AERMOD Model Overview and Downwash Update

2021 International MACCS User Group

U.S. EPA / OAQPS / Air Quality Modeling Group

September 20-22

Chris Owen and Clint Tillerson

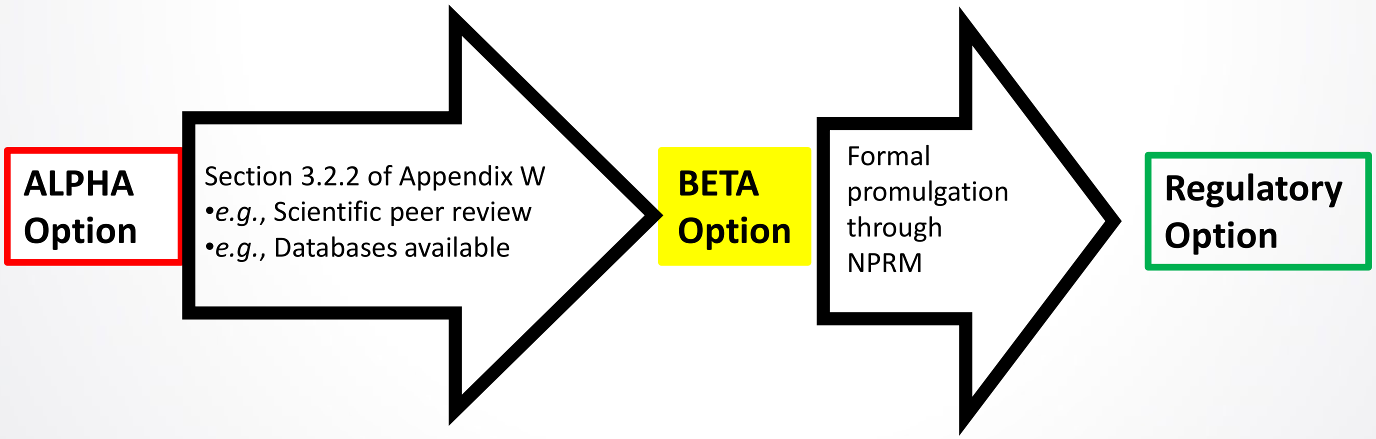
owen.chris@epa.gov

General Release Information

- Version 21112 (April 22, 2021)
  - AERMOD, AERMET, AERSCREEN
- Posted to SCRAM on Tuesday, May 11, 2021
  - https://www.epa.gov/scram/air-quality-dispersion-modeling-preferred-and-recommended-models#aermod
- AERMOD
  - Alpha options (Downwash, NO_2 Conversion, Low Wind, RLINE 2-barrier)
  - RLINE Updates
  - Multiple buoyant line groups (BUOYLINE sources)
  - Turbulence treatment options
  - Deposition parameter default values (for limited set of pollutants)
- AERMOD, AERMET, AERSCREEN
  - Bug fixes

Facilitating Science Updates: Approach to Providing Non-Regulatory Options

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



Alpha Options for NO_2 Conversion

- Two new alpha options for NO_2 conversion
  - Travel Time Reaction Method (TTRM)
  - General Reaction Set Method (GRSM)
- TTRM
  - Limit conversion of NO to NO2 based on reaction time limitations based the travel time between the source and receptor.
  - Requires ozone background (OZONEVAL, O3VALUES, or OZONEFIL keywords)
- GRSM
  - Based on equilibrium chemistry between NO, NO2, and ozone.
  - Requires ozone background (OZONEVAL, O3VALUES, or OZONEFIL keyword)
  - Requires NOx background (using new NOXVALUE, NOX_VALS, or NOX_FILE keyword)

Alpha Options for Low Wind Treatment

- Two new alpha options for treatment of low winds
  - Minimum sigma-w (SWMin)
  - Time Period (BigT)
- Parameters added to LOW_WIND keyword
- SWMin
  - Minimum standard deviation of the vertical component of the wind speed
  - User-defined value to override AERMOD default value of 0.02 m/s
  - Allowable range for user-defined value: 0.0 to 3.0 m/s
- BigT
  - Time scale at which mean wind information at the source is no longer correlated with the location of plume material at a downwind receptor
  - User-defined value to override AERMOD default value of 24.0 hours
  - Allowable range for user-defined value: 0.0 to 48.0 hours

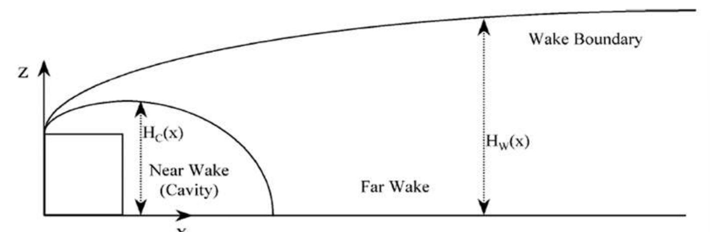
Alpha Options for Building Downwash

- Two new alpha options for building downwash
  - Developed by the Air & Waste Management Association (PRIME2 Subcommittee)
  - AWMAUTurbHX
  - AWMAEntrain
- Added to existing set of AWMA alpha options (keyword AWMADWNW)
  - AWAMUEff, AWMAUTurb, StreamLine
- AWMAUTurbHX *(extends AWMAUTurb)*
  - AWMAUTurb uses minimum of the final momentum plume rise or a representative PRIME plume rise height.
  - AWMAUTurbHX uses the final momentum plume rise at the downwind distance X.
- AWMAEntrain
  - Modifies beta (B) entrainment coefficient for PRIME downwash from default value of 0.60 to 0.35.
  - Enhances plume rise.

