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Surface Meteorological System (MET) Instrument Handbook

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ARM

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Acronyms and Abbreviations

AC	alternating current
AMF1	ARM Mobile Facility 1
AMF2	ARM Mobile Facility 2
AMF3	ARM Mobile Facility 3
ANX	Andenes, Norway (AMF1)
AOSMET	Aerosol Observing System Meteorological Sensor
ARM	Atmospheric Radiation Measurement
ASI	Ascension Island, South Atlantic Ocean (AMF1)
BNF	Bankhead National Forest, Alabama, United States (AMF3)
CMH	chilled mirror hygrothermometer
COR	Cordoba, Argentina (AMF1)
DQO	Data Quality Office
DQR	Data Quality Report
EF	Extended Facility
ENA	Eastern North Atlantic
GUC	Gunnison, Colorado, United States (AMF2)
KCG	Kennaook/Cape Grim, Tasmania, Australia (AMF2)
MAO	Manacapuru, Amazonas, Brazil (AMF1)
MET	surface meteorological system
NIM	Niamey, Niger (AMF1)
NSA	North Slope of Alaska
OLI	Oliktok Point
ORG	optical rain gauge
PGH	Ganges Valley, India (AMF1)
PWD	present weather gauge
PYE	Point Reyes, California, United States (AMF1)
QC	quality control
RH	relative humidity
RMS	root mean square
SGP	Southern Great Plains
TBRG	tipping bucket rain gauge
WMO	World Meteorological Organization

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1.0 Instrument Description

The surface meteorological system (MET) deployed by the U.S. Department of Energy Atmospheric Radiation Measurement (ARM) user facility consists of a set of instruments to record standard surface meteorological measurements: temperature, relative humidity, pressure, wind speed and direction, and precipitation. Most locations also include visibility and present weather measurements. Measurements are taken once a minute at standard heights, following World Meteorological Organization (WMO) guidelines (WMO 2008). Slight variations in instrumentation exist depending on site or mobile facility deployment.

1.1 Technical Specifications

All instrument specifications are as stated by the respective manufacturer in the operation manuals. The information below pertains to currently installed instrumentation. For historical instrument information, see Section 3.0.

1.1.1 Pressure

Vaisala PTB330 Barometer (all sites)

Range: 500-1100 hPa
Total accuracy: ± 0.15 hPa

1.1.2 Temperature and Relative Humidity

Vaisala HMP155 Humidity and Temperature Probe (AMF1, AMF2, AMF3-BNF, ENA, SGP)

Relative humidity range: 0-100%
Relative humidity accuracy (at -20-40°C): ± (1.0 + 0.008 x reading) % RH
Temperature range: -80-60°C
Temperature accuracy: ± (0.1 + 0.00167 x |temperature|) °C

Vaisala HMT337 Humidity and Temperature Transmitter (AMF3-OLI, NSA)

Relative humidity range: 0-100%
Relative humidity accuracy:
at 15-25°C: ± 1 % RH (at 0-90 % RH)
± 1.7 % RH (at 90-100 % RH)
at -20-40°C: ± (1.0 + 0.008 x reading) % RH
Temperature range: -70-180°C
Temperature accuracy: ± 0.1°C

RM Young 43502 Aspirated Radiation Shield (AMF1, AMF2, AMF3-BNF, ENA, SGP)
Radiation error: 0.2°C RMS at 1000 W/m^2 intensity

1.1.3 Wind Speed and Direction

RM Young 05103/05106 Wind Monitor (AMF1, AMF2, AMF3-BNF, ENA, SGP)

Wind speed range: 0-100 m/s
Wind speed accuracy: ± 0.3 m/s, or 1% of reading, whichever is greater
Wind direction range: 0°-360°
Wind direction accuracy: ± 3°

Vaisala WMT700 Ultrasonic Wind Sensor (AMF3-OLI, NSA)

Wind speed range: 0-75 m/s
Wind speed accuracy: ± 0.1 m/s or 2% of reading, whichever is greater
Wind direction range: 0-360°
Wind direction accuracy: ± 2°

1.1.4 Visibility and Present Weather

Vaisala PWD22 Present Weather Detector (all sites, except SGP EFs other than E13)

Visibility range: 0-20000 m
Visibility accuracy: ± 10% (at 10-10000 m)
± 20% (at 10000-20000 m)
Precipitation range:
Intensity: 0-999.99 mm
Amount: 0-99.99 mm
Snow: 0-999 mm
Precipitation accuracy: none listed

