Performance Audit Procedures For Meteorological Sensors

Volume V
Audit Procedures Manual for Air Quality Monitoring

QMB SOP Appendix S
Revision 3

Quality Assurance Section

Quality Management Branch

Monitoring and Laboratory Division

Approval Signatures	Approval Date
Ranjit Bhullar, Manager Quality Assurance Section	December 1, 2019
Manisha Singh, Ph.D. Chief, Quality Management Branch	December 1, 2019

PERFORMANCE AUDIT PROCEDURES
FOR METEOROLOGICAL SENSORS

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ACRONYMS AND DEFINITIONS

Acronym	Definition
AIS	Audit Information System
AQDA	Air Quality Data Action
AQS	Air Quality System (U.S. EPA database)
BP	Barometric Pressure
CAN	Corrective Action Notification
CARB	California Air Resources Board
ccw	counter-clockwise
CTS	Collocated Transfer System (method)
cw	Clockwise
°C	Degrees Celsius
DAS	Data Acquisition System
gm	gram
gm-cm	gram-centimeters
GPS	Global Positioning System
hPa	hectoPascal
HWS	Horizontal Wind Speed
inHg	inches of mercury
km/h	kilometers per hour
LCD	Liquid Crystal Display
M	meters
mb	millibars
MET	Meteorological
mmHg	millimeters of mercury
mph	miles per hour
MQO	Measurement Quality Objectives
m/s	meters per second
NCore	National Core (network)
NIST	National Institute of Standards and Technology
OT	Outdoor (or Ambient) Temperature
PAMS	Photochemical Assessment Monitoring Stations (network)
PSD	Prevention of Significant Deterioration (network)
psi	pounds per square inch
QAS	Quality Assurance Section
QMB	Quality Management Branch
RH	Relative Humidity
rpm	Revolutions-Per-Minute
RTD	Resistance Temperature Detector
SIP	State Implementation Plan
SLAMS	State or Local Air Monitoring Stations (network)
SOP	Standard Operating Procedure

Acronym	Definition
SR	Solar Radiation
U.S. EPA	United States Environmental Protection Agency
V	Volt
VWS	Vertical Wind Speed
WD	Wind Direction
WS	Wind Speed

S.1.0 INTRODUCTION

The California Air Resources Board (CARB) Quality Assurance Section (QAS) currently conducts performance audits on meteorological (MET) sensors in support of programs, such as Photochemical Assessment Monitoring Stations (PAMS), the National Core (NCore) network, or Prevention of Significant Deterioration (PSD) sites, that are federally mandated or that need to meet federal or state requirements. In addition, other non-regulatory applications exist, such as modeling, state implementation plan (SIP) development, and forecasting. Meteorological parameters can affect the dispersion of pollutants, and these audits provide confidence that data gathered, and used to make environmental decisions, are of adequate quality.

Parameters currently audited include wind direction (WD), wind speed (WS), ambient or outdoor temperature (OT), and barometric pressure (BP). Due to budgetary, time, and other restrictions, audits on parameters such as relative humidity (RH), solar radiation (SR), and precipitation are not conducted.

All audit equipment is brought to the air monitoring site where the sensors can be challenged in typical environmental conditions. Based on conditions, if operator or auditor safety is a concern, the audit may be postponed or not conducted. Audit data is collected and entered into the Audit Information System (AIS) from a worksheet. After calculations are done, a report is generated indicating pass or failure based on CARB audit criteria. Alternatively, criteria based on the measurement quality objectives (MQO) can be applied.

Note: All product names, logos, and brands are property of their respective owners. All company, product and service names used in this document are for identification purposes only. Use of these names, logos, and brands does not imply endorsement.

S.1.1 INTERFERENCES AND SITING

Interferences specific to each meteorological parameter being measured can be found in the related section.

Siting of meteorological equipment is critical in ensuring accurate and representative data. For example, poor placement of a wind direction sensor can cause errors due to obstructions changing the wind pattern near the sensor, resulting in biased data. Improper placement of any of the other meteorological sensors may also result in errors.

As a general rule, meteorological sensors should be sited at a distance beyond the influence of obstructions, such as buildings and trees; this distance depends on both the variable to be measured and the type of obstruction. In addition, the meteorological measurements should be representative of meteorological conditions in the area of interest. Secondary considerations such as accessibility and security must be taken into account but should not compromise the quality of the data.

Ideal siting may not always be attainable; in fact, in many urban areas where air quality studies are traditionally made, it may be impossible to find a site that meets air quality and meteorological siting criteria. It is incumbent upon an agency gathering data to carefully describe the meteorological siting deficiencies in a site and, if possible, quantify or at least evaluate the probable consequences of the siting deficiencies on the data. Additional information about siting of meteorological sensors can be found in the U.S. EPA's Quality Assurance Handbook for Air Pollution Measurement Systems, Volume IV: Meteorological Measurements, Version 2.0 (March 2008).

S.1.2 PERSONNEL QUALIFICATIONS

All new CARB auditors undertake a one year training program that is documented and monitored by the Quality Assurance Section (QAS) manager. The training includes in-office reading and coursework, hands-on field experience conducting audits, and shadowing an experienced auditor for one year along with several in-field evaluations by the QAS manager.

U.S. EPA reviews CARB's training program regularly for approval as an equivalent to U.S. EPA's national certification and recertification courses. Auditors should be familiar with the regulations and guidance cited in the references section (S.8.0) prior to conducting any audits without supervision. Each auditor is expected to have a minimum level of on the job training and familiarity with the audit equipment prior to conducting the audit(s).

The U.S. EPA's Quality Assurance Handbook for Air Pollution Measurement Systems, Volume IV: Meteorological Measurements, Version 2.0 (March 2008) should be considered as required reading prior to conducting meteorological audits.

NOTE: A station operator familiar with the meteorological equipment must be present during the entire audit to perform the required manipulations of the tower and sensors, as needed. Auditors should check for proper orientation before lowering the tower, or changing its normal operating position (refer to Section S.2.2 below).

S.1.3 HEALTH, SAFETY, AND CAUTIONS

All personnel must follow any general health and safety guidelines as described by the facility where the audit is conducted. All audit equipment, including audit vehicles, should be used only for the purpose and in the manner described in this standard operating procedure (SOP) and in the appropriate operator's manual.

Falls from portable ladders are one of the leading causes of occupational fatalities and injuries. Appropriate safety precautions should be taken and auditors should be familiar with, and trained on, proper ladder usage.

Care should be taken when accessing sensors, especially on station rooftops or meteorological towers. All equipment being audited should be easily and safely accessible. MET towers or equipment that require climbing, or are otherwise inaccessible, will not be audited.

S.2.0 WIND DIRECTION (WD)

S.2.1 INTRODUCTION

Wind direction sensors indicate the direction from which the wind is blowing. The wind direction is expressed as an azimuth angle on a 360° circle where 0° or 360° indicates north and 180° indicates south. Wind direction sensors use a tail assembly positioned on a vertical shaft to detect wind direction. Wind applies a force to the tail assembly of the sensor forcing the assembly to turn into the wind seeking a position of minimum force. The shaft of the sensor rests on low friction precision grade bearings and is connected to a low torque potentiometer. The potentiometer yields a voltage output proportional to the wind direction. The starting threshold of the sensor is controlled by the relationship of shape, size, and distance from the axis of rotation of the tail assembly to the vertical shaft, bearings, and potentiometer torque requirements. The proper orientation of the sensor, efficient operation of the bearing assembly, and correct potentiometer function are factors that affect the quality of wind direction data. Thus, performance audits of wind direction sensors quantify the correct function of these components.

Sonic anemometer systems are based on the principle that wind changes the transit time of a sound pulse across a fixed distance. Sonic systems can be designed in two dimensions for horizontal wind speed and direction as a replacement for the cup and vane or propeller units, or in three dimensions for both horizontal and vertical wind measurements. Methods for testing and evaluation of the performance of sonic systems are generally not practical for field implementation, and require a Collocated Transfer System method (CTS). Refer to section S.6.0 for further information on sonic systems and CTS. Figure S.1 shows a variety of wind speed and wind direction monitoring systems.

Figure S.1 Wind Speed and Wind Direction Monitoring Systems

S.2.2 GENERAL OPERATING PROCEDURES

The largest source of error in a wind direction measurement is the wind vane orientation off from true north. Orientation error is a fixed bias that can be removed from a data set. The method of wind vane orientation must be capable of 1° accuracy with 2° as the upper limit of the error. Two steps are necessary to achieve wind vane orientation:

- True north location must be determined accurate to < 1 degree, and
- Wind vane "reference position" must be fixed to true north accurate to < 2 degrees.

The degree of magnetic declination is used to correct a magnetic compass reading to obtain true north.

A compass, pocket transit or Global Positioning System (GPS) can be used to check the orientation of the wind direction sensor. They are used to verify the orientation of the boom and wind direction sensor center line or index to true North. The U.S. EPA Volume IV criteria provide for an agreement of less than or equal to 3 degrees relative to the sensor mount or index (less than or equal to 5 degrees absolute error for the installed system). This alignment check should be done before the MET tower is lowered or any changes are made to sensor positioning.

CAUTION: The magnetic compass reading is subject to errors due to aberrations in the local magnetic field. These aberrations could be due to soil types (high ferrous content), ferrous metal debris buried underground, or nearby metal structures.

