})$ is saturation vapor pressure at the air temperature given by the ATMOS 41.

The saturation vapor pressure is calculated using the Magnus-Tetens equation (Equation 2) with the following coefficients described by Buck (1981).

$$e_s T_{air} = a\,exp\frac{bT_{air}}{c+T_{air}}$$ **Equation 2**

Water	a = 0.611 kPa	b = 17.502	c = 240.97 °C	T_{air} = Temperature in °C
Ice	a = 0.611 kPa	b = 21.87	c = 265.5 °C	T_{air} = Temperature in °C

Unlike relative humidity, vapor pressure does not depend on temperature, and is generally conservative over time and space. The vapor pressure of the atmosphere near the relative humidity sensor is the same as the vapor pressure at the relative humidity sensor, even if the relative humidity sensor is not at the same temperature as the atmosphere. Additionally, it is the vapor pressure of the atmosphere (not RH) that controls the rate of vapor phase water transport (e.g., evaporation, transpiration, and distribution of water vapor). Therefore, vapor pressure is a much more useful measure of atmospheric moisture than relative humidity.

When powered on, the ATMOS 41 measures the vapor pressure once every 60 s and records the instantaneous values. When queried, the ATMOS 41 outputs the average of the instantaneous measurements since the last query.

3.5 RAIN GAUGE

The ATMOS 41 contains a 9.31-cm diameter rain gauge. During rain events, the flared hole (Figure 7) forms the rain into drops that pass by the drip counter. The spring (Figure 7) acts as a filter to keep out large particles but still allows enough flow so water does not back up. Gold pins (Figure 7) measure each drop of rain. Because the flared hole forms a drop of a known size, the ATMOS 41 counts the drops and calculate the water volume. As the rain intensity increases, the drops become smaller, but the ATMOS 41 firmware contains an algorithm to automatically compensate for drop size as the rain increases.

When powered on, the ATMOS 41 counts water drops continuously and adds each drop to an accumulated total. When queried, the ATMOS 41 outputs the total rainfall (in mm) that has accumulated since the last query.

IMPORTANT: The ATMOS 41 must be within approximately ±2 degrees of dead level (0, 0) in both the X and Y directions to accurately measure rainfall. If not within this range, drops from the flared hole can miss the gold electrodes entirely.

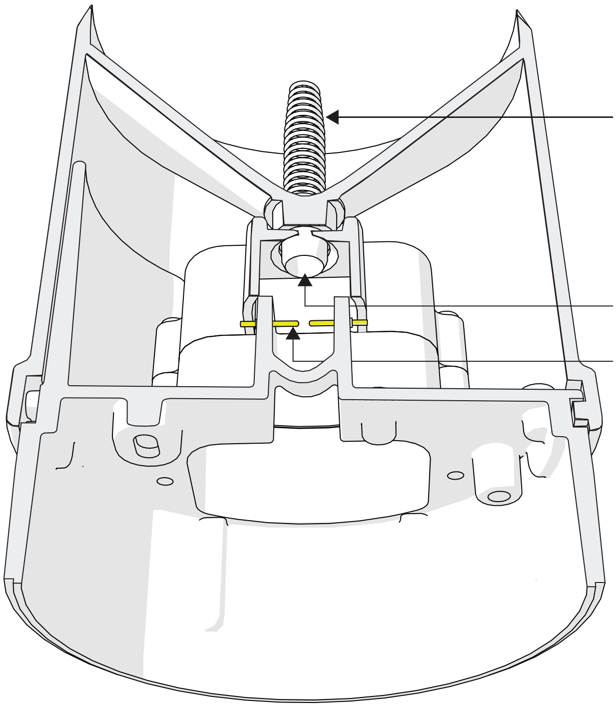


Figure 7 Rain gauge

The rain gauge locks in place using two pegs on the side of the rain gauge funnel. Follow the steps below to get inside the rain gauge.

1. Line up the lock/unlock graphic located on the side of the rain gauge funnel with the notch on the interface plate.
2. Press the rain gauge funnel down against the spring and turn counter clockwise until it clicks in place.

   ATTENTION: UNPLUG THE PYRANOMETER CONNECTOR INSIDE THE FUNNEL BEFORE FULLY REMOVING THE FUNNEL.
3. Before replacing the cover, be sure to reattach the pyranometer connector by mating the two halves of the white connector and seating firmly together until the tabs lock.

