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Meterological Monitoring
Quality Assurance Plan

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1.0 PURPOSE AND FOCUS OF THE MET QA HANDBOOK

The purpose of this Quality Assurance handbook is to provide information and guidance for both the meteorologist and non-meteorologist who must make judgments about the validity and representativeness of meteorological data and the accuracy of the individual measurement systems. In addition to this, data quality is also dependent on many factors including location, upkeep, topography, and time.

The focus of this manual is to provide the reader with background information regarding siting, installation, routine operation, maintenance, and calibration of sensors and equipment. The handbook contains procedures for the quality assurance of measurement systems and collected data. Adherence to all operational and quality assurance guidelines is crucial to maintaining maximum data integrity.

Although the number of parameters collected at a meteorological site varies with the purpose of data collection, only the most fundamental parameters will be discussed. Definition, purpose, and general guidance are provided for each parameter, followed by a brief discussion of special considerations for the tower and site. The parameters discussed in this handbook are:

1. Wind Speed
2. Wind Direction
3. Temperature
4. Relative Humidity
5. Precipitation
6. Barometric Pressure
7. Solar Radiation
8. UV-B

The information and guidelines provided in this manual are derived from procedures and equipment used by the Maine Department of Environmental Protection.

2.0 SITING AND EXPOSURE

Siting (horizontal and vertical placements of probes) and exposure (spacing from obstructions) of meteorological instruments and towers for eight parameters are covered in this section. The collection of quality meteorological data for the purposes of modeling and monitoring becomes increasingly difficult as more variables are introduced. Complex terrain, coastal sites, and other topographic settings that exert a major influence on local flow make establishing and operating a meteorological site even more complicated.

Site an instrument away from the influence of obstructions such as buildings and trees, and locate it in a position that measures conditions representative of the general state of the atmosphere for that area. Secondary considerations, such as accessibility and security, must be taken into account but not allowed to compromise the quality of data collection. To avoid errors that may affect the integrity of the data, obtain consultation and approval for site or equipment selection and site operation from the Maine Department of Environmental Protection (DEP).

2.1 GENERAL GUIDANCE

2.1.1 Wind Speed

Although wind is a vector quantity and may be considered a primary variable in itself, wind speed (magnitude) and direction (orientation) are considered separately as scalar parameters more commonly. Wind speed is used in dispersion models to determine the dilution of pollutants in a plume. Wind speed and other indicators of atmospheric stability are used in modeling to determine the dispersion of a plume.

2.1.2 Wind Direction

Wind direction is defined generally as the orientation of the wind vector in the horizontal. Wind direction for meteorological purposes is the direction *from which the wind is blowing* and is measured in degrees clockwise from **TRUE NORTH**. In a dispersion model, wind direction determines the transport direction of a plume. The standard deviation of the wind direction, known as sigma theta, also may be derived from the wind direction and may be used with wind speed to characterize atmosphere stability.

A. Probe Placement

The standard height of wind instruments over level, open terrain is 10 meters (m) above the ground. Open terrain is defined as an area where the distance between the instrument and any obstruction is at least ten times the height of that obstruction. Take the slope of the terrain near the site into account when determining the relative height of an obstruction. The obstruction may be man-made (buildings, industrial stacks) or natural (hills, trees). Document the sensor height, its height above obstructions, and the height or character of nearby obstructions. Where an ideal exposure is not available, install the anemometer at the 10 meter level above the ground. Using the following table as a guide, site the tower to achieve the best exposure for the wind speed sensor.

DISTANCE FROM TOWER (M)	SLOPE (BETWEEN) %	MAX. OBSTRUCTION OR VEGETATION HEIGHT (M)
0 - 15	± 2	0.3
15 - 30	± 3	0.5 - 1.0 (most veg. <0.3)
30 - 100	± 7	3.0
100 - 300	± 11	10 x ht. must be less than distance to obstruction

In terrain with significant topographic features, different levels of the tower may be under the influence of different meteorological regimes at the same time. Such conditions should be well documented.

If the source emission point is substantially above 10m, make additional wind measurements at the lesser of either stack-top height or 100m. Maximum practical meteorological tower heights are about 100m. Determine wind data at heights greater than 100m by remote sensing or SODAR. To develop site-specific wind profiles, locate instruments at multiple heights (at least three). For facilities with more than one stack, determine the number and height of each required wind measurement required individually. The factors that must be considered are the relative differences in stack heights, the magnitude of emissions from the various sources, the size of the facility, and the site specific features of the facility (terrain, demography, geography, etc.).

B. Obstructions

Buildings

Aerodynamic effects from buildings and other major structures, such as cooling towers, play a crucial role in the siting of a meteorological tower. If wind instruments must be mounted on a building or other large structure because of lack of suitable open terrain, locate the meteorological tower at a sufficient height to avoid the aerodynamic wake of the structure. Approximately 2.5 times the height of the building is a good estimate of the total depth of a building wake. This is particularly critical for wind speed and wind direction sensors since they will be unduely influenced by the wake effects of the obstruction.

Trees

Consider tree growth rates and the seasonal variations of deciduous species when siting. For dense, continuous forest growth where an open exposure is unavailable, take measurements at 10m above the height of the vegetative canopy.

Towers

Sensors mounted on towers are used frequently to collect wind speed measurements at more than one height. To avoid the influence of the structure itself, do not use closed towers, stacks, and similar structures to support wind collection instruments. Open-lattice towers are preferred. Locate towers at or close to plane elevation in an open area representative of the area of interest.

2.1.3 Temperature

Temperature is an important parameter used in modeling. It is used to determine the amount of rise a plume will experience after exiting a source.

A. Probe Placement

The recommended heights for probe placement are 2m for temperature and 2m and 10m for temperature difference. Adjustments to the height of the temperature sensor may be necessary for sites that receive large amounts of snow, but do not place the temperature sensor above 10m. In Maine, 3m is an acceptable height. Locate the instrument over a plot of open level ground at least 9 meters in diameter and it should not be closer to obstructions such as trees and/or buildings than a distance equal to four (4) times their height. It should be at least 30 meters from large paved areas and not close to steep slopes, ridges or hollows. Also, place the instruments more than 30 meters from any water body or paved area. Securely mount a temperature instrument on a boom attached to a tower. The boom length should be at least one tower diameter/diagonal away from the tower structure and the probe should be located at the end of the boom.

B. Siting Consideration

Protection from thermal radiation and significant heat sources and sinks is critical in siting temperature sensors. Sensors should be housed in aspirated radiation shields to prevent bias of temperature.

2.1.4 Relative Humidity

Relative humidity is not used for modeling but is used to characterize ground level ozone formation and ozone transport.

2.1.5 Precipitation

Precipitation is not used by existing EPA regulatory models, although it provides useful information for the data review and validation process. Precipitation is important also in considering the effects of wet deposition.

A. Probe Placement

Mount a rain gauge so the mouth is horizontal and opens to the sky. Cover the underlying surface with short grass or gravel. Keep the height of the opening as low as possible (minimum of 30cm), but high enough to avoid splashing in from the ground and so that it will not be covered by snow. As a "rule of thumb" when siting the probe, the opening of the rain gauge should be positioned one (1) meter above the average snow level.

Standard rain gauges should be used having the design of either a weighing-type gauge or the tipping bucket-type gauge.

B. Obstructions

Nearby obstructions can create adverse effects on precipitation measurements. Avoid funneling, reflection and turbulence. Precipitation measurements may be highly sensitive to wind speed, however, especially where snowfall contributes a significant fraction of the total annual precipitation. Balancing these two opposite effects requires subjective judgment.

In sheltered areas where the height of the objects and their distance to the instrument is uniform, try to place the instruments twice the distance from the obstructions. In open areas, the distance to obstructions should be at least two, and preferably four, times the height of the obstruction.

C. Siting Considerations

In view of the sensitivity to wind speed, make every effort to minimize the wind at the mouth of the precipitation gauge. Windshields represent an essential accessory to improve the catch of precipitation, especially snow in windy conditions. One design consists of 32 free swinging but separated leaves supported ½ inch above the level of the gauge collecting orifice.

2.1.6 Barometric Pressure

The collection of on-site barometric pressure is desirable but not necessary for meteorological modeling. For dispersion calculations the standard atmospheric pressure for the station elevation often will be of sufficient accuracy to represent true pressure. See Section 4 for information on the siting of barometric pressure instruments.

2.1.7 Solar Radiation

Solar radiation is an important parameter in plume dispersion modeling. The solar radiation parameter is collected to estimate the stability characteristics of the atmosphere.

A. Probe Placement

Locate pyranometers used for measuring incoming solar radiation in a location with an unrestricted view of the sky in all directions during all seasons, having the lowest solar elevation angle possible. Sensor height is not critical for a pyranometer, but a tall platform or rooftop is desirable.

B. Obstructions

Locate pyranometers to avoid obstructions, including MET towers, that may cast shadows on the sensor at any time. Avoid light colored and artificial sources of radiation.

C. Siting Considerations

Measure solar radiation in open areas, free of obstructions.

2.1.8 UV-B

Ultraviolet-B (UV-B) is part of the radiation reaching the earth's surface from the sun. Solar UV-B has a wavelength of 280 to 315 nanometers (nm), and light in this region of the electromagnetic spectrum is responsible for many biologically harmful effects on both plants and animals. UV-B measurements provide valuable data for health effect determinations and baseline data for the possible detection of long term global changes in the stratospheric ozone layer and subsequent changes in UV-B radiation.

A. Probe Placement

Place the UV-B sensor on a stable, level platform that is not subject to movement from wind.

