The Importance of Terrain and Building Definitions for Transport and Dispersion CFD Simulations of Pollutants

Fernando E. Camelli[1]
David W. Wong[2]
Mukul Sonwalkar[2]
Rainald Löhner[1]

[1] Department of Computational and Data Sciences
[2]Department of Geography and Geoinformation Science,
George Mason University
Fairfax, VA 22030

Outline

- FEFLO-Urban model description
- CFD and GIS
- Simulation set up
- Comparison: Raster and Flat
- Comparison: Building Heights
- Conclusions
- Future work

FEFLO-URBAN Model

- Pre-Processing
  - CAD → FECAD
  - Grid generation → FRGEN3D
- Solution
  - Flow solution → FEFLO
- Post-Processing
  - Visualization → ZFEM

Inputs for CFD Models

- Topography of landscape
- Building heights with footprints (locations)
- Other characteristics:
  - Surface roughness
  - Vegetative covers
  - Building materials
- Data are 3D in nature
- Some are commonly stored in GIS

From GIS Data to CFD

- Critical GIS data for CFD: topography
- Three typical GIS formats:
  - Contours
  - Raster (DEM)
  - Triangulated irregular network (TIN)
- Research Questions:
  - ***How efficient is to use 3D GIS data for CFD models? (automate the data conversion)***
  - ***How sensitive are CFD results to different input formats?***

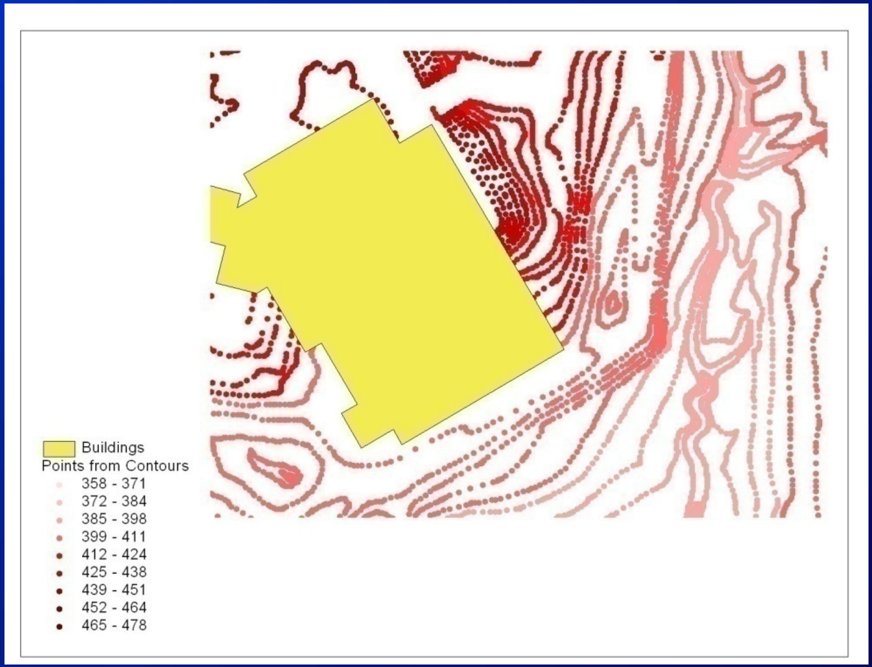
George Mason University, Fairfax, VA

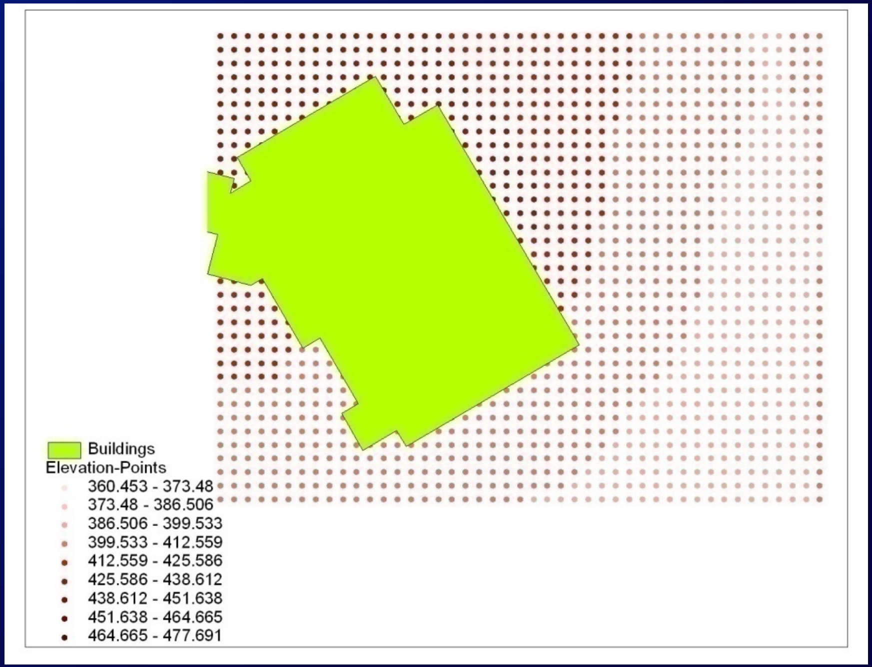
GIS Data

- Topographic and Building data for GMU-Fairfax campus, VA
- Original data: 5-feet contours
- Converted to raster (grid) and TIN

Step 1: Exporting GIS Data

- For 3D data to be used by CFD models, topographic data have to be converted into points with elevation

