Issues Related to Plume Meander in the AERMOD System

Overview of Issues

AERMOD accounts for plume meander (i.e., the slow lateral back and forth shifting of the plume from low frequency, non-diffusing eddies) as the plume travels downwind from the source. This is one of many formulation enhancements to dispersion over AERMOD's predecessor, the Industrial Source Complex (ISC) model. Meander decreases the likelihood of observing a coherent plume after long travel times and results in a greater plume spread and increased dispersion downwind. Currently, plume meander is only applied to point and volume sources within AERMOD and is not applied to area sources, though an area source plume is expected to exhibit similar behavior downwind of the source.

In addition, under the current default options, AERMOD has shown a tendency to overpredict in low wind conditions for some sources, especially during nighttime stable conditions. There is a need to better understand how plume meander is affected in low wind conditions and its potential influence in situations where overprediction occurs. As discussed in more detail in the next section, plume meander in AERMOD consists of two limiting components: a coherent plume and a random plume (i.e., pancake plume). The random plume results in some amount of the plume dispersed upwind of the source, whereas the coherent plume maintains the entire mass of the plume downwind of the source.

EPA first provided beta options to address model overprediction for low wind conditions within AERMOD version 12345. These beta options included:

- ADJ_U* which adjusts the surface friction velocity (u*) during stable, low wind conditions;
- LOWWIND1 which increases the minimum value of the lateral turbulence intensity (sigma-v) from the default value of 0.2 m/s to 0.5 m/s; sigma-v is used to determine the lateral plume dispersion coefficient (sigma-y); and
- LOWWIND2 which increases the minimum value of sigma-v to a value of 0.3 m/s.

A fourth beta option, LOWWIND3, was included in the release of AERMOD version 15181. LOWWIND3 also increases the minimum value of sigma-v to 0.3 m/s. In addition to modifying minimum sigma-v, LOWWIND1, LOWWIND2 and LOWWIND3 each include changes from the default implementation of plume meander that is applied when the AERMOD is run in the default regulatory mode. Meander was not a consideration in the ADJ_U* option that was promulgated as a regulatory option in the release of AERMOD version 16216r. LOWWIND1, LOWWIND2, and LOWWIND3, however, remain beta options.

With regards to the LOWWIND options and meander, LOWWIND1 turns off the horizontal meander component altogether, whereas LOWWIND2 incorporates meander with an adjustment on the default upper limit of the meander factor (FRAN) from 1.0 to 0.95. LOWWIND2 also includes an adjustment to the default time scale at which the mean wind is assumed to no longer be correlated with the location of plume material at a downwind receptor. The time scale was changed from the default value of 24 hours to 12 hours for LOWWIND2. LOWWIND3 uses the default time scale of 24 hours. LOWWIND3 includes the same adjustment to the upper limit on FRAN as used for LOWWIND2 but eliminates upwind dispersion of the plume.

EPA is focused on the following two issues related to plume meander in the AERMOD dispersion model:

1) Meander is only applied to point and volume sources such that we intend to pursue adding meander for area sources.

2) Understanding the appropriate response of the plume in low wind conditions with regard to meander and the effect meander has on concentrations in low wind conditions. The influential aspects of meander that EPA has identified to date include the upper limit of FRAN, the time scale for which there is no correlation between the location of the plume near the source and downwind of the source, the degree to which upwind dispersion should be applied or eliminated, or whether meander should be eliminated altogether.

Current Implementation in AERMOD

AERMOD accounts for plume meander by interpolating between two concentration limits: the coherent plume limit (which assumes that the wind direction is distributed about a well-defined mean direction with variations due solely to lateral turbulence) and the random plume limit, (which assumes an equal probability of any wind direction).

For the coherent plume, the horizontal distribution function (F_{yC}) has the familiar Gaussian form:

$$F_{yC} = \frac{1}{\sqrt{2\pi}\sigma_y} \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \quad \textit{eq.1}$$

where σ_y is the lateral dispersion parameter. For the random plume limit, the wind direction (and plume material) is uniformly distributed through an angle of 2π. Therefore, the horizontal distribution function F_{yR} takes the simple form:

$$F_{yR} = \frac{1}{2\pi x_r} \qquad \textit{eq. 2}$$

where x_r is the radial distance to the receptor. Although the form of the vertical distribution function remains unchanged for the two plumes, its magnitude is based on downwind distance for the coherent plume and radial distance for the random plume.

Once the two concentration limits (C_{Ch} - coherent plume; C_R - random plume) have been calculated, the total concentration for stable or convective conditions ($C_{c,s}$) is determined by interpolation. Interpolation between the coherent and random plume concentrations is accomplished by assuming that the total horizontal "energy" is distributed between the wind's mean and turbulent components. That is,

$$C_{c,s} = C_{Ch}\left(1 - \sigma_r^2/\sigma_h^2\right) + C_R\left(\sigma_r^2/\sigma_h^2\right) \qquad \textit{eq. 3}$$

where $\sigma_h{}^2$ is a measure of the total horizontal wind energy and $\sigma_r{}^2$ is a measure of the random component of the wind energy. Therefore, the ratio $\sigma_r{}^2 / \sigma_h{}^2$ is an indicator of the importance of the random component and can therefore be used to weight the two concentrations as done in eq. 3.