B. Obstructions

Avoid obstructions that may cast shadows on the UV-B sensors. Artificial light sources should not affect the sensor, but eliminate them if possible. Consider other sources that may reflect UV-B radiation and remove these before monitoring. If the reflective sources cannot be removed, they must remain for the duration of the monitoring effort.

C. Siting Considerations

The horizon and to ten degrees above the horizon should be free of obstructions in all directions. Obstructions due north of the sensor are permissible as long as the obstruction is permanent. Stable land use is an important consideration, especially for long term monitoring to determine baseline UV-B levels. Try to locate the UV-B monitor in an area that will not change substantially over time, e.g., forest land that will remain forest or a city that expects no major changes in building or pavement area. The ideal site for a UV-B monitor is on the ocean or on a 20km lake that does not freeze in winter, or on an unobstructed mountain summit.

3.0 EQUIPMENT DESCRIPTION

3.1 WIND SPEED

Wind speed measurements are made with photo-chopper type wind sensors having three-cup rotating anemometer assemblies. The interrupted light pulse frequency is passed to a translator that converts the signal to a 0-5 volt linear output suitable for continuous recording and logging.

3.2 WIND DIRECTION

Wind direction is measured with potentiometer-type sensors and counter-balanced wind vane assemblies. The potentiometer output is proportional to the position of the wind vane. The wind direction translator spreads the sensing range from 0-540 degrees for voltage outputs of 0-1 or 0-5 volts. Extending the sensing range to 540 degrees eliminates the crossover problems that occur when the vane rotates past 360 degrees.

3.3 TEMPERATURE

Temperatures are measured with dual element thermistor temperature sensors mounted in aspirated temperature shields. A bridge circuit measures the resistance of the sensor in a temperature/temperature difference translator, the difference being measured between two distinct meter levels.

3.4 RELATIVE HUMIDITY

Relative humidity is determined with an extremely accurate and sensitive sensor that responds to a full range of 0 - 100% humidity. The sensor is designed to be housed in a radiation shield when used outdoors. Certain models also contain a high-accuracy linearized temperature sensors, permitting simultaneous measurement of relative humidity and temperature.

3.5 PRECIPITATION

Precipitation is measured with a weighing-type recording gauge or a tipping-type recording gauge which can be used for collecting both liquid and frozen precipitation.

3.6 BAROMETRIC PRESSURE

The barometric pressure sensor uses an active solid-state device to detect barometric pressure. Self-contained electronics provides a regulated voltage to the solid state sensor and amplification for the signal output.

3.7 SOLAR RADIATION

Solar radiation is measured with either a black and white or photovoltaic pyranometer configured with a translator. The pyranometer measures total sun and short-wave sky radiation received at a given location. The sensor is encased in a precision ground and polished glass dome and mounted in a fixed position facing skyward.

3.8 UV-B

Two types of instrumentation are available: 1) a low cost broad band UV-B monitor, or 2) a high cost scanning spectro-radiometer. The broad band instrument will be based on the Robertson-Berger model with a spectral response of 280 to 330 nm, a cosine response of greater than ± 5% for zenith angles of 0 to 60 degrees, and temperature compensated. The unit will have a National Institute of Standards Technology traceable calibration and be calibrated against the sun. The sensor will have a zero to five volt output. The scanning spectro-radiometer will have a spectral range of 200 to 800 nm, a wavelength accuracy of 0.2 nm, and a wavelength precision of 0.1 nm. For this instrument, a double monochrometer is recommended.

Additional information and manufacturer's specifications are provided in the manuals available at each site.

4.0 INSTALLATION

4.1 GENERAL CONSIDERATIONS

From a quality assurance viewpoint, the most important aspect of installation is siting. See Section 2.0 for general siting criteria and discussion. Site selection for meteorological equipment is critical but may have to be compromised if the site is selected for other measurements, such as pollution monitoring. In such cases, situate meteorological towers and poles to record the most accurate readings, taking into account what may be unavoidable interference from trees and buildings. Occasionally the only option may be locating wind sensors so that they record wind information accurately only for the directions of primary concern; e.g., for directions that would take an effluent toward a residential area.

A single well-placed measurement site will provide representative wind measurements for non-coastal, flat terrain, rural situations. Locate the instruments over level, open terrain at a height of 10m above the ground and at a distance of 10 times the height of any nearby object. When suitable open terrain is not available, meteorological towers can be installed on rooftops or other structures. The towers must be 10 meters high or 2.5 times the height of the structure, whichever is higher, to avoid the aerodynamic effects caused by the structure.

Mount wind instruments on booms into the prevailing wind direction at a distance of at least twice the diameter/diagonal of the tower (from the nearest point on the tower) . Where the wind distribution is strongly bi-modal from opposite directions, as in up-valley and down-valley flows, mount the booms at right angles to the predominant wind directions. The booms must be sufficiently strong not to sway or vibrate in high winds to reduce the standard deviation (sigma) value bias. Folding or collapsible towers are not recommended for heights greater than twenty meters. They may not provide sufficient support to prevent vibrations and may not be rigid enough to ensure proper instrument orientation. Place the wind sensors at heights with a minimum number of diagonal cross members and above or below horizontal cross-members. Since practical considerations may limit the maximum boom length, wind sensors on large towers may provide accurate measurements only over a certain arc. In such cases, two boom systems on opposite sides of the tower may be needed to provide accurate measurements over the entire 360º arc. When using such a dual system, specify the method of switching from one system to another. A wind instrument mounted on top of a tower must be at least one tower diameter/diagonal above the top of the tower structure.

Wind sensors must be reached and removed easily for routine maintenance, inspections, and repairs. Plan for accessibility before installation. Sensors can be reached by elevators, telescoping towers, or climbing. Any damage to the delicate sensors most likely will occur during the trip up and down the tower and during removal and reinstallation. Therefore, keep the method of access to and removal of the sensors easy to accomplish.

In cold climates, use heater cables to prevent wind sensors from freezing. Keep the cables plugged in during months of below freezing temperatures and unplug them when temperatures remain above freezing.

Install the instruments used for measuring barometric pressure, temperature, and relative humidity 2m above the ground (or above the anticipated average annual snowfall) or at the top of 10m meteorological towers. Install solar radiation measuring devices on a stable platform. Do not locate solar radiation measuring devices on the meteorological tower. A precipitation gauge mouth, as a rule, should be positioned one (1) meter above the anticipated average snow level.

During siting and installation, plan the operating environment for the signal conditioner, data access system, recorder, and other electronic components used with the sensors. Locate these instruments within 500 feet of the sensors and do not expose them to dust, corrosive gases, vibrations, noise, excessive humidity, or direct sunlight. If possible, house the instruments in an environmentally controlled shelter, since they operate effectively within the temperature range of 20 - 30 ^{o}C. If using an unheated building, install the instruments in a protective cabinet. A 100 watt light bulb in the cabinet may provide adequate heat during winter. Be careful not to place any of the instruments, paper supplies, manuals, etc., too close to the bulb or overheating and fires may occur.

Reliable electrical power is essential to these delicate instruments. Use power surge protector boards to protect the instruments from large power surges during lightning strikes. In areas where power is unreliable or fluctuates, use a battery backup system such as an uninterrupted power source (UPS). Ground all instruments and probes according to manufacturer's specifications.

4.1.1 Wind Speed

The wind speed sensor is most susceptible to errors from shadowing and interference. Mount wind speed and wind direction instruments to avoid interference from the tower or other objects (See Siting, Section B, Towers). Verticality is a primary consideration along with exposing the anemometer properly for cup anemometers. A small angle (1 degree or less) in mounting is acceptable only if the cup wheel is well balanced. If the cup wheel is not well balanced, the starting threshold will be degraded. To ensure verticality, level concrete foundations and tower base plates during construction and installation. Confirm the verticality of the tower before the installation of the crossarm and sensors.

4.1.2 Wind Direction

A. Exposure

The problem with verticality for the direction vane is identical to that of wind speed. For a well-balanced vane assembly, a small angle from vertical is not important. If the vane assembly is not well balanced, however, the starting threshold will be raised and the readings for the predominant directions for light winds will not be accurate.

B. Orientation

The orientation of the wind direction sensor to **TRUE NORTH** has the potential and reputation of being the greatest source of error for wind direction measurements. Poor orientation results in a fixed bias to the data. The method of wind vane orientation must be capable of 1 degree accuracy with 2 or 3 degrees as the upper limit of the error. Two steps are necessary to achieve an oriented wind vane. First, find the location of true north to an accuracy of less than 1 degree. Second, aim the wind vane at that location with an accuracy of better than 2 degrees.

1. Determining True North by Magnetic Compass

True north, as distinguished from magnetic north, is usually found by reading a magnetic compass and applying the correction for magnetic declination. Obtain the declination for the site location from maps, such as a Maine or United States Geological Survey map. For example, the magnetic angle of declination for Augusta, Maine is 17.5 degrees West. This indicates that magnetic north is 17.5 degrees west of true north. To determine true north, add 17.5 degrees to the 360 degree compass reading. Greater accuracy can be achieved with the help of two assistants. An assistant with a compass walks a good distance from the tower due north (due south if north is not possible). The greater the distance the assistant walks from the tower, the greater the alignment accuracy. The assistant uses the compass set to true north to verify that he is exactly north of the tower. The person on the tower aligns either the cross arm or the wind vane exactly toward the assistant on the ground. The assistant verifies that the sensor is aligned true north. A second assistant with a compass stands true south of the tower to verify that the tower and the assistant to the North are in alignment. Then both assistants may verify crossarm or vane alignment. Use two landmarks chosen from a map to verify the accuracy of the alignment.