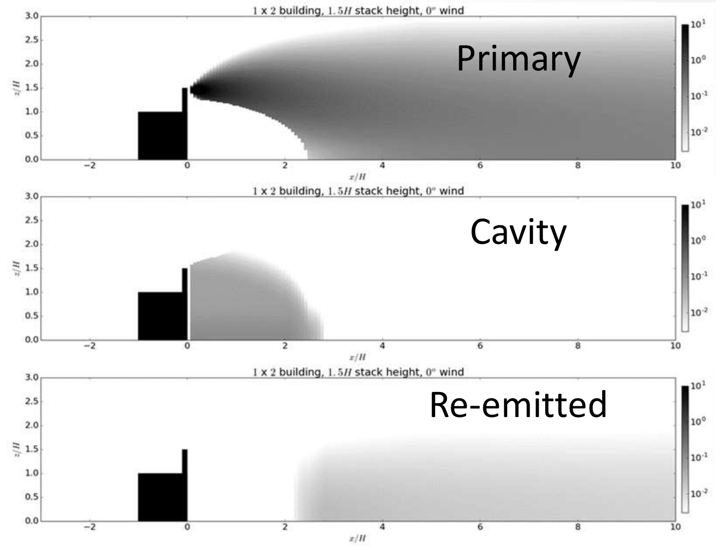
Building Downwash in AERMOD

How PRIME works:

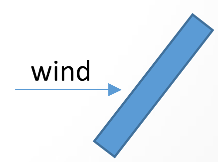
- Defines near & far wake boundaries
- Deflects the plume centerline based on building-affected streamlines
- Partitions the plume: Primary, Cavity & Re-emitted
- Adjusts plume growth rate in wake based on wake turbulence

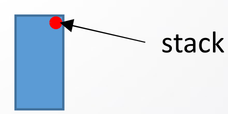


Schulman et al., 2011



Background Information *(Cont.)*

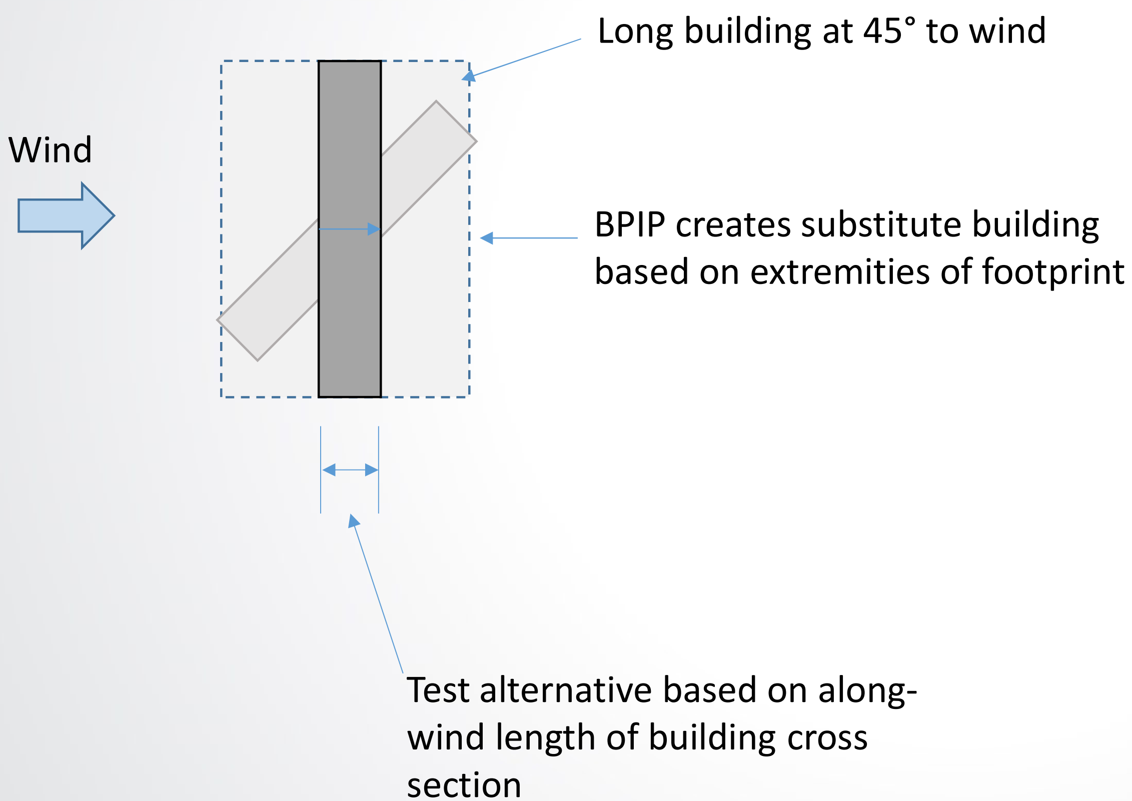
- Analyses have shown AERMOD to both overpredict and underpredict in the building wake
- Performance is related to stack height, stack location, and the orientation of the building relative to the wind direction
- Overprediction and underprediction have been demonstrated in analyses of single, one-tiered rectangular buildings, including:
    - Elongated buildings, 
    - Buildings angled relative to the wind direction, and 

    - Buildings with stacks located near a building corner 

Building Downwash - Development

- **Collaboration:** EPA's Office of Research and Development (ORD) & Air and Waste Management Association (A&WMA)
- **AERMOD: 8 alpha** options; **3** developed by **ORD** and 5 developed by **A&WMA (PRIME2)**
  - ORDUEFF: *Height of effective wind speed calculation*
  - ORDTURB: *Maximum vertical turbulence intensity*
  - ORDCAV: *Cavity discontinuity*
  - AWMAUEFF: *Height of effective wind speed calculation* (similar but different from ORDUEFF)
  - AWMAUTURB: *Enhanced turbulence and velocity deficit calculations*
  - AWMAUTURBHX: *Enhanced turbulence and velocity deficit calculations w/distance-based plume rise*
  - AWMAENTRAIN: *Modifies beta (B) entrainment coefficient for PRIME downwash*
  - STREAMLINE: *Enhanced turbulence and velocity deficit calculations for streamlined buildings*
- ***BPIP (Building Profile Input Program)***
  - *Modify building footprint assumptions*

