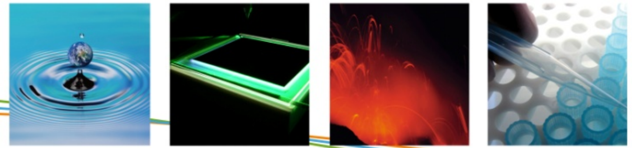


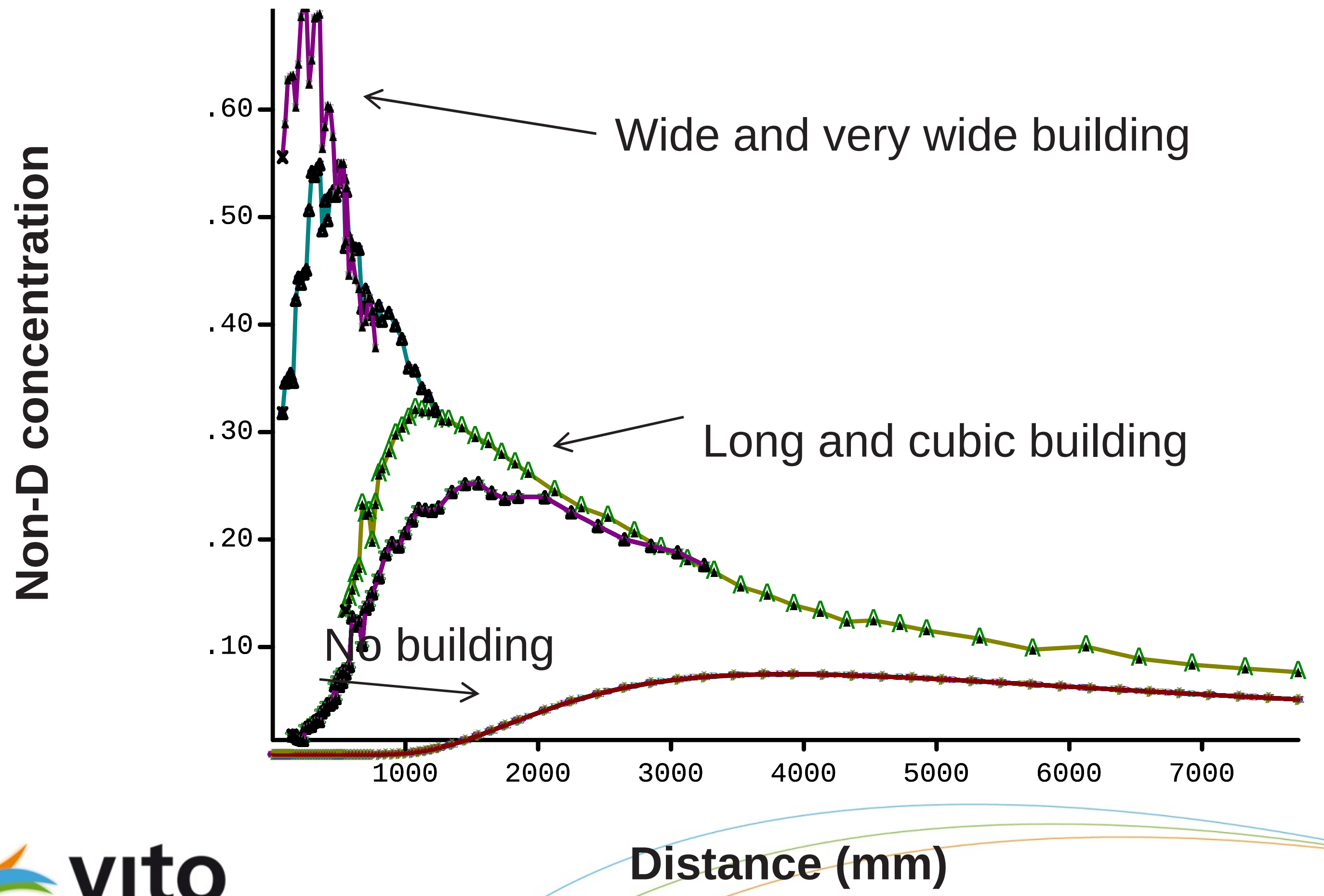
08/11/2011

Simple building downwash formulas for ground-level concentrations and plume rise

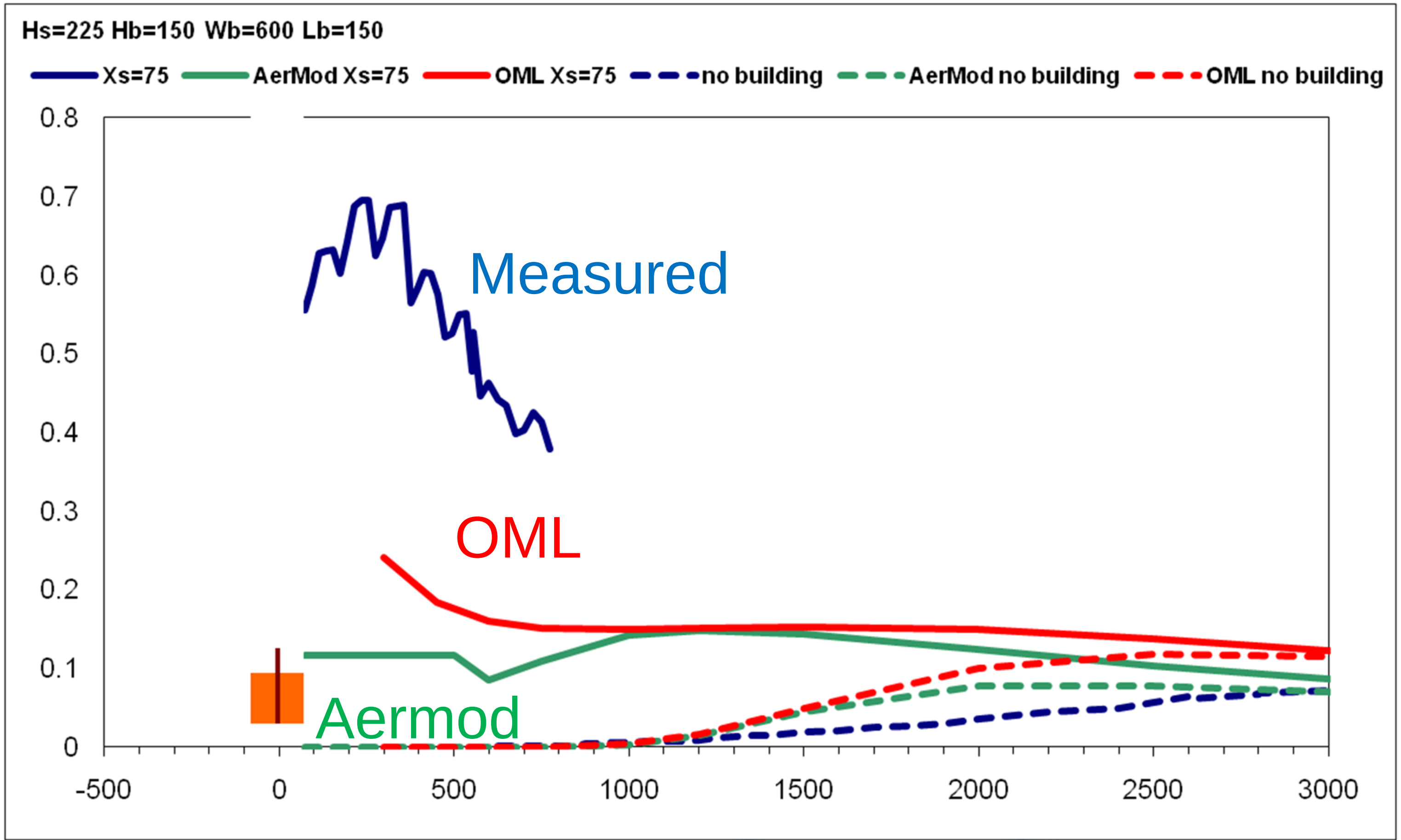
Guido Cosemans

Harmo 14, Kos, Greece

Impact building downwash on GLC-profile: BH=150mm, Hs=225 mm, stack midway of roof



Existing models fail to reproduce near-source peak concentrations (NERI)



Thompson data set 1/3

US-EPA meteorological windtunnel

This wind-tunnel has a test section that is 3.7 m wide, 2.1 m high and 18.3 m long

- Measurements of ground-level centreline concentration profiles for 350 combinations of building shape, stack height and stack location relative to the building
- Non-buoyant plume
- Neutral atmospheric stability conditions

vision on technology

Thompson data set 2/3

- 350 combinations, with approx. 45 000 ground-level concentrations measured

- **Building types**:
- (Side cube = 150 mm)