The starting threshold of the wind vane is important to record accurate directions at low wind speed. A K-factor, which is pre-programmed into AIS based on the WD model, along with the starting torque of the vane assembly provides a threshold wind speed. The torque gauge or torque disc are used to quantify the torque of the wind direction sensor.

The accuracy measurement for WD sensors can be performed by manually orienting the vane to various directions using a degree fixture attached to the sensor. After attachment, the vane is positioned at known increments on the degree fixture to measure the linearity of the transducer or potentiometer.

S.2.3 AUDIT EQUIPMENT

1. Binoculars with internal compass, or GPS.
2. Brunton F-3008 pocket transit and tripod with ball/socket joint.
3. R.M. Young 18331 vane torque gauge (range: 0-60 gm-cm).
4. R.M. Young 18310/18312 torque disc (range: 0-15.0 gm-cm).
5. Wind Direction degree fixture (varies):
    a. R.M. Young 18212

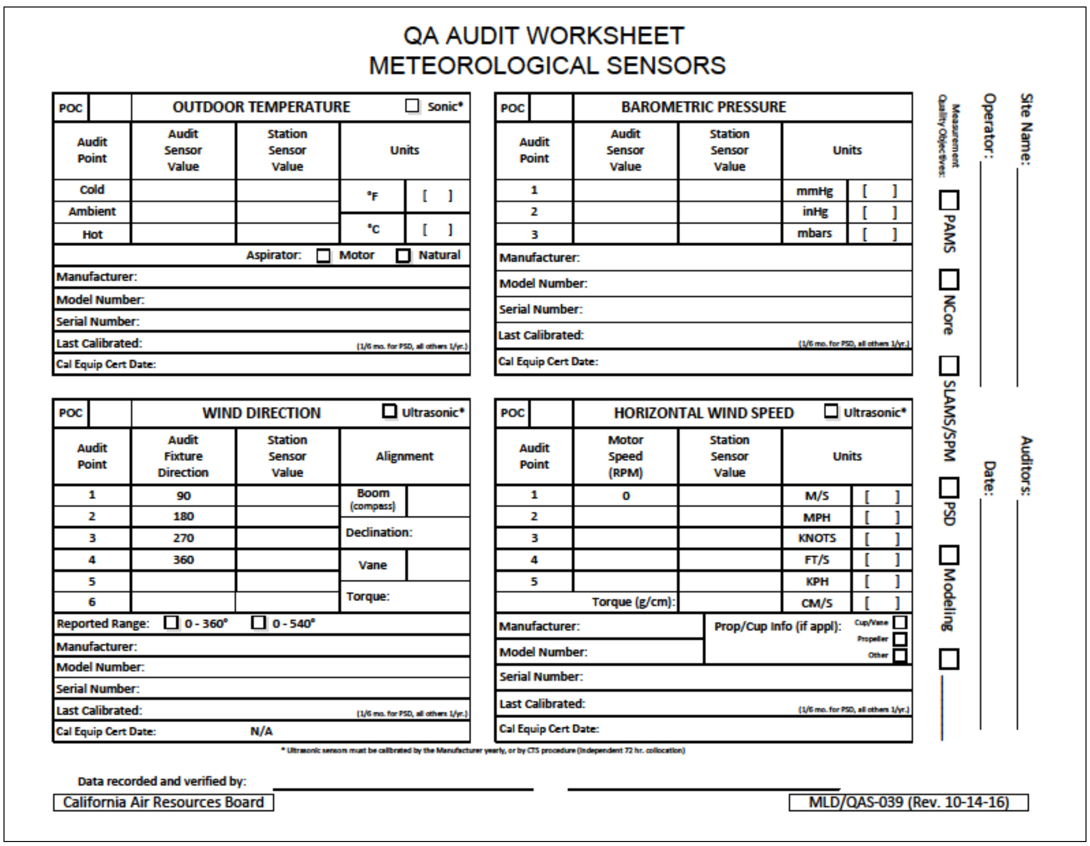
b. Climatronics 10175

c. Met One 040

d. Met One 044

6. Field service tools, including allen wrenches and screwdrivers.

7. QA MET Audit Worksheet (Worksheet, Figure S.2) and Audit Information System (on laptop or computer) for calculations and accuracy criteria.



QA AUDIT WORKSHEET
METEOROLOGICAL SENSORS

POC		OUTDOOR TEMPERATURE	☐ Sonic*	
Audit Point	Audit Sensor Value	Station Sensor Value	Units	
Cold			°F	[ ]
Ambient				
Hot			°C	[ ]
Aspirator: ☐ Motor ☐ Natural				
Manufacturer:				
Model Number:				
Serial Number:				
Last Calibrated:			(1/6 mo. for PSD, all others 1/yr.)	
Cal Equip Cert Date:				

POC		BAROMETRIC PRESSURE		
Audit Point	Audit Sensor Value	Station Sensor Value	Units	
1			mmHg	[ ]
2			inHg	[ ]
3			mbars	[ ]
Manufacturer:				
Model Number:				
Serial Number:				
Last Calibrated:			(1/6 mo. for PSD, all others 1/yr.)	
Cal Equip Cert Date:				

POC		WIND DIRECTION	☐ Ultrasonic*	
Audit Point	Audit Fixture Direction	Station Sensor Value	Alignment	
1	90		Boom (compass)	
2	180		Declination:	
3	270			
4	360		Vane	
5				
6			Torque:	
Reported Range: ☐ 0 - 360° ☐ 0 - 540°				
Manufacturer:				
Model Number:				
Serial Number:				
Last Calibrated:			(1/6 mo. for PSD, all others 1/yr.)	
Cal Equip Cert Date:	N/A			

POC		HORIZONTAL WIND SPEED	☐ Ultrasonic*	
Audit Point	Motor Speed (RPM)	Station Sensor Value	Units	
1	0		M/S	[ ]
2			MPH	[ ]
3			KNOTS	[ ]
4			FT/S	[ ]
5			KPH	[ ]
	Torque (g/cm):		CM/S	[ ]
Manufacturer:		Prop/Cup Info (if appl):	Cup/Vane ☐ Propeller ☐ Other ☐	
Model Number:				
Serial Number:				
Last Calibrated:			(1/6 mo. for PSD, all others 1/yr.)	
Cal Equip Cert Date:				

* Ultrasonic sensors must be calibrated by the Manufacturer yearly, or by CTS procedure (independent 72 hr. collocation)

Site Name: ______ Auditors: ______
Operator: ______ Date: ______
Measurement Quality Objectives: ☐ PAMS ☐ NCore ☐ SLAMS/SPM ☐ PSD ☐ Modeling ☐ ______

Data recorded and verified by: ______ ______

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Figure S.2 QA Audit Worksheet for Meteorological Sensors

S.2.4 PERFORMANCE AUDIT PROCEDURES

S.2.4.1 VANE ORIENTATION

The wind direction sensor and vane orientation is verified before the accuracy or starting torque audit is performed. The sensor orientation is also re-verified after all portions of the audit are completed and the wind direction sensor is back in operating position on the tower.

Prior to going into the field, the declination of the station can be obtained by entering the station's latitude and longitude online at:

https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml#declination

The position of the magnetic North Pole can vary slightly from year to year and should be checked annually. Once the station declination is known, it is subtracted from 360° to provide the magnetic North value. Record the declination value on the Worksheet.

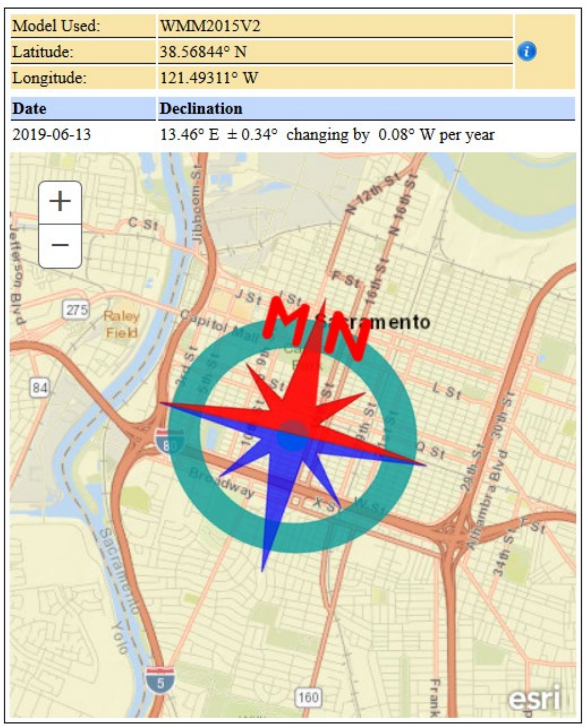

Figure S.3 Example of Magnetic Declination

Check the vane alignment (and its relation to the cross-arm or boom) using one of the following methods:

1. Direct Transit Reading Method Using a Pocket Transit:

a. Set the tripod on a flat stable surface with the legs extended. Attach the transit (Figure S.4) to the socket head with the clamp screw.