   NOTE: The connector is polar so it can only mate in one orientation.
4. Check to be sure the downspout screen is in place on the water exit downspout (Figure 12). This keeps bugs out of the interior of the sensor.

3.6 TEMPERATURE SENSOR

The ATMOS 41 temperature measurement (Figure 8) is made in the center of the anemometer area where a small stainless steel needle containing a tiny temperature sensor (thermistor) extends from the middle of the four sonic transducers in the center of the anemometer. Unlike most air temperature measurements, the weather station sensor is not covered with louvered plates to protect from solar heating. Instead, it sits in open air, susceptible to solar heating of the instrument body. However, the ATMOS 41 calculates the air temperature accurately because solar radiation and the wind speed are known. These are the two main parameters that determine the error between measured air temperature and the actual air temperature. Therefore, it is possible to solve the energy balance to get what the actual temperature should be based on the solar load of the body and the convective cooling of that temperature sensor.

When powered on, the ATMOS 41 measures the air temperature once every 10 s and records the instantaneous values. When queried, the ATMOS 41 outputs the average of the instantaneous measurements since the last query.

NOTE: The ATMOS 41 body and especially the temperature sensor should not be painted or coated.

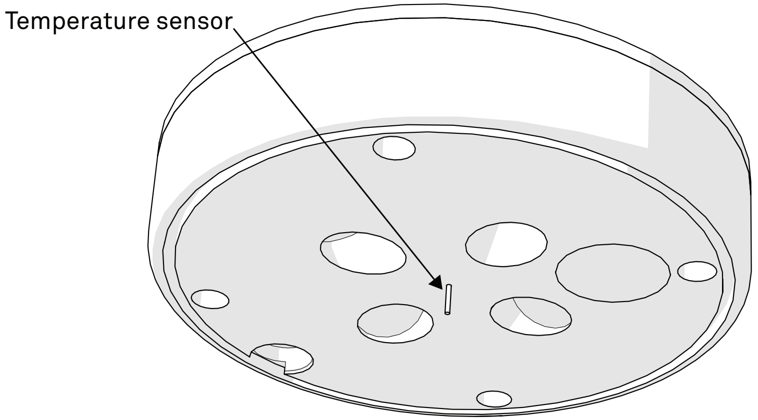


Figure 8 Temperature sensor

3.7 LIGHTNING SENSOR

The lightning sensor acts much like an AM radio. During a thunderstorm, the crack of the lightning disrupts the AM signal. The integrated circuit inside the sensor listens for this crackle, and when the sensor detects a disturbance, it registers the time of and distance (intensity of signal) to the strike. The sensor outputs the total number of strikes and average distance to these strikes in the measurement period. The sensitivity of the lightning sensor can be adjusted using the ProCheck (Section 3.8).

When powered on, the ATMOS 41 counts lightning events continuously and adds each detected event to an accumulated total. When queried, the ATMOS 41 outputs the total number of lightning events that have been detected since the last query.

3.8 CONFIGURE THE LIGHTNING SENSOR USING PROCHECK

A ProCheck can be used to configure the ATMOS 41 lightning sensor for optimal performance. To make these modifications, the weather station must be plugged into the ProCheck via the stereo port.

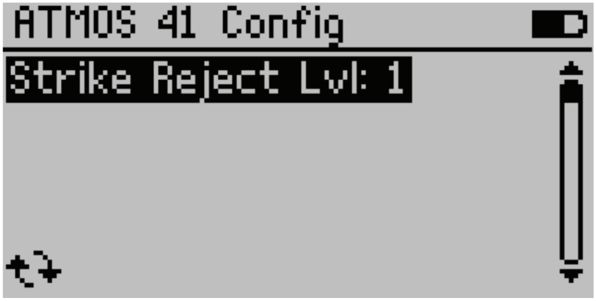


Figure 9 ATMOS 41 configuration screen using ProCheck

The `Strike Reject Lvl` adjusts the lightning sensor threshold used to differentiate between man-made electrical noise and lightning strikes. The higher the value, the less likely man-made electrical noise will cause a false lightning strike, but the more likely lightning strike events from far away will be filtered out and missed. A value between 0 and 15 can be used. Generally, a small deviation of 1 or 2 from the default value (5) is sufficient to tune the level to the installation environment.

