Petersen Research and Consulting

Building Downwash Panel

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Charge Questions

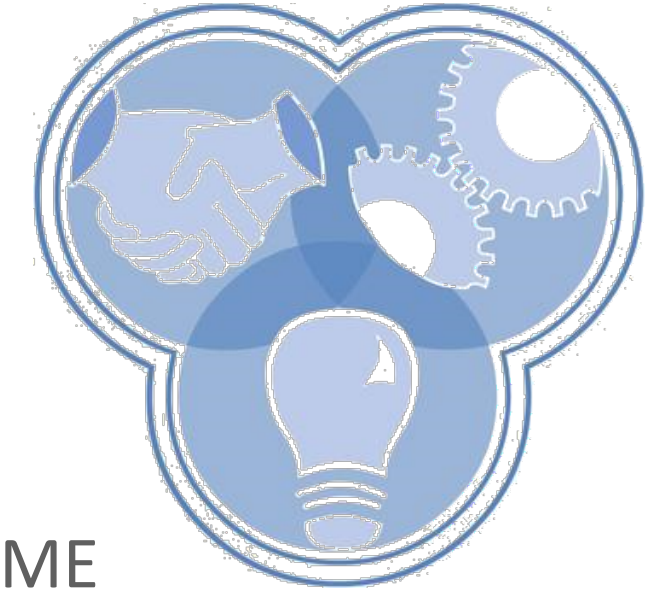
1. Comment of EPA's collaborative activities and this approach to include options in to AERMOD to make them available to the user and scientific communities for testing and evaluation. Specific comments or thoughts regarding the updates to AERMOD version 19191 based on work by ORD and by the AWMA.
2. What should be EPA's highest development priorities regarding building downwash
3. Should EPA focus its energy on continuing to improve and maintain the PRIME algorithm or replace PRIME altogether? Also provide any insights regarding the short-term and long-term path forward.

Charge Question 1

1. Comment of EPA's collaborative activities and this approach to include options in to AERMOD to make them available to the user and scientific communities for testing and evaluation. Specific comments or thoughts regarding the updates to AERMOD version 19191 based on work by ORD and by the AWMA.

Genesis of PRIME2

- Technical problems with PRIME presented at 2016 11th EPA Modeling Conference and 2016 AWMA Path Forward Conference
- PRIME2 Subcommittee of AWMA's APM Formed to:
  - Establish a mechanism to review, approve and implement new science into the model for this and future improvements
  - Provide a technical review forum to improve the PRIME building downwash algorithms



Genesis of PRIME2

- CPP obtained industry funding in late 2016 and early 2017
  - Electric Power Research Institute
  - American Petroleum Institute
  - American Forest & Paper Association
  - Corn Refiners Association
- Initial results presented at EPA's 2016 Regional, State, and Local Modelers' Workshop

  http://www.cleanairinfo.com/regionalstatelocalmodelingworkshop/archive/2016/Presentations/1-14_CPP_AERMOD-PRIME-Next-Generation_Downwash_Model.pdf
- Journal article published in JAWMA documenting the main issues with the current downwash theory, August 2017

  https://www.tandfonline.com/doi/full/10.1080/10962247.2017.1279088
- 2017 EPA Releases White Papers
  - EPA ORD has been doing building downwash research and has made some improvements to PRIME
  - JAWMA article referenced

New Equation Documented

Journal of Wind Engineering & Industrial Aerodynamics 173 (2018) 67–78

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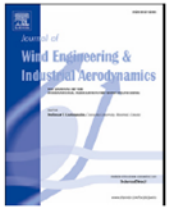

PRIME2: Development and evaluation of improved building downwash algorithms for rectangular and streamlined structures

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ABSTRACT

Theoretical flaws in PRIME (the building downwash formulation in AERMOD) have recently been documented. To improve PRIME, an industry funded research study was initiated with the following overall objectives: 1) correct the known problems in the theory; 2) incorporate and advance the current state of science; 3) expand the types of structures that can be accurately handled (e.g., streamlined, long, wide); 4) properly document and verify the model formulation and code for the updated PRIME (PRIME2); and 5) collaborate with EPA to work toward implementing the improved model. This paper presents the results from the wind tunnel study used to develop a database of wind speed and turbulence intensity measurements downwind of various rectangular and streamlined structures for three different approach turbulence conditions. Based on those measurements, new equations were developed to estimate the velocity deficit and turbulence intensity increase in the building wake as a function of downwind distance, height, building shape, and approach turbulence intensity. Comparisons of the new equations versus wind tunnel observations showed good agreement; whereas, the equations in PRIME do not agree well above the height of the building and show mixed agreement below the top of the building.

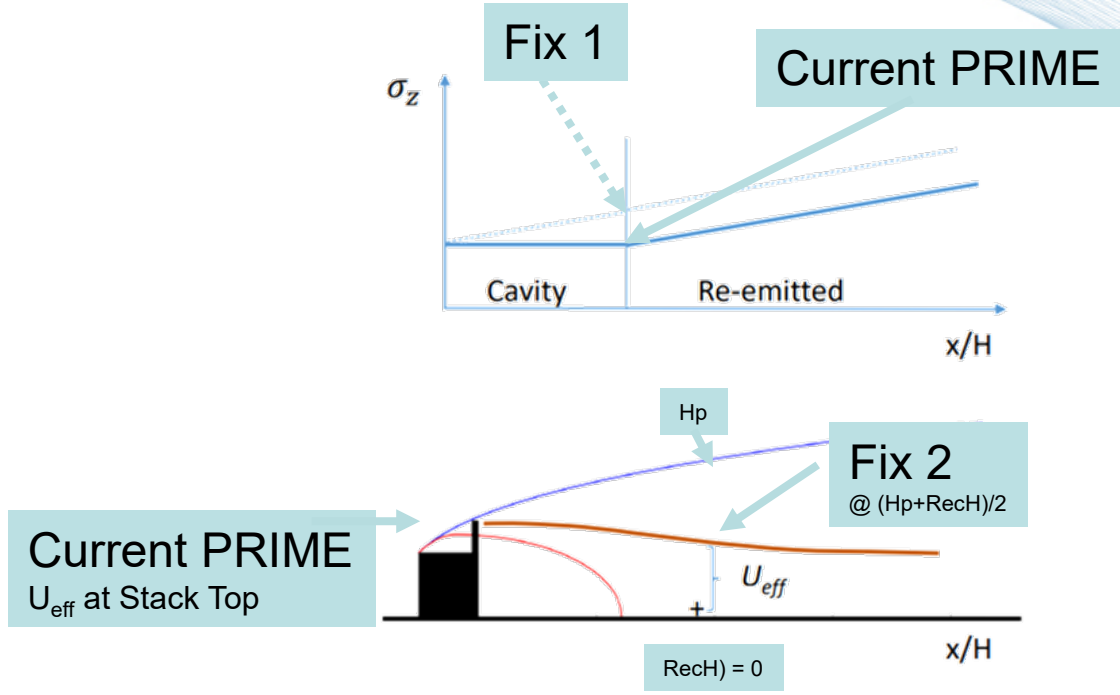
https://doi.org/10.1016/j.jweia.2017.11.027

