WIND ENGINEERING &
AIR QUALITY CONSULTANTS

Building Downwash – Problems, Solutions and Next Generation

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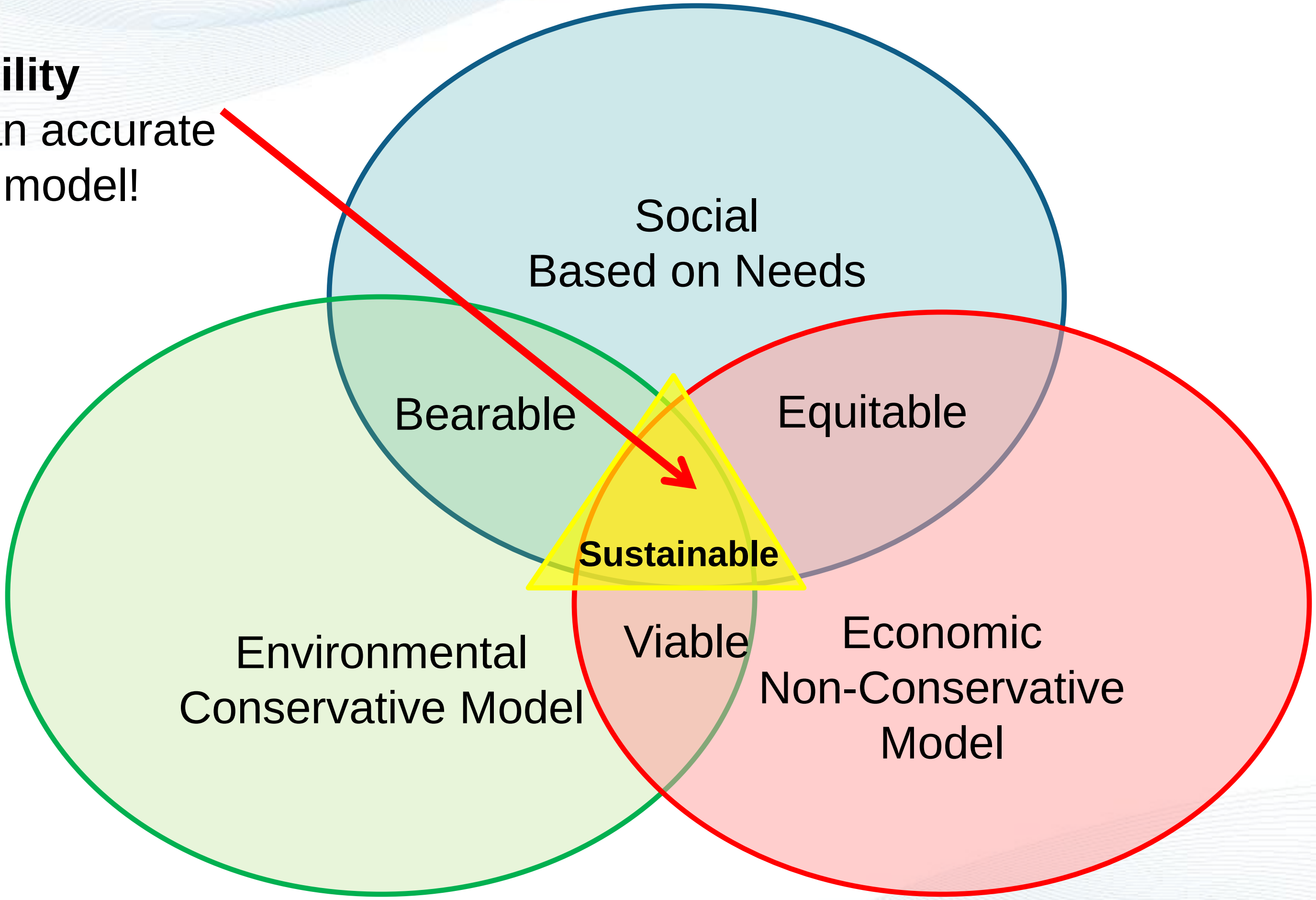
Why is this Important?

Its About Sustainability

Sustainability
We need an accurate dispersion model!



Overview of Problems with Building Downwash

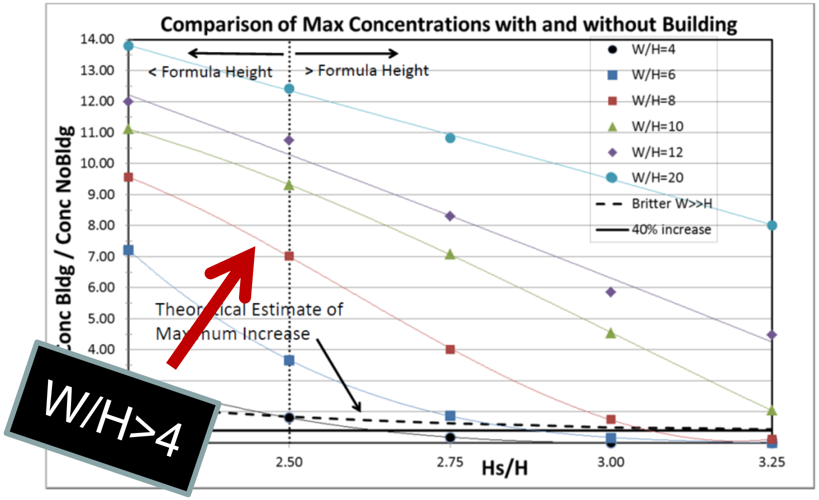
- Downwash theory based on research done before 2000
- Original theory based on a limited number of “solid” building shapes
- Schulman and Petersen documented problems for long and wide buildings and tall stacks at 10th modeling conference
- Theory is not suitable for porous, streamlined, wide or elongated structures
- CPP’s evaluation of theory has identified deficiencies and inaccuracies
- Recent and past model comparisons with observations

Examples Problems -Overprediction

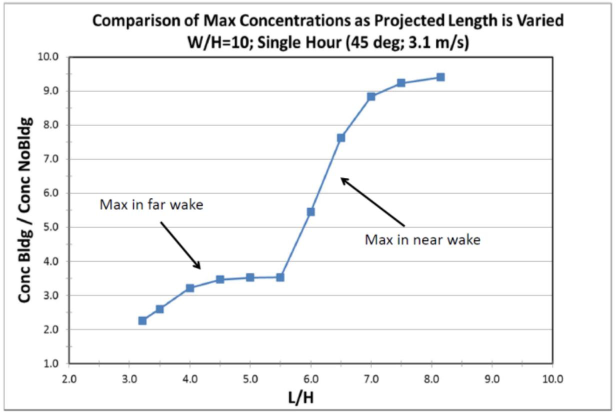
From 10th Modeling Conference

Schulman, 2012, Wide/Long Building Issue

- Wide Buildings: Concentration increased by **factors of 3 to 14** when Width > 4 x Height
- Long Buildings: Concentration increased by **factors of 4 to 10** when Length > 4 x height for GEP stack.
- Field Observations at ALCOA TN wide/long facility: Model **overpredicts by factor of ~10.**