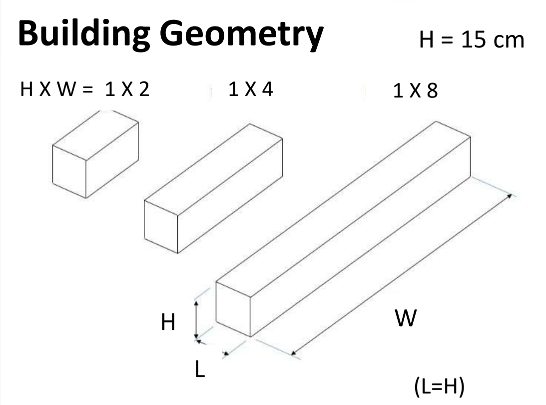
Proposed Update to BPIP

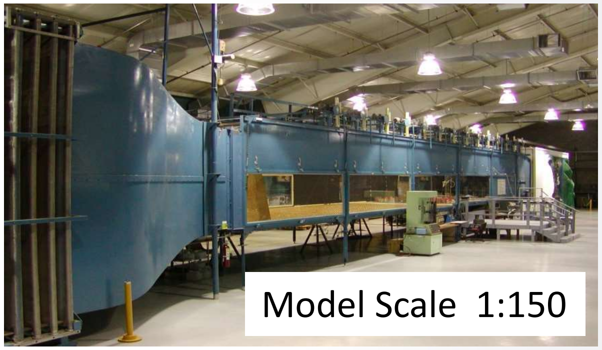


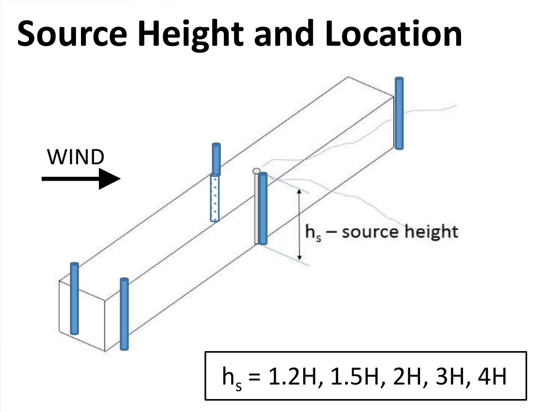
4th Enhancement for non-perpendicular winds:

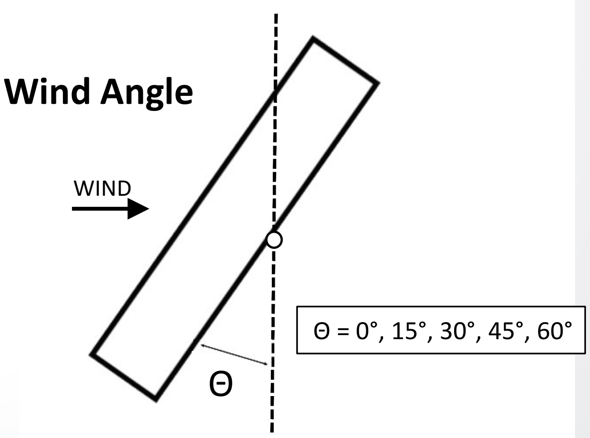
BPIP – AERMOD's building pre-processor

Wind Tunnel Study





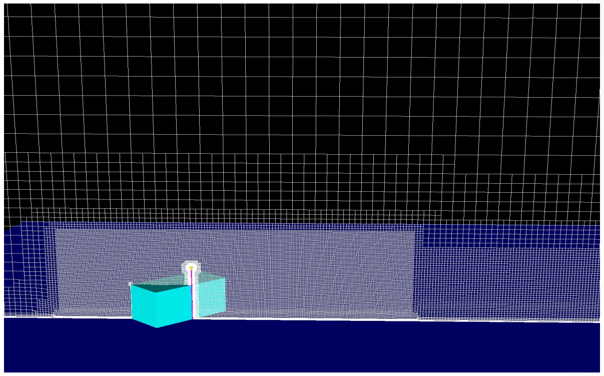




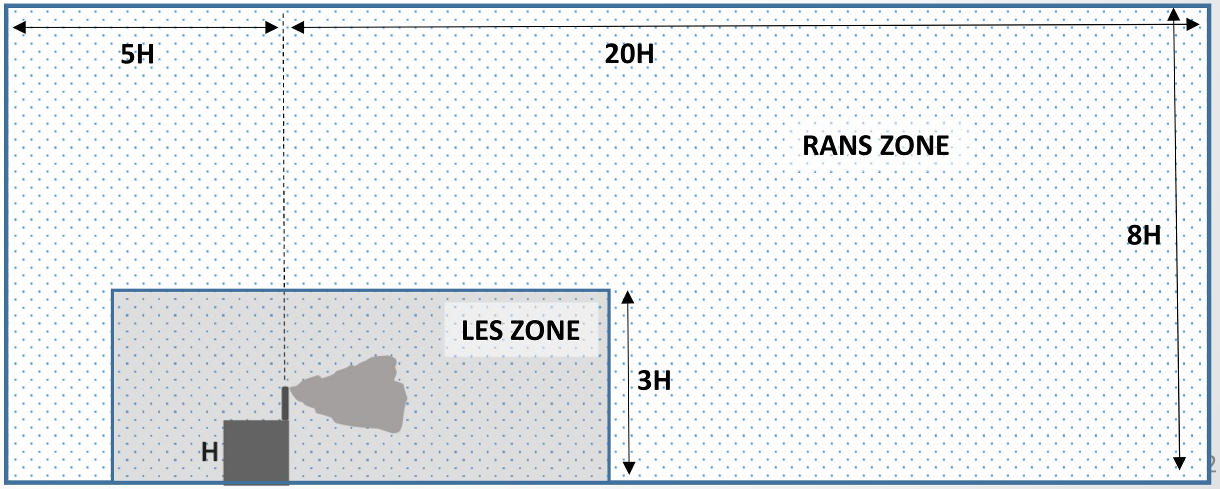
Large Eddy Simulations (LES)

