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White Paper Issues for AERMOD – Where Are We in 2020?

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Abstract

– At the 12th Conference on Air Quality Modeling, the United States Environmental Protection Agency (EPA) reviewed several development initiatives to improve the AERMOD model. These initiatives include the following areas:

1) low wind speed conditions,
2) building downwash,
3) NO_2 modeling issues,
4) mobile source modeling,
5) source characterization / plume rise issues, and
6) treatment of the penetrated plume component / convective pdf modeling.

– This presentation will address comments received and ongoing progress in these areas by mid-2020.

Outline of Presentation

– EPA's White Paper approach for AERMOD development
– Low wind options
– Building downwash updates
– NO_2 modeling enhancements
– Mobile source modeling
– Plume rise – source characterization
– Convective conditions – penetrated plume and vertical mixing parameterizations

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EPA’s Concept of AERMOD White Paper Issues

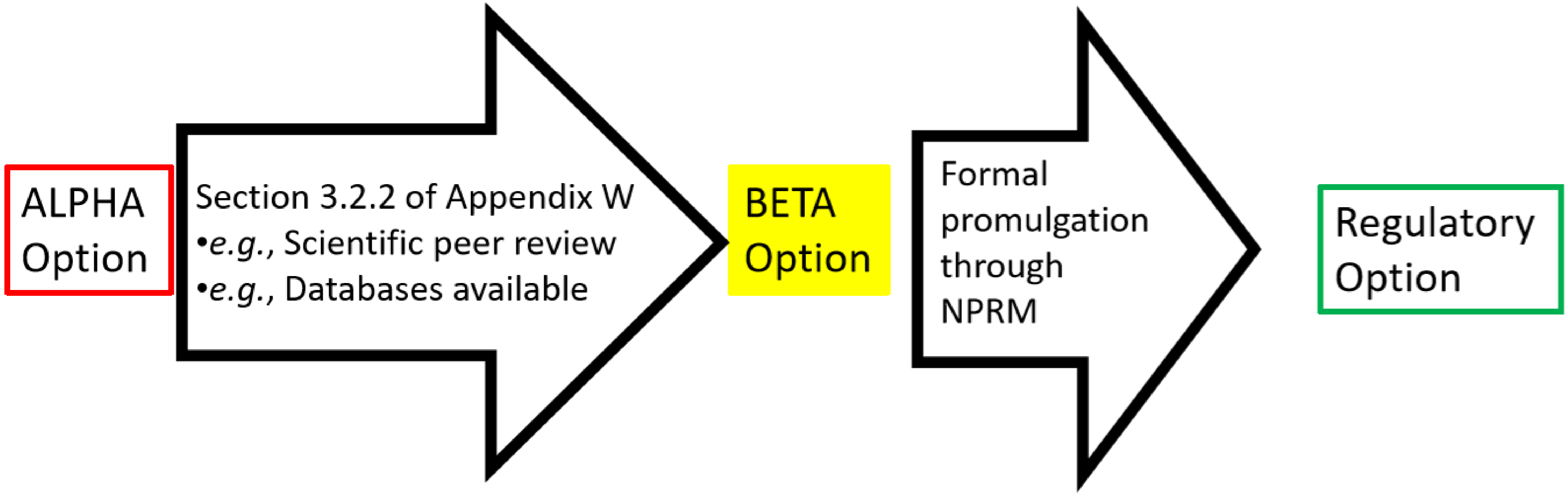
- AERMOD is EPA’s key dispersion modeling systems for transport out to 50 km
- EPA wants enhanced engagement and coordination with the community on research and development for AERMOD updates
- EPA wants clear and transparent priorities for model updates
- Process allows feedback on planned updates
- Process identifies and fosters collaborative opportunities
- Approach will ensure that EPA priorities match community needs
- Alternative model approval process will be facilitated
- Process will maximize scientific advancements for alternative model approval with broad benefits to the modeling community

Effects of COVID-19

- US EPA’s annual modeling workshop was cancelled
- We are engaging EPA’s Office of Air Quality Planning and Standards in a livestreamed panel session at the virtual A&WMA annual meeting
- This panel session is scheduled for Tuesday, June 30, 4:30 – 6:30 PM EDT (I am a session co-chair), and we will have some EPA presentations plus Q&A to make up for the canceled annual modeling workshop
- Otherwise, progress on white paper issues seems to have slowed down due to the stay-at-home regimen

