# DRI STANDARD OPERATING PROCEDURE

## Performance Audit of Meteorological Instruments

**DRI SOP #4-104.2**


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# 1.0 GENERAL DISCUSSION

## 1.1 Purpose of Procedure

This document provides procedures for the performance audits of meteorological instruments operated by Atmospheric Research and Analysis (ARA), Inc. at the Southeastern Aerosol Research Characterization (SEARCH) study sites and covers the following continuous meteorological monitoring instruments:

- Wind speed
- Wind direction
- Ambient temperature
- Relative humidity
- Solar radiation
- Barometric pressure
- Precipitation gauge

This procedure will be followed by all audit personnel of the Division of Atmospheric Science of the Desert Research Institute.

## 1.2 Measurement Principles

### 1.2.1 Wind Speed

The wind speed sensor measures speed with a propeller that turns as air moves by the sensor. The propeller turns a magnet that generates an a.c. sine wave with frequency proportional to wind speed. The data acquisition system (DAS) converts the frequency to wind speed.

The audit consists of a torque test to determine the required torque to start the propeller moving and the application of several known constant rotation rates to the propeller shaft to compare the DAS outputs to the wind speed versus frequency expression for the sensor.

### 1.2.2 Wind Direction

The wind direction sensor measures direction with a wind vane that aligns itself along the wind. The vane is coupled to a potentiometer that when given an excitation voltage by the DAS returns a voltage that is proportional to the angular direction of the vane.

The audit consists of first measuring the bearing to a particular fixed item on the meteorological tower with a magnetic compass to determine the orientation of the sensor or tower relative to magnetic and true North. Then the sensor is placed on a vane angle fixture and held at several directions, including aligned along the fixed item previously sighted with the compass. The wind directions output by the DAS are compared to the audit angles relative to true North.

1.2.3 Ambient Temperature

Ambient temperature is measured with a thermistor or a platinum resistance thermometer that when given an excitation voltage returns a voltage that is proportional to temperature. The probe is housed in an aspirated radiation shield.

The audit consists of operating a thermistor or platinum resistance thermometer near the site sensor for the period of the audit. The audit sensor is housed in an aspirated radiation shield. The site temperature readings collected and averaged by the DAS are compared to the audit temperature readings collected and averaged by the audit DAS.

1.2.4 Relative Humidity

Relative humidity is measured by a device that changes its capacitance as it absorbs water vapor in proportion to the relative humidity. The DAS supplies an excitation voltage to the sensor and receives a voltage that is proportional to the relative humidity. The probe is housed in an aspirated radiation shield.

The audit consists of operating a capacitive relative humidity device near the site sensor for the period of the auditor. The audit sensor is housed in an aspirated radiation shield. The site relative humidity readings collected and averaged by the DAS are compared to the audit relative humidity readings collected and averaged by the audit DAS.

1.2.5 Solar Radiation

Solar radiation is measured by a pyranometer containing a photosensitive silicon sensor that outputs a signal that is proportional solar radiation. The sensor is exposed to light from the entire hemisphere above a horizontal plane.

The audit consists of operating a precision spectral pyranometer near the site sensor for the period of the audit. The site solar radiation readings collected and averaged by the DAS are compared to the audit solar radiation readings collected and averaged by the audit DAS.

1.2.6 Barometric Pressure

Barometric pressure is measured with a solid state device that when supplied with an excitation voltage by the DAS returns a voltage that is proportional to the barometric pressure.

The audit consists of operating a barometric pressure sensor near the site sensor for the period of the audit. The site barometric pressure readings collected and averaged by the site DAS are compared to the audit barometric pressure readings collected and averaged by the audit DAS.

1.2.7 Precipitation Gauge

Precipitation is measured by a tipping bucket collector. Precipitation is gathered by a collector that has a diameter of approximately 15 cm. Water is funneled to one side of a two-sided bucket until it fills and the bucket tips. Water is then funneled to the other side to the bucket. Each tip represents 0.01 inch (0.254 mm) of precipitation. Each tip generates a pulse that is accumulated by the DAS to record the amount of rain in a particular period of time.

The audit consists of introducing water to the gauge in a controlled manner from a buret to measure the amount of water necessary for each bucket to fill and tip. Several series of up to 10 tips are generated. The amount of water required for each tip is determined and compared to the gauge specifications. The number of tips recorded by the DAS is compared to the actual number of tips observed by the auditor.

1.3 Measurement Interference

1.3.1 Wind Speed

The wind speed versus frequency relation has been developed by the manufacturer for propellers of particular specifications. The relationship will not be correct if the propeller does not have the proper specifications.

1.3.2 Wind Direction

There is some error in sighting the fixed target on the wind sensor or meteorological tower. When the meteorological tower is lowered the orientation of the sensor may change if the tower twists. While the magnetic declination changes slowly, a current value should be used. There may be a magnetic anomaly near the site or a metallic object near the compass that would affect the reading.

1.3.3 Ambient Temperature

Small differences in the locations on the tower for the audit and site sensors have a slight affect on the comparisons.

1.3.4 Relative Humidity

Small differences in the locations on the tower for the audit and site sensors have a slight affect on the comparisons.

1.3.5 Solar Radiation

Siting difficulties can result in different exposures for the audit sensor and site sensor. Differing reflections or shadows from nearby objects will change the readings for the audit and site sensors.

1.3.6 Barometric Pressure

Differences in the locations for the audit and site sensors have a slight affect on the comparisons.

1.3.7 Precipitation Gauge

A high rate of introducing the water to the gauge will result in a smaller amount of water required for a tip than would be found for actual precipitation.

1.4 Ranges and Typical Values

Ranges and typical values for meteorological parameters are as follows:

| Parameter | Sensor Range | Audit Range |
|---|---|---|
| Wind speed | 0.0 to 60 m/s | 0 to 18 m/s |
| Wind direction | 0 to 360° | 0 to 360° |
| Ambient temperature | -40 to 60 °C | -5 to 40 °C |
| Relative humidity | 0 to 100% | 30 to 100% |
| Solar radiation | 0 to 1500 w/m$^2$ | 0 to 1000 w/m$^2$ |
| Barometric pressure | 800 to 1060 mb | 950 to 1020 mb |
| Precipitation | 4.7 ml/tip | 4.5 to 5.0 ml/tip |

1.5 Lower Quantifiable Limits, Precision and Accuracy

The following table lists the lower quantifiable limits, precision, and accuracy of the audit measurements.