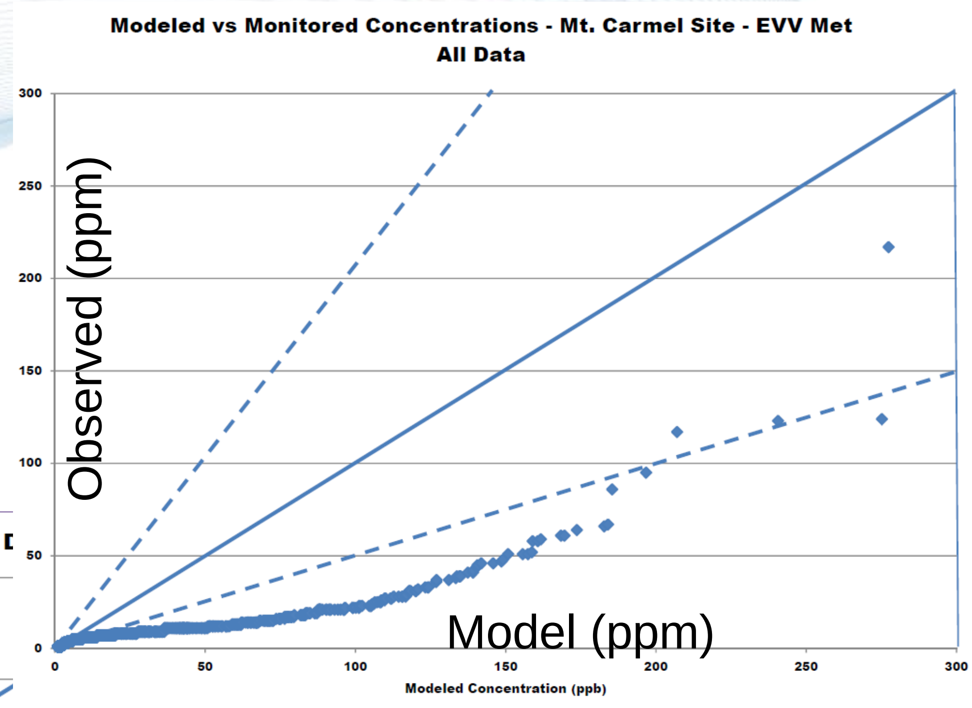


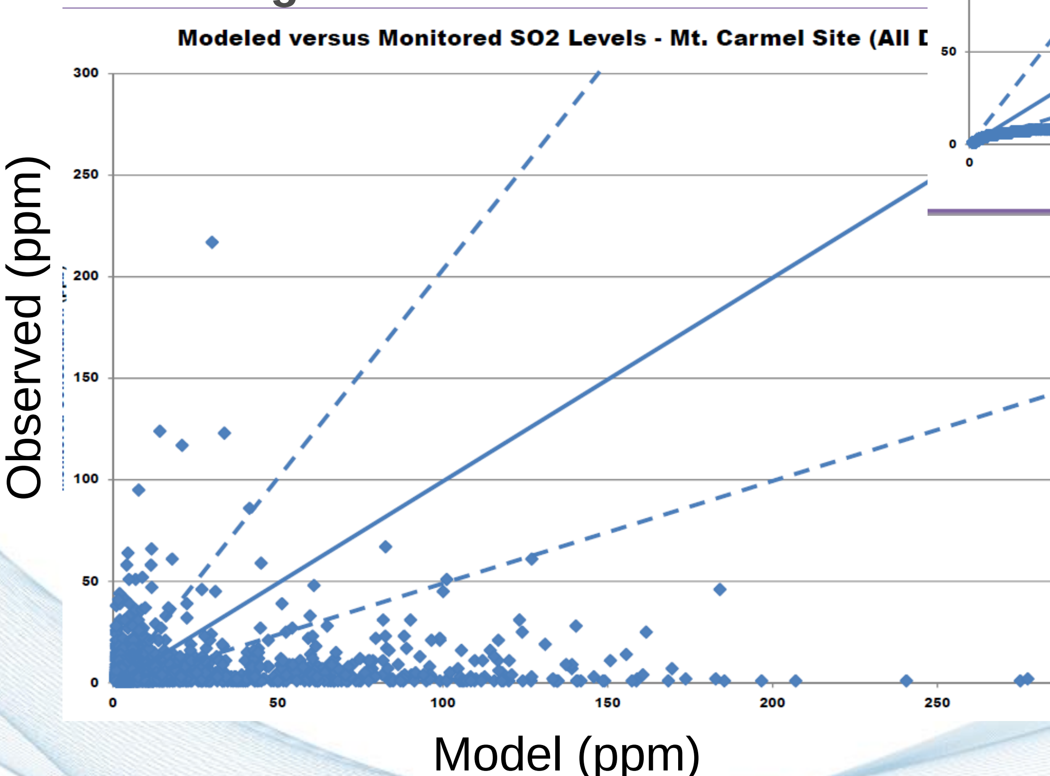
Hs/Hb = 2.5



An Assessment of the AERMOD by IDEM
Keith Baugues, Assistant Commissioner

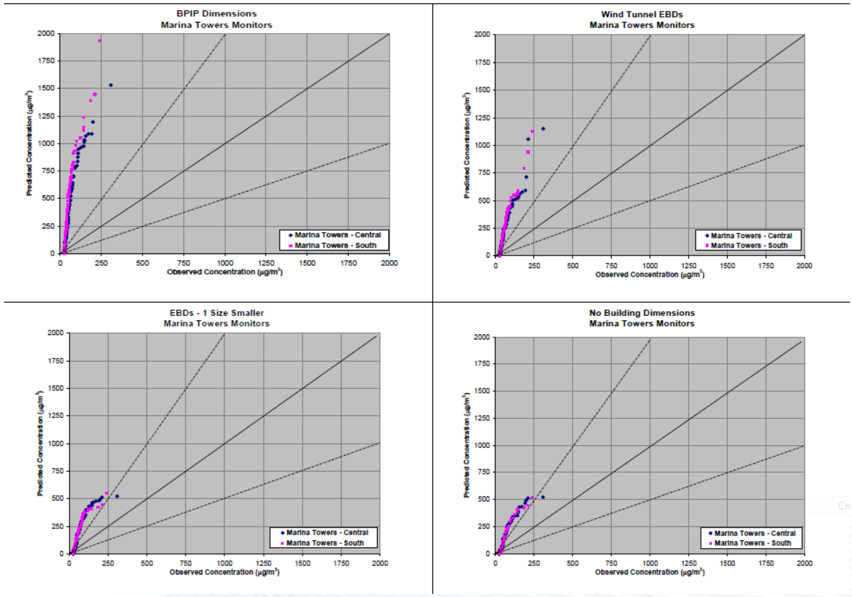
- Q:Q: Model Overpredicts by Factor of 2 or More
- Paired: Very Poor Agreement





AECOM Field Study at Mirant Power Station (Shea et al., 2012)

- Model overpredicted by factor of 10 on residential tower
- Better agreement with EBD, but still overpredicted by factor of 4
- Best agreement with no buildings, still overpredicted by factor of 2.
- In reality, plume is not affected by building downwash.