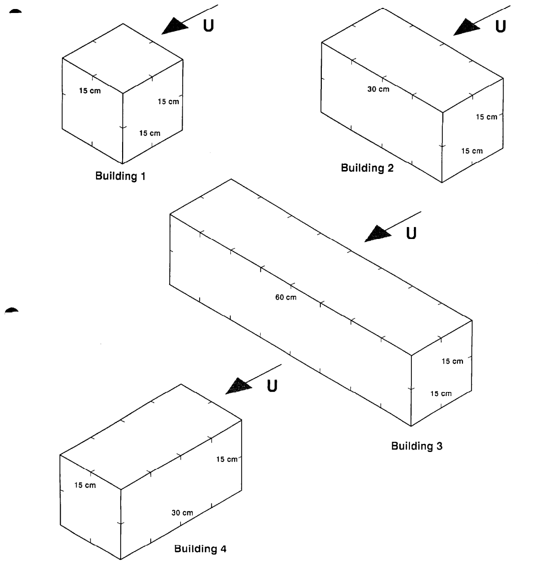
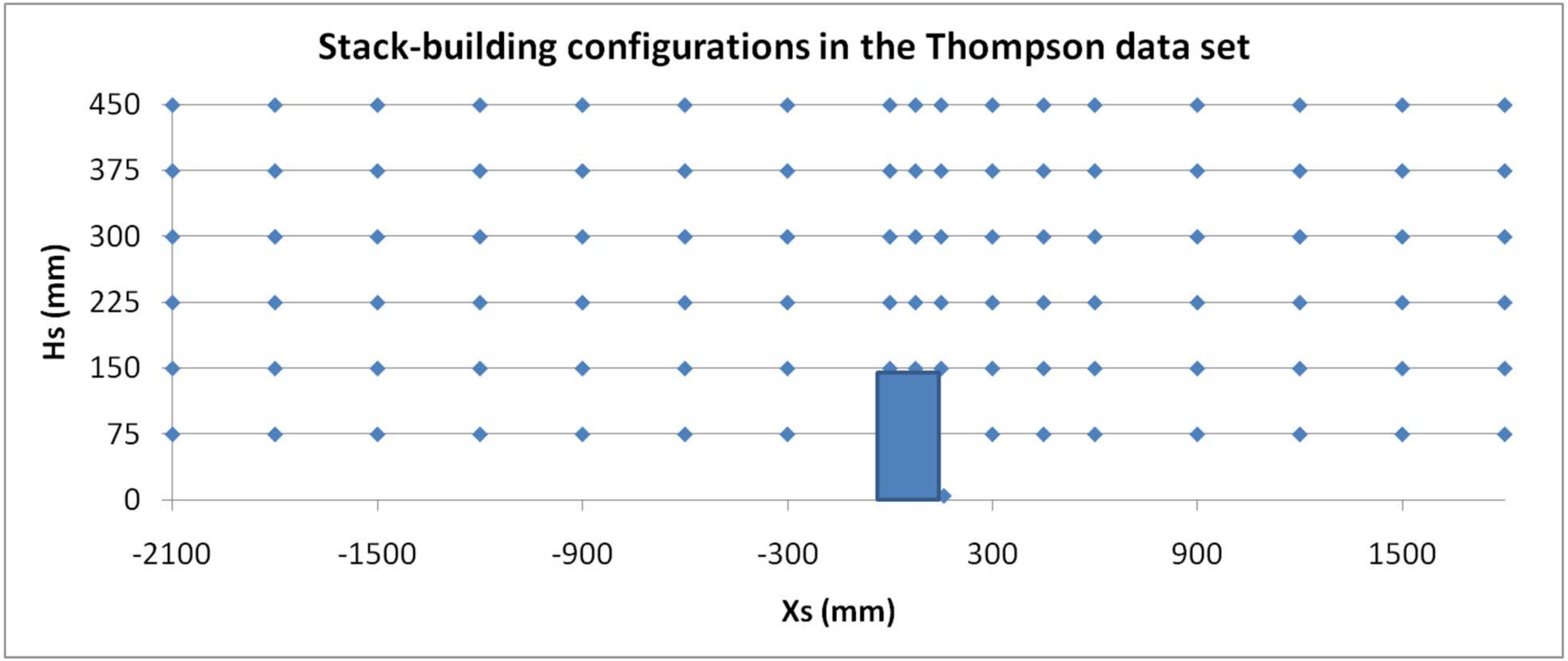


Figure 1. Geometry of the four building models.

19

Data used



Stack-building configurations in the Thompson data set
450
375
300
225
150
75
0
Hs (mm)
-2100
-1500
-900
-300
300
900
1500
Xs (mm)

Gaussian equation for building downwash

The GLC-profiles measured by Thompson can be reproduced by:

$$C(x, H_S) = \frac{Q}{\pi \ u(H^*)\sigma_y(x^*)\sigma_z(x^*)} \exp\left(-\frac{1}{2}\left\{ \frac{H^*}{\sigma_z(x^*)} \right\}^2 \right)$$

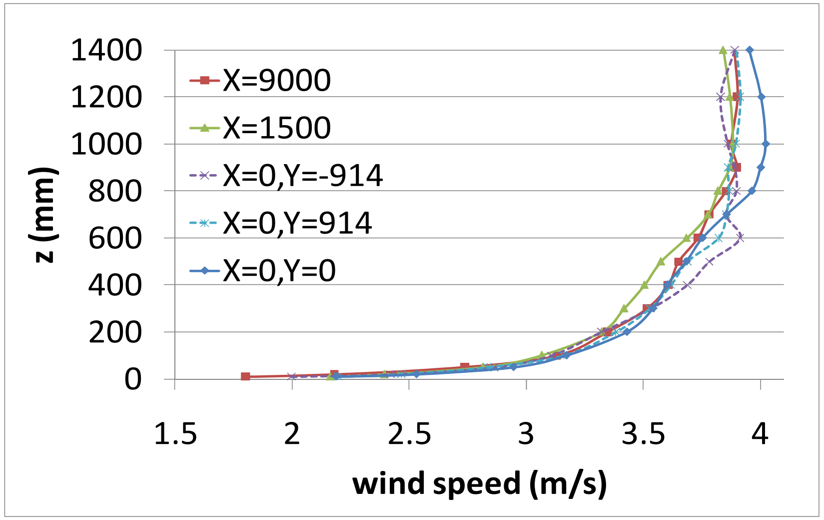
where:

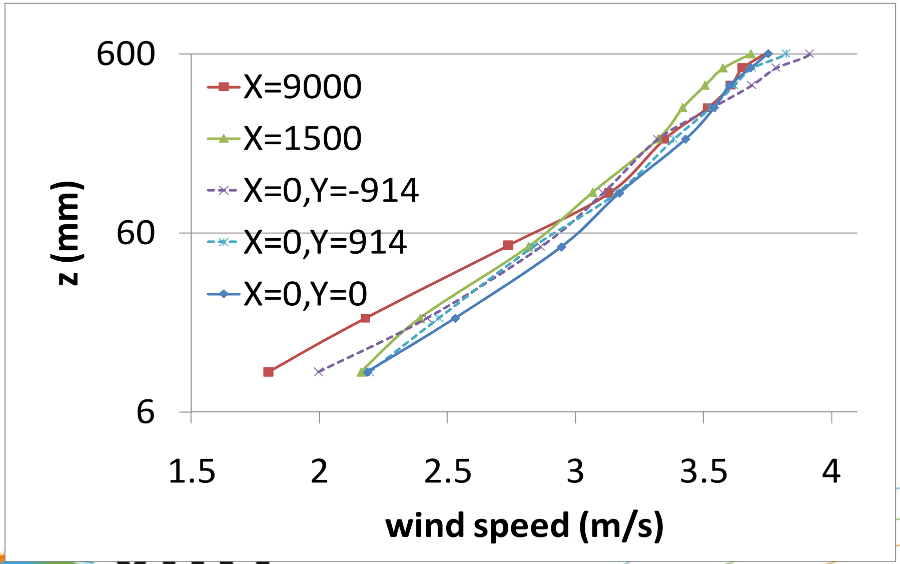
$u(z)$, $\sigma_y(x)$ and $\sigma_z(x)$ are as for an isolated stack

H^* and x^* refer to a receptor dependent virtual plume origin.

1-A: the measured vertical wind speed profile

- $u(z) = 2.2\,(z/10)^{0.136}$
- $u(z)=0.35\ \ln[(z-2.62)/0.015]$
- free-flow wind speed is 4 m/s at z=800
- at z = 75 wind speed is 3 m/s.





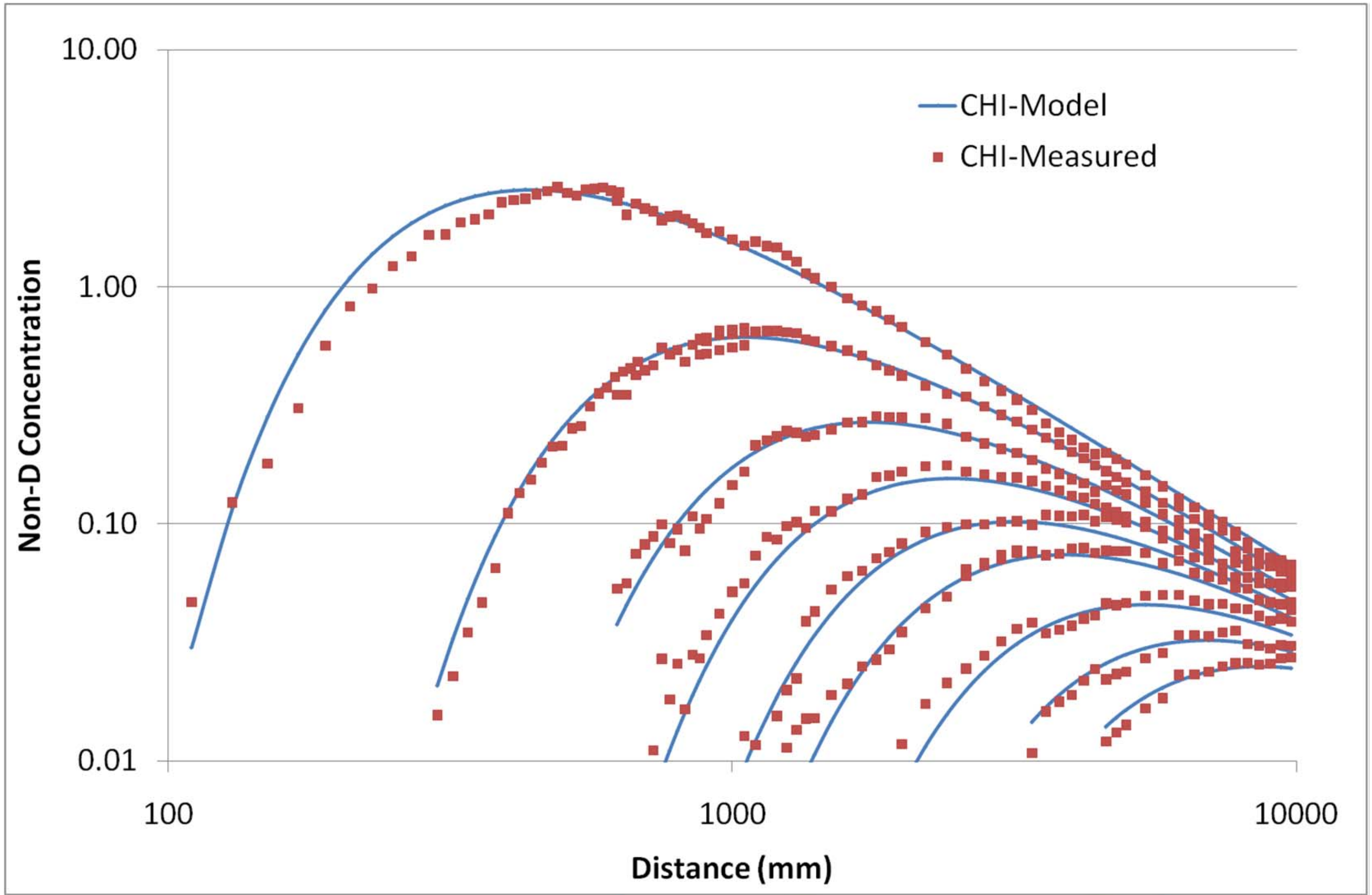
Dispersion parameters for isolated stack (Scale: 1 mm-1 m)

- $\sigma_y(x)=(\ 0.418 - 0.0001(4.5H + 500))\ \mathbf{x^{0.796}}$
- $\sigma_z(x)= (0.382 + 0.0001(4.5H - 0.0005(H-150)^2))\ \mathbf{x^{0.711}}$

These σ's are comparable to the σ's in the field (Bultynck-Malet, Flemish Regulatory IFDM-model)

between slightly stable till neutral atmospheric conditions.

