CERN

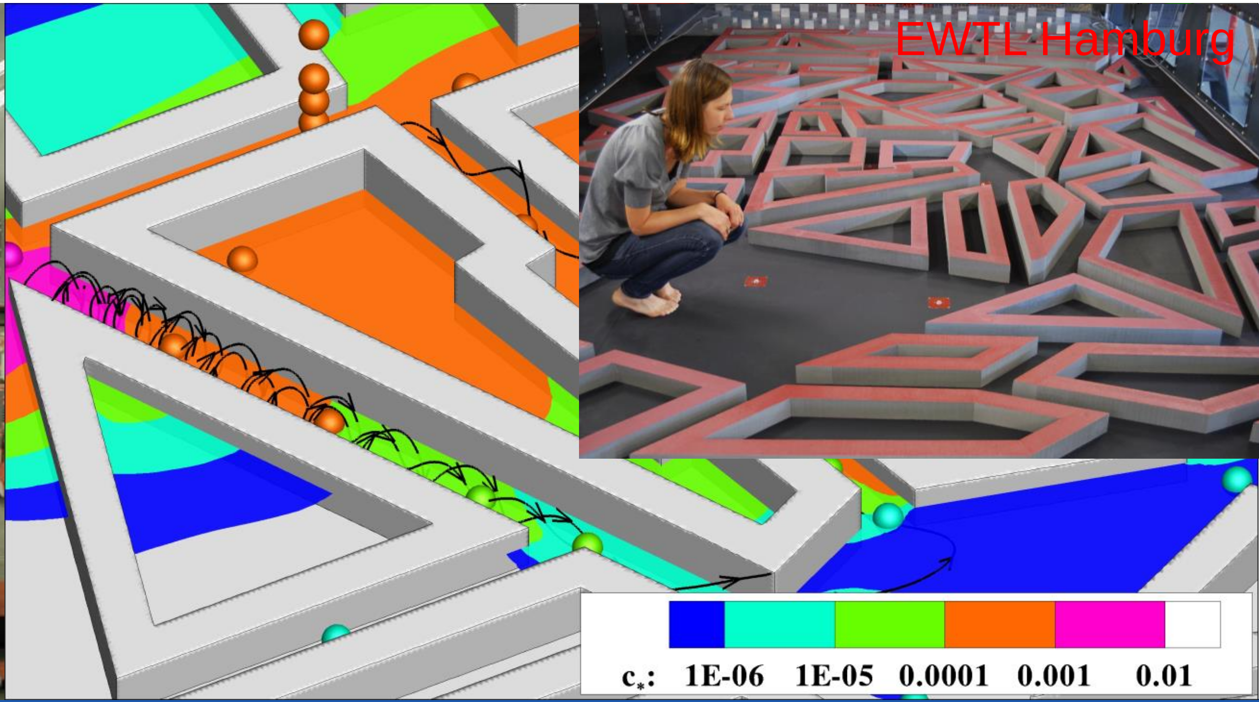
Environmental release simulations based on the Navier-Stokes equations

Seminar on Fire Prevention for Physics research facilities, 7-8 October 2015

Aniko Rakai, Ph.D., EN-CV-PJ

Question:

Is it possible/worth to model the wind flow between buildings and the related heat and mass transfer processes at CERN?



Outline

1. General overview
2. CERN Meyrin site study

Outline

1. General overview
2. CERN Meyrin site study

Keywords

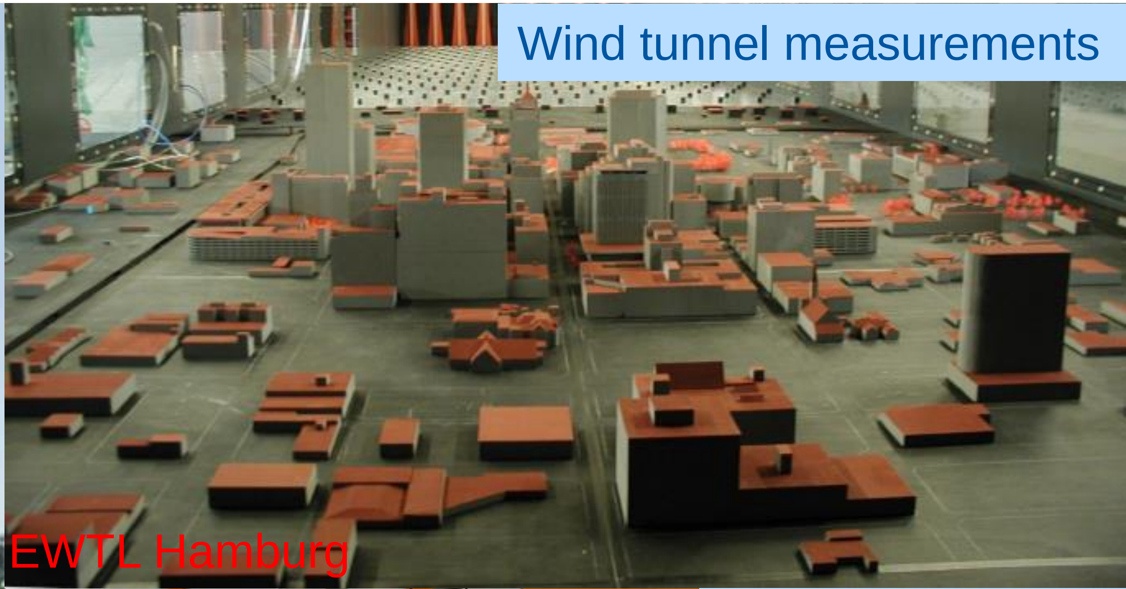
- Wind engineering
- Microscale meteorology
- Urban physics