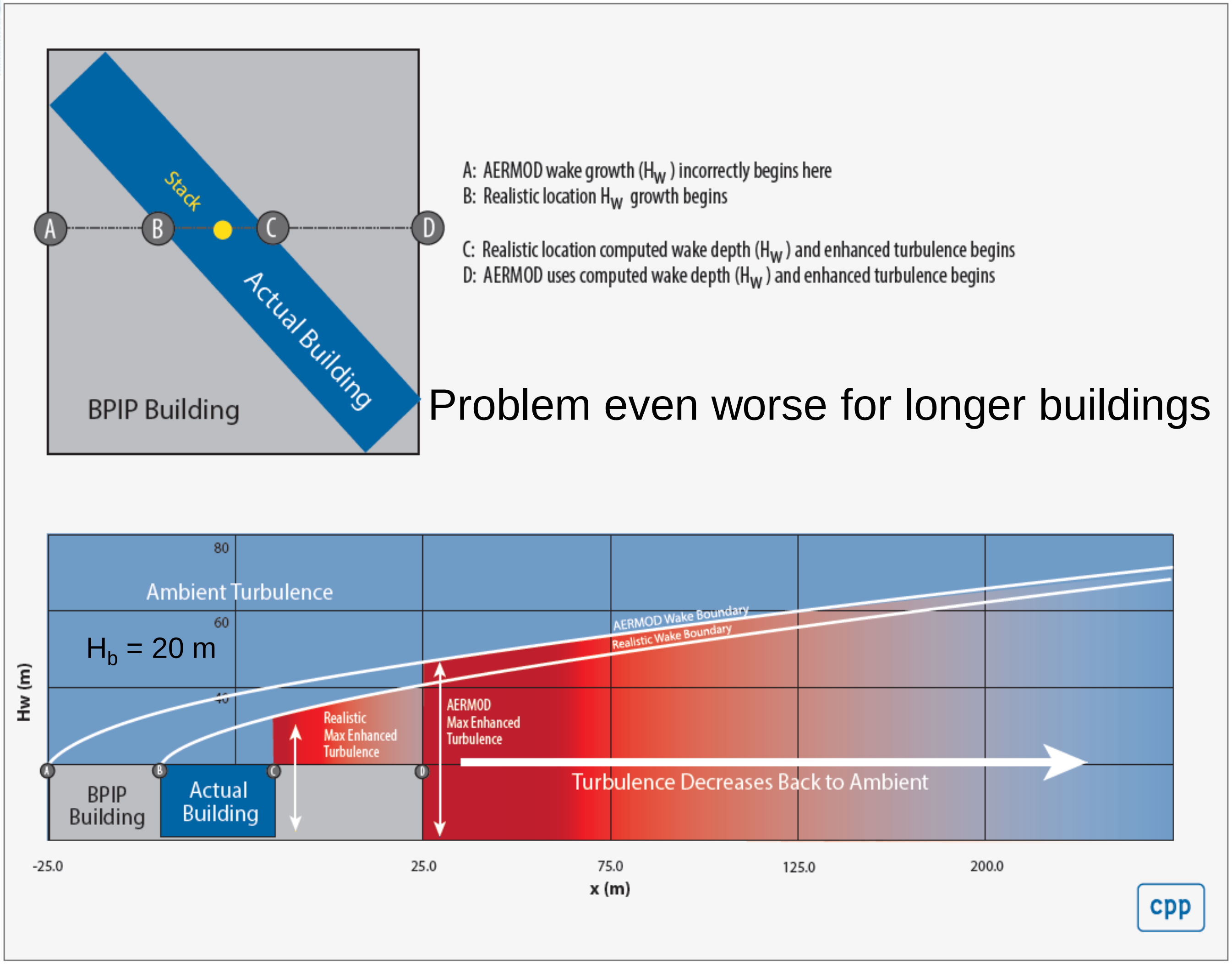


[2]Shea, D., O. Kostrova, A. MacNutt, R. Paine, D. Cramer, L. Labrie, "A Model Evaluation Study of AERMOD Using Wind Tunnel and Ambient Measurements at Elevated Locations," 100th Annual AWMA Conference, Pittsburgh, PA, June 2007.

What’s Causing These Problems?

AERMOD Building Wake Problems –
AERMOD Overestimates Downwash

- Wake height overestimated: need higher plumes to avoid downwash.
- Start of maximum building downwash farther downwind than in reality



Turbulence Calculations in Wake Flawed

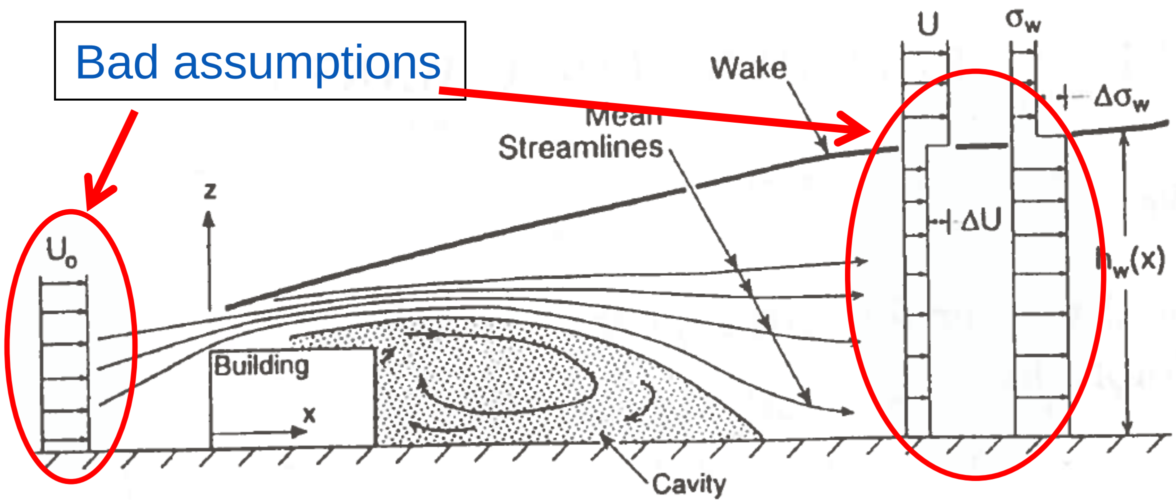
- Constant downwash enhancement up to wake height (Fix?)

- Downwash enhancement decrease to ambient flawed (Fix?)

Starting Relation

$$i_z = i_o \left[\frac{1 + \frac{\Delta\sigma_{wo}}{\sigma_{wo}} \left(\frac{\xi}{R}\right)^{-\frac{2}{3}}}{1 + \Delta U_o / U_o \left(\frac{\xi}{R}\right)^{-\frac{2}{3}}} \right]$$

Bad assumptions



Where:

Wake Velocity Deficit:

$\Delta U_o / U_o = -0.7$

Wake Turbulence Deficit:

$\Delta\sigma_{wo} / \sigma_{wo} = 0.7$

i_z = vertical turbulence intensity in wake

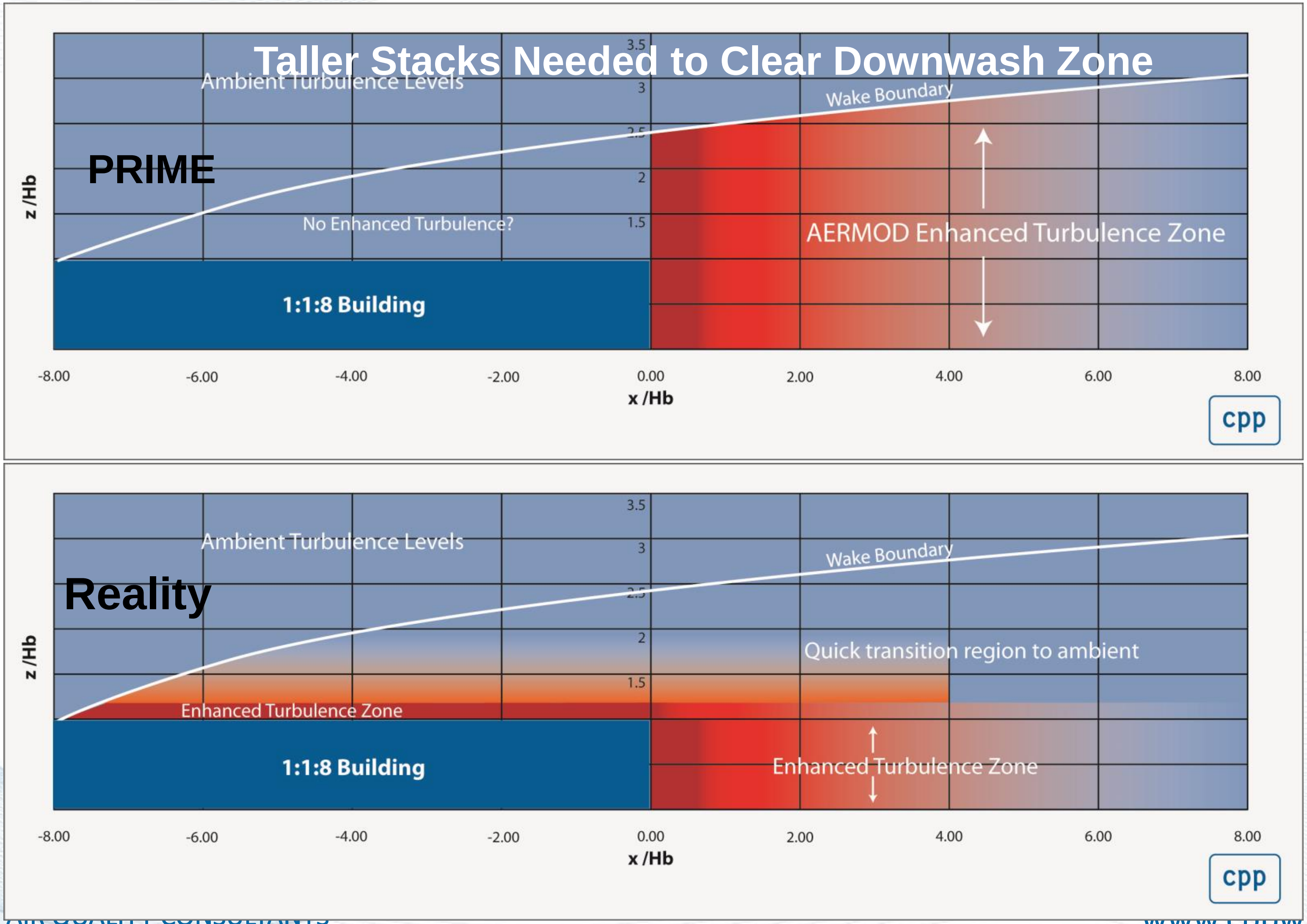
i_o = upstream vertical turbulence intensity

ξ = distance from lee edge of building

J.C. Weil, *A New Dispersion Model for Stack Sources in Building Wakes*, 9th Joint Conference on Air Pollution Meteorology with A&WMA, 1996.