To set the `Strike Reject Lvl` follow the steps below:

1. Press **Enter** to begin changing the `Strike Reject Lvl`.
2. Press the **UP** and **DOWN** arrows to select the new level.
3. Press **Enter** or **SAVE** to save the new `Strike Reject Lvl` to the sensor.
4. Check the settings.

3.9 BAROMETRIC PRESSURE SENSOR

The barometric pressure sensor is located behind the Teflon screen next to the relative humidity sensor. It measures the atmospheric pressure of the environment in which the ATMOS 41 is deployed. With a range from 50 to 110 kPa, it is suitable for measurement across a wide range of elevations, but keep in mind that the magnitude of sensor output will depend chiefly on the installation altitude with subtle changes caused by weather.

When powered on, the ATMOS 41 measures the barometric pressure once every 60 s and records the instantaneous values. When queried, the ATMOS 41 outputs the average of the instantaneous measurements since the last query.

3.10 TILT SENSOR

The ATMOS 41 is also equipped with a tilt sensor similar to those found in smartphones. The primary use of the tilt sensor data is to ensure the ATMOS 41 remains level at all times. Regularly check X and Y tilt data to ensure the ATMOS 41 is level; if it has tilted, return to the site and level again. Even a few degrees off level can cause errors in the rain and solar radiation measurements. Although this sensor may be used to level the instrument, it is much easier to use the small bubble level on the bottom of the anemometer plate.

When powered on, the ATMOS 41 measures the tilt in the X and Y orientation once every 60 s and records the instantaneous values. When queried, the ATMOS 41 outputs the average of the instantaneous measurements since the last query.

3.11 THEORY

The following sections explain the theory of wind speed, wind direction, and air temperature measurements.

3.11.1 WIND SPEED AND DIRECTION

The theory behind the anemometer comes from Campbell and Unsworth (1979). The speed c (m/s) of sound in still air depends on air temperature T (K), vapor pressure e (kPa), and atmospheric pressure, p (kPa), as shown in Equation 3.

$$c = 20.067\sqrt{T(1+\frac{0.32e}{p}} \quad \text{Equation 3}$$

For a given sound path length, d (m), the number of wavelengths, n, in still air is determined with Equation 4.

$$n = \frac{vd}{c} \quad \text{Equation 4}$$

Here v is the frequency of the sound (Hz). When the air is moving, the speed of sound is the sum of the wind speed and the speed of sound in still air. The anemometer transmits a sound pulse in a forward direction, then a similar pulse in the reverse direction. The difference in n between the two points is computed. If the vector magnitude of the wind in the direction of the sound is u (m/s), then

$$n - \Delta n_+ = \frac{vd}{c+u} \quad \text{Equation 5}$$

$$n - \Delta n_- = \frac{vd}{c-u} \quad \text{Equation 6}$$

for sound traveling with and against the wind. Subtracting the result of Equation 5 from the results of Equation 6 creates Equation 7.

$$\Delta n = \Delta n + \Delta n_{+} = \frac{2vdu}{c^2 - u^2}$$ **Equation 7**

Even at the maximum wind speeds for the anemometer, u^2 is only about 1% of c^2, so the equation can be simplified as shown in Equation 8.

$$x \cong \frac{c^2}{2vd} \Delta n$$ **Equation 8**

This is the basic equation for the anemometer. Delta (Δ) n is proportional to the phase difference between the forward and reverse sound pulses. The sound comes from a 40 kHz ultrasonic transducer in the head of the anemometer. A sound pulse is transmitted diagonally across the anemometer, bouncing off a sintered glass plate in the center. The sound pulse is then received by another transducer in the anemometer head that is opposite the first. Once the sound pulse is received, the receiver becomes the transmitter and the process is repeated. Two more sensors, mounted at 90 degrees from the first two, give the other horizontal component of the wind. The sound travels a total distance of about 72 mm from transmitter to receiver, but d in the equations is just the horizontal distance, which is 40 mm.