PRIME2 Enhancements

- Building wake effects decay rapidly back to ambient levels above the top of the building.
- Lateral turbulence enhancement in the wake is less than vertical turbulence enhancement (currently PRIME has them identical).
- The approach turbulence and wind speed are calculated at a more appropriate height.
- Wake effects for streamlined structures are reduced.
- Wake effects decrease as approach roughness increases.

ORD Developments

1. Fix mismatch in plume vertical spread at transition between cavity and far wake.
2. Use effective wind speed, Ueff, for primary plume versus stack height for concentration calculations where Ueff is the wind speed at the average between plume height and receptor height.
3. Adjust the vertical turbulence intensity, wiz0 from 0.6 to 0.7.



PRIME2 Alpha Version

- 2/28/2018: Downwash Summit
  - Building downwash workshop at RTP to go over new PRIME2 model and ORD enhancements. Very beneficial!
  - EPA OAQPS confirmed that the PRIME2 updates can be included as an Alpha option in a future model release.
  - Review of PRIME2 from OAQPS could take between 3-4 months but will depend on workload.
  - EPA OAQPS preferred that each of the PRIME2 and ORD updates be implemented separately as “switches” that can be turned “on” and “off” for evaluation purposes.
  - Requirements from App W Section 3.2.2 would be needed before an Alpha version becomes Beta. Many of these requirements have already been met!

Next Steps: Implementation

Alpha option needs to meet the alternative refined model requirements in App W, Section 3.2.2 before it can become a Beta option. These requirements include:

1-Model has received a scientific peer review;

2-Model can be demonstrated to be applicable to the problem on a theoretical basis;

3-The data bases to perform analysis are available and adequate;

4-Appropriate performance evaluations show model is not biased toward underestimation;

5-A protocol on methods and procedures to be followed has been established

Timeline

- 5/3/2018: Meeting between Petersen Research and EPA to discuss making PRIME2 into Alpha version. Followed plan recommended by EPA
  - PRIME2 and ORD formulations should be included as separate options
  - Switches should be used to apply (turn on/turn off) different options
  - AERMOD must be able to run in the regulatory model as well as with the new options
- 10/3/2018: PRIME2 code with switches to turn on/off downwash options was submitted to EPA

Timeline

- 3/26/2019: PRIME2 committee and EPA met to discuss path forward to Alpha version of PRIME2
  - A bug was identified in previous PRIME2 submittal and EPA agreed to fix it before next release.
  - Future potential industry research discussed (PRIME plume rise, streamline, platform structures).
  - Future EPA ORD research discussed. Elongated buildings and updated BPIP.
- 8/21/2019: AERMOD 19191 released with PRIME2 and ORD Alpha options.

Conclusions

- From the start of research to getting PRIME2 code to EPA, it took about 13 months
- Getting to an implemented PRIME2 Alpha version took about 10 months once the code was provided to EPA
- Interaction with EPA along the was very good and useful, especially since this was the first time.

Recommendations / Questions

- If bugs are found with PRIME2, how can they be fixed quickly and changed in the current release?
- If major improvement in the PRIME2 or ORD options are found, how can they be added to the current AERMOD release quickly? Currently, we have to wait for the next AERMOD update
- Alpha options may be best dealt with outside of EPA's AERMOD releases

Charge Question 2

2. What should be EPA's highest development priorities regarding building downwash

Suggested Highest Priorities Related to Building Downwash

1. Building dimension inputs, BPIPPRM.
   a) The projected width problem with elongated buildings with wind at an angle is a critical issue that extends the downwash zone significantly. The draft BPIP released by EPA corrects this projected length issue and we support that this version be made default.
   b) Also, the formulation that summarized complex sites into a single building needs to be reviewed and updated.
2. Update the wake turbulence and wind speed calculations based on the PRIME2 research. Current PRIME assumptions are not valid.
3. Evaluate and update the streamlines equation in PRIME.
4. Evaluate and update the plume rise predictions in PRIME.