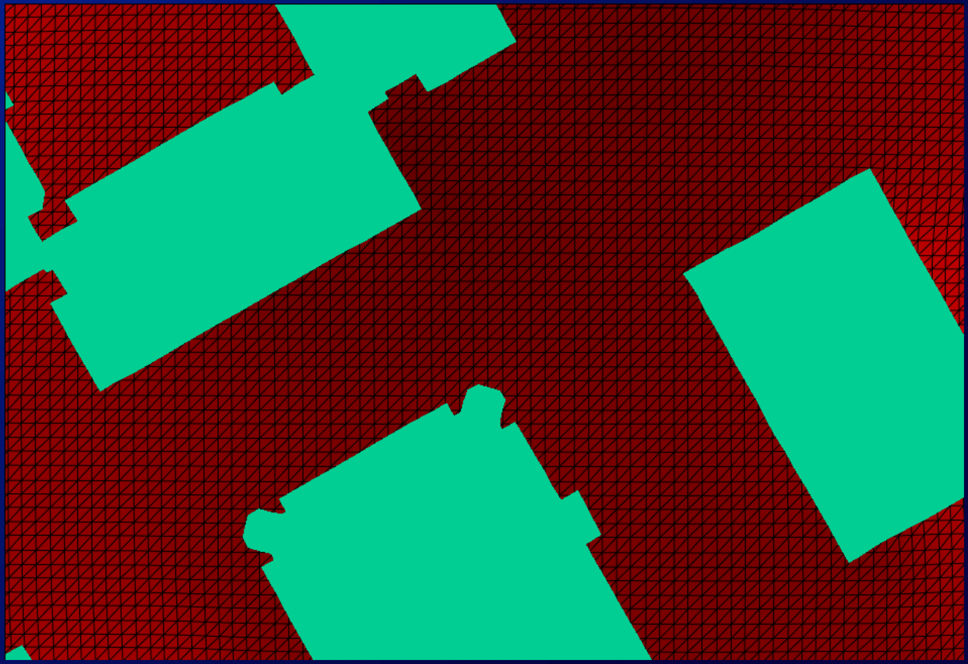


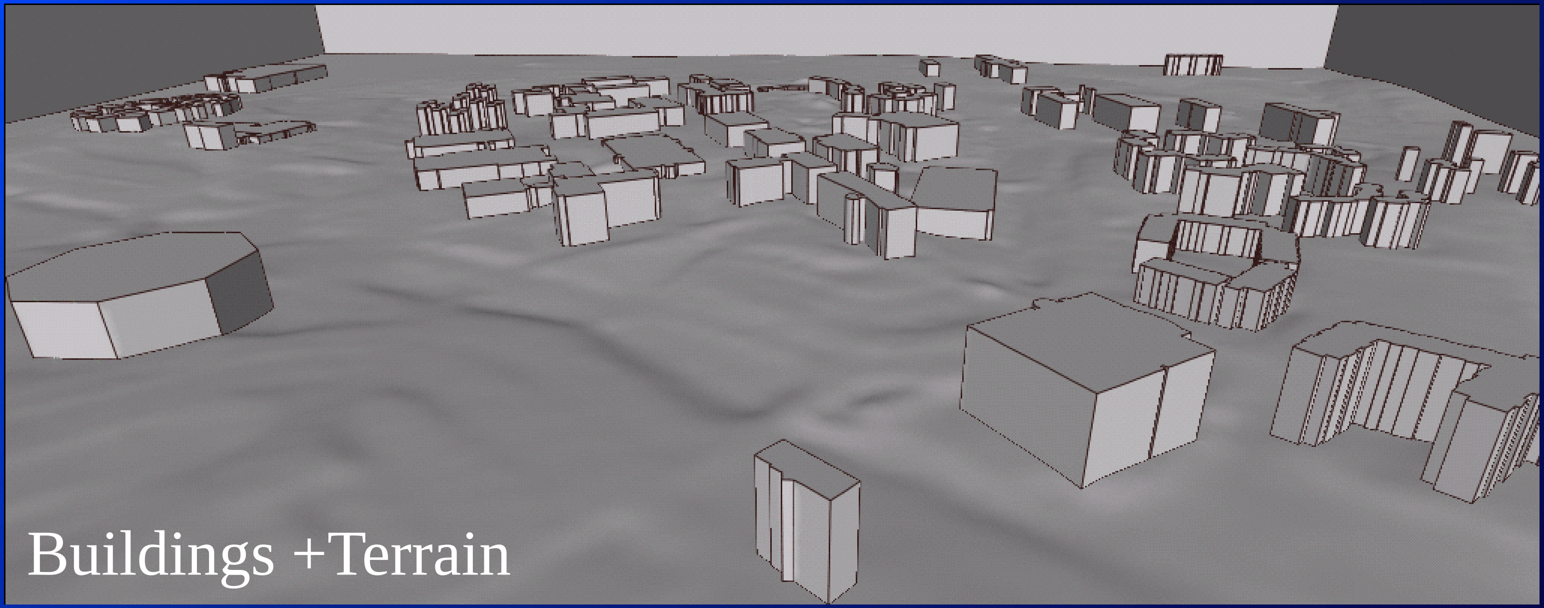


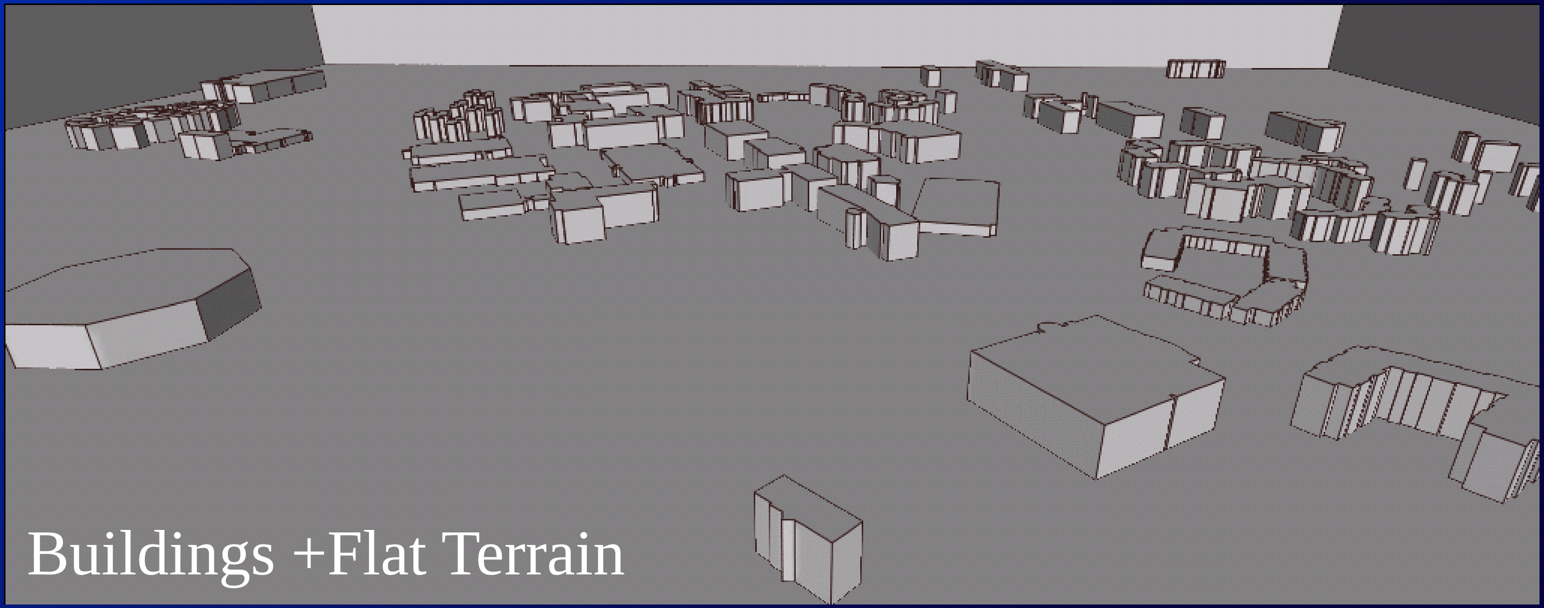
Step 2: Input for CFD

- A mesh has to be built based upon points data with elevation

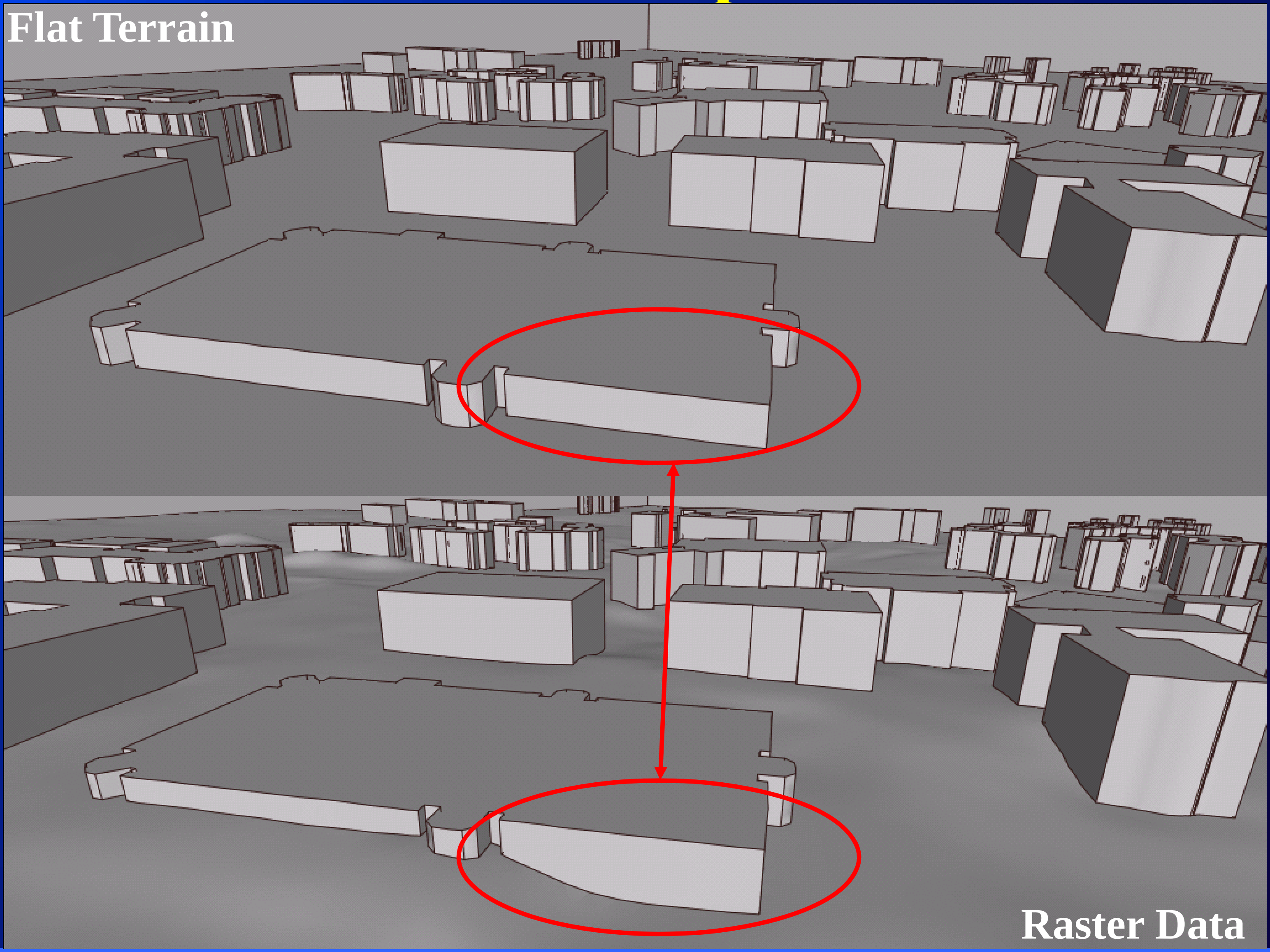
Raster Data – Zoom



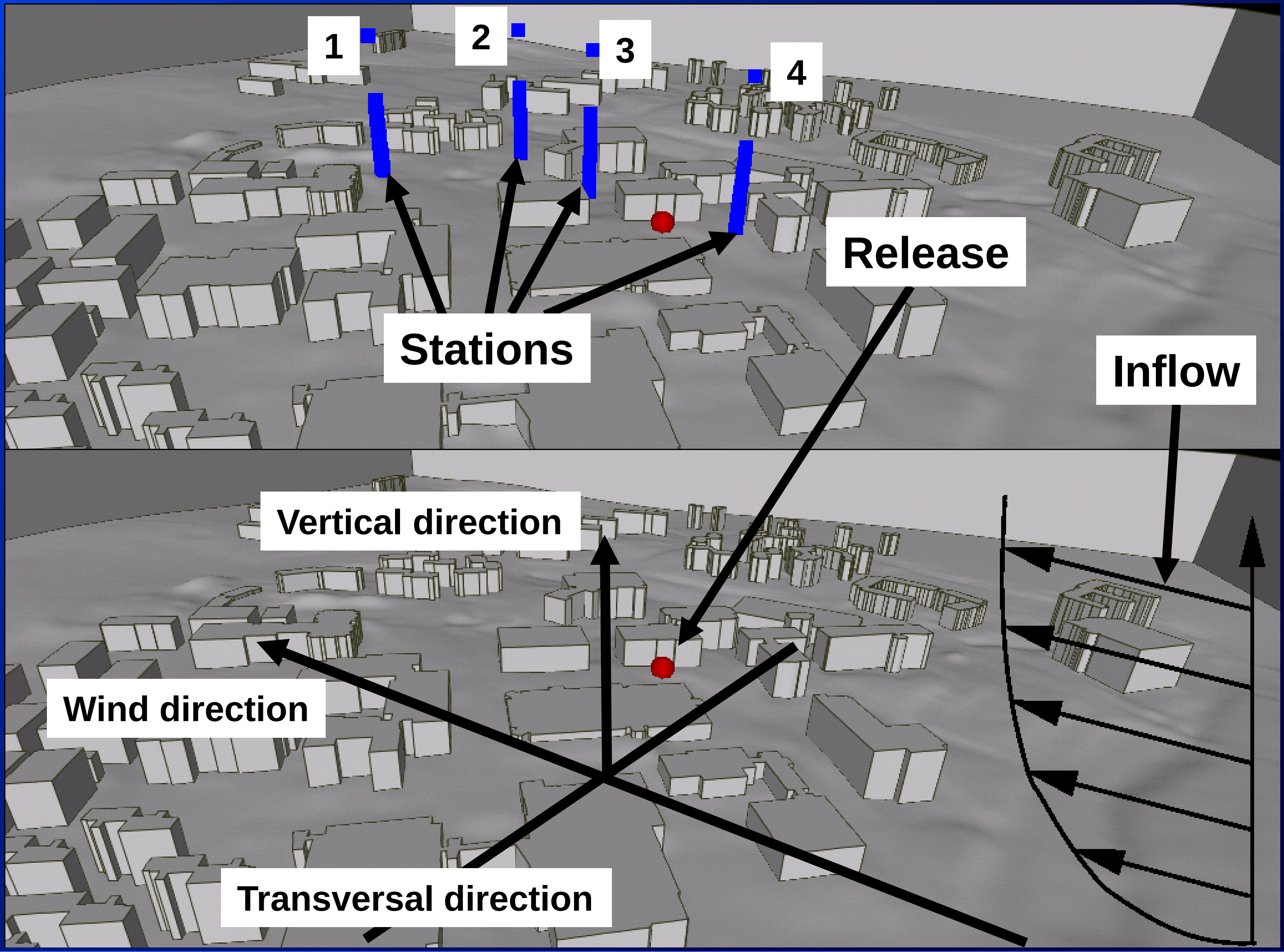

Buildings +Terrain


Buildings +Flat Terrain

Surface Comparison



Step 3: CFD Simulation



Navier-Stokes and Concentration Equations

- Conservation of mass $\nabla \cdot \mathbf{v} = 0$
- Conservation of momentum $\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} + \nabla p = \mu \nabla^2 \mathbf{v}$
- Transport and diffusion $\frac{\partial c}{\partial t} + (\mathbf{v} \cdot \nabla) c = \nabla \cdot (D \nabla s)$
- No buoyancy effects considered
  - Neutral adiabatic case

Solver

- FEFLO $\rightarrow$ General-purpose flow solver code
- Pressure projection
- Multi-stage explicit advective prediction scheme
  - Allows larger Courant number
- Very Large Eddy simulation (VLES)
  - Smagorinsky
- Unstructured mesh
  - Tetrahedral elements (linear)

Boundary Conditions

- Fixed inflow condition – Logarithmic profile
  - Neutral boundary layer
- Pressure is prescribed and velocity is extrapolated at the downwind outflow
- Pressure is prescribed at the top and the normal velocity may be nonzero
- Temperature effects neglected
- Logarithmic wind flow
  - U=7 m/s at 10 meters from the surface

