Minimum value for lateral turbulence (aka, minimum σ_v)

Overview of Issue

The lateral turbulence (or the standard deviation of lateral velocity to the average wind direction), commonly referred to as σ_v, is the amount of fluctuation in the wind speed in the direction perpendicular to the mean wind and represents the turbulent flow across a plume in the boundary layer. The lateral dimension of a plume is directly correlated to the value of σ_v, with larger σ_y values resulting in larger plumes and lower concentrations. Thus, the observed or estimated value of σ_v has a direct impact on model predicted concentrations. The formulations to calculate σ_v result in values of σ_v of zero when wind speeds approach zero (i.e., low wind conditions). However, field data suggests that the minimum values of σ_v do not approach zero. As a result, a minimum value for σ_v has been implemented in the AERMOD dispersion model (and other dispersion models) to adhere with the observed field data.

In other words, estimates of σ_v in low wind conditions are often too small (approaching zero), requiring a minimum value to be set. During these low wind conditions, plume volumes are inherently small, generally resulting in higher concentrations. Increasing the minimum σ_v will result in lowering the maximum concentrations estimated for surface releases. For elevated releases, specifically when terrain considerations are important, increasing the minimum σ_v may increase or decrease concentrations, depending on conditions. It is expected to likely lower most concentrations, though this may not correspond to the highest modeled concentrations.

Current Implementation in AERMOD

The calculation of σ_v in AERMOD is described in section 4.1.6 of the AERMOD Formulation and Evaluation Document. The total lateral turbulence is the sum of the mechanical (σ_{vm}) and convective (σ_{vc}) portions:

$$\sigma_{vT}^2 = \sigma_{vc}^2 + \sigma_{vm}^2$$

The mechanical turbulence at the surface is a function of the surface friction velocity (u_*):

$$\sigma_{vm}^2 = 3.6 * u_*^2$$

and varies linearly from the surface up to the top of the mechanically mixed layer. The convective turbulence within the mixed layer is constant and is a function of the convective velocity scale (w_*):

$$\sigma_{vc}^2 = 0.35 * w_*^2$$

And decreases linearly from the convective mixing height up to 0.25 m^2/s^2 at $1.2*z_{ic}$ (the convective mixing height). Above $1.2z_{ic}$, s^2_{vc} is held constant. The default version of AERMOD sets a lower limit for the calculated σ_v of 0.2 m/s. The lower limit of σ_v is adjusted with the beta LOWWIND options. LOWWIND1 uses a minimum σ_v of 0.5 m/s, and LOWWIND2 and LOWWIND3 use a minimum σ_v of 0.3 m/s. The minimum σ_v value is set as the SVMIN parameter in the subroutine MODOPT in the COSET.f file in the AERMOD code.

Summary of Current Literature or Research

The lateral turbulence parameter, σ_v, has been discussed in a number of journal articles over the past few years; however, there is not a specific emphasis on demonstrating what value should be selected as the minimum σ_v.

Hannah et al., 1985

The more current literature suggests that this paper is the basis for the default selection of the minimum σ_v in AERMOD. Figure 3 of this paper shows observation data collected aboard a research vessel operated off the California coast from four different research cruises. The σ_v values for this analysis were calculated as the product of the mean wind (U) and the standard deviation of the wind direction (σ_θ). The figure shows the range of σ_v values, with an apparent lower limit of 0.175 m/s and a mean value of 0.5 m/s.

Luhar, 2009

This work examines the various experimental and analytical methods employed to determine σ_v and σ_u, or the longitudinal turbulence. There is particular emphasis on the methodologies under low-wind conditions, when the accuracy of existing methods is more sensitive to the method selection. The work identifies two equations typically used to determine σ_v from field data:

$$\sigma_v = \overline{U} * \sin \sigma_\theta$$

and

$$\sigma_v = \overline{U} * \tan \sigma_\theta$$

where $\overline{U}$ is the mean scalar wind speed and σ_θ is the standard deviation of horizontal wind direction fluctuations. At low wind speeds, these functions converge to:

$$\sigma_v \approx \overline{U} * \sigma_\theta$$

The paper reviews several attempts to relate measured data to derived values of σ_v, particularly for low wind conditions. The paper presents an analysis of the various parameterizations of σ_v and σ_u against meteorological data collected under low wind-speed, inversion conditions at the Idaho National Laboratory in south-eastern Idaho in 1974 (Sagendorf and Dickson 1974). The paper also presents an evaluation of an alternative formulation for the calculation of σ_v and σ_u. Estimates of σ_v are slightly improved, while estimates of σ_u show greater improvements. Notably, the smallest observed values of σ_v appear to be on the order of 0.05 m/s.

Hannah and Chowdhury, 2014

This work examines several modifications evaluated with the release of AERMOD version 12345. Specifically, modifications to the estimation of u_*, changes to the application of the random plume (i.e., the pancake plume), and alternative values for the minimum σ_v and σ_w, or the vertical turbulence. Of these options, the adjusted u_* was adopted as a non-beta option in AERMOD version 16216r, while the changes to the so-called “pancake plume” and the alternative values of minimum σ_v evaluated in the paper form pieces of the LOWWIND beta options in AERMOD. The model settings are compared to the equivalent settings in the SCICHEM model, a Lagrangian puff model originally developed as SCIPUFF, but currently being updated to include chemistry options. With respect to the minimum σ_v, the paper points out that SCICHEM uses a minimum σ_v of 0.5 m/s (and a minimum σ_w of 0.1 m/s, versus AERMOD's minimum σ_w value of 0.02 m/s). The paper proposes that at low wind speeds, these two differences alone could result in AERMOD having concentrations 12.5 times higher than SCICHEM.

The paper also presents a model evaluation between SCICHEM, the base version of AERMOD 12345, and one version of AERMOD that applies the adjusted u* approach, a minimum σ_v of 0.3 m/s, and modification to the application of the pancake plume for the Oak Ride and Idaho Falls field study databases. The results suggest improved model performance for the beta AERMOD options, though it is unclear which of the options have the greatest impact on performance. SCICHEM performance is similar to the beta AERMOD performance.

Hoinaski et al., 2017

This work examines the estimates of σ_v and resulting estimates of σ_y in AERMOD based on two field studies in USA's Round Hill II (Cramer, 1957) and Germany's Uttenweiller (Bächlin, 2002) experiment databases. The work emphasizes the effect of the averaging time for the calculation of the meteorological model inputs and concentrations. The work does not directly address the minimum σ value, but demonstrates the sensitivity of modeled results (and modeled over-predictions) to the estimation of the σ_v by also running AERMOD with on-site values of σ_v. The work suggests that the Lagrangian time scale might also need examination, particularly for longer travel times. It should be noted that the data from these field studies range from 30-s averaging times up to 10-min, well below the standard time step for AERMOD (1-hour).

Considerations for Updates in Model System

As outlined above, the σ_v value has a very direct impact on plume size and modeled concentrations. It may seem like adjusting the minimum sigma v is straightforward way to address modeled over-predictions for low wind conditions for surface releases. However, the findings in these papers show clearly that σ_v values can be lower than the current default of 0.2 m/s. Additionally, adjusting the minimum σ_v values may "fix" some over-predictions for surface releases, but may negatively affect modeled predictions for elevated releases. The reviewed literature points to several methods to determine the σ_v value that should be considered rather than simply adjusting the minimum σ_v value. The data sets analyzed are also fairly limited, which suggest more data sets should be identified or made available to investigate the issue.

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