Reproduction GLC-profiles for isolated stacks



vision on technology

also: $X_{Cmax} = 15\ Hs$

$$X_{Cmax} = 18\ [Hs + \Delta H_{BD}(X_{Cmax})]$$

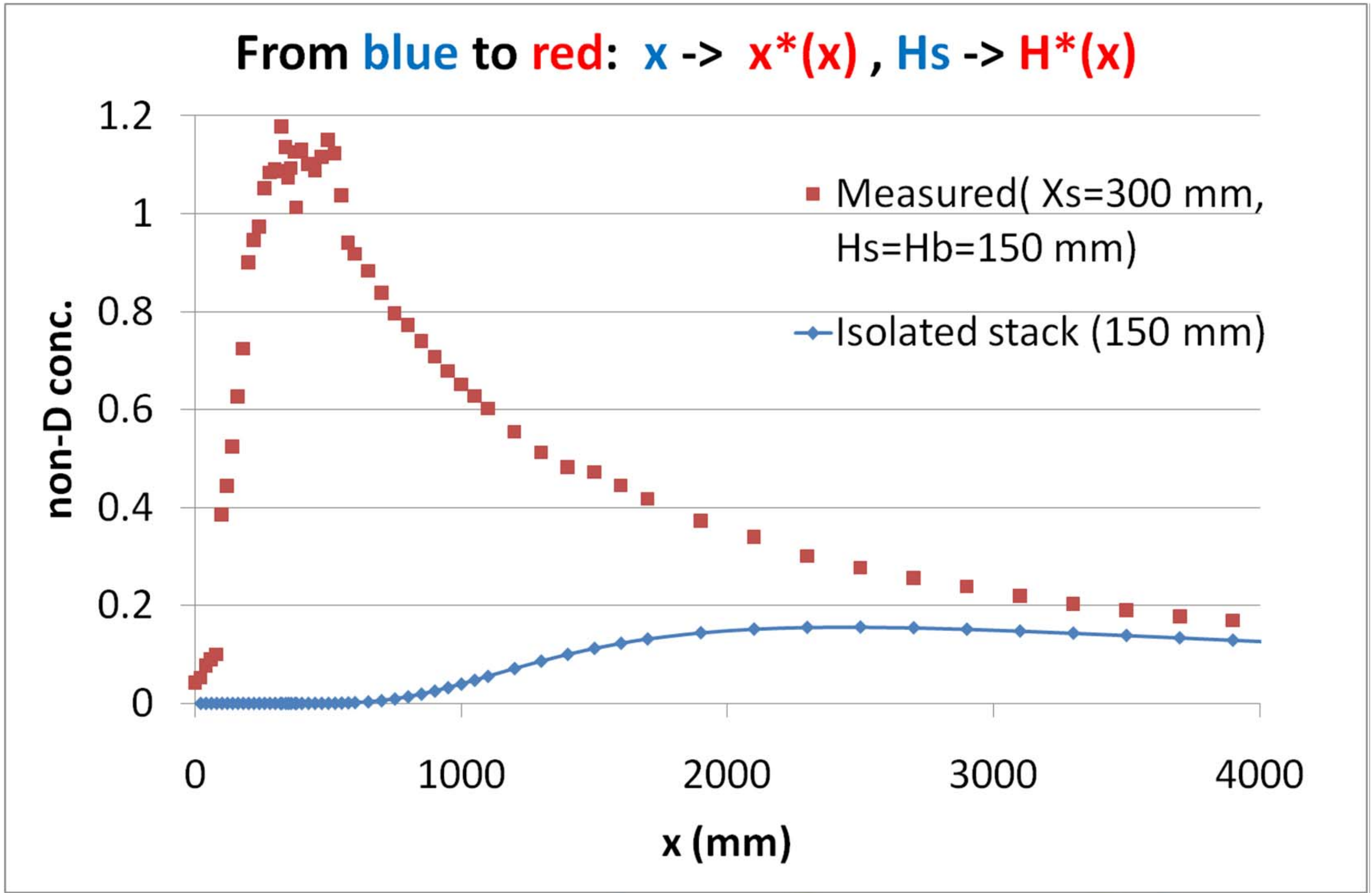
$$= 18\ H_{final}$$

vision on technology

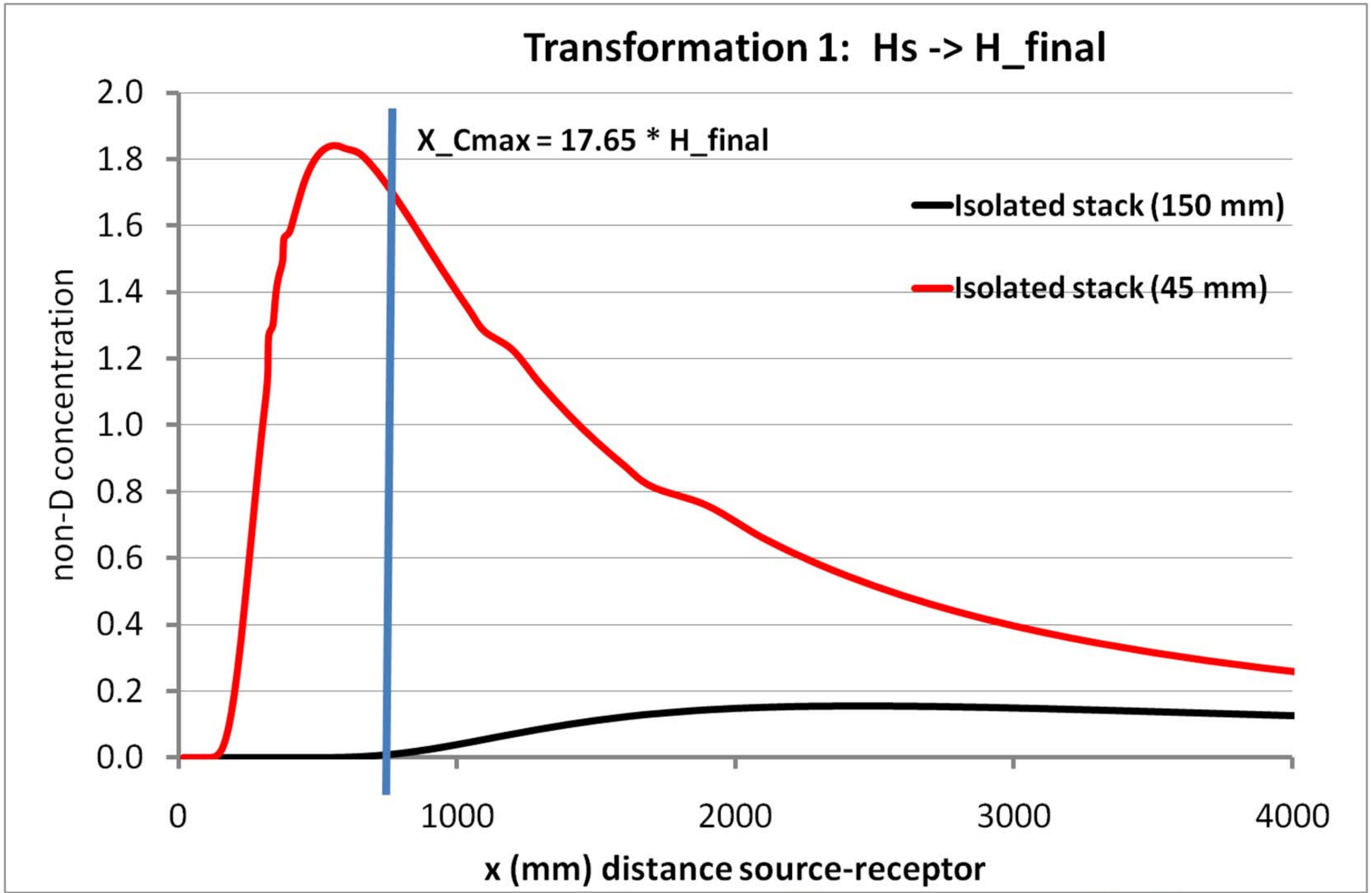
receptor dependent virtual plume origin

- Complete description of formulas can be found in extended abstract (formulas 5 and 6)