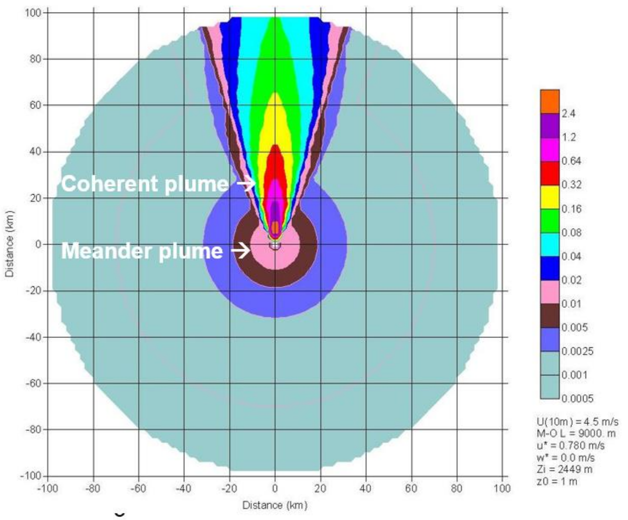
Progression of Nonguideline Options to Promulgation

- <u>ALPHA options</u> – “experimental”, i.e., developmental options not available for regulatory use
- <u>BETA options</u> – Peer-reviewed options that are potentially ready for consideration as alternative model(s)



AERMOD White Paper Topics: Low Wind Speeds

- Issue: at low wind speeds, the steady-state assumption fails, and for zero wind speeds, the concentrations go to infinity
- Key issues involve minimum values for dilution wind speed and turbulence values (e.g., sigma-v) used for plume spreading rate calculations
- If the values get too small, the model will simulate a plume that is too concentrated
- Latest Appendix W changes promulgated a change in the friction velocity calculation that prevents too small of a value for turbulence and mixing height for low-wind stable conditions
- Additional parameters to be tested:
  - Minimum sigma-v (horizontal wind fluctuations)
  - Meander fraction
  - Time scale for portion of random and coherent plumes



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Low Wind Issues – Research Findings

- Anfossi, D., D. Oettl, G. Degrazia, A. Goulart. 2005. An analysis of sonic anemometer observations in low wind speed conditions. *Boundary Layer Meteorology*, 114, 179–203.
- Slow mesoscale motions (wind fluctuations with periods of 20-30 minutes) exist under all meteorological conditions
- As the small-scale turbulence decreases with low wind speeds, these low frequency mesoscale motions <u>become the most important factor</u> for the total variance
- When the wind speed decreases below a certain threshold value (about 1.5 m/s), it is no longer possible to define a precise mean wind direction, and the wind direction oscillates with periods of the order of 30 minutes (well below currently-assumed 24 hours!)
- The slow mesoscale motions set a lower limit for the horizontal wind variance component

Low Wind Evaluation Databases to Consider

- Low-level releases:
  - Project Sagebrush (2013 and 2016: 13 trials of SF_6 tracer releases)
  - Three Mile Island (1972: 5 trials of SF_6 tracer releases)
  - Idaho Falls (1974: 11 days of SF_6 releases)
  - Oak Ridge (1974: 11 days of SF_6 releases)
- Elevated releases:
  - Lovett (1988 – 1 full year with 9 monitors, most of them on high terrain)
  - Tracy (1984 – 14 days of SF_6 releases from tall stack, mostly at night)
  - Hogback Ridge (1982 – 11 days of SF_6 releases from crane toward 2-D ridge)
  - Cinder Cone Butte (1980 – 18 days of SF_6 releases from crane toward Gaussian-shaped hill, Idaho)
  - Bull Run (1982 – 38 days of SF_6 releases from tall stack)
  - Kincaid (1980-1981 – 16 weeks of SF_6 releases from tall stack)
  - Laurel Ridge, PA (1990-1991) – full year of SO_2 releases from area plants, 4 monitors)

AERMOD White Paper Topics: Building Downwash

- A building substantially changes the flow and can cause a plume to descend to the ground quickly: “building downwash”
- This can result in much higher ground-level concentrations than without downwash
- Modeling this is challenging for just one building, much less several in a cluster
- Downwash effects depend upon:
  - Stack height relative to building height
  - Building shape
  - Approach flow direction
  - Stack location relative to the building
  - Stack exhaust parameters
  - Ambient conditions (stable, unstable, wind)

- Current downwash model - PRIME (Plume Rise Model Enhancements)

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Why Update the PRIME Building Downwash Model?

