APPENDIX A

Bay Area Air Quality Management District

Meteorological Monitoring Guidance for Manual of Procedures, Volume VI: Air Monitoring Procedures

(Adopted July 20, 1994)
(Latest Revision March 21, 2006)

Meteorological data used in analyses submitted to the Bay Area Air Quality Management District ("District") must be accurate and representative. These data may be used as input for modeling of new or modified sources, for health risk assessments, for analyses of "Ground Level Monitoring" (GLM) exceedances, and for analyses of odor complaints. This memorandum outlines District-recommended guidelines for the measurement of valid meteorological data. These recommendations are not written as absolute requirements, recognizing that some flexibility may be needed. However, to insure that meteorological data are acceptable for analyses, facilities choosing to deviate from District recommendations should consult with the District before embarking upon data collection.

In the Bay Area, meteorological data are collected on a routine basis by various government agencies such as the National Weather Service at airports, by sewage treatment plants, and by the District. Meteorological data are also collected by some large facilities, such as refineries, power plants, and chemical plants. Most of these data are now archived by the District. Because geographic features can affect airflow, the areas of representativeness of the meteorological data are limited by the site's proximity to complex terrain, large structures, or major water bodies. Facilities wishing to use data from a particular site in their air quality analyses must demonstrate that the area of representativeness of the meteorological data includes both the source and receptor areas of interest.

Facilities that choose to collect their own meteorological data should keep in mind that the instruments should be sited so as to characterize the airflow field between the source and the receptor areas. In flat terrain, or where receptors are close to the source, one meteorological site may be adequate. In complex terrain, meteorological data from numerous sites may be needed to accurately characterize the airflow field. Unless the terrain is open and flat, facilities should request that the District review and approve the monitoring plans before purchase or installation of equipment.

Aspects of a well-run meteorological monitoring system include use of proper equipment, instrument siting and maintenance practices, together with periodic audits and frequent data review. These are discussed in the following sections.

MEASUREMENTS

Standard surface meteorological measurements for air quality purposes usually include the following variables.

1) Wind Speed
2) Wind Direction
3) Sigma Theta
4) Temperature
5) Delta-T (optional).
6) Humidity (optional)
7) Gust (optional)
8) Rainfall (optional)
9) Solar Radiation (optional)

For meteorological purposes, wind direction is defined as the direction from which the wind is blowing, and is measured in degrees from true north. For each averaging time, wind speed and direction shall be scalar averaged (*not vector averaged*). Because wind direction has a numerical discontinuity between 360 and 001 degrees, scalar averaging of the wind direction is usually calculated using the unit vector method [*EPA, 2000*].

Sigma Theta is not measured directly, but is the standard deviation of wind direction. It *can be* used to calculate atmospheric stability, *and as an indicator of wind direction sensor problems.* Data loggers have incorporated this statistic into their software, and use the Yarmartino Method [Yarmartino, 1984] to average the standard deviations.

Delta-T is the temperature difference between two elevated levels on a tower. Along with solar radiation, it is commonly used to estimate surface layer stability (SRDT method). Solar radiation is also a good indicator of daytime cloud cover.

Gust data are useful when investigating damage caused by windstorms, and when designing structures.

SAMPLING FREQUENCY

Sampling rates for data loggers should be frequent enough so that mean values are based on at least 60 samples, and standard deviations are based on at least 360 samples. A sampling rate of once per second is commonly used and will result in 900 samples per fifteen-minute period.

The sampling rate for multipoint analog recorders should be at least once per minute.

SENSOR ACCURACY REQUIREMENTS IN REGULATORY APPLICATIONS

Meteorological data to be used in most regulatory applications shall meet the accuracies and resolutions listed in Table 5-1 of EPA's "*Meteorological Monitoring Guidance for Regulatory Modeling Applications [EPA, 2000]*." The accuracies are:

<u>Wind Speed Sensors</u>

For wind speed sensors, the starting threshold shall be rated as no higher than 0.5 meters per second. If there is some suspicion that the site would have a significant number of hours of wind speeds less than 0.5 m/s, we recommend using sensors with a lower threshold (the District routinely uses sensors with a threshold of 0.22 m/s).