Height of Building Downwash Overestimated

(High Turbulence Zone >> AERMOD Overestimates)



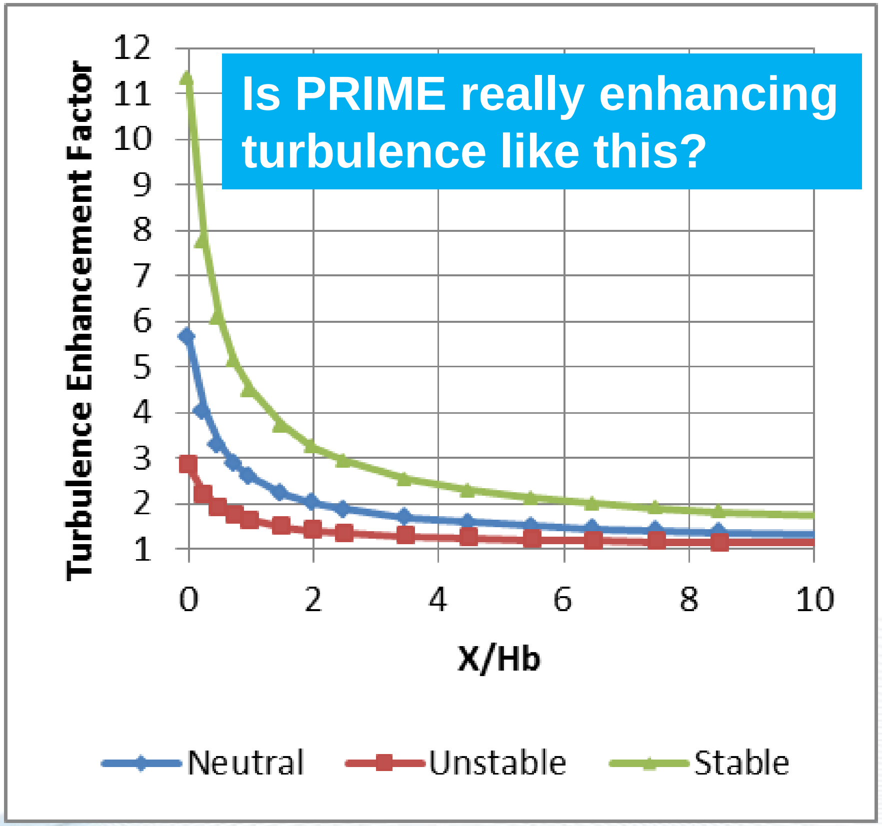
More AERMOD Overestimates

Downwash (turbulence) enhanced by factor of ~10 under stable conditions: not documented (Fix?).

AERMOD Turbulence Enhancement Factor Starting at Lee Wall of Building

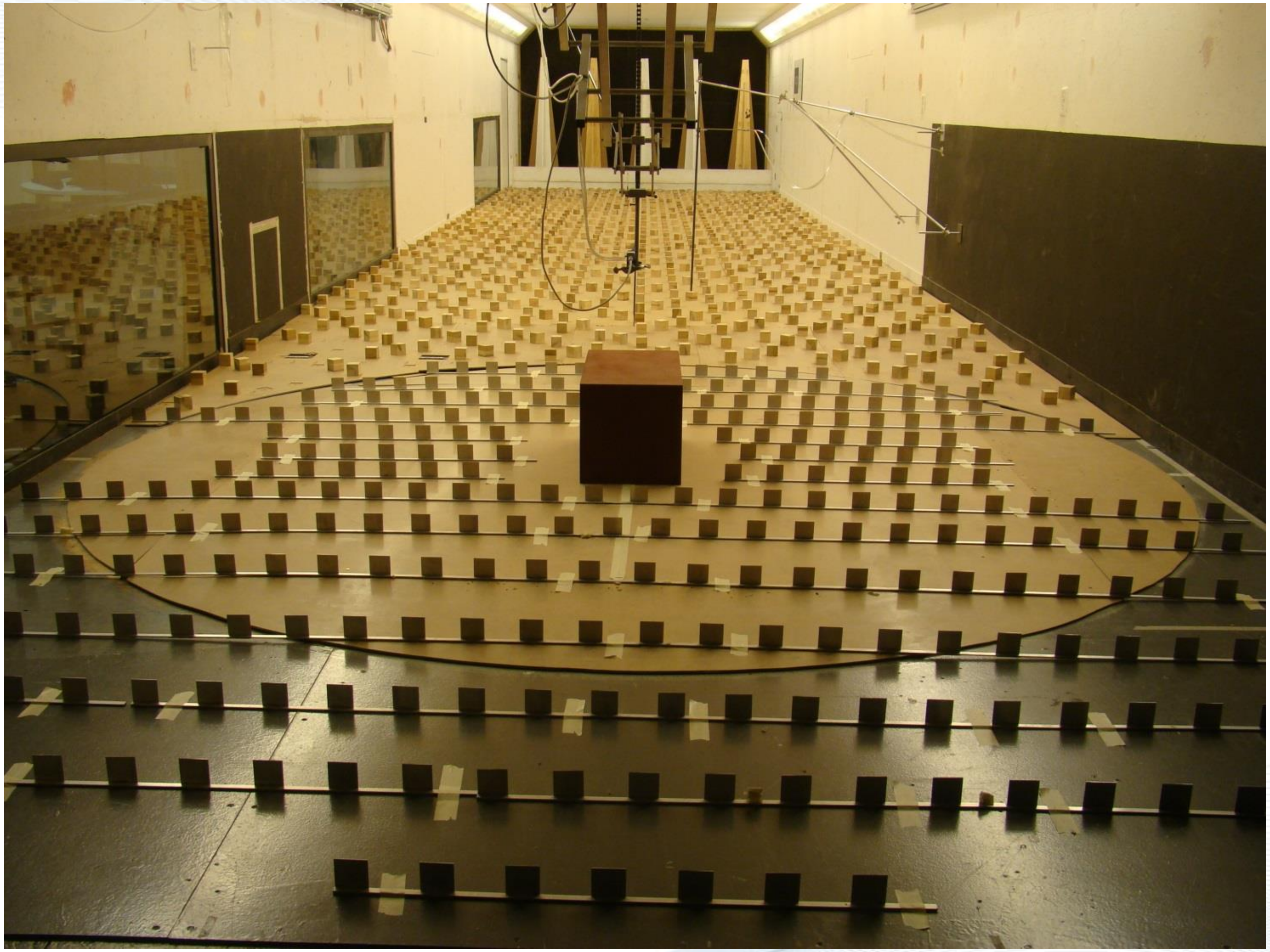
$$i_z = i_{zo}\left[1 + \frac{\left(\frac{1.7 i_{zN}}{i_{zo}} - 1\right) + \frac{\Delta U_o}{U_o}}{\left(\frac{\xi}{R}\right)^{\frac{2}{3}} - \left(\frac{\Delta U_o}{U_o}\right)}\right]$$

No Evidence Supporting This is Provided!!