| Parameter | Lower Quantifiable Limit | Precision | Accuracy |
|---|---|---|---|
| Wind Speed | 0.3 m/s | ±1.5% or ±0.11 m/s | ±1.5% or ±0.11 m/s |
| Wind Direction | N/A | ±5° | ±5° |
| Temperature | N/A | ±0.4 °C | ±0.4 °C |
| Relative Humidity | 0% | ±5% | ±5% |
| Solar radiation | 1 $w/m^2$ | 10 $w/m^2$ | 10 $w/m^2$ |
| Barometric pressure | N/A | 1 mb | 1 mb |
| Precipitation | 0.254 mm | ±0.2 ml/10 tips | ±0.1 ml/50 ml |

1.6 Audit Criteria

Audit criteria quantify the results of the performance audits of the meteorological instruments. The audit results that exceed the criteria should be viewed as indicators of potential problems that require additional investigation by the auditor and the site operator. The following criteria for the meteorological sensors have been derived from U.S. EPA (1989):

| Parameter | Criteria |
|---|---|
| Wind Speed | ±0.25 m/s for WS ≤ 5.0 m/s<br>±5% for WS > 5.0 m/s |
| Wind Direction | ±5 degrees |
| Temperature | ±1 °C |
| Relative Humidity | ±5% |
| Solar Radiation | ±70 $w/m^2$ (±0.1 Ly/min) |
| Barometric Pressure | ±5 mb |
| Precipitation gauge | ±0.25 ml/tip |
| | ±1 tip in 10 tips |

## 1.7 Personnel Responsibilities

The Field Auditors should read and understand the entire standard operating procedure prior to conducting a performance audit. Familiarity with the operation of the sampling equipment and the audit equipment is necessary for valid measurements. In addition the Field Auditor generates a preliminary report of the audit results at the time of the audit to be presented to the site operator.

It is the responsibility of the Audit Supervisor to ensure the audit procedures are properly followed, to examine and document all documentation, to arrange for maintenance and repair of audit equipment, to maintain the supplies necessary to insure uninterrupted measurements, and to generate a report summarizing the audit results.

## 1.8 Definitions

The following terms are used in this document:

| | |
|---|---|
| Performance audit: | Comparison of instrument response to audit standards. |
| Audit standards: | Standards provided by auditor for comparison. |

## 1.9 Related Procedures

DRI SOP #4-209.1: Calibration of Pressure Transfer Standard
DRI SOP #4-210.1: Calibration of Temperature Transfer Standard
DRI SOP #4-211.1: Calibration of Relative Humidity Transfer Standard

## 2.0 APPARATUS, INSTRUMENTATION, REAGENTS AND FORMS

### 2.1 Apparatus and Instrumentation

#### 2.1.1 Description

| | |
|---|---|
| Wind Speed: | R.M. Young Anemometer Drive, 0-10,000 RPM, Model 18801 |
| | R.M. Young Anemometer Drive, 0-1,000 RPM, Model 18831 |
| | R.M. Young Propeller Torque Disk, Model 18310 |
| Wind Direction: | Brunton Magnetic Compass, Model Pocket Transit |
| | Brunton Tripod, Model 3051 |
| | R.M. Young Vane Angle Fixture, Model 18212 |
| | R.M. Young Vane Torque Gauge, Model 18310 |
| Temperature: | Campbell Scientific, Inc., Temperature Probe, Model 107 |
| | Vaisala T/RH probe, Model HMP45C |
| | WeatherMeasure Aspirated Radiation Shield, Model 8152-A |
| | Vaisala T/RH probe, Model CS500 |
| | R.M. Young Gill Aspirated Radiation Shield, Model 43408 |
| Relative Humidity: | Vaisala T/RH probe, Model HMP45C |
| | WeatherMeasure Aspirated Radiation Shield, Model 8152-A |
| | Vaisala T/RH probe, Model CS500 |
| | R.M. Young Gill Aspirated Radiation Shield, Model 43408 |
| Solar Radiation: | Eppley Precision Spectral Pyranometer, Model PSP |
| Pressure: | Vaisala Pressure Transducer, Model PTB101B |
| Precipitation Gauge: | Buret, Model 100 ml |

Data Acquisition System for Temperature, Relative Humidity, Solar Radiation, and Pressure: Campbell Science, Inc., Data Logger, Model 21X.

#### 2.1.2 Maintenance

| | |
|---|---|
| Wind Speed: | Drive batteries are rechargeable and will eventually require replacement. The tubing to connect the drive to the anemometer should be inspected to see that it is intact without cracks. The torque wheel should be inspected to see that it is not warped or cracked. |
| Wind Direction: | The compass should be inspected to see that the needle stand is straight and that the mirror is not cracked. The string on the torque gauge |
| T/RH: | The motor on the aspirator should be inspected before each audit to see that it is operational and that all wires are properly connected. |

| | |
|---|---|
| | The cover on the probe should be inspected for cleanliness and replaced if visibly dirty. |
| Solar Radiation: | The glass cover on the pyranometer should be wiped with a soft cloth before deployment. The color of the silica gel in the drying chamber should be checked before deployment and replaced if it has lost its blue color. |
| Pressure: | The open tube on the pressure transducer should be inspected to see that it is not blocked. The wires to the sensor should be inspected to see that they are intact. |
| Precipitation Gauge: | The buret tip should be inspected to see that it is not cracked or broken. The buret tube should be inspected for being out of round or bent. |
| DAS: | The batteries of the DAS are rechargeable and need to be charged before use. They should be replaced if they do not hold a charge. The enclosure for the DAS should be checked to see that its seal is intact and that the connectors are not damaged. |

2.2 Spare Parts

| | |
|---|---|
| Wind Speed: | Extra tubing for connecting the drive to the anemometer. Extra screws for the torque wheel. |
| Wind Direction: | String for the torque gauge. |
| T/RH: | A spare motor for the aspirator. A spare cover for the probe. |
| Solar Radiation: | Silica gel. |
| Pressure: | Wire and connector for connection to DAS. |
| Precipitation Gauge: | Spare tip. |
| DAS: | Spare batteries. |

2.3 Forms

The audits are documented in an Excel workbook with a worksheet for each of the audited instruments. The raw audit inputs are recorded in a log book and transcribed to the worksheets.

The audit forms for the meteorological sensors are shown in the following Figures. These are picture copies of the electronic worksheets.

