CFD simulation of the impact of a vegitation barrier along a motorway on the local air quality

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Outline

- Intro – project background
- Envi-met model
- Model setup
- Model results
- Conclusions

Introduction

- Air Quality Innovation Project (IPL)
  - Initiated by 2 Dutch ministries:
    - Transport, Public Works and Water Management
    - Housing, Spacial Planning and Environment
- Research programme: stratigies to improve air quality in the vicinity of motorways
- 7 Braches of which:
  - Effect of line vegetation

www.ipluchtkwaliteit.nl

IPL - vegetation

- Investigation effects line vegetation
- Measurement campaigns
  - In situ measurement campaigns
  - Vaassen (2006, 2008), Zetten (2008)
- Modeling campaigns:
  - Validation study
  - Understanding / *quantifying* of the physics

Model description

- Envi-met: Micro climate + Air quality
  - Prof. M . Bruse, University of Mainz, Germany (www.envi-met.com)
- CFD based
  - Reynolds Averaged Navier Stokes
  - K-ε Turbulence model
  - Resolution 1 – 10m
- Soil model
  - Water content
  - Temperature
- Radiative flux model
  - Sw / Lw
  - Clouds / shadows
- Gas/PM dispersion model
  - Dry deposition
  - Ozone chemisry: $NO + O_3 \leftrightarrow NO_2 + O_2$
- Vegetation model

Vegetation module

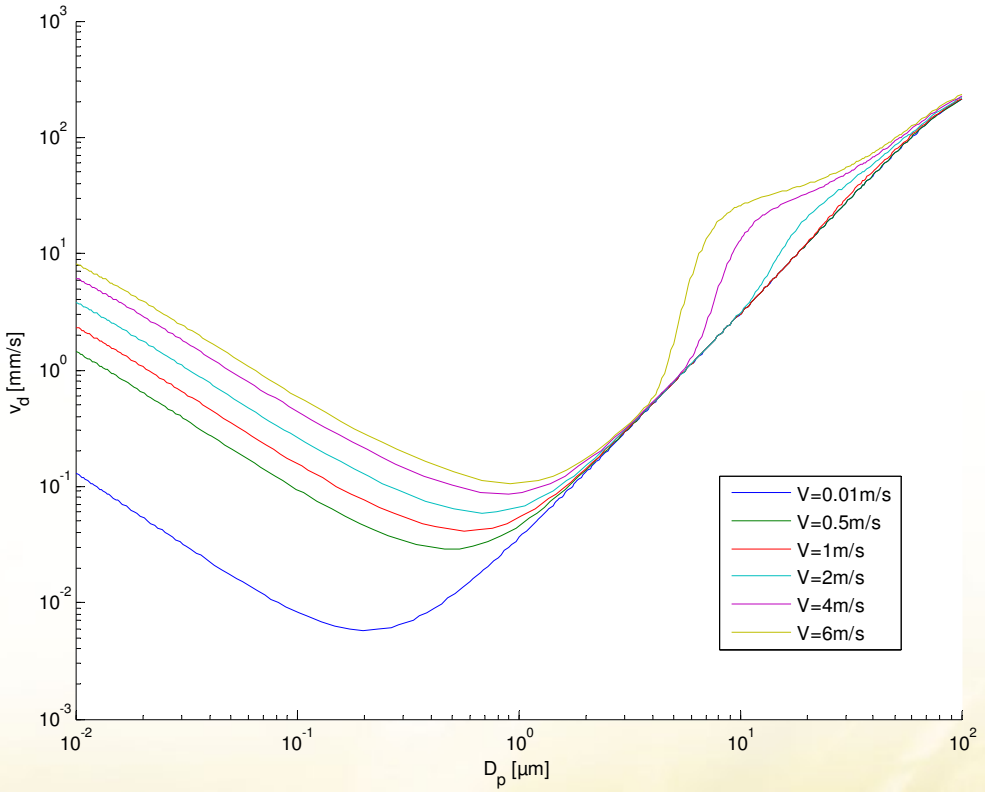
- Porous elements
- Momentum: $S_i = c_d LAD\, V\, u_i$
- Turbulence: $Q_E = (V^2 - 4E) c_d LAD\, V$

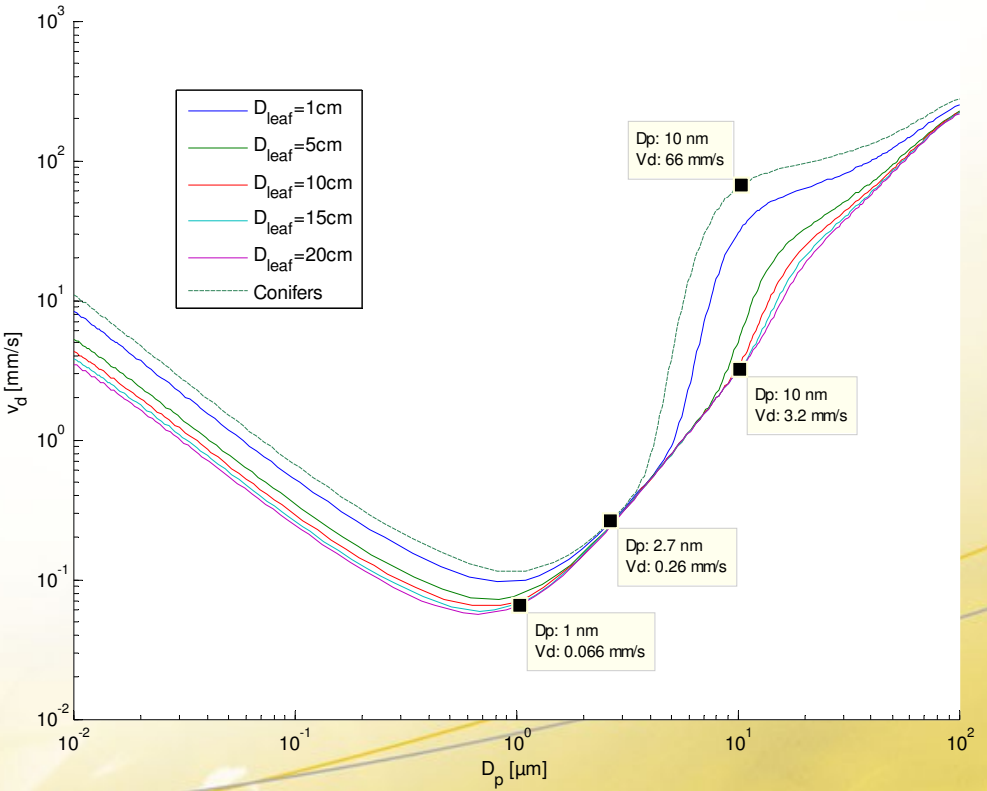
  $Q_\varepsilon = (1.5V^2 - 6\varepsilon) c_d LAD\, V$

- Deposition inside vegetation:
  - Gas: $v_d = (r_a + r_b + r)^{-1}$
  - PM: $v_d = (r_a + r_b + r_a r_b v_s)^{-1} + v_s$