This method is subject to errors from the influence of nearby metallic objects, imprecise application of the declination correction, and variations in the isogonic field. Good training and equipment, however, will reduce these errors to an acceptable level. An isogonic field relates to an area where the magnetic field is uniform in strength.

2. Determining True North by Astronomical Observation

Other ways to determine true north employ astronomical observation. Polaris, the North Star, will provide true north within 1 degree without correction on any clear night from any location in the northern latitudes. The only drawback to this method is that the work must be done at night. The True Solar Noon method, outlined below, will provide the north-south direction to within 0.1 degree on any clear day, given the station longitude, the date, and an accurate clock.

True Solar Noon Method

The True Solar Noon (TSN) method finds the time for a specific date at a specific longitude when the sun is in the north-south plane passing through the North Pole, the South Pole, and the longitude selected. If the sun is not directly overhead (elevation 90 degrees), the azimuth line to the sun is true north or true south. Two calculations are required. First find the time of the Local Apparent Noon (LAN) from the longitude.

Example:
For July 6, 1995
Augusta Airport ......Longitude = 69 47' 33", which in decimal form is 69.7925

T(LAN) = 12:00:00 + 4 (Longitude - 15 n), where n is the number of time zones from the Prime Meridian at Greenwich, England. Table 4.1 is a list of "n" values for continental United States time zones.

Another means for accurately determining longitude is to us a geo positioning system (GPS) equipment.

Table 4-1: TIME ZONES - Based on Standard Time

Time Zones	n
Eastern	5
Central	6
Mountain	7
Pacific	8

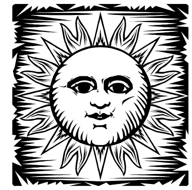
T(LAN)Augusta Airport = 12:00:00 + 4 (69.7925 - [15 x 5])
= 12:00:00 - 20.83
= 11:39.17
= 11:39:10 Eastern Standard Time

Second, correct for the Equation of Time from the "Ephemeris of the Sun" table.*
T(TSN) = T(LAN) - A, where A is the correction found in Table 4.2, for July 6th.
T(TSN)Augusta, Airport = 11:39:10 + 4:35 = 11:43:45 Eastern Standard Time

* The equation of time varies slightly from year to year. For greatest accuracy, use a nautical almanac or ephemeris for the current year.

Table 4-2:
EPHEMERIS OF THE SUN

FROM THE 1995 NAUTICAL ALMANAC



Date	Equation of Time m.	s.	Date	Equation of Time m.	s.	Date	Equation of Time m.	s.	Date	Equation of Time m.	s.
Jan.1	+ 03	11	Apr.1	+ 04	10	Jul.3	+ 04	02	Oct.1	- 10	03
4	+ 04	36	4	+ 03	17	6	+ 04	35	4	- 11	00
7	+ 05	57	7	+ 02	25	9	+ 05	04	7	- 11	55
10	+ 07	13	10	+ 01	35	12	+ 05	29	10	- 12	46
13	+ 08	24	13	+ 00	47	15	+ 05	50	13	- 13	33
16	+ 09	30	16	- 00	02	18	+ 06	07	16	- 14	15
19	+ 10	30	19	- 00	40	21	+ 06	20	19	- 14	52
22	+ 11	23	22	- 01	18	24	+ 06	27	22	- 15	23
25	+ 12	09	25	- 01	53	27	+ 06	30	25	- 15	49
28	+ 12	49	28	- 02	22	30	+ 06	27	28	- 16	08
31	+ 13	21	May 1	- 02	47	Aug.2	+ 06	18	31	- 16	20
Feb.3	+ 13	46	4	- 03	08	5	+ 06	04	Nov.3	- 16	25
6	+ 14	03	7	- 03	23	8	+ 05	44	6	- 16	24
9	+ 14	14	10	- 03	34	11	+ 05	19	9	- 16	15
12	+ 14	16	13	- 03	40	14	+ 04	49	12	- 15	58
15	+ 14	12	16	- 03	40	17	+ 04	14	15	- 15	34
18	+ 14	02	19	- 03	36	20	+ 03	34	18	- 15	01
21	+ 13	45	22	- 03	26	23	+ 02	50	21	- 14	21
24	+ 13	22	25	- 03	11	26	+ 02	03	24	- 13	34
27	+ 12	54	28	- 02	52	29	+ 01	11	27	- 12	40
Mar.2	+ 12	22	31	- 02	29	Sep.1	+ 00	17	30	- 11	39
5	+ 11	44	Jun.3	- 02	01	4	- 00	41	Dec.3	- 10	33
8	+ 11	03	6	- 01	31	7	- 01	41	6	- 09	21
11	+ 10	18	9	- 00	58	10	- 02	43	9	- 08	04
14	+ 09	30	12	- 00	22	13	- 03	46	12	- 06	43
17	+ 08	39	15	+ 00	15	16	- 04	50	15	- 05	18
20	+ 07	47	18	+ 00	53	19	- 05	55	18	- 03	51
23	+ 06	53	21	+ 01	32	22	- 06	59	21	- 02	22
26	+ 05	59	24	+ 02	11	25	- 08	01	24	- 00	52
29	+ 05	04	27	+ 02	50	28	- 09	03	27	+ 00	38
			30	+ 03	27				30	+ 02	06

This is the time when the sun will be on the longitude used in the formula. At this point it is necessary to use a vertical tower. Use the meteorological tower itself after verticality has been established and, ideally, before the crossarm has been installed. With an accurate watch to indicate TSN, draw a line at the end of the shadow cast by the tower at the exact TSN moment. A true north-south line can then be established by drawing a straight line from the base of the tower to this line.

There are several drawbacks to the TSN method. If the sun is obscured at TSN, the observation cannot be made. If other activities command higher priorities, the time of TSN may be inconvenient for the siting. If the TSN method is done around the time of the Winter Solstice (December 21) with towers located on a roof, shadows may be so long that they extend beyond the roof's edge. At the time of the Summer Solstice (June 21) shadows may be so short that accuracy cannot be maintained. Despite these disadvantages, however, the US EPA, in the Quality Assurance Handbook, Volume IV, considers the TSN method the most accurate .

After the north-south line has been established, a distant object may be selected as the orientation target for true north. Align the cross-arm to true north(consult the manufacturer's manual), and the vane then will be aligned automatically. Place the wind speed sensor on the north end of the cross-arm with the vane on the south end. After installation and orientation of the sensors and before operation, perform a field calibration. The field calibration check is discussed in Section 8.5 of this manual.

4.1.3 Temperature

Choose the installation location to represent the temperature relevant to the application. The height above ground is the first consideration. Because of snow accumulations in Maine, the DEP recommends locating temperature sensors at least three but no more than ten meters above the ground. Bias from surrounding structures is another concern. House temperature sensors in aspirated radiation shields to protect them from solar, terrestrial, and other types of radiation. Place temperature sensors mounted on towers at least one tower diameter/diagonal away from the tower structure. Use a boom if the mounting hardware does not allow enough distance. If there is a prevailing wind, place the temperature sensor on the side of the tower into the prevailing wind, so that the wind reaches the sensor before it passes through the tower.

4.1.4 Relative Humidity

It is preferable that the relative humidity sensor come mounted in a radiation shield to prevent bias from heat radiating objects or sunlight, which can affect measurements. The sensor can be mounted on the meteorological tower along with other weather instruments, so long as any influences from the tower are avoided.

4.1.5 Precipitation

Firmly anchor the support or base of any precipitation gauge on a level surface, so that the sides of the gauge are vertical and the collector is horizontal. Check the collector with a carpenter's level placed at two intersecting positions. Place the gauge high enough to avoid splashing in from the ground and use wind shields to minimize the wind at the opening of the gauge. Avoid nearby obstructions since they can interfere with precipitation reaching the gauge. Locate the gauge at a distance at least 2.5 times the height of a building or object. For winter operations, add two quarts propylene glycol antifreeze to the collector. The level of antifreeze represents the baseline from which precipitation is measured. Stir this mixture once a week and empty and recharge the collector once the gauge is over the 6 inch range.

4.1.6 Barometric Pressure

Place the barometric pressure sensor at least 2m above the ground (or one meter above the expected average annual snow level), or locate it in a convenient location on the tower with the pressure inlet port facing **downward**.

4.1.7 Solar Radiation

Select a site for an upward-looking pyranometer that is free from any obstruction above the plane of the sensor and readily accessible for cleaning and maintenance. Locate the sensor so that shadows do not fall on it, and install it away from light colored walls or other objects likely to reflect sunlight. A flat roof is a good choice; but if such a site is not available, use a rigid stand with a horizontal surface some distance from buildings or other obstructions. Make a site survey of the angular elevation above the plane of the radiometer surface through 360°.

Take precautions to avoid subjecting the radiometer to mechanical shock during installation. Install the radiometer securely and level it using the circular spirit level attached to the instrument.

4.1.8 UV-B

The broad band UV-B sensor must be level to be accurate. Secure the monitor so that it cannot be moved. Locate the instrument so that it is easily accessible for maintenance.

4.2 DATA ACQUISITION SYSTEM OPERATING PROCEDURES

4.2.1 General Description

Data acquisition systems (DAS) currently in use by the Maine Department of Environmental Protection consist of ESC 8816 Data Logger. This instrument serves as digital data acquisition and recording system. They allow the operators to assess the operating status, calibrations, and data output of the meteorological systems in use.