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# WIND SPEED AUDIT RECORD

REV 08/01

Network : SEARCH
Auditor :
Operator : ARA

Site Name :
Site Code :
AIRS # : NA

Date :
Start Time : EST/CST
End : EST/CST

**Site Instrument Data:**

Manufacturer : RM Young
Model No. : Wind Monitor AQ
Sensor S/N :
Sensor Type : AC generator
Propellor Type : Carbon Fiber
Propellor S/N :
Chopper Holes : NA

Sensor Range min : 0.0 max : 50.0 mps
Instrument min : 0.000 max : 1.000 VDC
Chart Recorder min : 0.0 max : 100.0 %

DAS: Primary : ARA
DAS Channel : WS
Chart Recorder : NA

RPM Multipier : 0.00512
Offset : 0.00

| | | |
|---|---|---|
| Carbon Fiber | 0.00512 | S/N 53404 and greater |
| EPS | 0.00500 | S/N 72863 and greater |
| Both | 0.00490 | Earlier S/N |

**Audit Instrument Information:**

Manufacturer : RM Young
Model No. : 18801
Serial No. : NA

Signal generator : NA
Frequency Counter : NA
Oscilloscope : NA

**Audit Results**

| Audit Input RPM | Audit Input mps | Sensor Response DAS mps | Sensor Response Corrected mps | Difference DAS | Difference Corrected | Units |
|---|---|---|---|---|---|---|
| 0 | 0.00 | | | | | m/s |
| 323 | 1.65 | | | | | m/s |
| 600 | 3.07 | | | | | m/s |
| 900 | 4.61 | | | | | m/s |
| 1200 | 6.14 | | | | | % |
| 1800 | 9.22 | | | | | % |
| 3600 | 18.43 | | | | | % |

| Zero | DAS | Corrected |
|---|---|---|
| Slope | | |
| Intercept | | |
| Correlation | | |

| | | |
|---|---|---|
| < 5 m/s: difference in m/s | | |
| Average | | |
| Std Dev | | |
| > 5 m/s: difference in % | | |
| Average | | |
| Std Dev | | |

Comments: ______________________________

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## WIND DIRECTION AUDIT RECORD

REV 08/01

| | | | | | |
|---|---|---|---|---|---|
| Network : | SEARCH | Site Name : | | Date : | |
| Auditor : | | Site Code : | | Start Time : | EST/CST |
| Operator : | ARA | AIRS # : | NA | End : | EST/CST |

**Site Instrument Data:**

| | | | | |
|---|---|---|---|---|
| Manufacturer : RM Young | Sensor Range | min : 0.0 | max : 360.0 | deg |
| Model No. : Wind Monitor AQ | Instrument | min : 0.000 | max : 5.000 | VDC |
| Sensor S/N : | Chart Recorder | min : 0.0 | max : 100.0 | % |

Sensor Type : Potentiometer
DAS: Primary : ARA
DAS Channel : WD
Chart Recorder : NA

**Audit Instrument Information:**

Compass Mfg : Brunton
Model : NA
Serial No. :
Compass Wheel: RM Young

Target Directions

| Sensor orientation Description | Bearing Mag. | Bearing Declin. | Bearing True |
|---|---|---|---|
| Sight pipe from north - 1 | | | |
| Sight pipe from north - 2 | | | |
| Average | | | |

**Audit Results**

Tail lined with pipe

| Wheel Deg | Difference from True Bearing Deg | DAS deg |
|---|---|---|
| | | |

| Audit: Wheel Input Deg | Audit: Relative True North Deg | Sensor Response DAS deg | Difference: Relative Wheel deg | Difference: Relative True North deg |
|---|---|---|---|---|
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| | | Average | | |
| | | Std Dev | | |
| | | Slope | | |
| | | Intercept | | |
| | | Correlation | | |

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**TEMPERATURE AUDIT RECORD**

**REV 08/01**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Network : | | Site Name : | | Date : | | |
| Auditor : | | Site Code : | | Start Time : | | EST/CST |
| Operator : | | AIRS # : NA | | End : | | EST/CST |

**Site Instrument Data:**

Manufacturer : RM Young
Model No. : Aspirated
Sensor S/N :
Sensor Type : Thermistor
DAS: Primary : ARA
DAS Channel : Temp
Chart Recorder : NA

| | min | max | |
|---|---|---|---|
| Sensor Range | -50.00 | 50.00 | deg C |
| Instrument | 0.000 | 5.000 | VDC |
| Chart Recorder | 0 | 100 | % |

**Audit Instrument Information:**

Thermometer Mfg :
Model :
Thermometer ID :

Collocated Sensors:
Start: End:

**Audit Results**

| Date | Start Time | Audit | Site | Diff. | Date | Start Time | Audit | Site | Diff. |
|---|---|---|---|---|---|---|---|---|---|
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| | Audit | Site | Diff. |
|---|---|---|---|
| Average : | | | |
| Std. Dev. | | | |
| Max : | | | |
| Min : | | | |
| Number: | | | |

Comments: ____________________

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**RELATIVE HUMIDITY AUDIT** REV 08/01

Network : SEARCH
Auditor :
Operator : ARA

Site Name :
Site Code :
AIRS # : NA

Date :
Start Time : EST/CST
End : EST/CST

**Site Instrument Data:**

Manufacturer : RM Young
Model No. : Humitter
Sensor S/N :
Sensor Type : NA
DAS: Primary : ARA
DAS Channel : RH
Chart Recorder : NA

Sensor Range min : 0.00 max : 100.00 %
Instrument min : 0.000 max : 1.000 VDC
Chart Recorder min : 0.0 max : 100.0 %

**Audit Instrument Information:**

RH Mfg :
Model :
Serial No. :
Therm. ID :

Collocated Sensors:
Start: End:

**Audit Results**

| Date | Start Time | Audit | Site | Diff. | Date | Start Time | Audit | Site | Diff. |
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| | Audit | Site | Diff. |
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| Average : | | | |
| Std. Dev. | | | |
| Max : | | | |
| Min : | | | |
| Number: | | | |

Comments:

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## SOLAR RADIATION AUDIT RECORD

REV 08/01

| | | | | | |
|---|---|---|---|---|---|
| Network : | SEARCH | Site Name : | | Date : | |
| Auditor : | | Site Code : | | Start Time : | EST/CST |
| Operator : | ARA | AIRS # : | NA | End : | EST/CST |

**Site Instrument Data:**

| | | | | |
|---|---|---|---|---|
| Manufacturer : Li-Cor Inc. | Sensor Range | min : 0.00 | max : 2.50 | kw/m2 |
| Model No. : Pyranometer | Instrument | min : 0.000 | max : 5.000 | VDC |
| Sensor S/N : | Chart | min : 0.0 | max : 100.0 | % |

Sensor Type : Silicon Pyranometer
DAS: Primary : ARA
DAS Channel : Solar
Chart Recorder : NA

**Audit Instrument Information:**

Radiometer Mfg :
Model :
Serial No. :

Collocated Sensors:
Start: End:

**Audit Results**

| Date | Start Time | Audit | Site | Diff. | Date | Start Time | Audit | Site | Diff. |
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| Average : | | | |
| Std. Dev. | | | |
| Max : | | | |
| Min : | | | |
| Number: | | | |

Comments: ______________________________________________

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## BAROMETRIC PRESSURE AUDIT RECORD