$$r_a = A\sqrt{D/V}$$

Vegetation deposition model PM

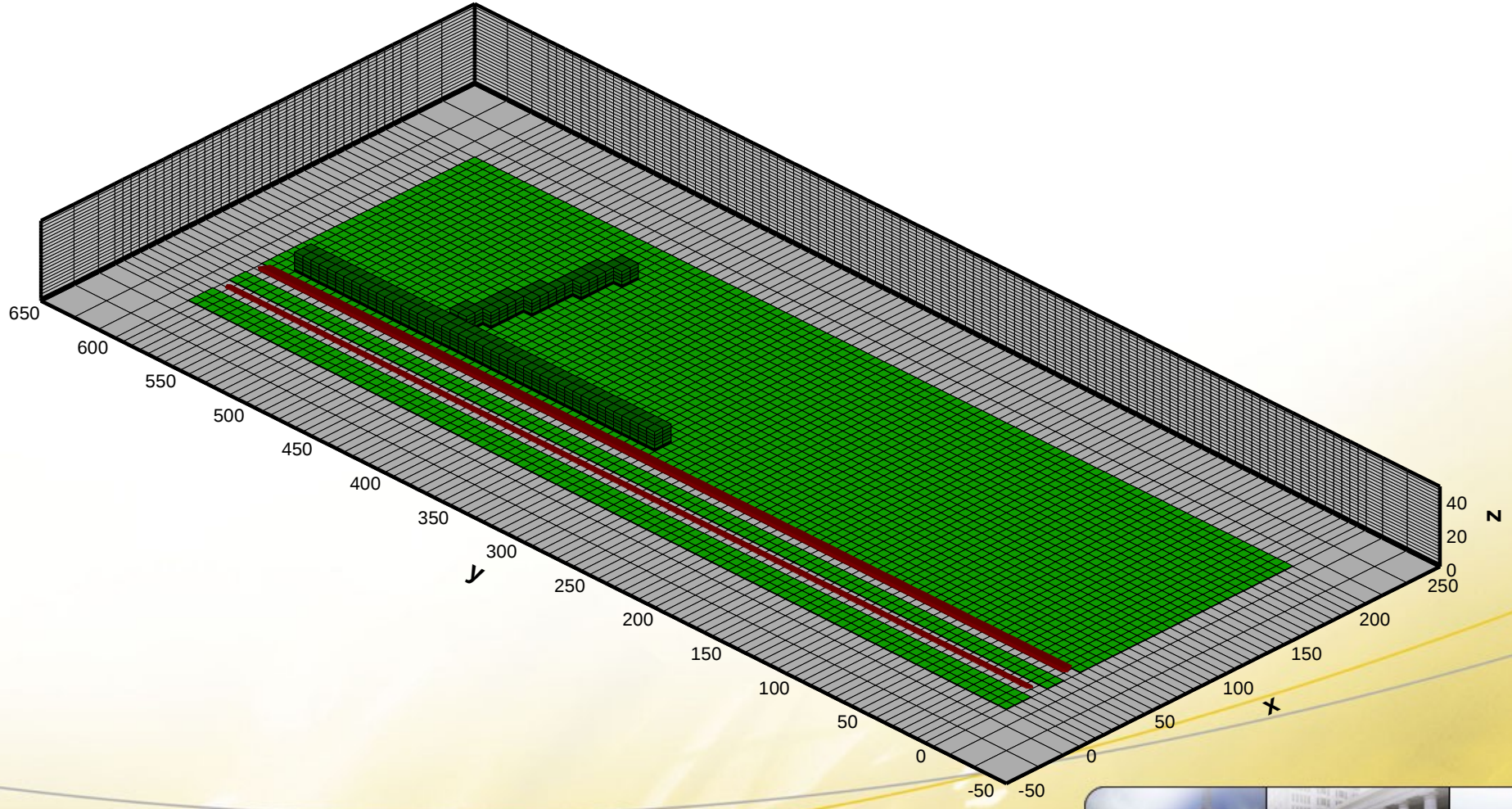




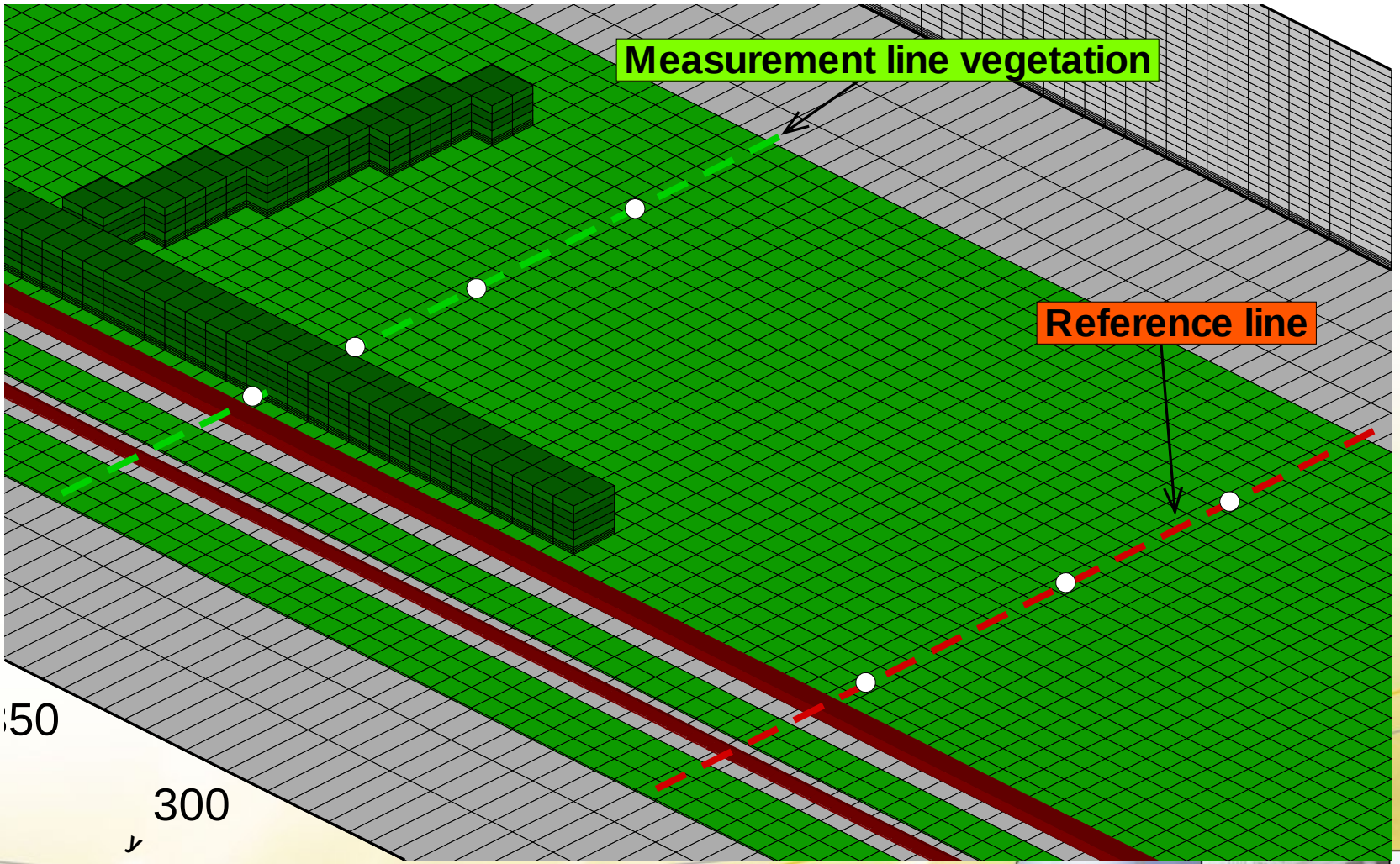
Model setup

- $x \times y \times z = 200 \times 600 \times 50m$
- $\Delta x \times \Delta y \times \Delta z = 6 \times 6 \times 2m$
- 121.688 nodes
- 5 days modeled ~ measurement campaign
- Wind components
- Temperature, humidity
- Lw/sw radiation
- Gas components: CO_2, NO, NO_2, O_3
- $PM_{2.5}$, PM_{10}