Comparison between Real and Flat Terrain

20 s

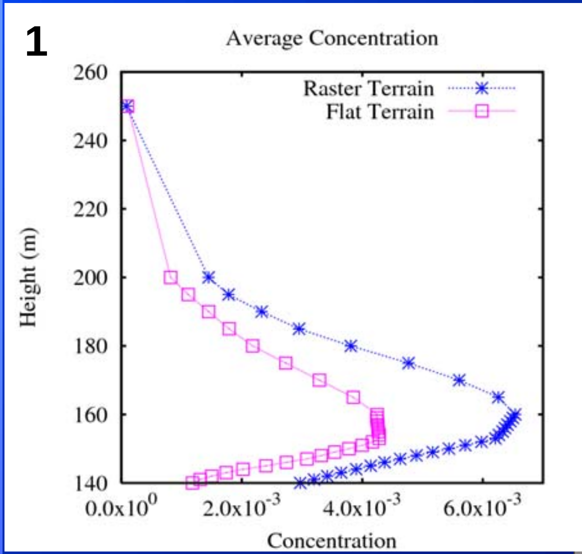
40 s

60 s

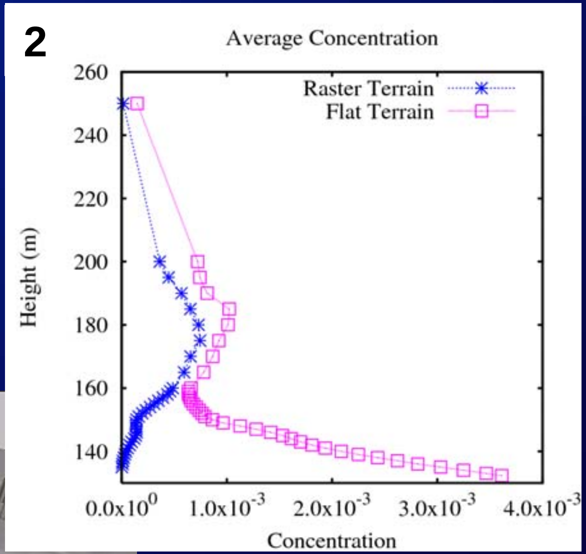
Length Difference

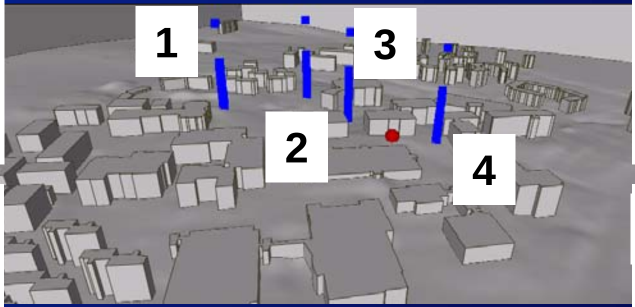
Upwind Difference

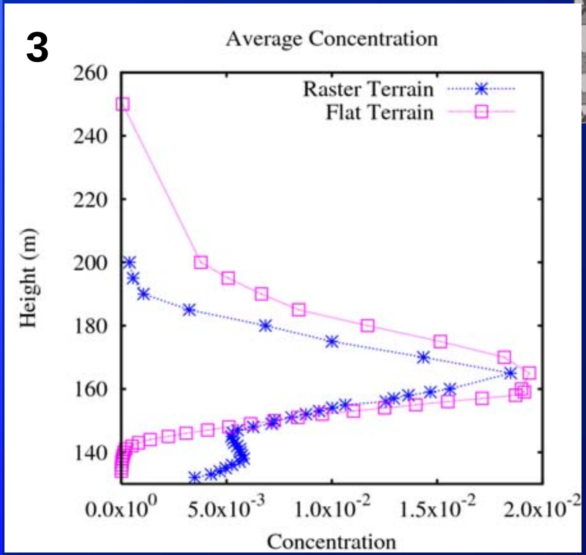
Concentration Profiles

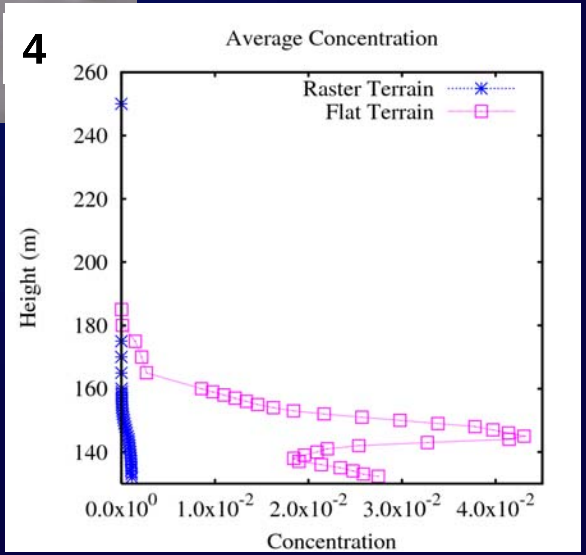


Average over 180 s

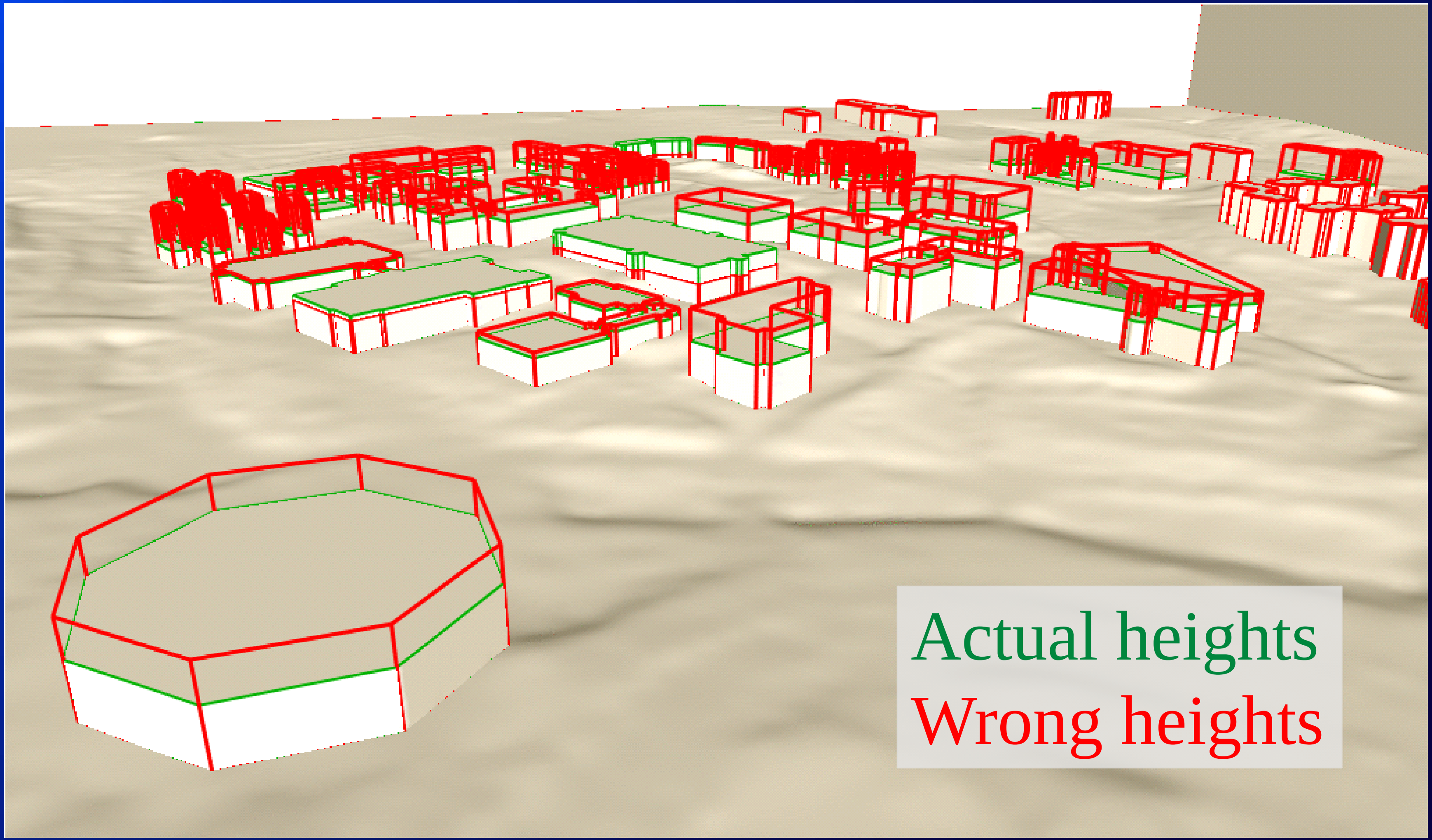




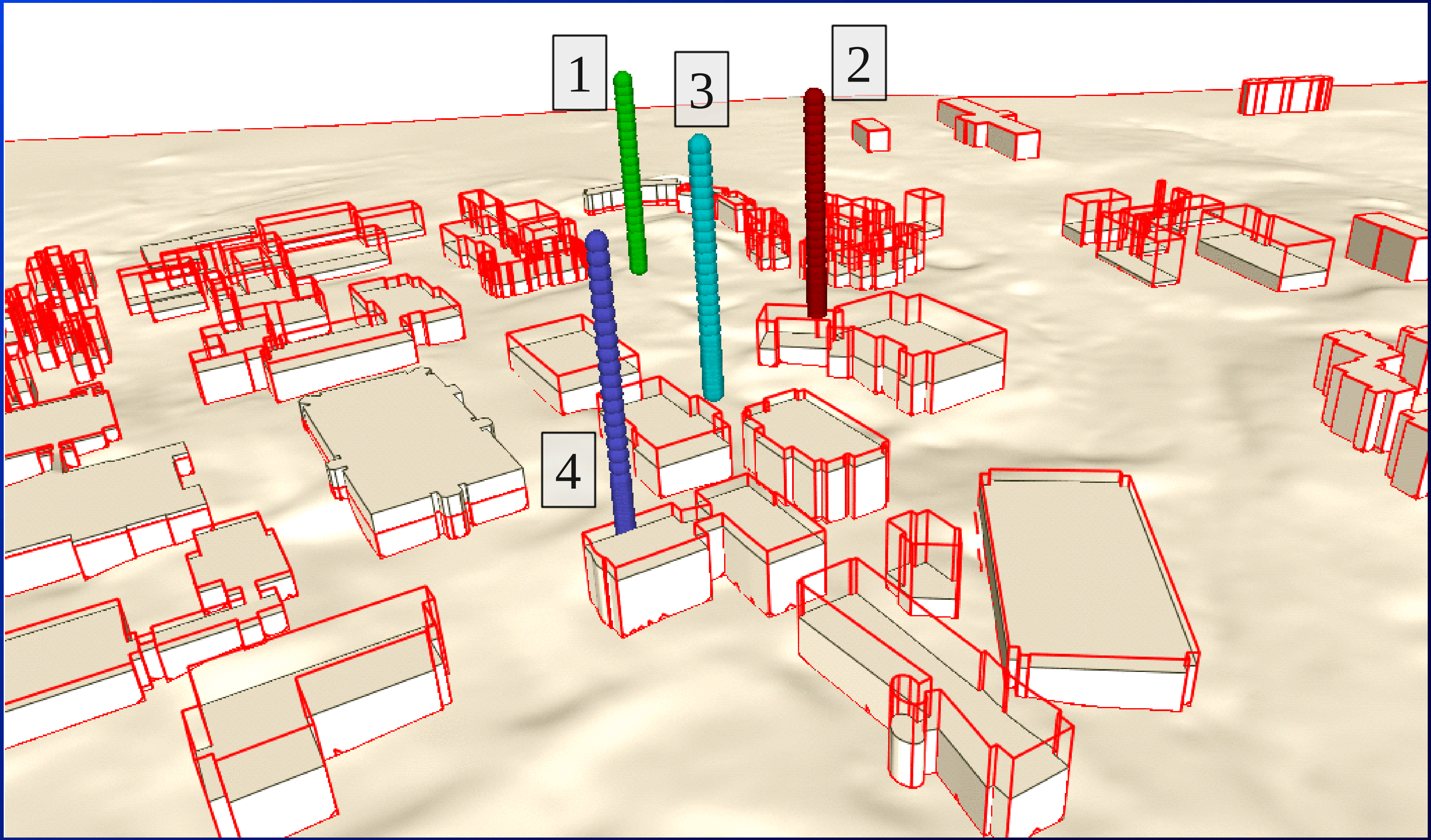




Building Heights