**REV 08/01**

Network : SEARCH
Auditor :
Operator : ARA

Site Name :
Site Code :
AIRS # : NA

Date :
Start Time : EST/CST
End : EST/CST

**Site Instrument Data:**

Manufacturer : Vaisala
Model No. : PTB101C
Sensor S/N :
Sensor Type : Transducer
DAS: Primary : ARA
DAS Channel : Press
Chart Recorder : NA

| | min | max | |
|---|---|---|---|
| Sensor Range | 900 | 1100 | millibar |
| Instrument | 0.000 | 1.000 | VDC |
| Chart Recorder | 0.0 | 100.0 | % |

**Audit Instrument Information:**

Altimeter Mfg. :
Model :
Serial No. :

Collocated Sensors:
Start: End:

**Audit Results**

| Date | Start Time | Audit | Site | Diff. | Date | Start Time | Audit | Site | Diff. |
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| | Audit | Site | Diff. |
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| Average : | | | |
| Std. Dev. | | | |
| Max : | | | |
| Min : | | | |
| Number: | | | |

Comments: ____________________

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**PRECIPITATION AUDIT RECORD** **REV 08/01**

| | | | | | | |
|---|---|---|---|---|---|---|
| Network : | SEARCH | Site Name : | | Date : | | |
| Auditor : | | Site Code : | | Start Time : | | EST/CST |
| Operator : | ARA | AIRS # : NA | | End : | | EST/CST |

**Site Instrument Data:**

Manufacturer :
Model No. :
Sensor S/N :
Sensor Type : Tipping Bucket
DAS: Primary : ARA
DAS Channel : Precip
Chart Recorder : NA
Meas. Dia.:
Manu Dia., in: Dia., cm: mm/tip Vol/tip, ml:

| | | | |
|---|---|---|---|
| Sensor Range min : 0.00 | max : 10.00 | inches |
| Instrument min : 0.000 | max : 1.000 | VDC |
| Chart Recorder : --- | max : 100.0 | --- |

**Audit Instrument Information:**

Burret Mfg. : Nalgene
Model : 100 ml
SN : NA

**Audit Results**

Volume of water comparison

| Time EST | Input: Tips | Input: Vol ml | Input: Calc Precip mm | Instrument Calc Precip mm | | Difference: Precip mm | Difference: Precip % |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
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| | | | | | | | |
| | | | | Average | | | |
| | | | | Std Dev | | | |

Tips registered by DAS

| Time EST | Input Tips | DAS Tips | Difference Tips |
|---|---|---|---|
| | | | |
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Comments: ____________________

## 3.0 CALIBRATION STANDARDS

### 3.1 Preparation, Ranges, and Traceability of Standards

#### 3.1.1 Wind Speed

The wind speed calibration motor is checked at several rotation rates with a strobe light.

#### 3.1.2 Wind Direction

No direct calibration of the Brunton compass is done. It is inspected for damage. The difference in the readings of the two ends of the compass pointer is compared to 180°.

#### 3.1.3 Temperature

The CSI 107 temperature sensor is calibrated at approximately 0 and 30 °C in a water bath using a Brooklyn Thermometer (29 – 31 °C) S/N 10772 NIST-traceable.

#### 3.1.4 Relative Humidity

The Vaisala relative humidity sensor is calibrated with relative humidity generated by closed chambers containing saturated salt solutions.

#### 3.1.5 Solar Radiation

The Eppley pyranometer is calibrated at Eppley Laboratories by comparison to a Standard Precision Spectral Pyranometer under controlled conditions.

#### 3.1.6 Barometric Pressure

The Vaisala barometer is checked with a Fortin-type mercury-in-glass barometer. The barometer reading is corrected for temperature and altitude using corrections provided by the Smithsonian Meteorological Tables (List, 1951).

#### 3.1.7 Precipitation Gauge

The capacity of the buret is measured by weighing the amount of water held in 100 ml. The density of water is corrected for temperature.

3.2 Use of Standards

The audit equipment are calibrated prior to the field audit. If questions arise as to audit results, the audit equipment are calibrated after the audit.

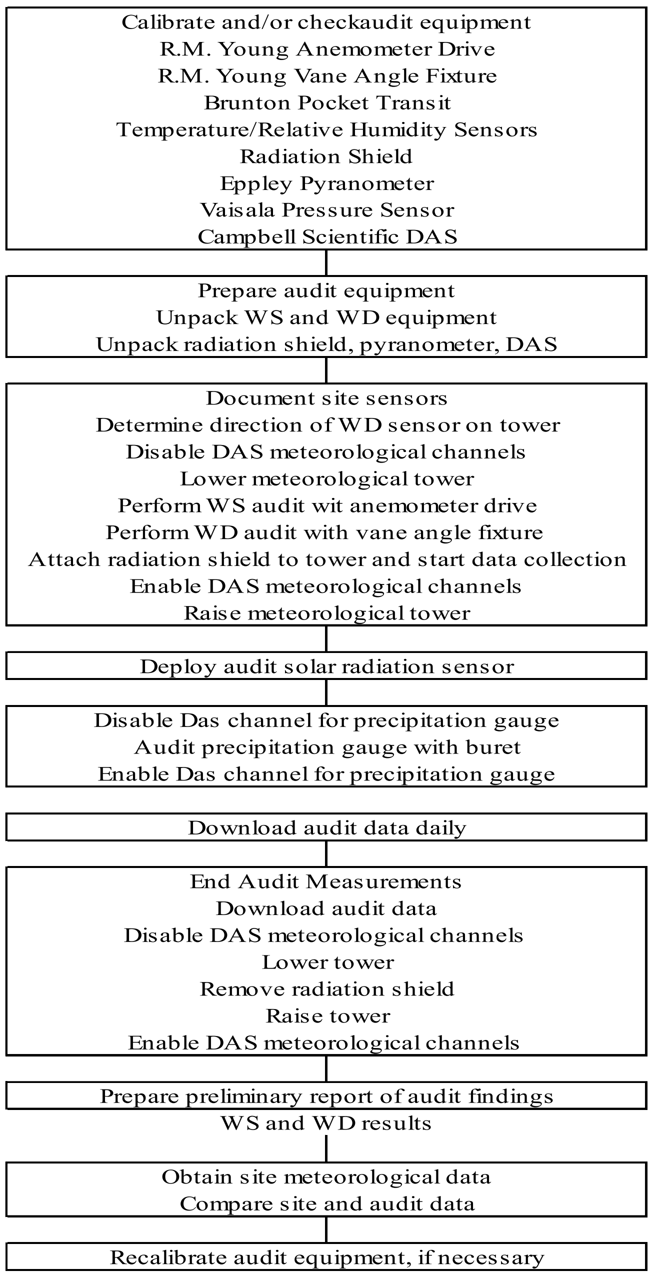
3.3 Typical Accuracy of Calibration Standards

The accuracy of the temperature standard is ±0.01 °C. The accuracy of the relative humidity standards are ±3%. The accuracy of the pressure standard is ±1 mb.