Wind speed systems shall be accurate to within 0.2 m/s + 5% of observed speeds.

<u>Wind Direction Linearity</u>

Most wind direction sensors use a potentiometer to determine the direction the vane is positioned. Potentiometers have non-linear errors in their output, usually equivalent to ±1.8 degrees of direction. EPA recommends testing for the linearity error and that it not be larger than ± 3 degrees (EPA, 1995).

The method involves testing the wind direction sensor at 30-degree intervals, both clockwise and counterclockwise, using a linearity test fixture. Measured angles are subtracted from the expected angles. The angles are then normalized by subtracting the individual readings from the mean value. If any normalized value falls outside a ± 3 degree range, then the potentiometer should be replaced.

<u>Wind Direction Sensors</u>

For wind direction sensors, the starting threshold shall be rated as no higher than 0.5 meters per second. Wind direction system errors shall not exceed 5 degrees. The 5-degree error includes the sum of orientation errors and linearity errors (EPA, 1995, 2000). The error is calculated as follows.

Eq (1) $Error_{total} = Error_{orientation} + Error_{linearity}$
Eq (2) $Error_{orientation} = Azimuth_{target} - Azimuth_{corrected\text{-}measured}$
Eq (3) $Azimuth_{target} = Azimuth_{magnetic} + declination_{local}$
Eq (4) $Declination_{local} = Declination_{magnetic} + Interferences_{local}$
Eq (5) $Azimuth_{corrected\text{-}measured} = Azimuth_{measured} + Linearity_{azimuth\ angle}$
Eq (6) $Error_{linearity}$ = *Linearity error that results in the highest* $Error_{total}$

Equation (1) shows that the total wind direction error is the sum of the orientation error and the linearity error. As stated above, it should not exceed 5 degrees. The orientation error (2) is the difference between the target azimuth, usually taken along the crossarm, and the corrected-measured azimuth. The target azimuth (3) is the sum *of the magnetic bearing to the target and the local declination (if one has a GPS unit, one can alternatively determine the target azimuth by walking parallel to and from the target).*

The local declination (4) is the sum of the magnetic declination and local interferences (if any), such as magnetic irregularities, pieces of metal or water cavities. Magnetic declination can be found listed on USGS topographical maps, and on the USGS web page (www.usgs.gov). If local interferences are suspected, then it is best to use the solar method for determining local declination. Contact BAAQMD staff for information on this method.

Before subtracting from the target azimuth, the measured azimuth must first be corrected by adding the linearity error for that measured azimuth angle. This is obtained by averaging the clockwise and counterclockwise normalized linearity values for each of the 30-degree increments. Then, by assuming the errors are linear between these 30-degree increments, one can linearly interpolate to obtain the linearity error for any desired azimuth angle. Add this error to the measured azimuth (5), keeping track of any positive or negative signs, to get the corrected-measured azimuth.

The wind direction error is the sum of the orientation error and the averaged normalized linearity error (of the 30-degree increments) that results in the highest total wind direction error (6). Due to sign differences, this linearity error may not correspond to the highest normalized linearity error found in the Wind Direction Linearity section above. These calculations are best made on a spreadsheet.

Temperature and Humidity

Temperature system errors shall not exceed 0.5^{o}C. This may be difficult to demonstrate without the use of a water bath or a thermal mass (see Figure 4.3.5.1 in EPA, 1995) audit technique. If the co-located temperature measurements are made in ambient air, then an accuracy of $\pm$1.0^{o}C is the best that can be expected.

The humidity standard is stated as a dewpoint value. The dewpoint error shall not exceed 1.5^{o}C. When humidity is measured as RH, for calibration and audit comparisons, it should be converted to a dewpoint equivalency. The equation in Attachment 1 of this document will make that conversion.