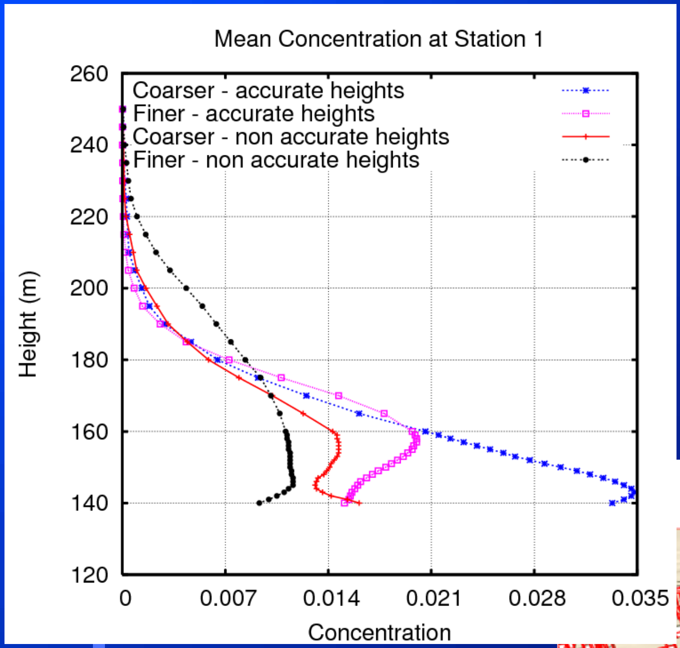


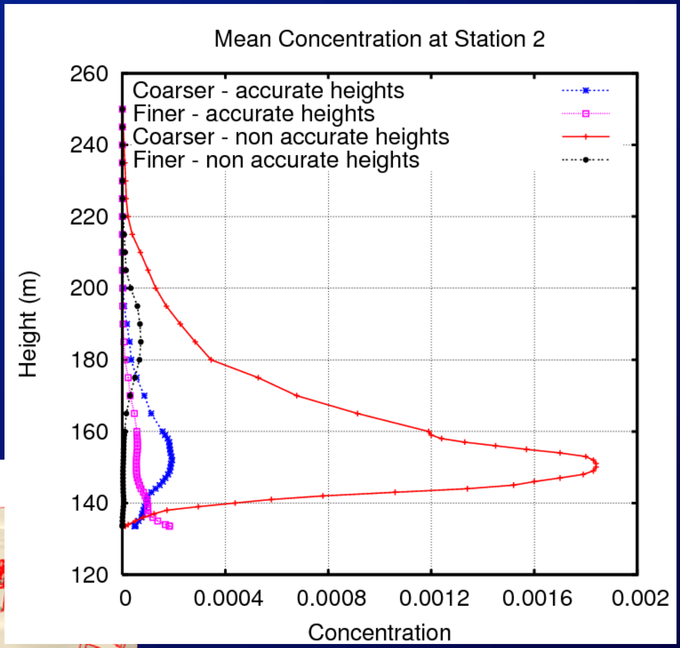
Stations

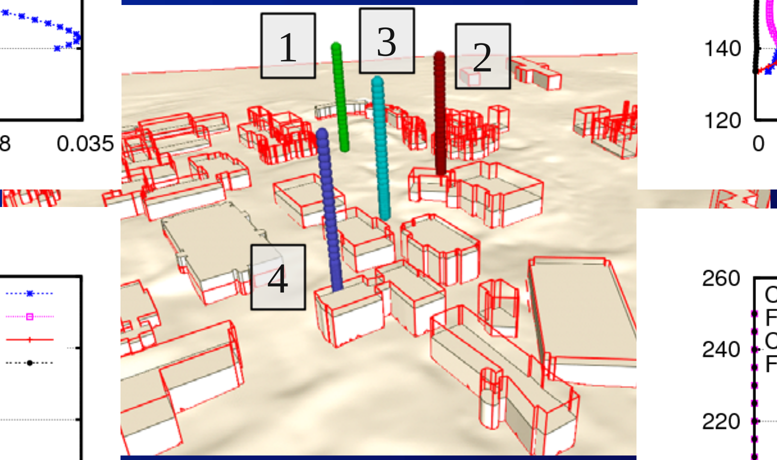


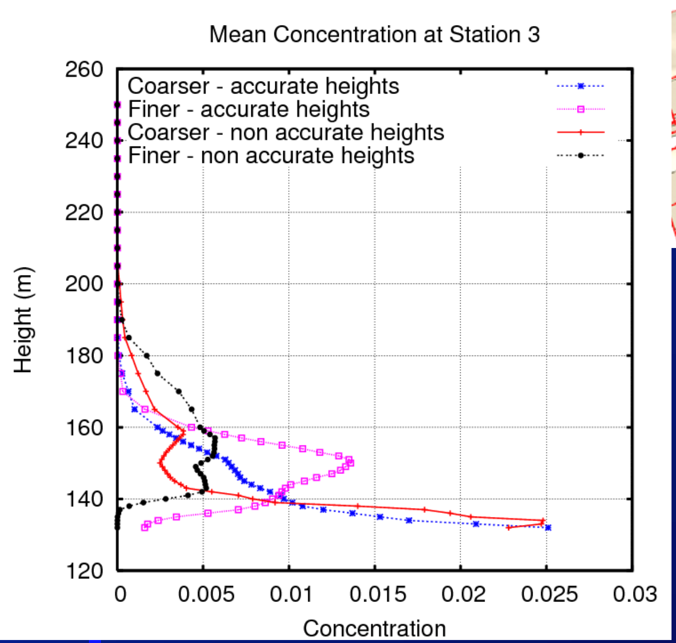
Average Concentration

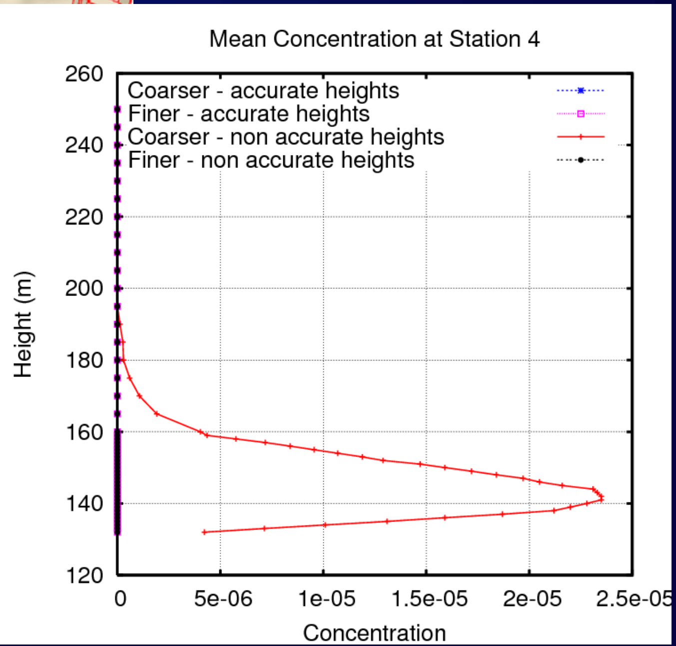
Coarse and Fine resolution





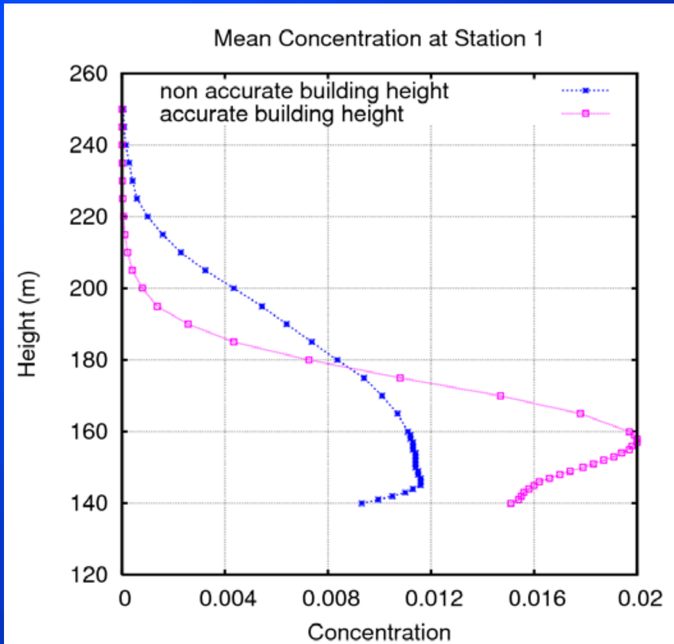


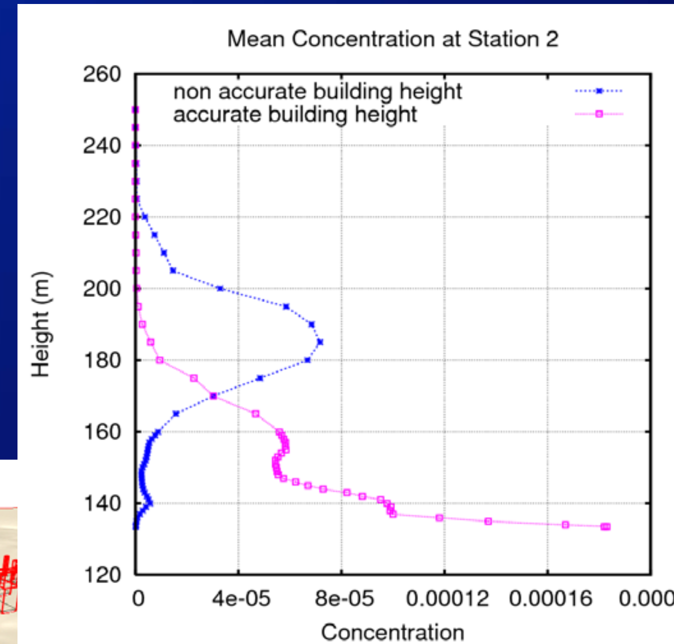


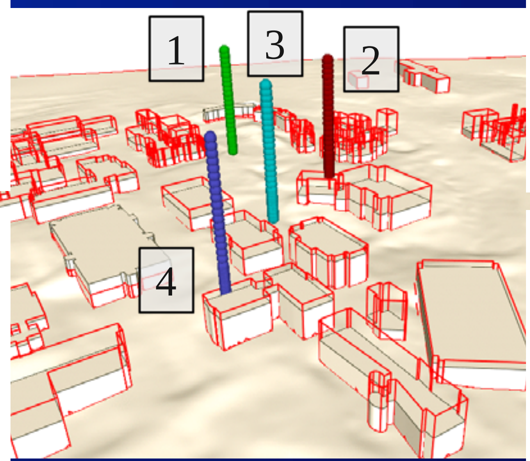


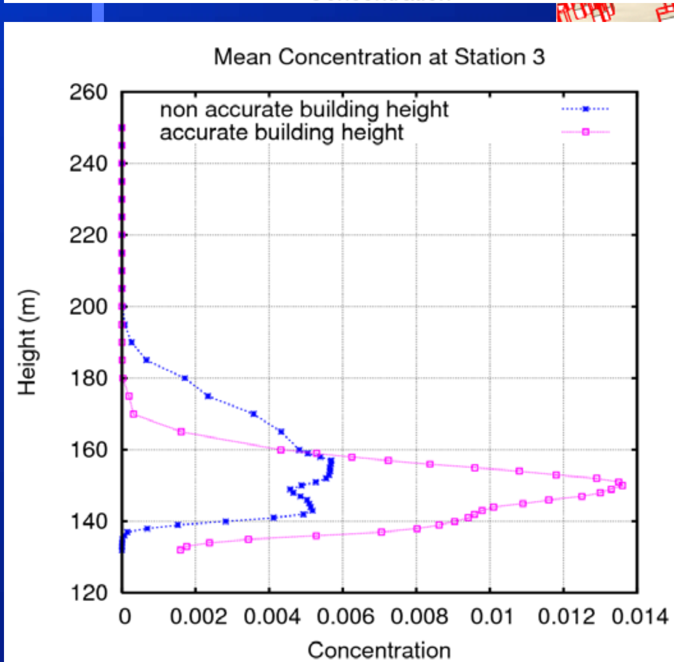
Average Concentration