1.1.5 Precipitation

Novalynx 260-2500E-12 Tipping Bucket Rain Gauge (AMF1, AMF2, AMF3-BNF, ENA, SGP)

Precipitation accuracy: ± 1% (at 1 - 3 in/hr)
± 3% (at 0 – 6 in/hr)

Optical Scientific ORG-815-DS Optical Rain Gauge (AMF1, AMF2, AMF3-BNF, ENA, SGP-E13)

Precipitation intensity range: 0.1-500 mm/hr
Precipitation accumulation range: 0.001-999.999 mm
Precipitation accuracy: ± 5% accumulation
Snow intensity range*: 0.01-50 mm/hr, liquid equivalent
Snow Accumulation Range*: 0.001-999.999 mm, liquid equivalent
Snow accuracy*: ± 10%

*This instrument is not typically used for snow due to performance issues.

1.2 Instrument/Measurement Theory

1.2.1 Pressure

Vaisala PTB330 Barometer (all sites)

Vaisala PTB330 barometers measure atmospheric pressure using the Vaisala proprietary BAROCAP silicon capacitive absolute sensor. The barometer microprocessor adjusts for pressure linearity and temperature dependence. The barometer is located inside the electronics enclosure at a standard height of 1 meter. A silicon tube is used to route the pressure port of the barometer to an opening in the enclosure.

1.2.2 Temperature and Relative Humidity

Vaisala HMP155 Humidity and Temperature Probe (AMF1, AMF2, AMF3-BNF, ENA, SGP)

Vaisala HMP155 probes measure temperature and humidity by using a Pt100 resistive platinum sensor (temperature) and the Vaisala proprietary HUMICAP 180 capacitive thin film polymer sensor (humidity). The sensor is located inside an RM Young 43502 aspirated radiation shield mounted on a crossarm at a standard height of 2 meters.

Vaisala HMT337 Humidity and Temperature Transmitter (AMF3-OLI, NSA)

The Vaisala HMT337 is used to measure ambient temperature, relative humidity, and dew point by preventing saturation at high humidity. A warmed probe is heated when ambient conditions are above 95% humidity to keep the sensor above environmental temperature and prevent saturation. An additional probe measures ambient temperature. The actual relative humidity is calculated from the warmed probe relative humidity and temperature, and ambient temperature. The warmed probe is housed in a modified Vaisala HMT330MIK Meteorological Installation Kit, and the additional temperature probe is mounted in an RM Young 43408 aspirated radiation shield. The standard measurement height is 2 meters.

1.2.3 Wind Speed and Direction

RM Young 05103/05106 Wind Monitor (AMF1, AMF2, AMF3-BNF, ENA, SGP)

The RM Young 05103 and 05106 propeller anemometers measure wind speed by using a helicoid four-blade propeller. An AC sine wave signal is produced by the rotation of the propeller that is proportional to wind speed. A 10 kilo Ohm potentiometer transmits the vane position by producing an output voltage proportional to the wind direction when a precision excitation voltage is applied. The standard mounting height for the wind sensor is 10 meters.

Vaisala WMT700 Ultrasonic Wind Sensor (AMF3-OLI, NSA)

Vaisala WMT700 ultrasonic wind sensors output horizontal wind speed and direction by measuring the transit time for a pulse to travel between three transducers. There are no moving parts, which makes them ideal for climates where snow, ice, and frost can limit mechanical operation. The transducers (and sensor body, depending on model) are heated to prevent icing. The standard measurement height is 10 meters.

1.2.4 Visibility and Present Weather

Vaisala PWD22 Present Weather Detector (all sites, except SGP EFs other than E13)

The Vaisala PWD22 present weather detector senses current weather conditions and visibility using light-scattering principles and a Vaisala RAINCAP Rain Sensor capacitive device. Precipitation intensity (proportional to droplet volume) is calculated by analyzing the amplitude of rapid signal changes. The ratio of water equivalence to volume is used to determine precipitation type. At sites with extreme cold, a hood-heated option is used. The instrument is mounted on a tripod or crossarm at 2-3 meters.

1.2.5 Precipitation

Novalynx 260-2500E-12 Tipping Bucket Rain Gauge (AMF1, AMF2, AMF3-BNF, ENA, SGP)

The Novalynx 260-2500E-12 tipping bucket rain gauge measures precipitation. The electrically heated bucket collects precipitation in a 12”-diameter orifice that funnels to a magnetic reed switch. One tip at the switch equates to .254 mm precipitation. Frozen precipitation is melted using a thermostatically controlled heater. An Alter shield is used to increase the reliability of rain collection in high winds.