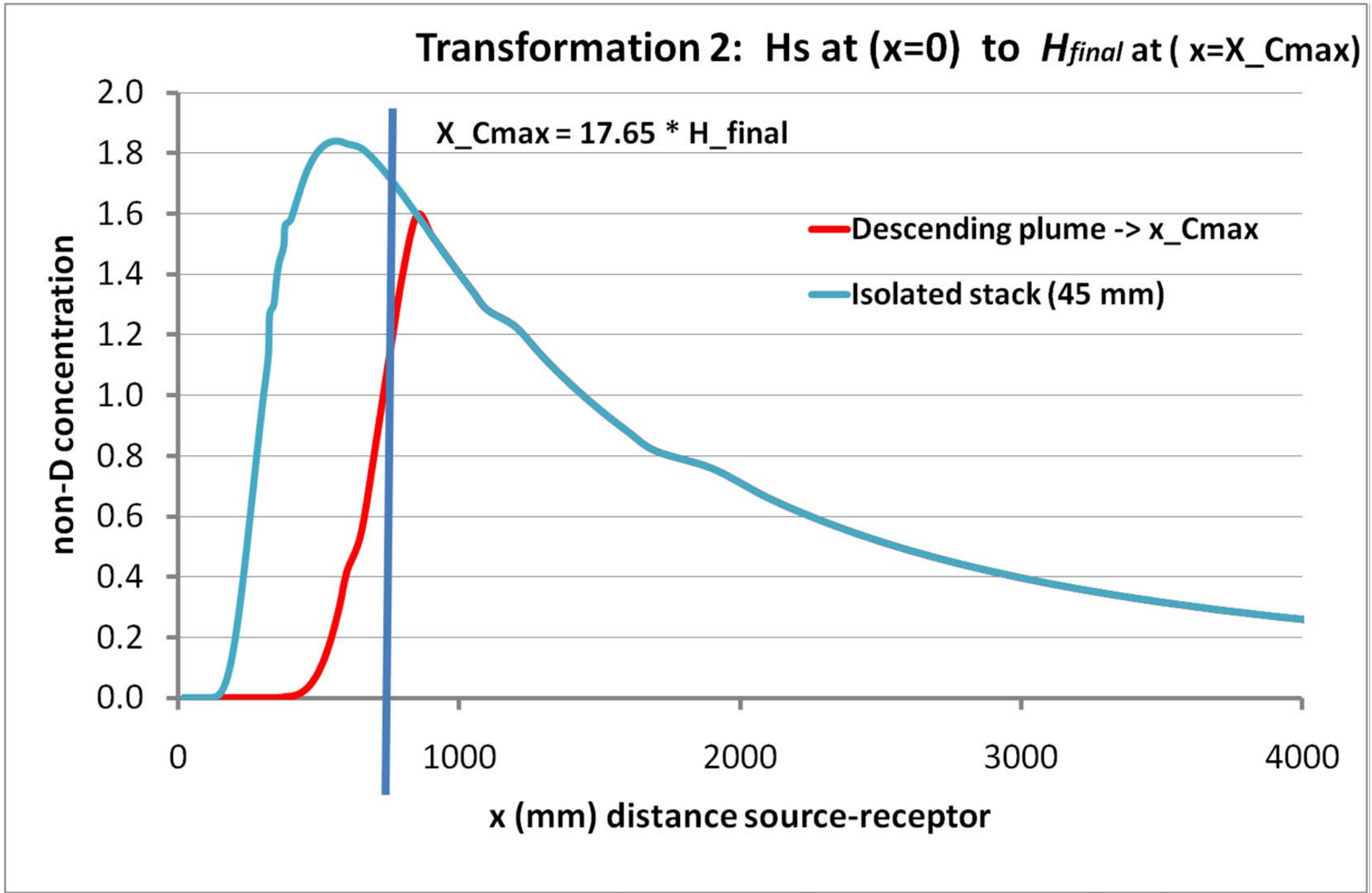
Change x and Hs in the Gaussian plume equation into x*(x) and h*(x) so that the blue curve is transformed into the red curve…



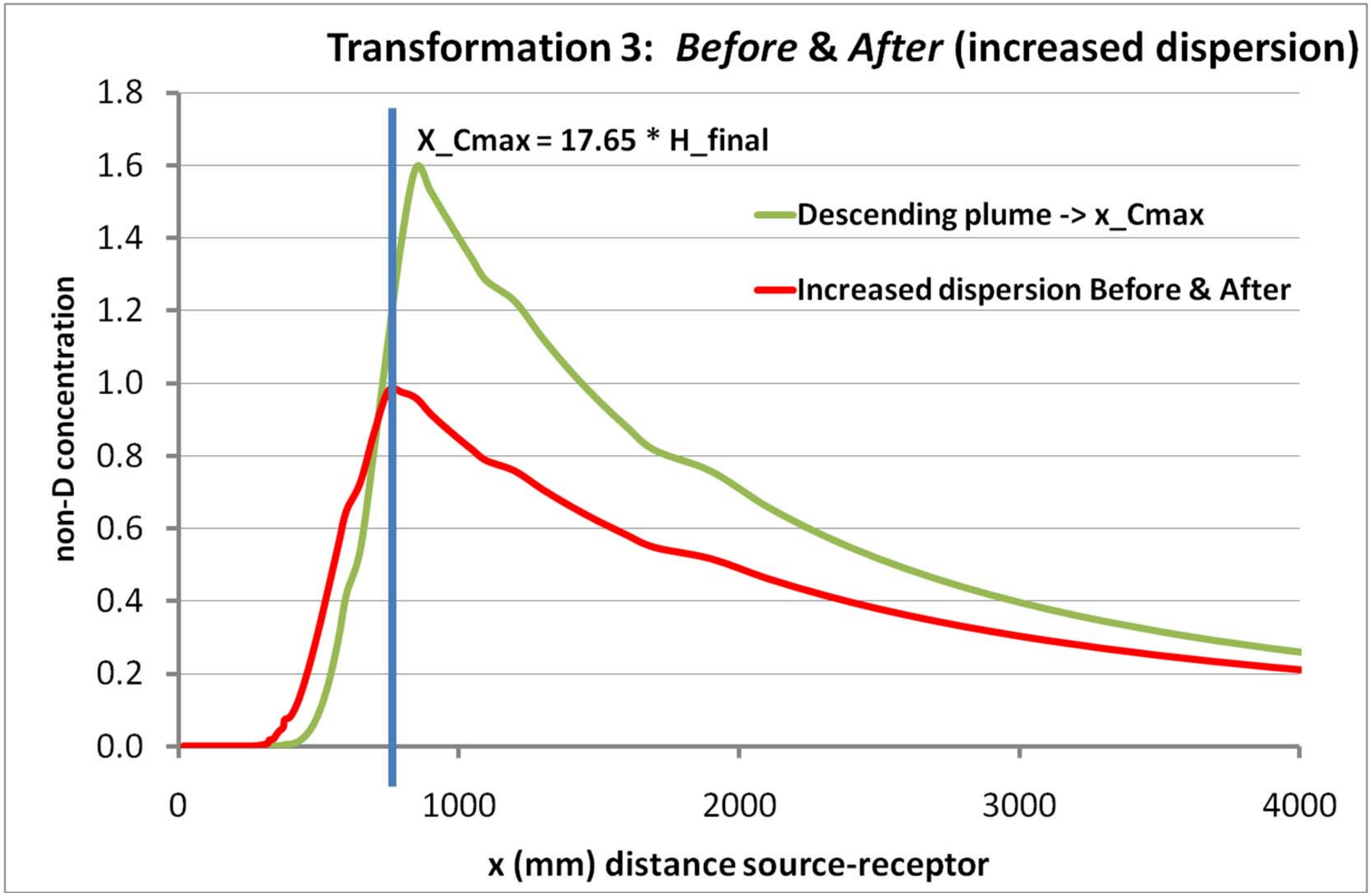
1/4: Higher maximum by lower virtual stack height



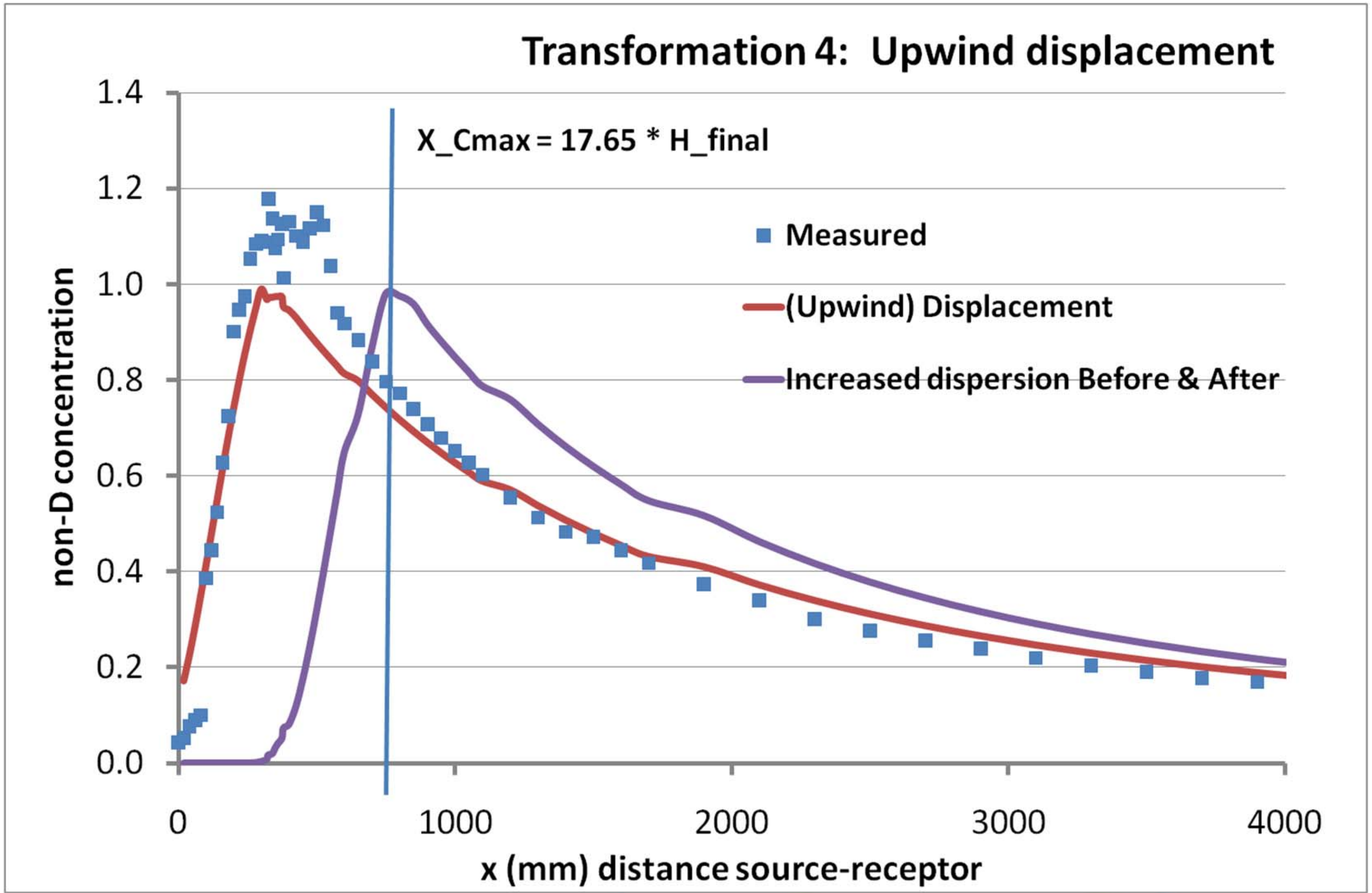
2/4 : Steeper slope by gradual change of virtual stack height over the interval 0 – $X_{\_Cmax}$