CFD Mesh



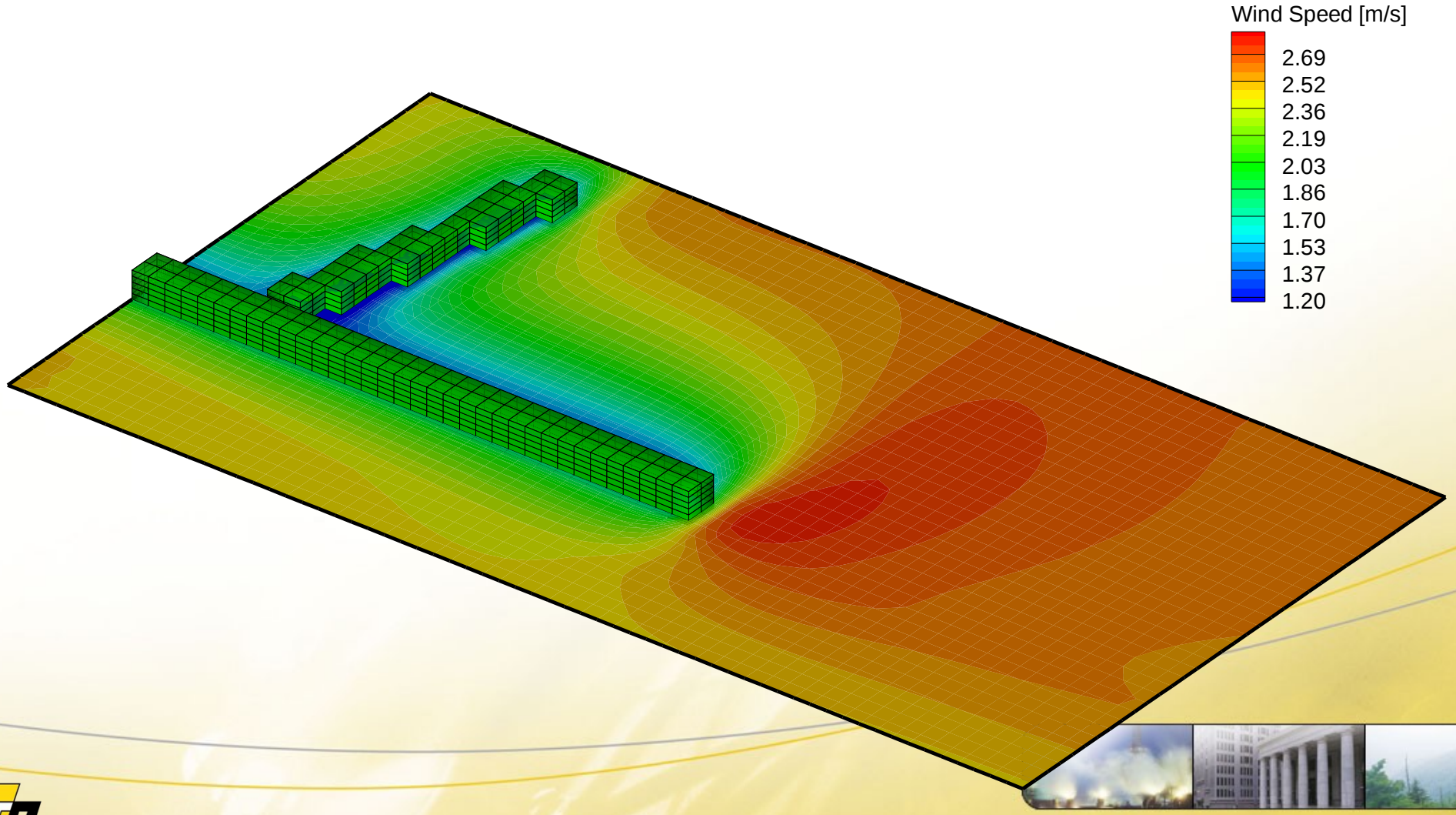
Mesh detail



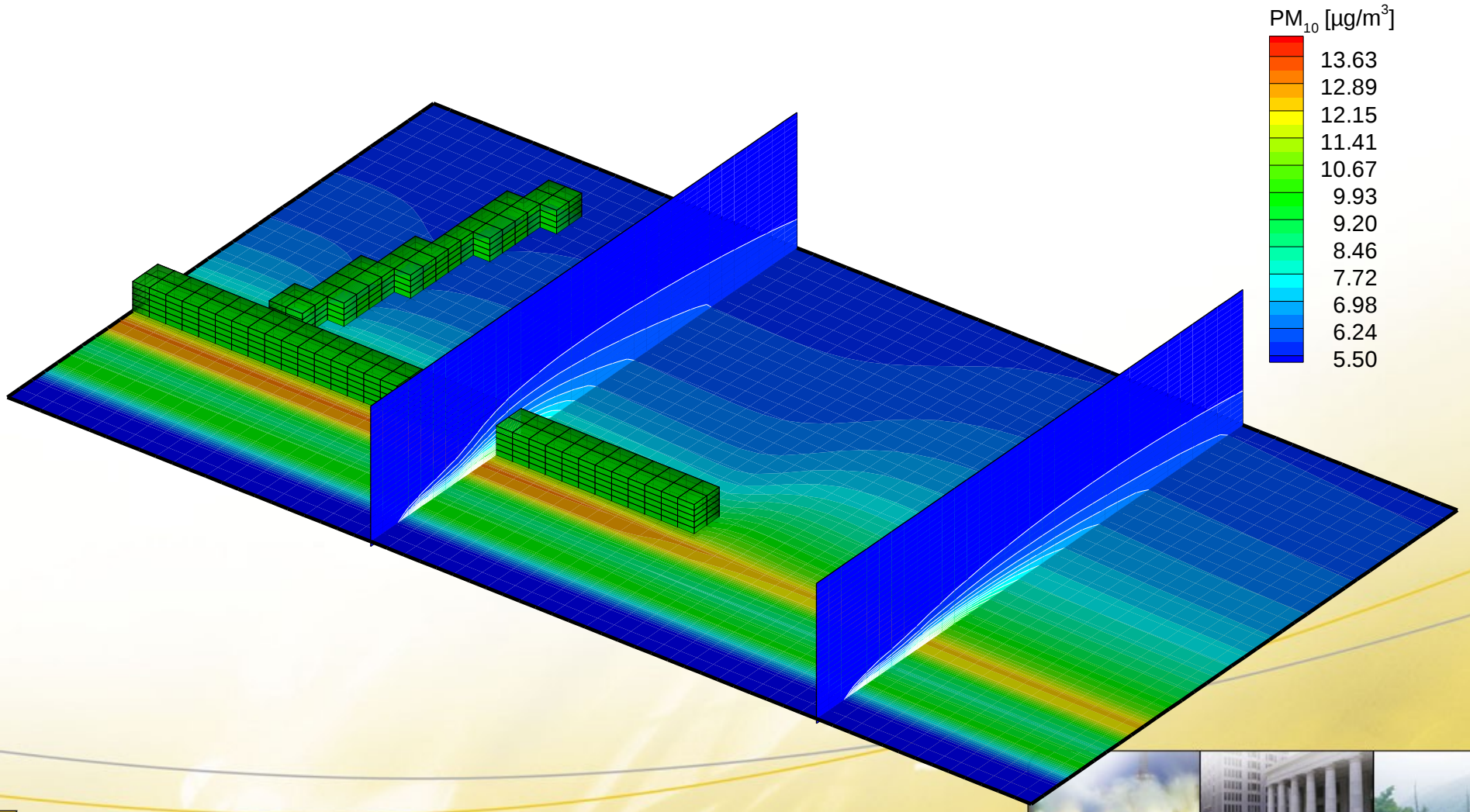
Model uncertainties

- No upwind measurements
  - Meteo boundary conditions: HIRLAM
  - Background bdc's: 3 measurement stations
- Leaf Area Density: *'quite dense'*
- Traffic emissions:
  - PC-HDV counts per lane
  - VROM emission factors
- No O_3 or radiation measurements (validation of ozone chemistry module…)