Delta Temperature

For delta-T measurements, a system accuracy of $\pm$0.1^{o}C is required with a resolution of 0.02 ^{o}C.

Gust

Gust is the highest instantaneous wind speed that occurs during each averaging period. Because gusts are not used as input for pollutant modeling, EPA has not defined how long instantaneous lasts. In the past, gusts have been averaged over a period of 1 to

20 seconds. Now, in an effort to standardize the data, there has been recent agreement among the World Meteorological Organization, ASTM, and the National Weather Service to define the gust averaging time as a 3-second running average. Consequently, if gust data are to be collected, we recommend saving the maximum 3-second running average, so that it will be comparable with data from other sources. Attachment 2 illustrates how to collect that parameter using code for Campbell Loggers.

Precipitation

Precipitation errors shall not exceed 10% of observed or 0.5 mm. *If a tipping bucket raingage is used, each bucket shall also meet the 10% requirement.*

Solar Radiation

Solar radiation errors shall not exceed 5% of observed.

Time

The logger time shall be within 5 minutes of the correct time.

RECORDING DEVICES

Data may be recorded on strip chart recorders, or on data loggers. If data loggers are used, the District does not require the use of strip chart recorders as backup.

Data loggers are preferable to strip chart recorders because they are more precise, require very little maintenance, and allow data to be transmitted by telephone or radio to a central computer. Data loggers are also essential for calculating sigma theta values, used to compute stability.

STABILITY CALCULATIONS

Stability is a measure of the potential for vertical motions in the atmosphere. Generally this variable is not measured directly, but is derived from standard surface measurements. At airports, where measurements of wind speed, cloud cover and ceiling height are available, EPA recommends using the Pasquill-Turner method to derive stability [EPA, *2000*].

At sites where cloud cover observations are not taken, current EPA guidance recommends calculating stability by either the solar radiation/delta-T (SRDT) method or using wind fluctuation statistics (sigma theta method) [EPA, *2000*]. The SRDT method uses surface layer wind speed in combination with measurements of total solar radiation during the day and a vertical temperature difference (delta-T) at night. The sigma theta method uses measurements of surface wind speed and standard deviation of wind direction.

AVERAGING TIMES

General Purposes

Typical meteorological data includes wind speed, wind direction, stability, and temperature. Most uses require hourly-averaged data as input. Shorter averaging periods may also be desirable for analyzing short-term phenomena or when reviewing the data for intermittent sensor errors. In order to minimize meander effects, EPA recommends determining the hourly sigma theta values by taking the square root of the average of the squares of the four 15-minute sigma thetas [EPA, *2000*]. Most data loggers have already incorporated this algorithm into their hourly-average software.

For GLM Analyses

District Regulation 9 requires sources producing sulfur dioxide and hydrogen sulfide to collect SO_2, H_2S, and wind data. This is known as the Ground Level Monitoring (GLM) program and generally affects refineries, sulfuric acid plants and other specified facilities. Regulation 9 has SO_2 and H_2S standards for averaging times of 3 minutes, 60 minutes, and 24 hours. To facilitate analyses for the 3 minute and 60 minute standards, the District requires that these sources collect either continuous wind data on strip chart recorders, or one-minute averaged wind data using data loggers. Analyses for the 24-hour standards can be satisfied by using strip chart recorders, or by collecting 60-minute averaged wind data using data loggers. Regulation 1-1-543 requires that these data be kept for a minimum of two years. See the Data Reporting section for data reporting requirements.

While temperature and humidity measurements are not required, they are desirable. For these parameters, fifteen-minute or hourly averages are sufficient.

