AERMOD Low Wind Speed Evaluation Study

(photo by James Shuepp, provided by Larry Mahrt)

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Outline of Presentation

• Why are low wind speeds a concern?
• Review of current AERMOD formulation
• Evaluation study approach
• Meteorological evaluation results
• Tracer study evaluation results
• Findings and recommendations
Concerns Noted by EPA and the Modeling Community

• Brode USEPA 2007 Modeling Workshop from AERMOD Implementation Workgroup Highlights
  – “Mandatory Work: Light winds. Revise AERMOD’s treatment of light winds to avoid unrealistically high concentrations”

• Reported at USEPA’s 9th Modeling Conference - Air & Waste Management Association Comments
  – Many investigators report that the worst-case AERMOD impacts occur for very low wind speeds at night, especially for low-level sources

• AERMOD has limited evaluation for these conditions – very few hours with wind speed < 1 m/s
Current AERMET/AERMOD Approach

• AERMET computes the friction velocity ($u_*$), which is an important parameter for nocturnal hour estimates of mixing height, sigma-z, and sigma-y

• AERMOD approach in low winds is reasonably simple, and involves a combined solution of a coherent plume (traditional Gaussian shape) and a random (pancake) plume

• Weighting of the two solutions depends upon wind speed and turbulence provided to AERMOD
Approach for this Study (2009)

• We initiated a new evaluation study to understand AERMOD’s performance under low wind speeds
• The evaluation study featured existing research-grade meteorological and low wind speed tracer databases
• Guideline and alternate versions of AERMET/AERMOD were tested in this study
• Collaboration with USEPA and AERMIC review was important for this study
• However (to my knowledge), AERMIC has provided limited review to date
Phase 1: Meteorological Evaluation Study

- Requested by EPA; evaluation focused upon $u_*$
- Research-grade databases were selected for low wind speeds and sonic anemometer to get observed $u_*$
- Evaluation focused upon nocturnal, low wind conditions
- Cardington (flat, grassy site in the UK) was included in the evaluation
- Other met databases (USA) were:
  1. Bull Run (mixed land use/terrain Tennessee site)
  2. FLOSS II (Fluxes Over Snow Surfaces, Phase 2: flat open site in northern Colorado)
Meteorological Evaluation Results

- Single-level friction velocity predictions by AERMET were found to be too low for low wind, stable hours.
- An adjustment to the formulation was suggested by the data, and appeared to greatly improve the AERMET single-layer performance.
- This adjusted formulation was tested on all three met databases.
$u^*$ (y axis) vs. u for Bull Run
Nocturnal Stable Hours

AERMET formulation is underpredicting friction velocity

Curves adapted from AERMET formulation

---Transition point where single layer quadratic equation has real solution
(transition point is arbitrary)

Observed values in light blue

$z_0 = 0.51$

L.I. Residential, Clear
L.I. Residential, 50% Cloud Cover
L.I. Residential; 100% Cloud Cover
Single-Layer Model
Observed
Improvement to Single-Layer Method

New AERMET transition point for cloudy skies. This avoids the “dip” by connecting the origin to 1.25 times the transition wind speed $U^*$.

Agreement with observations is much better!

Current AERMET transition point for cloudy skies

$z_0 = 0.51$
Comparisons for $u^*$ with Cardington data (low wind speed, stable hours)

Current AERMET

Modified AERMET

Single layer
Conclusions from Met Evaluation

• Current AERMET formulation will likely underpredict $u^*$ in low wind speed, stable conditions

• This would be expected to result in higher predicted concentrations (lower dilution speed and dispersion rate)

• This happens for both the single-layer and 2-layer (Bulk Ri) methods

• Met model performance with the suggested improvements is better overall

• These changes were carried forward into the tracer evaluation phase of the study
Phase 2: Tracer Database Evaluation

- Study focused on 3 databases:
  1. Bull Run, TN (tall stack, buoyant plume)
  2. Idaho Falls, ID (low-level releases)
  3. Oak Ridge, TN (low-level releases)
Candidate Models

• Candidate models based on changes to AERMET/AERMOD

• Results presented for 3 cases:
  1. Base AERMET
  2. Modified stable $u^*$ formulation in AERMET
  3. AERMET/AERMOD with minimum $\sigma_v = 0.4 \text{ m/s}$
     - Current minimum $\sigma_v = 0.2 \text{ m/s}$
Why Adjustments to Minimum Sigma-v?