# 4.0 PROCEDURES

## 4.1 General Flow Diagram

Figure 4-1 shows a general flow diagram of operating procedures for performance audits of meteorological instruments.



## 4.2 Onsite Audit Preparation

With the meteorological tower in its upright position, inspect its integrity and that of the installed instruments. Note that tower framework is intact, straight, and vertical. Check that the guy wires are tight. Check that tower is locked in its upright position.

Determine fixed-direction indicator on the tower. Most towers have a pipe attached to the tower just below the Wind Monitor that points to the North. In some instances, the visible indicator is the flat part on the south side of the base of the Wind Monitor.

Unpack equipment for meteorological audit. Place anemometer drive, torque wheel, and vane compass fixture near the location that the instruments will be when the hinged tower is lowered. Unpack the aspirated radiation shield, electrical cabling, and box containing solar radiation sensor and place near base of tower. Unpack enclosure that contains the Campbell Data Logger and place near base of tower. Attach Brunton compass to tripod. Check that zero on the compass scale is set to the zero pin, i.e., it is set to zero magnetic declination. Close compass lid so that its balance mechanism is secure in case the tripod accidentally falls. Find magnetic declination for site and note in log book. By convention an easterly declination is positive and a westerly declination is negative. The bearing relative to true North is obtained by adding the magnetic declination to the magnetic bearing.

## 4.3 Meteorological Instrument Audit

### 4.3.1 Wind Direction Checks with Tower Up

Determine location to North of tower from which the direction indicator can be viewed with an unobstructed line of sight. It should not be near metallic objects like a fence or vehicle. The distance from the tower base should be approximately 15 to 25 meters. Place center of compass and tripod on the line that visually runs through the North indicator. Belt buckles and other metallic objects should not be near the compass during readings. Using the mirror method, determine the magnetic bearing to the North indicator. Add the declination to the magnetic bearing to determine the bearing of the North indicator relative to true North. Subtract 180° from this bearing to obtain the direction toward which the indicator is pointing. This direction should be near 0°. Repeat magnetic bearing measurements a second time from the North side to confirm the first measurement.

Move to South of tower and determine a line that lies along the North indicator. Since the North indicator will be hidden behind the tower, its bearing will have to be estimated. Determine magnetic bearing to tower, calculate bearing relative to true North, and compare to bearing measured from North side.

If the North indicator is not available, visually determine the line that is perpendicular to the flat side at the base of the Wind Monitor, measure its magnetic bearing, and calculate the bearing relative to true North. Since the flat side should be pointing toward the South, the bearing to the side should be near 0° relative to true North.

4.3.2 Audit Checks with Tower Down.

Lower Tower

Disable wind speed, wind direction, temperature, and relative humidity on site computer DAS and record time. Lower hinged tower so that Wind Monitor can be accessed on the ground. Take care that Wind Monitor does not hit guy wires or ground. Tie off rope to keep Wind Monitor at constant level above the ground.

Wind Speed

Record serial number of Wind Monitor that is stamped on side of rectangular enclosure. Remove propeller from Wind Monitor and record serial number that is stamped on front. Inspect propeller to see that it is intact and without flaws. Set propeller aside so that it cannot be damaged. Turn propeller shaft to see that it turns freely without binding or excessive noise. Record the physical state of the propeller and shaft. Prepare propeller torque wheel with small black screw (0.1 g in weight) in the 3 cm hole to give a torque of 0.1 g times 3 cm or 0.3 g-cm. Attach torque wheel to anemometer shaft. Hold the vane/anemometer horizontal and the torque wheel with the screw in the same horizontal plane. When the torque wheel is released, it should rotate so that the screw moves downward. In normal operations, the propeller rotates in a counter-clockwise direction when viewed from the front. This is the direction of rotation that should be tested. If the wheel does not rotate, then move the screw to the next outward hole and repeat test until the wheel does turn. If the silver screw is used, its weight is 1.0 g. Record the torque necessary to start the shaft turning.

Compare serial number of propeller to list of serial numbers for frequency to speed conversion factor. For propellers made prior to Nov., 1992 (S/N 53403 and lower), the multiplier is 0.00490 m/s per RPM. For propellers made after Nov., 1992 (S/N 53404 and higher), the multiplier is 0.00512 m/s per RPM. Attach 10000 RPM anemometer drive motor to Wind Monitor. With shaft not turning, record the DAS reading for the wind speed. Place switch of anemometer drive control box in CCW position, enter 36 in small window with push switches, and turn drive on. The drive and connecting tube may have to be aligned to start turning. Allow the drive to reach a steady value which will usually be 100 times the number entered or 3600 RPM for this point. Record the RPM and DAS reading. Repeat at 1800, 1200, 900, 600, and 300 RPM. All but 300 RPM will generally be reach steady values at 100 times the switch setting. At the nominally 300 RPM, the motor usually reaches 305 to 320 RPM with a variation of ±2 RPM. Estimate the average RPM reading and record along with the DAS reading.

The following Table contains the calculated wind speed responses for the audit rotation rates:

| Rotation Rate RPM | Wind Speed in m/s | |
|---|---|---|
| | Prop 53403 and below | Prop 53404 and above |
| 0 | 0.0 | 0.0 |
| 3600 | 17.64 | 18.43 |
| 1800 | 8.82 | 9.22 |
| 1200 | 5.88 | 6.14 |
| 900 | 4.41 | 4.61 |
| 600 | 2.94 | 3.07 |
| 300 | 1.47 | 1.54 |

Enter the rotation rates and the sensor responses into the electronic audit form. Compare sensor responses to audit criteria. Recheck those results that show responses that exceed the audit criteria.

Wind Direction

Check that the orientation key for the Wind Monitor is securely attached to the tower and that the key on the orientation ring is in the slot at the base of the Wind Monitor. Loosen hose clamp at base of Wind Monitor and remove sensor from tower. Be sure not to loosen hose clamp on orientation ring. Install Vane Angle Fixture to tower with orientation key in slot of angle fixture. For some towers, the vane angle fixture will not slide all the way down to engage the orientation key. In this situation, line the fixture slot so that a line along the key bisects the slot. A straightedge can be used to accomplish this. Tighten hose clamp on fixture. Attach Wind Monitor to Vane Angle Fixture and install arm to hold tail.

First, align the tail of the Wind Monitor along the North orientation device on the tower. Record the angle of the pointer on the Vane Angle Fixture. This angle will be used to reference the Fixture to true North. Also record the DAS reading for wind direction

Align the Wind Monitor so that the Vane Angle Fixture points to 5°, 90°, 180°, 270°, and 350°. At each direction, record the DAS reading for the wind direction.