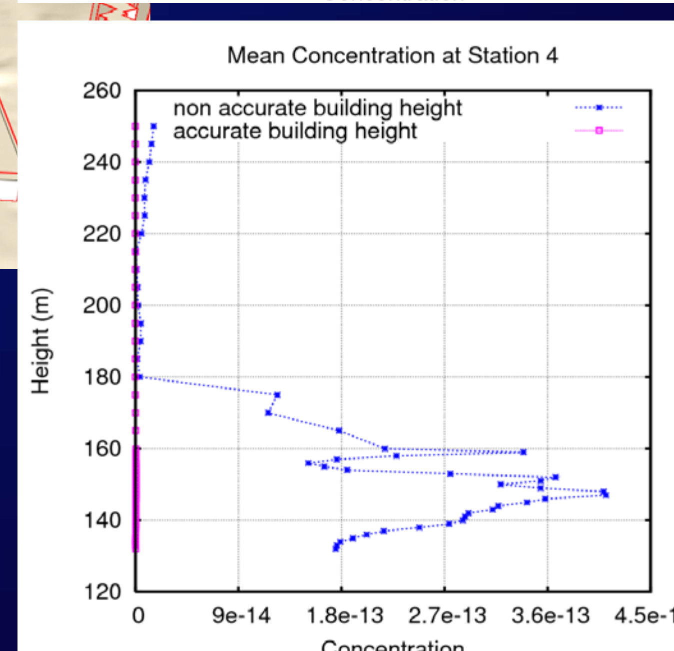
Finer resolution





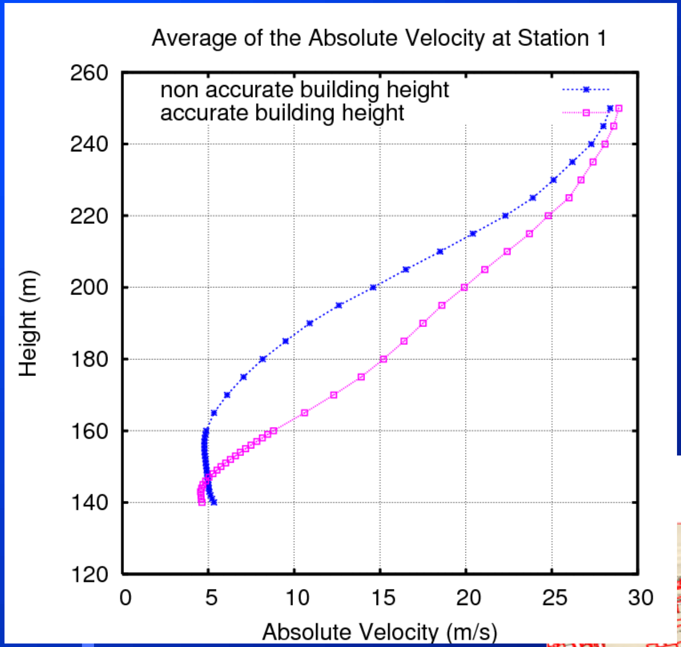


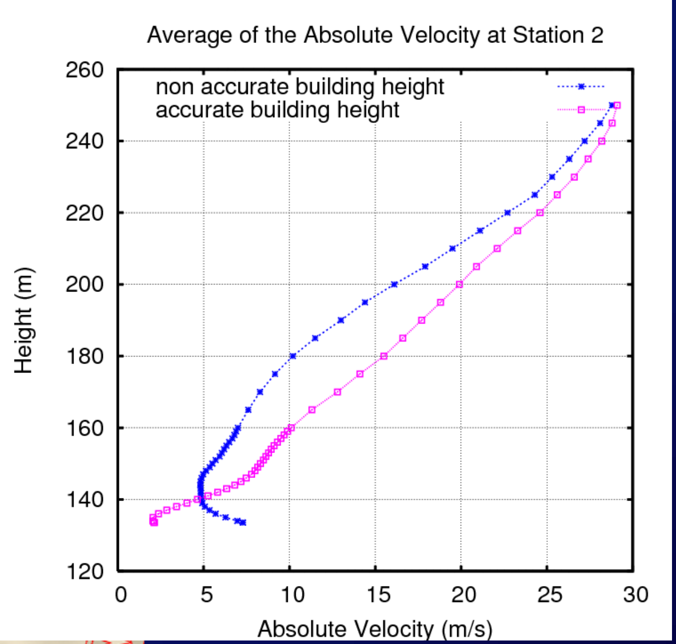


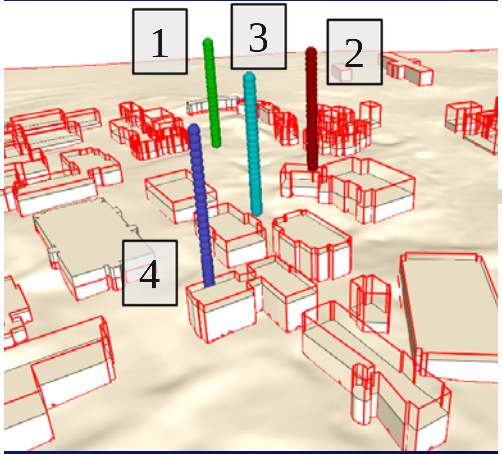


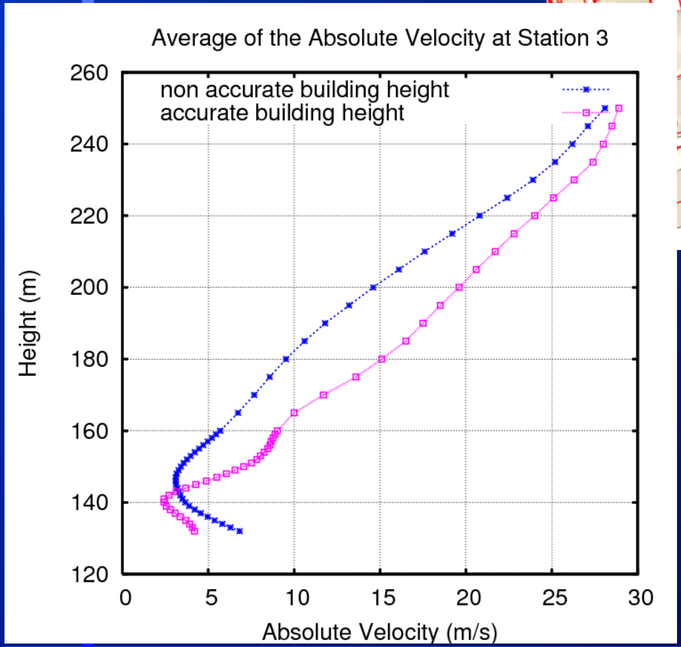
Average Wind velocity

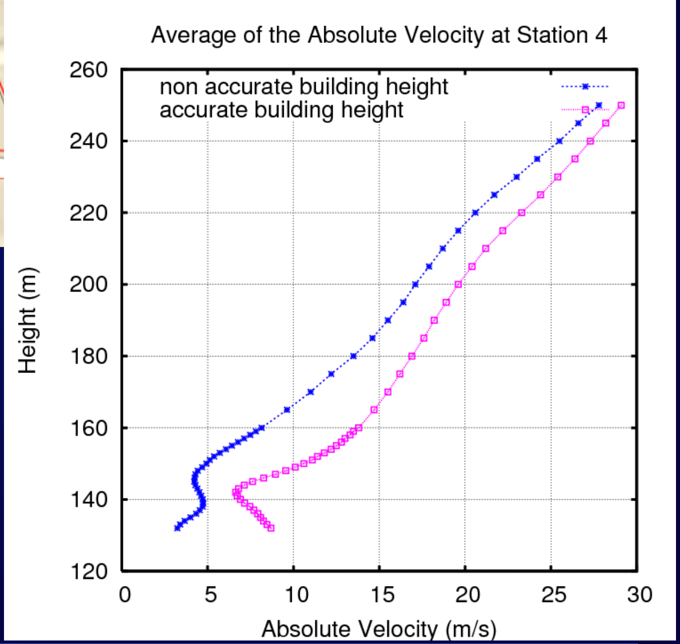
Finer resolution





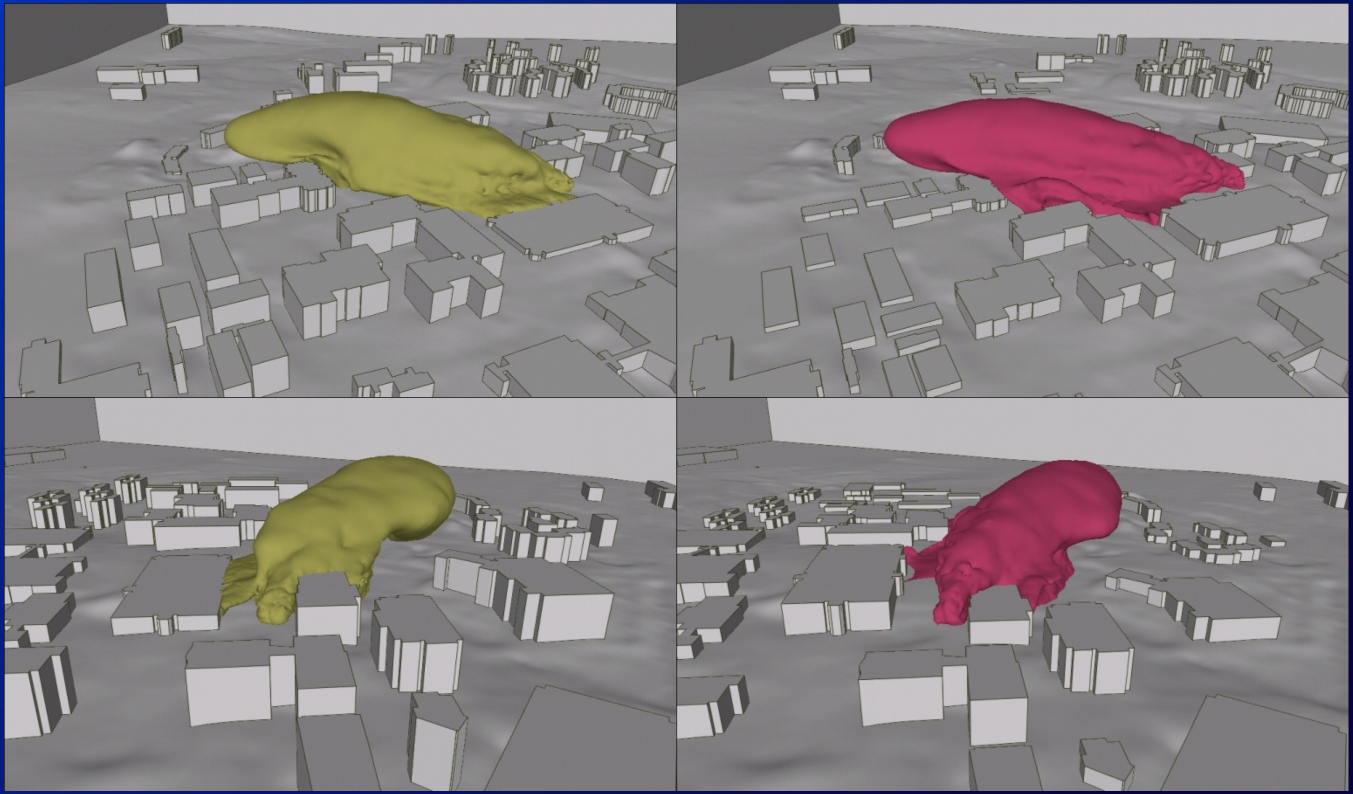






Concentration Iso-surfaces

- Concentration Clouds

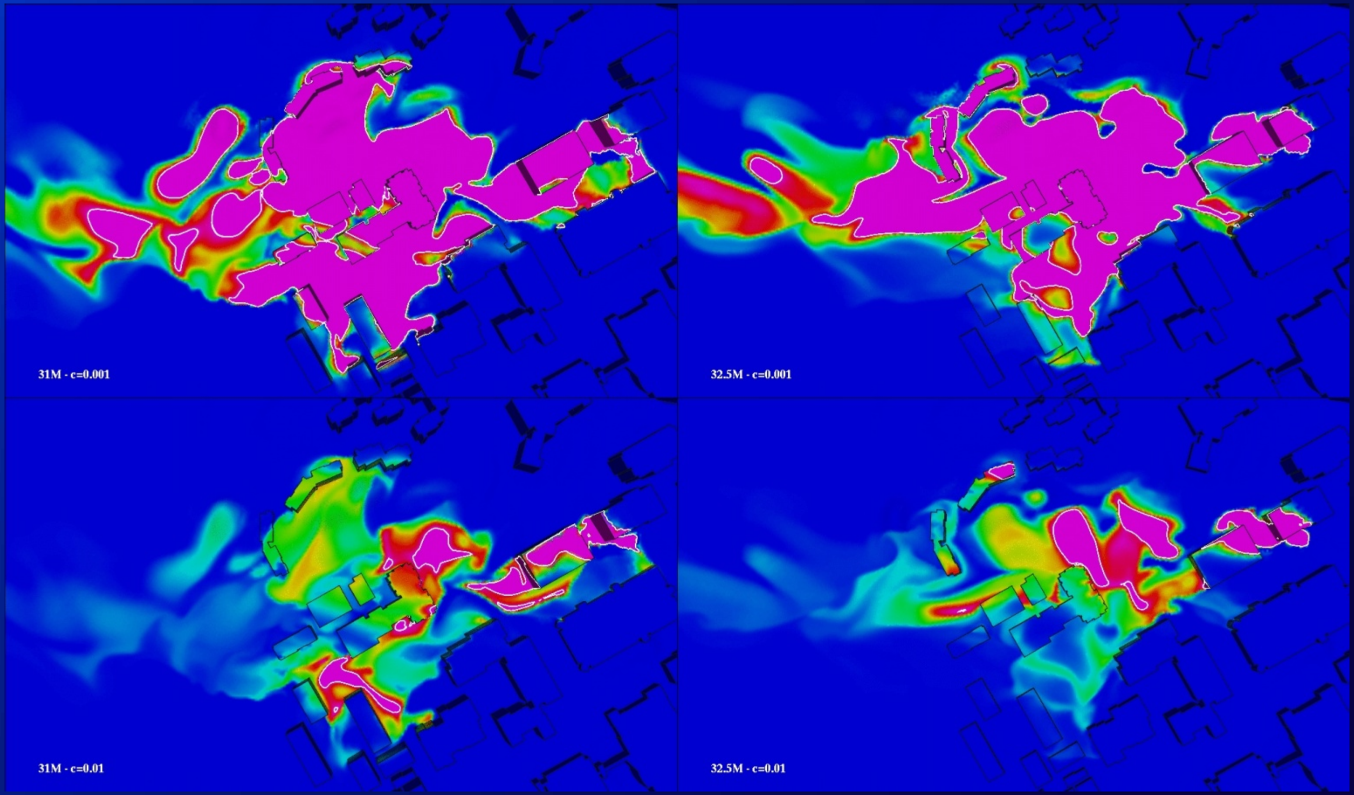


Wrong heights