Embedded LES Approach

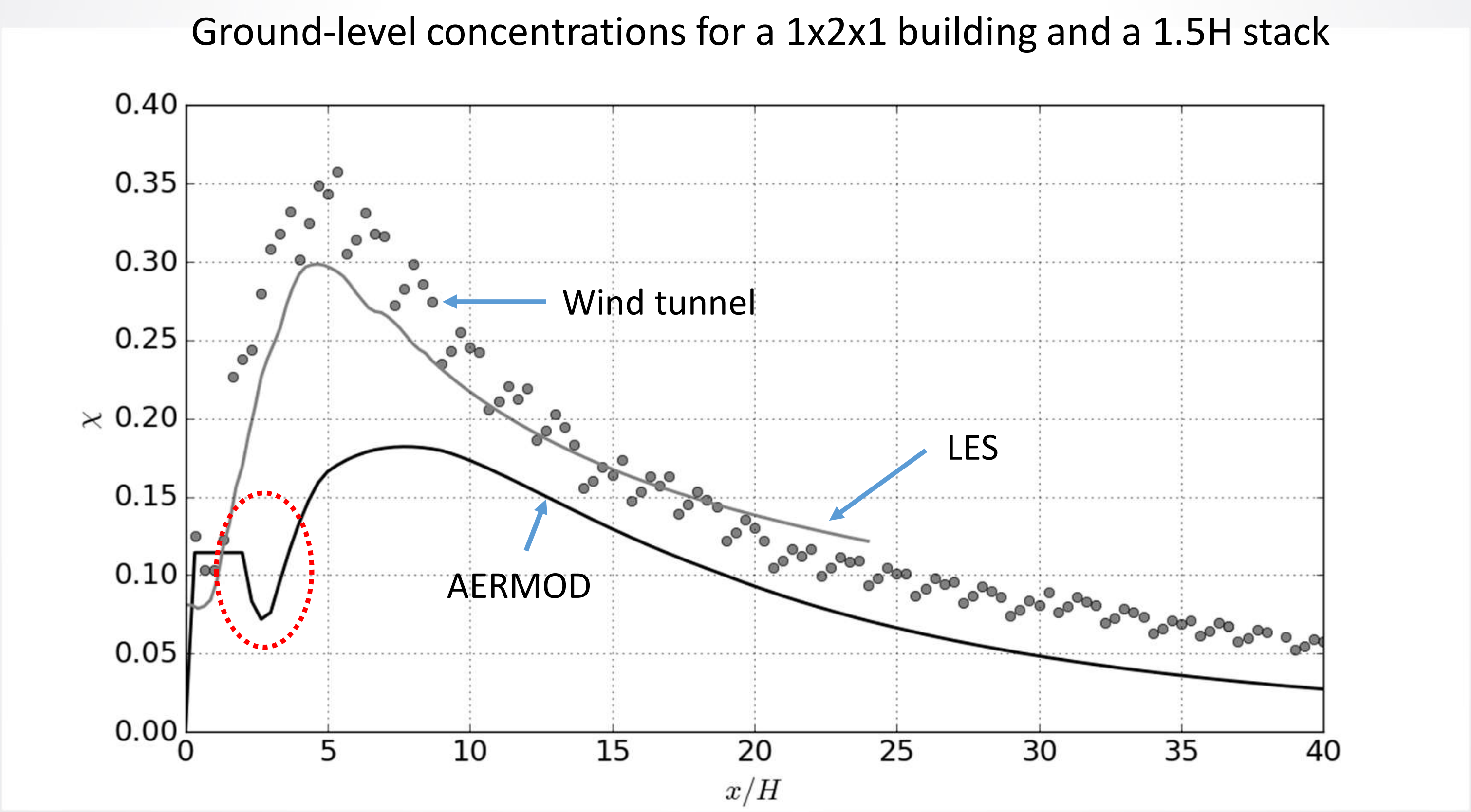
- LES zone subgrid-scale model
  - WALE (Wall-Adapting Local Eddy viscosity)
- RANS zone:
  - Shear-Stress Transport k-ω model
  - Schmidt number = 0.7
- Interface treatment:
  - Vortex method



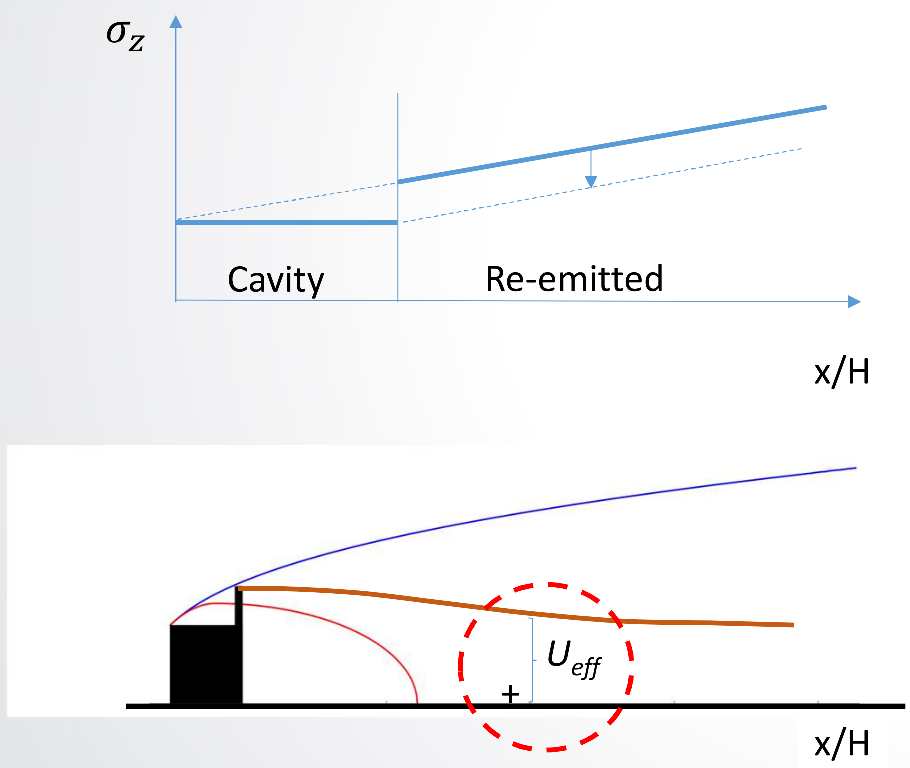
3D Computational Mesh (x-z slice)
~ 6 million grid cells in domain



