6. METEOROLOGICAL DATA PROCESSING

This section provides guidance for processing of meteorological data for use in air quality modeling as follows: Section 6.1 (Averaging and Sampling Strategies), Section 6.2 (Wind Direction, and Wind Speed), Section 6.3 (Temperature), Section 6.4 (Stability), Section 6.5 (Mixing Height), Section 6.6 (Boundary Layer Parameters), Section 6.7 (Use of Airport Data), and Section 6.8 (Treatment of Missing Data). Recommendations are summarized in Section 6.9.

6.1 Averaging and Sampling Strategies

Hourly averaging may be assumed unless stated otherwise; this is in keeping with the averaging time used in most regulatory air quality models. The hourly averaging is associated with the end product of data processing (i.e., the values that are passed on for use in modeling). These hourly averages may be obtained by averaging samples over an entire hour or by averaging a group of shorter period averages. If the hourly average is to be based on shorter period averages, then it is recommended that 15-minute intervals be used. At least two valid 15-minute periods are required to represent the hourly period. The use of shorter period averages in calculating an hourly value has advantages in that it minimizes the effects of meander under light wind conditions in the calculation of the standaard deviation of the wind direction, and it provides more complete information to the meteorologist reviewing the data for periods of transition. It also may allow the recovery of data that might otherwise be lost if only part of the hour is missing.

Sampling strategies vary depending on the variable being measured, the sensor employed, and the accuracy required in the end use of the data. The recommended sampling averaging times for wind speed and wind direction measurements is 1-5 seconds; for temperature and temperature difference measurements, the recommended sample averaging time is 30 seconds [3].

6.2 Wind Direction and Wind Speed

This section provides guidance for processing of in situ measurements of wind direction and wind speed using conventional in situ sensors; i.e., cup and propeller anemometers and wind vanes. Guidance for processing of upper-air wind measurements obtained with remote sensing platforms is provided in Section 9. Recommendations are provided in the following for processing of winds using both scalar computations (Section 6.2.1) and vector computations (Section 6.2.2). Unless indicated otherwise, the methods recommended in Sections 6.2.1 and 6.2.2 employ single-pass processing; these methods facilitate real-time processing of the data as it is collected. Guidance on the treatment of calms is provided in Section 6.2.3. Processing of data to obtain estimates of turbulence parameters is addressed in Section 6.2.4. Guidance on the use of a power-law for extrapolating wind speed with height is provided in Section 6.2.5. The notation for this section is defined in Table 6-2.

Table 6-1

Notation Used in Section 6.2

Observed raw data

u_i	signed magnitude of the horizontal component of the wind vector (i.e., the wind speed)
θ_i	azimuth angle of the wind vector, measured clockwise from north (i.e., the wind direction)
w_i	signed magnitude of the vertical component of the wind vector
ϕ_i	elevation angle of the wind vector (bivane measurement)
N	the number of valid observations

Scalar wind computations

$\overline{u}$, $\overline{U}$	scalar mean wind speed
$\overline{u_h}$	harmonic mean wind speed
$\overline{\theta}$	mean azimuth angle of the wind vector (i.e. the mean wind direction)
$\overline{w}$	mean value of the vertical component of the wind speed
$\overline{\phi}$	mean elevation angle of the wind vector
σ_u	standard deviation of the horizontal component of the wind speed
σ_A, σ_θ	standard deviation of the azimuth angle of the wind
σ_w	standard deviation of the vertical component of the wind speed
σ_E, σ_ϕ	standard deviation of the elevation angle of the wind

Vector wind computations

$\overline{U}_{RV}$	resultant mean wind speed
$\overline{\theta}_{RV}$	resultant mean wind direction
$\overline{\theta}_{UV}$	unit vector mean wind direction
V_e	magnitude of the east-west component of the resultant vector mean wind (positive towards east)
V_n	magnitude of the north-south component of the resultant vector mean wind (positive towards the north)
V_x	magnitude of the east-west component of the unit vector mean wind
V_y	magnitude of the north-south component of the unit vector mean wind
x,y,z	standard right-hand-rule coordinate system with x-axis aligned towards the east.

6.2.1 Scalar Computations

The scalar mean wind speed is:

$$\overline{u} = \frac{1}{N}\sum_{1}^{N} u_i \qquad (6.2.1)$$

The harmonic mean wind speed is:

$$\overline{u_h} = \left(\frac{1}{N}\sum_{1}^{N}\frac{1}{u_i}\right)^{-1} \qquad (6.2.2)$$

The standard deviation of the horizontal component of the wind speed is:

$$\sigma_u = \left[\frac{1}{N}\left\{\sum_{1}^{N} u_i^2 - \frac{1}{N}\left(\sum_{1}^{N} u_i\right)^2\right\}\right]^{1/2} \qquad (6.2.3)$$

