Developments in modelling building wake effects on dispersion in ADMS

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19th April 2016

London

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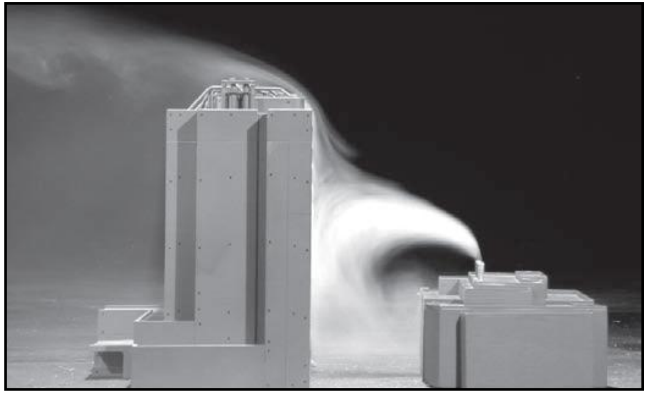
Real world building effects

Photograph by Martin Tasker



Photographs from the US EPA / US Dept of Energy document on 'On Modeling Exhaust Dispersion for Specifying Acceptable Exhaust/Intake Designs

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Buildings influenced flow & dispersion

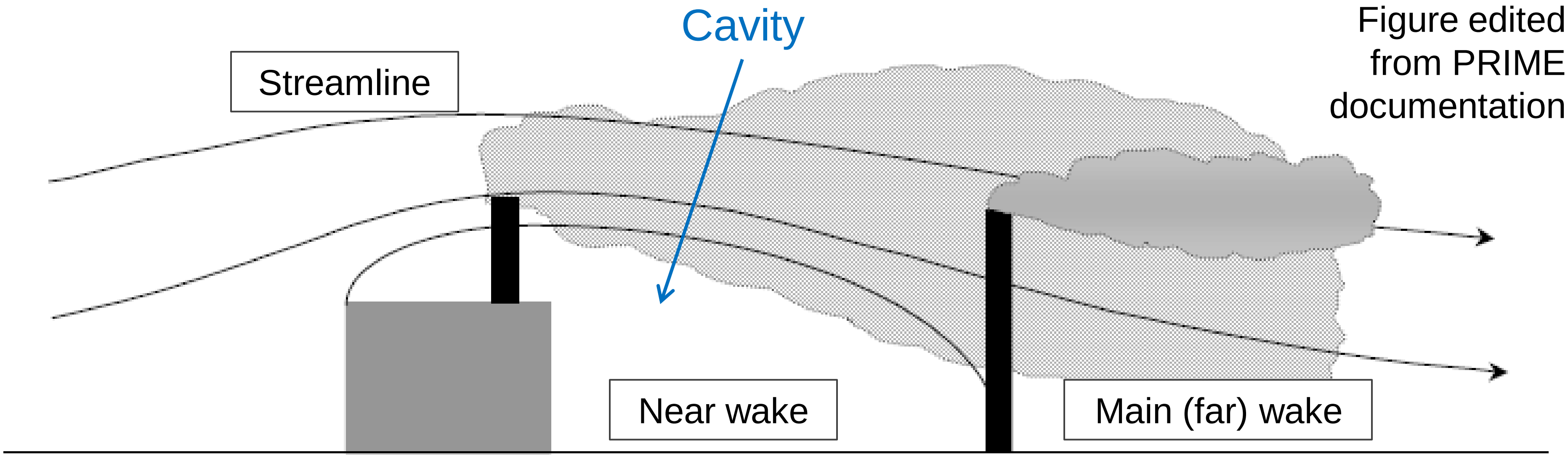
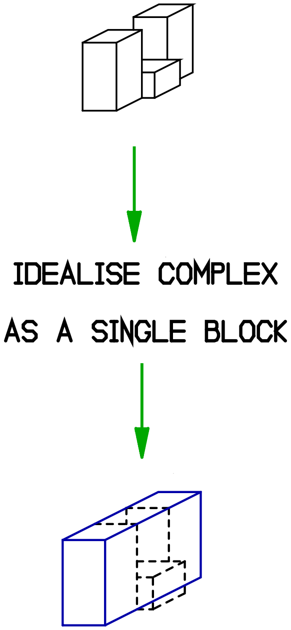


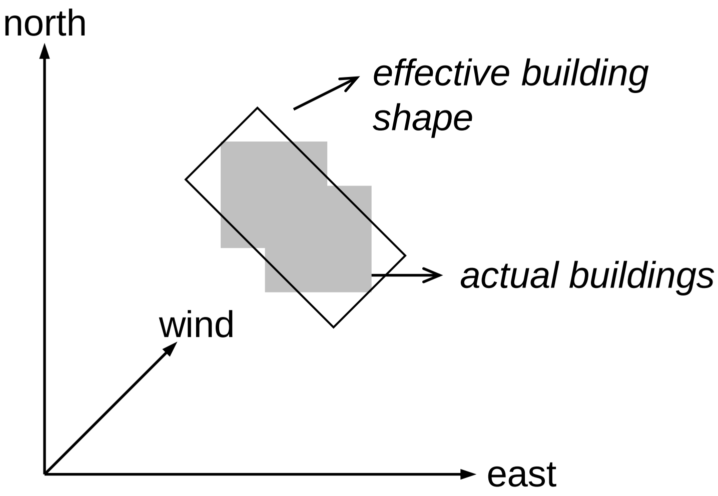
Figure edited from PRIME documentation

- ADMS & AERMOD include:
  - Near wake (cavity)
  - Main wake (descending streamlines)
  - Two plume approach

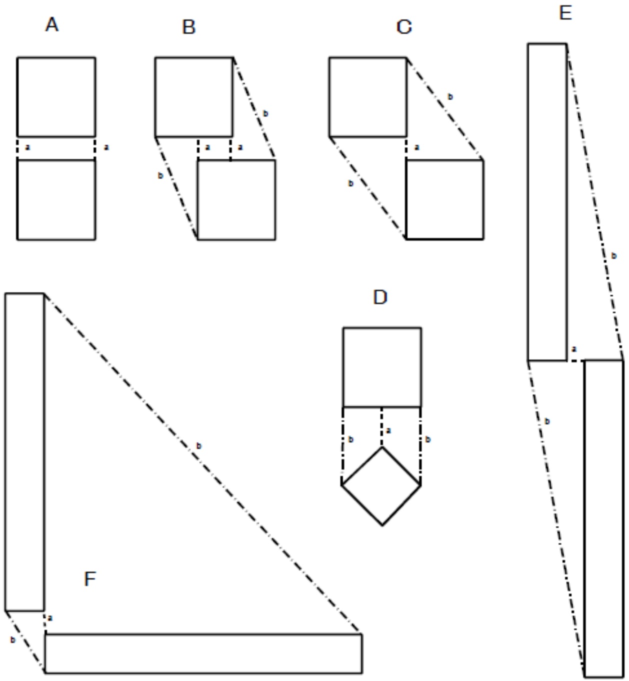
Using ADMS and AERMOD to model building effects

ADMS





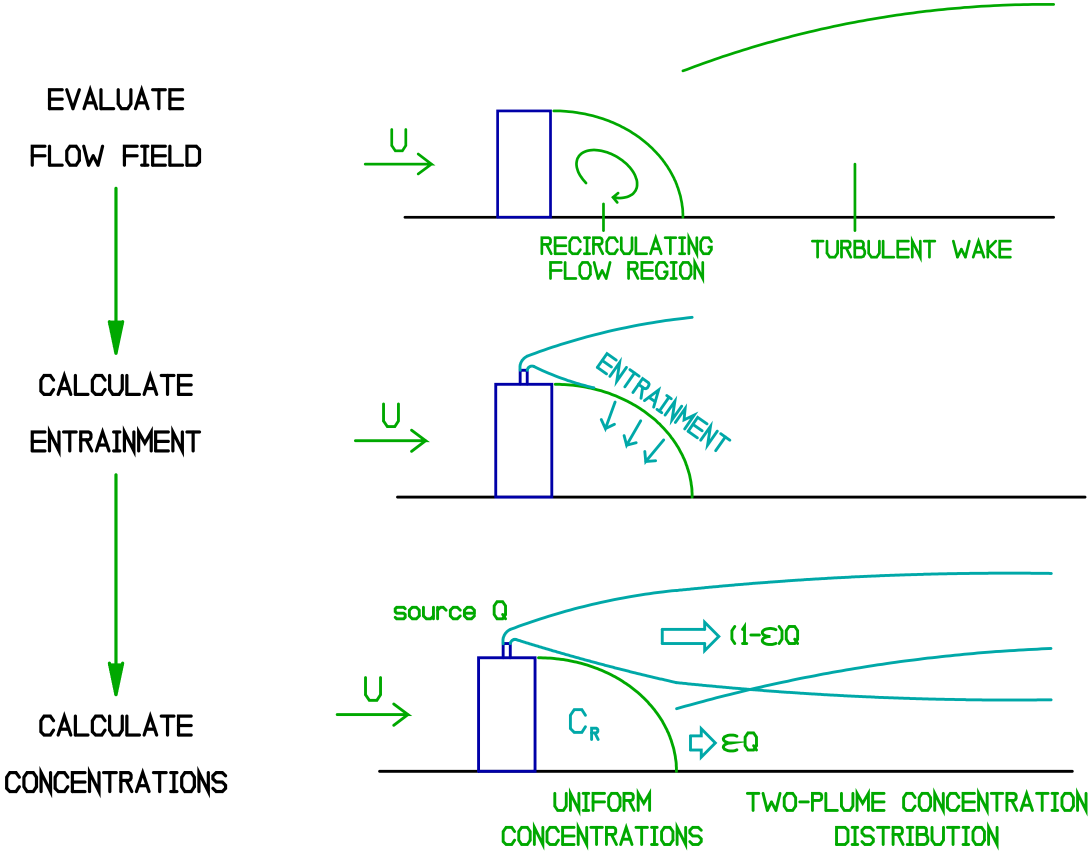
AERMOD (PRIME)



BPIP combines buildings using the 'a' lines and only those 'b' lines that are less than L. All 'a' lines are assumed to be less than L. The outside portion of the lines used form the perimeter of the Gap-Filling Structure (GFS).