If u is the magnitude of the wind vector in the east-west direction (east +) and v is the magnitude in the north-south direction (north +), then wind speed is computed with Equation 9.

$$S = \sqrt{\overline{u}^2 + \overline{v}^2}$$ **Equation 9**

Where the overbar indicates an average of the values sampled every 10 s, wind direction is computed with Equation 10.

$$\theta = tan^{-1}(\overline{v} / \overline{u})$$ **Equation 10**

The wind measurement through more frequent SDI-12 commands requires 42 ms to complete. An additional 60 ms are required for the computations to determine phase differences. The anemometer samples every 10 s (or more often if requested). The gust speed reported is the highest instantaneous wind speed measured during the selected averaging interval (must be >20 s or gusts will equal speed).

The ATMOS 41 uses a wind speed spike rejection scheme to protect against the inclusion of spurious wind speed spikes in the averaged wind speed data. The ATMOS 41 measures wind speed every 10 s and keeps a running average of the last 10 measurements. If an instantaneous measurement is more than eight times the running average, then the instantaneous measurement is rejected and not reported as the maximum gust or included in the data that are averaged over the output interval.

For normal ATMOS 41 use cases, this is an effective method for eliminating inaccuracy resulting from spurious spikes in wind speed (e.g., bumblebee investigating the ultrasonic path). In special use cases where data are output frequently and large step changes in wind speed are present (e.g., turning on a wind tunnel), this spike rejection algorithm may result in an error code being output.

NOTE: Cup anemometers average over a much longer interval than 42 ms, so the gusts measured with a sonic anemometer will have a larger peak-to-mean ratio than one would see with a cup anemometer.

3.11.2 TEMPERATURE SENSOR

The ATMOS 41 uses an energy balance correction to adjust measured temperature to actual air temperature according to Equation 11.

$$T_{corr} = T_{uncorr} - \left(\frac{\alpha_S S_t}{c_p k \sqrt{u / d}} \right)$$

Equation 11

where:

- α_s = the absorptivity of the surface to solar radiation
- S_t = the total solar radiation measured
- c_p = 29.3 J mol^{-1} C^{-1}, k is a constant
- u = the wind speed
- d = the characteristic dimension

Although these values can be assumed, some (α_s and k) were optimized using a Levenberg Marquardt Least Squares analysis. Optimal air temperature was obtained using an Apogee TS-100 Aspirated Radiation Shield. Data were collected over several weeks and final values are shown in Table 2.

A maximum value optimization for S_t was added because radiation values higher than that cause the corrected temperature to deviate from actual values more than when a maximum S_t was used.

Table 2 Optimized values for air temperature correction

a_s	d (m)	k	c_p (J $mol^{-1}K^{-1}$)	Max S_t (W/m^2)
0.295	0.00083	0.0984	29.3	352.3

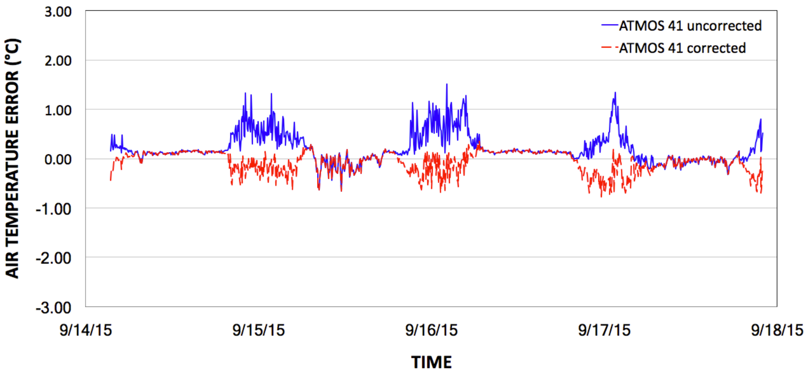


Figure 10 Corrected air temperature comparison with the aspirated radiation shield using 1-min measurement intervals

Figure 10 shows the results from the temperature correction compared to the aspirated temperature, which shows data sampled at 1 min and not averaged over time. The estimated accuracy of the air temperature measurement, based on two standard deviations (95% confidence interval), is 0.42 °C. To provide an idea of how comparable the data are, a concurrently tested temperature sensor in a radiation shield (typical measurement approach) showed an accuracy of 0.66 °C, also based on a two-standard deviation estimate. Thus, the temperature correction of the ATMOS 41 appears to give a better estimate of actual air temperature than the generally accepted radiation shield technique.