CPP’s Limited Research

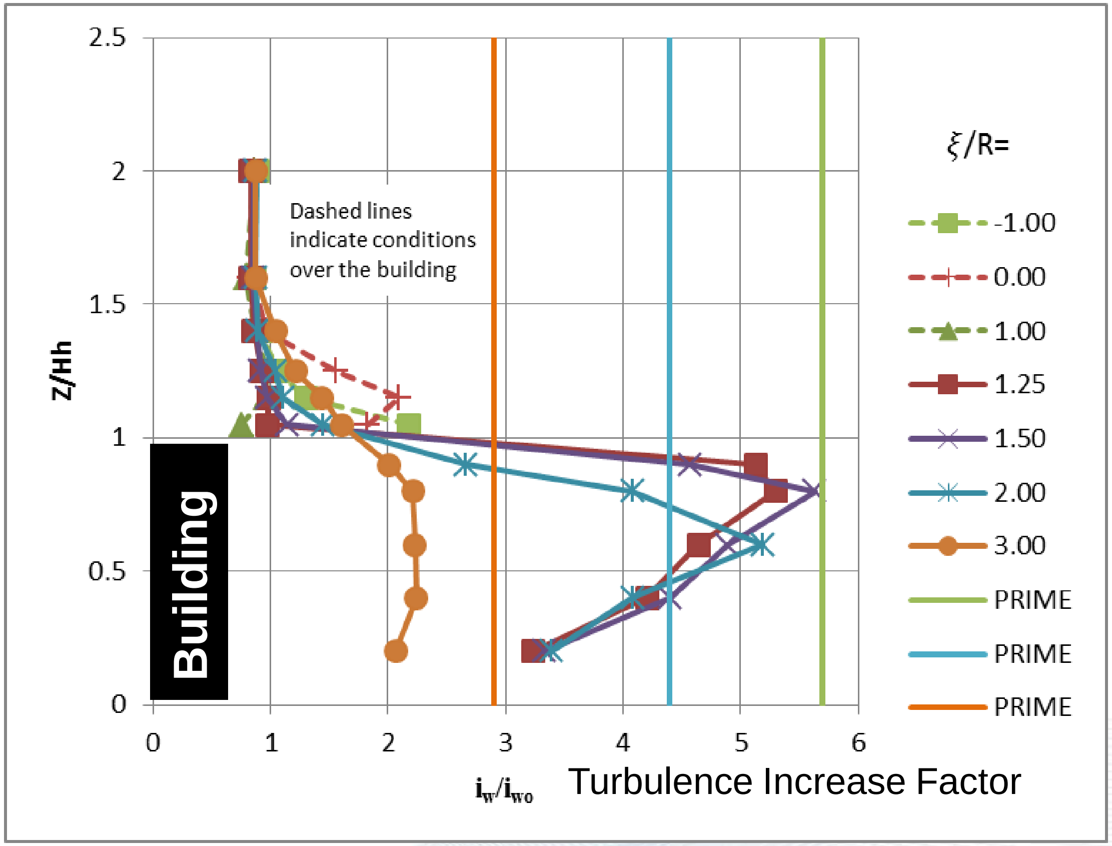
Velocity Mapping for 1:1:2 Building



Findings from CPP's Limited Research

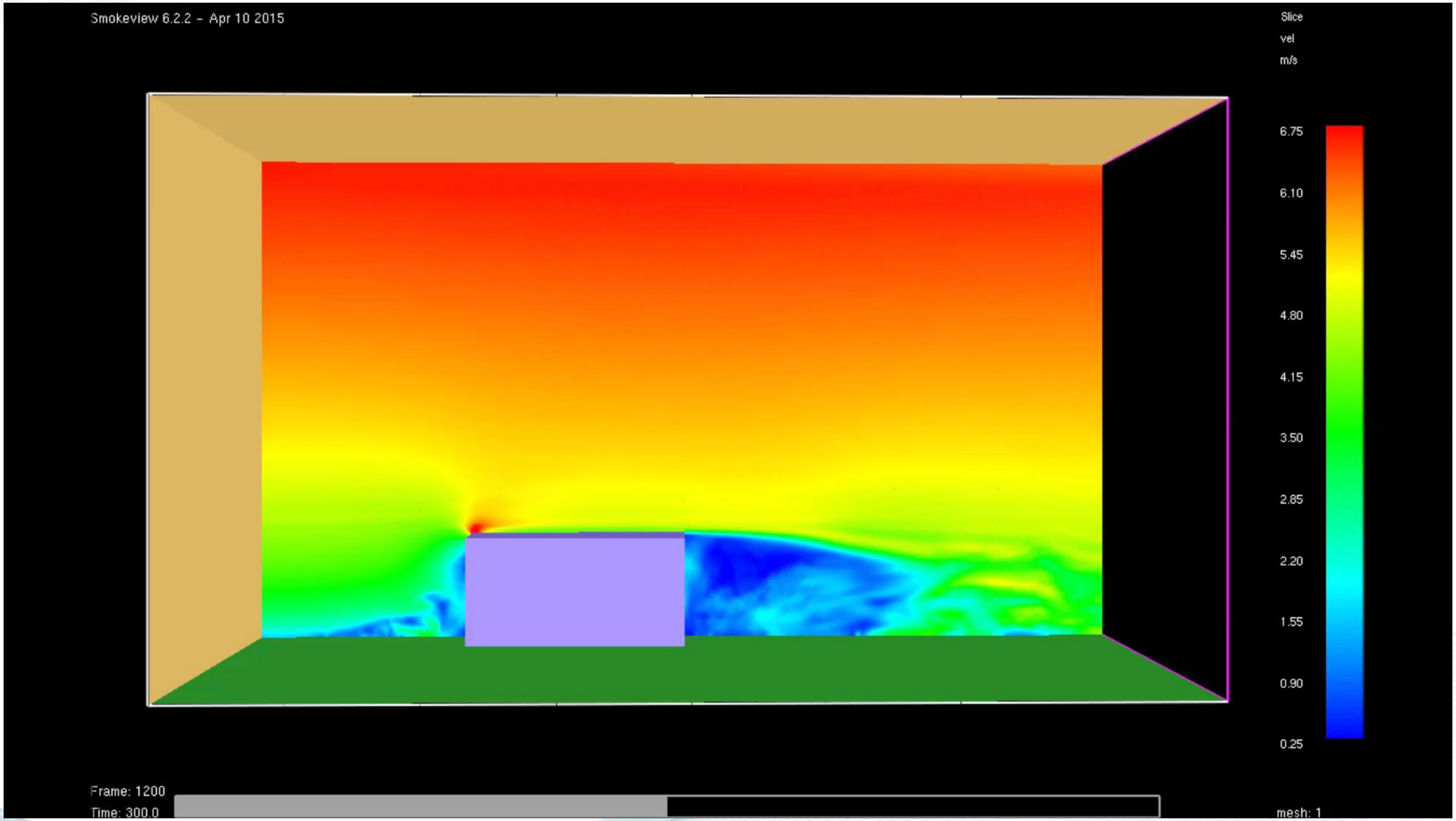
- Wind tunnel measurements show little enhancement above building height (Fix?)

Distance	Turbulence Increase Factor	
ξ/Hb	AERMOD	Observed
1	5.7	1.0 to 5.7
2	4.4	1.0 to 5.2
3	2.9	1.0 to 2.2



FDS LES Simulation for 1:1:2 Building

Very little downwash enhancement above the building



Other Problems

Streamline Calculation Comparison Flawed (Bug?)

Given:

- H=W=L=R

PRIME Logic

- If L> 0.9R (= 0.9L) reattachment occurs, and Hr = H

For this case,

- L>0.9R = 0.9L, therefore
- Hr = H

That means all streamlines should be horizontal and they are not in example.

What is PRIME really doing?