Enter the magnetic bearing of the North orientation arm, the magnetic declination, the angle of the Vane Angle Fixture relative to the orientation arm, and the sensor responses at the different angles into the electronic audit form. Compare sensor responses to audit criteria. Check those results that show responses that exceed the audit criteria

The final task for the wind direction is a test of the starting torque. Have the site operator disconnect the Wind Monitor cable and remove the sensor from the tower to a location with minimal air motion such as inside the shelter away from the air conditioner. Place the Wind Monitor on the Vane Angle fixture without its tower attachment base. Place the vane torque gauge on the Wind Monitor with mark aligned with the direction turning axis. This gives a moment arm of 5.7 cm from the axis of rotation to the point the force is applied. Check that the direction axis points vertically. Attach a light thread to the moment arm of the vane torque gauge. Pull the thread to deflect the moment arm until the vane starts to move. Note and record the reading on the gauge. The readings on the audit gauge are in grams of force. With a moment arm of 10 cm, the torque is calculated from Reading times 10 cm. Repeat tests with the vane starting at 4 angles that are approximately 90°apart. Do tests for both clockwise and counter-clockwise rotations. Record required starting force for each tests, the moment arm distance, and the starting torque calculated from 5.7 cm times the force in grams. Manufacturer specifications for the Wind Monitor-AQ have a starting threshold of 0.5 m/s at an angle displacement of 10°. The starting torque for these specifications from K values given in U.S. EPA (1989) is 9.25 g-cm. For the 5.7 cm moment arm, the starting force is 1.6 grams.

Replace Wind Monitor on tower. Reattach propeller.

<u>Temperature/Relative Humidity</u>

With the tower in the down position, attach the audit temperature/relative humidity aspirated radiation shield and probes to the tower. The shield should be attached at a position above the site radiation shield so that the two inlets will be approximately at the same height above the ground when the tower is raised. One bracket of the audit shield should be attached to the vertical leg that the site shield is not attached to. The other bracket should be attached to the vertical leg that the site radiation shield is not attached to. The inlet of the audit shield should be the same side of the tower as the that of the site inlet. Attach signal and aspirator cables to radiation shield and secure cables to tower with tie wraps or electrical tape.

Before lifting tower, plug aspirator power cord into 110 VAC power to check that the aspirator motor is operating. Plug signal cable into side of audit DAS box. Connect storage module to DAS. Turn DAS on. Program will load from the storage module automatically. A successfully loaded program returns a display value of 13. Press *6A to display instantaneous data readings. Press “A” twice to display temperature from 107 probe (channel 3), one time to display temperature from the Vaisala probe (channel 4), and one time to display relative humidity from the Vaisala (channel 5). Pressing "B" returns to previous channel. Confirm that data are reasonable.

Set time on DAS. Press *5 for time. Press "A" to display year. Enter last 2 digits of year (02 for 2002) and press "A". Enter day of year (182 for July 1 of non-leap year) and press "A". Enter hour and next minute in Standard Time for site using WWV as time standard. When time reaches next minute, press "A" to set time.

Raise Tower

Raise tower to upright position, taking care to keep cables straight. Secure locking mechanism. Tape or tie wrap cables to the tower in several locations. Enable wind speed, wind direction, temperature, and relative humidity channels on site DAS. Record time that site equipment is operational.

If possible, move audit DAS to sheltered location. If not, the enclosure is sufficient to protect the DAS and electrical connections from most storms.

Download Audit Data from Audit DAS

Once a day, the data from the audit DAS should be downloaded to determine that reasonable data are being collected. Remove the storage module from the audit DAS enclosure and download to the audit portable computer using the Campbell Scientific PC208W software. Check that data were collected and that the values have the expected diurnal variations.

4.3.3 Audit Additional Meteorological Instruments

Solar Radiation

The audit pyranometer should be placed near the site pryanometer so that the two have similar exposure. Shadows and reflections from nearby objects should be minimized. In addition, the audit pryanometer has to be placed within the length of the electrical cable to the audit DAS.

Place pyranometer tripod near site pyranometer. Attach 1 inch pipe to tripod and pyranometer stand to pipe. Attach audit pyranometer loosely to stand using three fixed screws. Level pryanometer using three leveling screws. Tighten fixed screws. Attach signal cable to pyranometer and to connector on outside of DAS enclosure.

Check DAS for solar radiation data. Press *6A and advance to channel 5 to display solar radiation. Value should be above zero during daylight hours and in the range of 500 to 1000 w/m$^2$ at mid-day.

Pressure

The pressure sensor is contained in the DAS container and will start when the DAS is turned on. Its instantaneous data is displayed in channel 19. To skip to this channel, press *6 19 A. Value should be near 1000 mb.

Precipitation

The precipitation audit consists of introducing water to the sampler, determining how much water is necessary to produce a tip, and comparing the number of tips on the DAS with the number counted by the auditor. The audit should not be started if precipitation is occurring or has a possibility to occur in the next 30 minutes or so.

Disable site DAS channel for precipitation and note time. Inspect precipitation gauge for dirt and debris in the inlet and in the buckets themselves. Debris that might be blocking the inlet should be removed so that water can be introduced through the inlet. Debris in the buckets should be left so that the as is condition of the gauge is audited. Also note if the buckets contain water from a previous rain event. Measure gauge diameter. If gauge opening appears not to be round, measure along several diameters to check roundness. Compare diameter measurements to manufacturer's specification. Compute amount of water required to provide one tip (0.01 inches or 0.254 mm of water). Document gauge condition.

Fill 100 ml buret with distilled water to a level above the 0 ml line. Tap buret gently to remove air bubbles. Attach buret to precipitation gauge with clamps. Buret tip should be aligned near the edge of the small inlet hole so that water from the buret will hit the metal cone before entering the inlet. Open the buret valve to allow water to drip into gauge at a rate of about a 1 drop/second. Allow enough water for three tips to wet the gauge. Turn the valve off immediately after the third tip. Record that 3 tips were done before the audit started.

Remove buret from clamps. Fill buret to above the 0 ml line. With buret tip away from the gauge, open the valve and allow water to run out until the bottom of the meniscus lines up with the 0 ml line. Return the buret to the clamps taking care not to jar the buret and loosen water from the tip. Open buret valve so that drops form and fall at a rate of about 1/sec. This will give about 1 tip/minute. Record starting time. A total of 10 tips will be done for each set of checks. After each tip, record the tip number and estimate volume reading on buret as the bucket tips. Immediately after the 10$^{th}$ tip, turn the valve off. Record level of buret. Record ending time. Check the site DAS to see how many tips were recorded. The DAS records each tip as 0.254 mm. More than one tip per minute should be indicated as a multiple of 0.254. If the buret contains more than 50 ml, open buret valve to start drops falling at 1/sec to generate 10 more tips following the above procedures. Repeat two more sets of 10 tips each

Compare water necessary for 10 tips to the manufacturer's specification. Compare number of tips that are heard to the number of tips that the site DAS recorded.