NOTE: Without correction, the accuracy of the temperature measurement is ±2 °C.

3.12 LIMITATIONS

The ATMOS 41 is engineered to be a robust device with minimal downtime. However, it does have limitations that will affect its measurements under some conditions.

3.12.1 SNOW AND ICE ACCUMULATION

The ATMOS 41 is not heated, so it will not measure frozen precipitation until snow and ice that have accumulated in the funnel melt. In locations with heavy snowfall or long periods below freezing, it is almost certain that snow accumulation will fill the funnel and no longer accumulate, leading to inaccurate precipitation measurements even when the precipitation melts. Accumulation of snow, ice, or frost will also adversely affect the accuracy of the solar radiation measurement and can compromise the wind measurements if accumulation occurs in the anemometer acoustic pathway or on the acoustic mirror (Section 4.3).

3.12.2 HEAVY RAIN AND STRONG WIND

During strong storm events, water can splash off of the horizontal bottom plate of the anemometer envelope and interrupt the signal passing between the sonic transducers. The spikes on the bottom plate help dissipate the energy of rainwater to minimize splashing and reduce the likelihood that the wind measurements are interrupted. Additionally, specially treated hydrophobic porous polyethylene membranes protect the ultrasonic transducers from direct splashing and the sintered (porous) glass construction draws water from the upper surface of the acoustic mirror to keep a constant sound path length. Despite these features heavy rain and strong wind can still cause water to reach the membranes and also cause temporary water buildup on the acoustic mirror. The hydrophobic nature of the transducer protective membranes and the quick-draining ability of the acoustic mirror should limit wind measurement interruptions to heavy rain events and should bring wind measurement back online soon after extreme conditions abate.

3.13 ATMOS 41 MEASUREMENTS WITH METER LOGGERS

METER EM60G and ZENTRA series data loggers query the ATMOS 41 once every minute and record the appropriate accumulations, averages, and maximums from the ATMOS 41 in memory. When the measurement interval is reached, the 1-min measurements are processed into the appropriate accumulations, averages, and maximums and output to final storage (see the METER logger manual for more information). Table 3 describes the quantities output from the ATMOS 41 and how they are processed in the logger for each ATMOS 41 measurement.

Table 3 ATMOS 41 output quantities processed in data logger

ATMOS 41 measurement	Data output by ATMOS 41 every min	Data saved by METER logger each measurement interval (m = # of min)
Solar radiation	Average of six 10-s solar radiation measurements	Average of m 1-min averages of solar radiation
Wind speed and direction	Average of six 10-s wind speed measurements in both horizontal wind vectors	Wind run is calculated from each 1-min average of both horizontal wind vectors. METER logger saves average wind run from m 1-min averages.
Wind direction	Average of six 10-s wind speed measurements in both horizontal wind vectors	Weighted direction calculated from horizontal wind vectors
Wind gust	Maximum of six 10-s wind speed measurements	Maximum wind gust recorded over measurement interval
Vapor pressure	Instantaneous measurement of vapor pressure	Average of m instantaneous vapor pressure measurements
Rainfall	Rainfall accumulation over 1-min period	Accumulation of rainfall over m 1-min periods
Air temperature	Average of six 10-s air temperature measurements	Average of m 1-min averages of air temperature
Lightning strikes	Lightning strikes detected of 1-min period	Accumulation of lightning strikes detected over m 1-min periods

Table 3 ATMOS 41 output quantities processed in data logger (continued)

ATMOS 41 measurement	Data output by ATMOS 41 every min	Data saved by METER logger each measurement interval (m = # of min)
Lightning distance	Average distance for all strikes detected over 1-min period	Average of m 1-min averages of lightning distance (yields approximate distance to edge of storm)
Barometric pressure	Instantaneous measurement of barometric pressure	Average of m instantaneous barometric pressure measurements
Tilt	Instantaneous measurements of tilt in X and Y orientation	Average of m instantaneous measurements of tilt in X and Y orientation

4. SERVICE

This section contains calibration and recalibration information, calibration frequencies, cleaning and maintenance guidelines, troubleshooting guidelines, customer support contact information, and terms and conditions.