Each system can scan wind direction and wind speed voltage inputs at 5 second intervals. The 5 second voltage readings are converted to engineering units and used to compute hourly values for most all wind speed and direction parameters. Additional input channels are available to collect input voltages from temperature, dew point, relative humidity, and any other parameter with a voltage output in the 0.1, 1.5 or 10 volt ranges. Functions available to calculate hourly values are standard averaging, vector wind direction and speed, scalar wind direction, rainfall, peak values, sigma theta, sigma A (standard deviation of horizontal wind direction fluctuations, sigma W (standard deviation of the vertical wind speed fluctuations and sigma E (standard deviation of the elevation angle or vertical wind direction) fluctuations, and a calculation column. Each unit has a battery back-up to record power failures and flag data when the equipment is not operating because of power failures. Additional features are available through these units to initiate calibrations and to activate alarms (See operators' manuals for the specific units and for additional details).

A. Basic Features

Features of the ESC systems and of other acceptable data acquisition systems will include the following:

- 5-second scanning rate for all sensor channels(and an optional 1 second scanning rate for wind direction?).
- Calculation of 5 minute, (15 minute if needed), hourly and daily averages.
- Data flagging ability.
- 5 minute and hourly vector computations for wind parameters.
- Output of 5 minute, [15 minute (if needed)?], hourly and daily averages, including flag status and error messages.
- Visual display of the latest sensor values in volts and engineering units.

- Battery back-up for power failures.

B. Data Calculations for Meteorological Parameters

Data acquisition software must be available to make the calculations for the various parameters that are part of the meteorological monitoring program:

Measured Variable	Output	Units
Wind Speed	Scalar Wind Speed Vector Wind Speed	MPH or M/S MPH or M/S
Wind Direction	Scalar Wind Direction Vector Wind Direction Sigma Theta	Degrees, compass Degrees, compass Degrees, compass
Temperature	Temperature Δ Temperature	Degrees, F or C Degrees, F or C
Barometric Pressure	Pressure Hg	Millibars or Inches
Relative Humidity*	Relative Humidity	0-100% Relative Humidity
Dew point**	Dew point	Degrees, F or C
Solar Radiation	Solar Radiation	Watts/meter^2
Ultra-Violet b	Ultra-Violet b	Watts/meter^2
Rainfall	Rainfall	Inches or millimeters

* *Can be calculated from air temperature and dew point.*
** *Can be calculated from air temperature and relative humidity.*

Time based values corresponding to 1 minute, 5 minute, 1 hour and 24 hour averaging periods are calculated from individual scans of each measured parameter as follows:

- One minute values are based on the average of twelve 5-second scans.
- Five minute values are computed from five 1-minute averages in each 5 minute period (4 minutes are needed for a valid 5 minute value).
- One hour values are computed based on sixty 1-minute averages during each hour (45 minutes are needed for a valid 1 hour value).
- Daily averages are based on the average of 24 hourly values (18 hourly values are needed for a valid daily average). Daily averages are computed for a calendar day from midnight to midnight.
- More frequent scans are acceptable. The data calculations are based on the scans of the input voltages corresponding to the measurement range of each

sensor. For example, the measurement range corresponding to the 0-5 volt inputs for the Climatronics F460 sensors are as follows:

Parameter	Input voltage	Output
Wind Speed	0-5 volts	0-100 MPH
Wind Direction	0-5 volts	0-540 Degrees

Each scan takes the input voltage and converts it to the appropriate scientific units. The scientific units then are used in the subsequent data calculations. The actual data calculation formulas are described in On-Site Meteorological Program Guidance for Regulatory Modeling Applications, Section 6.1. Additional information for the ETC systems is provided in Application Note AN83-027.

C. Systems Operations

System Start Up

Whenever possible the data acquisition system should have a modem and phone line installed at the monitoring location. This allows for remote checks of the system without physically visiting the site, as well as routine data retrieval. If all the parameters to be measured at the site and their input voltages are known, the data acquisition system can be programmed at the office. The sequence for starting up a system is as follows:

1. Power connections
2. Cable connections
3. Analog input connections
4. Software programming:
   - Program the hardware options
   - Set password(s)
   - Set system parameters
   - Set events(if needed)
   - Set calibration(if needed)
   - Set alarm(if needed)
   - Specify reports

Specific details for the above steps can be found in the operator's manual for each of the ETC data acquisition systems in use. Additional information on programming modems, setting alarms, initializing, setting events, initiating remote checks, and wiring diagrams can be found in the Guide to Remote DAS and Analyzer Control.

Routine Operator Checklist

The following checks should be done before and during each site visit to verify DAS operation:

- Poll the site if it has a phone line and modem before the site visit and verify that data collection appears to be normal.
- Check date and time at the site.
- Visually estimate wind speed and direction from the sensors and check the scalar speed and direction channels for accuracy.

For wind direction, use known reference points such as stacks, buildings or landmarks that are a specific compass heading away from the site
For wind speed reference points, may be sea conditions or a flag on a pole.

Refer to specific DAS Operators Manual to perform the following functions:

- Check each channel on the display for reasonable response.
- Mark channels down if maintenance or calibrations are to be performed.
- Mark all channels up prior to leaving site if instruments are recording valid data.

5.0 FIELD OPERATIONS

5.1 WEEKLY SITE VISIT CHECK LIST

Check maintenance schedule to see whether weekly visit coincides with any required quarterly or semiannual maintenance.

5.1.1 Items needed

- Keys to site building
- Keys for gates
- Card for card activated security gates
- Tools to carry out periodic maintenance.

5.1.2 Site Supplies

- Recorder chart paper
- Recorder pens
- Log sheets, maintenance and calibration
- Lightbulbs
- Batteries

5.1.3 Site Activities

- Check tower to verify condition, orientation of vane, and rotation of cups.
- Mark down channel.
- Write time, date, site, and operator initials on chart.
- Remove chart for previous week.
- Change paper if necessary.
- Change recorder pen if necessary.
- Write time, date, site, and operator initials on chart before replacing paper cartridge
- Print calibration.
- Mark up channel.
- Check that DAS is displaying time and date.
- Check DAS for trouble indicator lights.
- Clear power failure indicators.
- Record any problems, adjustments, etc. on chart and site checklist.

- Make a visual inspection of the UV-B data to see if they appear OK. Clean sensors with lens paper and an ethanol based solvent (other cleaners will leave a UV-B absorbing film).

6.0 MAINTENANCE AND TROUBLESHOOTING

6.1 DAILY MAINTENANCE

Daily polling provides the first warning of problems at the site. Problems may appear as power failure flags, or, for example, a set of identical hourly averages that indicate a frozen wind vane, worn (and therefore sticking) bearings in the speed sensor, or a loose wire.

Maintain a log for each site. Keep a copy of the log at the site and at the office.

☑***NOTE***: In the event technical assistance is needed for repairs, the site operator should call the service department of the instrument manufacturer.

6.2 WEEKLY MAINTENANCE

The weekly site visit is a time to re-supply the site and make visual checks.

6.2.1 Supplies

Supplies for the site will include:

- chart paper
- log sheets
- recorder pens
- batteries
- light bulbs
- bearings

6.2.2 Heater Cable

Heater cable: Direct sunlight in winter can shut off the heater's thermostat prematurely even when ambient temperatures are below freezing, sometimes freezing up the wind vane and speed cups. Check the heater cable to make sure it is plugged in and working properly.

6.2.3 Wind Recorder

Wind Recorder: Check for loose wires (particularly if an odd reading appears on the DAS).

6.3 MONTHLY MAINTENANCE

6.3.1. Solar Radiation

Clean sensor window monthly or more often if needed, using a clean rag or tissue. Remove ice and snow accumulation as needed.

6.4 QUARTERLY MAINTENANCE

6.4.1 Wind Recorder

Wind Recorder: Voltage checks. Refer to appropriate technical manual. See sample calibration form at end of QA Plan, Figure 5, Voltage Check Form.

6.5 SEMI-ANNUAL MAINTENANCE

☑ ***NOTE***: To facilitate this task, serious consideration should be given to conducting these checks during April and October when the weather is acceptable to determine that the sensors meet specs prior to the summer and fall/winter monitoring seasons.

6.5.1 Sensors

Both Sensors: Bearing changes. Refer to appropriate technical manual.

6.5.2 Wind Speed Sensor

Wind Speed Sensor: Often no calibration is required; but the sensor can be tested with a wind speed torque meter. Use a variable speed motor and check three different speeds. Refer to Figure 1 - Wind Speed/Wind Direction Audit Form at the end of QA Plan.

6.5.3 Wind Direction Sensor

Wind Direction Sensor: Re-calibrate. Consult appropriate technical manual.
Refer to Figure 1 - Wind Speed/Wind Direction Audit Form at the end of QA Plan.

6.5.4 Wind Direction Sensor

Wind Direction Sensor: Alignment (orientation) check. Refer to the appropriate technical manual. Refer to Figure 1 - Wind Speed/Wind Direction Audit Form at the end of QA Plan.

6.5.5 Tower

Tower: Check cables for rust and fraying; if a cable is supported by ties, check these for fraying. Check the tower's ground connection.

6.5.6 Solar Radiation

Check sensor and cable for proper operation. Check translator module calibration and adjust if necessary. If either sensor or translator module have been changed and the two are not matched, perform bench calibration.

6.5.7 UV-B

Evaluate the accuracy of the Data Acquisition System (DAS) using a voltage generator and a digital voltmeter. Follow the procedures outlined in the DAS manufacturer's manual.

Maintenance is minimal on the instruments used to measure temperature, barometric pressure, and relative humidity. Replace these instruments if they fail.