Suggested Highest Priorities Related to Building Downwash

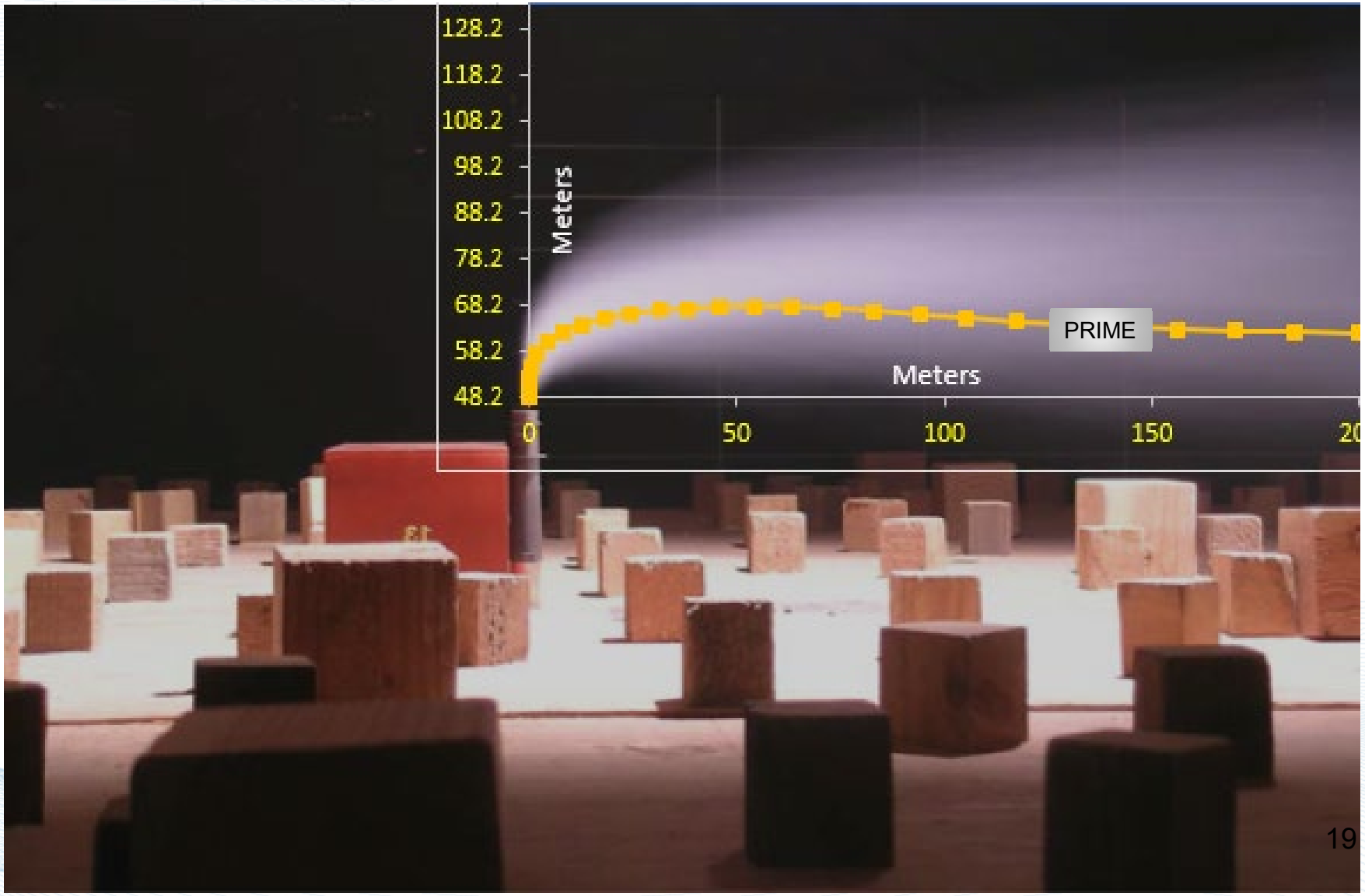
5. Corner vortex – AERMOD is currently underpredicting.
6. Upwind terrain wakes– AERMOD is currently underpredicting
7. Platform and porous structures
8. Rotated elongated building and lateral plume shift
9. Cavity plume issues. All plumes are moved closer to center of building.
10. The appropriate wind speed for computing concentrations

Areas of Needed Improvement for PRIME

High Priority for PRIME2

1. Plume rise evaluation and improvements.
   a) The plume rise model in PRIME has never been tested against wind tunnel or field observations in building wakes
   b) Petersen showed PRIME is underpredicting for one wind tunnel database.
   c) An example change showed significant improvement for Bowline Point.
   d) Not as critical for AERMOD/PRIME due to model formulation.
2. Update the PRIME plume rise code so that the computed plume rise is available in the PRIME wake subroutines at each receptor location.
   a) PRIME2 needs the computed plume rise at each receptor location to take full advantage of the new theory.
   b) Currently the minimum of the final Briggs momentum plume or PRIME plume rise at 1st receptor location is used.
3. The equation for the height of the wake versus downwind distance needs evaluation based on PRIME2 research results.