The horizontal wind is composed of a mean component $\bar{u}$, and random components σ_u and σ_v. Thus, a measure of the total horizontal wind "energy" (given that the along-wind and crosswind fluctuations are assumed equal i.e., $\sigma_u = \sigma_v$), can be represented as

$$\sigma_h^2 = 2\tilde{\sigma}_v^2 + \bar{u}^2 \qquad \textit{eq. 4}$$

where $\bar{u}$ = $(\tilde{u}^2 - 2\tilde{\sigma}_v{}^2)^{1/2}$. The random energy component is initially $2\tilde{\sigma}_v{}^2$ and becomes equal to $\sigma_h{}^2$ at large travel times from the source when information on the mean wind at the source becomes irrelevant to the predictions of the plume's position. The evolution of the random component of the horizontal wind energy can be expressed as

$$\sigma_h^2 = 2\tilde{\sigma}_v^2 + \bar{u}^2(1 - \exp(-x_r/\tilde{u}T_r)) \qquad \textit{eq. 5}$$

where T_r is a time scale (= 24 hrs) at which mean wind information at the source is no longer correlated with the location of plume material at a downwind receptor. Analyses involving autocorrelation of wind statistics (Brett and Tuller 1991) suggest that after a period of approximately one complete diurnal cycle, plume transport is "randomized." Equation 5 shows that at small travel times, $\sigma_r{}^2 = 2\tilde{\sigma}_v{}^2$, while at large times (or distances) $\sigma_r{}^2 = 2\tilde{\sigma}_v{}^2 + \bar{u}^2$, which is the total horizontal kinetic energy ($\sigma_h{}^2$) of the fluid. Therefore, the relative contributions of the coherent and random horizontal distribution functions (eq. 3) are based on the fraction of random energy contained in the system (i.e., $\sigma_r{}^2 / \sigma_h{}^2$).

Summary of Current Literature or Research

Mortarini et al., 2016

Mortarini et al. studied meander during low-wind cases from field campaigns in Italy and Brazil. Meander and non-meander cases were identified using Eularian autocorrelation functions (EAF) of the horizontal wind-velocity components and temperature. The study concluded that meander does not depend on stability; however, meander does depend on wind speed and is further influenced by the presence of buildings. The standard deviation of the horizontal wind speed is generally large during low wind conditions. The researchers demonstrate that meander and non-meander cases can be identified based on the ratio of the standard deviations of the vertical and horizontal velocity components. Non-meander cases exhibit a larger ratio than meander cases.

Moreira et al., 2013

This work resulted in a new formulation for the parameterization of turbulence associated with meander in a shear driven stable boundary layer. The formulation is based on a relationship between turbulence and the meander period in which patterns of movement are characterized by a weighting of turbulence and meander. The formulation was tested with a Lagrangian stochastic dispersion model against field observations at the Idaho Engineering Laboratory (INEL). Results are presented which demonstrate good performance.

Hiscox et al., 2010

Hiscox et al. used aerosol lidar measurements from the JORNADA field campaign in the New Mexico desert to study plume spread and meander. The turbulent scale was separated from the submesoscale using multiresolution decomposition, and durations of turbulent kinetic energy (TKE) stationarity and wind steadiness were used to characterize the local scale and submesoscale turbulence. The researchers found that in strong stability during weak and variable winds, horizontal plume spread was primarily from plume meander caused by submesoscale motion, and small scale turbulence had little influence. During periods of higher wind speeds and weaker stability, meander was still dominant but the ratio of the meander to small scale turbulence decreased. The study concluded that measure of wind steadiness and the turbulence stationarity are closely related and could be viable parameters to describe plume diffusion and meander in the stable boundary layer.

Considerations for Updates in AERMOD Model System

The EPA welcomes input from the community on possible implementations of meander for area sources.

In terms of the influence of meander during low wind conditions, the EPA is currently focusing its examination on the following parameters:

1) upper limit on the meander fraction (FRAN);
2) time scale at which there is assumed to be no correlation with the location of the plume near the source and a downwind receptor; and
3) degree or existence of upwind dispersion from the random or pancake plume.

EPA expects that the use of beta options as part of future releases of AERMOD will provide the ability to adjust, at a minimum, a subset of parameters through user input for research and experimental purposes. The EPA plans to engage with the community and welcomes input that can lend additional insight on the appropriate role of plume meander, particularly under low wind conditions. The ultimate goal for the treatment of meander is a robust beta option with values of relevant parameters set that best or most appropriately reflect the role of meander in low wind conditions.

References

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