6.6 MAINTENANCE SCHEDULE **

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC
VC			VC			VC			VC		
			BC						BC		
			(CAL)						(CAL)		
			AL						AL		

VC = Voltage Check
BC = Bearing Change
(CAL) = Re-calibrate WD if cap has slipped relative to shaft
AL = Alignment/orientation check of crossarm

** This is a sample maintenance schedule, but because of equipment availability this schedule can be rearranged as convenient, keeping in mind that the maintenance must be done every six months. Consult the appropriate technical manual for specific maintenance information.

7.0 DATA PROCESSING / VALIDATION / REPORTING

7.1 VALIDITY REQUIREMENTS FOR METEOROLOGICAL DATA

For data collected by meteorological instruments to be considered "valid", i.e., representing conditions over a certain time, the instruments must collect data for at least 75% of the time. The requirements for specific time periods are described in the Maine Department of Environmental Protection's quality assurance plan for collecting ambient air quality data. The data validity requirements for meteorological data are identical to these for the time periods that are common to both.

7.2 VALIDITY REQUIREMENTS FOR LONG TERM DATA SETS FOR METEOROLOGICAL MODELING

The valid time periods for meteorological data sets are set forth in the Department of Environmental Protection Regulations, Chapter 115, Appendix A, Sections 4.3, as follows:

> "In applications for an air emission license for new sources, one (1) year of on-site meteorological data is the preferred database. Five (5) years of off-site meteorological data are required in the modeling-based compliance demonstration if no on-site meteorological data are available. Off-site meteorological data are from National Weather Service (NWS) stations or from universities, the Federal Aviation Administration (FAA), military stations, industry, and pollution control agencies whose data are equivalent in accuracy and detail to the NWS data. A minimum of one (1) year of on-site meteorological data or five (5) years of off-site data are required for renewals and for new sources or modifications. If more than one (1) year and up to five (5) years of on-site meteorological data are available, then those data must also be used. A five (5) year database is ultimately the objective for a sequential modeling demonstration.
>
> To allow for the unexpected, such as a gap in data from a catastrophic incident or a persistent but subtle problem that evades detection, a five (5) year meteorological database acceptable for modeling purposes need not be compiled from either five (5) consecutive years or sixty (60) consecutive months of data. If this is the case then the applicant must write to the Department requesting an exemption from the consecutive five (5) year database requirement.

Once a five (5) year on-site database is developed, the database will be considered to remain climatologically valid and, hence, appropriate for regulatory purposes. If data requirements, source configurations, or characteristics of the surrounding area change, the database may need to be updated after consultation with the Department. However, a requirement to collect a new database will neither preclude the applicant's ability to use the existing database in the interim data collection period nor require the applicant to repeat any previously submitted analyses that used the original database."

7.3 MISSING DATA

Missing data and gaps in data collection are described in Section 6.5.3 of the following regulation, "On-Site Meteorological Program Guidance for Regulatory Modeling Applications, EPA, 1987" as follows:

> "Substitutions for missing data are allowed but may not exceed ten (10) percent of the hours (876 hours per year) in the database. Guidance on treatment of missing on-site meteorological data as well as treatment of calms can be found in the 'Guidelines on Air Quality Models' (Revised), EPA 1993a, and On-Site Meteorological Program Guidance for Regulatory Modeling Applications, EPA, 1987. Procedures for Substituting Values for Missing NWS Meteorological Data for Use in Regulatory Air Quality Models, Atkinson and Lee, 1992, contains guidance on treatment of missing off-site meteorological data."

As stated in Chapter 115, five years of meteorological data are required for modeling in all cases when the data are generated off-site from the emission source. In cases where there is a gap in data collection, the Department may, at its discretion, allow the use of data gathered from non-consecutive periods. The data set must, at a minimum, provide an accurate representation of five similar seasonal cycles, i.e. a year of Met data may consist of a non-calendar year, June '96 to May '97.

8.0 QUALITY ASSURANCE AUDIT PROCEDURES

The performance audit is a quantitative assessment of the accuracy of the collected data. It consists of a series of actual field calibration checks on the individual sensory and sampling systems and on elements of the data acquisition and recording system (i.e., measured input versus processes output relative to specific test criteria). Audits must be conducted by a person other than the analyzer or operator and auditing devices must be different from those used for analyzer calibration. Audit equipment and field calibration check devices may be referenced to the same primary standards.

Field audit procedures will be the same as the field calibration check procedures with the exception that they will be conducted semi-annually and will be incorporated with the quarterly field calibration checks. To the extent possible, audits are scheduled during the transitional seasons of spring and fall (e.g., April and October) to provide comfortable working conditions for the field work; and, more importantly, to check the system more thoroughly immediately before and after the more extreme weather conditions that occur during winter and summer.

8.1 AUDITOR

Auditor will require the following equipment:

- psychrometer
- psychrometric tables
- 4½ digit DVM
- RM Young Model 18801 variable speed calibration motor
- torque disc and weights
- compass, topographic maps
- wind direction linearity jig
- RM Young vane deflection torque gauge
- Assmann Aspirated Psychrometer
- reference pyranometer (Eppley)
- reference barometer

8.2 PERFORMANCE AUDIT

8.2.1 Acceptance Criteria For Field Audits

Listed below are the limits of acceptability for field sensor calibration check results on the various instruments. These tolerance limits conform to limits specified by the U.S. Environmental Protection Agency (US EPA) for meteorological measurements recorded as part of Prevention of Significant Deterioration (PSD) monitoring programs and 40 CFR Part 50, Appendix J, for PM_{10} sampling. These limits are assumed to be appropriate for this program in that meteorological data are being collected primarily in support of air quality related issues. These limits help ensure that the data will be acceptable to regulatory agencies if future applications include use in air quality dispersion modeling activities.

Wind Speed:	1.0 mph threshold ± 0.5 mph accuracy to 10 mph; ± 5% above 10 mph
Wind Direction:	1.0 mph threshold ± 3° accuracy
Temperature:	± .5°C (±0.9 °F) accuracy
Solar Radiation:	10 w/m threshold
Humidity:	± 2% (0% to 90% RH) accuracy ± 3% (90% to 100% RH)
Barometric Pressure:	± 0.04 in Hg
UV-B:	threshold observed

When field or laboratory calibration check results fall within the above limits, the instruments will be assumed to be operating in calibration and providing data accurate to within specified program tolerances. Results falling outside these limits do not automatically require deletion or adjustment of the data or replacement of sensory components. Rather, they imply that further assessments should be made case-by-case, depending upon how far out-of-limit the results were. Possible follow-up and remedial actions include:

1. Repeating the calibration check under a set(s) of ambient conditions different from those under which the audit checks were conducted.

2. Subjecting the sensor to additional, more accurate laboratory tests.

3. Replacing the sensor and assessing whether the newly installed component yields more satisfactory results.

4. Altering the limits of acceptability if confident that revised accuracy limits would not jeopardize the usefulness, credibility, representativeness, or defensibility of the data relative to stated purposes.

In any case, the results of all field audit checks and laboratory calibration results will be made available to all users of the data, so they can independently assess whether data accuracy is sufficient to meet requirements for each specific application.

8.2.2 General Instructions

The following instructions generally apply to the field calibration sensor checks of all sensors and samplers. Some instructions are specific to individual instruments.

1. Scheduling

Try to schedule field work on days with "favorable" weather. If possible, avoid working under extremely high wind conditions(could damage vanes during alignments), or extremely cold temperatures (could interfere with temperature calibrations). Also, favorable conditions increase working comfort and decrease the possibility of technician error.

Schedule a window of 2 or more days for field work initially. Then check the latest area weather and forecasts and select the best day(s) from that window.

Also, schedule ample time to complete all work in a systematic manner, allowing for possible logistical or mechanical problems, and include a provision for repeating certain tests if necessary. Usually full-scale system and performance audits are scheduled for completion over a 2-day period.

2. Materials & Supplies

Make sure that all materials, supplies, tools, documentation records, reference materials, and certifications needed to perform the work are available and are in good order before arrival on site. See Section 8.3 for equipment and associated documentation.

3. Activity Coordination and Planning

Because of a variety of factors and considerations, the actual sequence of events during full field performance audits are not always the same. Therefore, before initiating any actual work, the on-site audit crew fully assesses any constraining factors (time, weather, etc.) and formulates a plan for the day that most effectively allows specified tasks to be accomplished. Be sure to account for all required procedures and documentation.

4. Weather Condition Constraints

Certain field calibration checks provide meaningful and accurate measures of instrument performance only if they are performed under reasonable conditions. For example:

- Avoid temperature and relative humidity checks during strong wind conditions or during midday hours if skies are clear and solar intensity is high. Perform these checks during light winds, cloudy skies, or during the early morning or late evening hours when the sun's intensity is decreased and there is ample shaded area in which to conduct the test.

- Avoid performing wind sensor checks and sampler audits during high wind speeds. Strong winds can make it difficult to check bearing performance on speed sensors or to hold vanes sufficiently steady for accurate alignment checks. Attempting to oppose wind forces during these checks may result in damage to the cups or vanes.

- Avoid performing wind direction vane alignment checks if obstructions to visibility (fog, haze, precipitation) prevent a clear view of azimuth markers.

5. Ambient Meteorological Conditions

Before initiating any on-site work, document the existing ambient weather conditions. This includes noting the current output readings from the on-site sensors as well as the technician's observation regarding sky condition, cloudiness, visibility, obstructions to visibility, etc. Also, document any significant changes in weather that occur during the activity. This information is used to perform meteorological consistency checks as outlined in Section 6.0. It is also useful in after-the-fact evaluations of field audit results.