Optical Scientific ORG-815-DS Optical Rain Gauge (AMF1, AMF2, AMF3-BNF, ENA, SGP-E13)

The Optical Scientific ORG-815-DS optical rain gauge measures precipitation rate. An infrared optical beam is transmitted between two lenses. Scintillation intensity within the sample volume is translated to precipitation rate and type using internal algorithms. The lenses are heated to reduce dew, frost, and snow buildup. The instrument is mounted on a tripod or crossarm at 2-3 meters.

2.0 Data

2.1 Data Description

The MET system collects raw data once a minute that is then processed into a daily quality-flagged file available for download. The naming convention for MET data is [site]met[facility].b1. Information regarding variables and data quality flags can be found in the file headers.

2.2 Data Quality and Uncertainty

Data Quality Reports (DQRs) are provided with MET data downloads for specified times and variables where data quality may have been compromised. Examples include (but are not limited to) instrument problems, power outages, calibration issues, known environmental events that impacted data collection, etc. These events are not necessarily flagged by the automated quality control variables, so we suggest viewing these reports before using data. In most cases, suggestions for use are included in the report and discretion can be used on how to proceed.

2.3 Examples of Data

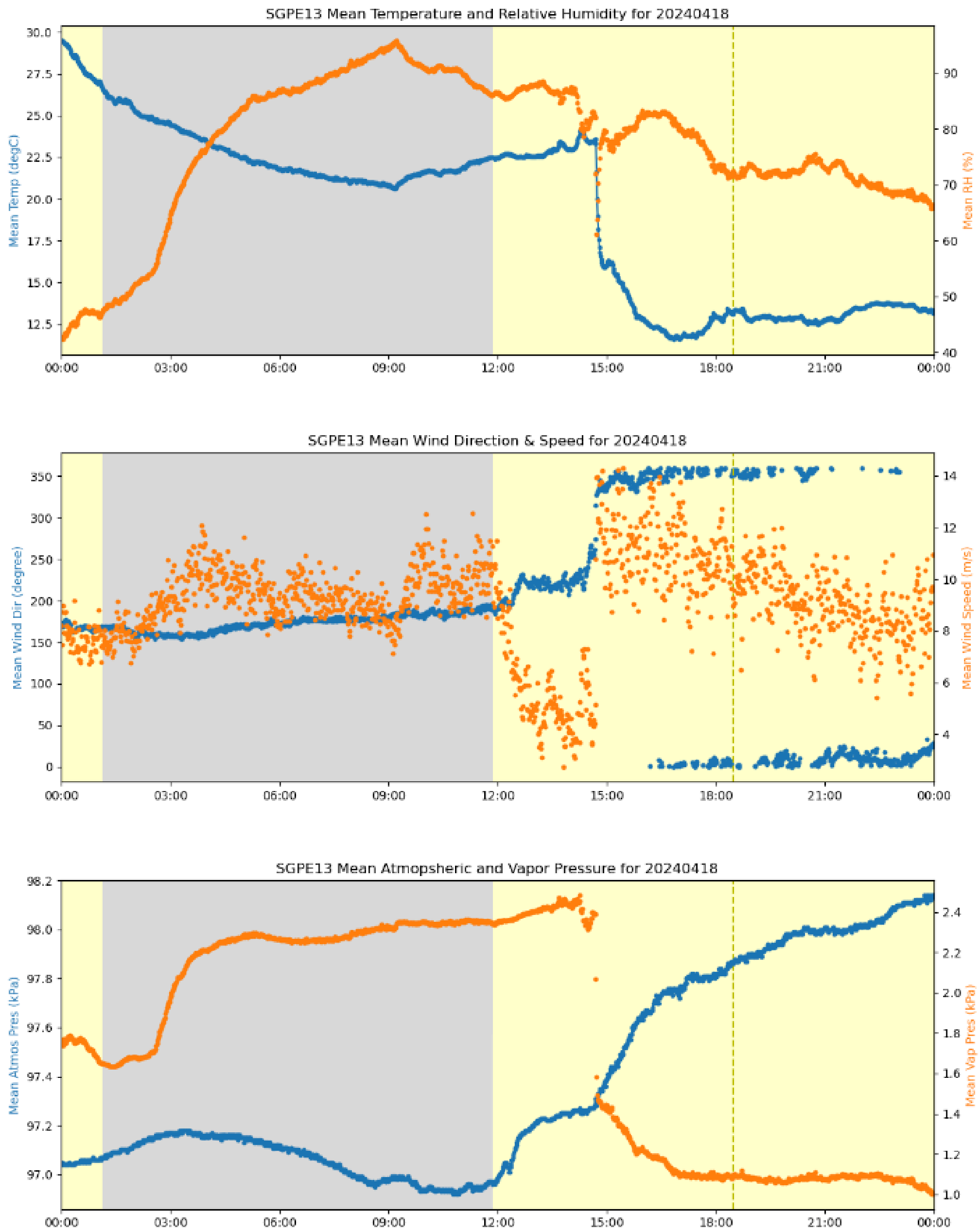

Figure 1. Meteogram provided by the Data Quality Office (DQO) showing standard MET data.

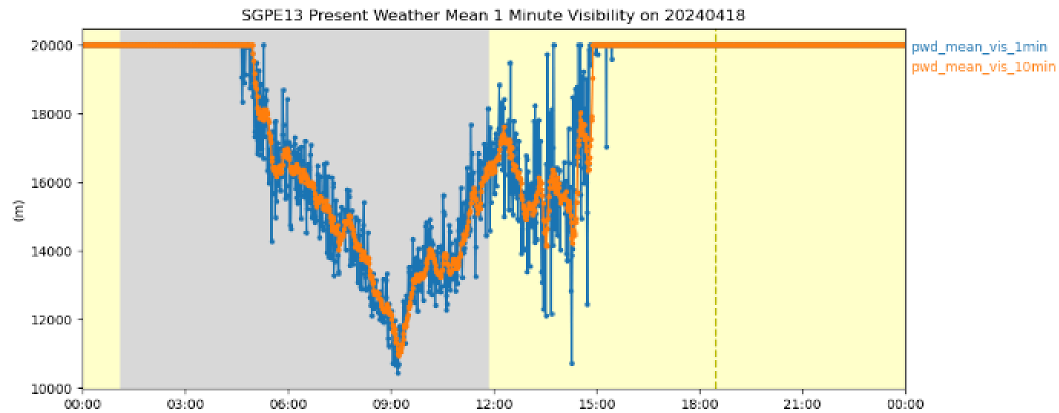

Figure 2. MET visibility data provided by the DQO.

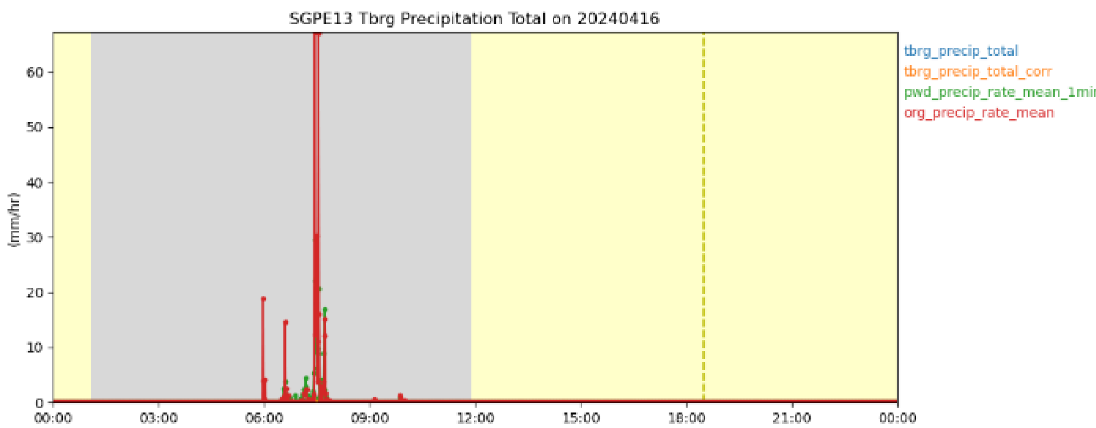

Figure 3. MET precipitation data provided by the DQO.

3.0 Historical Background

The MET system has occasionally undergone instrument changes to keep up with siting limitations, changing technology, and local climatology influences. The core measurements remain the same but may vary slightly by site or year. Major instrument changes or differences in standard siting are noted below.

3.1 AMF1

During the PYE and NIM deployments, the wind sensor was mounted at 3m instead of the standard 10m height.

During the COR deployment, the wind sensor was mounted at 12m instead of the standard 10m height.

