Processing of Velocity and Concentration Time Series

The velocity time series were collected with the sonic anemometers over a 24 h period. Partition the data from each sonic anemometer into 30-minute records (e.g., 0000-0030, 0030-0100, 0100-0130, ..., 1130-0000). For each data record from each sonic anemometer, compute the following quantities. In what follows, the overbar denotes the time average over the relevant period of interest, and a primed quantity is used to denote a fluctuation from the mean.

1. Given the probe orientation of the sonic anemometer, the velocity field is rotated into a common coordinate system. The common coordinate system is chosen as follows: (a) the x-axis is chosen to be parallel to the normal of the wide face of the obstacles; hence, take the positive x-axis to point 30° W of N; (b) the y-axis is then perpendicular to the x-axis, so take the positive y-axis to point 120° W of N; and, (c) the z-axis is taken to be vertical (viz., normal to the ground surface). Hence, x, y, and z form a right-handed coordinate system. For consistency of notation, let us denote by U, V, and W, the components of the velocity along the x-, y-, and z-axes, respectively.

2. Calculate the mean velocity in each direction: $\overline{U}$, $\overline{V}$, and $\overline{W}$ (m s^{-1}). Note that W will not be available for the two-axis sonic anemometers mounted on the pnuematic masts just upstream and downstream of the MUST array.

3. Calculate the instantaneous wind direction: $\alpha = \tan^{-1}\big(V/U\big)$ (degrees CCW with respect to the positive x-axis). Use this time series to determine the mean wind direction $\overline{\alpha}$ and the standard deviation in the mean wind direction $(\overline{\alpha'^2})^{1/2}$. In addition, calculate the maximum excursion of the wind from the array normal, viz. $\alpha_{\max} = \max_{i=1,2,\ldots,N} \alpha_i$ and the number of reversals of wind direction during the 30-minute sampling interval, viz., the number of times when $|\alpha_i| > 90°$ $(i = 1, 2, \ldots, N)$. Also, calculate the horizontal mean wind speed, $S \equiv \sqrt{\overline{U}^2 + \overline{V}^2}$.

4. A sonic temperature time series from the velocity of sound is calculated from

$$T_s = \frac{M c^2}{\gamma f R},$$

where T_s is the sonic temperature in K; $M = 28.9666$ kg kmol^{-1} is the molecular weight of dry air; c is the velocity of sound in air (measured by the sonic anemometer) in m s^{-1}; $\gamma = 1.40$ (dimensionless) is the ratio of specific heat capacities of dry air at constant pressure and volume; $f = 0.9997$ (dimensionless); and, $R = 8314.36$ J kmol^{-1} K^{-1} is the universal gas constant. This will be used as a measure also of the absolute temperature of the air.

5. Calculate the velocity variances in the x, y, and z directions: $\overline{u'^2}$, $\overline{v'^2}$, and $\overline{w'^2}$ (m^2 s^{-2}) as well as the turbulence kinetic energy, $k \equiv \frac{1}{2}(\overline{u'^2} + \overline{v'^2} + \overline{w'^2})$; the mean sonic temperature, $\overline{T_s}$ (K), and sonic temperature variance $\overline{T'^2}$ (K^2); the following covariances,

$\overline{u'v'}$, $\overline{u'w'}$, and $\overline{v'w'}$ in m^2 s^{-2}; the following higher-order covariances: $\overline{w'u'^2}$ and $\overline{w'v'^2}$ in m^3 s^{-3}; the third order velocity moments: $\overline{u'^3}$, $\overline{v'^3}$, and $\overline{w'^3}$ in m^3 s^{-3}; the fourth order velocity moments: $\overline{u'^4}$, $\overline{v'^4}$, and $\overline{w'^4}$ in m^4 s^{-4}; the skewnesses: $Sk_u \equiv \overline{u'^3}/\sigma_u^3$, $Sk_v \equiv \overline{v'^3}/\sigma_v^3$, and $Sk_w \equiv \overline{w'^3}/\sigma_w^3$; the kurtoses: $Kr_u \equiv \overline{u'^4}/\sigma_u^4$, $Kr_v \equiv \overline{v'^4}/\sigma_v^4$, and $Kr_w \equiv \overline{w'^4}/\sigma_w^4$. Here, $\sigma_u \equiv (\overline{u'^2})^{1/2}$, $\sigma_v \equiv (\overline{v'^2})^{1/2}$, and $\sigma_w \equiv (\overline{w'^2})^{1/2}$ are the standard deviations of the velocity fluctuations in the x, y, and z directions.