L=min (building height, projected building width)

Using ADMS and AERMOD to model building effects



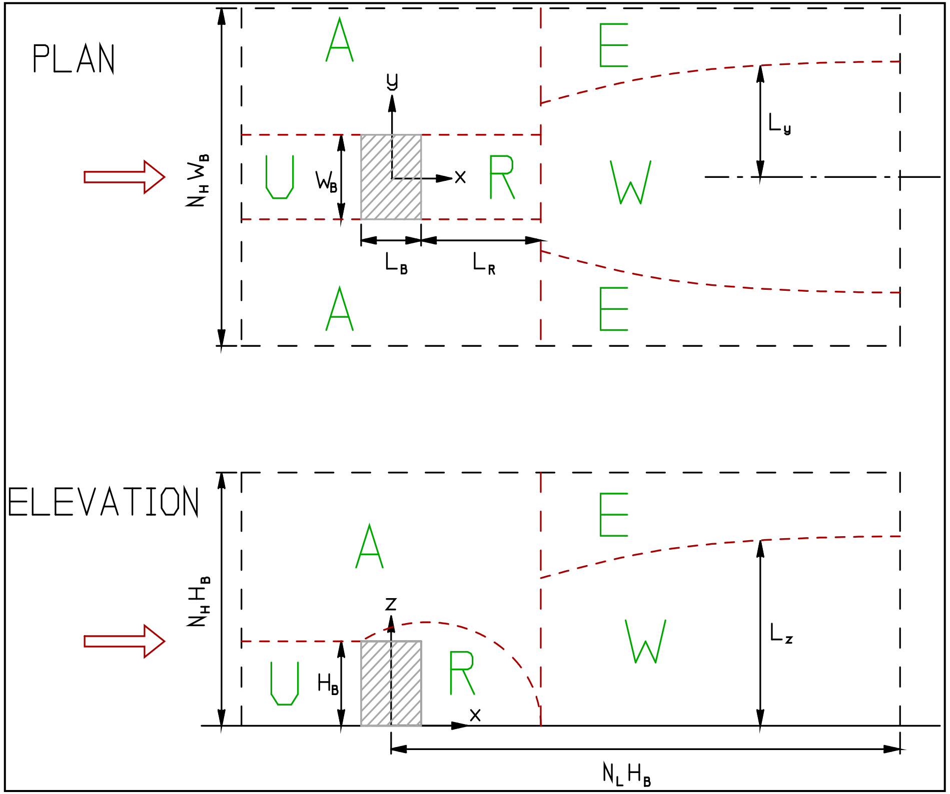
Using ADMS and AERMOD to model building effects

Item	Comparison	Details
Mean flow in main wake	Different	ADMS uses wake deficit model; AERMOD uses a fractional deficit of 0.7 modified by the location within the wake
Turbulence	Different	ADMS assumes velocity variances increase in proportion to the wake-averaged surface shear stress; AERMOD derives the turbulent velocity from empirical expressions and ambient values.
Effective building	Different	ADMS applies an algorithm that assesses each building in the vicinity of the 'main' building in terms of its relative height and crosswind separation; AERMOD combines buildings if they are separated by less than a characteristic dimension of each building (larger of height and projected width).
Cavity length and height	*Similar*	*n/a*
Wake height/width	Different	AERMOD depends solely on effective building properties; the ADMS formulation also includes a dependence on u_*/U_H.
Streamline defl^n	Different	Similar concepts but different expressions used.
Plume spread	Different	ADMS: calculates wake-affected spread parameters from non-building parameters accounting for differences in flow & turbulence; AERMOD models a p.d.f. growth (near wake) transitioning to eddy diffusivity growth (far wake).
Cavity concentration	Different	Both models determine a fraction entrained into the cavity, but the expressions used for the amount entrained and for the resulting cavity concentrations differ.
Wake concentration	Different	Both models have sum a non-entrained part of the original plume and a ground based plume from the cavity region; the formulations of those expressions differ.

Building module formulation

ADMS wake modelling

- Divided into regions:
  - R – recirculating flow (near wake)
  - W – wake
  - U – directly upwind
  - A – remainder of perturbed flow around building
  - E – region external to the wake
- W and E form the main wake



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Building module formulation

ADMS wake modelling – near wake

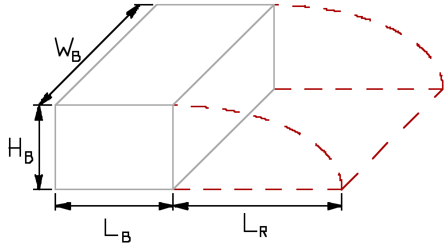
$$L_R = \frac{AW_B}{1 + BW_B/H_B}$$

$$A = 1.8\left(\frac{L_B}{H_B}\right)^{-0.3}, B = 0.24$$

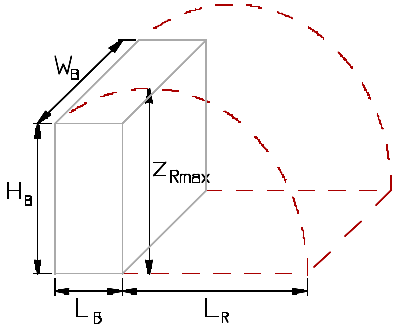
$L_B \geq \min(H_B, 0.5W_B)$ - roof flow reattaches

$L_B < \min(H_B, 0.5W_B)$ - roof flow separates

Roof flow reattached



Roof flow separated



ADMS wake modelling – main wake

- Flow field:

$$u = U_H\left\{1 - \hat{u}\left[\frac{W_B}{2\lambda_y}\right]\left[\frac{H_B}{\lambda_z}\right]^2 g(\xi)h(\eta)\right\}$$

- similarly for v and w

$$\eta = \frac{y}{\lambda_y} \quad \xi = \frac{z}{\lambda_z}$$

$$\lambda_y(x) = \left\{\frac{D_y(x - x_0)}{U_H}\right\}^{1/2} \quad \lambda_z(x) = \left\{\frac{D_z(x - x_0)}{U_H}\right\}^{1/2}$$

- Wake averaging:

$$\frac{\Delta u}{U_H} = \frac{1}{2}\hat{u}\left(\frac{W_B}{2L_y}\right)\left(\frac{H_B}{L_z}\right)\left(\frac{H_B}{\lambda_z}\right) \qquad \Delta\tau = U_H \Delta u\left\{\frac{L_z}{(x - x_0)}\right\} \qquad \Delta\sigma_v{}^2/\sigma_v{}^2 = \Delta\sigma_w{}^2/\sigma_w{}^2 = \Delta\tau/u_*^2$$

- Wake spread parameters:

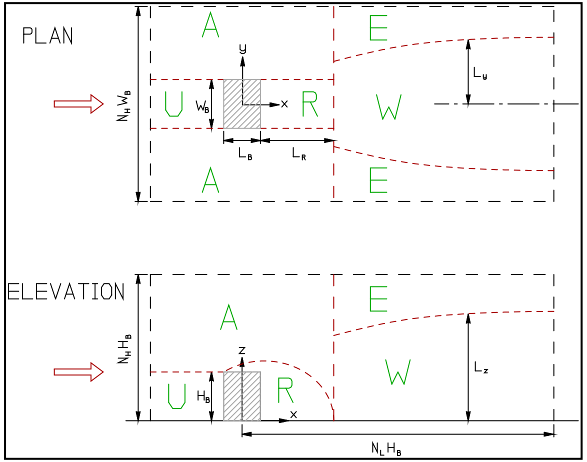
$$\frac{d\sigma_{YW}}{dx} = \left(\frac{\sigma_{YW}}{2}\right)\frac{d(\Delta u/U_H)}{dx} + \left[\left\{\left(1 + \frac{\Delta\sigma_V^2}{\sigma_V^2}\right)^{1/2}\right\}/\left(1 - \frac{\Delta u}{U_H}\right)\right]\frac{d\sigma_{YE}}{dx}$$

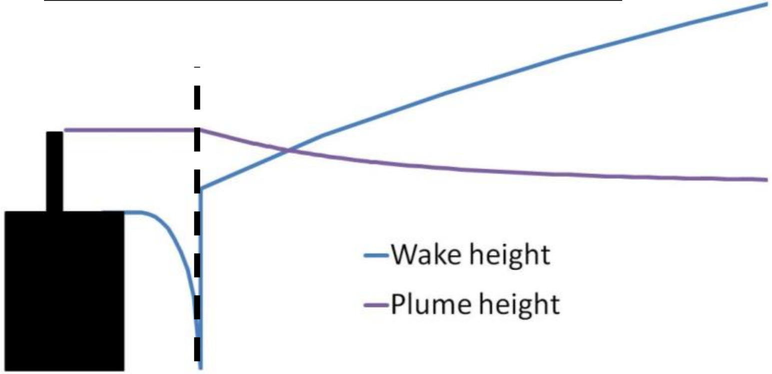
- similarly for w

Building module formulation

ADMS model developments

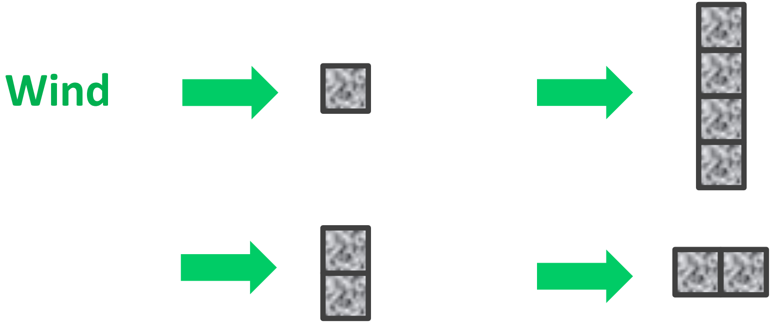
- Improvements to the transition between building effects regions:
  - smooth the concentration in the transition from the near wake to the main wake
  - Ensure plume spread continuity for a rising/falling plume crossing between the **W**ake and **E**xternal regions
- Adjustments for wide buildings when the flow may be close to 2-dimensional



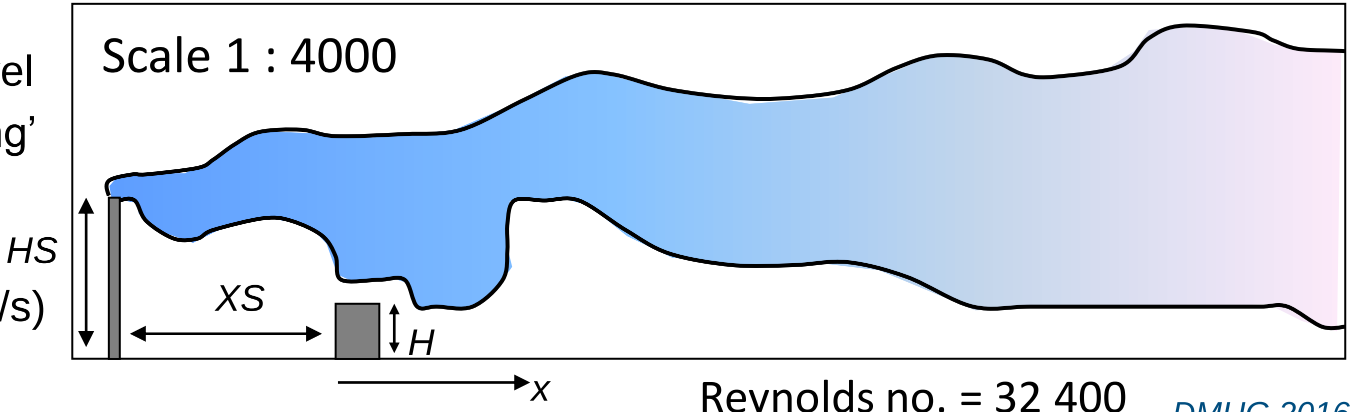


ADMS model validation
Thompson

- Wind tunnel study
- Varying stack heights & locations
- 4 different buildings:
  - a cube
  - a *wide* building (2 cubes aligned crosswind)
  - a *wider* building (4 cubes aligned crosswind,
  - a *long* building (2 cubes aligned along wind)
- Sources and receptors aligned with the building centreline
- Receptors at ground level
- 'Building' and 'no building' scenarios
- Neutral meteorology (free stream wind ~ 4 m/s)



Thompson R.S., 1993: *Building Amplification Factors for Sources Near Buildings: a Wind Tunnel Study.* Atmos. Environ. 27A, 2313-2325.