Figure S.4 Brunton Pocket Transit

b. Position the tripod/transit assembly where the previous orientation check of the wind direction sensor was performed. This position can be indicated by a mark on the ground or by the recommendation of the site operator. If it is difficult to sight the wind direction sensor, use binoculars for positioning the transit.

c. Place the transit in the horizontal position.

d. Open the mirrored lid so that the mirror faces away from you. The large sight is set perpendicular to the bottom case.

e. Tilt the mirror towards you so that you can look into it. The shaft of the wind direction sensor (or orientation cross-arm) should be visible in the mirror. Binoculars can help sight the sensors on the tower. If not, change the angle of the mirror until it is visible.

f. Confirm the black center-line on the mirror bisects both the reflection of the large sight and the sighted wind direction sensor (or orientation cross-arm/boom).

g. Center the bubble in the circular level.

h. Confirm the north seeking end of the needle points to the azimuth or bearing angle on the transit circle.

NOTE: The transit can be affected by magnetic materials or fields (watches, belt buckles, railroad tracks, power lines, etc.). To determine if the transit is being affected, slowly move the transit back and forth in a direction that is perpendicular to the compass needle pointing direction. If the compass needle changes direction more than 3 degrees, the transit is being affected by magnetic materials or fields. Move the transit to an unaffected area.

i. Record the azimuth angle of the sensor orientation on the audit worksheet under "Boom Alignment", in degrees.

j. Commonly, the sensor manufacturer specifies orienting the sensor in respect to true North. Alternately, it may be oriented to one of the other cardinal directions and adjustments should be made accordingly. In any case, the azimuth angle of the sensor orientation should be less than or equal to 3 degrees relative to the sensor mount (less than or equal to 5 degrees absolute error).

k. Verify the sensor orientation has not changed after all the meteorological audits are completed and the wind direction sensor is back in operating position on the tower.

2. Binoculars with compass:

a. Position yourself south of the MET tower, with a clear line-of-sight to the cross-arm (or boom) and sensor.

b. While looking at the cross-arm through the binoculars, move until you are parallel with the cross-arm.

c. Assuming that the sensor is oriented correctly, the compass reading in the binoculars should be equal to the declination value subtracted from 360° (i.e., magnetic north).

NOTE: The compass can be affected by magnetic materials or fields (watches, belt buckles, railroad tracks, power lines, etc.). To determine if it is being affected, slowly move back and forth in a direction that is perpendicular to the compass needle pointing direction. If the needle changes direction more than 3 degrees, it is being affected by magnetic materials or fields. Move to an unaffected area.

3. Verification using a GPS:

    a. Establish a reference point 20 meters (m) to 30 m from the cross-arm in line with the direction of the cross-arm.

    b. At the cross-arm reference point, turn on the GPS and allow the GPS to obtain a reference waypoint.

    c. Walk from the reference point to the ground location directly under the cross-arm.

    d. The GPS display provides a bearing or direction of travel directly related to the cross-arm direction.

    e. The procedure is repeated several times in directions toward and away from the cross-arm ground location to assure the GPS bearings are consistently 180 degrees from each other.

4. After the vane orientation has been checked and recorded, have the station operator flag or mark the appropriate channels as “offline” and lower the MET tower.

S.2.4.2 WIND DIRECTION SENSOR ACCURACY VERIFICATION

The various methods for auditing wind direction accuracy are presented below. In all methods, accuracy should be less than or equal to 3 degrees from the sensor mount (less than or equal to 5 degrees absolute error).

The physical design and specific use of the wind direction degree fixture or wheel will vary according to the manufacturer. Therefore, general procedures for orientation, with specific instructions pertaining to each degree wheel design are presented here.

Before the sensor is disconnected or removed, manually orient the tail assembly parallel to the cross-arm towards South. Record the value from the station’s DAS on the worksheet as the “Vane Alignment”, which is typically 360 degrees. Confirm that the values for east and west are reasonable (within 5 degrees of 90 and 270, respectively) by manually orienting the vane assembly perpendicular to the cross-arm. It is recommended that a pre-audit sensor orientation be identified, by either a mark or set-screw. This ensures that the sensor is returned to the same position post-audit and may help during any troubleshooting procedures.

S.2.4.2.1 Met One 040 Degree Wheel and pointer

The Met One model 040 (Figure S.5) degree wheel and pointer is used on Met One model 020B, 020C, 021B, and 021C wind direction sensors.

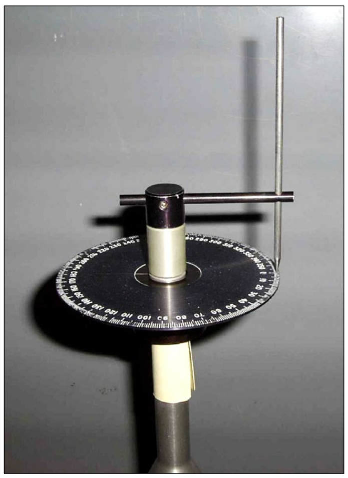

Figure S.5 Met One Degree Fixture

1. Disconnect the sensor from its electrical connection on the cross-arm. Slide the appropriate degree fixture over the shaft with the etched side facing up. Reattach the sensor to its electrical connection.

2. Remove the tail shaft from the spinning hub and attach the pointer. Slide the degree fixture up near the pointer and rotate until the pointer indicates 180 degrees on the fixture. Notches on the column of the sensor should line up with the notch on the spinning hub. Tighten the degree fixture to the shaft of the sensor to prevent changes or movement during the audit.

3. Rotate the pointer to 270, 360, 180, and 90 degrees. Include two additional representative points. Record the values indicated on the fixture and the station DAS for each point on the Worksheet.

4. Remove the pointer and disconnect the sensor from its electrical connection on the cross-arm. Slide the degree fixture off the shaft. Replace the tail shaft and reconnect the electrical connections.

S.2.4.2.2 Climatronics 101984 Linearity Test Fixture

The Climatronics 101984 Linearity Test Fixture (Figure S.6) is used on the Climatronics F460 (also referred to as 100075) wind direction sensor.

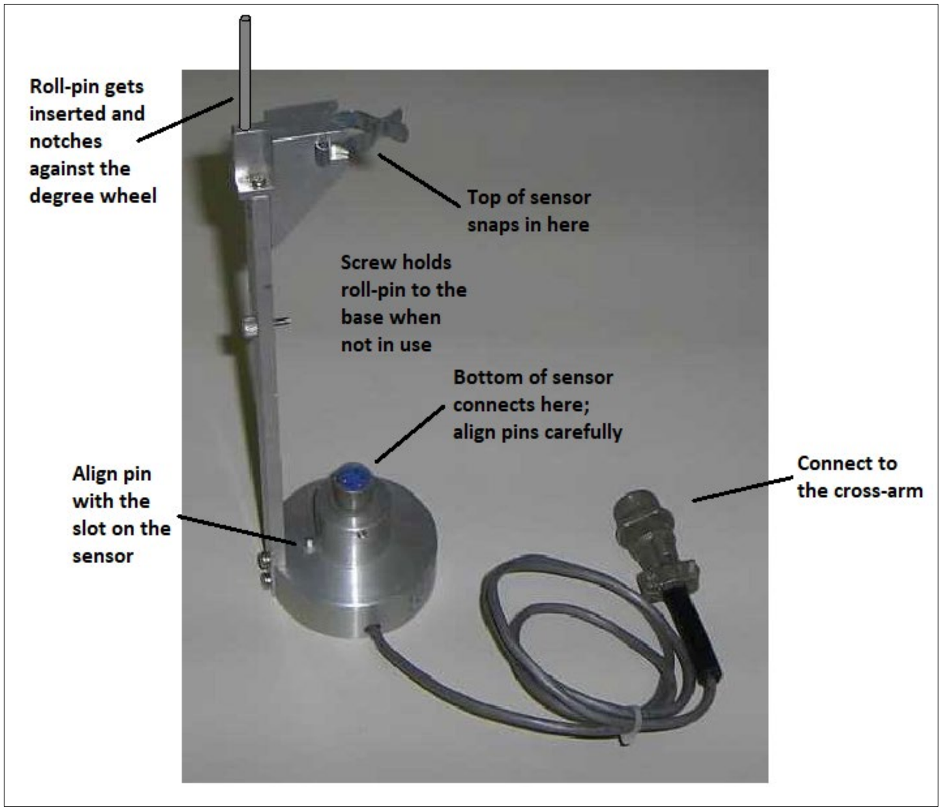

Figure S.6 Climatronics Linearity Test Fixture

The procedure requires a north-south orientation of the cross-arm, with the wind direction sensor at the southern end (Figure S.7)

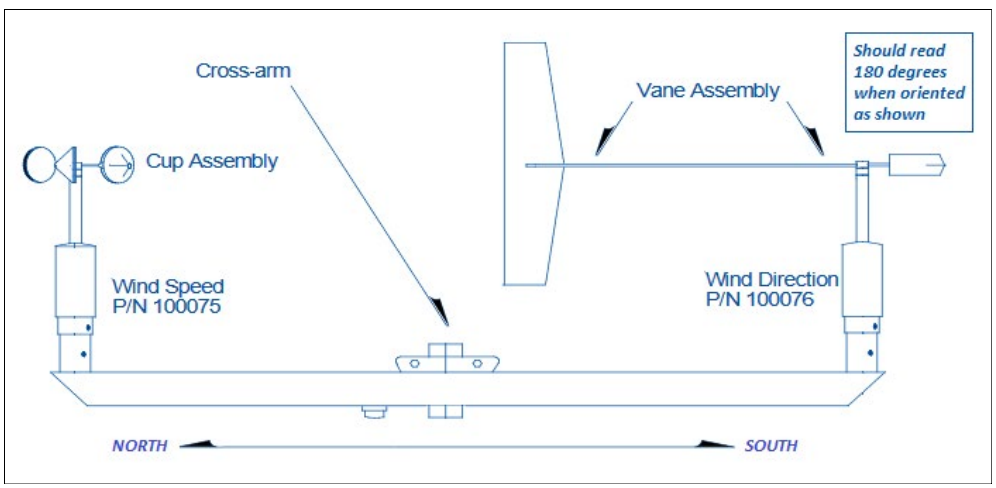

Figure S.7 Climatronics F460 Wind Sensors and Cross-arm

1. Verify the north-south orientation of the cross-arm with the wind direction sensor at the southern end. If the installation has been oriented atypically, consult the station operator and make adjustments accordingly. Note the deviation in the Audit Report.