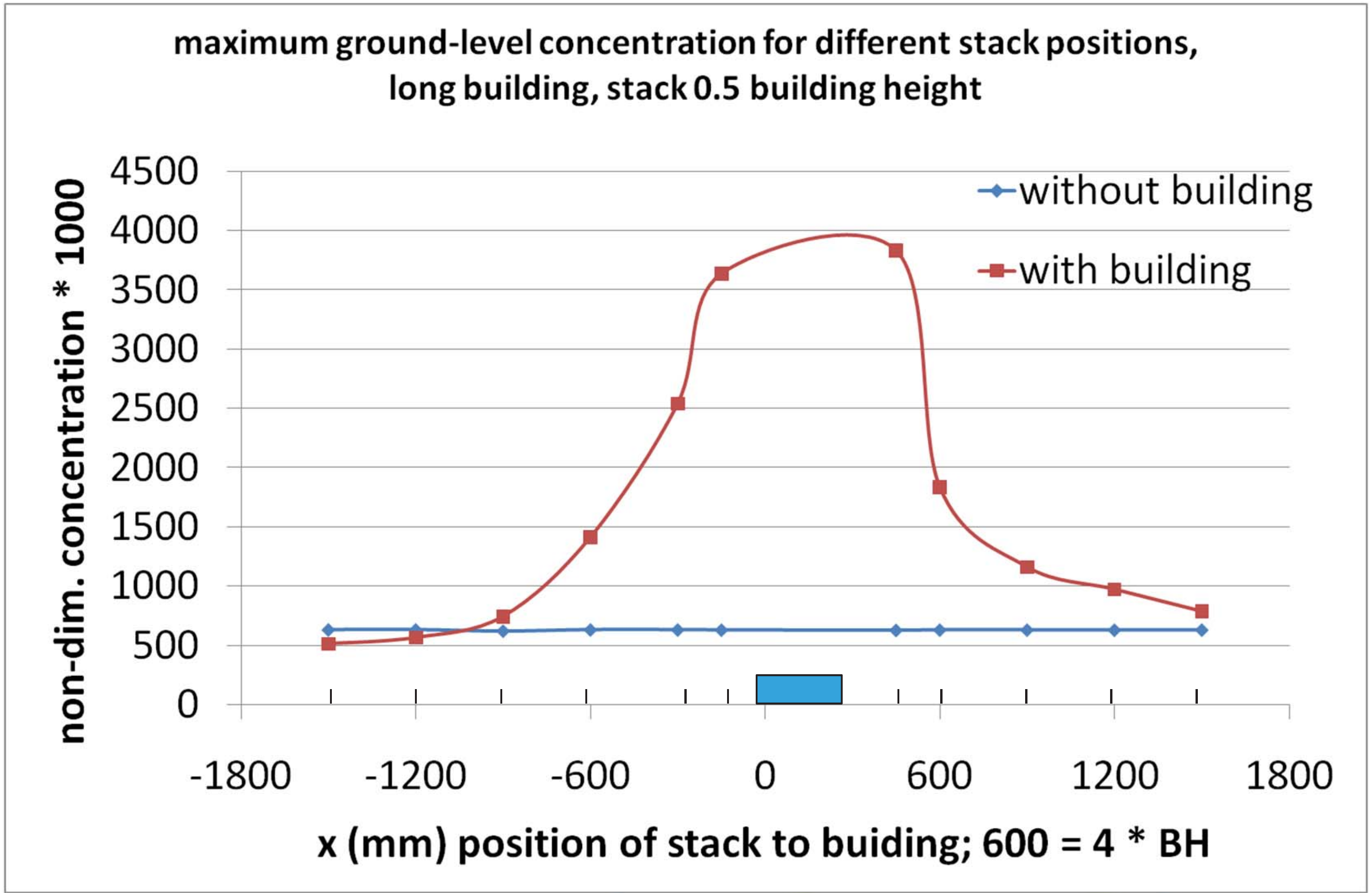
3/4: Changing the steepness before and after X_{Cmax} by increasing the distance between receptor and virtual origin



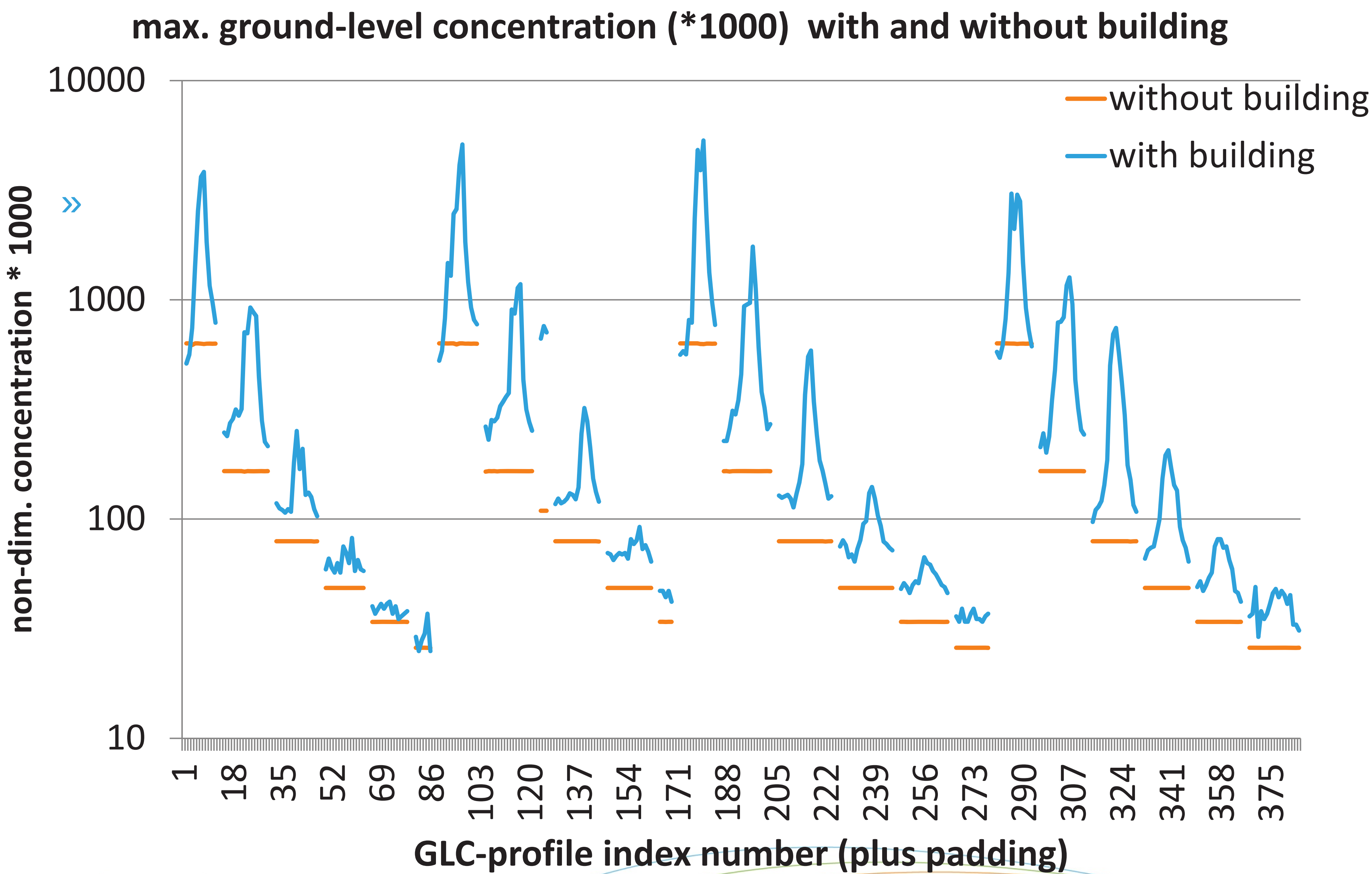
4/4: Upwind displacement



C_max*1000 for 75 mm stack, long building



vision on technology


max. ground-level concentration (*1000) with and without building
10000
1000
100
10
non-dim. concentration * 1000
without building
with building
1
18
35
52
69
86
103
120
137
154
171
188
205
222
239
256
273
290
307
324
341
358
375
GLC-profile index number (plus padding)