AERMOD, Wind Tunnel, LES Comparison



ORD – Proposed Changes to PRIME

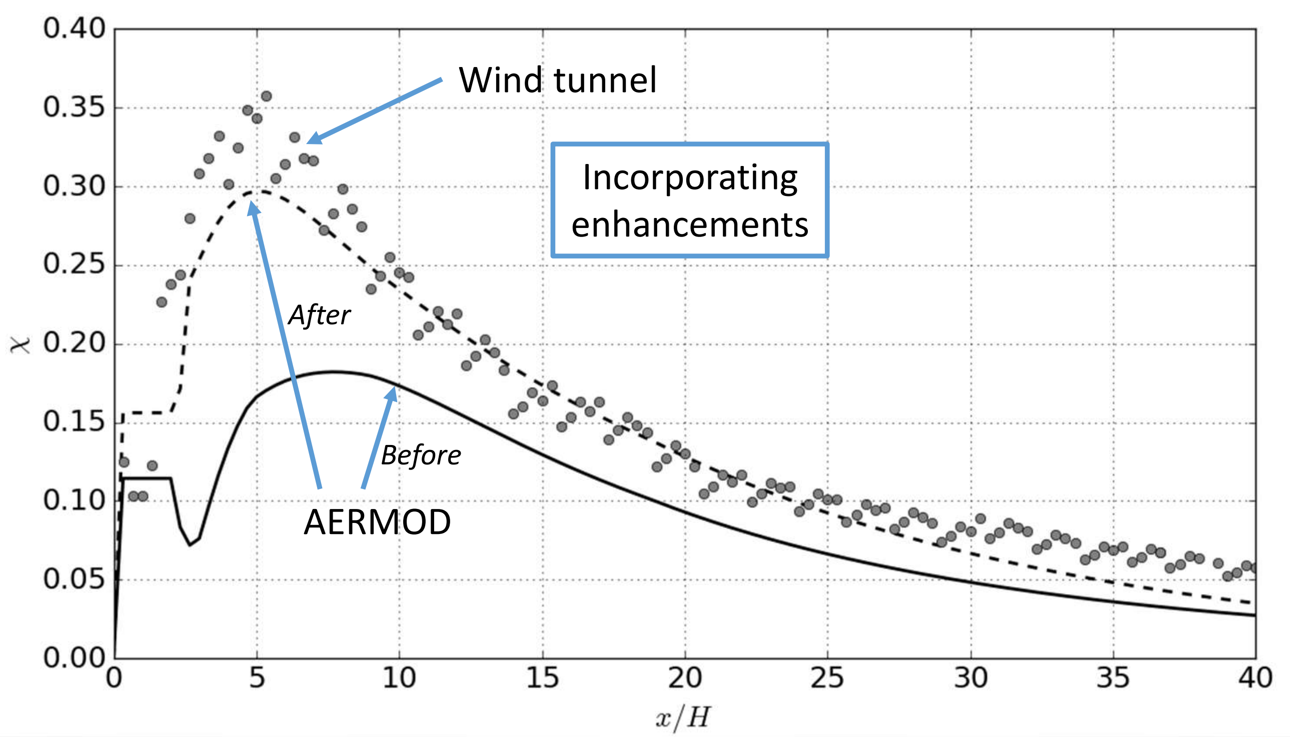


Three proposed model enhancements:

- Fix mismatch in plume width at transition between cavity and far wake
- Use effective wind speed for primary plume (currently using stack height wind speed)
- Adjust cap on ambient vertical turbulence intensity (0.06 – 0.07, based on Weil, 1996)

ORD – Changes Applied

Ground-level concentration for a 1x2x1 building and a 1.5H stack



Enhanced Building Downwash and Plume Rise Alpha Options in AERMOD 21112

2021 Regional, State, and Local (RSL) Dispersion Modelers' Workshop.
June 21, 2021, Virtual

By

Ron Petersen, PhD, CCM

Cell: 970 690 1344

rpetersen@petersenresearch.com

Acknowledgements: The continued advancements to the building downwash predictions in AERMOD would not be possible without the financial support of the American Petroleum Institute's Air Modeling Group.