4.1 CALIBRATION

- **Solar Radiation:** ATMOS 41 pyranometers are calibrated through side-by-side comparison to the mean of four Apogee model SP-110 transfer standard pyranometers (shortwave radiation reference) under high-intensity discharge metal halide lamps. The transfer standard pyranometers are calibrated through side-by-side comparison to the mean of at least two ISO-classified reference pyranometers under sunlight (clear sky conditions) in Logan, Utah. Each of four ISO-classified reference pyranometers are recalibrated on an alternating yearly schedule (two instruments each year) at the National Renewable Energy Laboratory (NREL) in Golden, Colorado. NREL reference standards are calibrated to the World Radiometric Reference (WRR) in Davos, Switzerland.
- **Precipitation:** ATMOS 41 rain gauges do not receive individual calibration. The critical parameter for accurate measurement is drop size (which is controlled by the geometry of the rain gauge nozzle), and the rain gauge nozzle is an injection molded piece with static geometry. A subsample of rain gauges is checked monthly for accuracy as part of routine QA/QC procedures.
- **Air Temperature:** The air temperature sensor is specified to be accurate to 0.1 °C by the original manufacturer. All sensors are verified against a nontraceable standard thermometer at the time of manufacture. The plan is to implement a NIST traceable calibration/verification process in the near future.
- **RH/Vapor Pressure:** ATMOS 41 relative humidity/vapor pressure sensors receive a three-point calibration using a METER WP4C chilled-mirror dew point sensor as the calibration standard at 20%, 50%, and 80% RH. The WP4C is calibrated every 3 months against four salt standards of known RH (Robinson and Stokes 1970) to be accurate to within 0.2% RH.
- **Barometric Pressure:** Each ATMOS 41 barometric pressure sensor is calibrated against the average of three secondary standard Measurement Specialties MS5611 pressure sensors. The MS5611 sensors are calibrated every 3 months against a GE Druck TERPS 8100-series pressure sensor. The GE pressure sensor is calibrated yearly at certified laboratory with NIST traceability.
- **Wind Speed:** The relationship between wind speed and phase is determined by geometry and the laws of physics. Since the geometry is tightly controlled in manufacture, no individual anemometer calibration is needed. The phase of each ATMOS 41 anemometer is initially set to zero in a zero wind-speed condition. Extensive wind-tunnel and field testing has shown this to result in accurate wind-speed measurements. A subsample of anemometers is checked monthly for accuracy as part of routine QA/QC procedures.

- **Wind Direction:** The ATMOS 41 wind direction measurement depends on the geometry of the ultrasonic transducers and the north orientation indicator on the ATMOS 41 body. This geometry is held to within 0.025-mm specifications through CNC milling procedures. Orientation of the ATMOS 41 toward North will introduce more error in the wind direction measurement than sensor geometry.
- **Sensor Tilt:** The ATMOS 41 tilt sensor is zeroed against the primary bubble level on the bottom side of the upper anemometer housing.
- **Lightning Strike Counter:** Calibration on ATMOS 41 lightning strike detector is performed by the original manufacturer of the lightning detection chip prior to integration into the ATMOS 41. No further calibration is performed during sensor integration.
- **Lightning Distance:** Calibration on ATMOS 41 lightning distance detector is performed by the original manufacturer of the lightning detection chip prior to integration into the ATMOS 41. No further calibration is performed during sensor integration.

4.2 RECALIBRATION RECOMMENDATIONS

Table 4 lists the recommended sensor calibration frequencies.

Table 4 Calibration frequencies

Sensor Function	Calibration Frequency
Solar Radiation	Every 2 years[a]
Barometric Pressure	Every 2 years[b]
Relative Humidity (RH)	Every 2 years[b]
All other sensors	Not Needed

[a] Contact Apogee Instruments for details on sending the pyranometer in for calibration: techsupport@apogeeinstruments.com +1.877.727.6433.

[b] ATMOS 41 barometric pressure and vapor pressure/RH sensors and their respective calibrations are housed on a module that sits behind the circular Teflon membrane in the same housing as the sonic transducers (see Figure 6). This module is field-swappable, so sensors in need of calibration can be removed and seamlessly replaced by a module with calibrated sensors. Please contact Customer Support for new sensor modules and instructions on how to swap them in for older modules in need of calibration.