2. Visually align the centerline of the vane assembly along the cross-arm with the vane tail pointing away from wind speed sensor. A reading near 360 degrees should be obtained. Record the DAS value for north (oriented to 360) on the Worksheet as the “Vane” alignment. Confirm that the values for east and west are reasonable (within 5 degrees of 90 and 270, respectively) by manually orienting the vane assembly perpendicular to the cross-arm.

3. Remove the wind direction sensor from the cross-arm. Use the allen wrench provided with the fixture to loosen the two set screws in the vane hub. Remove the vane assembly from the shaft.

4. Plug the connector at the end of the cable on the fixture into the cross-arm. Plug the sensor into the fixture base by aligning the slot in the wind direction sensor with the pin in the fixture base.

5. Loosen the thumb screw on the back of the pointer column to slide the pointer out of its storage groove. Slide the pointer into the hole located at the top of the pointer column.

6. Place the notched degree wheel over the shaft so that the index end of the pointer is in the 180 degree notch. Rotate the sensor cap until the dial hub fits on the stepped portion of the dial. The sensor should provide an output of 180 degrees. Record the DAS value on the Worksheet.

7. Move the pointer out of the 180 degree notch and rotate the dial to other points, including 90, 270, 360, and two other representative points. If the station reports readings up to 540 degrees, be sure to include at least one reading above 360 degrees. Record all corresponding values on the Worksheet.

8. Remove the notch dial and unplug the connector from the cable. Return the pointer to its storage groove on the back of the pointer column. Unplug the sensor from the fixture base. Reinstall the vane on the shaft and plug the sensor back onto the cross-arm.

S.2.4.2.3 R.M. Young 18212 Tower Mount Vane Angle Fixture and Degree Wheel

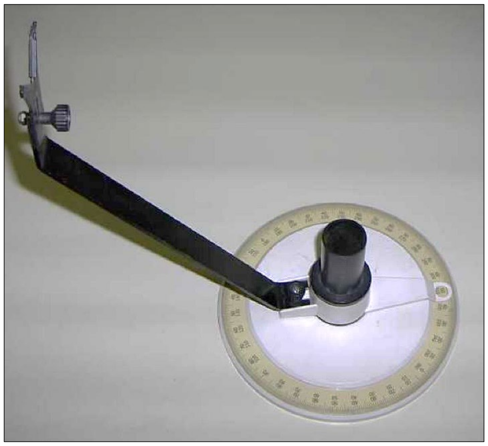

Figure S.8 R.M. Young Vane Angle Fixture and Degree Wheel

The R.M. Young Fixture (Figure S.8) is used with various R.M. Young wind monitors; most commonly models 05103 and 05305. Be sure to note the model and serial number for both the monitor and propeller on the audit Worksheet.

1. The wind monitor is installed on the Fixture with its South alignment notch engaging the index key on the Fixture.

2. Attach the tail assembly to the monitor shaft with the orientation notch coinciding with the orientation notch on the wheel.

3. Screw the tail support into position on the wheel and provide steady support during the orientation of the sensor.

4. Position the sensor to 360 degrees (North) and verify this with the number etched on the wheel face. Record the degree wheel and station DAS values on the Worksheet.

5. Rotate the sensor to 90 degrees (East). Record the values on the Worksheet. Repeat the sensor rotation and record each value on the Worksheet for 180 (South), 270 (West), and two additional points (based on the predominant wind direction). If the station reports data above 360 degrees (i.e. 470 or 540 degrees), be sure to include representative points.

6. Remove the tail support and degree wheel. Reinstall the wind direction monitor.

S.2.4.3 WIND DIRECTION SENSOR THRESHOLD TEST

The starting threshold of the wind direction sensor is influenced by the design of the vane. The K factor along with the measured starting torque of the vane will provide a starting threshold speed. To comply with the U.S. EPA Volume IV, Meteorological Measurements, the wind direction sensor should have a starting threshold less than or equal to the manufacturer's specifications. It is recommended that the station operator disconnect and reconnect the wind direction sensor from the electrical connections, as well as remove and reinstall the vane from the sensor shaft, if the torque check procedure requires it. Use one of the following two methods, depending on the model being audited.

S.2.4.3.1 R.M. Young 18331 Vane Torque Gauge

1. Remove the R.M. Young sensor from the tower and place it on a level surface, inside the station or similar structure. The area should be free of air movement.

2. Record the model of the sensor on the Worksheet, and enter it into AIS. This will provide you with the associated K factor, allow calculation of the starting threshold, and indicate the "highest allowable torque" based on a 0.5 m/s starting threshold.

3. Support the sensor in its normal operating position, using the R.M. Young vane angle fixture (Figure S.8).

4. Install the torque gauge (Figure S.9) on top of the sensor with the target directly over the "bearing centerline", as marked on the gauge. The leaf spring can be facing either direction if installed correctly.

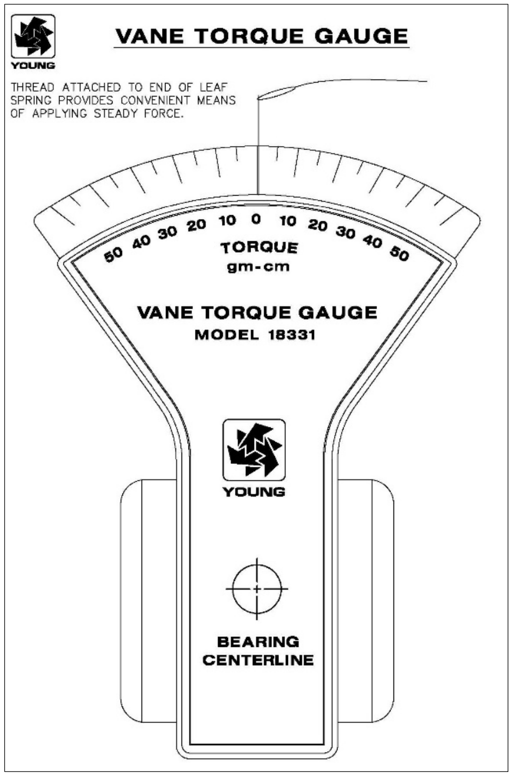

Figure S.9 R.M. Young Vane Torque Gauge (Model 18331)

5. Place your finger on the tip of the leaf spring and apply gentle pressure to move it. Note the value on the gauge when the sensor begins to rotate. The sensor should rotate through 360 degrees.

6. Repeat step e, but apply pressure on the leaf spring so that the sensor will rotate in the opposite direction. Record the indicated torque on the audit worksheet.

S.2.4.3.2 R.M. Young 18310/18312 Torque Discs

The R.M. Young torque disc (Figure S.10) may be used on wind direction and wind speed sensors with a torque less than 15 gm-cm. The torque disc (Model 18310 or 18312) used in the audit will be selected based on the proper fit of the disc on the sensor shaft.

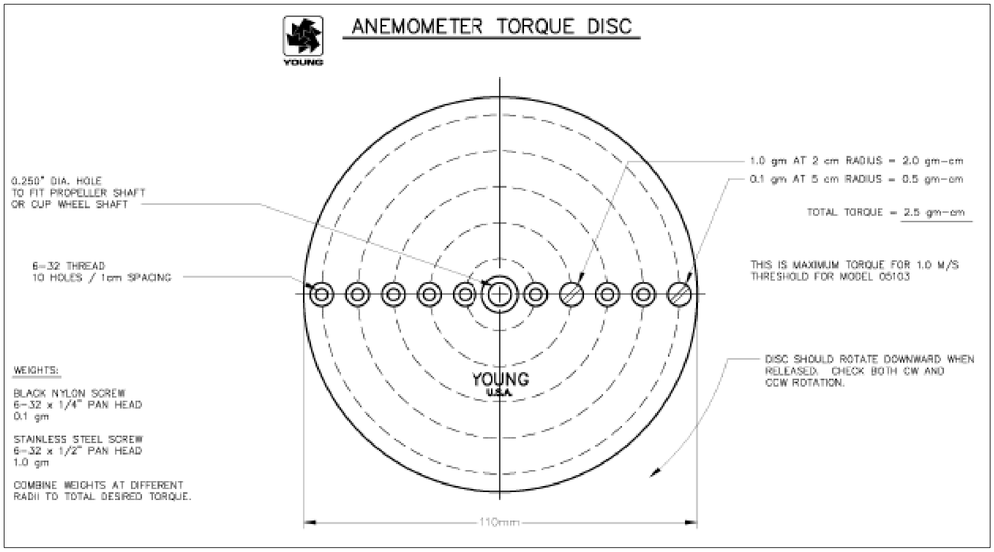

Figure S.10 R.M. Young Torque Disc

1. Remove the sensor from the tower and place it inside the station or similar structure. The area should be free of air movement.