8.3 METEOROLOGICAL SENSOR AUDIT CHECK PROCEDURES

The following sections describe the procedures for performing and documenting the results of field calibration checks on each sensory system comprising the meteorological monitoring portion of this program. **All of these checks are performed as part of both the six-month field calibration checks and quality assurance audits**.

The same procedures for field calibrating any given sensor must be performed and documented whenever a new component is placed in service. Do not automatically assume that ready spare components are in perfect calibration.

8.3.1 Wind Speed

A. Motor Response

Remove the anemometer cups from the sensor and mount the RM Young Model 18801 variable speed motor assembly to the sensor shaft. Select 300 rpm, and record the sensor's output on the wind speed calibration form. Repeat for 600, 900 and 1800 rpm, and record these values. Record the concurrent values from the voltmeter. See applicable technical instructions for designated wind speed values for suggested rpm's. If the difference between the designated value and anemometer response is greater than ± 5%, the instrument requires service.

B. Starting Threshold

Hold the sensor in horizontal position and replace the anemometer cups with torque disc. Adjust the weight on the torque disc until the starting threshold is determined. Record the starting threshold, and compare the value with the designated value in the appropriate technical instructions. Any sensor exceeding its designated value requires service.

8.3.2 Wind Direction

A. Orientation

Two horizon landmarks will be identified and the azimuth determined from a topographic map, compass, or previous survey. The sensor vane will be pointed to each landmark, and the recorded output logged on the wind direction calibration form. Record the readings from both the voltmeter and the data acquisition system. The tail of the vane will then be aimed at each landmark and the outputs recorded. The difference between the designated landmark azimuths and the sensor indicated value will be calculated and averaged. Averaged differences of greater than ±5° will require reorientation of the sensor.

B. Deflection Threshold

Affix the deflection threshold gauge to the wind direction vane. Deflect the vane, noting the grams of torque required to deflect the vane. Consult the appropriate technical instructions for the instrument's specific threshold limit. Sensors over limit require service.

C. Linearity

Affix the linearity test fixture onto the wind direction sensor and replace the vane with the compass wheel. Select four 90 degree increments on the compass wheel, and record the values from each indexed location. If any value is greater than ± 2 ° from 90° increments, the sensor is non-linear and requires service.

8.3.3 Temperature Performance Audit Colocated Transfer Standard (CTS)

Equipment and materials:

- Digital Voltmeter (DVM)
- Audit Form
- Assmann Aspirated Psychrometer

Use an Assmann aspirated psychrometer mounted near the shielded temperature sensor. Wind the Assmann and let it run five minutes. Wind again and after an additional two minutes, begin reading the mercury-in-glass thermometers. Use the anti-parallax magnifiers. Record the temperatures from the Assmann and from the system taken at the same time. Be sure the two sensor systems are sampling from air that has not been biased by local mounting structures.

8.3.4 Relative Humidity Performance Audit

Equipment and materials:

- DVM
- Audit Form
- Assmann-Type Psychrometer

Base the performance audit of a humidity measuring system upon a comparison with a collocated transfer standard (CTS). Parts of the system can be tested by conventional electronic tests, but this avoids so much of the measurement process that it should only be used to augment the total system test. The CTS may be any qualified instrument. The most accurate type is the cooled-mirror dew point instrument. The Assmann-type psychrometer with calibrated thermometers traceable to the National Bureau of Standards is acceptable for most data applications. It is also most convenient since it does not require commercial power and can be carried to elevated levels on a tower.

Given the qualifier that humidity is a very difficult measurement to make, a rule of thumb for judging the accuracy of a humidity monitoring system with an Assmann as the CTS is as follows: when the CTS and the challenged system agree in dew point temperature to within 1°C, the challenged system is assumed to be within 0.5 °C of the true value. This arbitrarily assigns an uncertainty in dew point temperature of +0.5 °C for the Assmann that is true for most of the range.

Auditing is best backed by authoritative standards. American Society of Testing Materials, 1982, 1983, 1984 and 1985 may be of selective value.

8.3.5 Precipitation Performance Audit

Challenge the measuring system with water amounts known to an accuracy of at least 1 percent of the total to be used. Use a rate of less than one inch per hour.

8.3.6 Barometric Pressure Performance Audit

Equipment and materials:

- DVM
- Audit Form
- Calibrated Aneroid Barometer

The audit instrument can be as simple as an aneroid barometer (altimeter) which has been compared to a calibrated barometer. The accuracy for this small instrument, when properly used, is 0.2% or about 2 hPa.

8.3.7 Solar Radiation Performance Audit

Equipment and materials:

- DVM
- Audit Form
- Eppley Black & White Pyranometer/Cable/Signal processor

A performance audit on a solar radiation system is only practical with a collocated transfer standard (CTS). The CTS must have the spectral response and exposure equivalent to the instrument being audited. One diurnal cycle will establish an estimate of accuracy sufficient for most air quality monitoring applications. The method of reporting the data from the monitoring instrument (daily integrated value, hourly integrated value, average intensity per hour, etc.) must be used in reducing the data from the CTS to provide a meaningful comparison. An audit frequency of at least six months is recommended.

8.3.8 UV-B Performance Audit

Return the instrument to the manufacturer for an annual calibration.

8.4 DOCUMENTATION

Meteorological checks and calibration documentation include:

Audit documentation -

- Audit forms should be completely filled out.
- Strip charts should be fully annotated.
- A summary of results must be included in the station log notes.

- Audit is thoroughly documented.

8.5 FIELD CALIBRATION AND WEEKLY SENSOR CHECKS

8.5.1 Introduction and Objectives

As part of the overall quality assurance program for aerometric monitoring systems, a series of quality assurance calibration checks and internal Quality Assurance Audits are conducted to assess the performance of the system, and the accuracy and credibility of collected data. This program includes checks of the past and current performance status of the system, checks of the operational and preventive maintenance procedures employed along with associated documentation, and a series of on-site field calibration checks of the various sensor and sampler system components. The key purposes are to provide a qualitative and quantitative assessment of the systems overall performance, to formulate recommendations for improving system performance or operation protocol, and to assess the adequacy of collected data relative to program objectives.

☑ ***NOTE***: *Meteorological calibrations will follow guidelines established in EPA-600/4-82-060, Rev. 0, September 1989, Quality Assurance Handbook for Air Pollution Measurement Systems: Volume IV. Meteorological Measurements. All measurement devices and calibration standards will be traceable to the National Bureau of Standards.*

8.5.2 Purpose and Applicability

This Standard Operating Procedure (SOP) is a guide for performing weekly checks and periodic field calibration sensor checks of the following sensors:

- wind speed
- wind direction
- temperature
- relative humidity
- solar radiation
- barometric pressure

A formal calibration is required under any of the following circumstances:

- whenever control limits are exceeded after a field calibration sensor check;
- prior to any corrective action, service, or maintenance to any portion of the instrument that affects its operational principle; or

- at a maximum interval of six months.

☑ ***NOTE***: *A formal calibration of a sensor may require that it be returned to the manufacturer. Refer to operator's manual for specific guidance on service, repair and calibration requirements and procedure.*

8.5.3 Responsibilities

A. Station Operator

The station operator is responsible for the routine observation and checking of meteorological instruments for proper operation and response (as compared to local observed conditions). The station operator also makes routine checks of the meteorological signal conditioning card's internal zero and span values. The station operator is also responsible for inspecting the sensor's physical condition, mounting hardware, tower, and interconnect cabling, and will arrange for any repair or maintenance required.

B. Field Specialist

The field specialist is responsible for the periodic field sensor calibration check and formal calibration where applicable, and servicing of the meteorological sensors and signal conditioning cards.

8.5.4 Required Equipment/Materials

A. Station Operator

The station operators require the following equipment:

- psychrometer
- psychrometric tables

B. Field Specialist

Field specialists require the following equipment:

- psychrometer
- psychrometric tables
- 4½ digit DVM

- RM Young Model 18801 Variable speed calibration motor
- torque disc and weights
- compass, topographic maps
- ARS wind direction linearity jig
- RM Young vane deflection torque gauge
- certified thermometers
- thermos bottles
- reference pyranometer
- replacement bearings for wind sensors
- replacement thermistors
- reference barometer

8.5.5 Methods

A. Principles and Policy

Routine observations will be made by the station operator during every station visit. These observations will verify the reasonable operation of the monitoring system. Signal conditioning card zero and span checks will be made weekly and recorded on specially prepared forms. Complete calibration and servicing will be performed by the Field Specialists at six-month intervals or as required (see Section 6.4).

B. Weekly Checks

Station operators will make the following observations weekly:

1. Wind Speed

Observe anemometer cups for proper operation and starting threshold. Estimate wind speed and compare with recorded value.

2. Wind Direction

Observe direction of wind vane and compare this value with the instrument output. Observe the vane for proper response and movement.

3. Temperature

Compare the recorded temperature with a glass thermometer located in a shaded area or from the dry bulb of the psychrometer. Check the temperature aspirator for cleanliness and proper operation.

4. Relative Humidity

Use a psychrometer to calculate the relative humidity and compare the observed value to the recorded value.

5. Precipitation

Visually inspect the instrument and compare the precipitation amounts measured with those reported by a reputable local weather station.

6. Barometric Pressure

Verify the recorded output against an on-site calibrated aneroid barometer.

7. Solar Radiation

Verify that the output recorded on the strip chart has a diurnal variation. Check the sensor for cleanliness and levelness.

8. UV-B

Verify the operation of the instrument. Clean the glass dome with a clean cloth and an alcohol based solvent according to manufacturer's instructions. Perform zero check as described in Section 4.1.8.