6. Calculate the following temperature fluxes: $\overline{u'T_s'}$, $\overline{v'T_s'}$, and $\overline{w'T_s'}$ in m s^{-1} K.

7. Calculate the buoyant production terms: $g\overline{u'T_s'}/\overline{T_s}$ and $g\overline{w'T_s'}/\overline{T_s}$, where $g = 9.8$ m s^{-2} is the gravitational acceleration. Units are m^2 s^{-3}

8. Some auxilary meteorological quantities of interest: (a) friction velocity, u_*, (m s^{-1}) defined as

$$u_* = \left[(\overline{u'w'})^2 + (\overline{v'w'})^2\right]^{1/2};$$

(b) local free convection velocity scale, w_*^L, (m s^{-1}) defined as

$$w_*^L = \left[\frac{gz}{\overline{T_s}}\overline{w'T_s'}\right]^{1/3},$$

which is computed only if $\overline{w'T_s'} > 0$ and z is the height (m) of the anemometer above the ground surface; (d) Monin-Obukhov length L, (m) defined as

$$L = -\frac{u_*^3\overline{T}_s}{\kappa g\overline{w'T_s'}},$$

where $\kappa = 0.4$ is von Karman's constant; (e) $H \equiv \rho C_{pa}\overline{w'T_s'}$ (W m^{-2}) is the sensible heat flux, where $\rho = 1.2$ kg m^{-3} is density of air, and $C_{pa} = 1005$ J kg^{-1} K^{-1} is specific heat capacity of dry air at constant pressure.

9. Calculate the integral timescales of turbulence (defined using Taylor's "frozen-eddy" hypothesis):

$$T_u = \int_0^\infty R_{uu}(\tau)\, d\tau,$$

$$T_v = \int_0^\infty R_{vv}(\tau)\, d\tau,$$

and

$$T_w = \int_0^\infty R_{ww}(\tau)\, d\tau,$$

where R_{uu}, R_{vv} and R_{ww} are the autocorrelation functions of velocity in the x, y, and z directions, respectively. These are defined as $R_{uu}(\tau) \equiv \overline{u'(t)u'(t+\tau)}/\overline{u'^2}$, $R_{vv}(\tau) \equiv \overline{v'(t)v'(t+\tau)}/\overline{v'^2}$, and $R_{ww}(\tau) \equiv \overline{w'(t)w'(t+\tau)}/\overline{w'^2}$. In order to compute T_u, T_v, and T_w (s) from finite datasets, the integration is carried out to the first zero crossing. Finally,

multiplying T_u, T_v, and T_w by horizontal mean wind speed S, we get the integral length scales of turbulence, Λ_u, Λ_v, and Λ_w, respectively (m).

The concentration time series were acquired over sampling times of 15 minutes for most of the steady release experiments. Because background meteorological conditions may be changing over the 15-minute sampling time duration, it will be necessary to apply conditional sampling to the concentration time series in order to extract the 3- to 5-minute period from each record of 15-minute duration with the least variation of mean wind direction and use this 3- to 5-minute period as the standard sampling period for computation of the plume concentration statistics. After the conditional sampling of concentration, it would be useful to compute the following concentration statistics:

1. Mean concentration: $\overline{\chi}$ (ppm)
2. Concentration variance: $\sigma_c^2 \equiv \overline{\chi'^2}$ (ppm^2)
3. Concentration fluctuation intensity: $i = \sigma_c/\overline{\chi}$
4. Time scale of concentration flucuations: T_c (s)—this is defined in an analogous manner to that of T_u, T_v, and T_w and involves computing the autocorrelation function of the concentration time series.
5. Determine the cumulative distribution function of concentration for various probability points (select enough points to give smooth curve of CDF on linear scale and EDF (= 1-CDF) on logarithmic scale). Some sort of judgement in selection of appropriate probability points will be required here. From this curve, we should be able to get the 99th-percentile of concentration (i.e., concentration level that is exceeded only one percent of the time) and use this value to calculate the peak-to-mean concentration: $\chi_{99}/\overline{\chi}$.
6. From extraction of these concentration statistics, we should be able to prepare plots of horizontal and vertical profiles of concentration statistics along the 4 horizontal sampling lines and 1 vertical sampling line at 32-m vertical tower.