Modelling approaches

Field experiments

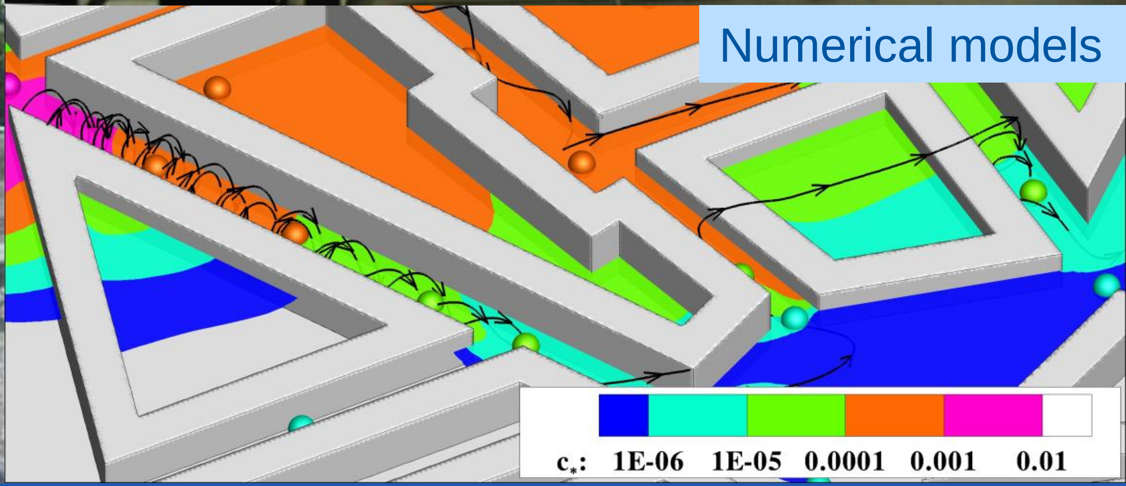
BUBBLE project

Wind tunnel measurements



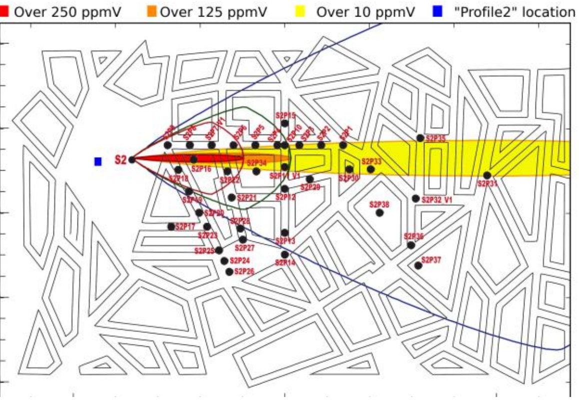
EWTL Hamburg

Numerical models

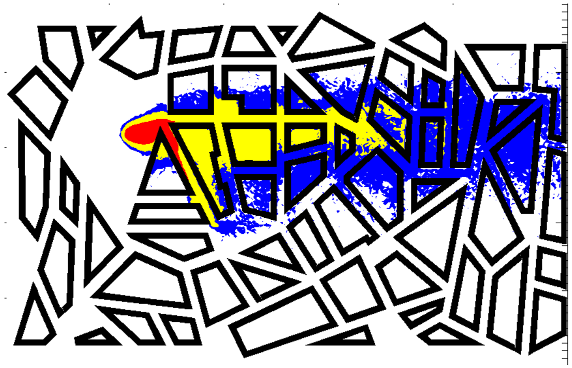


Numerical models

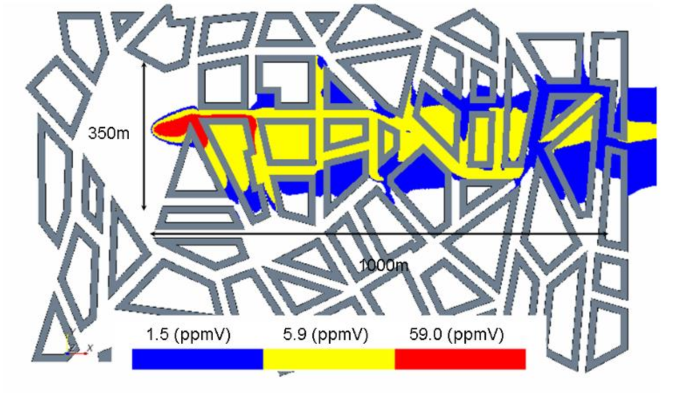
- Gaussian type, uniform flow field
- "Lagrangian" type, simplified flow field
- Resolving flow field based on the full Navier-Stokes equations (CFD – computational fluid dynamics)