9. Signal Conditioning Card Checks

Routine weekly checks will be made of each signal conditioning card's internal zero and span values. These values will be recorded on prepared forms. Adjustments to the zero and span value will be made whenever the observed value is greater than ± .1% of the designated value. See the individual technical instructions for specific values.

C. Formal Calibrations

Both pre- and post-maintenance calibrations of all sensors are required. Calibrations of sensors will be made by the field specialist where applicable.

8.5.6 Acceptance Criteria For Field Calibration Checks

Listed below are the limits of acceptability for field sensor calibration check results on the various instruments. These tolerance limits generally conform to limits specified by the U.S. Environmental Protection Agency (US EPA) for meteorological measurements recorded as part of Prevention of Significant Deterioration (PSD) monitoring programs and 40 CFR Part 50, Appendix J, for PM_{10} sampling. These limits are assumed to be appropriate for this program in that meteorological data are being collected primarily in support of air quality related issues. The limits help ensure that the data will be acceptable to regulatory agencies if future applications include use in air quality dispersion modeling activities.

The procedures for field calibration checks and performance audits are very similar, and the recommended practice is to conduct the field calibration and performance audit on the same day/s. Please refer to Sections 8.0 through 8.4 for information on performance audits.

Wind Speed:	1.0 mph threshold ± 0.5 mph accuracy to 10 mph; ± 5% above 10 mph
Wind Direction:	1.0 mph threshold ± 3° accuracy
Temperature:	± .5°C (±0.9 °F) accuracy
Solar Radiation:	10 w/m threshold ± 5% observed
Humidity:	± 2% (0% to 90% RH) accuracy ± 3% (90% to 100% RH)
Barometric Pressure:	± 0.04 in Hg
UV-B:	threshold observed

When field or laboratory calibration check results fall within the above limits, the instruments will be assumed to be operating in calibration and providing data accurate to within specified program tolerances. Results falling outside these limits do not automatically require deletion or adjustment of the data or replacement of sensory components. Rather, they imply that further assessments should be made case-by-case, depending upon how far out-of-limit the results actually were. Possible follow-up and remedial actions include:

1. Repeating the calibration check under a set(s) of ambient conditions different from those under which the audit checks were conducted.

2. Subjecting the sensor to additional, more accurate laboratory tests.

3. Replacing the sensor and assessing whether the newly installed component yields more satisfactory results.

4. Altering the limits of acceptability if confident that revised accuracy limits would not jeopardize the usefulness, credibility, representativeness, or defensibility of the data relative to stated purposes.

In any case, the results of all field audit checks and laboratory calibration results will be made available to all users of the data so they can independently assess whether data accuracy is sufficient to meet requirements for each specific application.

A. General Instructions

The following instructions generally apply to the field calibration sensor checks of all sensors and samplers. Some instructions are specific to individual instruments.

1. Scheduling

Try to schedule field work on days with "favorable" weather. If possible, avoid working under extremely high wind conditions (could damage vanes during alignments), or extremely cold temperatures (could interfere with temperature calibrations). Also, favorable conditions increase working comfort and decrease the possibility of technician error.

Schedule a window of 2 or more days for field work initially. Then check the latest area weather and forecasts and select the best day(s) from that window.

Also, schedule ample time to complete all work in a systematic manner, allowing for possible logistical or mechanical problems, and include a provision for repeating certain tests if necessary. Usually, full-scale system and performance audits are scheduled for completion over a 2-day period.

2. Materials and Supplies

Make sure that all materials, supplies, tools, documentation records, reference materials, and certifications needed to perform the work are available and are in good order before arrival on site.

3. Activity Coordination and Planning

Because of a variety of factors and considerations, the actual sequences of events during full field performance audits are not always the same. Therefore, before initiating any actual work, the on-site audit crew fully assesses any constraining factors (time, weather, etc.) and formulates a plan for the day that most effectively allows specified tasks to be accomplished. Be sure to account for all required procedures and documentation.

4. Weather Condition Constraints

Certain field calibration checks provide meaningful and accurate measures of instrument performance only if they are performed under reasonable conditions. For example:

- Avoid temperature and relative humidity checks during strong wind conditions or during midday hours if skies are clear and solar intensity is high. Perform these checks during light winds, cloudy skies, or during the early morning or late evening hours when the sun's intensity is less and there is ample shaded area in which to conduct the test.

- Avoid performing wind sensor checks and sampler audits during high wind speeds. Strong winds can make it difficult to check bearing performance on speed sensors or to hold vanes sufficiently steady for accurate alignment checks. Attempting to oppose wind forces during these checks may result in damage to the cups or vanes.

- Avoid performing wind direction vane alignment checks if obstructions to visibility (fog, haze, precipitation) prevent a clear view of azimuth markers.

5. Ambient Meteorological Conditions

Before initiating any on-site work, document the existing ambient weather conditions. This includes noting the current output readings from the on-site sensors as well as the technician's observation regarding sky condition, cloudiness, visibility, obstructions to visibility, etc. Also document any significant changes in weather that occur during the activity. This information is used to perform meteorological consistency checks as outlined in Section 8.2. It is also useful in after-the-fact evaluations of field audit results.

8.6 METEOROLOGICAL SENSOR CALIBRATION CHECK PROCEDURES

The following sections describe the procedures for performing and documenting the results of field calibration checks on each sensory system comprising the meteorological monitoring portion of this program. All of these checks are performed as part of both the six-month field calibration checks and quality assurance audits.

8.6.1 Wind Speed

A. Motor Response

Remove the anemometer cups from the sensor and mount the RM Young Model 18801 variable speed motor assembly to the sensor shaft. Select 300 rpm, and record the sensor's output on the wind speed calibration form. Repeat for 600, 900 and 1800 rpm, and record the values. See applicable technical instructions for designated wind speed values for suggested rpm's. If the difference between the designated value and anemometer response is greater than ± 5%, the instrument requires service.

B. Starting Threshold

Hold the sensor in horizontal position and replace the anemometer cups with torque disc. Adjust the weight on the torque disc until the starting threshold is determined. Record the starting threshold, and compare the value with the designated value in the appropriate technical instructions. Any sensor exceeding its designated value requires service.

8.6.2 Wind Direction

A. Orientation

Two horizon landmarks will be identified and the azimuth determined from a topographic map, compass, or previous survey. The sensor vane will be pointed to each landmark, and the recorded output logged on the wind direction calibration form. The tail of the vane will then be aimed at each landmark and the outputs recorded. The difference between the designated landmark azimuths and the sensor indicated value will be calculated and averaged. Averaged differences of greater than ±5° will require reorientation of the sensor.

B. Deflection Threshold

Affix the deflection threshold gauge to the wind direction vane. Deflect the vane, noting the grams of torque required to deflect the vane. Consult the appropriate technical instructions for the instrument's specific threshold limit. Sensors over limit require service.

C. Linearity

Affix the linearity test fixture onto the wind direction sensor and replace the vane with the compass wheel. Select the four 90° increments on the compass wheel, and record the values from each indexed location. If any value is greater than ± 2 ° from 90° increments, the sensor is non-linear and requires service.

8.6.3 Temperature

Remove the temperature probe from the aspiration system and suspend the probe in a water bath along with a certified thermometer. Agitate the water bath until both the thermometer and sensor responses stabilize. Record the values on the temperature calibration form. Prepare an ice bath and repeat the procedure. Compare the measured bath temperature and instrument response. Any difference greater than ± .2 °C requires investigation and corrective action.

8.6.4 Relative Humidity System Field Check

The relative humidity sensor is a thin film capacitor that is extremely accurate and sensitive responding to the full range of 0 - 100% humidity.

The following equipment and materials are needed to complete an operational check of the relative humidity sensor:

- motor operated or sling psychrometer
- a certified digital voltmeter
- strip chart recorded
- calibration form

The approximate calibration accuracy of the relative humidity sensor can be done with a motor-operated or sling psychrometer. Verify its performance under stable conditions at night or under cloudy conditions during the day. Several readings taken at the intake of the aspirator or shield are recommended.

8.6.5 Precipitation System Field Check

Challenge the instrument with an amount of water known to an accuracy of at least 1 percent of the total to be used. Use a rate of less than one inch per hour.

8.6.6 Barometric Pressure System Field Check

Equipment and materials needed to complete an operational check of the Barometric Pressure Sensor:

- calibrated barometer
- a certified digital voltmeter

- a strip chart recorder
- calibration form M115 - "Meteorological Instrument Calibration/Maintenance Sheet"

The barometric sensor uses an active solid-state device to sense barometric pressure. It has been calibrated at the factory, and will not change unless it is damaged. Should service or re-calibration become necessary, the sensor must be returned to the factory.

To check for proper operation of the sensor and module:

- check the module's output against a local weather service facility. Exact correlation is not to be expected, because of geographical and meteorological variations. The sensor reads absolute barometric pressure, whereas local weather services readings are normalized to sea level values.

OR

- A barometer that has been referenced to a known standard may be brought to the site to verify the accuracy of the sensor.

8.6.7 Solar Radiation

A reference solar radiation sensor will be attached to the existing solar radiation sensor support bracket. Several simultaneous measurements will be taken over several hours with both the reference sensor and the on-site sensor. The average of all comparisons must be within ± 5% of the reference sensor. If comparisons exceed ± 5%, corrective action will be required.

8.6.8 UV-B

Send the unit back to the manufacturer for calibration at a minimum of every two years. The current recommendation from the Federal Interagency UV Monitoring Group is every year. The best time of year for the calibration is in the summer. Unfortunately, summer is the worst time for monitoring need. Contact the manufacturer to plan the fastest turn-around time for the calibration. Keep the calibration forms from the manufacturer. Consult the manufacturer if a deficiency is found in the instrument that may affect the data.