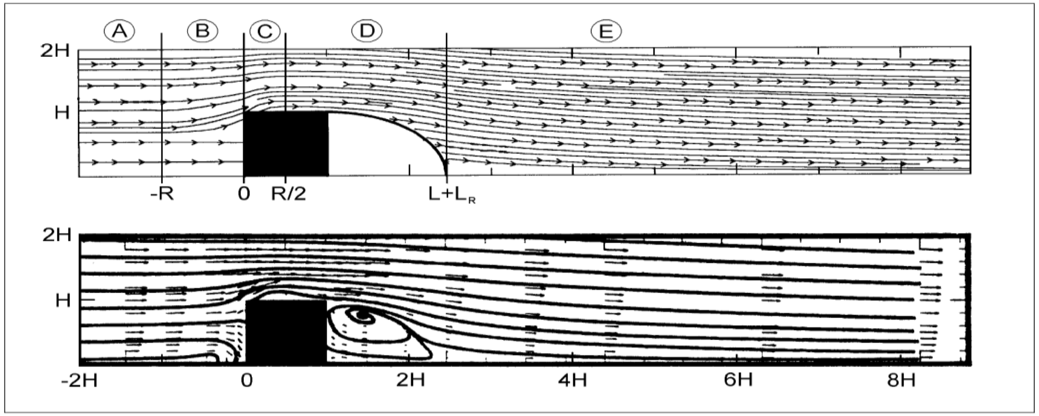
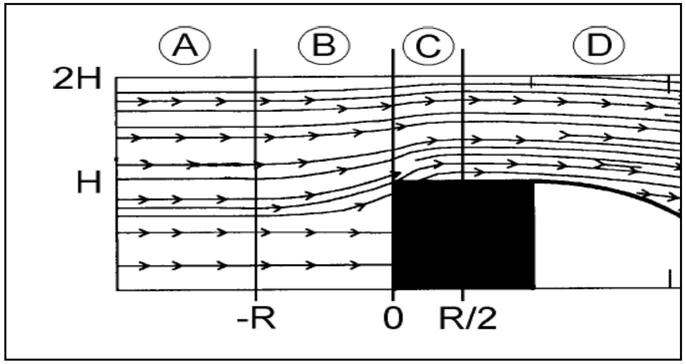


Figure 5. Comparison of streamlines predicted by the PRIME model with those observed in wind-tunnel simulations of a cubic building.[13] The five regions of streamline deflection (A–E) are noted. The height and distances are scaled by the building height, *H*.

Figure 6. Prime predicted and observed streamlines from Schulman[1]

A	$\frac{dz}{dx} = 0$	$(x<-R)$
B	$\frac{dz}{dx} = \frac{2(H_R - H)(x+R)}{R^2}$	$(-R \le x < 0)$
C	$\frac{dz}{dx} = \frac{-4(H_R - H)\left(\frac{2x}{R} - 1\right)}{R}$	$(0 \le x < 0.5R)$
D	$\frac{dz}{dx} = \frac{(H_R - H)(R - 2x)}{\left(L + L_R - \frac{R}{2}\right)^2}\left(\frac{z}{H}\right)^{0.3}$	$(0.5R \le x \le L + L_R)$

Another Streamline Calculation Problem (Bug?)



Region B and C calculations should be equal at x = 0

They are a factor of two different.

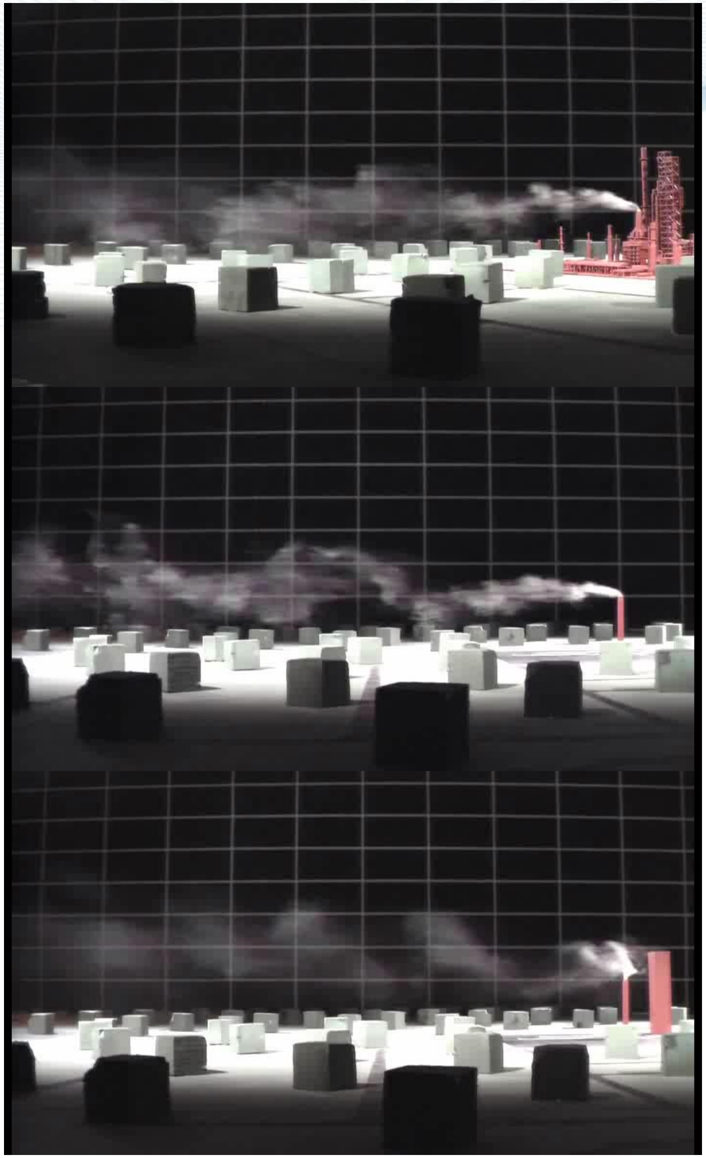
$slope = \frac{dz}{dx} = \mathbf{2} \left[\frac{H_r - H}{R}\right]$ at x = 0, Region B

$slope = \frac{dz}{dx} = \mathbf{4} \left[\frac{H_r - H}{R}\right]$ at x = 0, Region C

B $\quad \frac{dz}{dx} = \frac{2(H_R - H)(x + R)}{R^2} \qquad (-R \le x < 0)$

C $\quad \frac{dz}{dx} = \frac{-4(H_R - H)\left(\frac{2x}{R} - 1\right)}{R} \qquad (0 \le x < 0.5R)$

Streamlines for Lattice Structures Should be horizontal (Fix?)



Refinery Structures Upwind
- Horizontal flow

No Structures

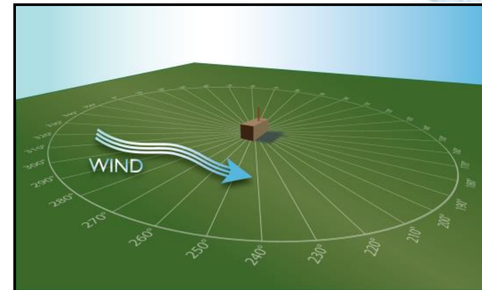
Solid BPIP Structure Upwind

Solutions and Next Generation (Sustainability)

- Short Term Fix: Use Equivalent Building Dimensions
  - EBDs are the dimensions (height, width, length and location) that are input into AERMOD in place of BPIP dimensions to more accurately predict building wake effects
  - Not a complete fix because of problems with the theory
  - Determined using wind tunnel modeling
- Next Generation: Improved AERMOD (and SCICHEM) and BPIP
- Collaboration between EPA and Industry