Gaussian



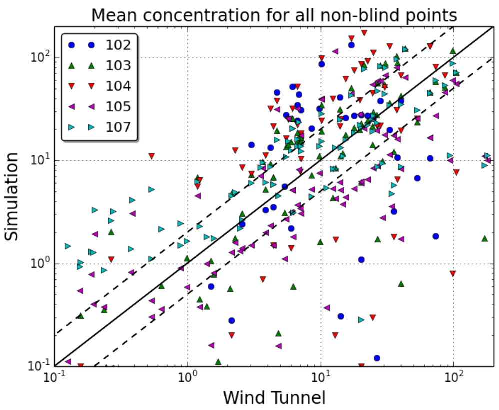
"Lagrangian"

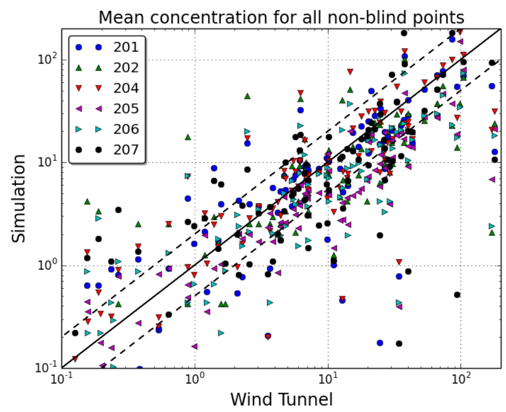


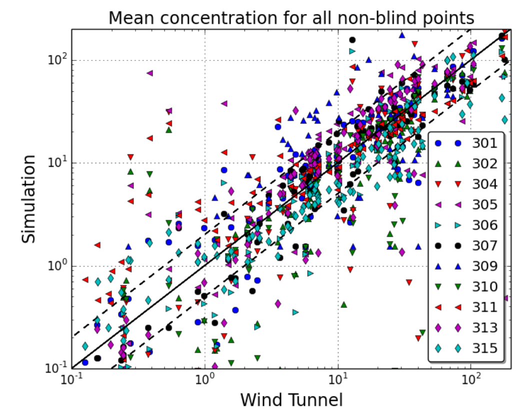
Full Navier-Stokes

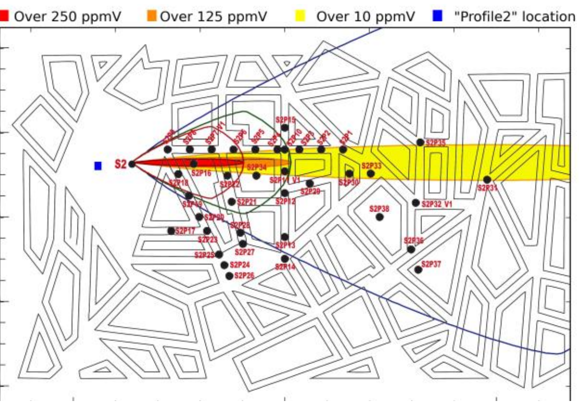
From COST Action ES1006

Numerical models

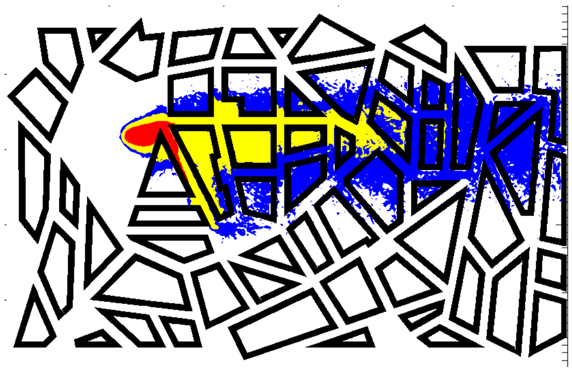




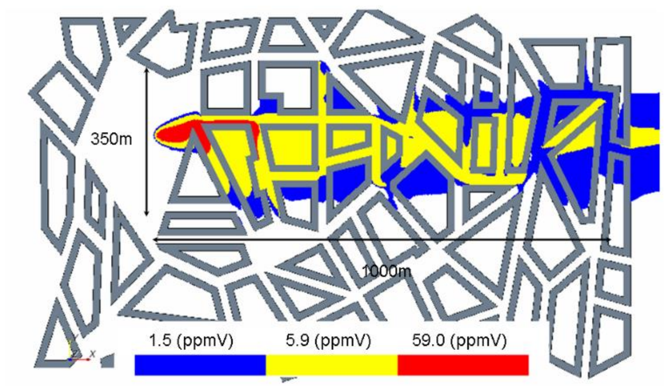




Gaussian
few seconds



"Lagrangian"
few minutes



Full Navier-Stokes
few hours or more

From COST Action ES1006

Navier-Stokes equations

Reynolds averaged, incompressible:

$$u_{ins} = U + u$$

$$\partial_i U_i = 0$$

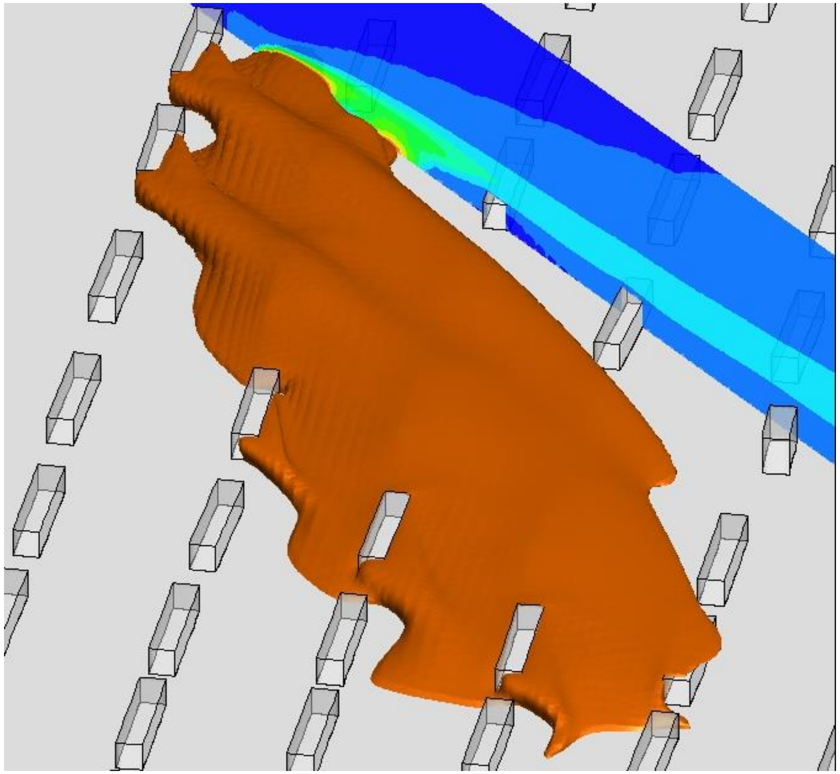
$$\partial_t U_i + \partial_j \left(U_j U_i - \nu U_{i,j} + \overline{u_i u_j} \right) = \frac{\partial_j p}{\rho}$$

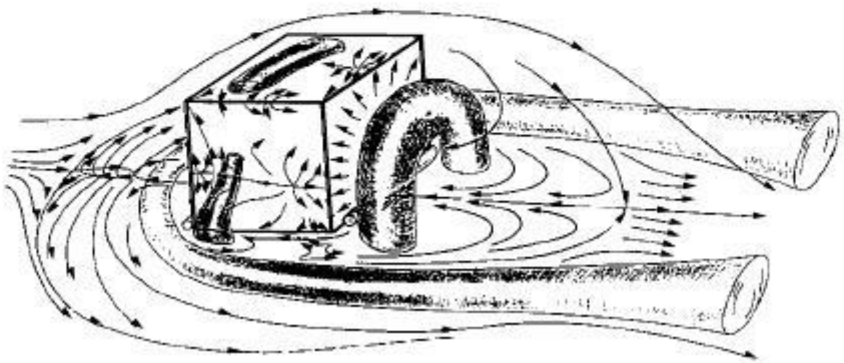
$$\partial_t (\rho E) + \partial_j \left(U_j (\rho E + p) \right) = \partial_j \left(k \partial_j T \right) \ldots$$

$$\partial_t C + \partial_j \left(U_j C \right) = \partial_j \left(D \partial_j C \right) - \partial_j \left(\overline{u_j c} \right) + \mathrm{Q}$$

Globally unstable flows

- Flow past a bluff body
- Turns into unsteady even with steady boundary conditions
- Formation of “new” turbulence, independent from the boundary layer





The turbulence closure question

CFD – Computational Fluid Dynamics:

- **RANS – Reynolds Averaged Navier Stokes**
- **SAS – Scale-Adaptive Simulation**
- DDES – Delayed Detached Eddy Simulation
- ELES/ZLES – Embedded/Zonal LES
- LES – Large Eddy Simulation