4.3 CLEANING AND MAINTENANCE

1. Make sure nothing is obscuring the temperature sensor or the sonic transducers shown in Figure 11 (cobwebs, leaves, wasp nests, etc.).
2. Check the following areas to make sure they are clear of miscellaneous environmental, animal (specifically bird droppings) and insect debris, or spider webs:
   a. Rain funnel (Figure 14)
   b. Pyranometer (Figure 14)

c. Ultrasonic transducer openings (Figure 11)

d. Sintered glass reflection plate (Figure 5)

3. Clean the ATMOS 41 body
   a. Scrub with light to medium pressure using a warm, damp cloth.

   b. Clean around posts and between crevices using a dry brush.

CAUTIONS

- **DO NOT** immerse the sensor in water.
- **DO NOT** touch the temperature sensor needle (Figure 11).

CAUTION: The temperature sensor needle lead wires are very delicate and can be easily damaged.

- Avoid more than light pressure on the sonic transducers (Figure 11).
- Be sure the sensor is level after cleaning.

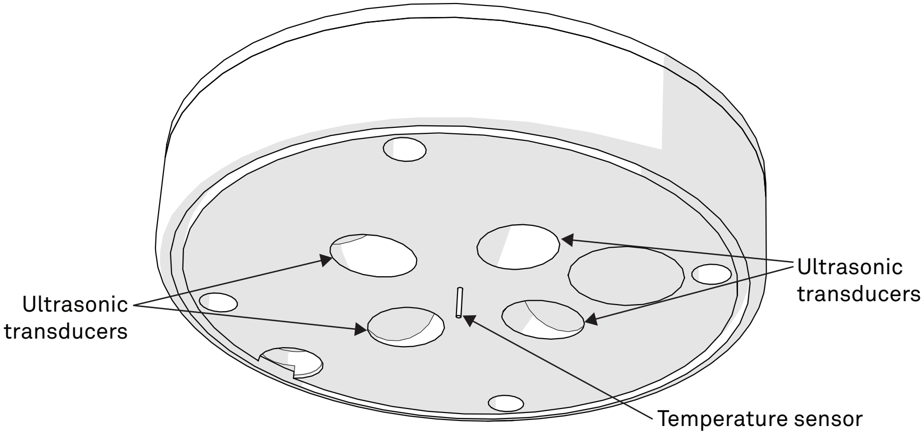


Figure 11 Temperature needle and ultrasonic transducers

NOTE: Do not allow water to enter the ultrasonic sensors (Figure 11). Water may corrode the metal parts inside the sensors and ruin them. Do not touch the temperature sensor when cleaning because it is very delicate and can be damaged if pushed into the ATMOS 41 body.

c. Check the downspout (Figure 12) for debris.

d. Observe the Teflon screen (Figure 13) to see if it is dirty.
   If the screen is dirty, it is best to replace it.

Contact Customer Support for a replacement Teflon screen.

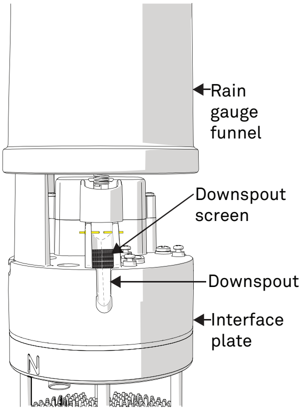


Figure 12 Downspout

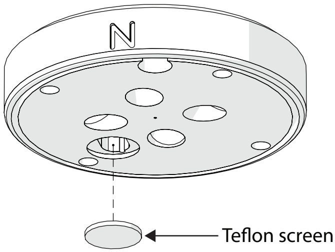


Figure 13 Teflon screen

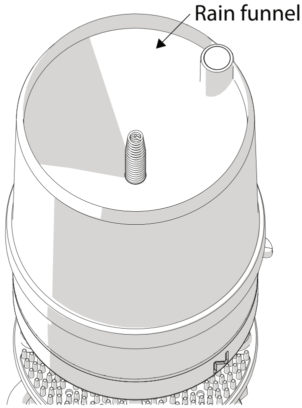


Figure 14 Rain funnel and pyranometer

4.4 TROUBLESHOOTING

Table 5 Troubleshooting the ATMOS 41

Problem	Possible Solutions
ATMOS 41 not responding	Check power to the sensor. Check sensor cable and 3.5-mm plug integrity. Try a different port on the data logger. Check data logger wiring to ensure the following connections: Brown—3.6 V to 15.0 V power supply Orange—digital out Bare—ground If sensor does not respond, use the ProCheck to make sure it is working satisfactorily.