Key Issues Addressed

Performed wind tunnel studies to investigate the following issues:

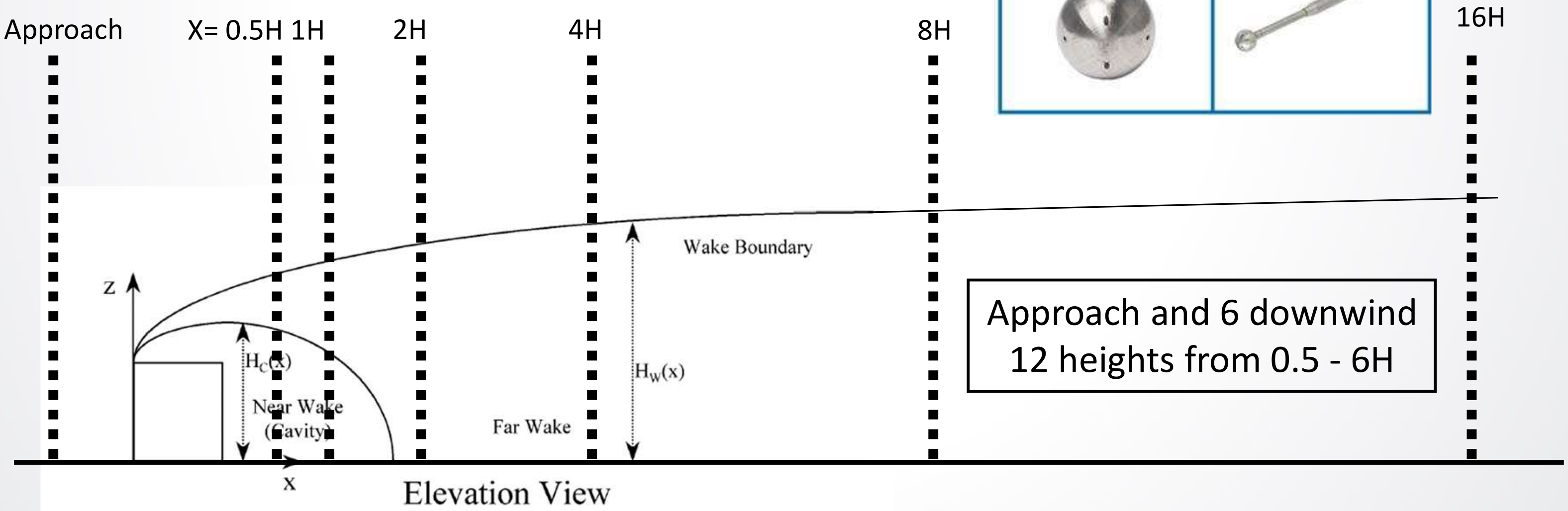
- Decay of building wake effects back to ambient levels
  - Decay occurs more rapidly than current theory in which wake effects can extend up to 3 building heights
- Turbulence enhancement
  - Lateral turbulence enhancement less than vertical in wake (equal in PRIME)
- Height at which approach turbulence and wind speed is calculated
  - Current height used is half of wake height at 15 building heights downwind
- Wake effects for streamlined structures – reduced from current PRIME
- Wake effects relationship to approach roughness – decreases with increased roughness

New Velocity Measurements

Approach
- Uo = Wind Speed
- I_{zo} = Vertical TI
- I_{yo} = Lateral TI

In Wake
- U = Wind Speed
- I_z = Vertical TI
- I_y = Lateral TI

Omniprobe used which can measure three components of velocity

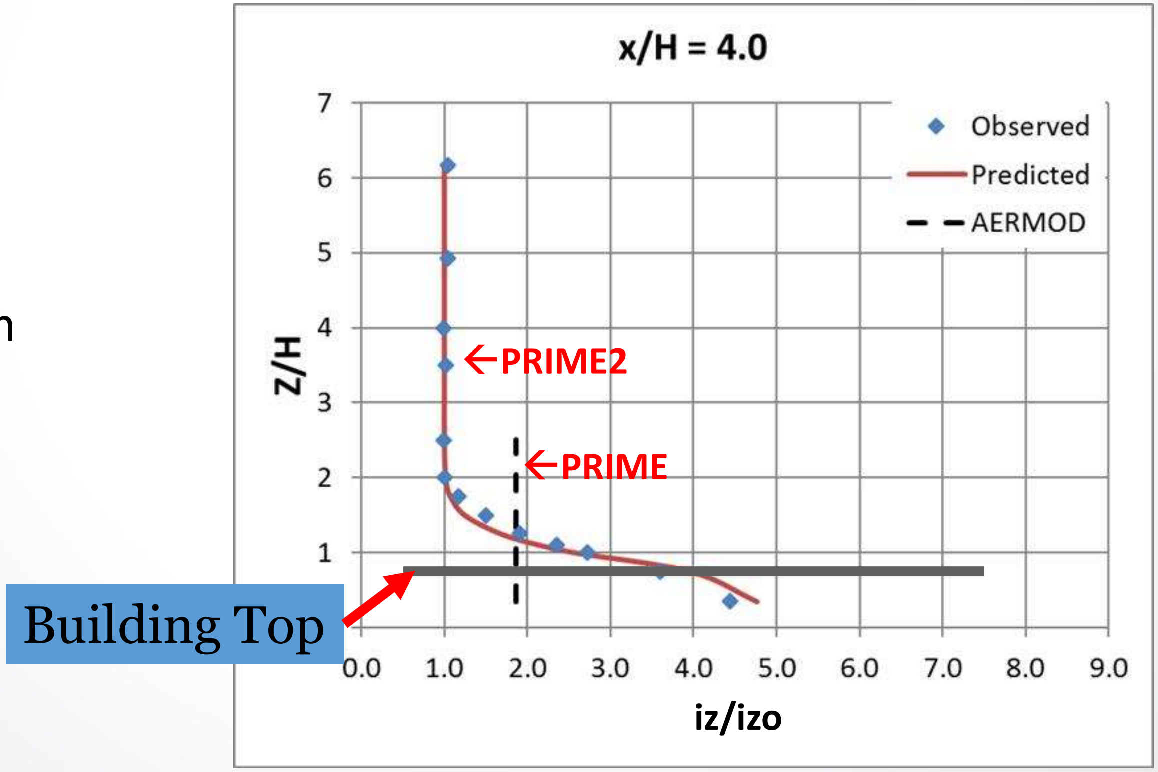


Sample Results

H:W:L

40:160:160 m

Vertical Turbulence Intensity Increase (iz/izo) Versus Normalized Height (Z/H)
Predicted and Observed for Medium Building