The wind direction is a circular function with values between 1 and 360 degrees. The wind direction discontinuity at the beginning/end of the scale requires special processing to compute a valid mean value. A single-pass procedure developed by Mitsuta and documented in reference **[23]** is recommended. The method assumes that the difference between successive wind direction samples is less than 180 degrees; to ensure such, a sampling rate of once per second or greater should be used (see Section 6.2.4). Using the Mitsuta method, the scalar mean wind direction is computed as:

$$\overline{\theta} = \frac{1}{N}\sum_{1}^{N} D_i \qquad (6.2.4)$$

Adj

where $D_i = \theta_i$; for $i = 1$

574 1 $D_i = D_{i-1} + \delta_i + 360$; for $\delta_i < -180$ and $i > 1$

575 2 $D_i = D_{i-1} + \delta_i$; for $|\delta_i| < 180$ and $i > 1$

576 3 $D_i = D_{i-1} + \delta_i - 360$; for $\delta_i > 180$ and $i > 1$

D_i is undefined for $\delta_i = 180$ and $i > 1$

$\delta_i = \theta_i - D_{i-1}$; for $i > 1$

θ_i is the azimuth angle of the wind vane for the i^{th} sample.

δ = delta
D_i = Di

The following notes/cautions apply to the determination of the scalar mean wind direction using Equation. 6.2.4:

- If the result is less than zero or greater than 360, increments of 360 degrees should be added or subtracted, as appropriate, until the result is between zero and 360 degrees.
- Erroneous results may be obtained if this procedure is used to post-process sub-hourly averages to obtain an hourly average. This is because there can be no guarantee that the difference between successive sub-hourly averages will be less than 180 degrees.

The scalar mean wind direction, as defined in Equation. 6.2.4, retains the essential statistical property of a mean value, namely that the deviations from the mean must sum to zero:

$$\sum (\theta_i - \bar{\theta}) = 0 \qquad (6.2.5)$$

By definition, the same mean value must be used in the calculation of the variance of the wind direction and, likewise, the standard deviation (the square root of the variance). The variance of the wind direction is given by:

$$\sigma_\theta^2 = \frac{1}{N} \sum (\theta_i - \bar{\theta})^2 \qquad (6.2.6)$$

The standard deviation of the wind direction using the Mitsuta method is given by:

$$\sigma_A = \sigma_\theta = \left[\frac{1}{N} \left\{ \sum_1^N D_i^2 - \frac{1}{N} \left(\sum_1^N D_i \right)^2 \right\} \right]^{1/2} \qquad (6.2.7)$$

Cases may arise in which the sampling rate is insufficient to assure that differences between successive wind direction samples are less than 180 degrees. In such cases, approximation formulas may be used for computing the standard deviation of the wind direction. Mardia [24] shows that a suitable estimate of the standard deviation (in radian measure) is:

$$\sigma_A = \sigma_\theta = [-2 \ln(R)]^{1/2} \qquad (6.2.8)$$

where

$$R = (Sa^2 + Ca^2)^{1/2}$$

$$Sa = \frac{1}{N} \sum_1^N \sin(\theta_i)$$

$$Ca = \frac{1}{N} \sum_1^N \cos(\theta_i)$$

Several methods for calculating the standard deviation of the wind direction were evaluated by Turner [25]; a method developed by Yamartino [26] was found to provide excellent results for most cases. The Yamartino method is given in the following:

$$\sigma_A = \sigma_\theta = \arcsin(\ )\ [1. + 0.1547\ \ ^3] \qquad (6.2.9)$$

where

$$= \left[1. - \left(\overline{\sin(\theta_i)}^{\,2} + \overline{\cos(\theta_i)}^{\,2}\right)\right]^{1/2}$$

Note that hourly σ_θ values computed using 6.2.7, 6.2.8, or 6.2.9 may be inflated by contributions from long period oscillations associated with light wind speed conditions (e.g., wind meander). To minimize the effects of wind meander, the hourly σ_θ (for use e.g., in stability determinations - see Section 6.4.4.4) should be calculated based on four 15-minute values averaged as follows:

$$\sigma_\theta(1\text{-}hr) = \left[\ \left\{(\sigma_{\theta_1})^2 + (\sigma_{\theta_2})^2 + (\sigma_{\theta_3})^2 + (\sigma_{\theta_4})^2\right\} /4\ \right]^{1/2} \qquad (6.2.10)$$

The standard deviation of the vertical component of the wind speed is:

$$\sigma_w = \left[\frac{1}{N}\left\{\sum_1^N w_i^2 - \frac{1}{N}\left(\sum_1^N w_i\right)^3\right\}\right]^{1/2} \qquad (6.2.11)$$

Similarly, the standard deviation of the elevation angle of the wind vector is:

$$\sigma_E = \sigma_\phi = \left[\frac{1}{N}\left\{\sum_1^N \phi_i^2 - \frac{1}{N}\left(\sum_1^N \phi_i\right)^2\right\}\right]^{1/2} \qquad (6.2.12)$$

Equation 6.2.12 is provided for completeness only. The bivane, which is used to measure the elevation angle of the wind, is regarded as a research grade instrument and is not recommended for routine monitoring applications. See Section 6.2.3 for recommendations on estimating σ_ϕ.

6.2.2 Vector Computations

From the sequence of N observations of θ_i and u_i, the mean east-west, V_e, and north-south, V_n, components of the wind are:

$$V_e = -\frac{1}{N}\sum u_i \sin(\theta_i) \qquad (6.2.13)$$