Reynolds no. = 32 400

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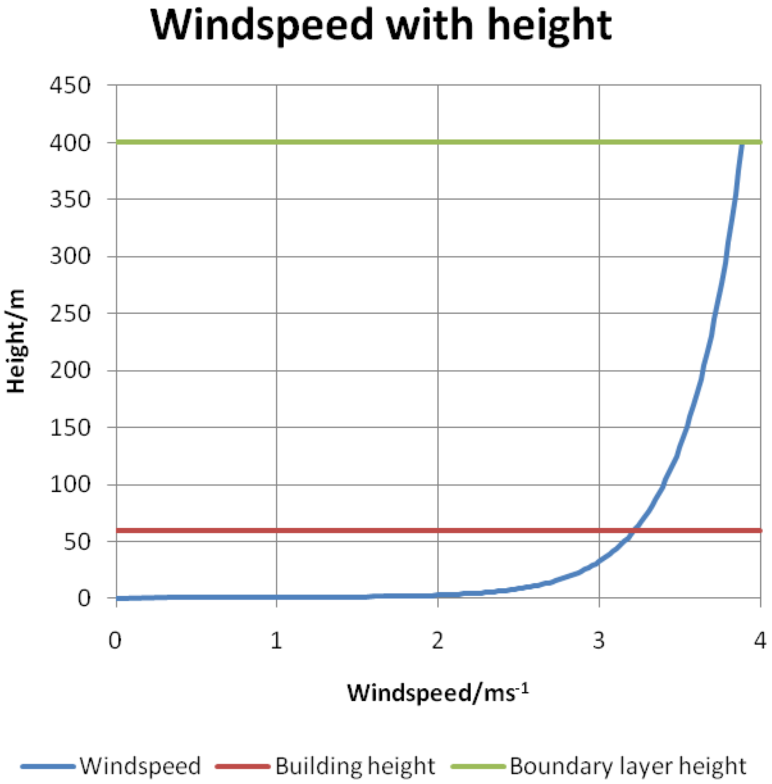
ADMS model validation
Thompson – Wind Profile

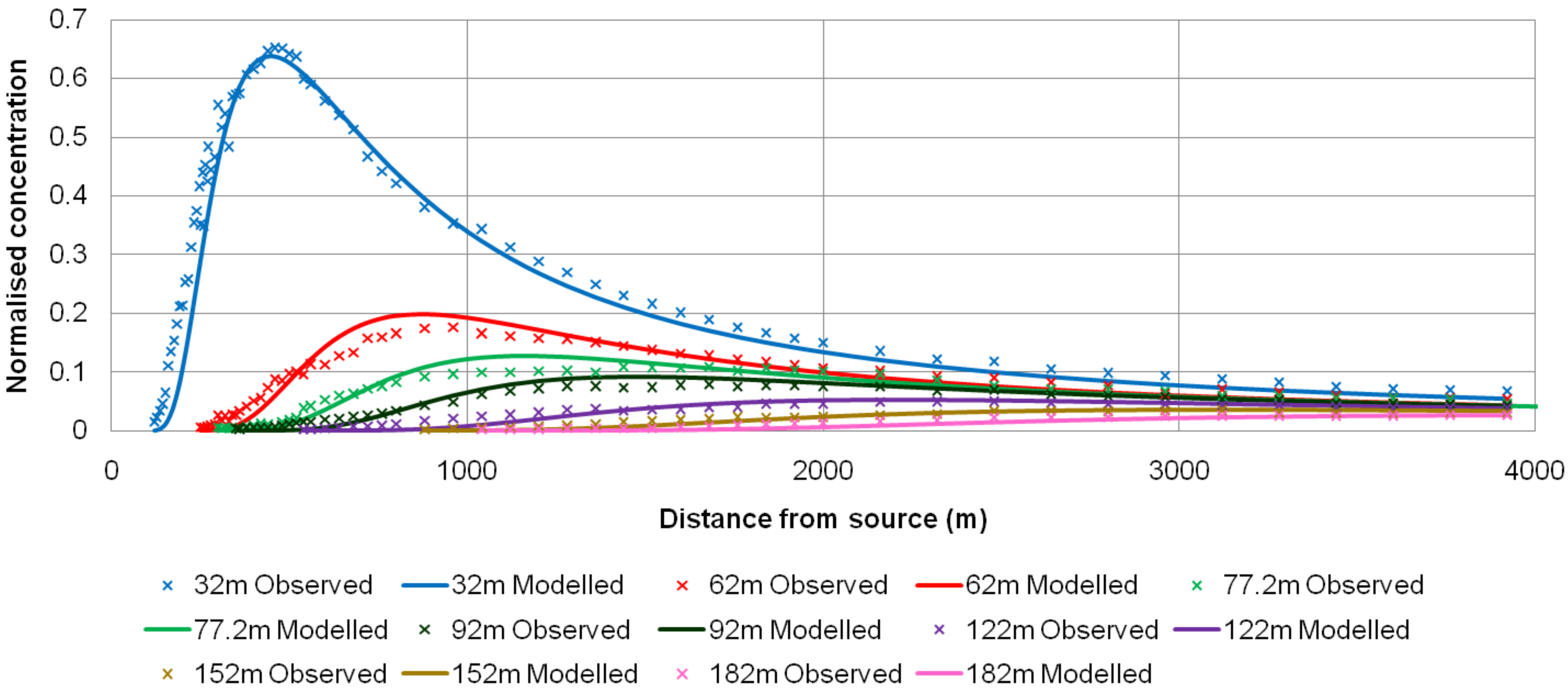


- 2 minute average for the results in Thompson study; concentrations reproducible within 5%.

- ADMS uses measured vertical profiles of wind speed and turbulence
  - Wind speed: $u(z) = 2.2(\frac{z}{10})^{0.136}$
  - Measured turbulence profiles show some decay along wind tunnel

ADMS model validation

Thompson – Observed and modelled data – No building



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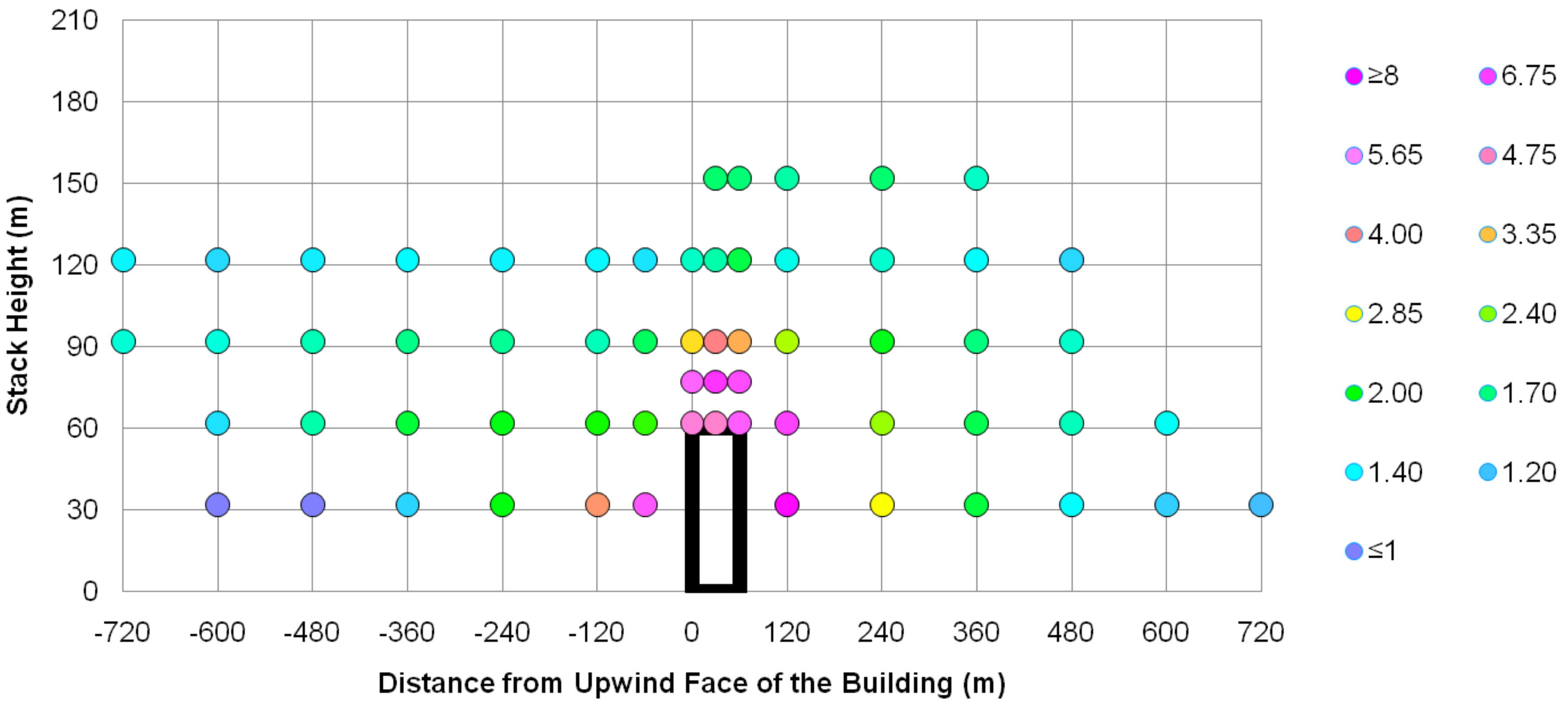
ADMS model validation