Mean wind speed at 2m height

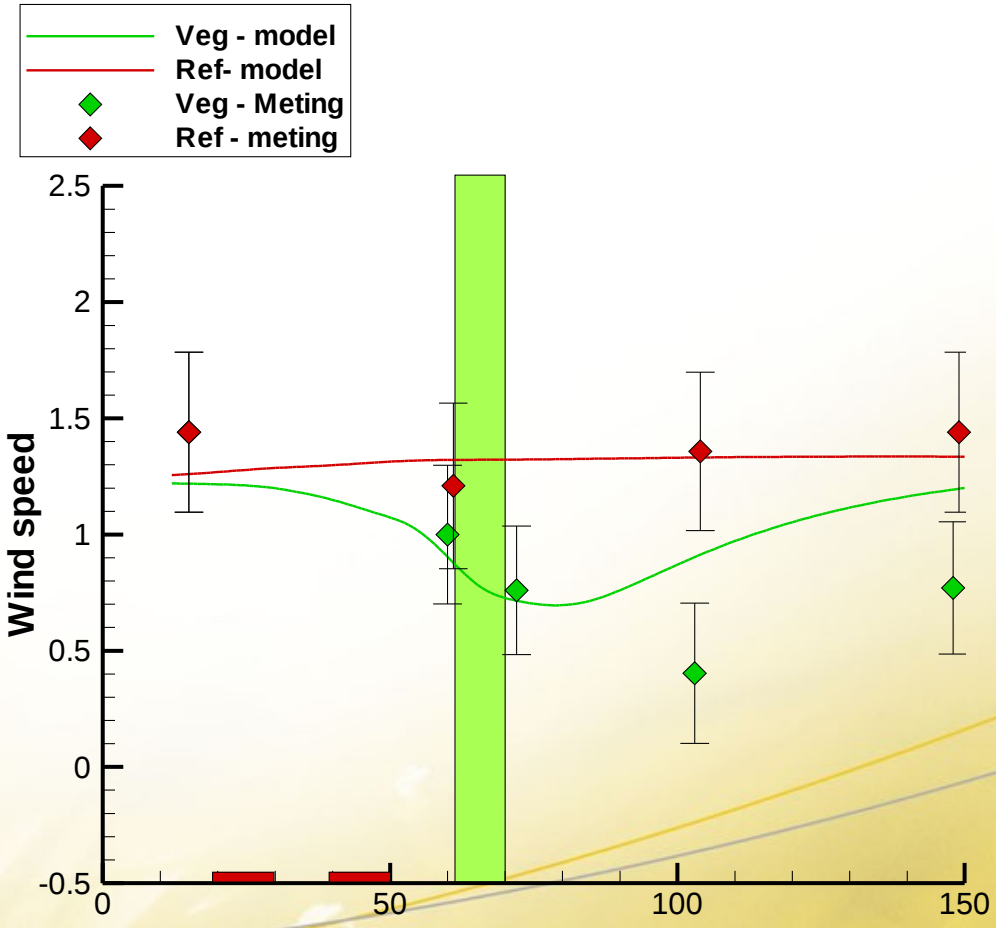


Mean PM_{10} at 2m height + crossectional planes

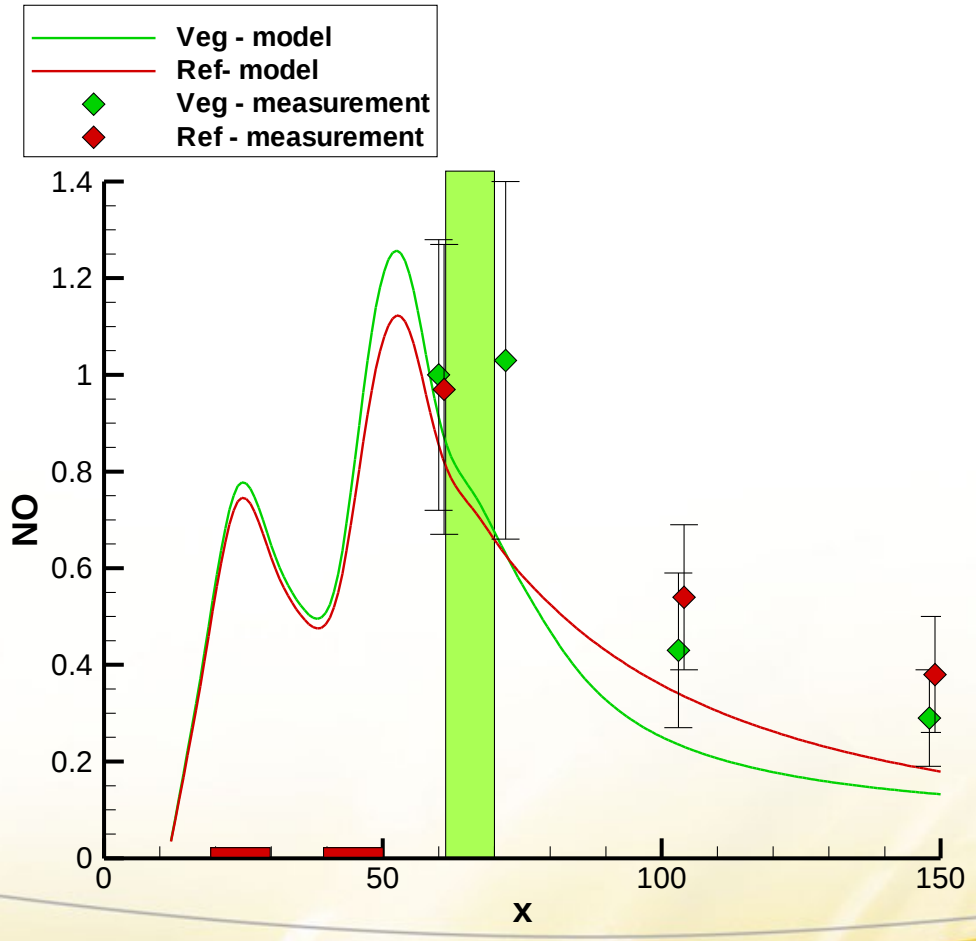


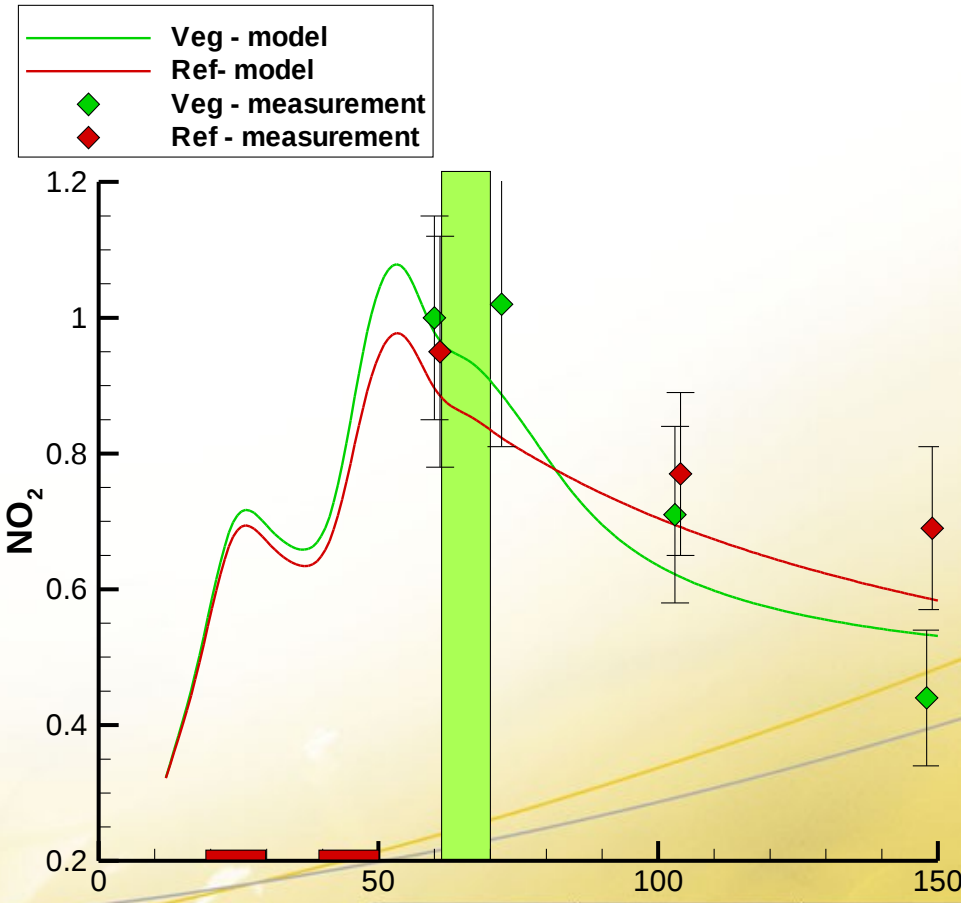
Comparison measurements

- Normalized mean
- 5 day measurements (3 days for PM)
- Limited measurment data due to exceptional weather conditions
- No turbulence measurements