- PRIME Downwash theory based on research done before 1995, but this was a significant improvement over the previous algorithms
- PRIME is implemented in AERMOD, CALPUFF, SCICHEM, etc.
- Original theory based on a limited number of “solid” building shapes
- Theory is not suitable for porous, streamlined, wide or elongated structures
- Theory based on theoretical assumptions that can be improved
- Recent and past model comparisons with observations have shown both under and over predictions
- Several scientists have documented formulation issues (e.g., for long and wide buildings) and model bias issues at several public forums (EPA and A&WMA modeling conferences)
- Two updated formulations: “PRIME2” and “ORD”
- Overwater drilling rigs is another downwash area that needs further review – BOEM plans to fund some wind tunnel studies

Downwash Progress to Date

- Even though the theoretical formulations of the PRIME2, ORD, and PRIME2+ORD models appear to correct shortcomings in the PRIME model, the evaluation results so far do not clearly show a better performance for the newer models
- Significant differences in performance are seen between stacks close to the building height vs. stacks approaching 2x building height
- In some testing results, the PRIME model is often predicting the lowest, and yet its performance appears to be no worse (sometimes better) than the newer models
- Since these databases all feature buoyant plumes, it could be that the plume rise in PRIME2 needs updating (may be an underestimate); see paper at A&WMA ACE
- Recommendation: many applications have multiple buildings, but BPIP has a rather “primitive” approach to select a single, dominant building
- A better approach might be a Computational Fluid Dynamics-based or Lagrangian particle model pre-processor to find an “equivalent” single building that can then be run in AERMOD

NO_2 Modeling Enhancements

- NO_2 is a reactive (secondary) pollutant that is transformed from NO emissions by oxidation; NOx = NO + NO_2 concentrations (NO_2 molecular weight assumed)
- AERMOD currently has simplistic formulations to compute NO_2 as a secondary pollutant
- Tier 1 assumes that all NO converts to NO_2 instantaneously
- Tier 2 uses ambient data with NO_2/NOx ratios for a semi-empirical approach
- Tier 3 uses ozone concentration data to determine hourly ratios of NO_2/NOx as a function of distance, stability, etc. (PVMRM)
- Current AERMOD algorithm does not consider:
  - Initial titration time for NO to convert to NO_2 (several tens of seconds)
  - Equilibrium between NO and NO_2 not accounted for – leads to reverse reaction to form ozone during the daytime

Limited Initial Conversion of NO to NO_2

- $NO + O_3 \rightarrow NO_2 + O_2$ (1)
- This reaction takes a couple of minutes to reach equilibrium
- In that time, emitted plumes can easily be well past the plant fenceline
- More realistic NO_2 conversion rates (available in next AERMOD release?):

Conversion Fraction

Travel time (sec)	Ozone = 35 ppb	Ozone = 55 ppb	Ozone = 75 ppb
10	0.130	0.196	0.257
20	0.242	0.353	0.448
30	0.340	0.480	0.590
40	0.426	0.582	0.696
50	0.500	0.664	0.774
60	0.565	0.730	0.832

NO_2 Field Studies

- Evaluate actual 1-hour NO_2 ambient air quality impacts from field operations in areas very close to the emission sources (i.e. near fenceline).
- Two ongoing databases being developed for model evaluation:
  - Drill rig in Denver-Julesburg Basin, Colorado (about 300 hours of data for 12 monitoring sites at the edge of a drill rig area)
  - Gas compressor station near Balko, Oklahoma (1 year of data for 4 monitoring sites near the station)
- These databases will assist in the evaluation of near-field NO to NO_2 conversion rates as well as building downwash issues
- These databases will also be tested with ADMSM, which is a model being installed within AERMOD that accounts for the initial reaction time of NO to NO_2 as well as the equilibrium and reverse reaction