Thompson Cubic building. Observed - Max building/Max no building



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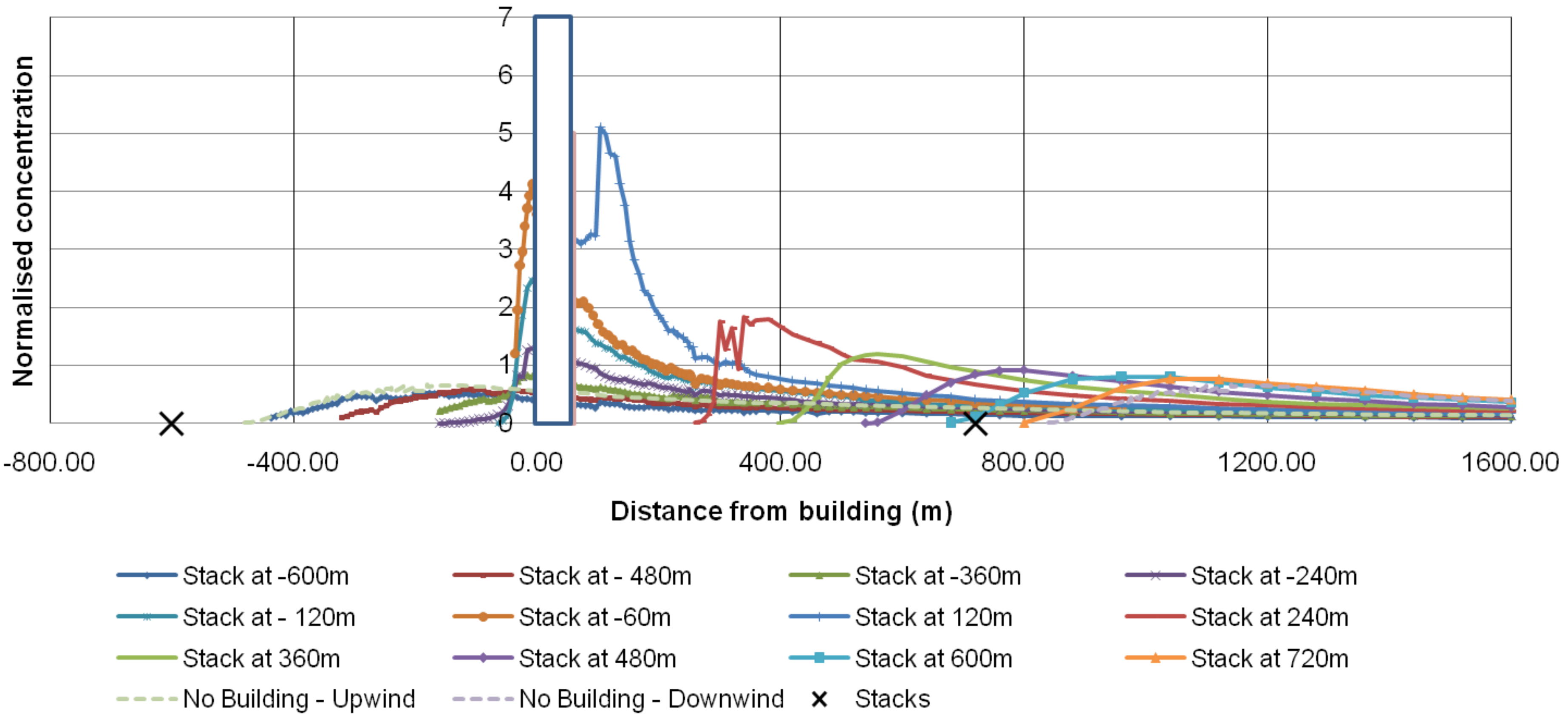
ADMS model validation

Thompson – Observed Data. 32m stack, cubic building



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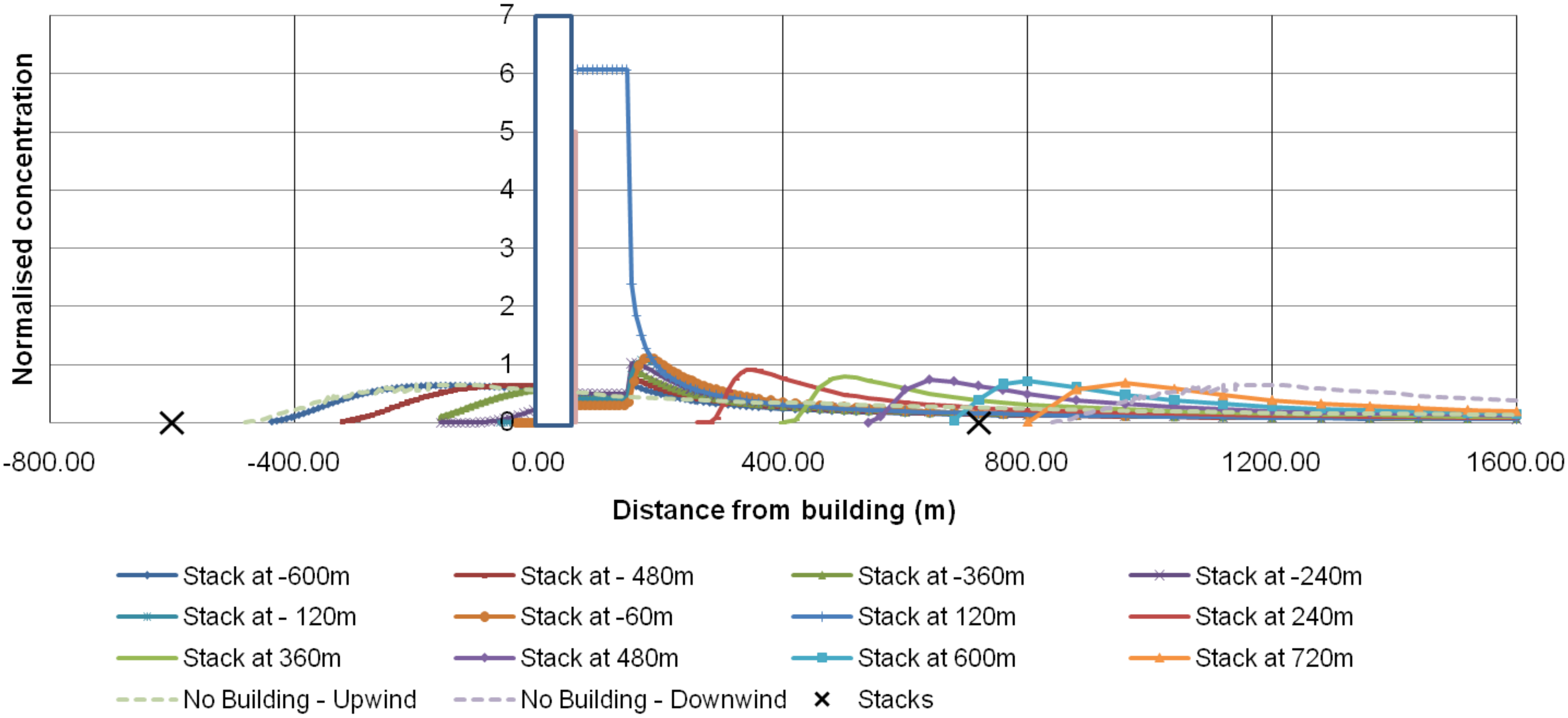
ADMS model validation

Thompson – Modelled Data. 32m stack, cubic building



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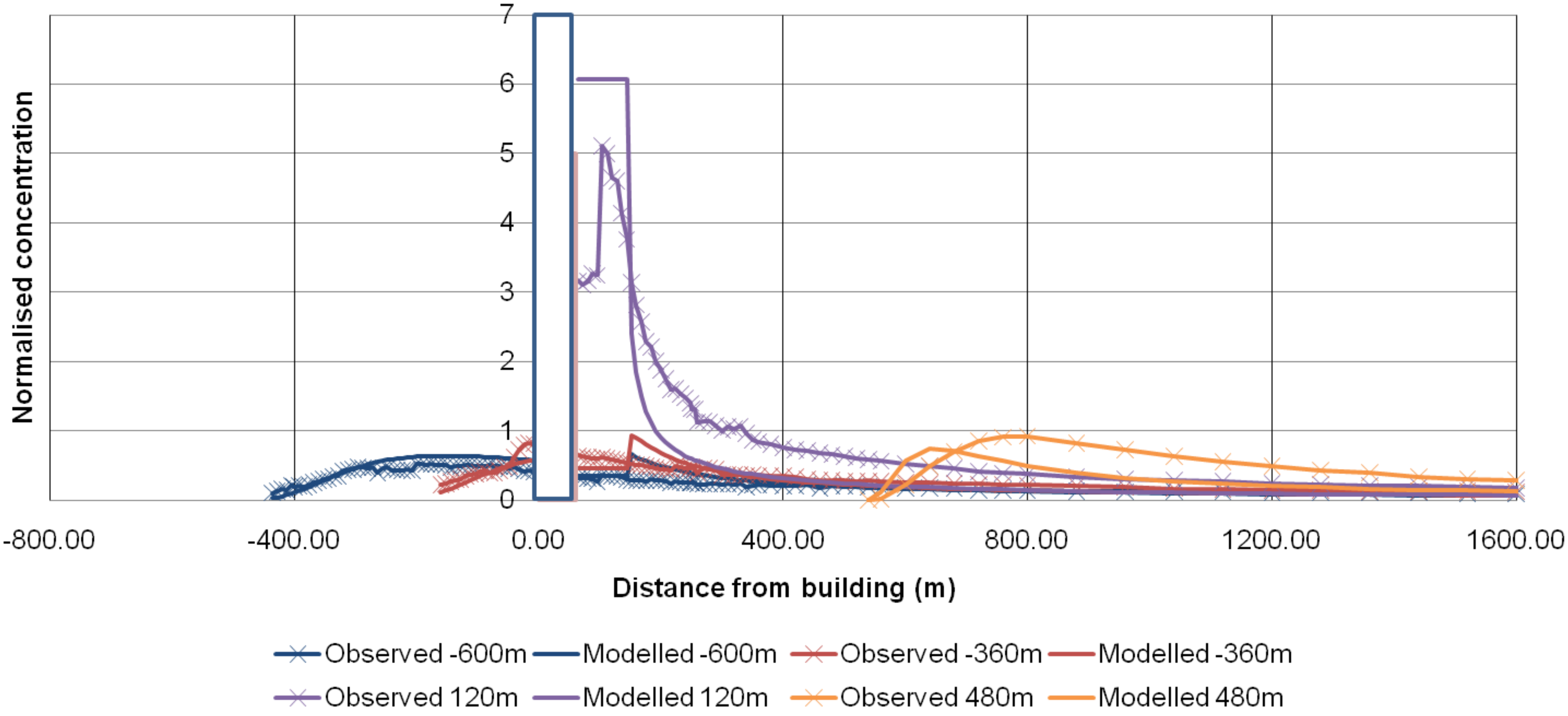
ADMS model validation