See Menter 2012 [1] for more details

Pollution dispersion

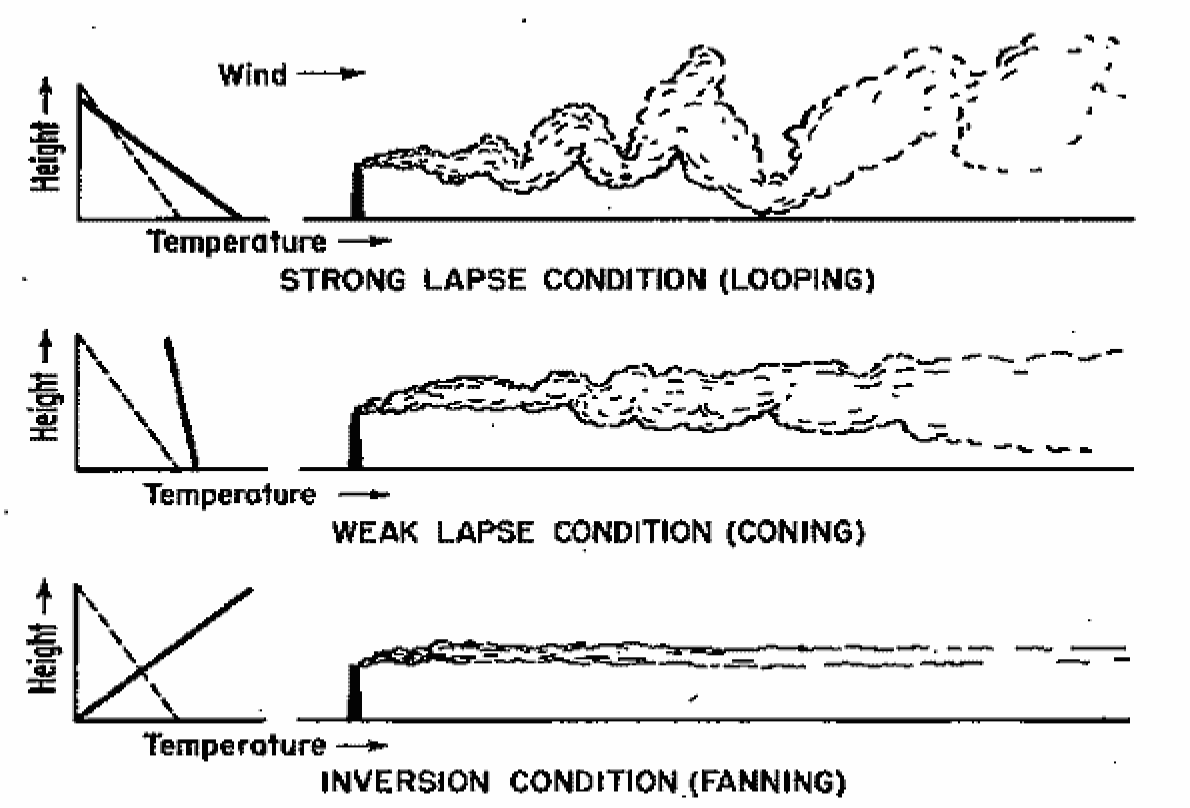
- AEE - Air exchange efficiency
- MAA – local mean age of air
- Residence time

- ↔ Passive scalar transport equation
- Turbulent scalar flux closure is questionable