For Odor Analyses

District Regulation 7 sets limitations on odorous substances. The regulation has no requirement to collect wind data, nor are there any specific standards to meet. Because of the fleeting nature of odors, the District considers wind data to be ancillary to an odor investigation. For facilities that wish to use wind data in odor complaint analyses, the District recommends that the facility collect 1-minute and either 15-minute or 60-minute averages. The facility may use either strip chart recorders or data loggers.

INSTRUMENT SITING

Wind Sensors

The standard height for measuring surface winds is 10 meters above ground over level, open terrain. Open terrain is defined as being away from obstructions to flow, such as buildings, hills or trees. Generally, the wind sensors should be located where the horizontal distance between the sensors and any obstruction is at least ten times the height of that obstruction.

If wind sensors are to be mounted on a building, they should be mounted at a height at least 1.5 times the building height above the roof. It is usually not a good idea to mount wind sensors on stacks, unless the sensors can be mounted on booms at least two stack widths away from the stack, and with a wind measurement system mounted on both sides of the stack.

Temperature/Humidity Sensors

To meet World Meteorological Organization standards, temperature and humidity sensors should be located at a height of 2 meters over an area of level, grassy or natural ground that is at least nine meters in diameter. However, for air quality purposes, there is more flexibility, and sensors may be mounted between 2 and *10* meters above ground level.

Sensors should not be closer to buildings or trees than a distance equal to 4 times the height of the obstruction, or within 30 meters of any large paved areas. If mounted on the roof of a building, sensors shall be placed high enough to avoid heating effects caused by the roof.

Delta Temperature Sensors

When measuring delta-T for the SRDT method, EPA guidance [EPA, *2000*] recommends the lower temperature sensor be placed $20z_0$ to $100z_0$ above ground level (but no lower than 1 m) and the upper temperature sensor at 5 times the height of the lower sensor. z_0 is a measure of the unevenness of the surrounding land, usually in the range of .01 to 1 meter. This usually places the lower sensor at about 2 meters and the upper sensor at about 10 meters.

For delta-T measurements, a motor aspirated radiation shield with a flow rate of 3 m/s or greater is needed. It is critical that the same motor aspirated shield design be used for both sensors used to measure delta-T. Furthermore, the temperature sensors must be a factory-matched pair, with identical resistance properties.

Rainfall Sensors

A raingage should be sited on level ground so the mouth is level and open to the sky. Ideally, the underlying surface should be covered with short grass or gravel. The height of the opening should be as low as possible, but should be high enough to avoid splashing up from the ground. Generally, a wind screen of some form increases the accuracy of the collection. The distance to nearby structures should be at least two to four times the height of the structures.

Solar Radiation Sensors

Pyranometers should be located with an unrestricted view of the sky in all directions during all seasons. Sensor height is not important for pyranometers. They should be located far enough away from structures so that no shadows fall on the instrument. They should be located away from light colored walls or sources of light.

CLOCK TIME

Data shall be recorded in Pacific Standard Time. *When reporting data, the preferred convention is for time-ending data. These times shall range from 0100 to 2400 for hourly averages, and 0015 to 2400 for 15-minute averages* For example, in an hour-ending data file, a time of 1300 hours means that the data were averaged from 12:00:01 through 13:00:00 hours.

MAINTENANCE

Vandalism, high winds, or birds can produce misalignment of the sensors. Although many system defects will be identified through data review procedures, misalignment problems may not be obvious in the data. Consequently, visual inspections shall be made at each site at least once a month (inspections may be done by the facility's trained staff). During the inspections, we recommend comparing the instantaneous data with hand-held instruments (compass, psychrometer, etc.) to see that the sensors are accurately reflecting the current conditions.

A calibration of the meteorological equipment shall be performed at least once every six months by a trained technician. The technician may be an employee of the facility or from an outside consulting firm. In corrosive or dusty areas, more frequent calibrations may be needed. A logbook of calibrations and repairs shall be kept.

For those sensors that can be calibrated in the field, we recommend keeping spare parts on hand. For those sensors that must be calibrated in the laboratory or at the factory, site operators should maintain a supply of spare sensors for use as replacements.