Thompson – Comparison. 32m stack, cubic building



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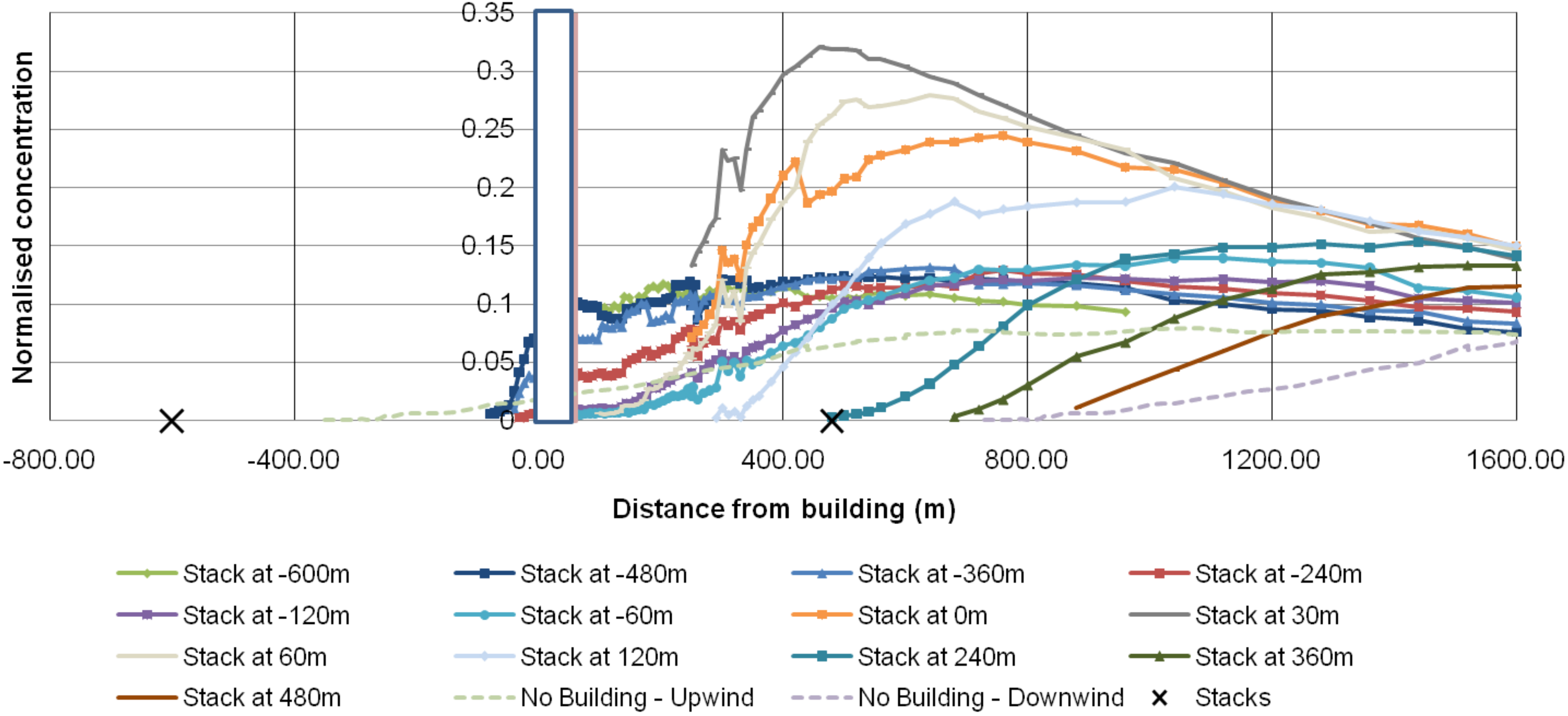
ADMS model validation

Thompson – Observed Data. 92m stack, cubic building



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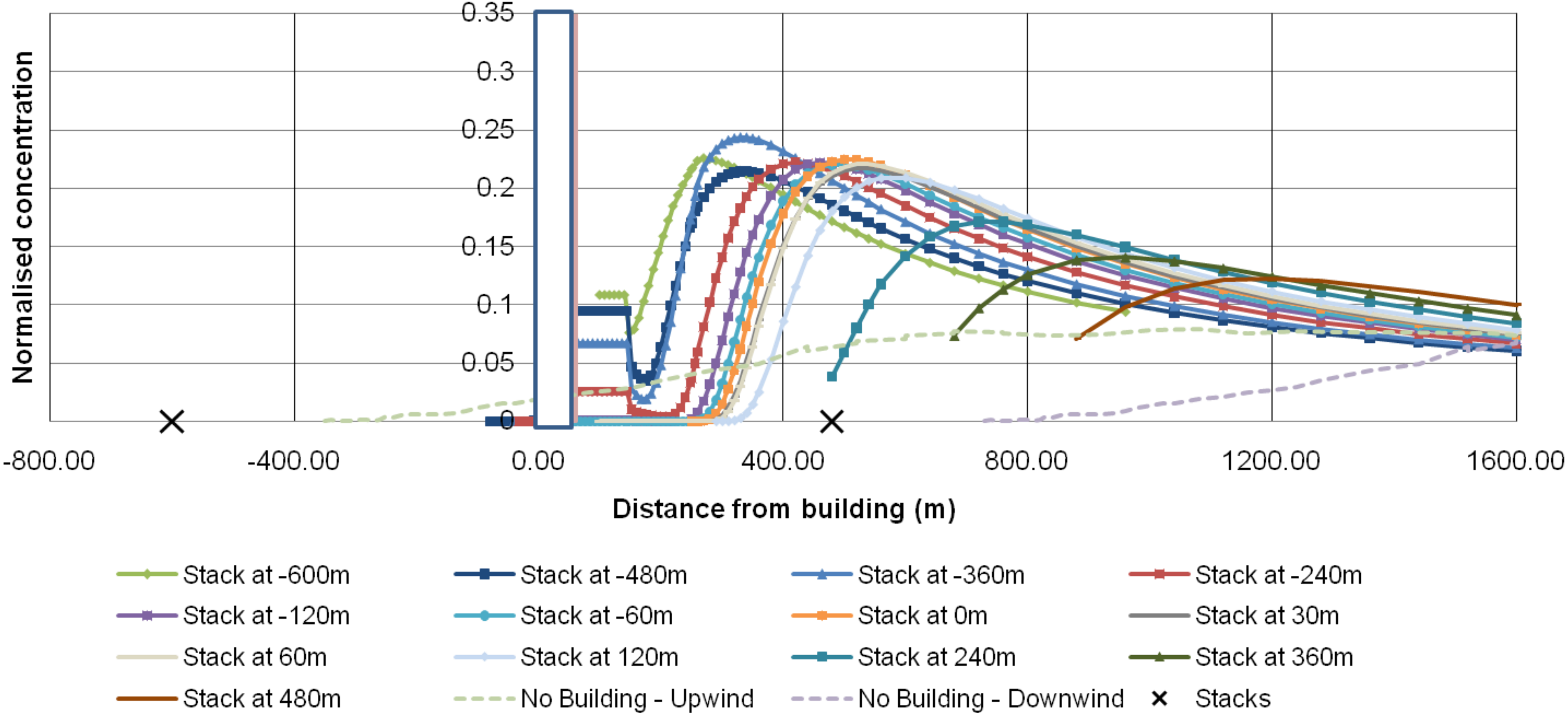
ADMS model validation

Thompson – Modelled Data. 92m stack, cubic building



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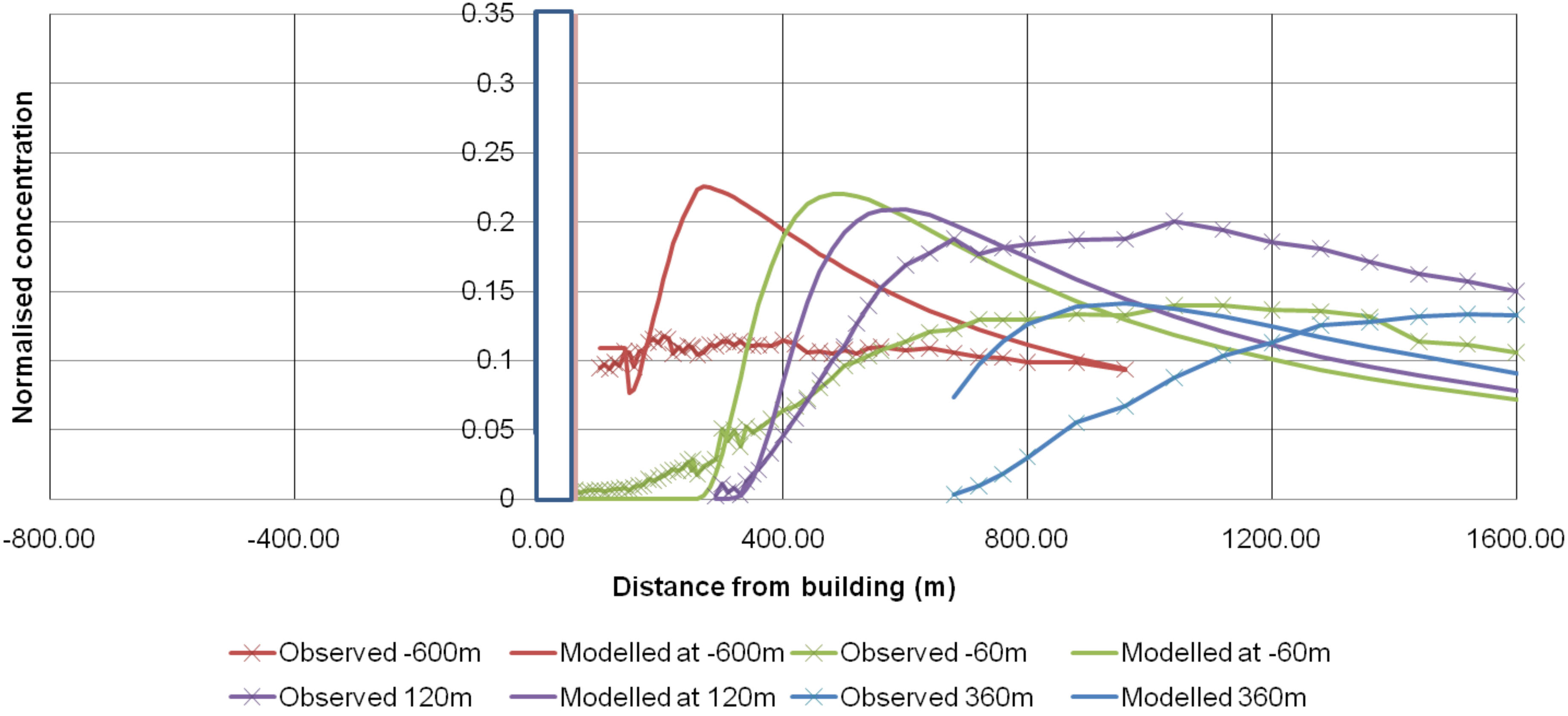
ADMS model validation