Hs = 48.2 m; Hb = 39 m; Hs/Hb = 1.24
PRIME Underestimates Plume Rise



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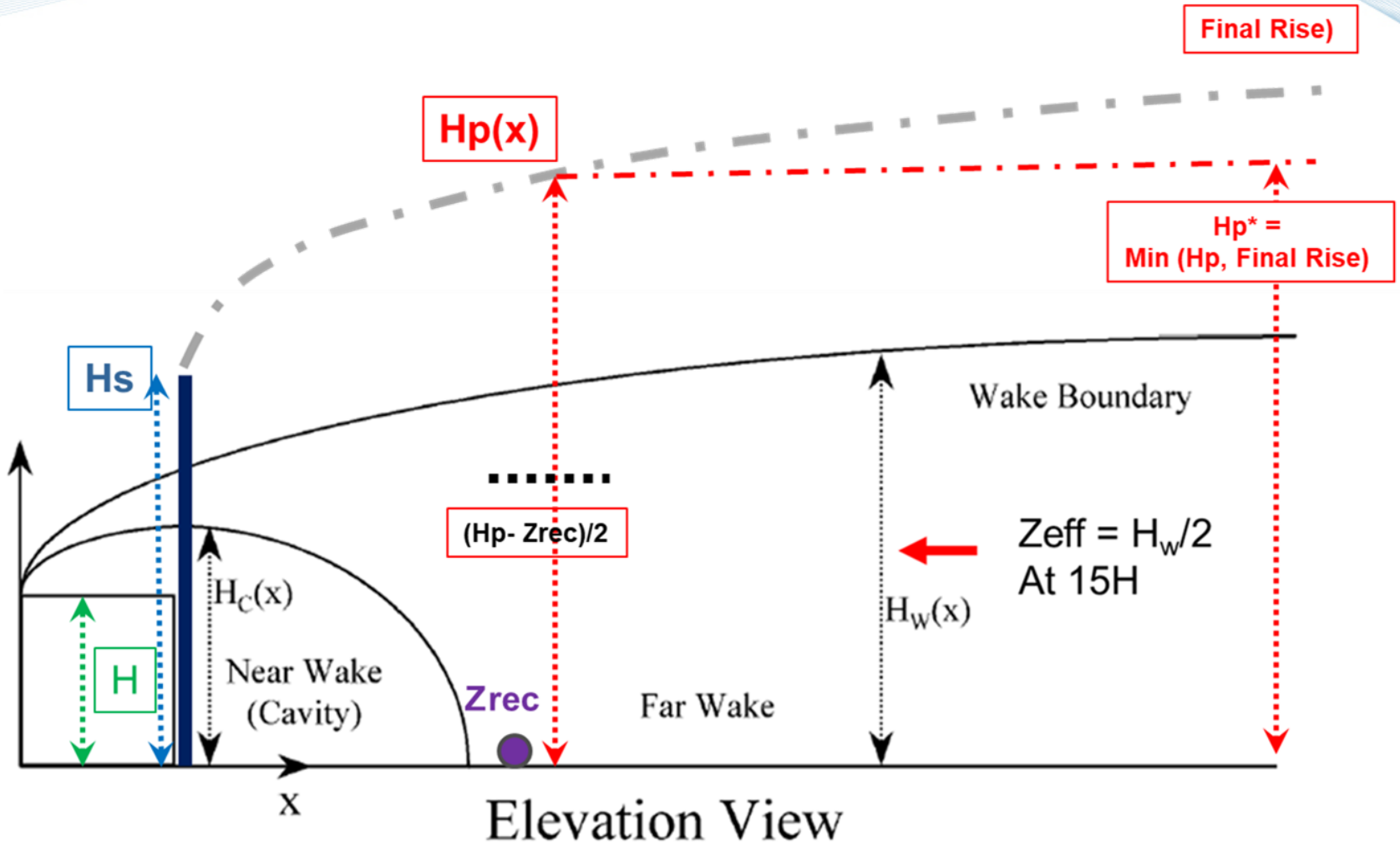
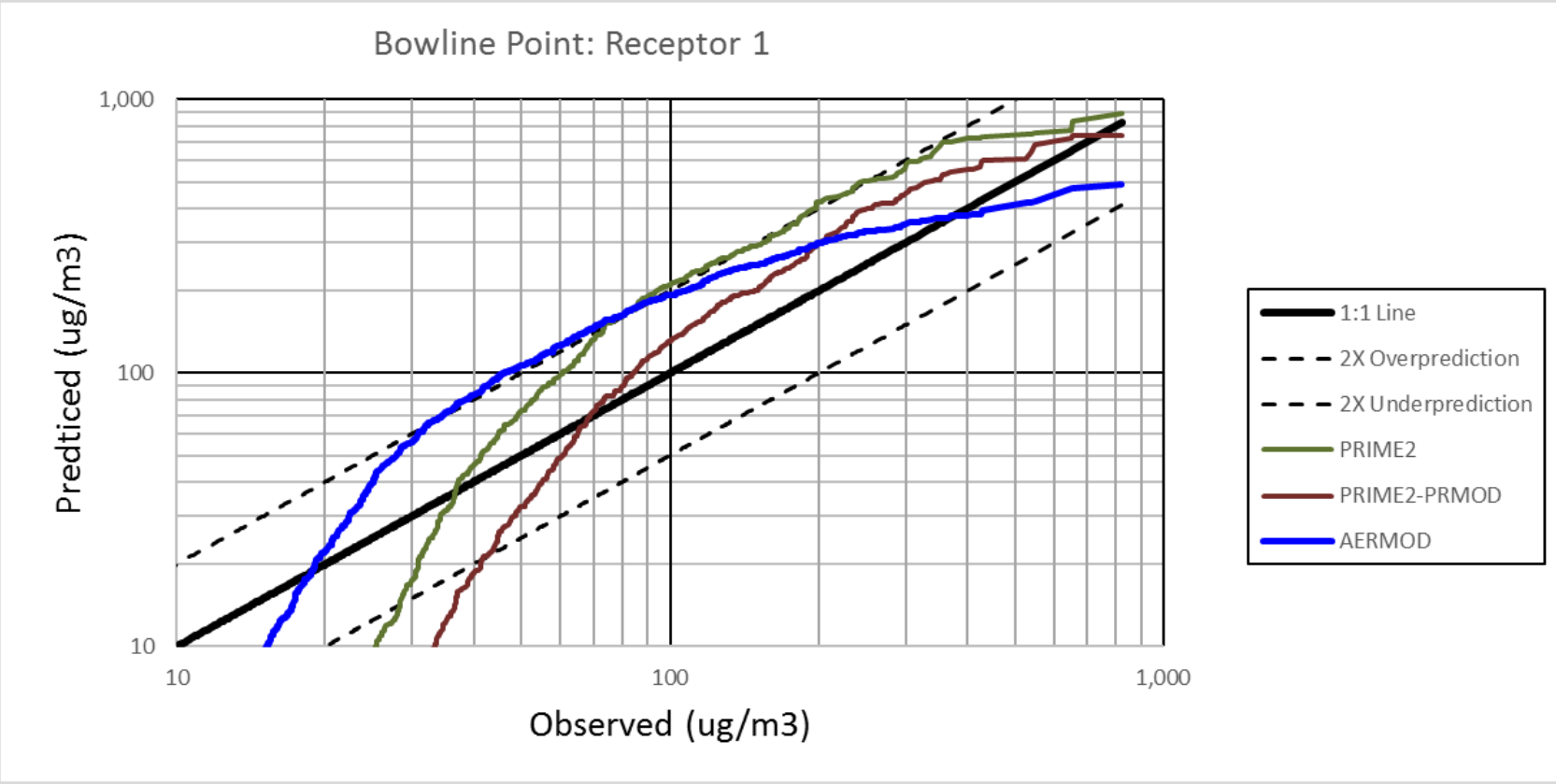
Wind Speed for Computing Concentrations