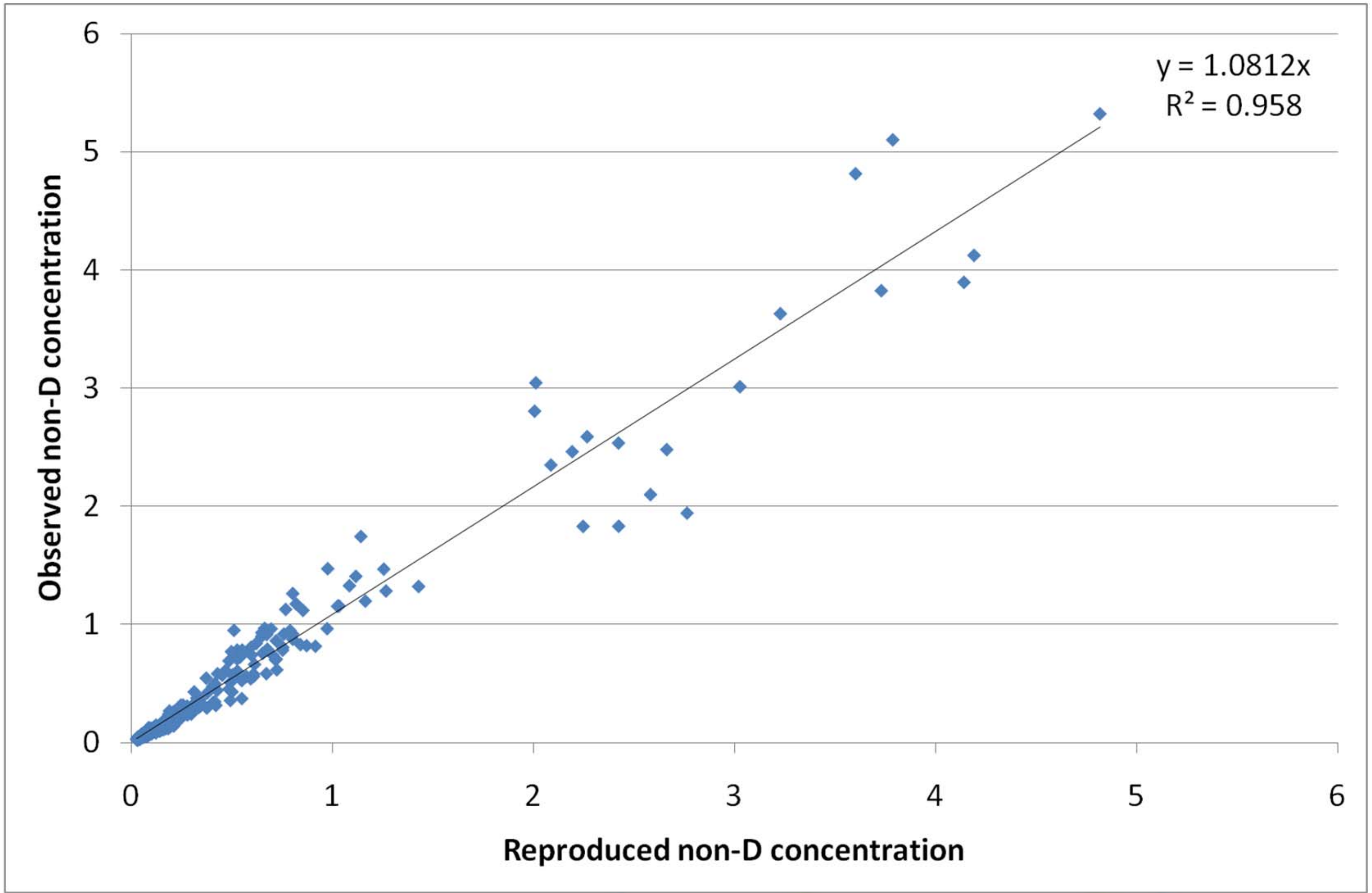
Coeficients of F(Xs) are fitted over Hs

-> for each building type, we now have functions (Xs,Hx) that give the required values of

- H*(x)
- Before(x)
- After(x)
- Displacement

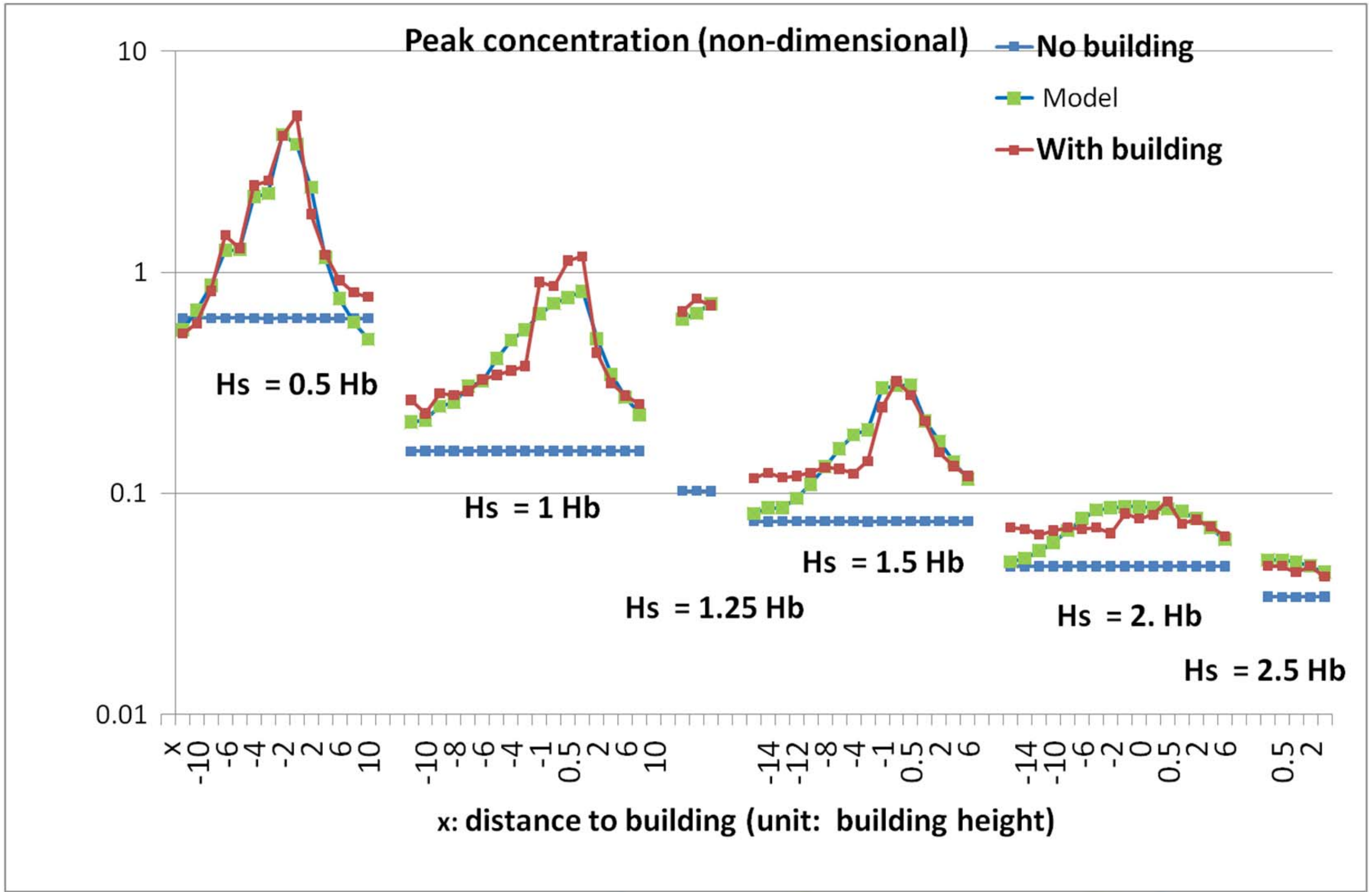
(where x is distance source-receptor).