Short Term:
Advanced AERMOD Modeling to ~Fix

EBD Test Model

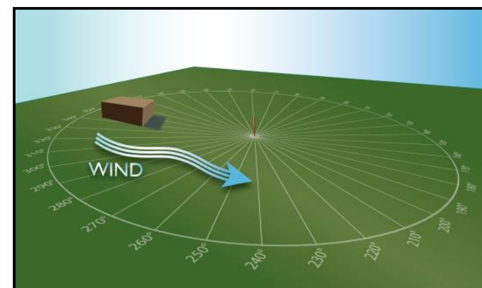


EBD Geometry for AERMOD

Actual Site

BPIP Diagnostic Shows Problems

BPIP



BPIP Geometry for AERMOD

Typical AERMOD Overprediction Factors When Using BPIP Inputs and Current Theory

FACTOR of 2 to 4
reduction when EBD used

Hyperbolic cooling towers

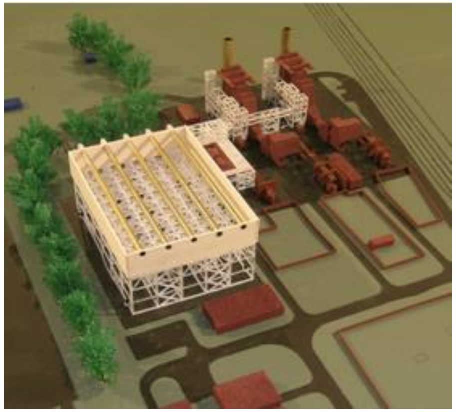
FACTOR of 4 to 8
reduction when EBD used