2. Remove the tail assembly from the shaft by loosening the small hex screw, which holds the tail assembly to the shaft. Place the sensor on its side on a flat surface, which provides comfortable access.

3. Attach the torque disc to the shaft. Make sure that the center fits the shaft properly without excess slippage. The center hole will require matching to fit the shaft of some sensors (Met One 020). If the sensor has a small shaft (Climatronics F460), 1/4" tubing is inserted inside the center hole of a cup torque disk. Slide the torque disk over the shaft, with the disk face flush with the sensor shaft.

4. Record the model of the sensor on the Worksheet, and enter it into AIS. This will provide you with the associated K factor, allow for calculation of the starting threshold, and indicate the "highest allowable torque" based on a 0.5 m/s starting threshold.

5. Orient the disc such that the holes are horizontally positioned from the shaft. Screw in a weight at the appropriate distance from the center hole to correspond to the estimated starting threshold torque. The nylon screws weigh 0.1 gm and the stainless steel screws weigh 1.0 gm.

6. If the disc does not turn, continue moving the weight until the disc turns. The torque can be increased or decreased by moving the weight further from, or closer to, the center, or combining different weights at different radii. The minimum weight used to get the disc to turn will determine gm-cm torque. If multiple weights are used, then the gm-cm are added for the total torque.

7. Once a torque is determined, test both directions of rotation by spinning the disc 180 degrees to see if the same weight will also turn the disc.

8. Record the gm-cm value from this measurement on the Worksheet.

S.2.4.4 POST-AUDIT CHECKS

After the performance audit is completed, the sensor should be checked to determine if it is operating correctly.

1. Check the sensor orientation. The sensor orientation should be re-verified by manually comparing the vane alignment to the cross-arm. The sensor orientation should not have changed from the pre-audit results. If the sensor orientation has changed, consult with the station operator and take corrective action as necessary.

2. Check the sensor movement. During windy conditions, the sensor should rotate freely and point into the wind. If the sensor does not rotate freely, consult with the station operator and take corrective action as necessary.

3. Check the data. Visually determine the general direction the sensor is indicating and compare it to the DAS values. They should be reasonably close (within ±5 degrees). If they are not, consult with the station operator and take corrective action as necessary.

S.2.5 AUDIT DATA CALCULATIONS

1. Declination Adjustment:

   Since wind direction sensors are oriented to true North, and the audit compasses operate with respect to magnetic North, it is necessary to adjust for the local declination. The declination is the angular difference between magnetic North and true North and is caused by variations in the Earth's magnetic field. The declination is found online here:

   https://www.ngdc.noaa.gov/geomag/calculators/magcalc.shtml#declination

   The magnetic orientation of a wind direction sensor is found by subtracting the declination from 360°.

2. Sensor Input Conversion:

   The wind direction sensor transducer or potentiometer converts the angle of wind direction into output voltage. The translator converts this output voltage into degrees. The audit is concerned with the accuracy of the entire wind direction system (wind direction sensor, translator, and data logger), so the read-out from the station's DAS, in degrees, is a sufficient check of the system.

3. Starting Threshold Speed:

   The QAS audit program (AIS) calculates the starting threshold by using the following equation:

   $$T = Ku^2$$

   Where: T is the torque
   u^2 is the square of the wind speed
   K is the constant supplied by the manufacturer

   The torque formula is converted to provide the starting threshold speed by the following relationship:

   $$\text{Starting Threshold} = (\text{Measured Torque/K Factor})^{1/2}$$

The calculated starting threshold should be less than or equal to the manufacturer's specifications for starting threshold. AIS calculates and displays the "highest allowable torque" based on a starting threshold limit of 0.5 m/s.

S.2.6 MAINTENANCE AND VERIFICATION

Care should be taken to keep all equipment clean and in protective cases when not in use.

The accuracy of the degree fixtures is based on correct installation of the fixture on the sensor shaft and interpretation of the direction indicators. Thus, calibration checks are not part of the equipment's accuracy.

Weights for the torque wheels threshold tests should be verified on a scale annually.

S.3.0 WIND SPEED (WS)

S.3.1 INTRODUCTION

Horizontal wind speed (HWS) sensors commonly utilize a cup or propeller assembly turning on either a vertical or a horizontal axis. The aerodynamic shape of the cups convert the wind pressure into torque. This will turn a shaft that is supported in low friction, precision bearings. The shaft rate of rotation is converted to wind speed by the use of a transducer. This process is known as the transfer function. Ideally, there is a linear relation between rate of rotation and wind speed (WS), above the starting threshold. A performance audit on this sensor provides physical verification that: 1) the sensor's starting threshold is within allowable tolerances, and 2) the transducer is properly converting cup rate of rotation in revolutions-per-minute (rpm) to wind speed.

The vertical wind speed (VWS) sensors typically employ a helicoid four-blade propeller. A miniature tach-generator produces an analog voltage proportional to the axial wind component. When propeller rotation reverses, signal polarity reverses. This produces a plus (+) or minus (-) direction of rotation. Performance audits verify starting threshold, rpm to wind speed conversion, and proper signal polarity reversal. VWS data is now rarely reported to the U.S. EPA's Air Quality System (AQS) in California, and VWS audits are no longer conducted by QAS.

An operator who is familiar with the meteorological equipment should be present during the audit to perform the required manipulations of the tower and sensors.

S.3.2 GENERAL OPERATING PROCEDURES

S.3.2.1 WIND SPEED SENSOR THRESHOLD TESTING

The starting threshold of a wind sensor is a function of torque. To relate the torque measured to wind speed and offset angle, a K-value is required, either from the manufacturer or from an independent test. K-values for known sensors have been entered into the Audit Information System database for calculation purposes. The sensor is removed from its location on the tower and the cups or propeller assembly are removed. The sensor is positioned horizontally to allow free access to the shaft. A torque disc (Figure S.10) is attached to the shaft. Weights are added to the disc, which at some point will provide sufficient torque to turn the anemometer shaft. The force of gravity provides a gram-centimeters (gm-cm) torque at the center of rotation. This gram-centimeters torque applied equals the weights and distances when the weights are in the same horizontal plane as the shaft. The wind speed starting threshold should be less than or equal to the manufacturer's specifications for starting threshold.

S.3.2.2 WIND SPEED ACCURACY VERIFICATION

The cups/propeller are removed from the sensor and a variable speed motor is attached with a coupling to the sensor shaft. The motor will provide a rotation of the wind speed shaft. This will challenge the relationship between rate of rotation and output wind speed. Figure S.11 provides a diagram of the R.M. Young anemometer drive unit (control unit, motor with display, and clamp and bar assembly).

Figure S.11 R.M. Young Anemometer Drive with Motor Assembly

The rotation rate provided by the motor is shown on a large 4-digit Liquid Crystal Display (LCD). The motor rotation and time base for display are referenced to an internal crystal oscillator, which provides 0.1 rpm accuracy. A suggested comparison of five points (including 0 rpm) is performed based on the expected wind speeds for the site, up to the rated operating range of the sensor model. The rpm applied to the sensor is converted to wind speed by using the transfer function provided by the sensor manufacturer. The relationship between wind speed and rate of rotation is calculated from transfer function information previously entered into the AIS database.

Following *PAMS Meteorological Monitoring Guidance*, the accuracy of the wind speed sensor should be within 0.2 meters per second (m/s) plus 5% of the observed speed from 0.5 to 50 m/s, with a resolution of 0.1 m/s. U.S. EPA *Ambient Monitoring Guidelines For Prevention of Significant Deterioration (PSD)* cites an accuracy of within 0.25 m/s for speeds less than or equal to 5 m/s, and 5% of observed speed above 5 m/s, not to exceed 2.5 m/s. The Audit Information System allows for selection of either criteria set, with the default being PSD (or CARB) criteria.

S.3.3 AUDIT EQUIPMENT

1. R.M. Young 18802 (200-15,000 rpm range motor) variable speed anemometer drive with 18830A motor assembly. Flexible tubing and attachments of varying diameters and lengths.

2. R.M. Young 18310/18312 torque disc (Range: 0.0-5.4 gram-centimeters). Nylon and stainless steel screws weighing 0.1 gram (gm) and 1 gm respectively.

3. Field service tools, including allen wrenches and screwdrivers.

4. QA Audit Worksheet for MET Sensors (Worksheet, Figure S.2) and Audit Information System (on laptop or computer) for calculations and accuracy criteria.

S.3.4 PERFORMANCE AUDIT PROCEDURES

NOTE: If wind direction (WD) is to be audited, refer to Section S.2.0 for wind direction boom orientation procedures before having the station operator take the MET tower down or make any changes to sensor positioning. In addition, data channels should be taken offline or flagged appropriately during the audit.

Prior to beginning the audit, inspect the condition of the wind speed sensor, cups/propeller, and associated cables. Review the maintenance and calibration records for the sensor. Record all pertinent information on the Worksheet, including the units (m/s, knots, mph, or km/h) used by the station. The WS sensor threshold test can be done before or after the accuracy test.