Quality of reproduction: maxima in GLC-profiles

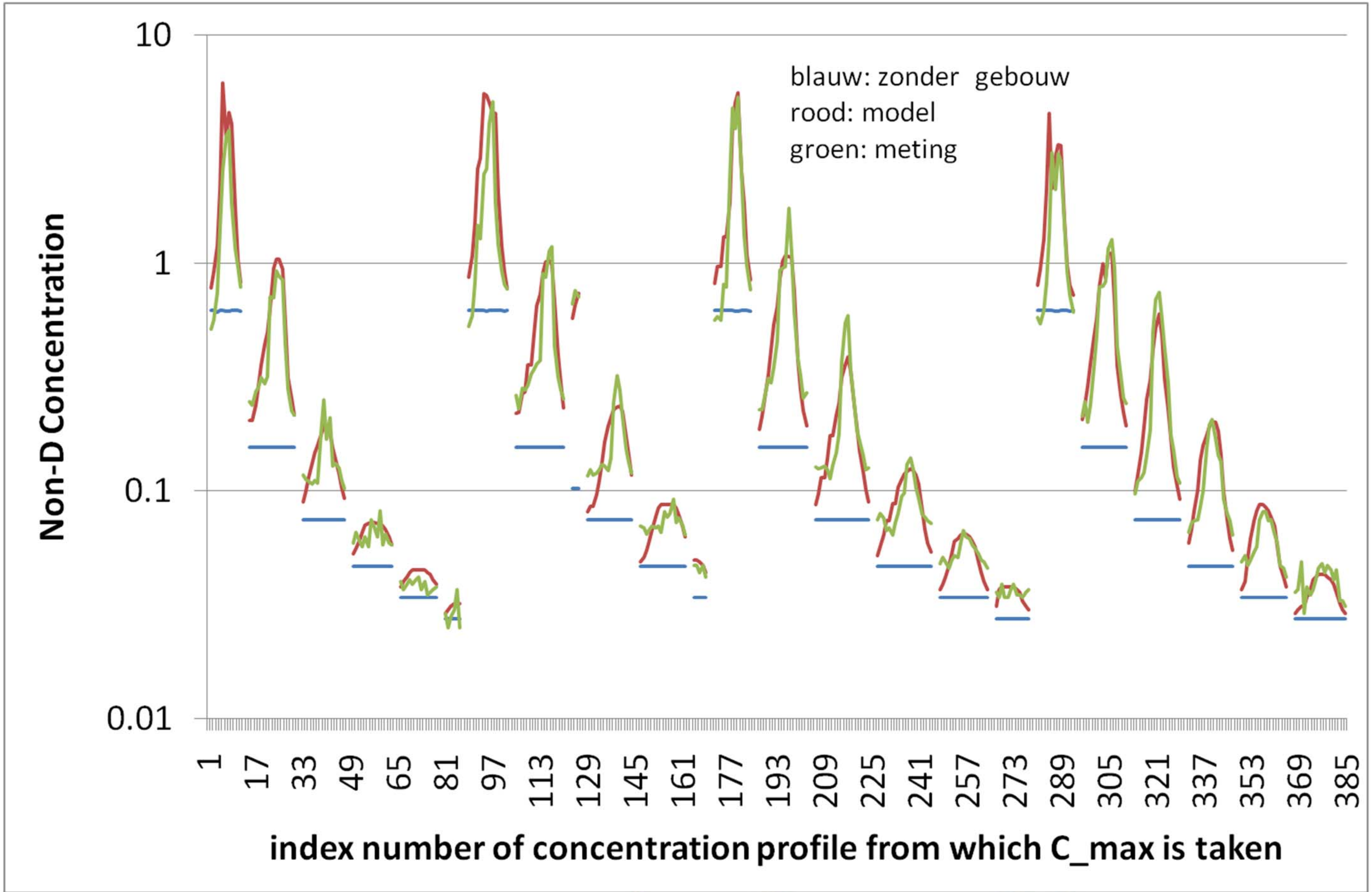


vision on technology

Reproduction of C_max (Hx,Xs) for cubic building

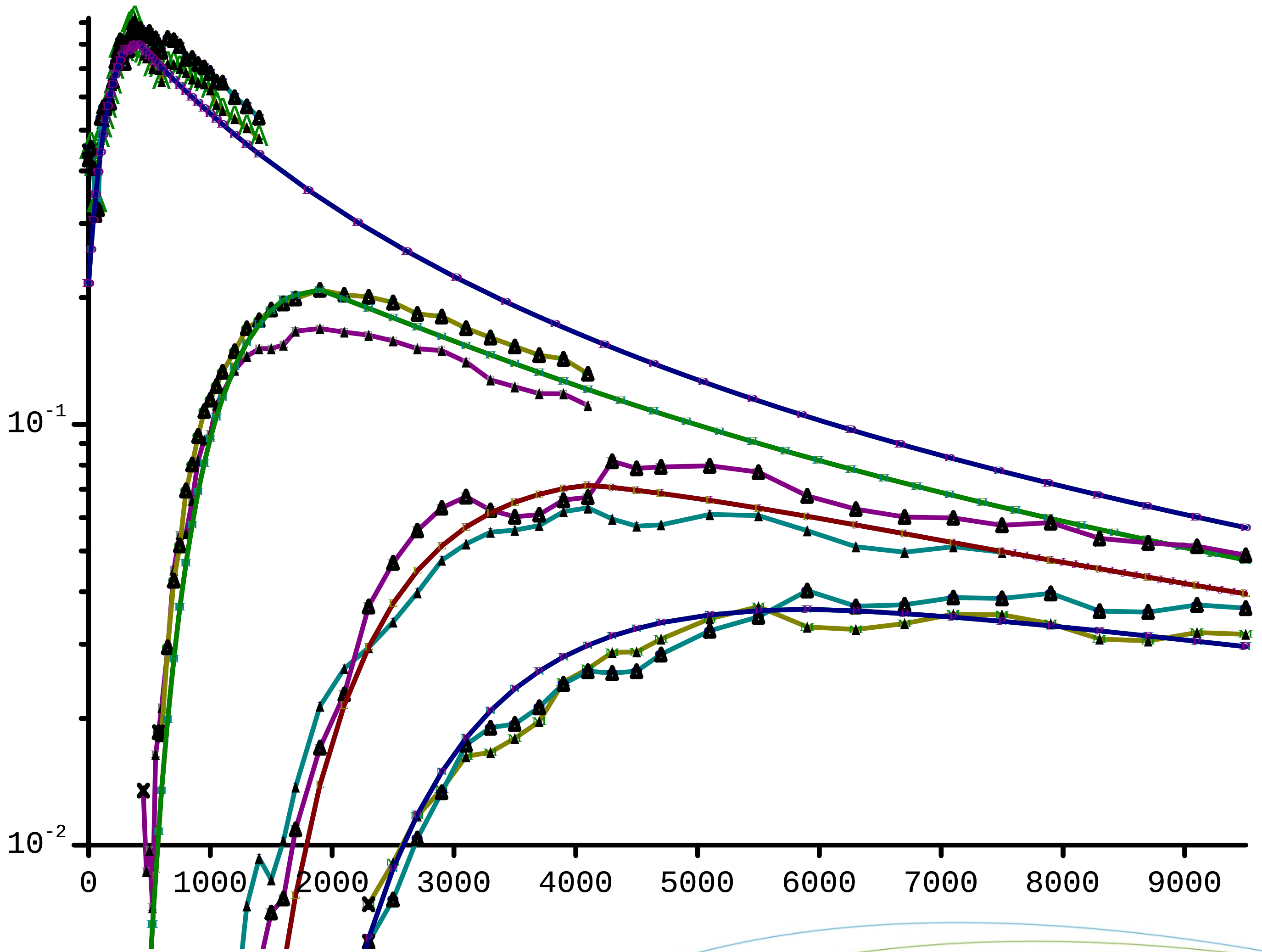


vito
vision on technology

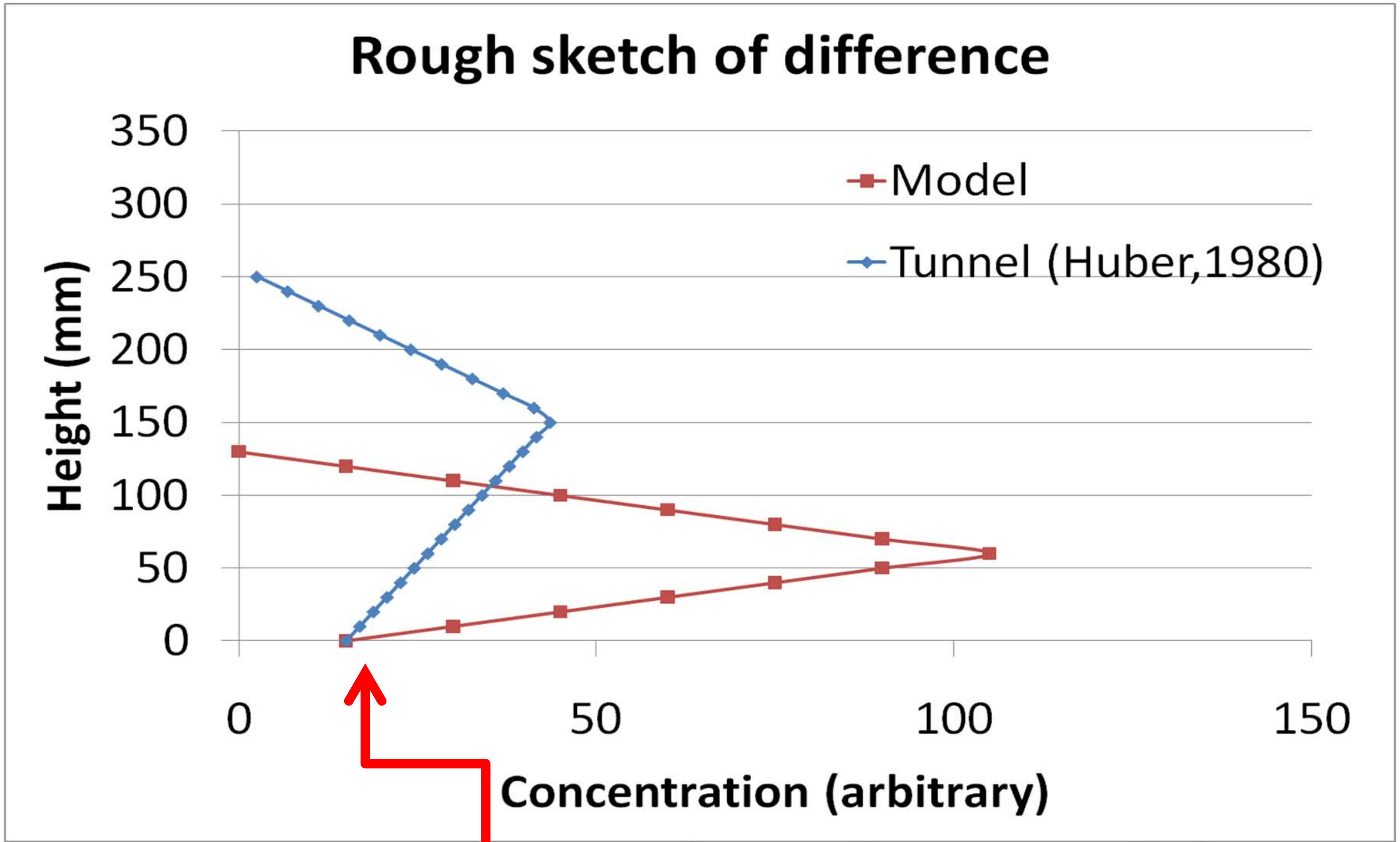


10
1
0.1
0.01
Non-D Concentration
blauw: zonder gebouw
rood: model
groen: meting
1
17
33
49
65
81
97
113
129
145
161
177
193
209
225
241
257
273
289
305
321
337
353
369
385
index number of concentration profile from which C_max is taken