• After running AERMOD with current AERMET, we constructed Excel spreadsheet to replicate AERMOD predictions during stable hours (Oak Ridge and Idaho Falls) w/ model debug output

• Found sigma-v becomes very important under low-wind speed conditions when sigma-theta data is not available because it helps define:
  – lateral dispersion (sigma-y)
  – fraction of the random plume used to calculate total concentration

• AERMOD was underestimating the lateral dispersion and fraction of the random plume

• This was causing the model to overpredict significantly for light winds
Why Adjustments to Minimum Sigma-v?

• Model debugging showed the following:
  – Random plume fraction is too low for very low winds
  – Coherent plume component dominates the total prediction
  – Availability of observed sigma-theta helps to increase lateral dispersion for the coherent plume
  – Without sigma-theta measurements, the minimum sigma-v needs to be increased from the current value of 0.2 m/s

• Key databases showing model overpredictions were near-surface releases (Idaho Falls and Oak Ridge)

• Tall stack evaluation study for Bull Run showed acceptable model performance for convective conditions
Idaho Falls Q-Q plot – 1 met level, no sigma-theta with current AERMET

Idaho Falls: Quantile-Quantile Plot - Observed (fitted) vs AERMOD (Base 1-Layer) Predicted Arc-wise Max @ Multiple Downwind Arcs

Large overpredictions, especially at 100-m arc (factor of 6, roughly)
Idaho Falls Q-Q plot – 1 met level, no sigma-theta with new AERMET processing (improved $u_*$)

Idaho Falls: Quantile-Quantile Plot - Observed (fitted) vs AERMOD (Modified AERMET 1-Layer) Predicted Arc-wise Max @ Multiple Downwind Arcs

$\leftarrow$ Better performance, but still overpredicting (factor of 3, roughly)

Predicted ($\mu g/m^3$)

Observed (fitted) ($\mu g/m^3$)
Idaho Falls Q-Q plot – 1 met level, no sigma-theta with new AERMET processing (improved $u_*$ and min sigma-v)

Idaho Falls: Quantile-Quantile Plot - Observed (fitted) vs AERMOD (Modified AERMET 1-Layer, 0.4 Min sigma-v) Predicted Arc-wise Max @ Multiple Downwind Arcs

Some improvement from modified $u_*$ case
Overall Results for Idaho Falls

• Overpredictions clearly evident at 100 m, better model performance further out

• Sigma-theta observations reduced overpredictions (better depiction of lateral plume spreading)

• Use of better AERMET (higher u*) reduced overpredictions by about a factor of 2
  – Higher effective dilution wind speed
  – Higher turbulence levels in vertical and horizontal

• Biggest improvement to model performance → reformulated u* in AERMET when lacking sigma-theta

• Increased minimum sigma-v resulted in additional performance improvements

• Single-level AERMET works as well as 2-level AERMET
Oak Ridge Q-Q plot – 1 met level, no sigma-theta with Current AERMET

- Large overpredictions, especially at 100-m arc (factor of 20+), dominated by stable hours
Oak Ridge Q-Q plot – 1 met level, no sigma-theta with new AERMET processing (new u*)

Oak Ridge: Quantile-Quantile Plot - Observed (fitted) vs AERMOD (Modified AERMET 1-Layer) Predicted Arc-wise Max @ Multiple Downwind Arcs

large overpredictions, but reduced from base case mostly during stable hours (factor of 10+)

better performance, but still overpredicting
Oak Ridge QQ-plot – 1 met level, no sigma-theta with new AERMET processing (improved $u_*$ and min sigma-$v$)

Oak Ridge: Quantile-Quantile Plot - Observed (fitted) vs AERMOD (Modified AERMET 1-Layer, 0.4 Min sigma-$v$) Predicted Arc-wise Max @ Multiple Downwind Arcs

*much better performance, but still overpredicting by factor of about 2-3*
Overall Results for Oak Ridge

• Substantial overpredictions occur, especially at closest distances

• Overpredictions mostly due to model’s poor performance during stable hours

• AERMOD does reasonably well for unstable conditions

• There is a need to predict a larger lateral spread of the plume for stable conditions (no sigma-theta data available here)

• Use of enhanced AERMET (higher $u_*$) reduces overpredictions
  – Higher effective dilution wind speed
  – Higher turbulence levels in vertical and horizontal

• Minimum sigma-v of 0.4 m/s substantially improves model performance
Findings and Recommendations

• API provided results, code, and modeler’s archive to EPA for review 2 years ago

• We encouraged EPA to add our code changes as a beta option to an AERMET/AERMOD release:
  1. Set minimum sigma-v = 0.4 m/s instead of 0.2 m/s
  2. Use alternative u* formulation for both single-level and 2-level approaches

• Low u* has other implications – results in very low mechanical mixing heights which leads to extremely low plume spreading for releases above the mixing height