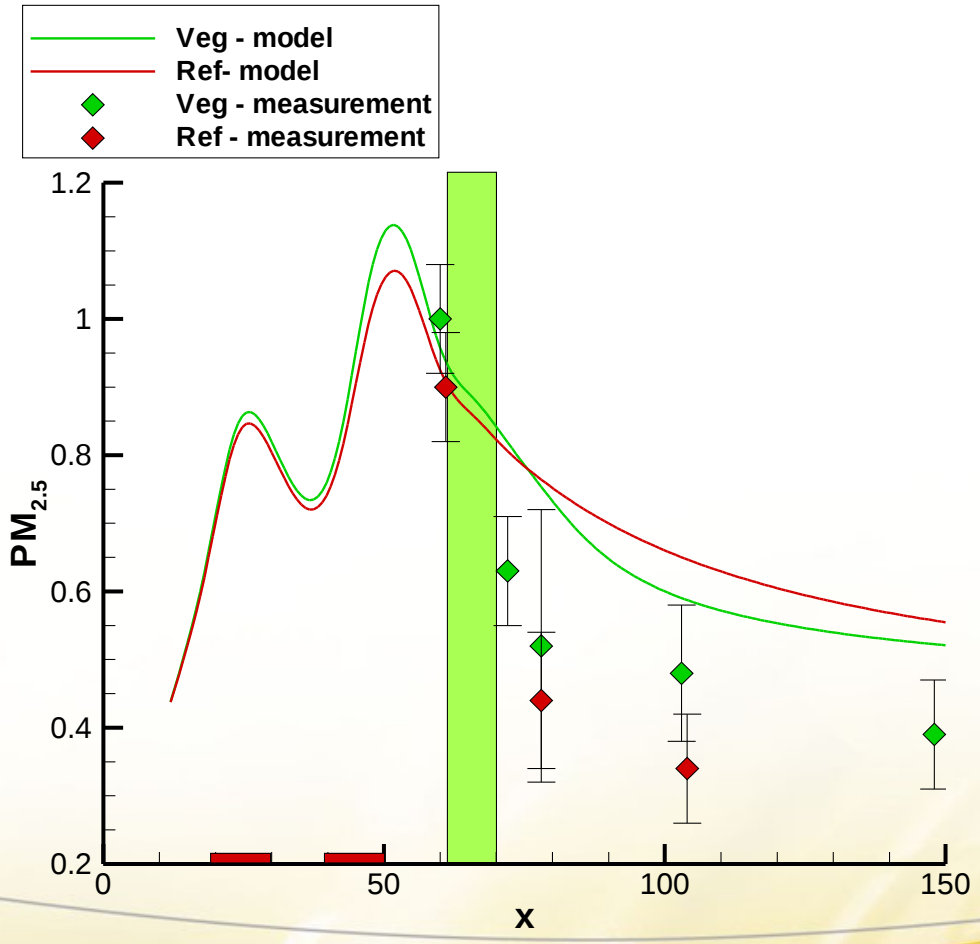


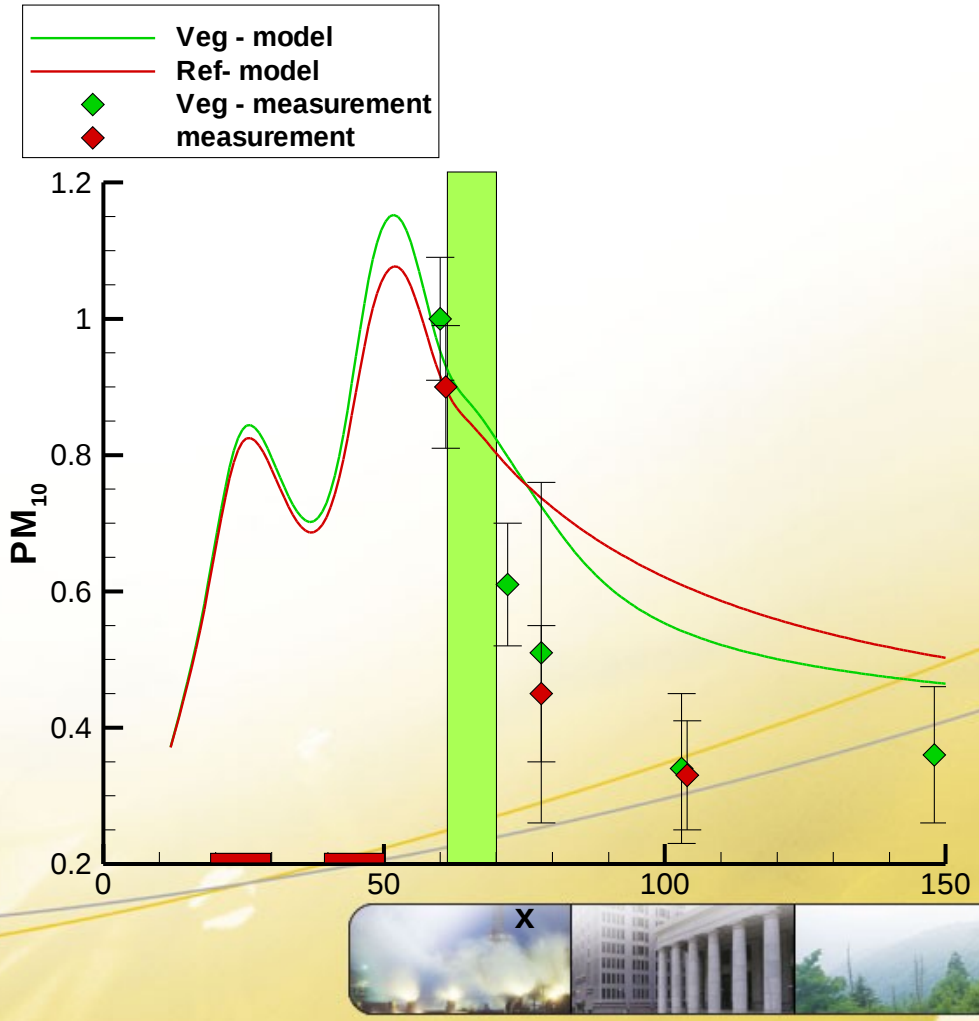
Normalized averages: NOx



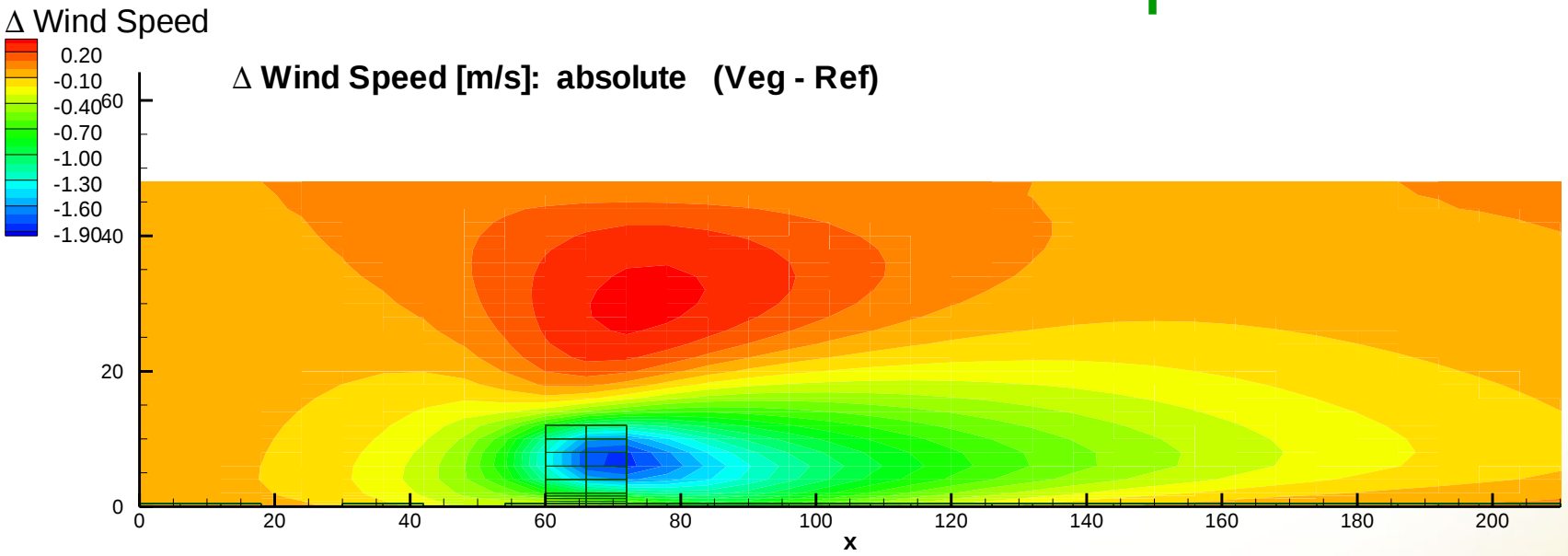


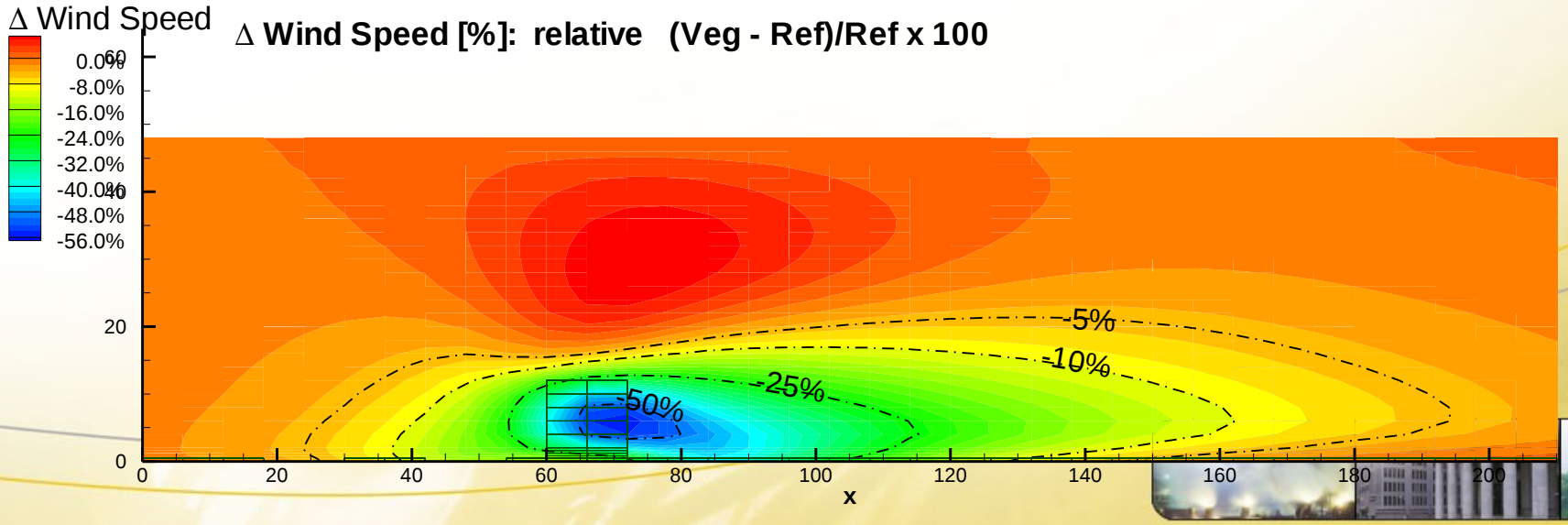
Normalized averages: PM



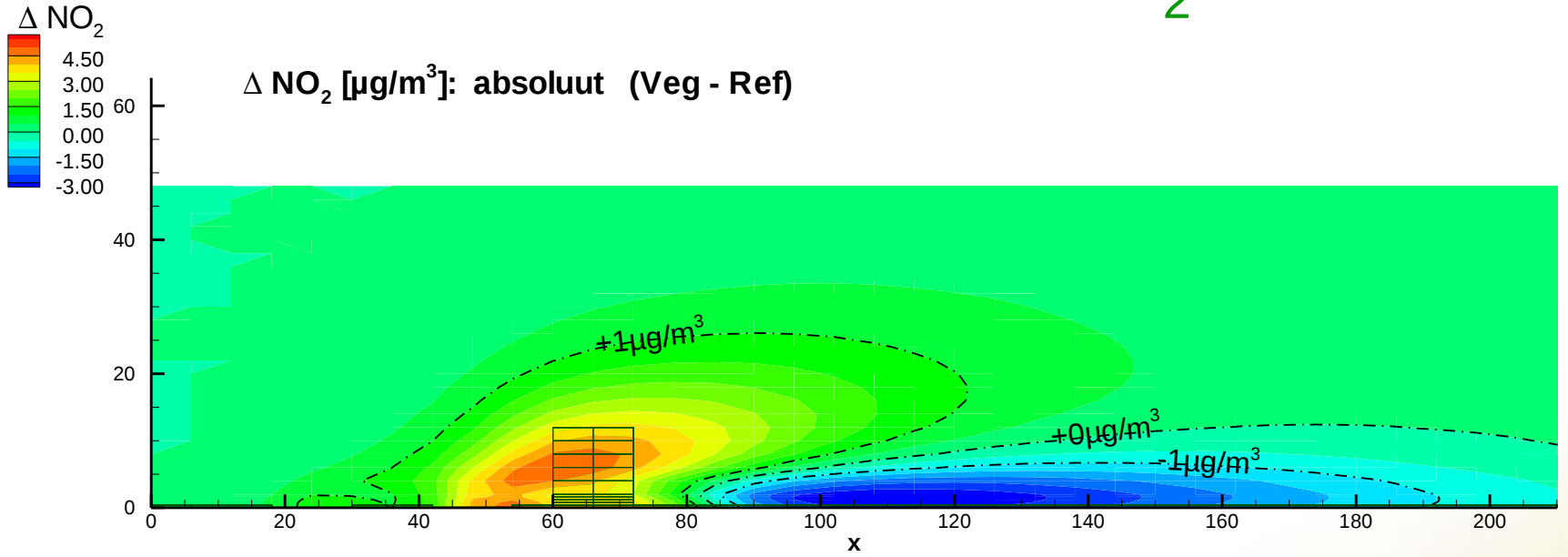


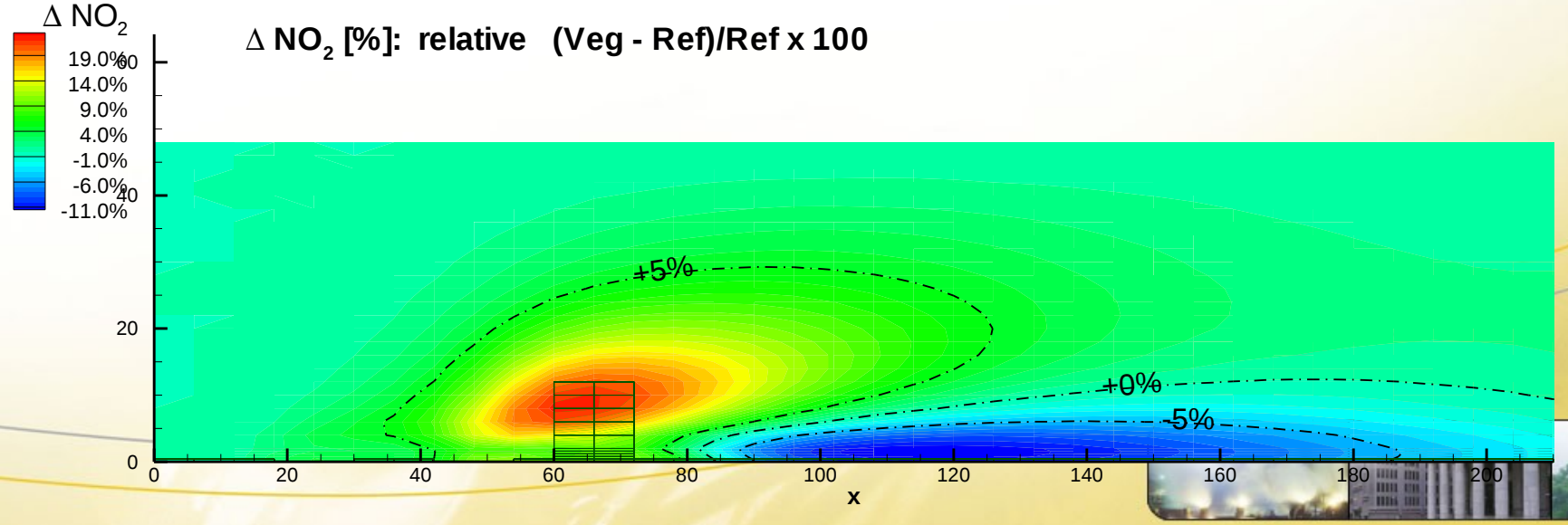