Thompson – Comparison. 92m stack, cubic building



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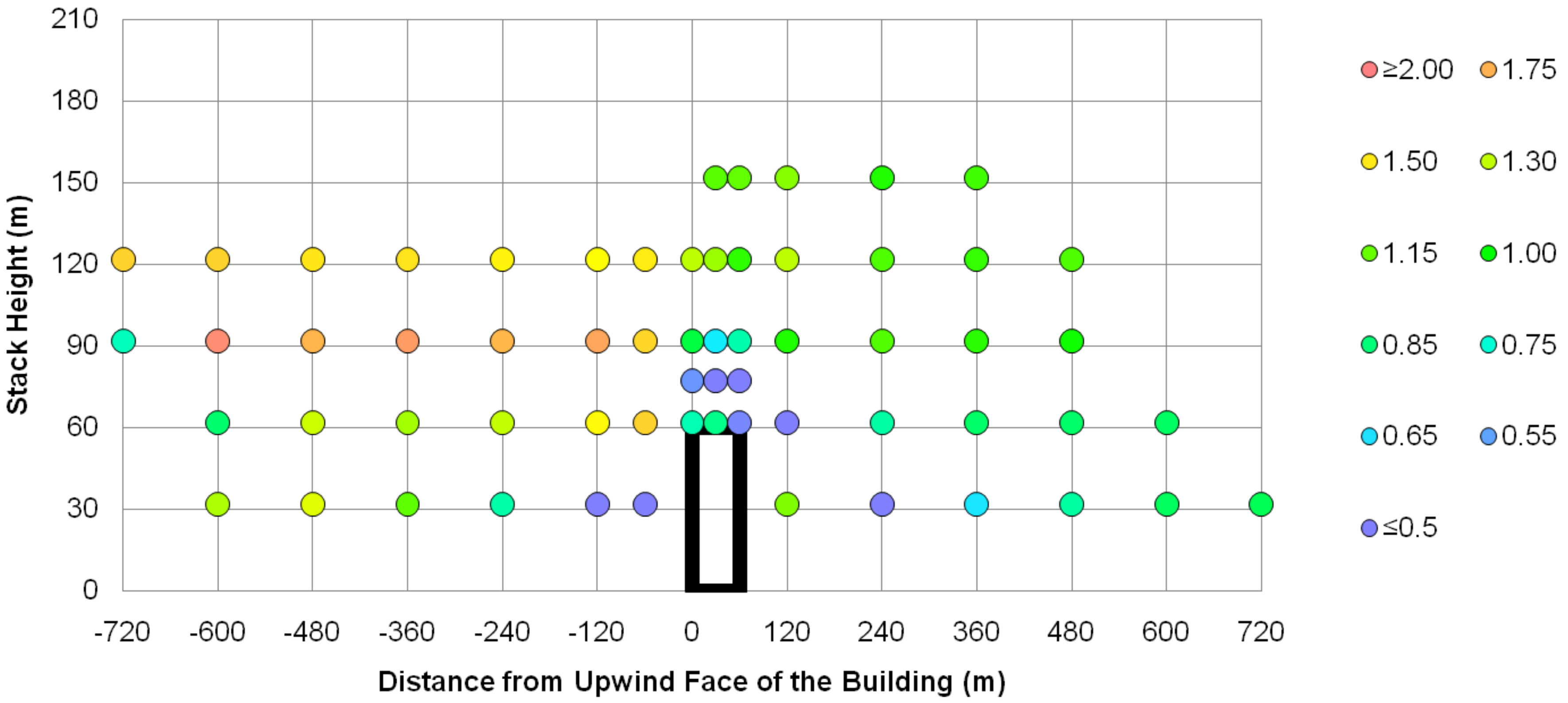
ADMS model validation
Thompson Cubic Building. Ratio Max Modelled/Max Observed



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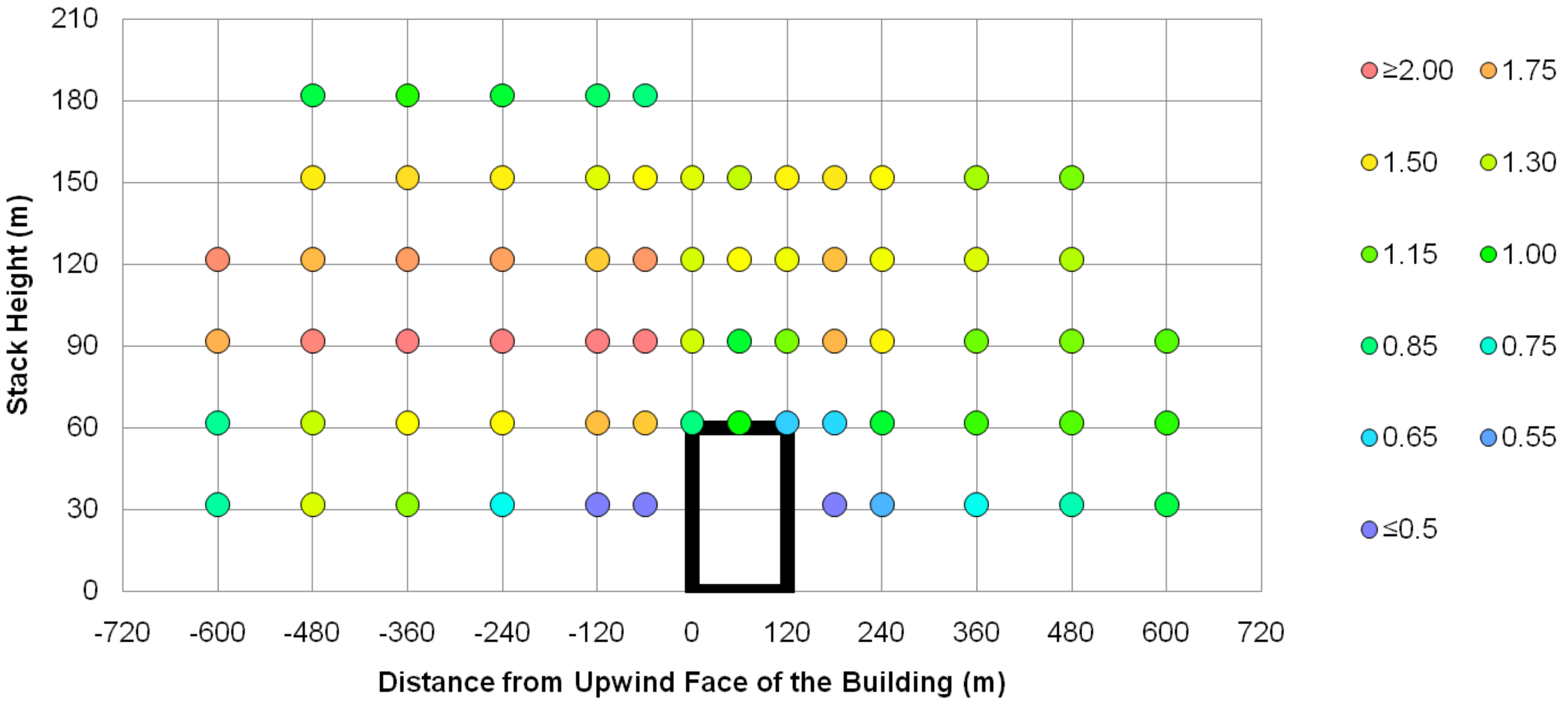
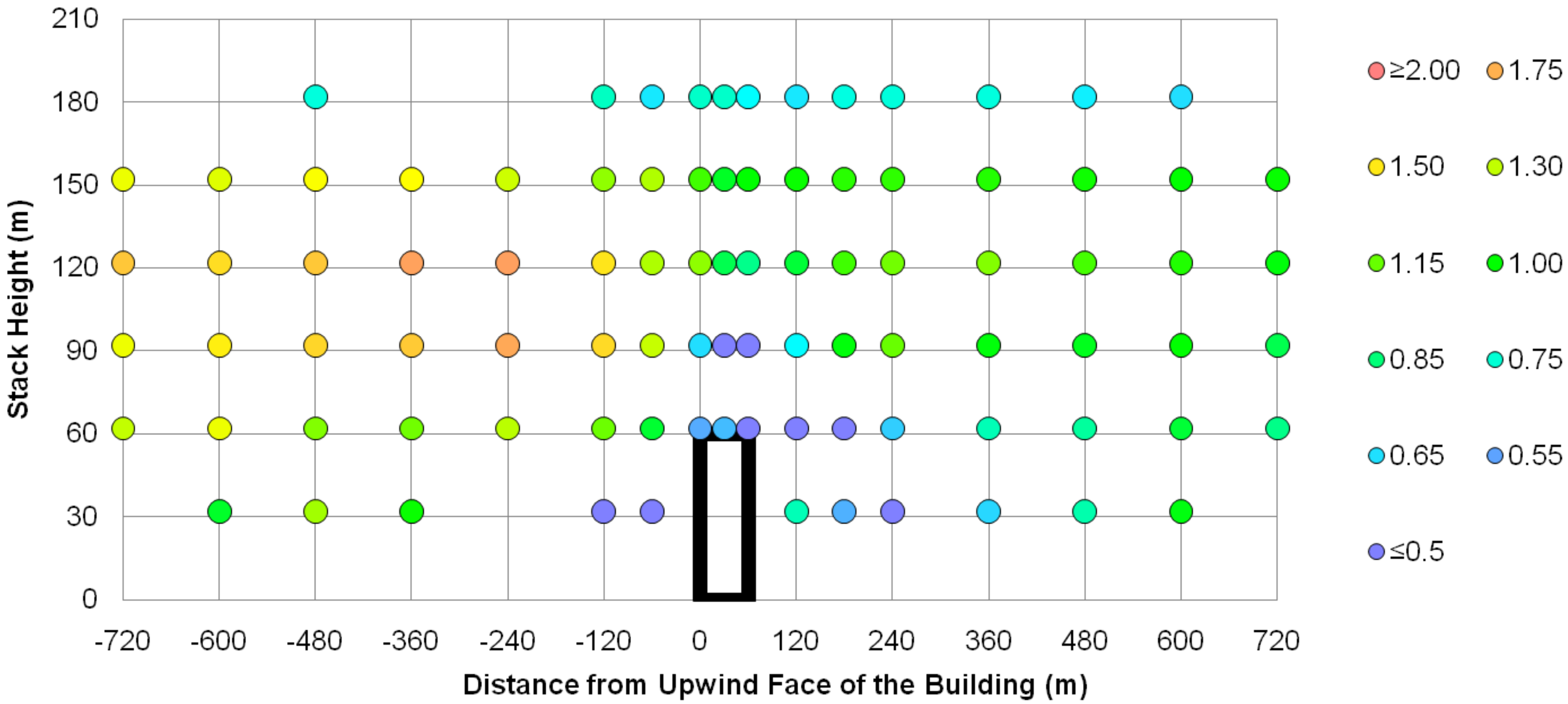
ADMS model validation