Table 5 Troubleshooting the ATMOS 41 (continued)

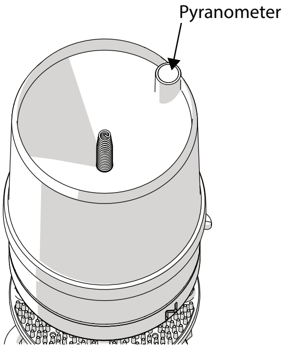
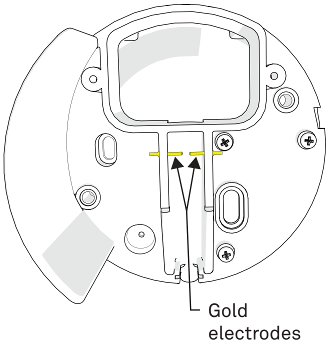
Problem	Possible Solutions
Not reading any rain	Remove any debris from rain gauge funnel. The ATMOS 41 must be within approximately ±2 degrees of dead level (0, 0) in both the X and Y directions to accurately measure rainfall. If not within this range, drops from the flared hole can miss the gold electrodes entirely. Use the internal level measurements that are available in the ATMOS 41 data stream to confirm that the ATMOS 41 is level. Gently twist the top of the weather station and remove the rain gauge funnel. **NOTE: BE CAREFUL TO UNPLUG THE PYRANOMETER CONNECTOR INSIDE THE FUNNEL BEFORE REMOVING THE FUNNEL COMPLETELY.** Check to make sure that there are no obvious problems and that the gold electrodes are aligned correctly Figure 16.  **Figure 15 Pyranometer**  **Figure 16 Gold electrodes**
Water not flowing through rain gauge	Check spring, screen, and the outflow to ensure there is no lodged debris.
No wind speed	Check anemometer pathway to make sure there is no debris blocking the path of the sonic transducer measurement (between transducers and acoustic mirror on base). Check the sonic transducers for water build-up; if there is moisture, take a dry cloth and dab it away. Check to see that the sintered glass plate (Figure 5) is not dirty. Clean by flushing with water and dry with a dry cloth (Section 4.3). Be sure the ATMOS 41 is level.
No temperature reading	Check the temperature needle to be sure it is not pushed in (pushing in the temperature sensor will break the thermistor wires and stop measurement). Do not to abuse the temperature sensor needle when cleaning, because its very delicate lead wires can be easily damaged.

Table 5 Troubleshooting the ATMOS 41 (continued)

Problem	Possible Solutions
No pyranometer reading	Carefully remove the rain funnel as described in Section 3.5. **NOTE: BE CAREFUL TO UNPLUG THE PYRANOMETER CONNECTOR INSIDE THE FUNNEL BEFORE FULLY REMOVING THE FUNNEL.** Make sure the pyranometer plug (Figure 15) is plugged in. If the pyranometer connect is accidentally damaged, contact Customer Support.

4.5 CUSTOMER SUPPORT

Customer service representatives are available for questions, problems, or feedback Monday through Friday, 7 am–5 pm Pacific time.

Email: support.environment@metergroup.com
sales.environment@metergroup.com

Phone: +1.509.332.5600

Fax: +1.509.332.5158

Website: metergroup.com

If contacting METER by email, please include the following information:

Name	Email address
Address	Instrument serial number
Phone	Description of the problem

NOTE: For ATMOS 41 All-in-One Weather Stations purchased through a distributor, please contact the distributor directly for assistance.

4.6 TERMS AND CONDITIONS

By using METER instruments and documentation, you agree to abide by the METER Group, Inc. USA Terms and Conditions. Please refer to metergroup.com/terms-conditions for details.

REFERENCES

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