INDEPENDENT AUDITS

Meteorological systems shall be audited twice per year. Audits should be performed by a qualified person not affiliated with the organization that maintains and calibrates the systems. It is common for the auditor to be assisted by a site operator who is familiar with the equipment.

An audit report shall be written and any problems noted shall be corrected as soon as possible. The audit report shall state whether each sensor passed the audit, and whether the data collection system (usually the data logger) has been programmed correctly. The determination of whether a sensor passes the audit should be based upon whether it meets EPA *recommended* standards, discussed in the Sensor Accuracy Requirements For Regulatory Applications section of this guideline.

Testing a sensor usually involves taking multiple readings of the instrument. The question may arise of whether to average the readings before comparison with the EPA standard, or whether to compare each reading with the standard. The general rule is that when the auditor can control the standard, such as using a constant speed motor or a water bath, then each individual data point needs to meet the standard. Where the auditor cannot control the input, then the average of the data points may be the best value to test against the standard.

When analyses are submitted to the District, audit reports covering the period of the data used in the analyses shall also be submitted.

DATA REVIEW

Meteorological data should be reviewed frequently, preferably on a daily basis. Much of this review can be done automatically by a computer. However, data should also be reviewed visually to look for any unusual situations. At a minimum, the review should cover checking for values out of range, periods of constant values, large changes over fifteen minutes (over an hour, if fifteen minute data are not available), incorrect clock times, and wind direction errors.

Frequent or persistent calm winds usually indicate worn bearings, or a high sensor threshold. Data sets with more than 10% calm winds on an annual basis will be considered suspect.

Bad data, as well as data collected during calibrations *and audits*, must be deleted from the database. A well-maintained meteorological system should be able to attain a 95% valid data recovery rate on an annual basis. The District requires at least a 90% data recovery rate on a quarterly basis.

DATA REPORTING

When reporting meteorological data, we recommend that the file contain a separate record for each time period (1-minute, 15-minute, or hourly). Each record should have the site ID, the year, the day, and the time at the beginning of the record. For GLM data, the District has further requested that the data be in a specific format. Contact the Meteorology and Data Analysis Section for a copy of the required format.

REFERENCES

Environmental Protection Agency, 2000. Meteorological Monitoring Guidance for Regulatory Modeling Applications, EPA-454/R-99-005.

Environmental Protection Agency, 1995. Quality Assurance Handbook for Air Pollution Measurement Systems - Volume IV - Meteorological Measurements (as revised March 1995), EPA-600/R-94/038d.

Yarmartino, R. J., 1984: A Comparison of Several "Single-Pass" Estimators of the Standard Deviation of Wind Direction. Journal of Climate and Applied Meteorology, 23, pp. 1362-1366.

Attachment 1

To calculate the dew point temperature T_d from air temperature T in degrees Celsius and relative humidity r in percent/100, use [EPA, 1995, Page 6 of Section 4.5.b.3]

$$Td = \frac{b\left[\ln r + \frac{aT}{b + T}\right]}{a - \left[\ln r + \frac{aT}{b + T}\right]}$$

Where: a = 17.27
b = 237.3

Attachment 2

Routine to calculate 3-second running average gusts in Campbell Scientific loggers.

```
5:  Z=X (P31)
   1:  1          X Loc [windspd]
   2:  20         Z Loc [ws1]

6:  Spatial Average (P51)
   1:  3          Swath
   2:  18         First Loc [ws3]
   3:  21         Ave Loc [ave_3sec]

7:  Block Move (P54)
   1:  2          No. of Values
   2:  19         First Source loc [ws2]
   3:  1          Source Step
   4:  18         First Destination Loc [ws3]
   5:  1          Destination Step


44: Maximize (P73)  -  this command under the output section.
   1:  1          Reps
   2:  0          Value Only
   3:  21         Loc [ave_3sec]
```