Short building with a large foot print

Typical AERMOD Overprediction Factors When Using BPIP Inputs and Current Theory

FACTOR of 2 to 3.5
reduction when EBD used

Lattice Structures

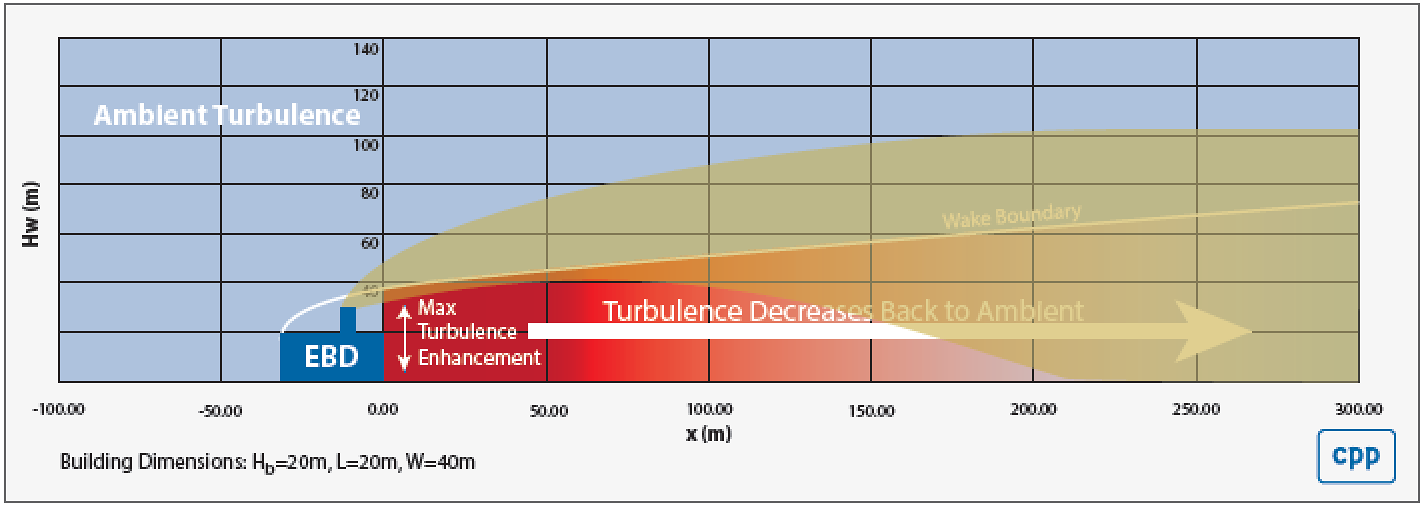


FACTOR of 2 to 5
reduction when EBD used

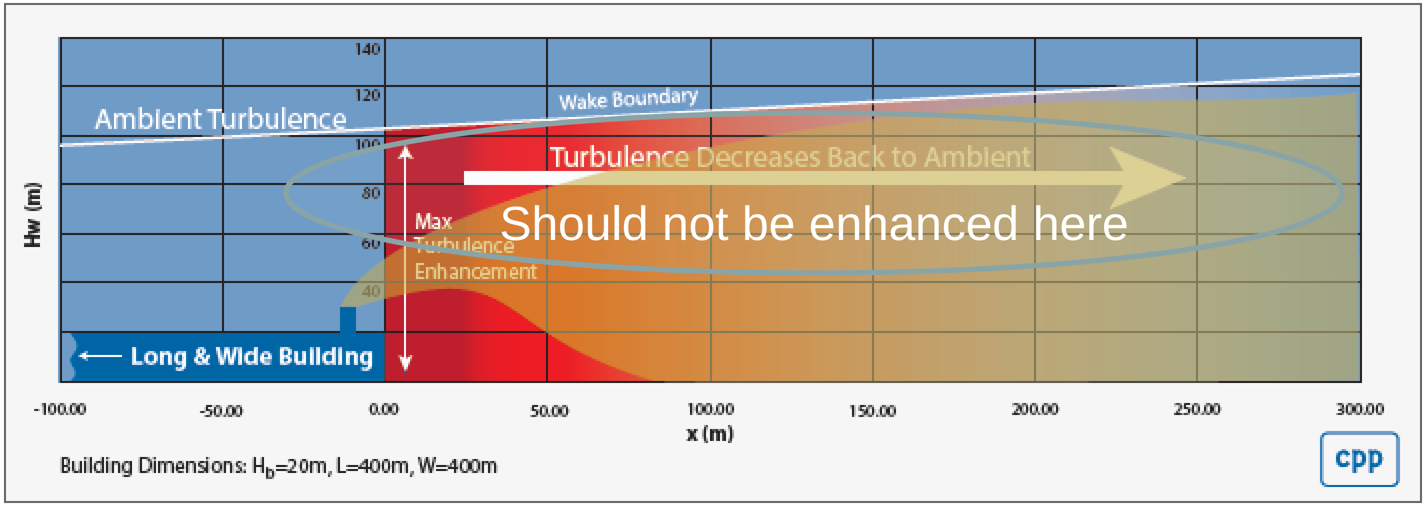
Very Wide/Narrow Buildings

Why EBD helps but doesn't solve problem

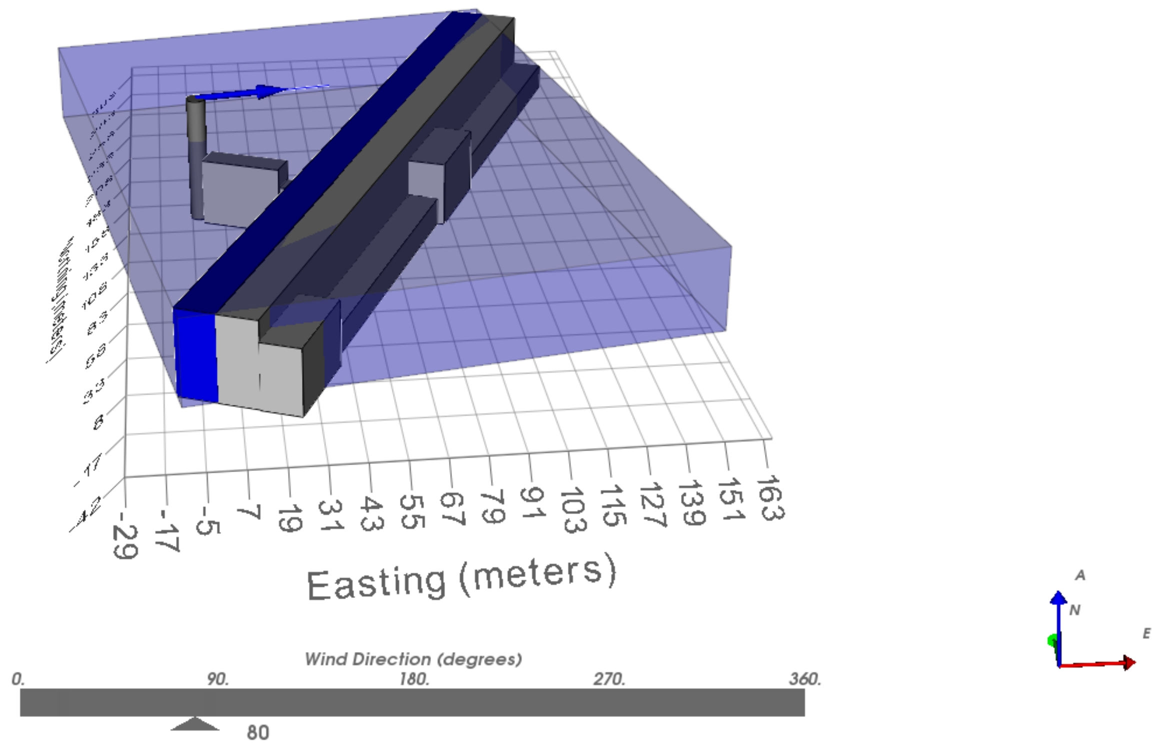
Why EBD
Helps
~ reality



Very Long
Building



Long Buildings with Wind at an Angle



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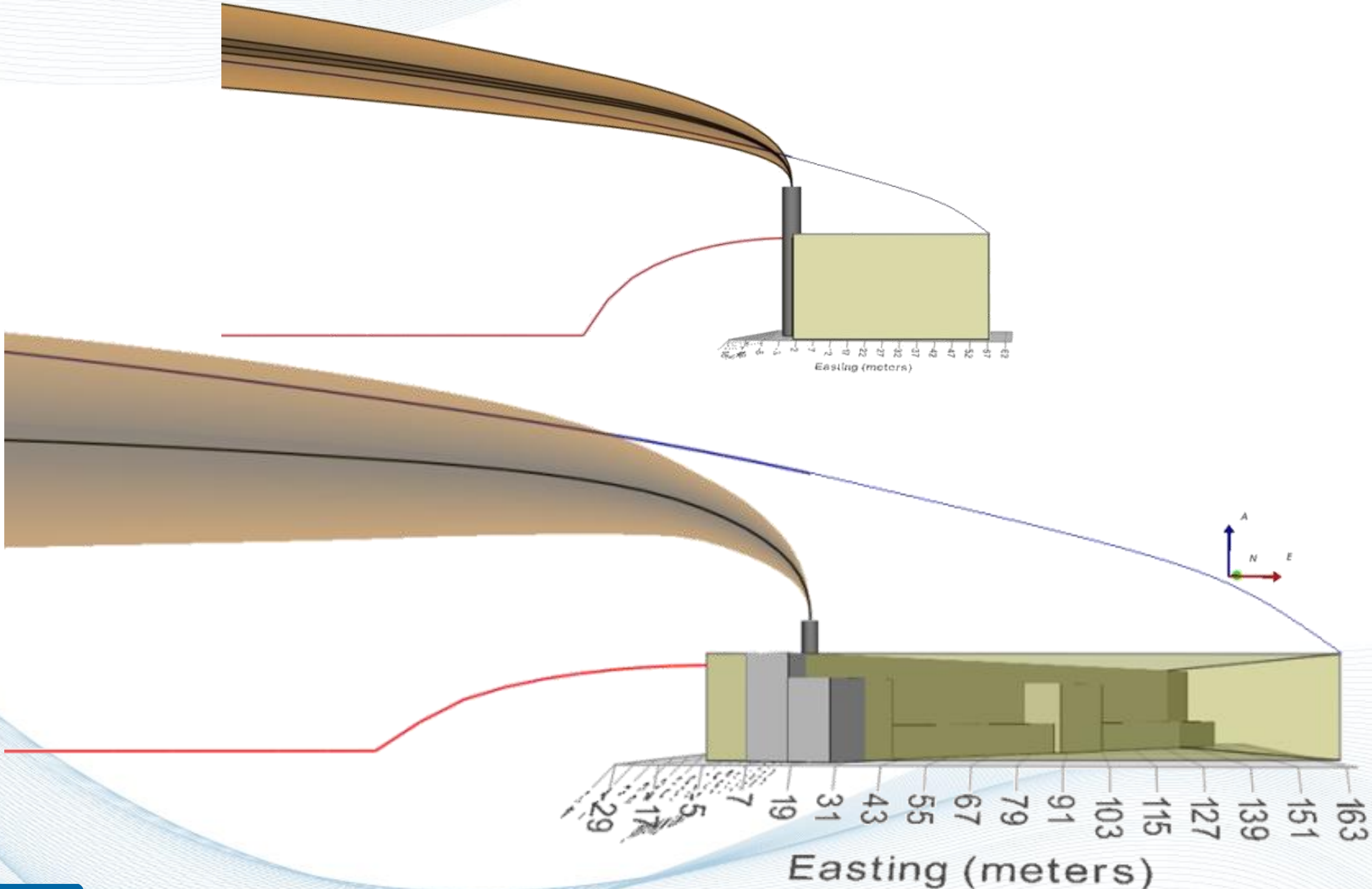
Downwash Based on EBD and BPIP



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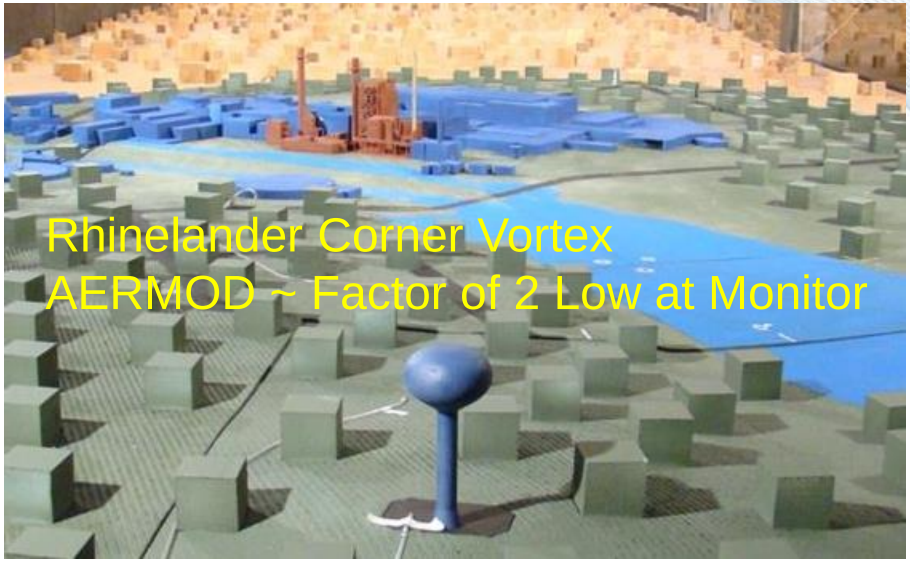
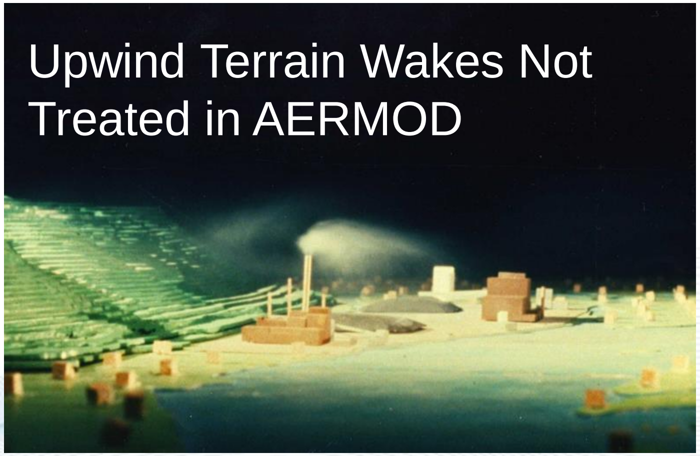
Typical AERMOD Underprediction Factors

- Factor of two: Corner Vortex



- Factor of 2-6: Upwind Terrain



The Next Generation Downwash Model Moving Toward Sustainability

- Correct all the bugs
- Fix the known problems in the theory
- Incorporate the current state of science
- Advance the current state of the science
- Expand the types of structures that can be accurately handled
- Well documented and verified model formulation document and code for PRIME
- Add section to Appendix W that outlines a method to update model based on current research.
- Collaborate with industry to work toward an improved model

Thank You!

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