Actual heights

Concentration Cut-planes

- **Concentration Cut-planes**

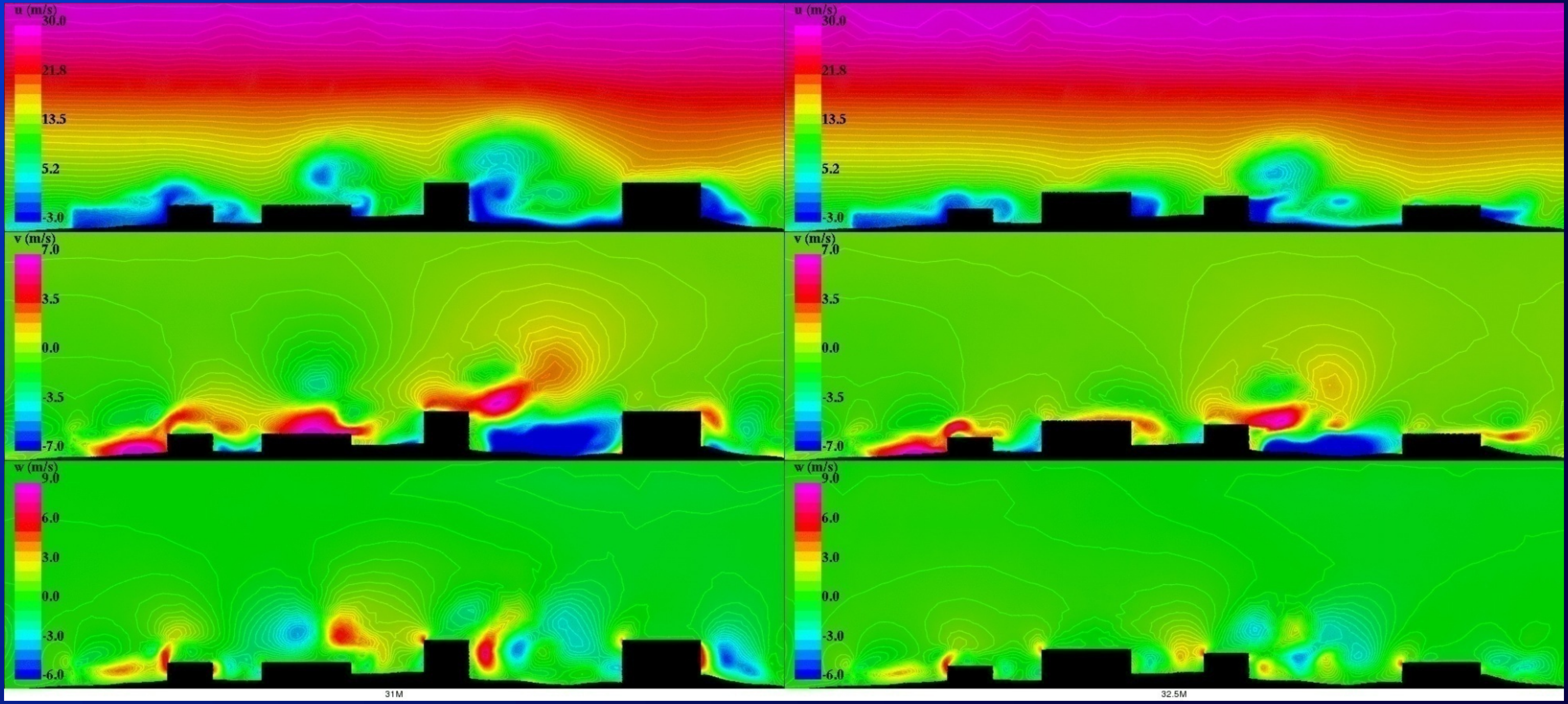


Wrong heights

Actual heights

Velocity Cut-planes

- **Velocity**



Wrong heights

Actual heights

Conclusions

- Efficient to manipulate raster format elevation data into mesh (highly automated)
- Discrepancies in model results from raster and flat data
  - Concentration levels are substantially different close to the surface
- Building height representations
  - Overall difference in concentration levels
  - Resolution is a factor in concentration difference too
  - Observed difference in absolute velocity

Future Work

- More testing on the discrepancies using data with different topographic characteristics (simulated data)
- Develop more efficient procedure(s) to match the topography and building footprint data – required to build the mesh
- Extend sensitivity analysis to other scenarios
- Add forest/tree models