S.3.4.1 WIND SPEED SENSOR THRESHOLD TESTING

It is recommended to have the operator disconnect the wind speed sensors from the electrical connections on the tower and remove the cups/propellers. Alternatively, with appropriate care and expertise, this can be done by the auditor. The sensor should be tested in an area free of wind or excess air movement.

1. Rotate or spin the shaft while listening to the sound of the bearings. The sound of abrasion or scraping, or abnormal rotation, may indicate an issue with the bearings.

2. The orientation of the wind speed sensor shaft will vary according to the type of sensor being audited. If a R. M. Young wind monitor is being audited, the sensor can be supported in its normal operating position. The R.M. Young sensor can be positioned in the R.M. Young wind direction degree wheel (with the tower mount fixture removed) on a bench or table. If the sensor is of the Climatronics F460 or Met One design, it is placed on its side, horizontally. Make sure that there is good access to the shaft and that it has freedom to turn easily.

3. The desired torque value, starting threshold speed, and K-factor are based on the sensor's specifications, and are pre-programmed into the Audit Information System. Record the model information and serial number on the Worksheet. Refer to section S.3.5 for the torque to starting threshold speed conversion formula.

4. There are two types of weights provided with the disc. There are the black nylon screws weighing 0.1 gram (gm), and stainless steel screws that weigh 1.0 gm. The weights can be combined at different radii to provide a total torque of up to 5.4 gm-cm. The nylon screws are typically used in wind speed torque measurements.

5. If any rough spots were noted in step 1, it is best to start the torque measurement at this point. Depending on the sensor model being audited, attach the appropriate torque disc to the shaft. Make sure that the fit is secure without excess slippage.

   - Place a nylon screw (0.1 gm) in the last hole from the center on the torque disk (refer to Figure S.10).

   - Orient the torque disk so that the screw is in a horizontal position.

- Release the torque disk and observe its response.
- If the screw moves from horizontal, the starting threshold is equal to, or less than 0.5 gm-cm. If the screw does not move from horizontal, the starting threshold may be greater than 0.5 gm-cm.
- Either the weight is moved to another hole inward from the center to decrease the torque, or another weight is added.
- The procedure is repeated until the torque disk stops moving from horizontal, determining the torque in gm-cm.

6. Record the measured torque on the Worksheet and enter the value into AIS. The wind speed starting threshold should be less than or equal to the manufacturer's specifications for starting threshold. AIS calculates and displays the "highest allowable torque" based on a starting threshold limit of 0.5 m/s.
7. Remove the torque disc from the sensor and proceed with the audit.

S.3.4.2 WIND SPEED SENSOR ACCURACY VERIFICATION

This procedure applies to those sensors that have cups/propellers that can be removed from the sensor shaft. If a sensor does not have removable cups/propellers, it may be possible to perform the audit by fabricating an appropriate coupling. If this cannot be done, the audit cannot be conducted.

The rate-of-rotation check is performed with the sensor electrical lines intact. It may be necessary to disconnect the sensor from the tower, and reconnect electrical lines in order to orient the sensor horizontally. Suggested input rotations are based on the expected wind speeds for the site, up to the rated operating range of the sensor model (which can be found in AIS). Five points should be covered, including zero, 2 m/s, and three additional evenly spaced upscale points. If desired, the full range of the sensor can be tested; however, this may not always be possible due to the limitations of the anemometer drive. Table S.1 shows examples of RPM ranges for common wind speed sensors. Normally, at zero rotation, there is a positive value on the station's data acquisition system (DAS) that represents the starting threshold value. The actual wind speed input is calculated by using the manufacturer's transfer function for the sensor.

Table S.1 Examples of RPM Ranges for Common WS Sensors

Manufacturer	Model	Range (m/s)	10%	30%	50%	90%	MAX
			% of range (RPM)				
Climatronics	100075	0 - 56	240	720	1200	2160	2400
Met One	010-C	0 - 50	185	555	925	1665	1850
R.M. Young	05305	0 - 50	185	555	925	1665	1850
R.M. Young	05103	0 - 100	2050	6150	10200	18360	20500

*15000 RPM = max range of the drive unit

1. Observe the orientation of the cups/propeller to determine the direction of rotation. This rotation can either be clockwise (cw) or counterclockwise (ccw). Remove the cups/propellers from the shaft. Ensure there is no rotation. Record the reading from the station's DAS on the Worksheet. This will be the zero rpm value.

2. Using the appropriate accessories (stiff tubing or a vendor-provided coupling) for the model being audited, attach the rpm motor to the shaft of the sensor. Once the motor is attached, plug the rpm motor into the anemometer drive (drive) and support the motor using the clamp and bar. If necessary, adjust the motor to ensure smooth rotation of the sensor tip.

   NOTE: Care should be taken at this step so that the propeller shaft turns at exactly the same speed as the motor. Any drag will produce erroneous readings.

3. If electricity is available, use the power adapter to provide power to the anemometer drive unit. Otherwise, run the drive on battery power. Turn the unit on and select the desired rotation rate (in rpm) by adjusting the rate on the anemometer drive. The rotation direction switch should be set to coincide with the normal rotation direction of the sensor cups/propeller (see step 1).

4. The motor will start turning the shaft and the control unit display will show a value. The display should be monitored to verify the stability of the rotation rate. Leave the motor at the specified speed until a constant reading can be recorded from the control unit display and station's DAS. Usually, a minute or less is adequate to show stability.

Record the input speed and sensor output speed on the audit worksheet.

5. Adjust the rpm value on the drive to the next desired reading. Be sure to keep the motor supported and the coupling properly aligned as the speed increases. Record readings on the Worksheet after stabilization occurs.

6. Repeat step 5 until five points are covered, including zero, 2 m/s, and three additional evenly spaced upscale points.

7. The five point wind speed verification is now complete. Turn off the power switch and disconnect the motor from the sensor. Disconnect the motor from the console. Disconnect the power adapter, if used.

8. Enter the data from the Worksheet, into the Audit Information System. The measured wind speed above the starting threshold should be within 0.25 meters per second (m/s) at speeds equal to or less than 5.0 m/s, and above 5.0 m/s it should be within ±5.0% of the observed speed (not to exceed 2.5 m/s difference). If the station is following PAMS guidelines, an alternate criteria can be selected in AIS: $\leq \pm 0.2$ m/s + 5% of observed.

S.3.5 AUDIT DATA CALCULATIONS

The AIS program will calculate the percent difference and starting threshold by using the following equations:

The actual wind speed (velocity) in meters per second (m/s) is calculated by applying the manufacturer's slope and intercept to the rpms of the audit device:

$$\text{Velocity} = \text{Reference RPM} * \text{Slope} + \text{Intercept}$$

The indicated speed of the sensor in m/s is calculated by multiplying the station's reported speed by a commonly known conversion factor (see Section S.5.5):

$$\text{Indicated Speed (m/s)} = \text{Reported Speed} * \text{Conversion Factor}$$

The conversion factor converts the station's units (knots, mph, etc.) into m/s. The percent difference is calculated from these two values.

The starting threshold is calculated using the measured torque (gm-cm) and the manufacturer's K-factor:

$$\text{Starting Threshold} = (\text{Measured Torque/K-Factor})^{½}$$

The calculated starting threshold should be less than or equal to the manufacturer’s specifications for starting threshold. AIS calculates and displays the “highest allowable torque” based on a starting threshold limit of 0.5 m/s.

S.3.6 MAINTENANCE AND VERIFICATION

S.3.6.1 R.M. YOUNG ANEMOMETER DRIVE UNIT

1. Periodic battery replacement is required (two 9 Volt alkaline or lithium batteries). The decimal points on the console display will blink when the voltage is low on the batteries.

2. Turn the power off when the unit is not in use and perform wind speed sensor audits in an efficient manner. Be careful not to drop the control unit or motors.

3. A verification of the generated rotation rate by comparison to a photo-tachometer or frequency counter is performed on an annual basis by the Standards Laboratory. Alternatively, the output of the integral high resolution optical encoder can be measured from a jack on the side of the console case. This output is connected to an external frequency counter (digital multimeter) to further confirm the motor speed. If there is any discrepancy between the selected rpm rate and the measured rpm rate, the manufacturer can be contacted to initiate a troubleshooting/repair sequence or return the defective unit to the factory.

S.3.6.2 R.M. YOUNG TORQUE DISC

1. Keep the disc and weights clean. Dirt, lint, etc. may add weight and affect the balance of the wheel.

2. Periodically, inspect the center hole of the disc for excessive wear to ensure that the disc continues to fit properly onto the anemometer shaft. If the center hole is too large or abraded, the disc should not be used for the torque measurement on that sensor.

3. The weights (0.1 and 1.0 grams) should be verified on a scale on an annual basis.

S.4.0 OUTDOOR TEMPERATURE (OT)

S.4.1 INTRODUCTION

For air quality applications, outdoor (or ambient) temperature (OT) is measured with a temperature probe in degrees Celsius (°C). The probe can be a thermistor, resistance temperature detector (RTD), or thermocouple. The probe should be located in a radiation shield to protect it from the effects of solar heating and wind variations. The shield can be naturally aspirated. However, a motor aspirated shield is strongly advised since its use will minimize potential radiation errors. The ambient temperature probe audit is performed by removing the probe from the radiation shield and immersing it, together, with the audit thermistor probe in water baths of three temperatures (cold, ambient, and hot). The results of each check are compared to provide the accuracy of the station temperature system. If the station ambient temperature probe cannot be immersed in water, a single-point comparison can be done as a check of the system. An operator who is familiar with the meteorological equipment must be present during the audit to perform the required manipulations of the tower and sensors.