The optical rain gauge and present weather detector were moved to separate tripod mountings from the 10m tower beginning with the PGH deployment in 2011.

The barometer inlet was routed outside the electronics enclosure beginning with the ASI deployment in 2016.

The barometer was upgraded from Vaisala PTB220 to PTB330 beginning with the COR deployment in 2018.

The temperature and humidity sensor was upgraded from Vaisala HMP45D to HMP155D beginning with the COR deployment in 2018.

A tipping bucket rain gauge was added to the AMF1 MET datastream beginning with ANX in 2019. For the COR, ASI, and MAO deployments, tipping bucket data was in a separate [site]raintb[facility].b1 datastream.

3.2 AMF2

A tipping bucket rain gauge was added to the AMF2 MET datastream for land-based deployments beginning with the GUC deployment in 2021.

The wind sensor was changed from ultrasonic Vaisala WS425F/G to mechanical RM Young 05106 beginning with the KCG deployment in 2024. Vaisala heated ultrasonic WMT700 will be used for future cold weather deployments when necessary.

3.3 AMF3

The barometer inlet was routed outside the electronics enclosure in mid-2016 during the OLI deployment.

The ultrasonic wind sensor was upgraded from Vaisala WS425 to WMT700 in late 2017 during the OLI deployment.

The chilled mirror hygrometer (TSL-1088) was removed in late 2019 during the OLI deployment due to poor performance in arctic conditions.

During the BNF deployment, many instrument models were changed or added to be consistent with non-arctic MET deployments. The temperature and humidity sensor was changed from Vaisala HMT337 to HMP155. The wind sensor was changed from Vaisala WMT700 to RM Young 05103. Both an optical and a tipping bucket rain gauge were added for this deployment.

3.4 ENA

The wind sensor was mounted at 6m until February 24, 2014. It has since been mounted at the standard 10m.

The optical rain gauge and present weather detector were moved to separate tripod mountings from the 10m tower in early 2014.

The barometer inlet was routed outside the electronics enclosure in mid-2016.

3.5 NSA

The optical rain gauge was removed from the NSA MET datastream in late 2003 due to poor performance in arctic conditions.

The wind sensor was upgraded from an unheated mechanical Vaisala WAA251/WAV151 to a heated ultrasonic WS425 in late 2008, and to the WMT700 in late 2017.

The temperature and humidity sensors were upgraded from Vaisala HMP45D to HMT337 in late 2008.

The present weather detector was upgraded from Vaisala FD12P to a heated PWD22 in late 2010.

The barometer inlet was routed outside the electronics enclosure in late 2015.

The barometer was upgraded from Vaisala PTB201A to PTB330 in late 2017.

The chilled mirror hygrometer (TSL-1088) was removed in late 2019 due to poor performance in arctic conditions.

3.6 SGP

The temperature and humidity sensors at all SGP sites were upgraded from Vaisala HMP35C to HMP45C in 2007, and from HMP45C to HMP155D in late 2017 (early 2018 at E13). All sites except E13 were non-aspirated until late 2017.

The barometers were upgraded from Vaisala PTB201 to PTB330 in late 2012.

The barometer inlets were routed outside the electronics enclosure in late 2015.

The optical rain gauge migrated to the MET datastream in 2016. Prior to 2016 the optical rain gauge was in a separate sgporgC1.b1 datastream.

4.0 Maintenance Plan

Site operations staff perform periodic checks of the MET system to identify problems and maintain integrity of data.

Daily: Live data are checked on a remote display to verify communications are functioning, data are updating, and no errors, dropouts, or flatlines have occurred.

Biweekly: Instruments, cabling, mountings, and electronics are inspected for physical damage, obstructions, and general cleanliness. A tip test is performed on the tipping bucket rain gauges to ensure the mechanism will register precipitation. If any problems are noted, the mentor is notified so corrective action can be taken and affected data are reviewed.

5.0 Calibration Plan

5.1 Pressure

Vaisala PTB330 Barometer (all sites)

- **Frequency:** Every 6 months. Also checked at installation and removal.
- **Procedure:** The barometer is field-checked using transfer standard equipment. If it is out of tolerance, the instrument is replaced and sent back to the manufacturer for calibration.

5.2 Temperature and Relative Humidity

Vaisala HMP155 Humidity and Temperature Probe (AMF1, AMF2, ENA, SGP)

- **Frequency:** Every 6 months. Also checked at installation and removal.
- **Procedure:** The temperature and relative humidity are field-checked using transfer standard equipment. If one or both are out of tolerance, the instrument is replaced and sent back to the manufacturer for calibration.