Different Heights Used in Each Model Version

Note: A lower height means a lower wind speed and higher concentration estimates

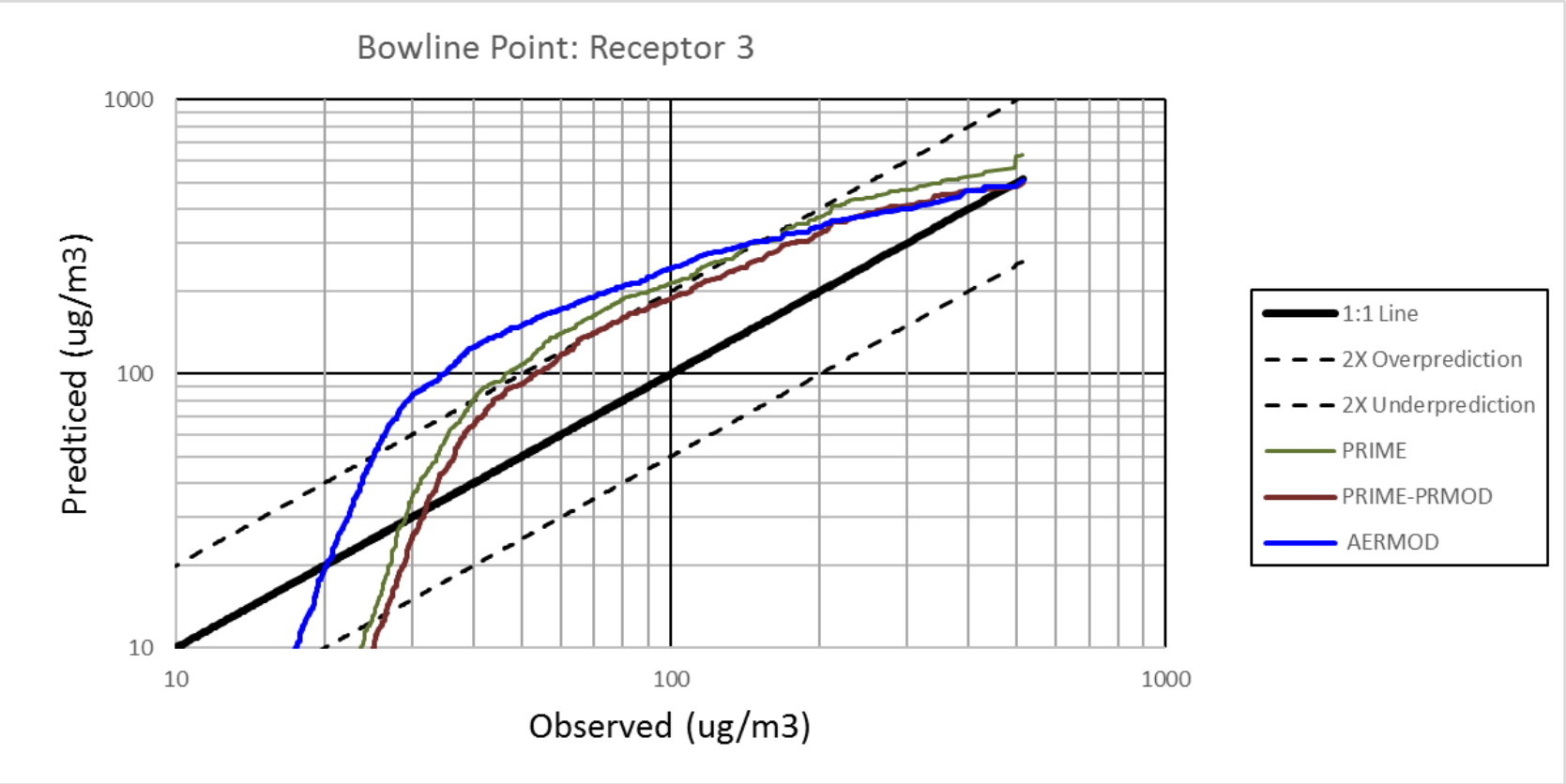


Bowline Point – Plume Rise Test



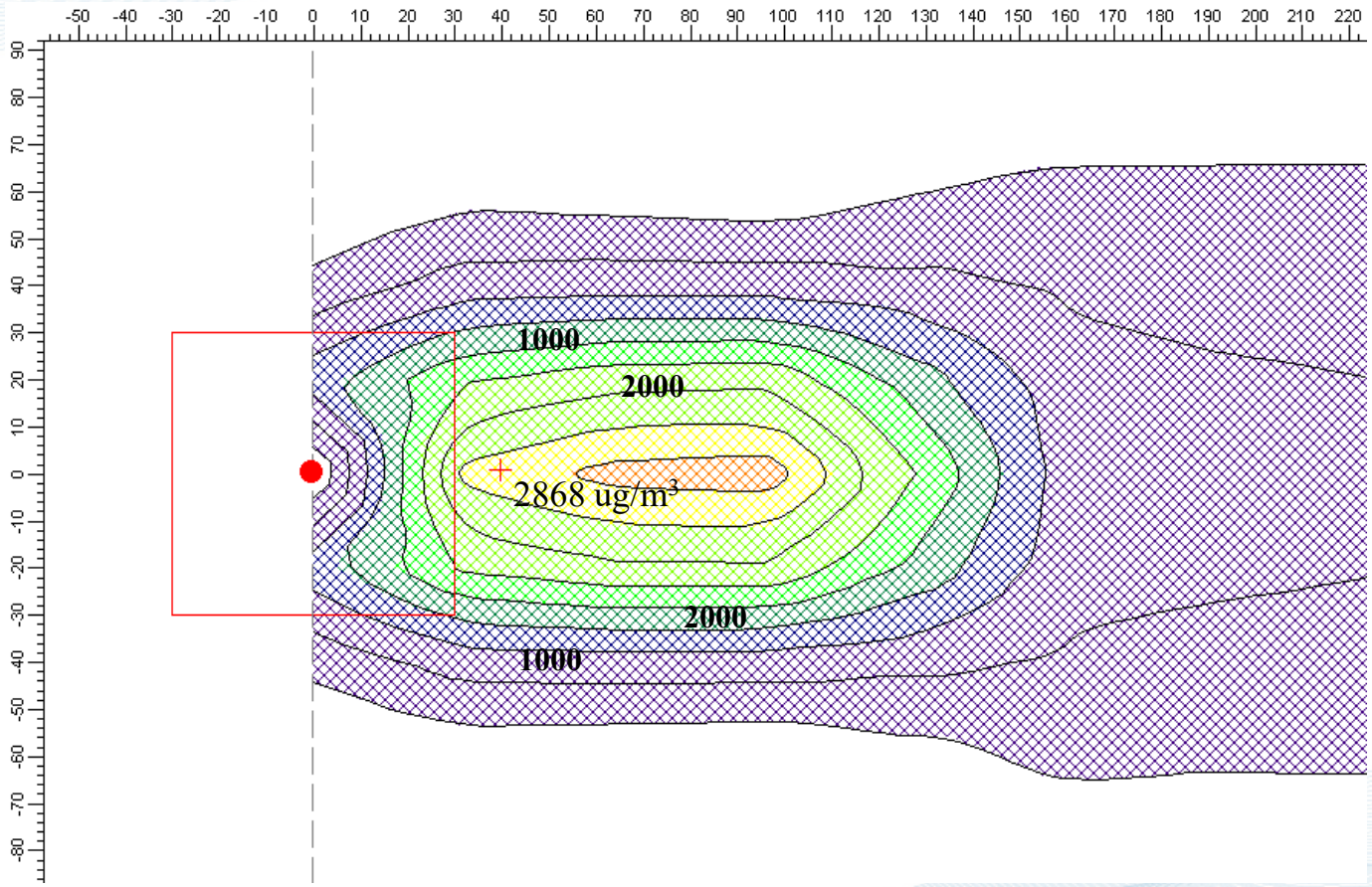
Model Scenario	RHC_{pre} (ug/m3)	RHC_{obs} (ug/m3)	RHC_{pre}/RHC_{obs}
PRIME2	1001.1	742.6	1.35
PRIME2-PRMOD	841.6	742.6	1.13
AERMOD	548.7	742.6	0.74