Long building, Xs=300, Hs = 150, 225, 300 & 375 mm



Comment on vertical concentration profile



Model gives correct ground-level concentration

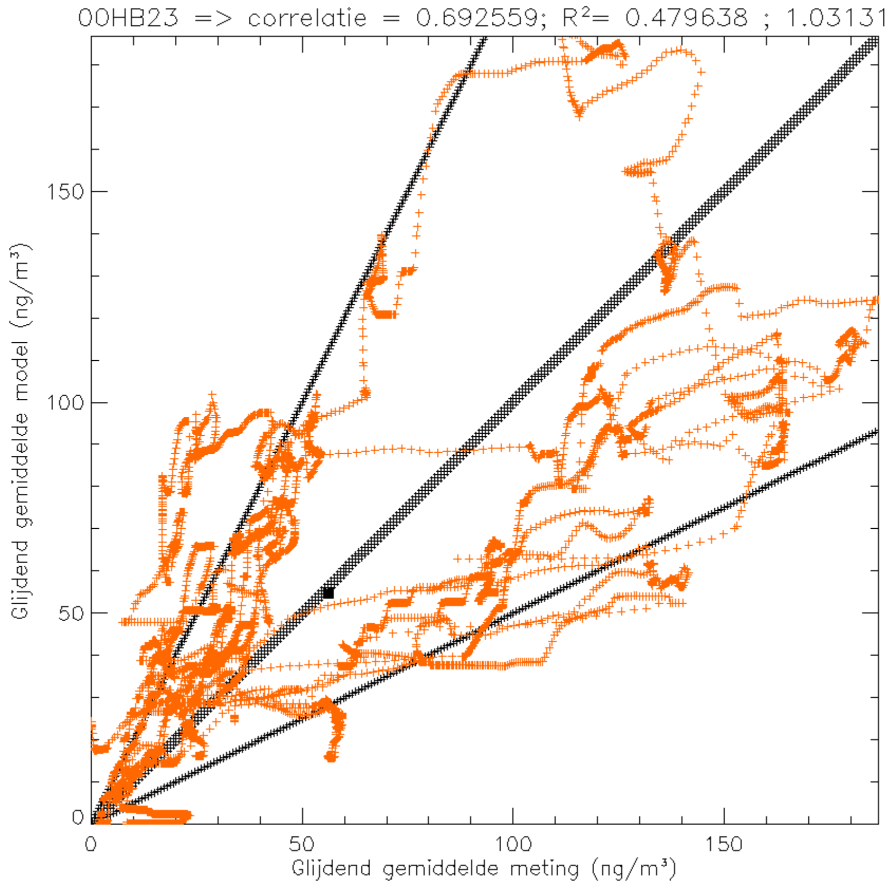
To the field …

Correction of plume rise

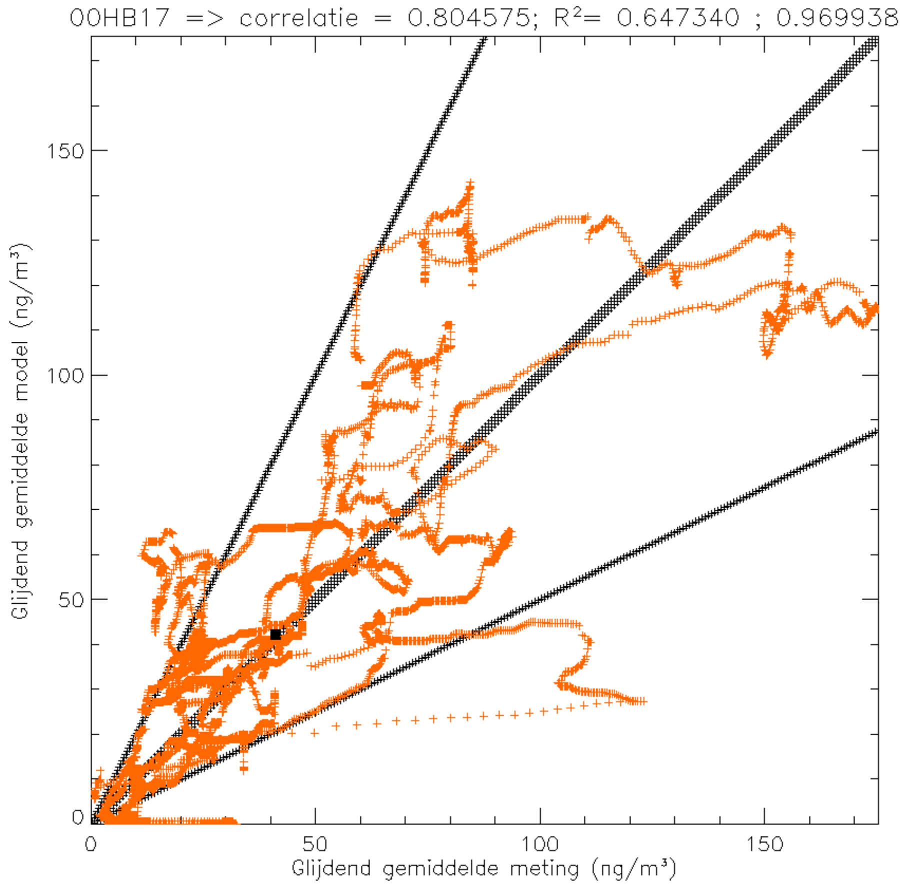
Dependency of *Δh on the wind speed*

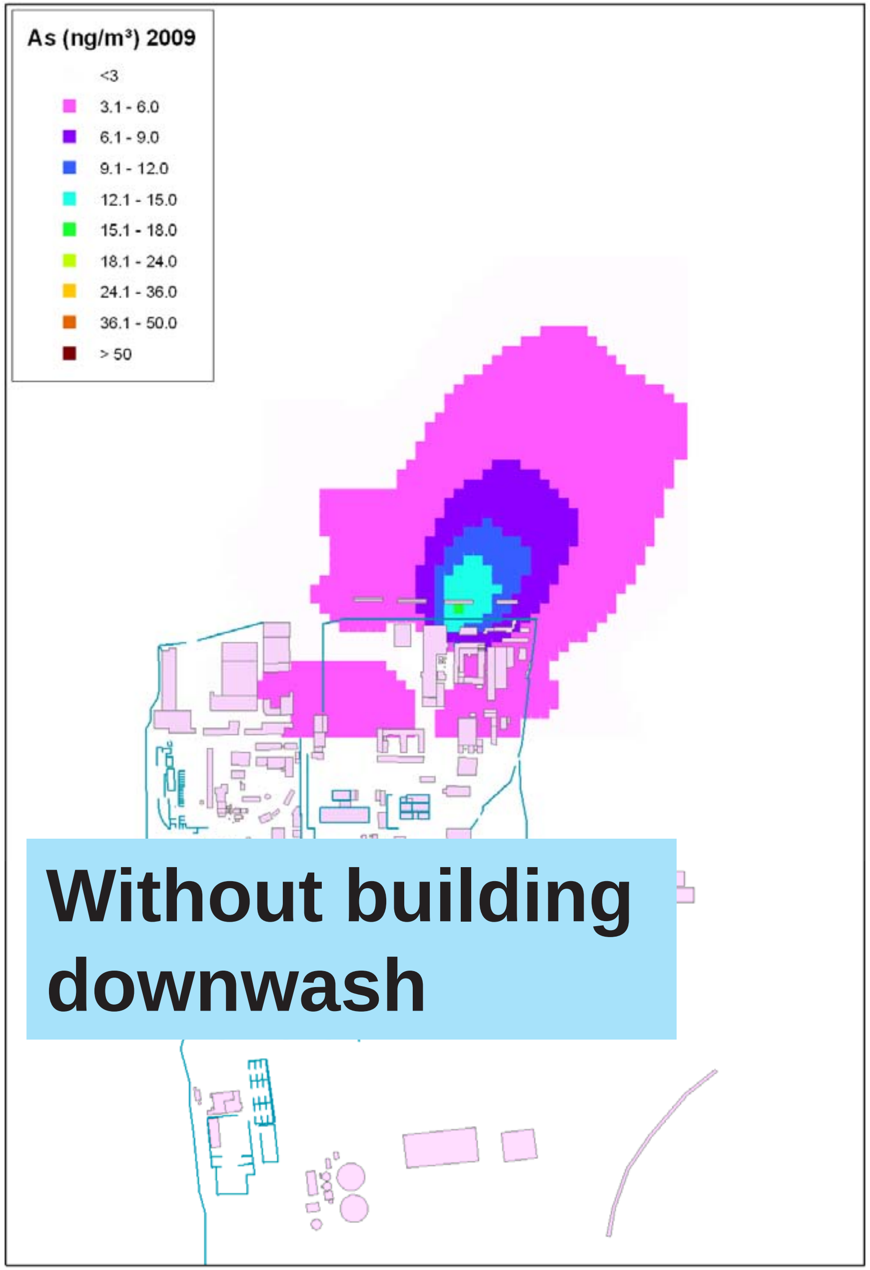
=> extended abstract (formulas 8 and 9)

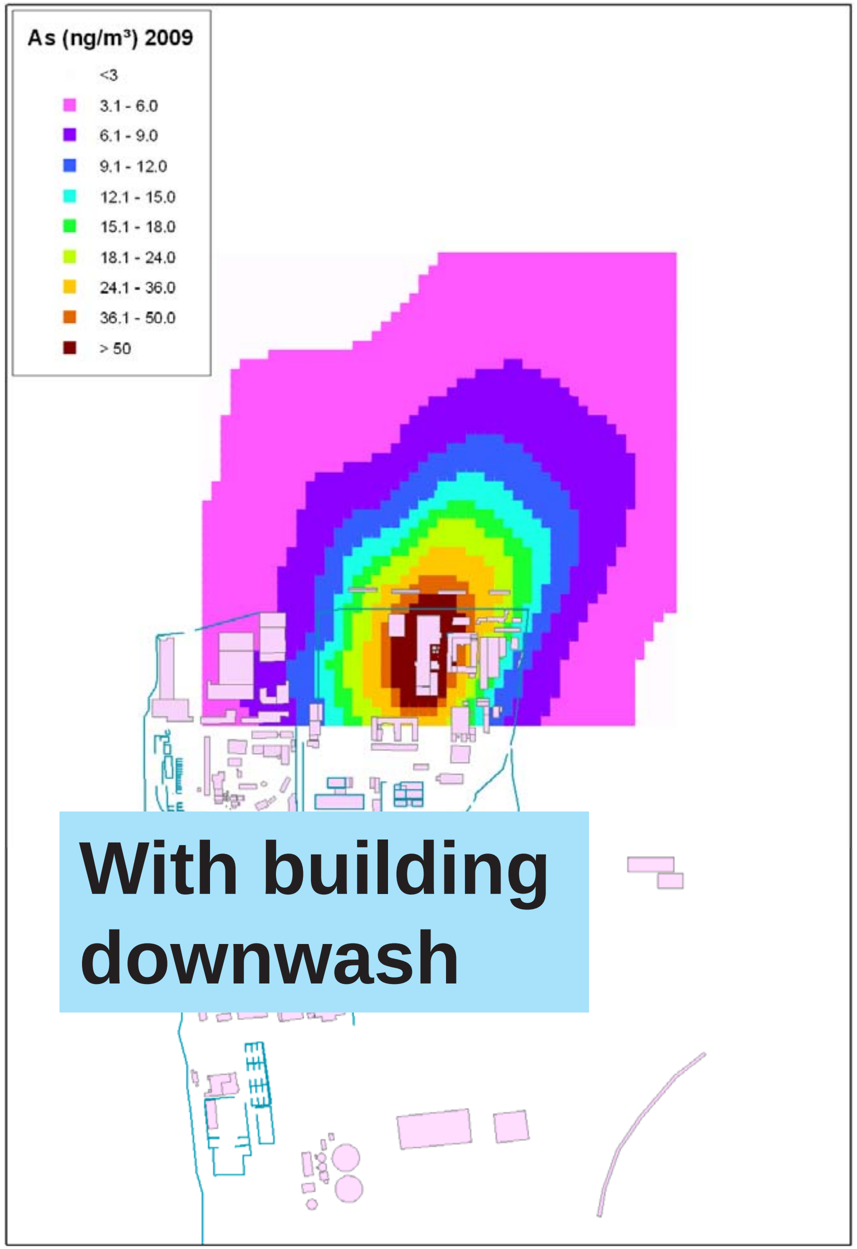
Results: Central moving 14-day averaged As-concentrations: monitoring site in the wake of a building with sources (HB23)



Results: Central moving 14-day averaged As-concentrations: monitoring site not in the building wake (HB17)




As (ng/m³) 2009
<3
3.1 - 6.0
6.1 - 9.0
9.1 - 12.0
12.1 - 15.0
15.1 - 18.0
18.1 - 24.0
24.1 - 36.0
36.1 - 50.0
> 50
Without building downwash


As (ng/m³) 2009
<3
3.1 - 6.0
6.1 - 9.0
9.1 - 12.0
12.1 - 15.0
15.1 - 18.0
18.1 - 24.0
24.1 - 36.0
36.1 - 50.0
> 50
With building downwash

Conclusions

- We presented a new approach to
- building downwash modelling.

- The resulting model reproduces the Thompson wind tunnel data set very well.

- Adaptations were made to apply the model on industrial emissions.

vito
vision on technology