S.4.2 GENERAL OPERATING PROCEDURES

The audit standard for OT audits is a thermistor with the following characteristics:

- Measurement range: -50°C to +50°C
- Accuracy: ≤ ±0.2°C NIST-traceable and certified over a range of -30°C to +30°C
- Resolution: ≤ ±0.1°C
- Re-Certification: annual

Figure S.12 shows an example of a digital thermometer and thermistor probe.

Figure S.12 Digital Thermometer and Probe

The audit standard probe (standard) and station temperature probe are inserted in three water baths of varying temperatures. Each water bath is held in a container designed to minimize temperature fluctuations. The standard and the station temperature probe readouts are compared. Following EPA Volume IV (Quality Assurance Handbook for Meteorological Measurements), the agreement should be ±0.5°C between the temperature readout of the audit standard and the station temperature probe. If the station temperature sensor cannot be in contact with water, a collocated check can be performed. The collocated check is a single-point comparison of the temperature readings from the audit thermistor and the station sensor. This comparison is performed by placing the audit thermistor within 5" of the station sensor, then recording the values from both temperature systems. The results are used to provide a check of the accuracy of the station sensor, but do not meet the criteria for an audit.

S.4.3 <u>AUDIT EQUIPMENT</u>

1. Digital thermometer and thermistor probe meeting the criteria outlined in section S.4.2.

2. Three containers for water that minimize temperature fluctuations (i.e., Thermos® or similar).

3. Ice water (at or near 0°C), ambient water (approximately 20°C), and hot water (near 40-45°C).

4. QA Audit Worksheet for MET Sensors (Figure S.2) and Audit Information System (on laptop or computer) for calculations and accuracy criteria.

S.4.4 PERFORMANCE AUDIT PROCEDURES

S.4.4.1 WATER BATH METHOD

Prior to using the water bath method, have the operator verify that the station sensor can be immersed in water. If it cannot be immersed, a collocated check can be performed (see Section S.4.4.2). The collocated method should be used if there is any concern that water may harm the station sensor.

In addition, ensure the station operator has flagged the station's DAS or marked the channel offline to avoid reporting erroneous readings.

1. Prepare the water baths a few minutes prior to the audit to allow temperature equilibrium to be reached. Pour ice into one of the containers. Fill it about one-half to three-quarters full of ice. Pour water over the ice, until it is nearly full, depending on the length of the sensor probe. The bath should be an easily penetrable slurry. Prepare the ambient temperature bath using tepid tap water. Heat water in the third container to about 40-45 degrees. With lids on, the containers can be shaken to ensure consistent water temperature.

2. Complete the Worksheet for the temperature sensor by recording instrument and calibration information, as appropriate.

3. Turn on the digital thermometer, allowing it to equilibrate to current conditions.

4. Remove, or have the operator remove, the station temperature probe from the radiation shield. The operator should check the probe for any signs of cracking or material degradation prior to immersion in the water baths. If there is visible damage to the probe do not proceed with the audit, until repairs or replacement are made. Also, have the operator re-verify that the station temperature probe can be immersed in water.

5. Immerse the audit probe and station temperature sensor into the ice bath. Gently agitate the water by moving the probe around. After

about 30 seconds, stop the agitation. The audit thermometer reading should be near 0°C. If it is not, repeat the agitation procedure.

CAUTION: Do not immerse either probe in the solution up to the connector caps. The station sensor may have exposed wires leading into the probe (e.g. Climatronics 10093 sensor). In this case, the station probe should only be immersed in the water bath from 1/2 to 3/4 of the probe length. This will prevent water from leaking into the electrical connections. Keep the two probes within 1" of each other in the water and at the same depth (i.e. the probes can be closer than 1" of each other, but not greater than 1" apart). During the audit, a cloth may be placed around the probes to cover the opening of the thermos container. This will help to keep the bath temperature constant.

6. When the station and audit temperature readings are stable (1 to 2 minutes without fluctuations greater than 0.1 to 0.2 degrees), record the audit standard temperature and the station sensor temperature values (from the station's DAS) on the Worksheet and in AIS.

7. Move the audit thermistor and station probe to the ambient temperature water bath.

8. Repeat steps 5 and 6 for the ambient bath and the hot bath.

9. Remove the audit thermistor from the water bath, and turn it off.

10. Place, or have the operator place, the station probe back into the radiation shield.

11. Check the electrical connections of the station probe and radiation shield. If the radiation shield is motor aspirated, verify that the aspirator fan is operating. Visually check the radiation shield for an excessive amount of dirt, insects, etc. Note any abnormalities on the Worksheet.

S.4.4.2 COLLOCATED METHOD

Until alternate methods can be developed, a collocated temperature check can be performed if the station probe cannot be immersed in water. Unfortunately, unless a wide variation in temperatures can be challenged (covering the range of the sensor), this method does not substitute for a performance audit.

1. Turn on the digital thermometer. Place the thermometer outside to equilibrate to ambient conditions.

2. Position the audit thermistor as close as possible to the temperature sensor (no greater than 5 inches apart). Protect the audit thermistor from direct sunlight or excessive air movement as much as possible. If feasible, the thermistor may be positioned near the air intake of the radiation shield. The operator may be required to position the audit thermistor, if the station sensor cannot be accessed from the ground.

3. When the audit thermometer and station (DAS) temperature readings are stable, record the values on the Worksheet, and as a comment in AIS.

    a. If time allows, and there is sufficient variation in the temperature (i.e., 5-10 degrees difference from other points), multiple comparison readings can be taken.

    b. Turn off the audit standard, and replace, or have the operator place, the station probe back into its normal operating position.

    c. Check the electrical connections of the station probe and radiation shield. If the radiation shield is motor aspirated, verify that the aspirator fan is operating. Visually check the radiation shield for an excessive amount of dirt, insects, etc. Note any abnormalities on the Worksheet.

S.4.5 POST-AUDIT CHECK

After completing the audit and reinstalling the station probe back into its normal operating position, check for correct sensor operation.

1. Determine the ambient air temperature using the audit thermometer by holding the thermocouple in the air for approximately two minutes.

2. Compare the ambient temperature to the temperature on the station data logger and/or chart recorder. The temperatures should be reasonably close, within +3°C, depending on the current ambient conditions. If the temperatures are not close or the station temperature sensor is malfunctioning, consult with the station operator and take appropriate action as necessary.

3. Remind the operator to mark the DAS channel as back online, or change flags, as appropriate.

S.4.6 AUDIT DATA CALCULATIONS

The U.S. EPA Volume IV QA Handbook states that the difference between the station temperature probe and the audit temperature readings be less than or equal to 0.5°C. The measured audit thermometer value is corrected by applying the slope and intercept from the annual calibration. The audit computer program (AIS) will automatically apply the correction factor, so only the raw audit thermometer values are required.

S.4.7 MAINTENANCE AND CERTIFICATION

The digital thermometer requires replacement of the batteries as needed.

The thermistor should be checked for any damage to the probe, the probe to cable interface, and connector plug, prior to each audit.

The digital thermometer and thermistor are certified annually by the Standards Laboratory, or a NIST-traceable certification facility.

S.5.0 BAROMETRIC PRESSURE (BP)

S.5.1 INTRODUCTION

Barometric pressure measurements can be used in modeling or used to correct an ambient measurement to standard conditions (25°C and 760 millimeters of mercury). For air quality and meteorological purposes, atmospheric pressure is generally measured with mercury, aneroid, or electronic barometers. Most electronic barometers of recent design use transducers that transform the sensor response into a pressure-related electrical quantity in the form of either analog or digital signals. Current digital barometer technology employs various levels of redundancy to achieve long-term stability and accuracy of the measurements.

Pressure is commonly measured in millibars (mb). However, barometric pressure can also be expressed in other units such as millimeters of mercury (mmHg), inches of mercury (inHg), hectoPascal (hPa), or pound per square inch (psi). The hectoPascal is the common expression for

International System of Units and is equivalent to millibars. The audit barometric pressure value is provided in mmHg. The formulas for converting units are provided in Section S.5.5.

S.5.2 GENERAL OPERATING PROCEDURES

The audit standard for BP audits is a NIST-traceable aneroid barometer with the following minimum characteristics:

- Measurement accuracy: ± 1 mb (0.75 mmHg)
- Measurement resolution: 0.1 mb (0.075 mmHg)
- Measurement range: 750 – 1050 mb (562.5 – 787.6 mmHg)

Figure S.13 shows an example of a digital aneroid barometer. The audit standard is collocated with the station’s barometer and a comparison is made. Conditions for both instruments should be the similar, including elevation, temperature, and environment, to eliminate any bias. The audit standard has a calibration slope and intercept that are derived from an annual certification, and are applied to the display reading when entered into the Audit Information System. The resultant value (in mmHg) is compared to the value from the station's barometric pressure sensor. CARB and U.S. EPA criteria require the station's sensor to be ≤ ± 2.25 mmHg (3 mb) from the audit standard.