Bowline Point – Plume Rise Test

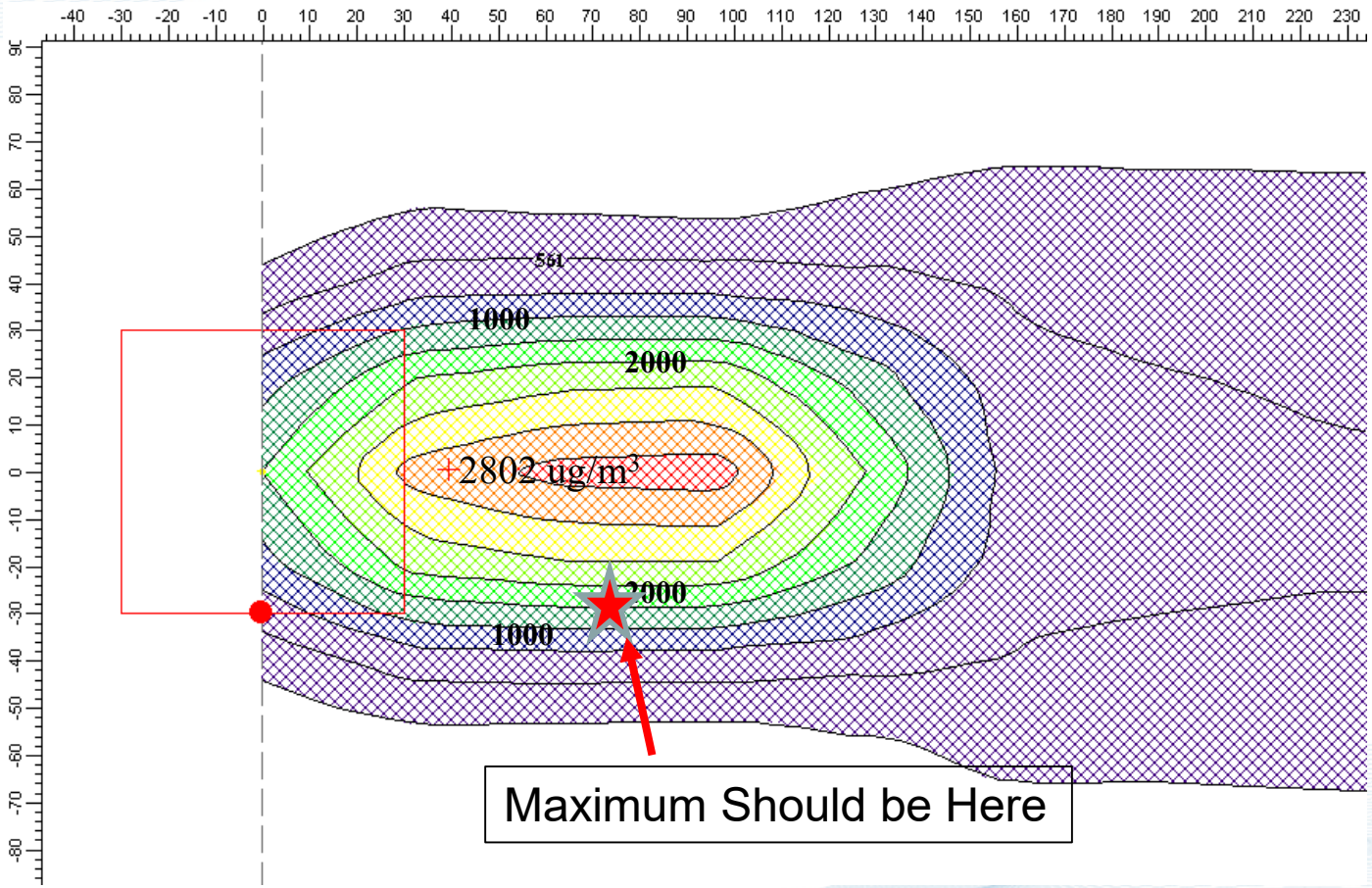


Model Scenario	RHC_{pre} (ug/m3)	RHC_{obs} (ug/m3)	RHC_{pre}/RHC_{obs}
PRIME	646.2	596.1	1.08
PRIME-PRMOD	543.2	596.1	0.91
AERMOD	547.7	596.1	0.92