Enable precipitation gauge on DAS. Record time of audit and number of tips that were recorded on the DAS.

## 4.4 End Meteorological Audit

The collocated audit of temperature, relative humidity, solar radiation, and pressure should last for at least 24 hours, and longer if possible. This will allow the comparisons to be made over range of values.

1) With the radiation shield still in place, remove the storage module from the audit DAS enclosure and download to the audit computer using the Campbell PC208W software. Check that data were collected for the entire period of the audit. If a period is missing, the entire storage module can be downloaded to see if the data are there. The DAS has a limited memory that holds up to several days depending on the averaging times. When all the data are accounted for, the audit DAS can be turned off and the cable inputs disconnected.
2) Disable site meteorological channels on the site DAS and record time.
3) Lower meteorological tower making sure that the Wind Monitor does not hit the guy wires or the ground. Disconnect the data and power cables from radiation shield and from tower. Remove the radiation shield from the tower.
4) Raise meteorological tower and secure. Enable meteorological channels on site DAS and record time.
5) Pack audit radiation shield and cables in packing container. Pack solar radiation sensor in box.

# 5.0 QUANTIFICATION

## 5.1 Calibration procedures

### 5.1.1 CSI 107 Temperature Probe

The CSI 107 temperature probe is calibrated at approximately 0 and 30 °C in a water bath using a Brooklyn Thermometer (29 – 31 °C) S/N 10772 NIST-traceable. The water bath can be in a small vacuum bottle for a single thermometer or in a temperature controlled bath if more thermometers are calibrated at the same time.

1) Remove CSI 107 temperature probe from radiation shield. Connect signal cable to audit DAS. Turn DAS on to activate temperature probe. Display CSI temperature reading (channel 3).
2) Fill bottle with cold water and chipped ice. Stir vigorously with a stirring rod – not with the Brooklyn thermometer. Check temperature of bath with the CSI probe.
3) As the temperature approaches 0 °C, place Brooklyn thermometer in the bath. Continue stirring of the bath but at a reduced intensity. The height of the mercury in the Brooklyn will eventually decrease to the point that it be in the near zero scale of the thermometer. The thermometer should be at the 6 inch immersion depth during the stirring but needs to be lifted out of the water to read the near zero scale. Read and record the Brooklyn thermometer values to 0.01 °C and CSI readings to 0.1 °C.
4) Fill the vacuum bottle with water that is near 31 °C. Place Brooklyn thermometer and CSI probe into water.
5) Hold Brooklyn thermometer and CSI probe side-by-side with the end of the CSI probe near the end of the bulb of the Brooklyn thermometer.
6) Gently stir water so that it is well-mixed. Be careful not to hit the side of the vacuum bottle with the thermometer.
7) Raise thermometer until the 6 inch immersion line is at top of water and read and record thermometer value to 0.01 °C and read and record CSI reading to 0.1 °C.
8) Repeat stirring and reading values for at least 3 sets of readings as the temperature of the water in the vacuum bottle gradually decreases.
9) Average the differences between the CSI probe and Brooklyn thermometer readings near 0 °C and near 30 °C. Add differences to 0 and 30 °C, respectively, to obtain CSI probe responses to temperatures at 0 and 30 °C. Generate a linear fit to the CSI and Brooklyn readings to obtain the following expression for the corrected CSI reading:

$$CorrCSI = \frac{30}{(30 + \Delta_{30} - \Delta_0)}(CSI - \Delta_{30})$$

where CorrCSI represents the corrected CSI temperature reading in °C,
CSI represents the CSI temperature reading in °C,
$\Delta_{30}$ is the difference between the CSI and Brooklyn readings near 30 °C,
$\Delta_0$ is the difference between the CSI and Brooklyn readings near 0 °C.

10) Replace CSI 107 probe in radiation shield.

5.1.2 Vaisala Temperature/Humidity Probe, Model 45C

The temperature part of the Vaisala Model 45C T/RH probe is compared to the CSI Model 107 probe when they are operated side-by-side during the audit. The probe serves as a backup in case the CSI probe fails.

The relative humidity part of the Vaisala Model 45C T/RH probe is checked by exposing to air in closed chambers containing saturated salt solutions. Each chamber provides an atmosphere with a fixed relative humidity that depends on the particular salt. The two salts that provide high and low relative humidities to cover the range of the sensor are potassium sulfate ($K_2SO_4$) for high values and lithium chloride (LiCl) for low values. The relative humidity over these solutions varies with temperature as follows

| Temperature (°C) | 10 | 15 | 20 | 25 | 30 | 35 | 40 |
|---|---|---|---|---|---|---|---|
| Salt | Relative Humidity (%) | | | | | | |
| $K_2SO_4$ | 97.9 | 97.5 | 97.2 | 96.9 | 96.6 | 96.4 | 96.0 |
| LiCl | 13.3 | 12.8 | 12.4 | 12.0 | 11.8 | 11.7 | 11.6 |

1) Remove Vaisala 45C T/RH probe from radiation shield. Connect signal cable to audit DAS. Turn DAS on to activate temperature probe. Display RH reading (channel 5).
2) Remove top of Vaisala Humidity calibrator. Check that the jars with $K_2SO_4$ and LiCl have visible crystals. If no crystals are visible, add dry chemical to jar and gently swirl to mix. Wait half an hour to see that crystals remain. Return jars to calibrator and secure top.
3) Connect serial port of DAS to computer serial port through the CSI model SC32A optically isolated interface and start the PC208 software. Connect to the DAS and start program to collect and plot temperature and RH from the probe.
4) Wrap a single piece of electrical tape around Vaisala T/RH probe body at the position that it will contact the top of the saturated salt jars. Remove rubber stopper from $K_2SO_4$ jar and insert Vaisala T/RH probe into hole checking to see that hole is sealed.
5) The reading from the RH probe should begin to increase. It will require a least an hour for the probe to reach its maximum value. When the reading of RH levels off at

a value near 97%, record the RH and the temperatures of the probe and of the thermometer that is attached to the humidity calibrator.

6) Remove probe from $K_2SO_4$ jar and insert into LiCl jar, again ensuring that the probe fits tightly into the hole. Allow probe to remain exposed to LiCl for at least an hour or until the reading levels off at a RH near 12%. Record the RH and the temperatures of the probe and thermometer.
7) Download data for period of calibration to determine RH response of instrument when exposed to the salts. If the limits are within ±3%, then the readings are used as is. If the differences are more than ±3%, develop a linear regression with the salt RH as the x variable and the probe as the y variable. Invert the regression to obtain the corrected RH reading.

$$CorrRH = \left( \frac{RH - Intercept}{Slope} \right)$$

where RH is the reading from the probe and
Slope and Intercept are the regression coefficients for RH vs. Salt RH

8) Replace Vaisala T/RH probe in radiation shield.