Thermal conditions

Solar radiation

Atmospheric stability

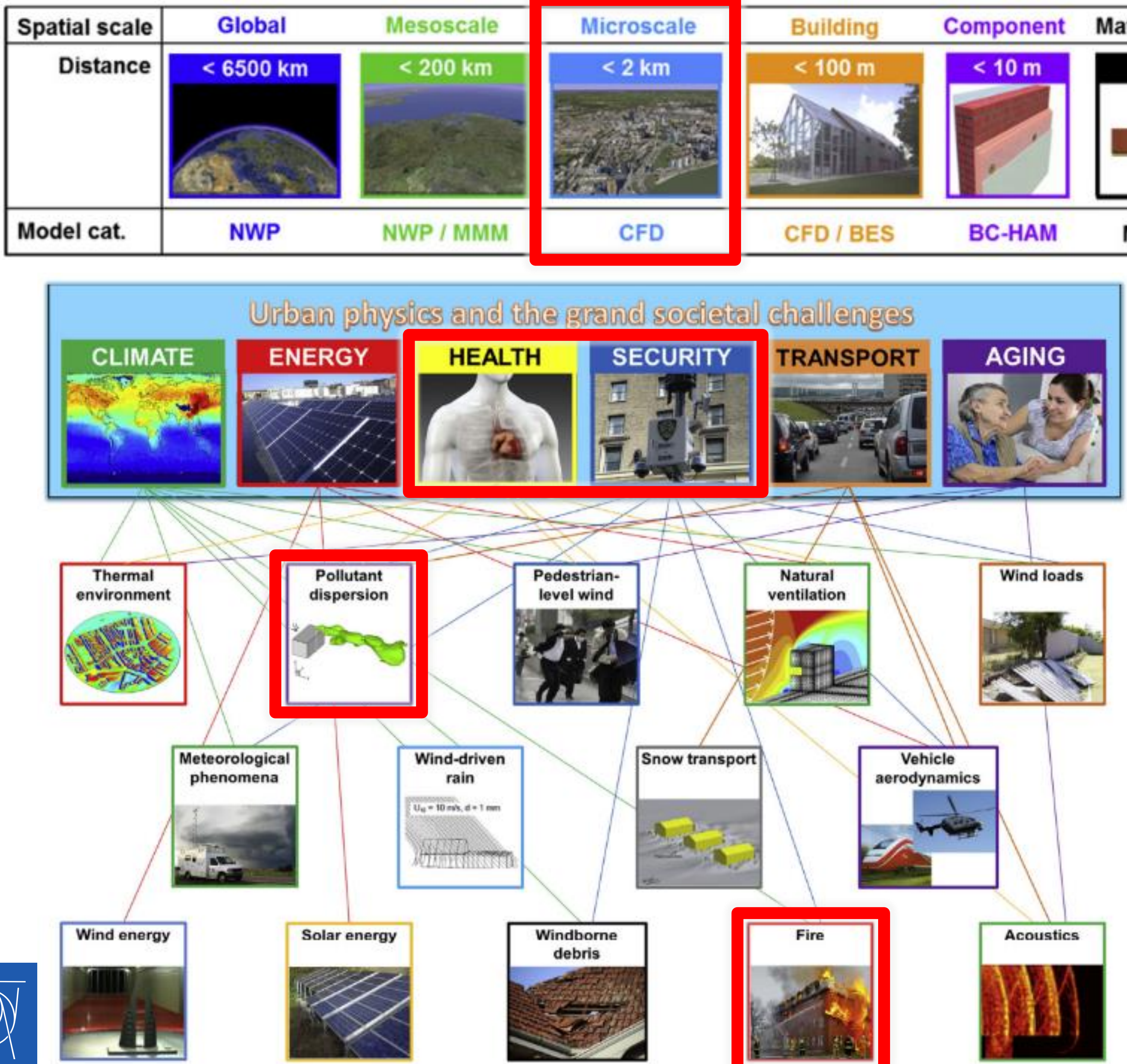


Motivation

Computational resources are rapidly growing.

Possible to learn more about:

- Wind comfort
- Building energy balance
- **Pollution/hazardous material dispersion**
- **Accidental preparedness**



NWP- numerical weather prediction
MMM – mesoscale meteorological model
CFD – computational fluid dynamics
BES – building energy simulation

From: Blocken 2015

Scientific background I

- COST Action C14: Impact of Wind and Storms on City Life and Built Environment, ended **2004**
- COST Action 715: Meteorology applied to Urban Air Pollution Problems, ended **2005**
- COST Action 732: Quality Assurance and Improvement of Microscale Meteorological Models, ended **2009**
- COST Action ES 1006: Evaluation, improvement and guidance for the use of local-scale emergency prediction and response tools for airborne hazards in built environments, ended **2015**

COST: European Cooperation in Science and Technology

Scientific background II

- Clean City project of Geneva [2]
- Already existing models at CERN [3]
- Urban Climate, HARMO, etc. conferences
- Ten tips and tricks from Blocken 2015 [4]
- Best Practice Guidelines:
  - ERCOFTAC (European Research Community on Flow, Turbulence and Combustion) [5]
  - COST 732 project [6]
  - AIJ (Architectural Institute of Japan) [7]