Figure S.13 Example of a digital barometer (Vaisala PTB330)

S.5.3 AUDIT EQUIPMENT

1. NIST traceable aneroid barometer meeting the criteria outlined in Section S.5.2.

2. QA Audit Worksheet for MET Sensors (Worksheet, Figure S.2) and Audit Information System (on laptop or computer) for calculations and accuracy criteria.

S.5.4 PERFORMANCE AUDIT PROCEDURES

Turn on the audit barometer. The barometer only needs a few seconds to stabilize before digital readings are available. Ensure the barometer is at an elevation similar to the station’s barometer, within a meter or so (1 meter difference can be equal to approximately 0.09 mmHg).

1. Record the instrument information requested on the audit worksheet. Confirm, with the station operator, the units provided by the station’s DAS.

2. Record the value from the van's barometer and the station's barometric pressure on the audit worksheet.

3. Repeat step 2, at various times throughout the day, two more times.

4. Enter the values into the computer to calculate the differences.

S.5.5 AUDIT DATA CALCULATIONS

The value from the audit barometer should be entered into AIS using the audit computer. The program will automatically apply the audit barometer’s slope and intercept to the display value. The error between the audit barometer and the station barometer should be ≤ ± 2.25 mmHg (3 mb) to meet CARB and U.S. EPA Volume IV guidelines.

If the station's readout is not in mmHg, a conversion program or the following formulas may be used to convert units:

Millibars x 0.7500616	=	Millimeters of mercury
Millibars x 0.02953	=	Inches of mercury
Millibars x 0.014504	=	Pounds/Square inch
Inches of Mercury x 33.864	=	Millibars

Inches of Mercury	x	25.4	=	Millimeters of mercury
Inches of Mercury	x	0.4912	=	Pounds/Square inch

S.5.6 MAINTENANCE AND CERTIFICATION

No specific maintenance is required beyond the usual care of electronic instrumentation.

The audit barometer is calibrated by the Standards Laboratory on an annual basis.

S.6.0 SONIC SENSORS

S.6.1 INTRODUCTION

Sonic anemometer systems are based on the principle that wind changes the transit time of a sound pulse across a fixed distance. Sonic systems can be designed in two dimensions for horizontal wind speed and direction as a replacement for the cup and vane or propeller units, or in three dimensions for both horizontal and vertical wind measurements. For those applications where the contribution of small eddies is important, sonic systems are an excellent choice. Sonic anemometers are being used in routine air monitoring networks; and are becoming more prevalent as technologies improve. Because the measurements are based on a different principle, sonic systems produce results that are difficult to compare with conventional systems in a timely manner.

For audits of sonic anemometer systems, collocation of a mechanical sensor (such as a cup/vane or aerovane anemometer) or another sonic system is required, but field implementation of these techniques is very limited. The Collocated Transfer System (CTS) method involves mounting carefully calibrated wind monitors in the vicinity of the sensor being audited. A comparison of the data generated is usually done over 72 hours. When the input conditions are not controlled, as with the CTS method, the accuracy determination has a larger uncertainty. Additionally, this method does not provide a measure of the starting threshold.

Due to the aforementioned limitations and the impracticality for field implementation, sonic sensors are not currently audited by QAS. Verification of orientation and sensor certification is performed when possible. Figure S.14 shows an example of a sonic anemometer.

A portable system capable of providing wind speed and direction verification for sonic systems is currently in development, and documentation will be issued at a later date.

Figure S.14 R.M. Young 3D Ultra Sonic Anemometer

S.6.2 VERIFICATION PROCEDURES

To ensure sonic sensors are functioning properly, certification from the manufacturer is required and should be valid from the date of installation. Auditors should document sonic sensor information, including serial number, certification date, and (if available) the installation date, in the Audit Report. In addition, an orientation check should be performed as instructed below.

S.6.2.1 ORIENTATION CHECK

Depending on the manufacturer or model, the methods for determining and maintaining proper orientation may vary, and the operations manual should be consulted. For example, a Met One model 50.5 sensor has markings for alignment and set-screws to ensure fixed orientation. When properly aligned, the R.M. Young model 81000 has a junction box that faces south. Figure S.15 shows an example of alignment verification for the R.M. Young model 81000. In all cases, the sensor should be oriented to True North. When a compass is used for verification, the reading should be taken away from influencing factors and should be corrected for declination of the magnetic north pole.

Auditors should perform an orientation check on the alignment of the sonic sensor and document it in the Audit Report. Assuming a compass is used, documented information should include the magnetic declination for the site and the sensor's orientation to magnetic north.

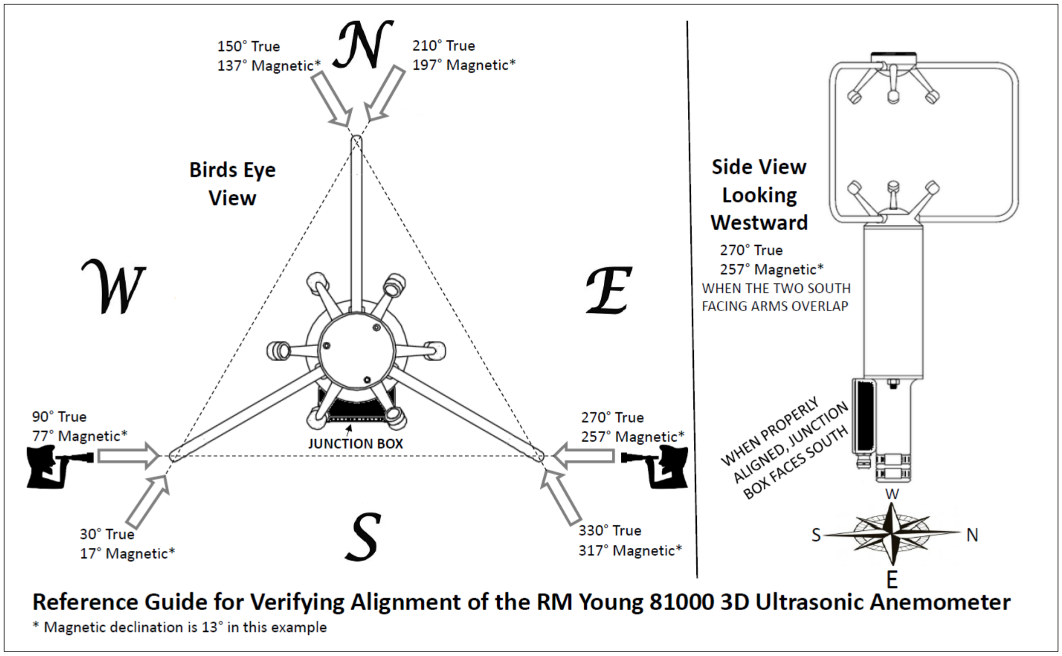

Figure S.15 Example of Verifying Alignment of the R.M. Young 81000 3D Ultrasonic Anemometer

S.6.3 VERIFICATION EQUIPMENT

The verification of alignment for sonic sensors requires a compass, binoculars with internal compass, or GPS. Documentation should be entered into the Audit Information System as a "comment" or "action item", as appropriate.

S.7.0 AUDIT CRITERIA

After all data has been entered into the Audit Information System and reviewed for accuracy, any exceedances of established audit criteria (see Table S.2 below) or deviation from operational standards may result in corrective action.

Currently, performance audits of meteorological parameters fall under the "Operational" category in the U.S. EPA's Quality Assurance Handbook, Volume IV, Appendix C (March 2008). This means a Corrective Action Notification (CAN) should be issued for most violations. Refer to CARB's Air Monitoring Quality Assurance Manual-Volume V: Audit Procedures for Air Quality Monitoring, Appendix AN for more information. However, if air quality data is adversely affected, management may reserve the right to issue an Air Quality Data Action (AQDA). Refer to CARB's Air Monitoring Quality Assurance Manual-Volume V: Audit Procedures for Air Quality Monitoring, Appendix AO in such cases.

Table S.2 Summary Table of Audit Criteria

Parameter	Tested Range	Acceptance Criteria (Compared to the Audit Standard)
Wind Speed	between 0.5 and 5 m/s	≤ ± 0.25 m/s
Wind Speed	above 5 m/s	≤ ± 5% (not to exceed 2.5 m/s)
Wind Speed	starting threshold	≤ 0.5 m/s, or manufacturer's specifications
Wind Direction	combined accuracy and orientation error	≤ ± 5°
Wind Direction	starting threshold	≤ 0.5 m/s, or manufacturer's specifications
Outdoor Temperature	0 – 50 °C	≤ ± 0.5 °C
Barometric Pressure	ambient conditions	≤ ± 2.25 mmHg (3 mb)

S.8.0 REFERENCES

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S.9.0 REVISION HISTORY

Subject	Revision 3 (2019)
New or Revised Sections	Added 'Acronyms and Definitions' section Added section for 'Acceptance Criteria' Added 'References' section Added 'Revision History' section Section regarding verification of sonic sensors added Relative humidity audit procedures removed Solar radiation sensor audit procedures removed Vertical wind speed audit procedures removed
Calibration and Audit Criteria	Starting threshold for wind speed and wind direction is now based on manufacturer's specifications rather than a fixed value
Audit Procedures	Removed reference to Waters torque watch gauge Removed "Manual Orientation" from WD Removed 3-point audit of non-submersible OT sensors; replaced with single-point verification Added verification of sonic sensor orientation and certification