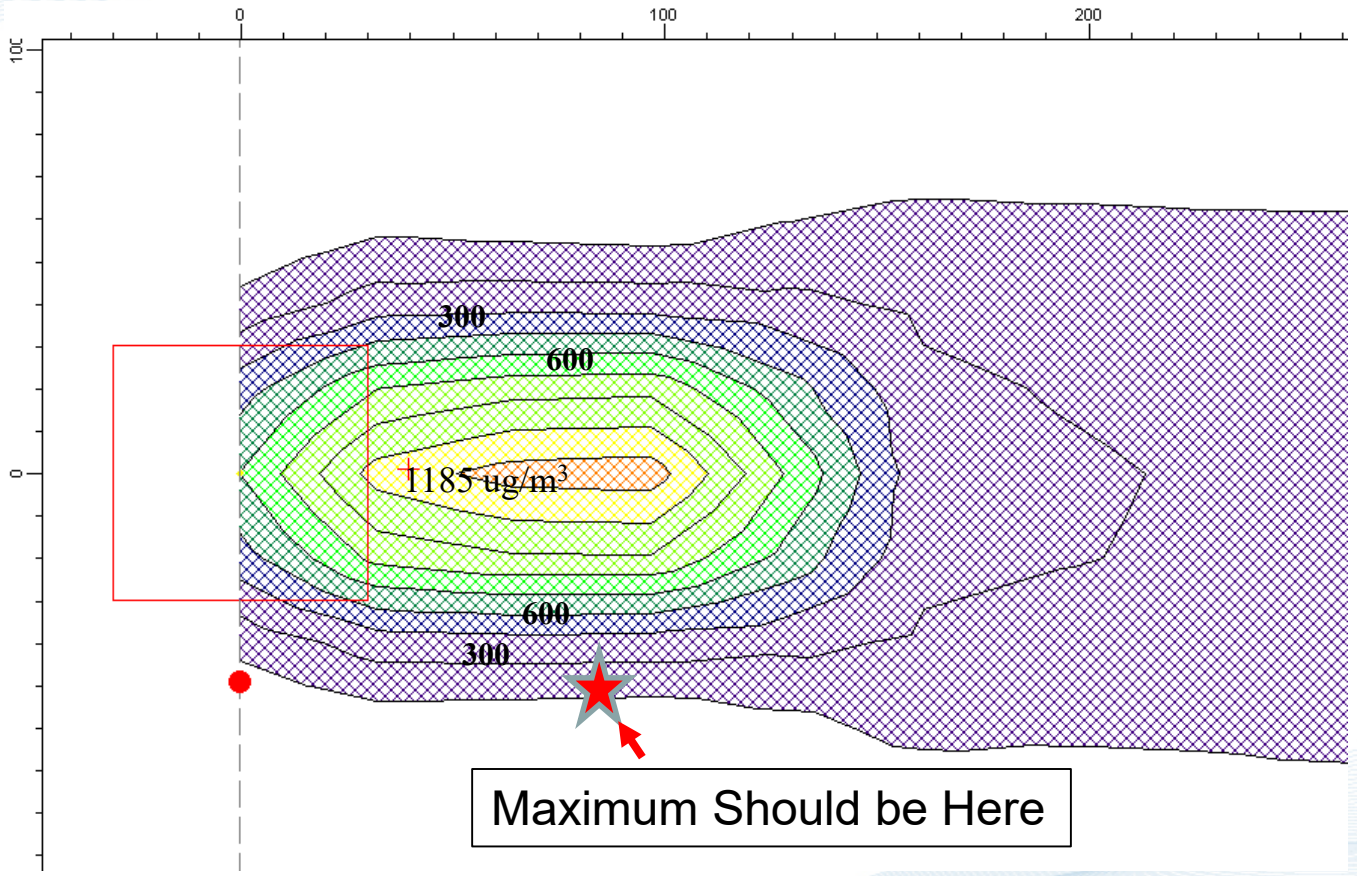
Stack at Building Center



Stack at Side Edge of Building



Stack 20m from Side Edge of Building



Charge Question 3

3. Should EPA focus its energy on continuing to improve and maintain the PRIME algorithm or replace PRIME altogether? Also provide any insights regarding the short-term and long-term path forward.

Continue with PRIME or Replace

- Continue but improve theoretical issues on a faster time schedule.
- Some of the theoretical issues are addressed by the PRIME2 theory. A major overhaul would need a significant effort and expense.
- Continuous improvements should be pursued based on the priority list in Question 2.

Current PRIME Theory

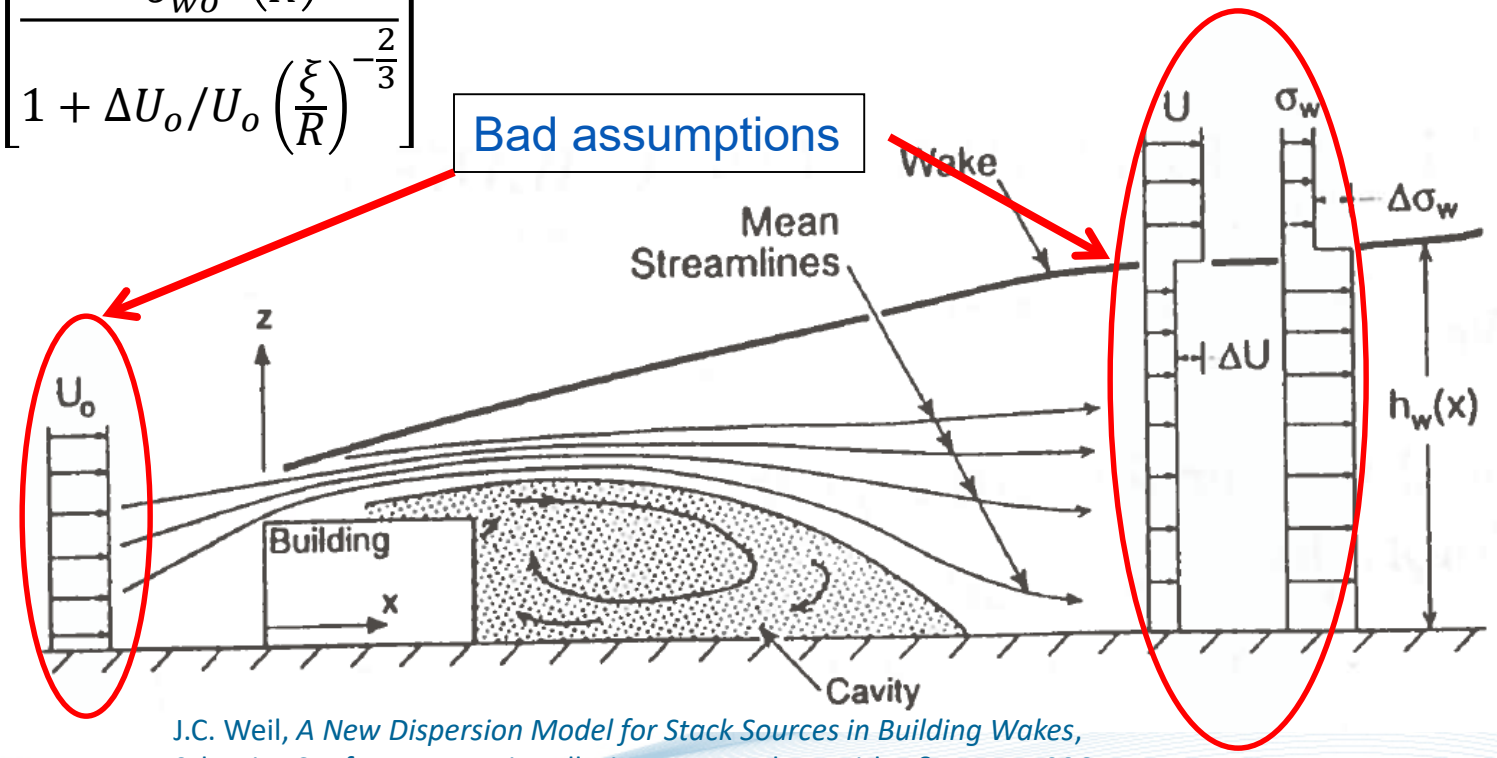
- Constant downwash enhancement up to wake height