Thompson Long Building. Ratio Max Modelled/Max Observed



ADMS model validation

Thompson Wide Building. Ratio Max Modelled/Max Observed



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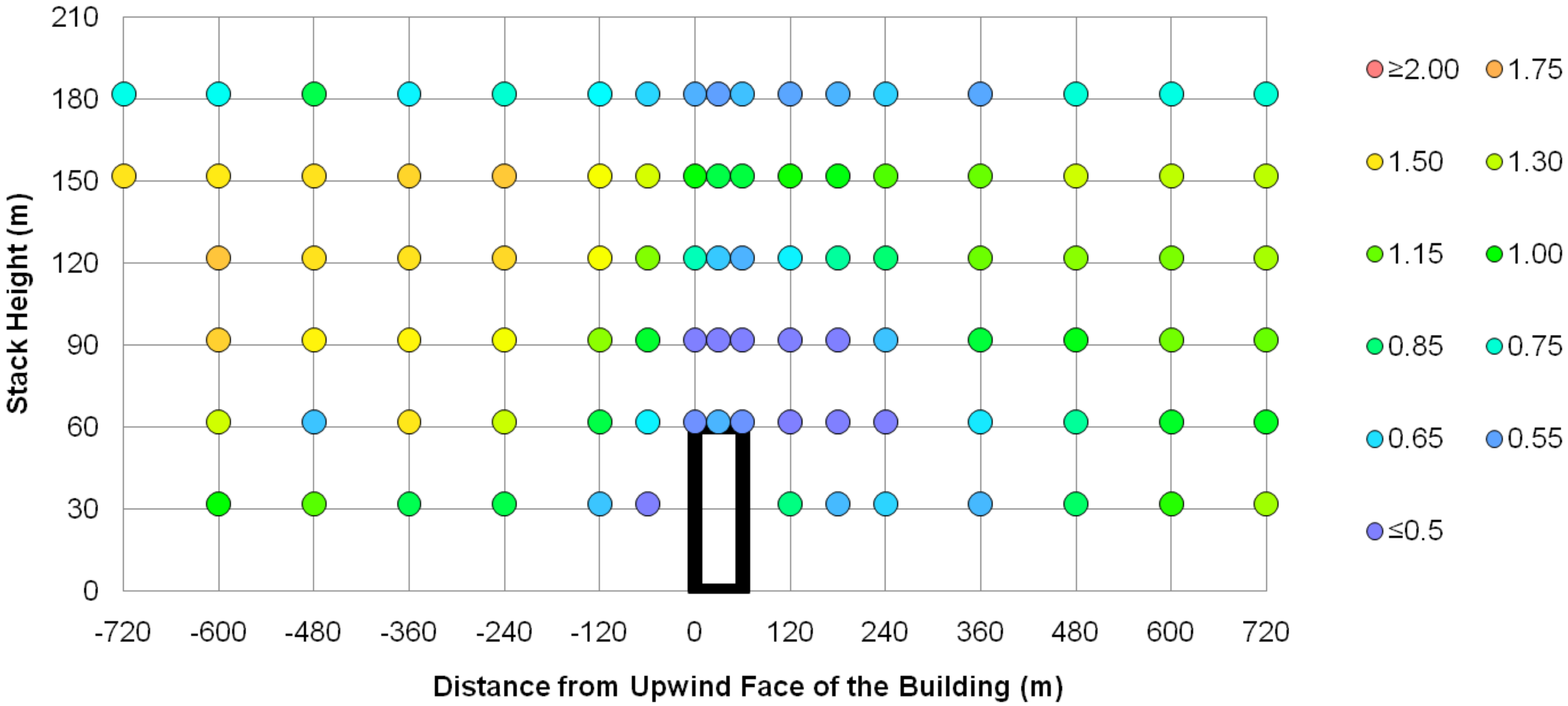
Thompson Wider Building. Ratio Max Modelled/Max Observed



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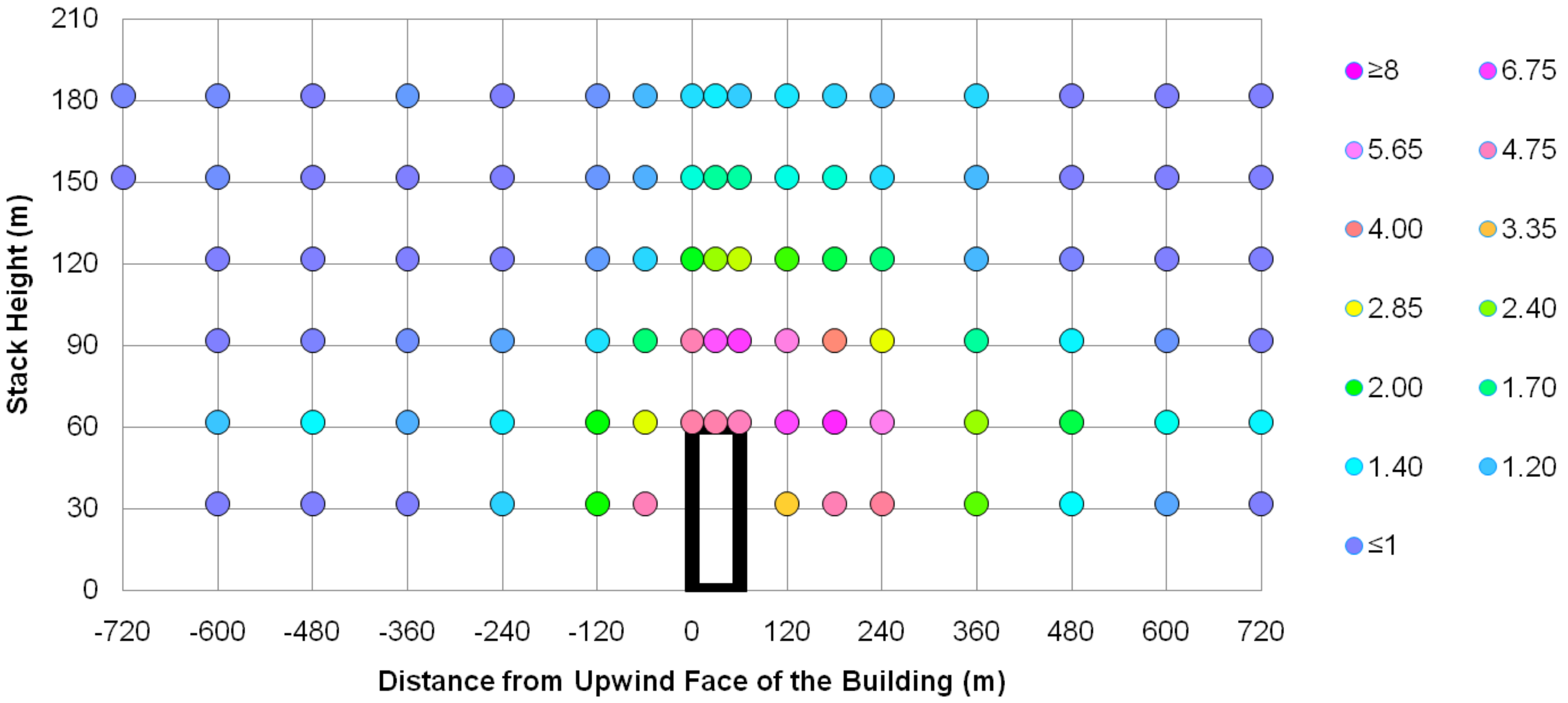
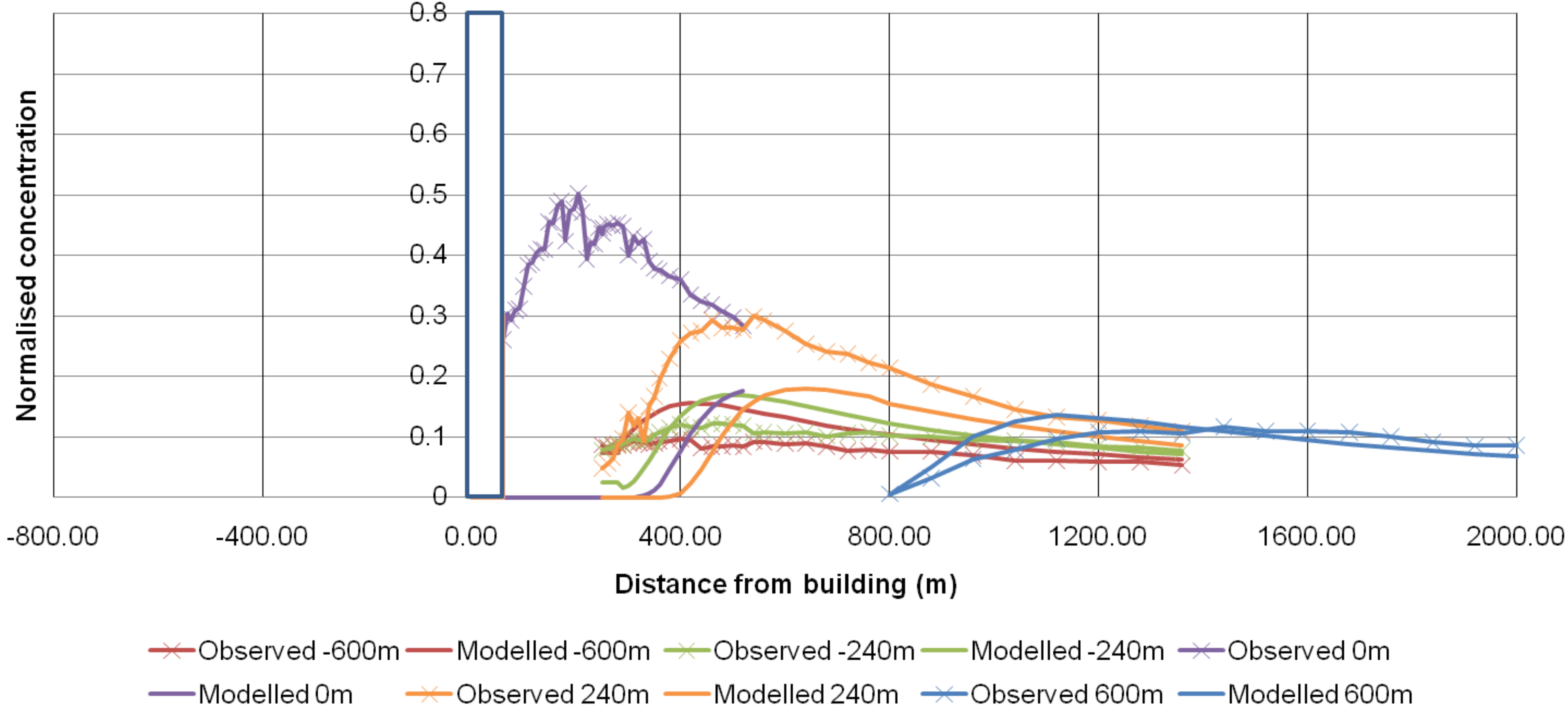
ADMS model validation