Plume Rise Databases

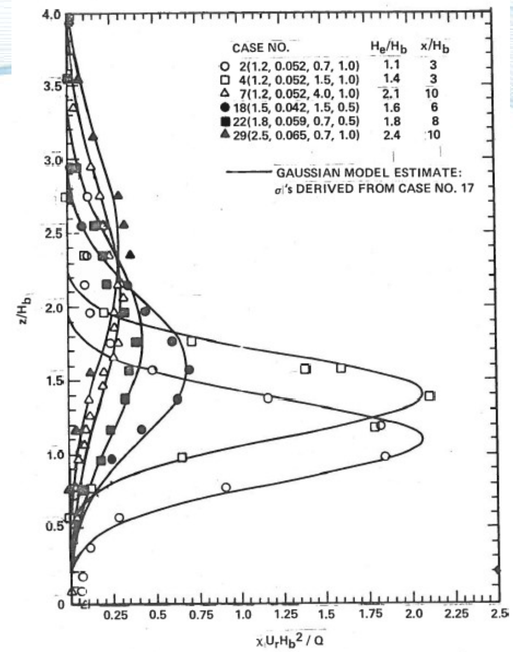


Figure 10. Vertical concentration profiles for isolated stack. In this and following legends, H_e/H_b identifies the presumed effective stack height as determined from analysis of vertical concentration profiles at position, x/H_b (see table 3).

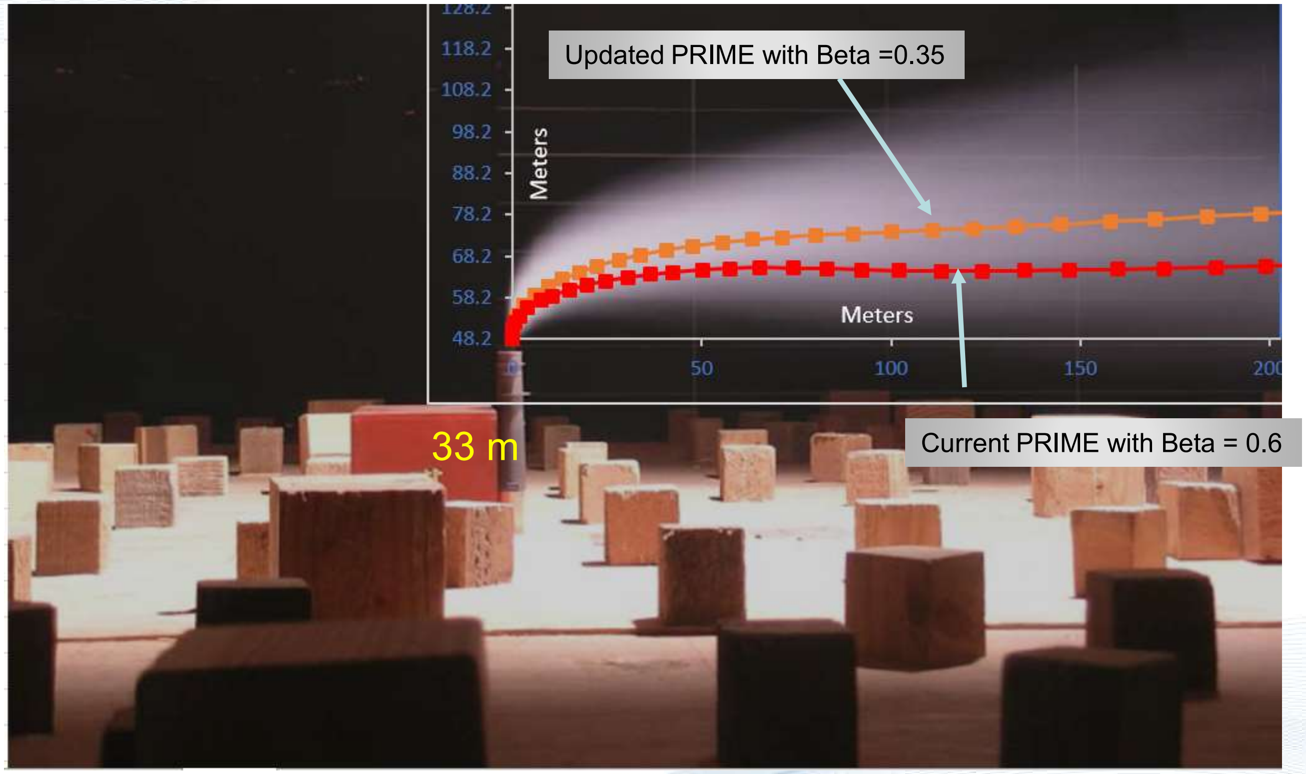
- EPA data base (Huber/Snyder).
  - Based on vertical concentration profiles for various stack heights to building height ratios.
  - All information is documented in a peer reviewed paper.

- CPP Wind Tunnel Data Base.
  - Based on plume visualizations.
  - Four cases were selected.
  - Building heights varied from 30 to 42 m.
  - Stack height = 48.2 m.