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Mobile Source Modeling Developments

- The January, 2017 update to the Guideline specified AERMOD and the preferred model for mobile sources, replacing CALINE3
- This followed considerable resistance from the Federal Highway Administration regarding this change
- Replacement of CALINE3 was based on 2013 ORD paper comparing AERMOD, R-LINE, ADMS, and CALINE
- AERMOD, R-LINE, and ADMS all had similar performance, CALINE3 and CALINE4 were the worst performing models
- In Spring, 2017, EPA entered into agreement with FHWA to integrate R-LINE into AERMOD

Mobile Source Modeling Developments, cont.

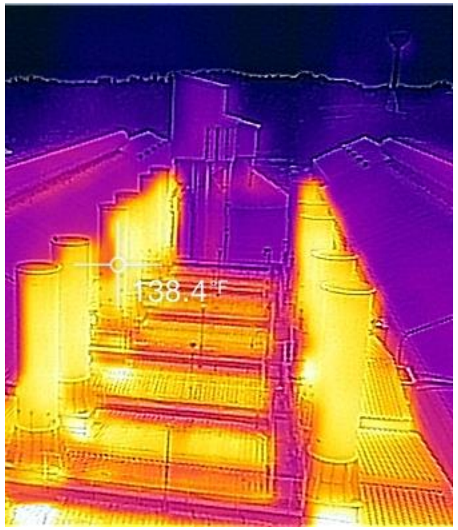
- R-LINE, developed by ORD, is a steady-state Gaussian model designed to simulate line type source emissions by numerically integrating point source emissions
- It includes meander, similar to VOLUME sources, but inputs are easy to use like the LINE source
- RLINE includes formulations for barriers and depressed roadways, which are important near-road features (implemented as ALPHA options)
- Limitations of current RLINE implementation:
  - Sources limited to FLAT terrain
  - More R&D needed for both the barrier and depressed roadway algorithms
  - Field studies needed for further model evaluation
  - Barriers configuration and barriers edge effects parameterizations needed
  - URBAN option has added, but it is an ALPHA option

Current Issues With RLINE

- Some state DOTs are concerned with AERMOD/RLINE overprediction tendencies
- They are not convinced that CALINE3 is inferior to AERMOD
- They want more evaluation, but the 3-year transition period ended on 1/17/20
- A possible coding bug may have been found in RLINE recently, but we are still waiting for EPA handling of this issue – might require a new version of AERMOD to be issued

Urban Dispersion Characteristics in Highly Industrialized Areas

- An “urban heat island” prevents the boundary layer from becoming stable at night
- Results in weak convective mixing at night within a deeper layer than experienced in rural areas
- U.S. Environmental Protection Agency’s (EPA) recommended dispersion model, AERMOD, has an urban model option that parameterizes the nocturnal boundary layer using a population input variable
- However, anthropogenic heat releases can also cause urban heat island effects, as noted by Irwin (1978) in an internal EPA memo
- Facilities that could cause these heat effects are:
  - Metal processing such as aluminum smelters or steel mills
  - Taconite processing facilities
  - Oil and gas refineries
  - Pulp and paper mills