Starting Relation

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

Wake Turbulent	=	Approach Turbulence	*	Function (ξ, Stability)

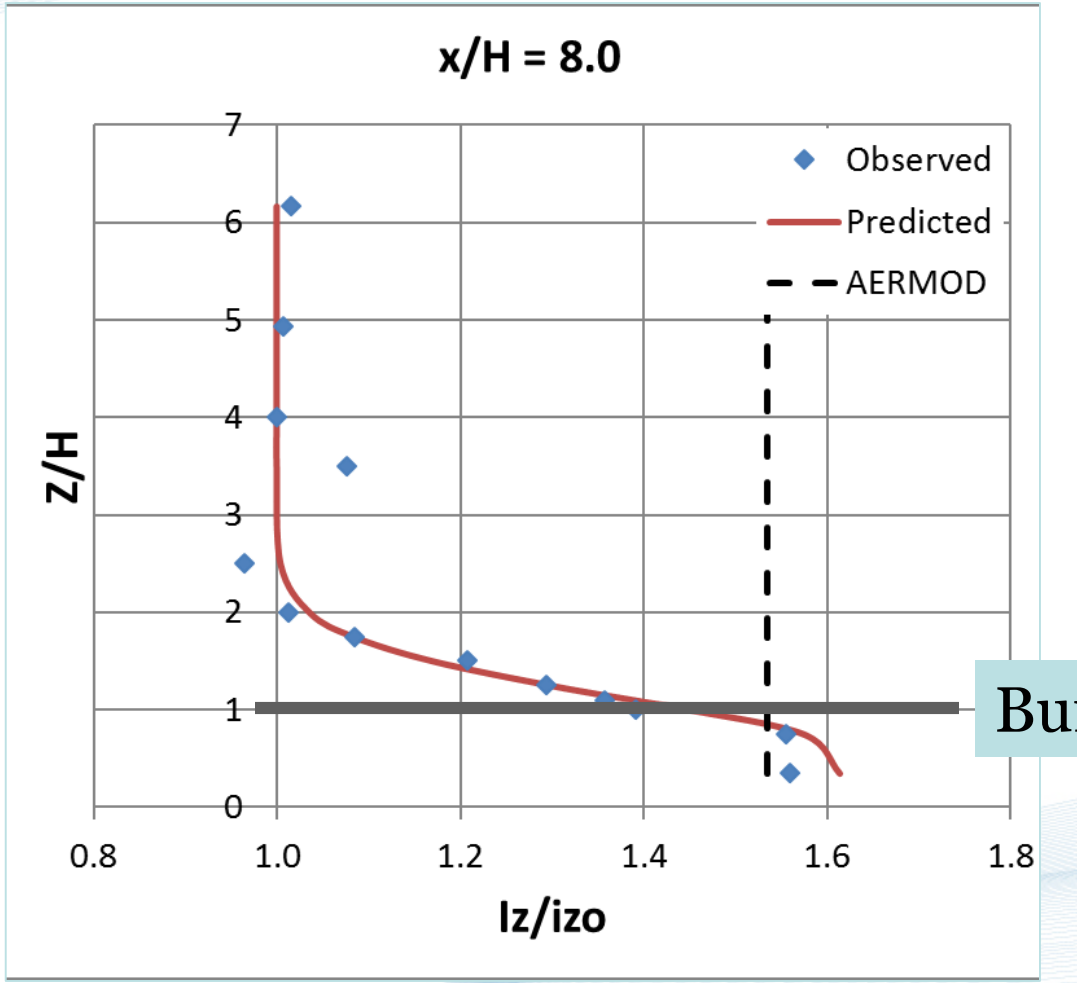
Bad assumptions



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

PRIME2 Wake Turbulence Validated Theory – Needs to be in PRIME

H = 40 m
H:W:L = 1:4:4



Building Top

How Can Research be Expedited?

- EPA Funded Research – Need to continue open communication between EPA and other research groups.
- Industry Funded Research – To address areas of industry interest not being pursued by EPA.
- A non-profit organization with crowd/donor funding.
  - Research will be continuous as long as the funding holds.
  - New model improvements not being pursued by industry/EPA can be made available to the modeling community quicker via the cloud for testing and evaluation.
  - The new research will not have any confidentiality limitations that would preclude its sharing and evaluation from interested parties.
  - This could expedite getting new research into future AERMOD releases.
  - Have ~$15K initially committed.
- Regular communication and information sharing between different research groups

Thank you!

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