Vaisala HMT337 Humidity and Temperature Transmitter (NSA)

- **Frequency:** Yearly. Also checked at installation.
- **Procedure:** Instrument is replaced with one calibrated at the manufacturer. Prior to installation, the temperature and relative humidity are field-checked using transfer standard equipment.

5.3 Wind Speed and Direction

RM Young 05103/05106 Wind Monitor (AMF1, AMF2, ENA, SGP)

- **Frequency:** Every 6 months.
- **Procedure:** The wind speed and direction are checked using the field calibration kit. If one or both are out of tolerance, the instrument is adjusted or replaced.

Vaisala WMT700 Ultrasonic Wind Sensor (AMF3, NSA)

- **Frequency:** None. Calibration not required.

5.4 Visibility and Present Weather

Vaisala PWD22 Present Weather Detector (all sites, except SGP EFs other than E13)

- **Frequency:** Yearly. Also checked at installation.
- **Procedure:** The PWD is checked using the field calibration kit. If it is out of tolerance, the instrument is adjusted or replaced.

5.5 Precipitation

Novalynx 260-2500E-12 Tipping Bucket Rain Gauge (AMF1, SGP)

- **Frequency:** Every 6 months. Also checked at installation.*
- **Procedure:** A known amount of water is passed through the rain gauge. If the number of tips registered is not within tolerance, the instrument is adjusted or replaced.

*Prior to each installation, the rain gauge is dynamically calibrated by comparing known rain rates to those measured by the gauge. Calibration coefficients are calculated and applied in the data logger program. Both raw and corrected data are maintained in the MET data files.

Optical Scientific ORG-815-DS Optical Rain Gauge (AMF1, AMF2, ENA, SGP E13 only)

- **Frequency:** None. Calibration not required.

6.0 User Notes and Known Issues

When the HMP45 temperature and relative humidity sensors were installed at SGP (approximately 2007-2018) a cold bias in high humidity was found to exist. There also may be drift issues with relative humidity readings. A technical report outlining these issues can be found here: https://www.arm.gov/publications/tech_reports/doe-sc-arm-tr-192.pdf

At sites where ultrasonic wind sensors are installed, there are occasionally wind data dropouts or spikes due to transducer interference. This typically happens in times of heavy wet snow or ice conditions. Bird interference can also cause occasional dropouts.

The optical rain gauge is not suited for solid precipitation measurements. In times of snow, the heated tipping bucket or present weather detector precipitation data may provide more accurate precipitation measurements.

The optical rain gauges are also prone to overestimating precipitation, especially in light or transitional rain conditions. They can be sensitive to fog or high humidity. Such cases may be reported as small precipitation events. It is suggested that precipitation data be cross-referenced with other sensors (TBRG, PWD, etc.) to verify validity.

When the chilled mirror hygrometers were installed at NSA and AMF3-Oliktok, a daily self-check of the mirror occurred that is evident in the relative humidity and dew point data as a spike/drop (Figure 4). On occasion, the mirror may take more than the typical few minutes to reach normal operating temperature (Figure 5). In these instances, it is best to compare with the HMT337 data to verify readings are similar, though usually obvious on a time series plot.

The present weather detectors occasionally encounter communication disruptions that momentarily cause the sensor serial number to report as rain rate (Figure 6). These values are flagged by QC and should be removed from study.