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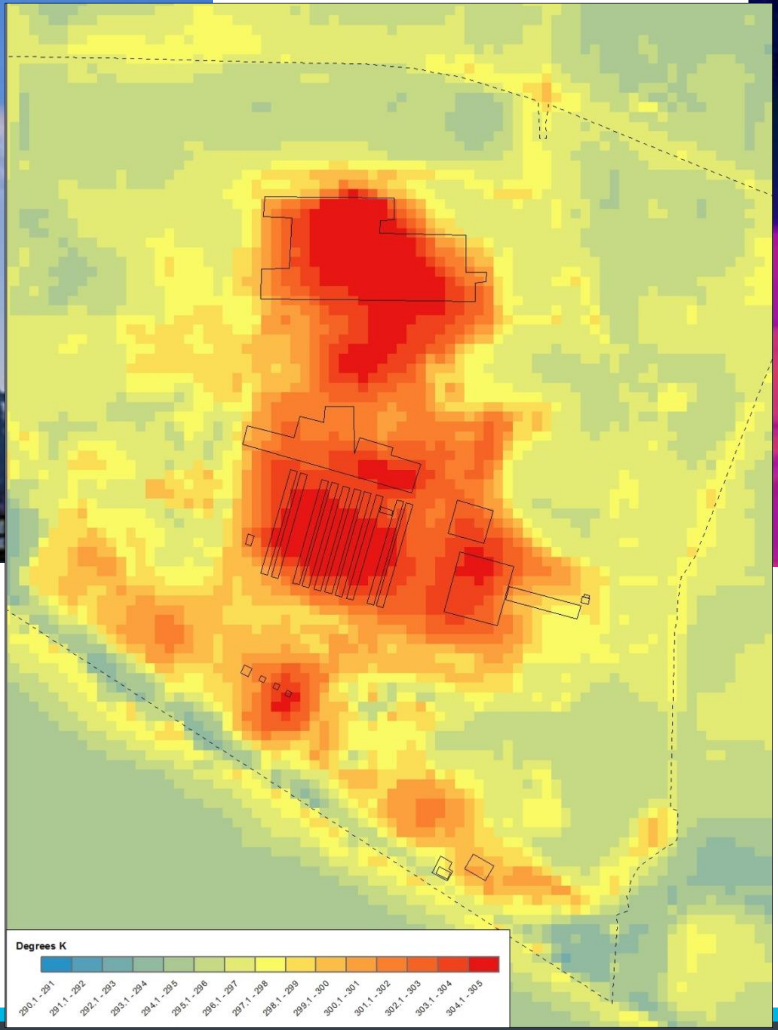
Urban Treatment for Highly Industrialized Areas (HIAs)

- HIAs in unpopulated areas can create an urban heat island effect
- Urban characterization of these HIAs in AERMOD has been shown to improve model performance when compared with monitored concentrations
- An equivalent population can be estimated by satellite data when other data are unavailable
- Facilities that generate heat during the industrial process and those that continuously operate day and night may create a HIA urban-like environment
- Often these are metal manufacturing facilities, but potential exists to use this technique for refineries and paper mills as well
- The latest updates to the Guideline on Air Quality Models (Appendix W) have allowed for this procedure with appropriate documentation
- With the approval of two aluminum smelter HIA urban characterizations, this source characterization technique is becoming more widely accepted without the need for an alternative model approval

Source Characterization and Plume Rise



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Effect of Plume Moisture on Plume Rise: “AERMOIST”

- Stacks with moist plumes can lead to latent heat release of condensation after the plume exits the stack
- This heat release leads to additional plume rise relative to that of a dry plume
- This effect has been neglected in many dispersion models that rely on the Briggs formulation including AERMOD resulting in an underestimate of plume rise for moist plumes
- “AERMOIST” uses a peer-reviewed /evaluated plume rise model called “IBJpluris”* to compute the plume rise difference for a plume with a specified moisture content vs. a dry plume
- AERMOIST then determines the relative change required for the buoyancy flux to produce the required plume rise, which is parameterized for model input by a change in the input stack temperature (the “equivalent temperature”)
- IBJpluris is run as an embedded executable in AERMOIST to compute the moist vs. dry plume rise ratio for a range of ambient temperature and relative humidity conditions to create a look-up table – used for interpolation for each modeled hour

Downwash for Sources with Excess Heat Releases

- In cases with significant heat releases, plumes will resist downwash effects, especially in light wind cases, and lift off from the building – PRIME does not consider this effect
- Heat can be estimated with a buoyancy flux term, Fb
- Hanna, Briggs, and Chang suggest a combined dimensionless buoyancy flux, F** = Fb/($Ueff^3$W), where Fb is the buoyancy flux, Ueff is the effective wind speed and W is the initial plume width
- Possible approach similar to low wind intermittency: Use a weighting factor between lift-off conditions (no downwash) and non-lift-off conditions (normal downwash) ranging from 0 to 1 from Hanna, Briggs, Chang paper:

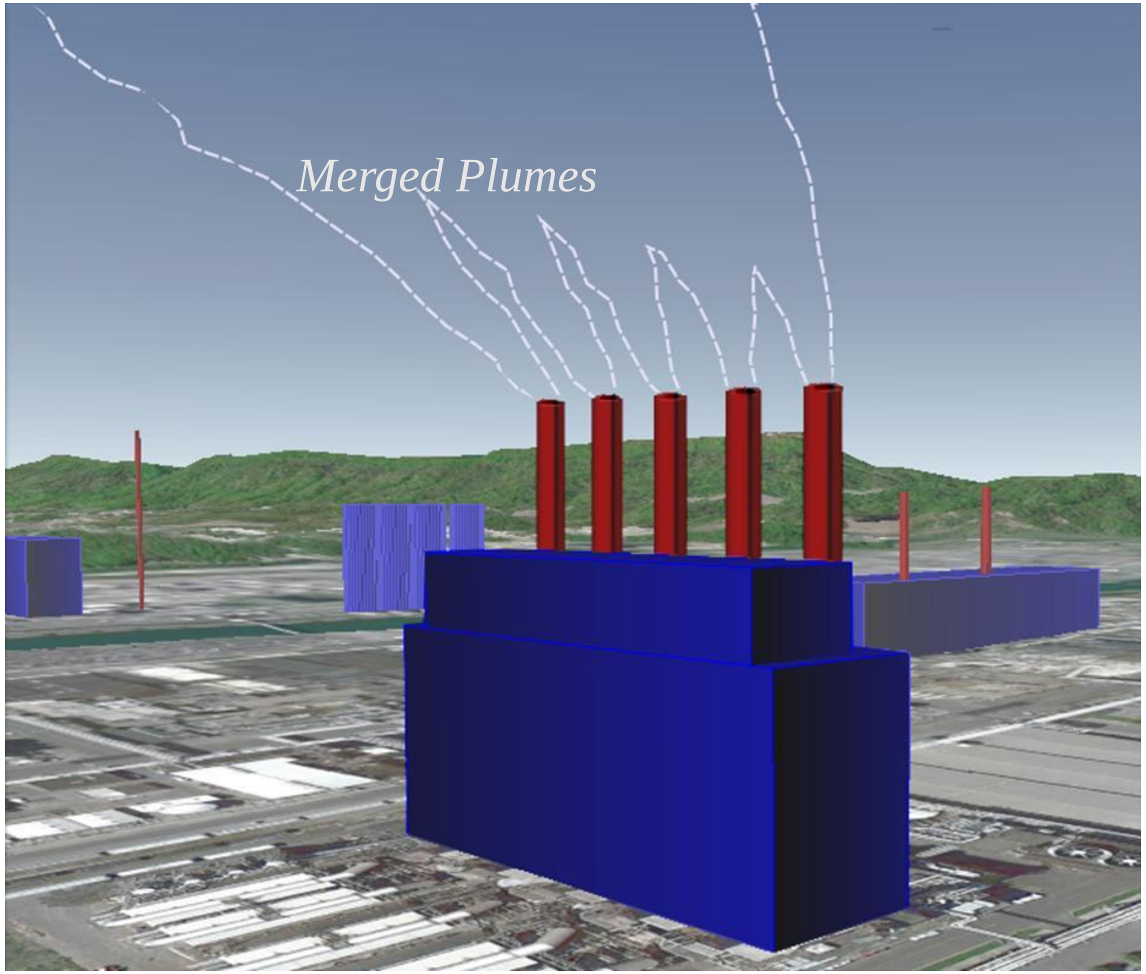
– exp (-6F**^0.4)

Aligned Multiple Sources

– If a component of the wind for an hour blows along the alignment angle of the stacks, it has been shown* that the stacks can be merged, in part

– This merging takes advantage of enhanced thermal buoyancy from the combined plume

– Done as a post-processor to AERMOD, then hourly emissions file creation for a second AERMOD run