Thompson Wider building. Observed - Max building/Max no building



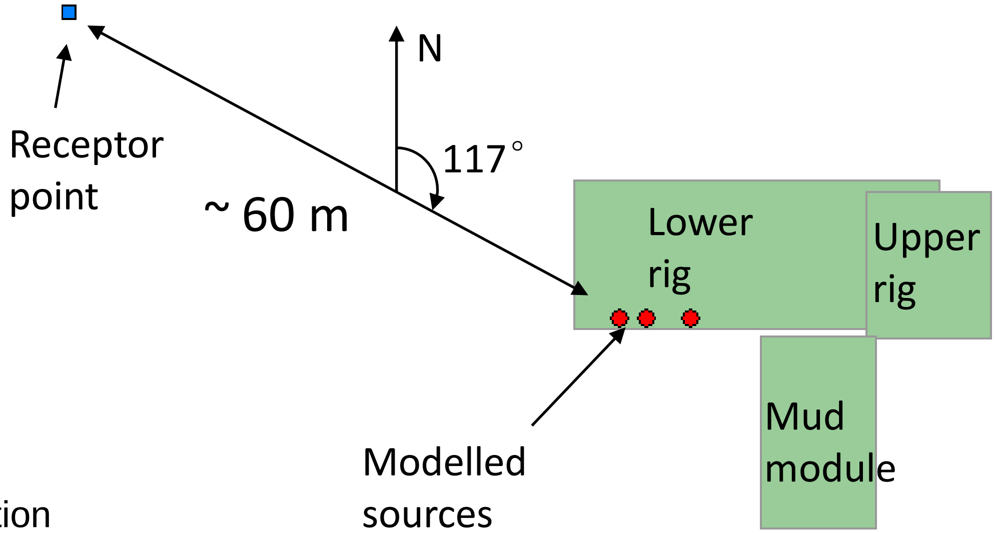
ADMS model validation

Thompson – Comparison. 92m stack, wider building



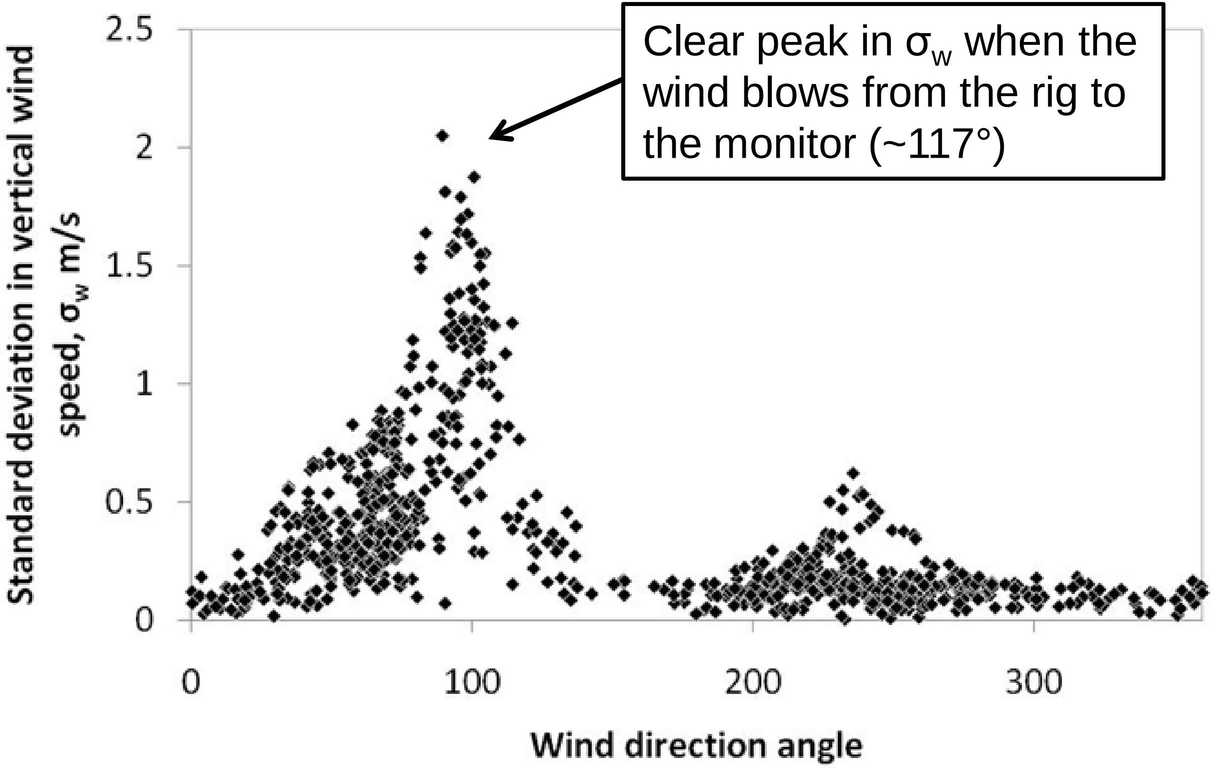
ADMS model validation
Prudhoe Bay

- Oil well pad on the North Slope of Alaska
- Modelled emissions from one drilling rig over 40 days
- Three main sources modelled
- One monitor, very close to sources
- Measured NO_x, NO_2 & O_3 concentrations
- Measured met conditions:
  - wind speed (horizontal & vertical) & direction
  - stand deviation of wind direction
  - temperature
  - total radiation
  - standard deviation of the vertical wind speed



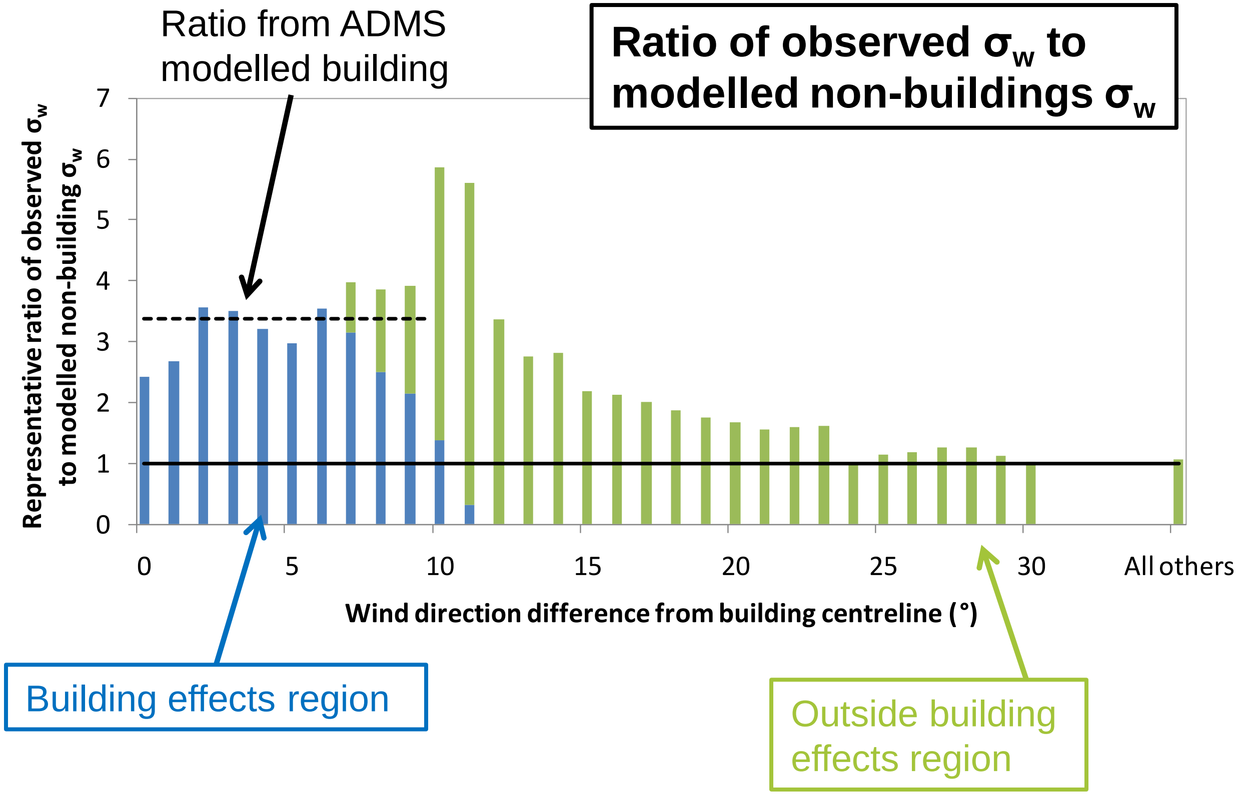
Acknowledgements: *BP International Limited funded the Prudhoe Bay ADMS validation study.*

ADMS model validation
Prudhoe Bay



- At Prudhoe Bay, met and concentration measurements were co-located, approximately 60 m from the rig.
- Look at how the standard deviation of the vertical wind speed, σ_w, varies with wind direction.
- The monitor is recording the increase in vertical turbulence generated by the rig structure.

ADMS model validation
Prudhoe Bay



- The ADMS predictions of σ_w are good when the model predicts the receptor to be in the 'building effects region'...
- ...but the 'building effects region' does not extend far enough laterally in these very stable conditions.

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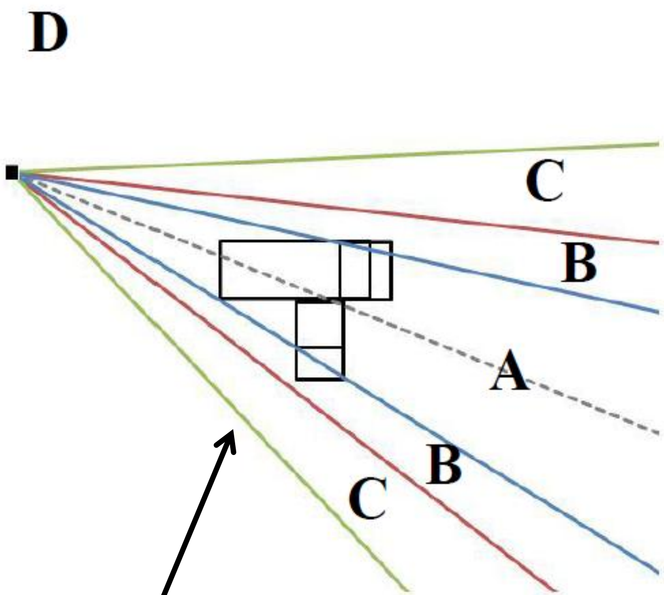
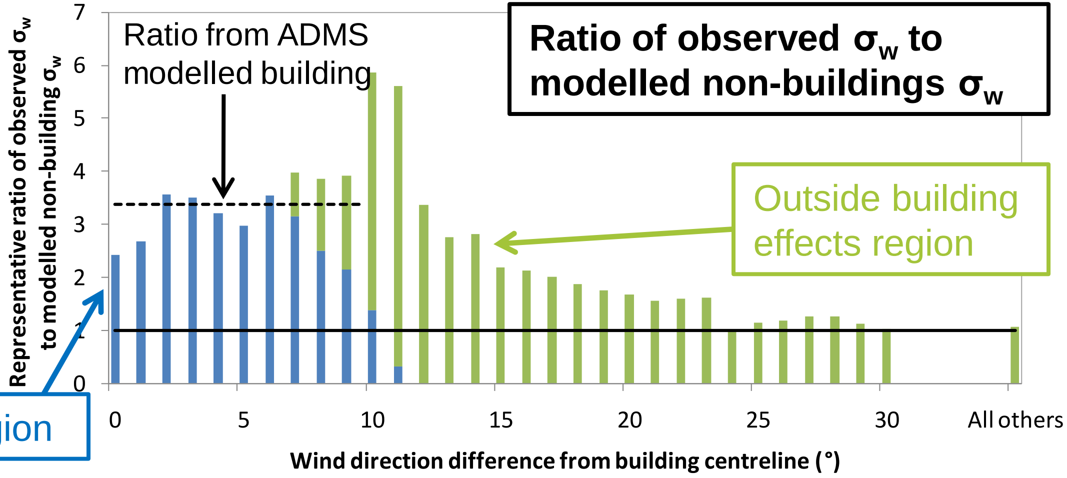
ADMS model validation
Prudhoe Bay



Building-influenced flow regions for the Prudhoe Bay study

Region A	-	ADMS models building-induced turbulence for the majority of wind directions
Region B	-	The measurements show a significant increase in turbulence, not modelled by ADMS
Region C	-	The turbulence decays away from an elevated value due to the presence of the buildings down to ambient values, not modelled by ADMS
Region D	-	Ambient values of turbulence



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Conclusions & further work

- For the Thompson experiment measurement-model comparisons are generally good except for high upwind sources and for some sources near buildings

  - Modification to vertical mixing for plume above main wake

  - Modification to vertical velocity above near wake (recirculation)

- The Prudhoe Bay field observations show that the transverse extent of enhanced turbulence is underestimated

  - Include generation of turbulence by buildings other than effective building