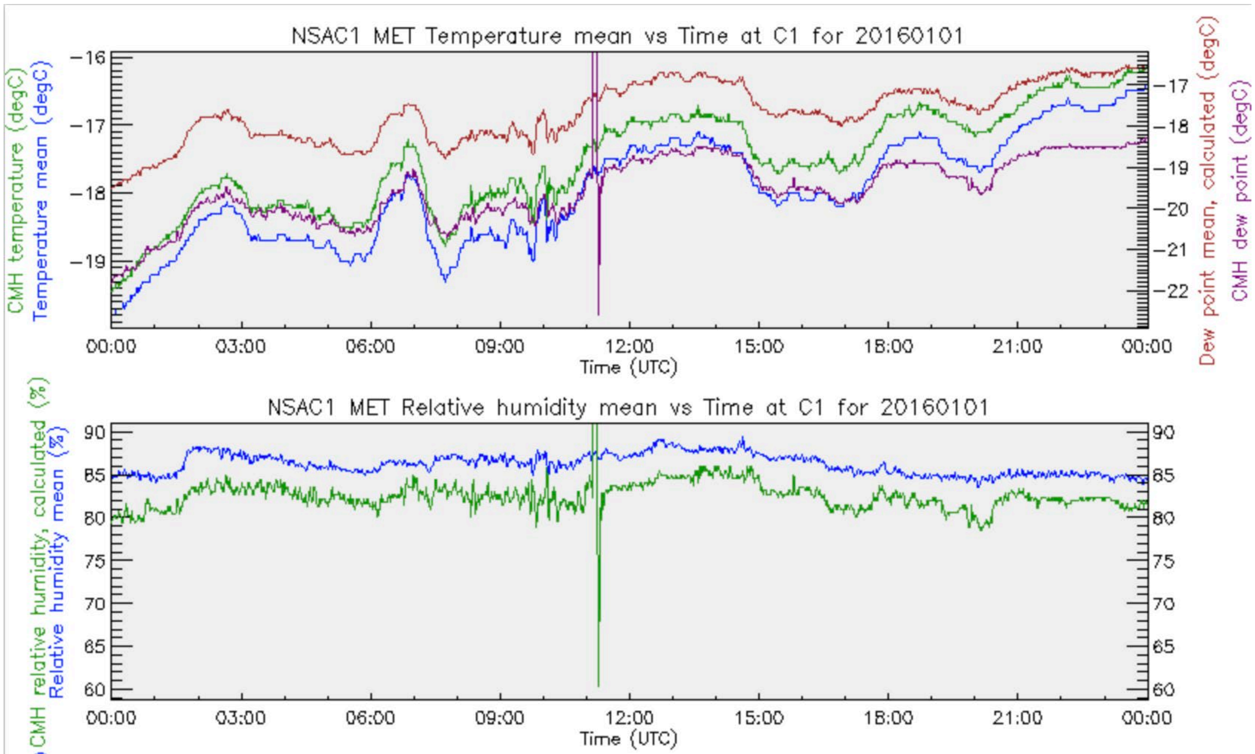

Figure 4. CMH daily self-check provided by the DQO.