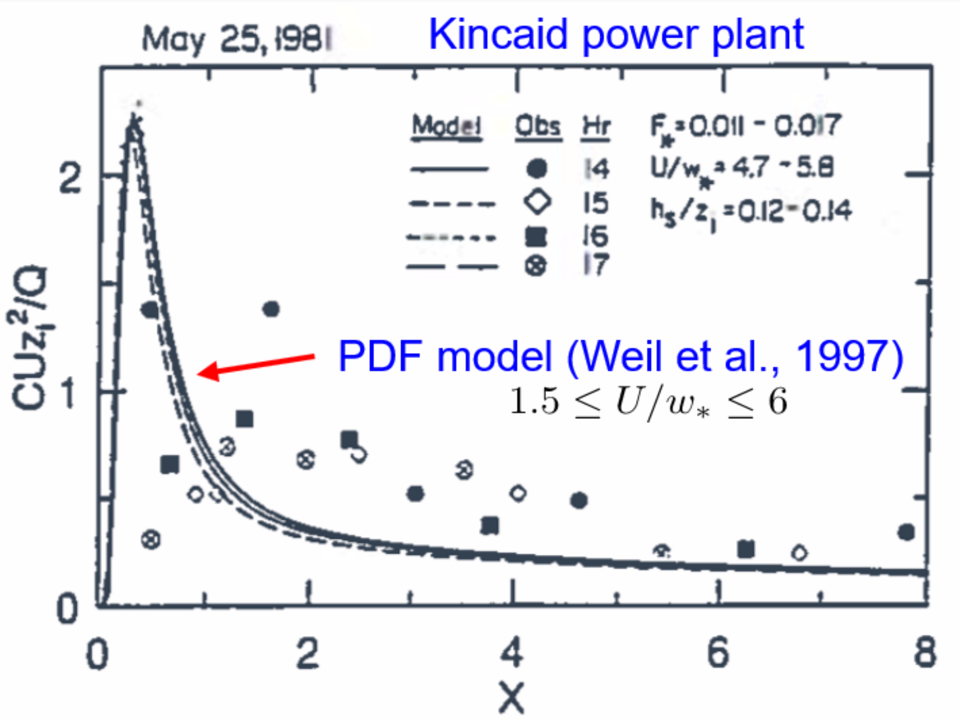
** Manins P, Carras J and Williams D, (1992), Plume Rise from Multiple Stacks. Clean Air (Australia). Volume 26, Part 2. pp 65-68*

New White Paper Issue: Penetrated Plume Problem

– Many modeling runs using AERMOD show a counterintuitive result in that the penetrated plume mixes to the ground rapidly and results in the highest concentration during the daytime
– This happens quite early in the morning, while observations show peak convective concentrations later in the day when (and after) the mixing height intercepts the penetrated plume
– Fix: compute the effective values for dispersion for the penetrated plume *at the plume level in the stable layer aloft* until the mixing height reaches the plume
– To do this, AERMOD could be modified to *look ahead* to the next hour’s mixing height to see if it rises above the height of the current hour’s penetrated plume
– If not, then take the effective parameters from the current plume level; do not average to the ground
– If the mixing height rises to capture the plume, then mix the plume to the ground for that portion of the hour

New White Paper Issue: Convective Conditions Vertical Mixing

- After the morning boundary-layer growth, the remainder of the day has elevated winds and "straight-forward" convective conditions
- These conditions have recently been associated with an AERMOD underprediction of ground-level concentrations at sites a few km from the source
- This is likely due to an overprediction of vertical dispersion in moderate-to-high winds
- The fix is a change to the formulation of the CBL treatment, involving the Lagrangian Lagrangian time scale and the pdf skewness



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Next Steps for AERMOD White Paper Issues

- Low wind issues: need more evaluations to settle on preferred options
- Downwash: need further work on plume rise and more evaluations
- NO_2: ADMSM and new Tier 2 approaches can be evaluated with new databases
- Mobile sources/RLINE: need to fix any bugs and conduct more evaluations to resolve concerns about RLINE overpredictions
- Plume rise/source characterization: urban approach for HIAs is already being approved; other issues need further evaluations and approvals as a case-by-case basis
- Penetrated plume / CBL treatment: need further testing and updates to the formulation
- Overall: EPA will continue to review new developments, looking for a new AERMOD model proposed for adoption by ~2022

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Thank You!

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