5.1.3 Vaisala Pressure Sensor

The Vaisala pressure sensor is checked with a Princo Fortin-type mercury-in-glass barometer. The barometer reading is corrected for temperature and altitude using corrections provided by the Smithsonian Meteorological Tables.

1) Place DAS enclosure with pressure sensor near Princo barometer.
2) Turn cistern adjustment screw at bottom of Princo barometer until white zero pointer in cistern just touches top of mercury.
3) Raise vernier above top of mercury meniscus and lower slowly until the front and back bottom edges of the vernier just appear to touch the top of the meniscus.
4) Read the millibar scale indicated by the vernier. The 1's, 10's and 100's places are given by the first line on the scale below the bottom of the vernier. The tenth's digit is given by the line on the vernier that aligns most closely with a scale line.
5) Read and record the temperature on the mercury-in-glass thermometer attached to the front of the Princo barometer.
6) Repeat steps 1) – 5) three times.
7) In Excel spreadsheet, "BARRCORR.XLS", for the next calibration, enter the Princo barometer and temperature readings and the altimeter reading. Duplicate calculations from previous calibrations to determine corrected barometer reading and difference between altimeter and Princo barometer.
8) If the pressure sensor reading differs from the corrected Princo barometer by more than ±3 mb, the data from the pressure sensor will require adjustment. With the

assumption that the difference is due to a shift in the span of the pressure sensor, the corrected sensor pressure reading is calculated from

$$Corr\ p_{Sensor} = p_{Sensor}\left(\frac{p_{Std\,Cal}}{p_{Sen\,Cal}}\right)$$

where Corr $p_{Sensor}$ is the corrected reading for the pressure sensor,
$p_{Sensor}$ if reading of the pressure sensor,
$p_{Std\ Cal}$ is the pressure reading the Princo barometer during calibration, and
$p_{Sen\ Cal}$ is reading of pressure sensor during calibration.

9) The following corrections are applied to the Princo barometer readings to correct for temperature, latitude, and altitude:

Temperature correction:

$$C_T = p_T - p_R = p_R\left(\frac{1 + L(T - T_S)}{1 + M(T - T_M)} - 1\right)$$

where $C_T$ is temperature correction,
$p_T$ is pressure in mb corrected for temperature,
$p_R$ is barometer pressure reading in mb,
L is coefficient of expansion for brass scale = 0.0000184 m/m°C,
$T_S$ is standard temperature for brass expansion = 0 °C,
M is coefficient of expansion for mercury volume = 0.0001818 $m^3/m^3$°C,
$T_M$ is standard temperature for mercury expansion = 0°C.

Altitude correction for gravity:

$$\begin{aligned} g_a = g &- [3.085462x10^{-4} + 2.27x10^{-7}\cos(2\varphi)]\,Z \\ &+ [7.254x10^{-11} + 10x10^{-18}\cos(2\varphi)]\,Z^2 \\ &- [1.517x10^{-17} + 6x10^{-20}\cos(2\varphi)]\,Z^3 \end{aligned}$$

where g is gravity at a latitude of 45° and elevation of 0 meters (= 980.616 cm-$s^{-2}$),
φ is latitude, and
Z is altitude above sea level in meters.

Latitude correction for pressure:

$$C_G = p_L - p_T = p_T\left\{\frac{g_a}{980.665}\left[1 - 2.6373x10^{-3}\cos(2\varphi) + 5.9x10^{-6}\cos(2\varphi)\right] - 1\right\}$$

where $C_G$ is correction for latitude,
$p_L$ is pressure in mb corrected for latitude, altitude, and temperature,
$p_T$ is pressure in mb corrected for temperature, and
980.665 is gravity for which correction tables were developed.

Final corrected barometer reading:

$$p_L = p_R + C_T + C_G$$

5.1.4 Buret Check

The buret used for the precipitation gauge is checked by measuring the amount of water that the buret holds. The measurements is accomplished by weighing the water and determining its volume from the density at the temperature of the calibration.

1) Turn Mettler balance, model AE100, on and rezero if necessary. Check balance with class S weights at 20, 30, and 50 g. Place clean, dry 100 ml beaker on balance, allow to reading to stabilize, record weight of beaker.
2) Fill 100 ml buret with distilled or deionized water.to above the 0 ml line. Gently tap the buret to force bubbles to the top surface. Open buret valve to lower bottom of meniscus to 0 ml line with water being discarded.
3) Attach buret to ring stand with tube clamps. Place 100 ml beaker under buret. Open buret valve to allow 50 ml of water as indicated by the buret to flow into the beaker. Measure and record temperature. Check and record zero on balance. Place beaker with water from buret on balance and record reading. Discard water and dry 100 ml beaker. Check and record zero of balance. Place beaker on balance to obtain a after reading. Adjust readings for before and after zeroes. Subtract weight of beaker from weight of beaker plus water to obtain the mass of water in the beaker. Determine the density of water at the measurement temperature from the Handbook of Chemistry and Physics and calculate the volume of water weighed in $cm^3$, which is nearly the same as the volume in ml and compare to the 50 ml indicated by the buret.
4) Repeat step 3) for water from the 50 to 100 ml mark on the buret.
5) Repeat steps 3) and 4) one time to obtain a total of 4 comparisons.

5.2 Calculations

5.2.1 Differences between Instrument and Audit Measurements

The results of the audit are quantified by comparing the displayed instrument values to the audit measurements for those quantities. The comparison includes the computation of the difference and the percent difference between the instrument values and the audit values. The difference and percent differences are computed from the following expressions:

$$Difference = Instrument - Audit$$

$$\%\ Difference = \left(\frac{Instrument - Audit}{Audit}\right)100$$

where Instrument represents the value of the audited quantity displayed by the instrument or DAS and
Audit represents the measurement of the audited quantity with the audit equipment.

5.3 Data Acquisition

Data acquisition is done manually for the wind speed, wind direction, and precipitation gauge audit by entering the instrument responses to the audit inputs in the audit notebook and into the audit worksheets. Average values of temperature, relative humidity, solar radiation, and pressure are collected by the audit DAS. Data are averaged for 5 minutes and for 1 hour. These data are compared to the averaged data from the site DAS.

## 6.0 QUALITY CONTROL

Quality control is maintained by periodic calibration of audit transfer standards with laboratory standards that are traceable to the National Institute of Standards and Technology. Calibrations are performed on at least an annual basis and before a major audit trip. Calibrations may also be performed following an audit trip if major discrepancies arose between the audit standards and the audited equipment.

## 7.0 REFERENCES

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