10 tips and tricks from Blocken

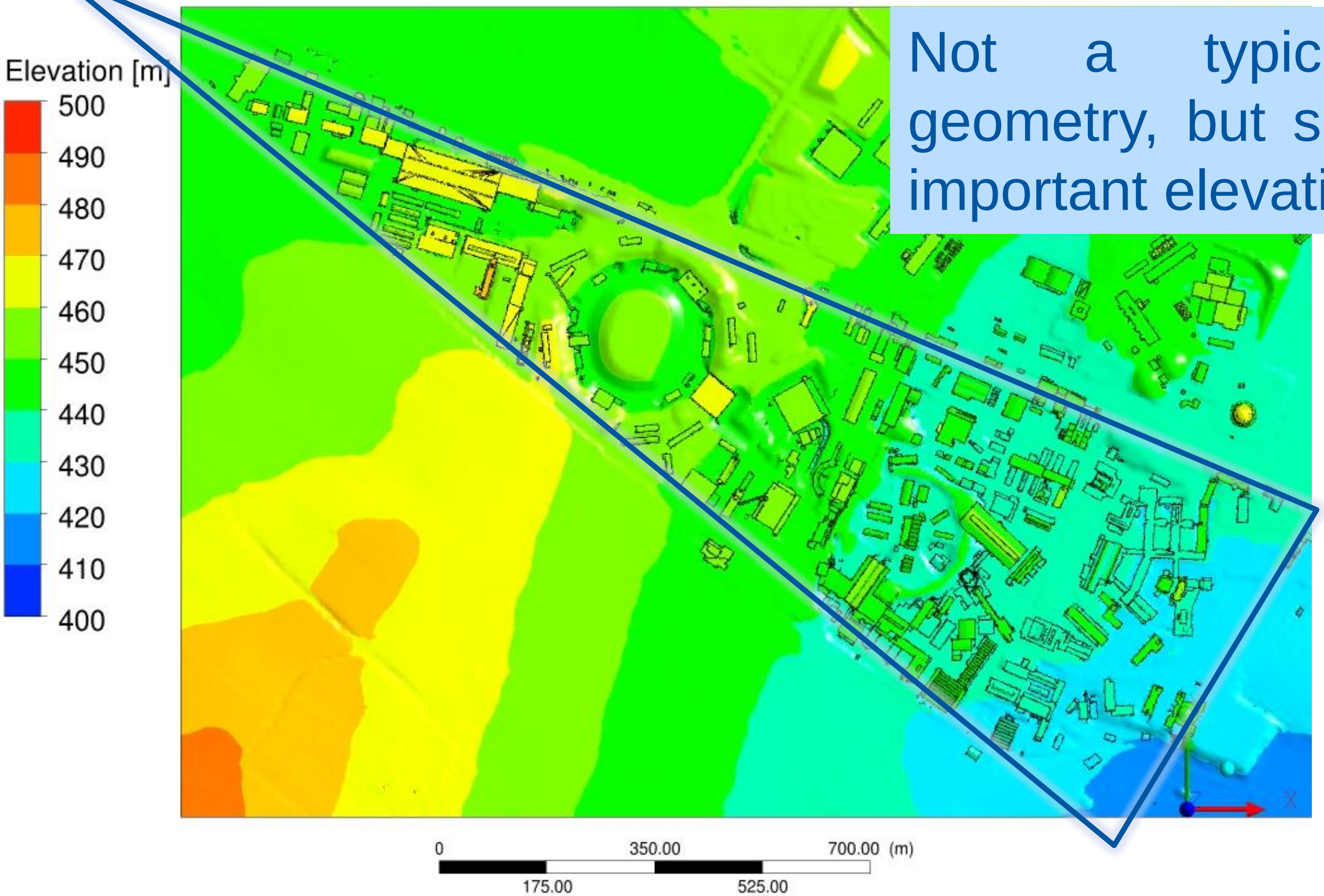
1. Domain based on directional blockage ratio
2. High-quality computational grid
3. Appropriate roughness parameters
4. Appropriate inlet boundary conditions
5. High-order discretization schemes
6. Stringent iterative convergence criteria
7. Testing of horizontal inhomogeneity
8. Grid convergence analysis
9. Validation study
10. Report essential elements on the modelling

Outline

1. General overview

2. CERN Meyrin site study

CERN Meyrin site



Not a typical urban geometry, but similar, with important elevation change

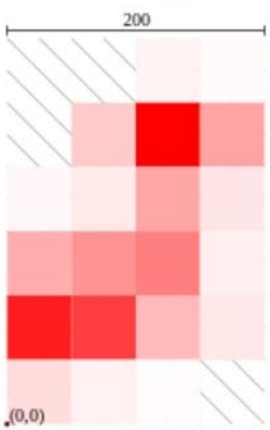
Input data

- Geometry: topography + buildings
- Meteorological data: measurements at CERN sites
- Emission data (or air exchange efficiency)

Topography

- From SITG (Le territoire Genevois à la carte)
- MN95 coordinate system
- ESRI grid raster format