Mean effect on wind speed



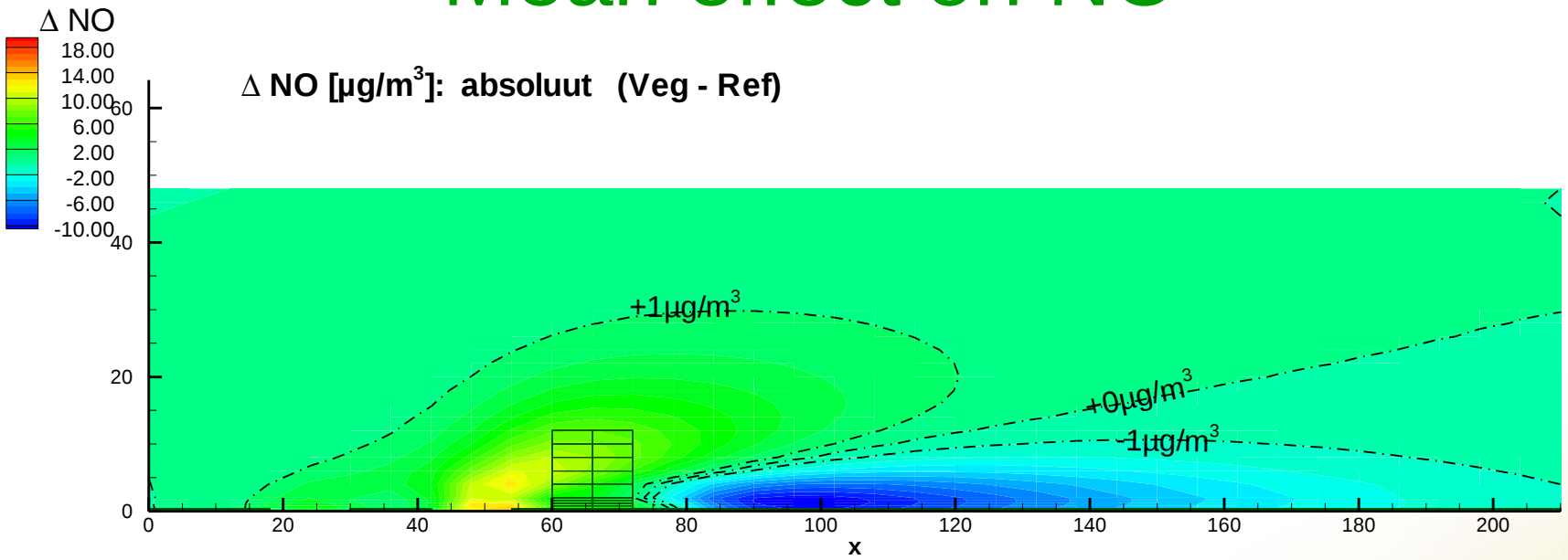


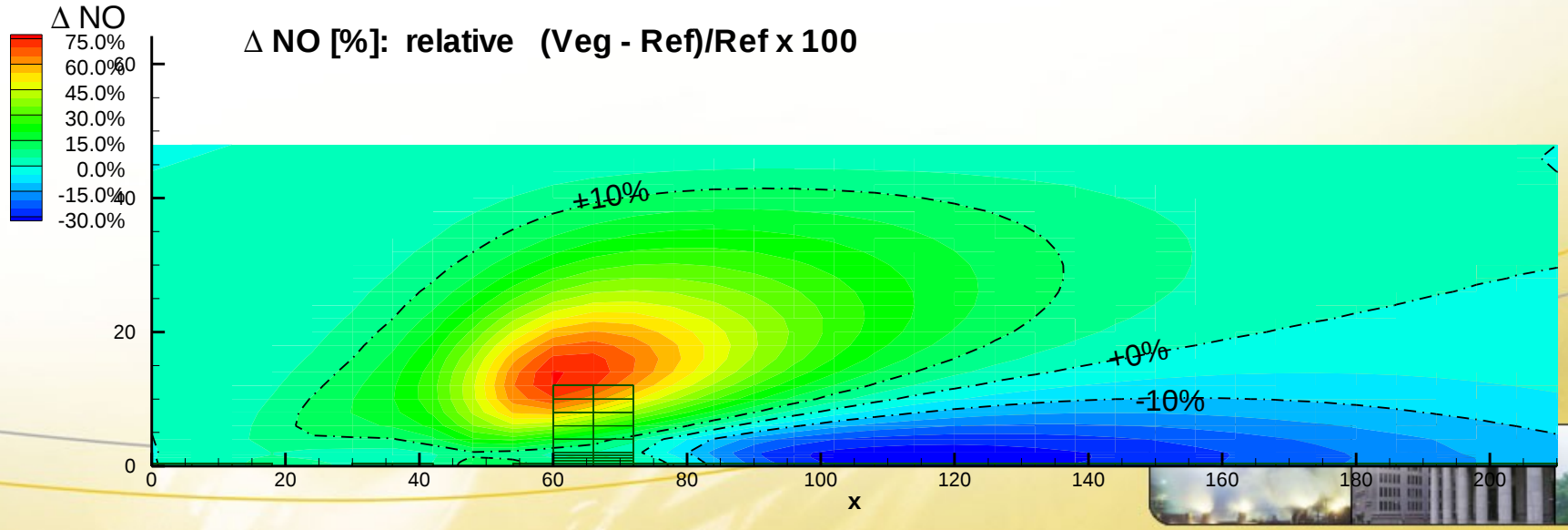
Mean effect on NO_2



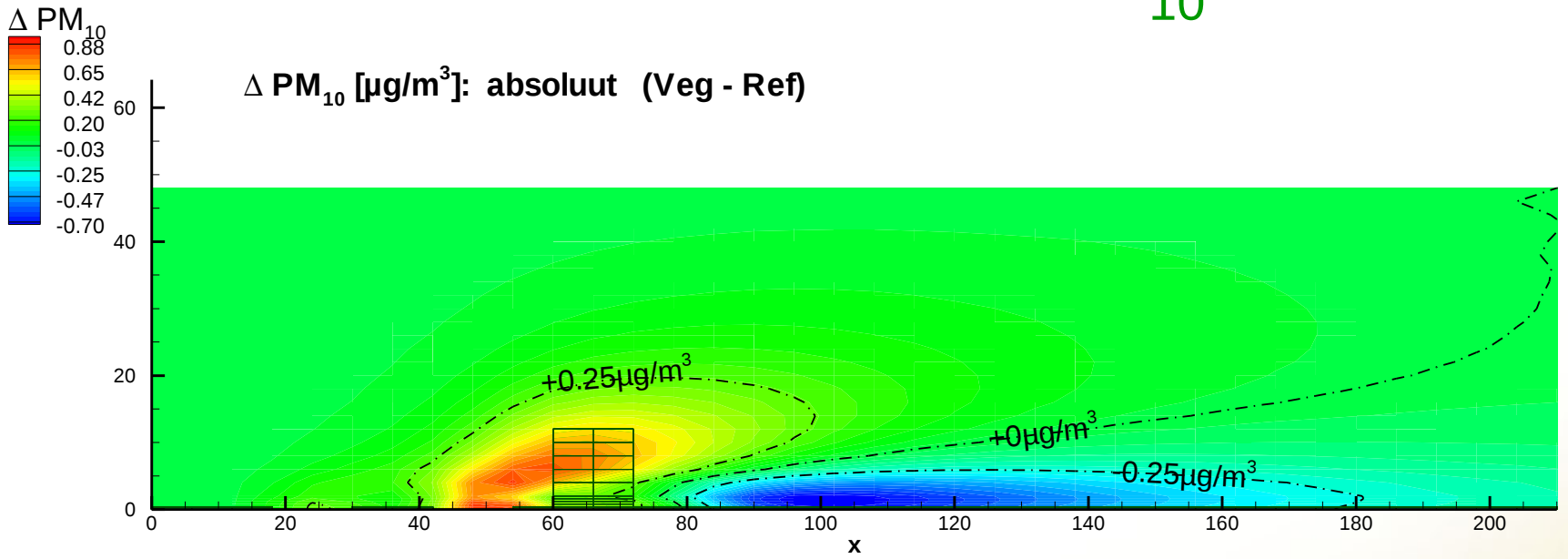


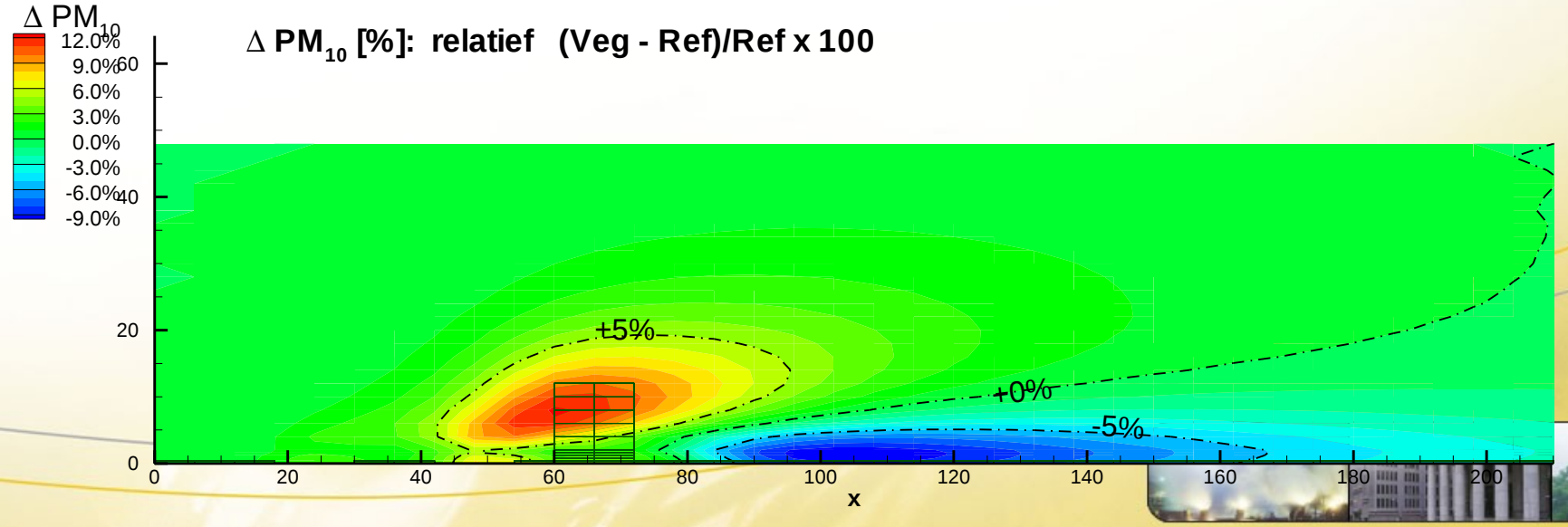
Mean effect on NO





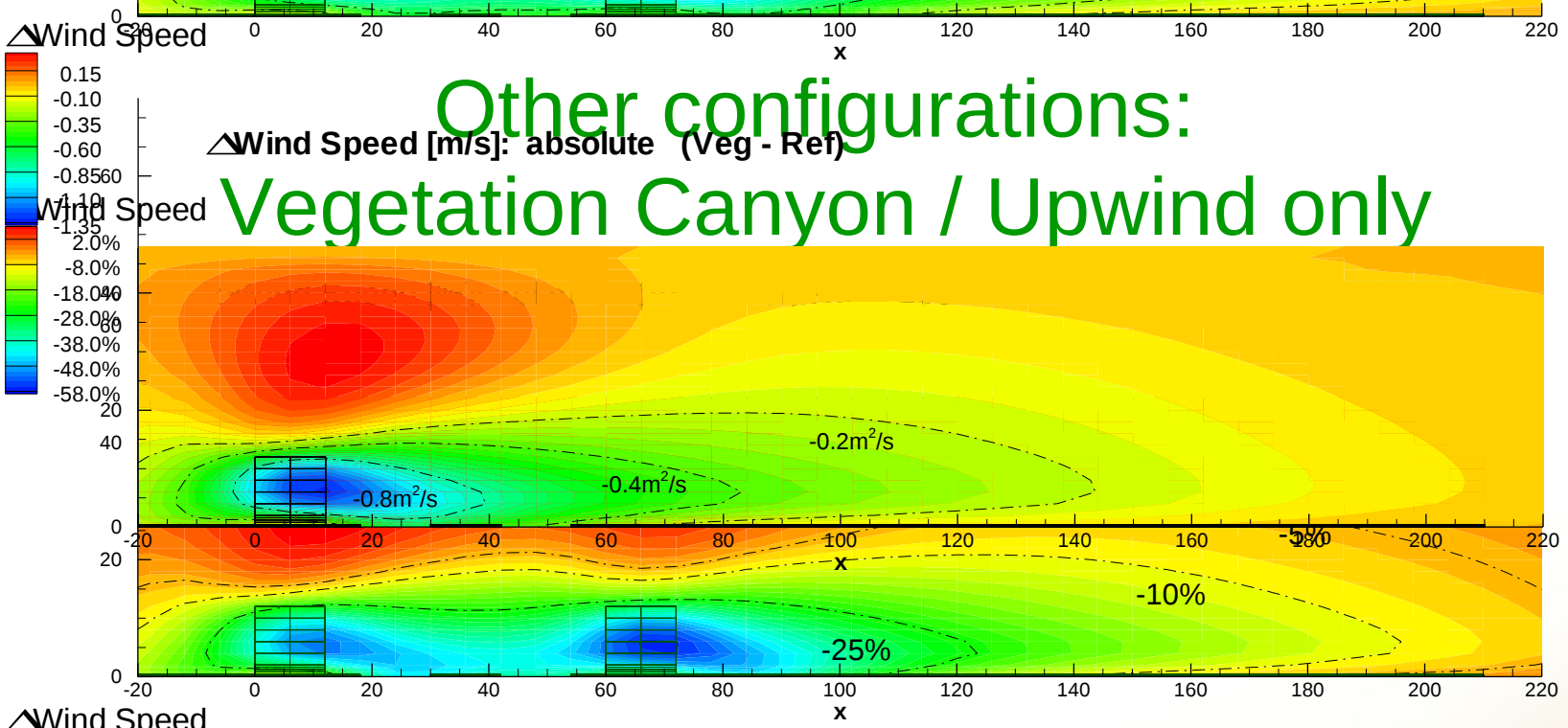