Typical Result

Mirant Data Base: Hs = 48.2 m; Hb = 33 m; Hs/Hb = 1.46

Current PRIME Underestimates Plume Rise; Modified PRIME Better



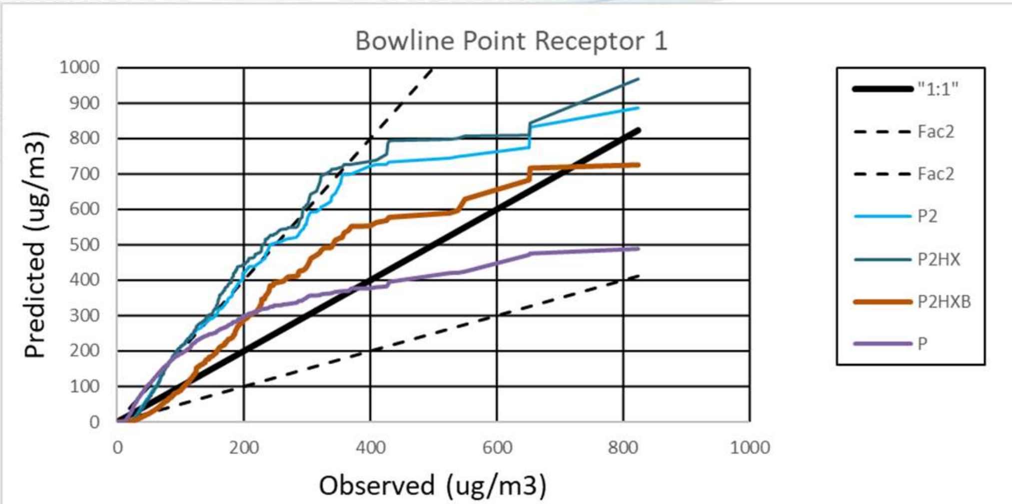
Databases & Evaluation

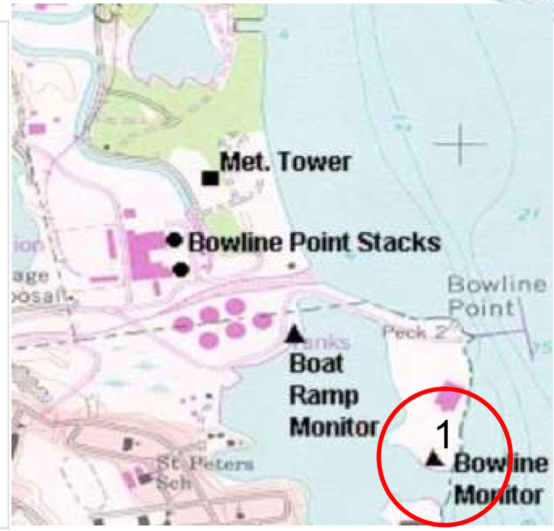
Bowline Point

- Buoyant , SO2 Source
- Hudson River Valley, New York
- 100m met tower
- No turbulence data
- Even split between stable and unstable hours
- Hourly emissions data
- Full year of data
- 4-Receptors (Recs 1 and 3 used)

	Q (g/s)	Hs (m)	Ts (K)	Vs (m/s)	Ds (m)
STACK	0 - 449.3	86.87	358 - 409	7.9 – 30.9	5.72

Bowline Point Receptor 1: X = 848m

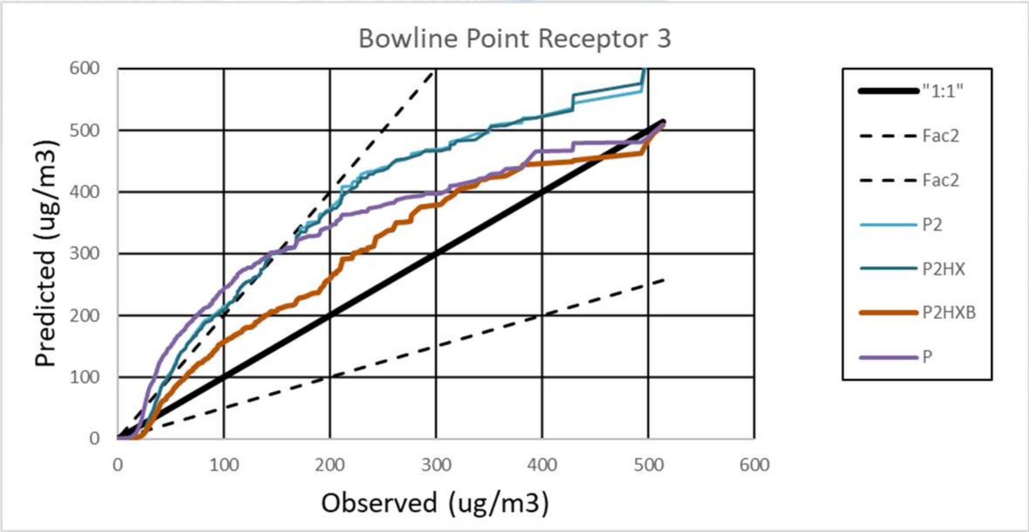


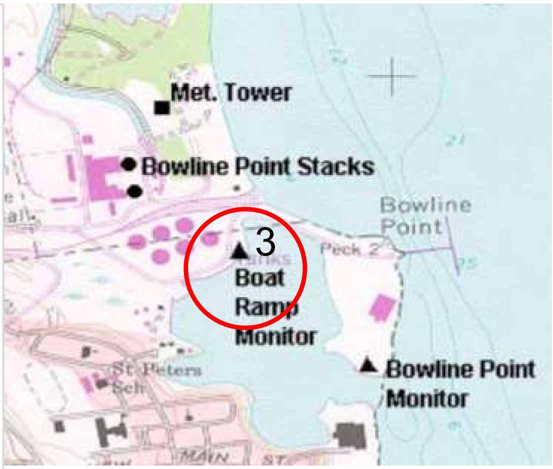


Model Scenario	RHC_{pre} (ug/m3)	RHC_{obs} (ug/m3)	RHC_{pre}/RHC_{obs}
P2	1001.1	742.6	1.35
P2HX	1085.2	742.6	1.46
P2HXB	**839.4**	**742.6**	**1.13**
P	480.9	742.6	0.65

Best Agreement

Bowline Point Receptor 3: X=376m





Model Scenario	RHC_{pre} (ug/m3)	RHC_{obs} (ug/m3)	RHC_{pre}/RHC_{obs}
P2	646.2	596.1	1.08
P2HX	663.2	596.1	1.11
P2HXB	**563.7**	**596.1**	**0.94**
P	547.7	596.1	0.92

Best Agreement