8.6.9 Signal Conditioning Cards

Signal conditioning cards will be tested individually for their internal zero and span reference checks. These values will be recorded on the ARS calibration form. Any recorded value greater than ± .1% of the designated value will require adjustment. The appropriate sensor will require a post-calibration if signal card adjustment was required.

8.7 Documentation

Meteorological checks and calibration documentation include:

- Weekly operator checks are documented by completing network-specific site weekly check sheets and/or documenting observations in the site log book.

- Calibration documentation includes:
    1. Calibration forms or computer laptop FORMS programs should be completely filled out. Where possible, use the FORMS program so that both a hard copy and digital record of the calibration can be maintained.
    2. Strip charts should be fully annotated.
    3. A summary of results and maintenance performed must be included in the station log notes.
    4. A calibration sticker is placed on all calibrated sensors.
    5. The calibration is documented thoroughly in a written site trip report.

8.8 Forms

The following forms are used to document meteorological calibrations:

- Wind speed/Wind Direction Calibration Form, Figure 1
- Temperature/Relative Humidity Calibration Form, Figure 2
- Solar Radiation Calibration Form, Figure 3
- Barometric Pressure Calibration Form, Figure 4
- Voltage Check Form, Figure 5
- Met System Signal Processor - Met One Instruments, Figure 6

METEOROLOGICAL CALIBRATION – WIND SPEED/WIND DIRECTION

Network:	Station:	Date:	By:

DVM Mfg:	S/N:	Last Calibration:
Mfg:	WS Model:	XLator S/N:
Height	WD Model	Xlator S/N:

To Landmark #1 °T Dec	Describe:
To Landmark #1 °T Dec	Describe:

WIND DIRECTION

	Initial	S/N:		***Final***	S/N:	
	DVM	Data Logger	Recorder	DVM	Data Logger	Recorder
To Landmark #1						
From Landmark #1						
To Landmark #2						
From Landmark #2						

Remarks:

WIND DIRECTION TRANSLATOR

	Initial			***Final***		
	DVM	Data Logger	Recorder	DVM	Data Logger	Recorder
Zero						
Span						
540						

Remarks:

WIND DIRECTION LINEARITY CHECK

90 ° READINGS	***Initial***			***Final***		
	DVM	Data Logger	Recorder	DVM	Data Logger	Recorder
1						
2						
3						
4						

Remarks:

CONTINUED ON BACK

FIGURE 1(page 1): Wind Speed/Wind Direction Audit Form

METEOROLOGICAL CALIBRATION – WIND SPEED/WIND DIRECTION (Continued)

WIND SPEED **Range:** **Units:**								
Motor Speed			***Initial***	S/N:		***Final***	S/N:	
RPM	Climatronics MPH	Qualimetric MPH	DVM	Data Logger	Recorder	DVM	Data Logger	Recorder
300	16	15.2						
600	32	30.0						
900	47.9	44.7						
1800	88.8	88.8						
Remarks:								

WIND SPEED TRANSLATOR						
	Initial	S/N:		***Final***	S/N:	
	DVM	Data Logger	Recorder	DVM	Data Logger	Recorder
Zero						
Span						
Other						
Remarks:						
Signature:						

FIGURE 1 (page 2): Wind Speed/Wind Direction Audit Form

METEOROLOGICAL CALIBRATION – Temperature / Relative Humidity

Network:	Station:	Date:	By:
DVM Mfg:	S/N:	Last Calibration:	
Mfg:	WS Model:	XLator S/N:	
Height	WD Model	Xlator S/N:	
Thermometer 1 Range:	Thermometer 1 S/N:		
Thermometer 2 Range:	Thermometer 2 S/N:		

S/N:	**TEMPERATURE**								
Initial					*Final*				
Bath	Temp C/F	DVM	Data Logger	Recorder	Bath	Temp C/F	DVM	Data Logger	Recorder
Warm					Warm				
Ice					Ice				

S/N:	**TEMPERATURE TRANSLATOR**			
	Initial		*Final*	
	Zero	Span	Zero	Span
DVM VDC				
Remarks:				

RELATIVE HUMIDITY									
RH S/N:			MFG:			MODEL:			
Ambient	Ref.	DVM	Data Logger	Recorder	Ambient	Ref	DVM	Data Logger	Recorder
RH					RH				

S/N:	**RELATIVE HUMIDITY TRANSLATOR**					
	Initial			*Final*		
	DVM	Data Logger	Recorder	DVM	Data Logger	Recorder
Zero						
Span						
Other						
Remarks:						
Signature:						

FIGURE 2: Temperature / Relative Humidity Audit Form

METEOROLOGICAL CALIBRATION – SOLAR

Network:	Station:	Date:	By:
DVM Mfg:	S/N:	Last Calibration:	
Reference Sensor:			
Mfg:	Model:	S/N:	
Calibration Constant:			
Remarks:			

S/N:	**SOLAR RADIATION**					
Mfg:			Model:			
	Initial			*Final*		
	DVM	Data Logger	Recorder	DMV	Data Logger	Recorder
Pyro output						
Ref. output						

Initial Δ %	Final Δ %

S/N:	**SOLAR RADIATION TRANSLATOR**					
	Initial			*Final*		
	DVM	Data Logger	Recorder	DMV	Data Logger	Recorder
Zero						
Span						
Other						

FIGURE 3: Solar Radiation Audit Form

METEOROLOGICAL CALIBRATION – BAROMETRIC PRESSURE

Network:	Station:	Date:	By:
DVM Mfg:	S/N:	Last Calibration:	
Reference Sensor:			
Mfg:	Model:	S/N:	
Calibration Check: (date)			
Remarks:			

S/N:	**BAROMETRIC PRESSURE**					
Mfg:		Model:				
	Initial			*Final*		
	DVM	Data Logger	Recorder	DMV	Data Logger	Recorder
Sensor output						
Ref. output						

Initial Δ %	Final Δ %

S/N:	**BAROMETRIC PRESSURE TRANSLATOR**					
	Initial			*Final*		
	DVM	Data Logger	Recorder	DMV	Data Logger	Recorder
Zero						
Span						
Other						

FIGURE 4: Barometric Pressure Audit Form

VOLTAGE CHECK FORM – Climatronics 460

Site:______________________________ Operator:________________________ Date:_________________

____ All Connections/Switches OK ______ Problems (See Comment Section)

☑ ***NOTE:*** when making adjustments, allow one minute before taking final reading.

	OK	OBSERVED	ADJUSTED TO
1.) System Voltage (6.40 ± 0.005)			
2.) System Zero Adjustments			
a.) WD Zero (0.000 ± 0.005)			
b.) WS Zero (0.025 ± 0.005)			
c.) WD Chart Setting (0°)			
d.) WS Chart Setting (0.5 mph)			
3.) System Span Adjustments			
a.) WD Span (3.33 ± - 0.005)			
b.) WS Span (1.285 ± 0.005)			
c.) WD Chart (360°)			
d.) WS Chart (25.7 mph)			
4.) System Span, 540° (3.33 ± 0.005)			

Comments____

____

____

____

____

Switch Settings for Operating Mode	
S-1	UP
S-2	UP
S-3	CENTER
S-4	UP
S-5	DOWN

______ ALL SWITCHES BACK TO OPERATING MODE

FIGURE 5: Voltage Check Form

MET SYSTEM SIGNAL PROCESSOR CHECKS

MET ONE INSTRUMENTS

SITE:		OPERATOR:		DATE:	

☑ ***NOTE:*** ***When making adjustments, allow one minute before taking final readings.***

			LOW CAL				HI CAL			
PARAMETER	RANGE	V OUT	REF.	OK	OBSERVED	ADJ. TO	REF.	OK	OBSERVED	ADJ. TO
Wind Speed	0-100 mph	0-5	0 mph/0 volt				85.2 mph/4.262 volt			
Wind Direction	0-540°	0-5	0°/0volt				540°/5 volt			
Temperature	-30 to +50°C	0-5	0°C/1.875 volt				46.37°C/4.773 volt			
Rel. Humidity	0-100%	0-5	0%/0 volt				100%/5 volt			
Solar Radiation	0-1400 watt/m2	0-5	0 watt/m2 / 0 volt				2000 watt/m2 /5volt			
Barometric Pressure	26-32 in Hg	0-5	26 inHg/0 volt				32 inHg/5volt			

9.0 REFERENCES

1. Application Note AN83-0274. 06-096 CMR, Chapter 115, Appendix A.

2. American Society of Testing Materials. 1982, 1983, 1984, 1985.

3. Climatronics F460 Wind System Instruction Manual. Climatronics Corporation, Bohemia, NY.

4. Guide to Remote DAS and Analyzer Control. Maine Department of Environmental Protection Standard Operating Procedure.

5. Meteorological Monitoring System Operation Manual (from Met One Instruments). Maine Department of Environmental Protection, Bureau of Air Quality. Augusta, ME, May 1994.

6. Quality Assurance Handbook for Air Pollution Measurement Systems Volume IV--Meterological Measurements. Revised August, 1989. U. S. Environmental Protection Agency, Office of Research and Development, Atmospheric Research and Exposure Assessment Laboratory. Research Triangle Park, NC.

7. The Nautical Almanac for 1995. Issued by the Nautical Almanac Office United States Naval Observatory, U.S. Government Printing Office, Washington, DC.

8. Westronics Series 1500 User Manual. Document Issue: D16.1, 10/90. Westronics, Inc., Fort Worth, TX.