Mean effect on PM_{10}

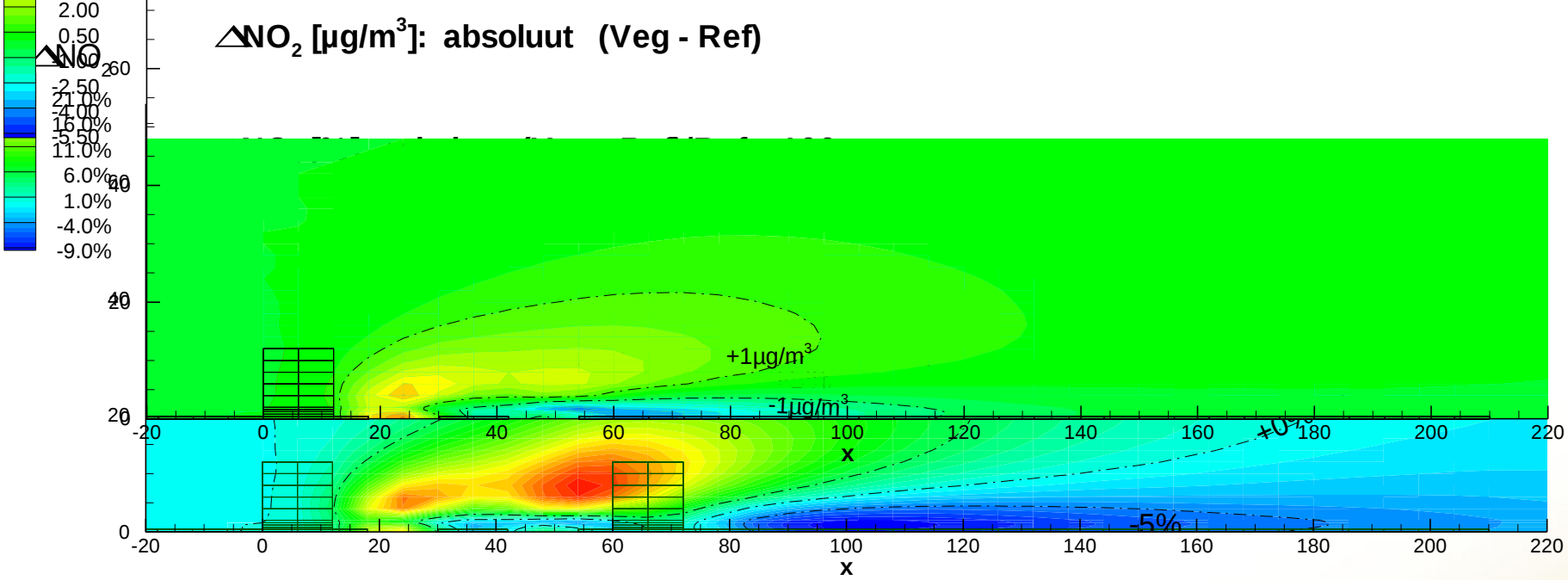


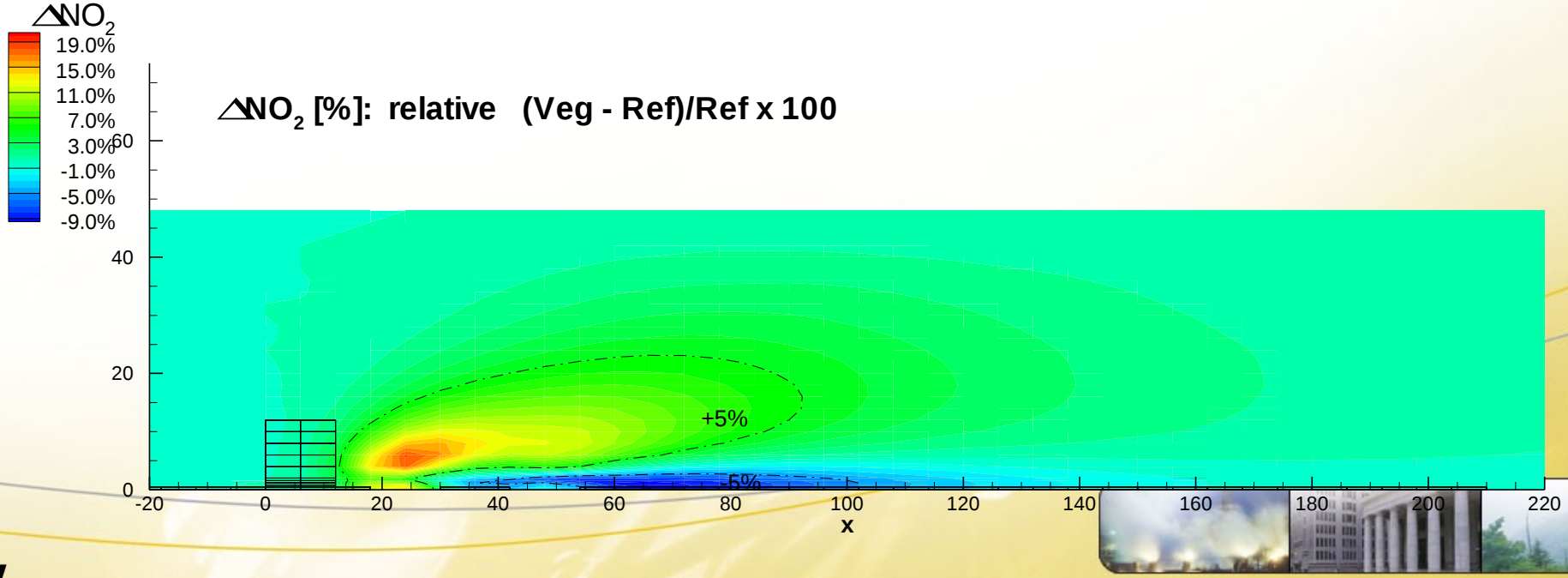


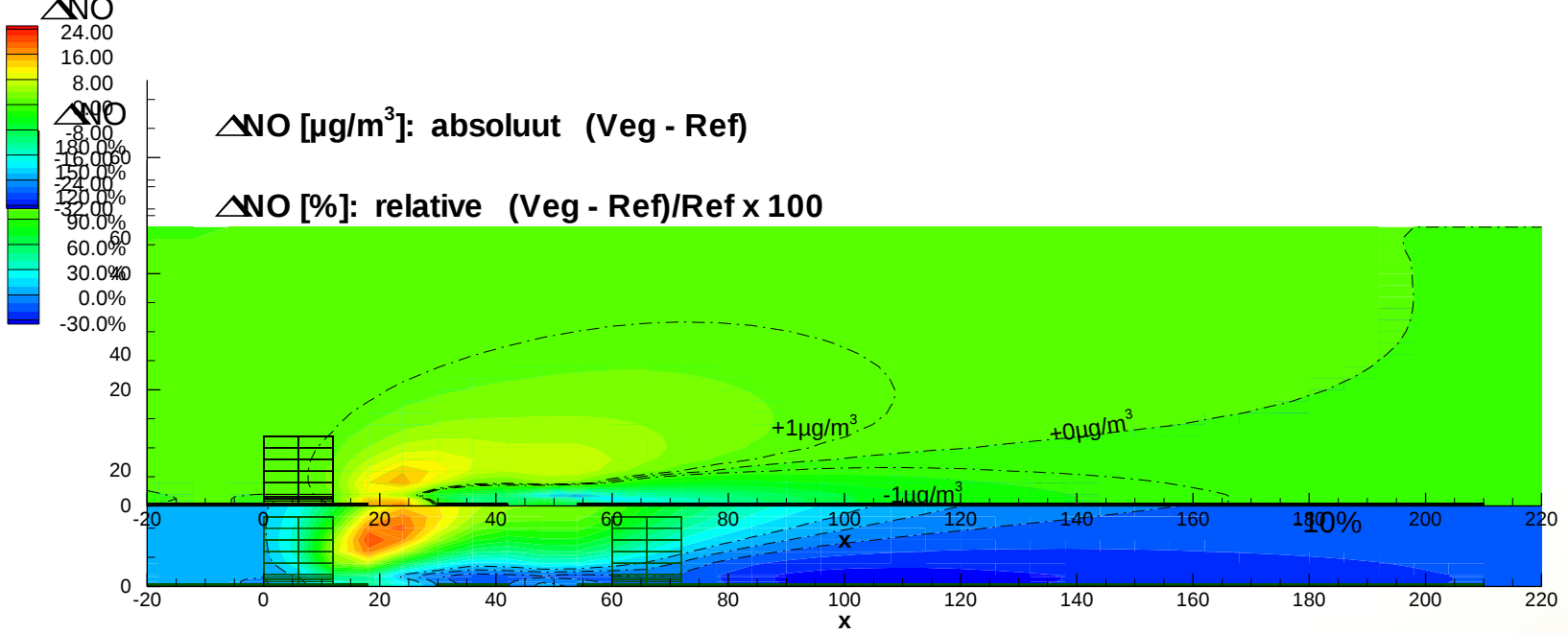
Other configurations:

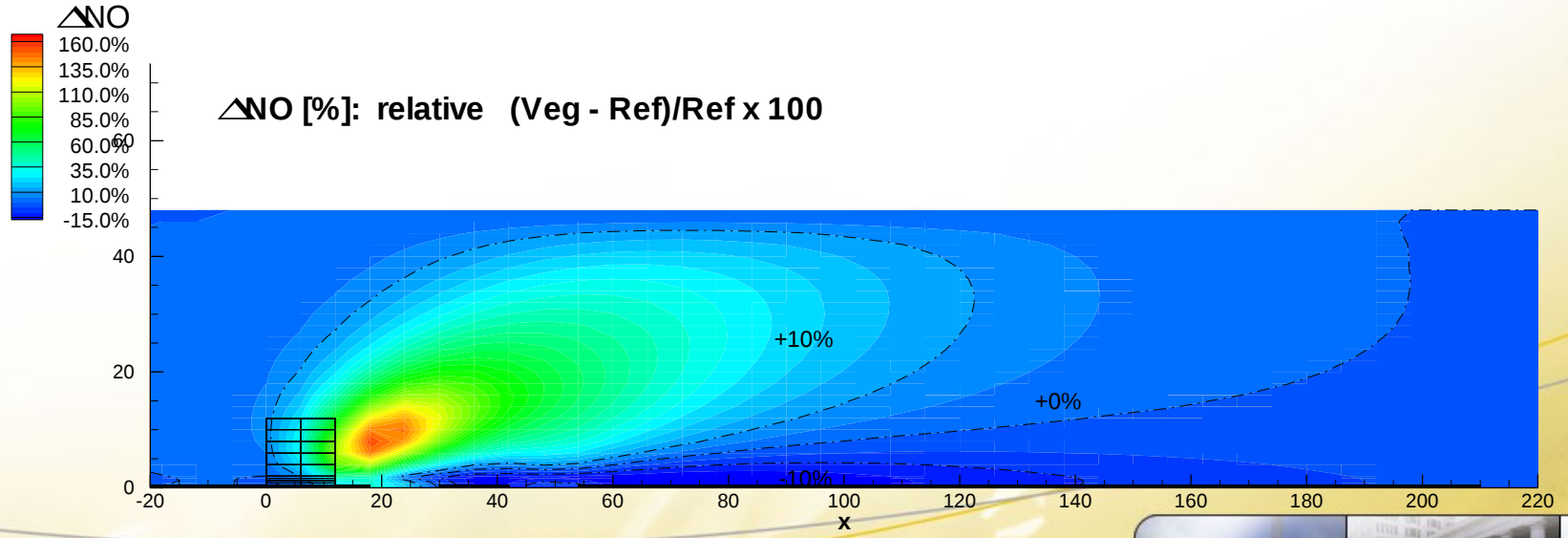
Vegetation Canyon / Upwind only