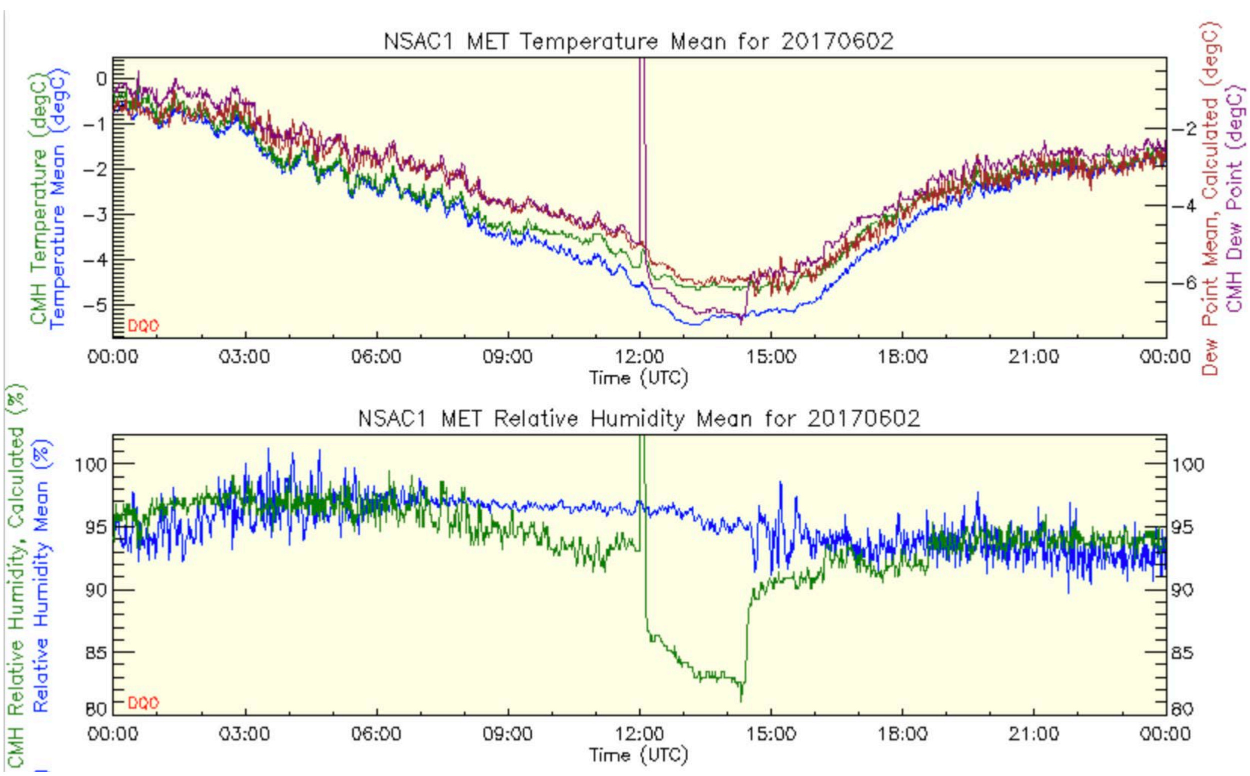

Figure 5. CMH daily self-check delayed operating temperature provided by the DQO.

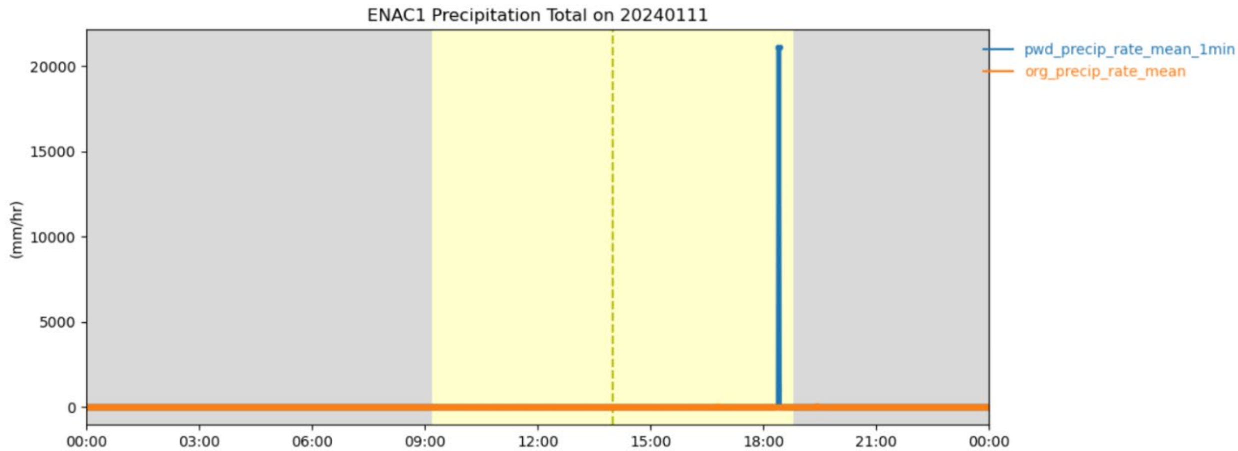

Figure 6. PWD communication interruption provided by the DQO.

7.0 Frequently Asked Questions

Q: Are pressure measurements corrected for sea level?

A: No. Pressure measurements are taken at 1m above ground-level (altitude) of the site and are not corrected for sea level. This is commonly referred to as the station pressure.

Q: Are wind measurements taken at standard meteorological height (10m)?

A: Yes, unless otherwise noted in Section 6.0.

Q: Are vapor pressure measurements corrected for over water/ice?

A: Yes. When calculating vapor pressure, the saturation vapor pressure equation for water/ice is used depending on ambient temperature. If the ambient temperature is below 0°C, the saturation vapor pressure over ice equation is used. The resulting saturation vapor pressure is then used with relative humidity to calculate the vapor pressure.

Q: At sites with multiple precipitation measurements, which is best to use?

A: It is best to cross-reference precipitation values between the TBRG and the ORG, when possible. The PWD precipitation data should only be used as a supplemental means of verification unless all other precipitation data are unavailable.

Q: What is the difference between MET and AOSMET data?

A: Primary support for surface meteorological data resides in the MET datastream. The AOSMET data are intended to be used specifically for hyper-local meteorological data relevant to the aerosol stack. On occasion, data from the AOSMET may be suggested as a secondary data source when the quality of MET data are compromised.

8.0 Citable References

Kyrouac, J, and A Theisen. 2018. Biases of the MET Temperature and Relative Humidity Sensor (HMP45) Report. ARM Climate Research Facility. DOE/SC-ARM-TR-192, https://doi.org/10.2172/1366737

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