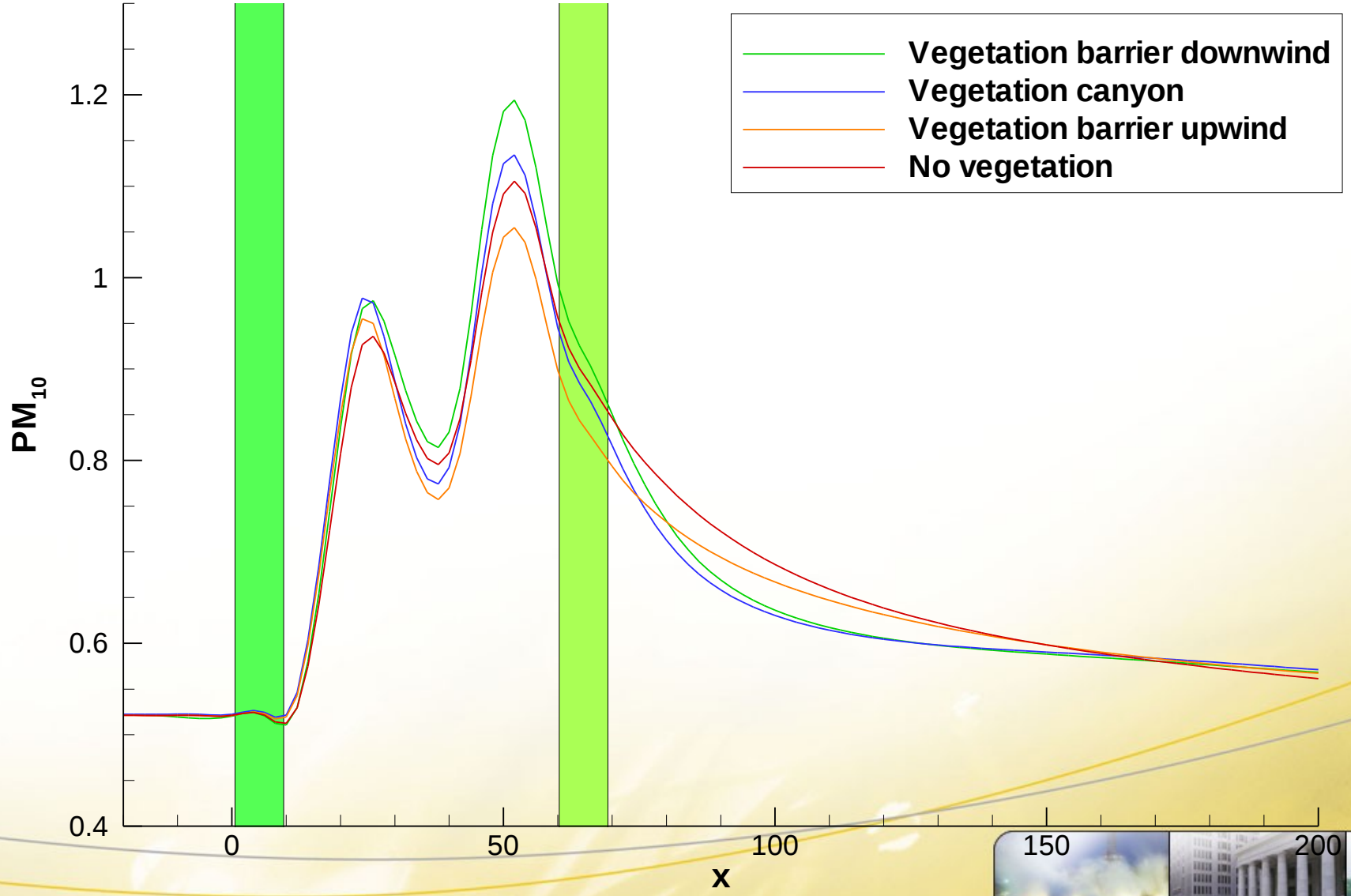












Conclusions

- Detailed measurements background concentrations / meteo conditions necessary
- Turbulence measurments desired
- Reasonable results wind speed, NO
- NO_2 systematically underestimated
- Vegetation barriers can have a local effect on air quality