Grid image

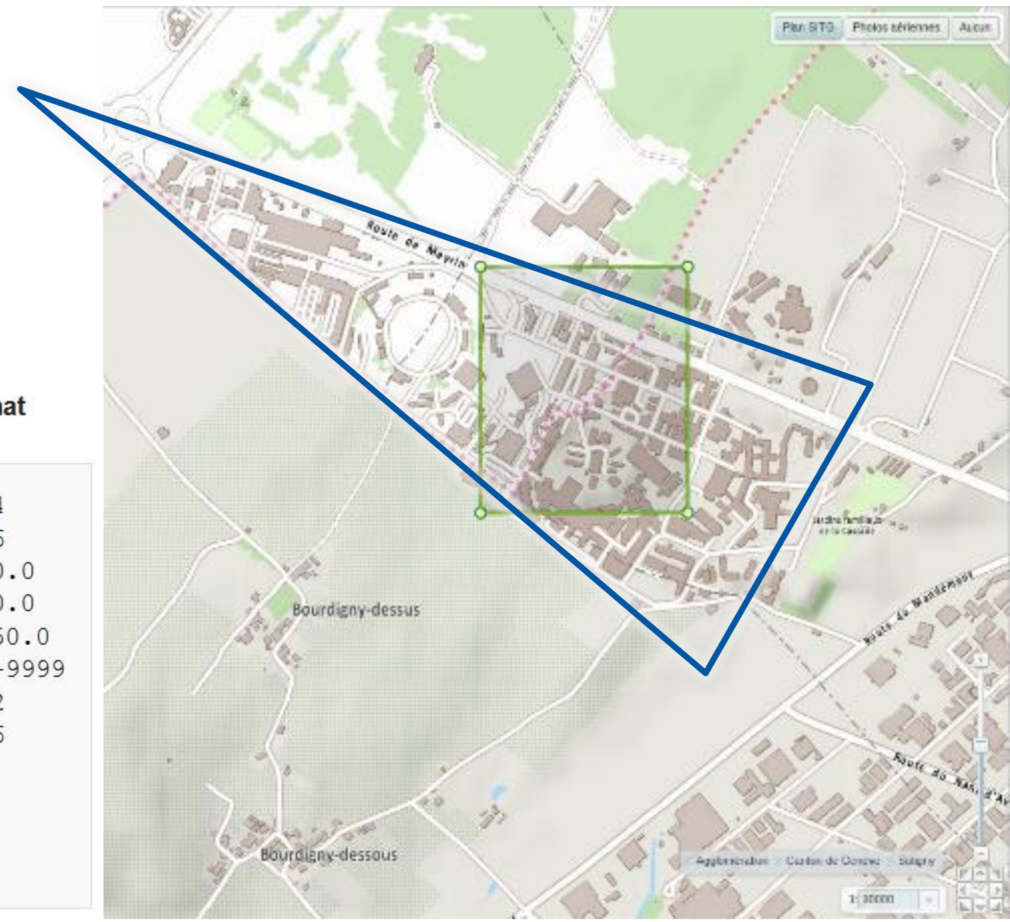


Values

	25	75	125	175
275	NA	NA	5	2
225	NA	20	100	36
175	3	8	35	10
125	32	42	50	6
75	88	75	27	9
25	13	5	1	NA

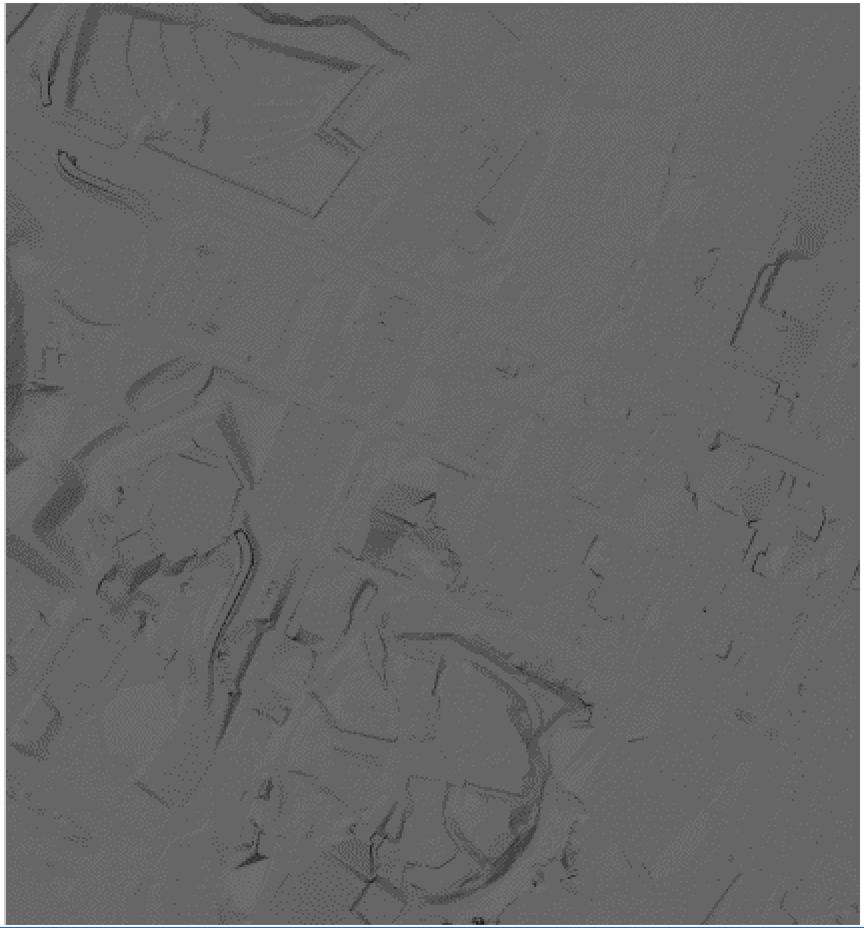
ASCII grid format

```
ncols         4
nrows         6
xllcorner     0.0
yllcorner     0.0
cellsize      50.0
NODATA_value  -9999
-9999 -9999 5 2
-9999 20 100 36
3 8 35 10
32 42 50 6
88 75 27 9
13 5 1 -9999
```



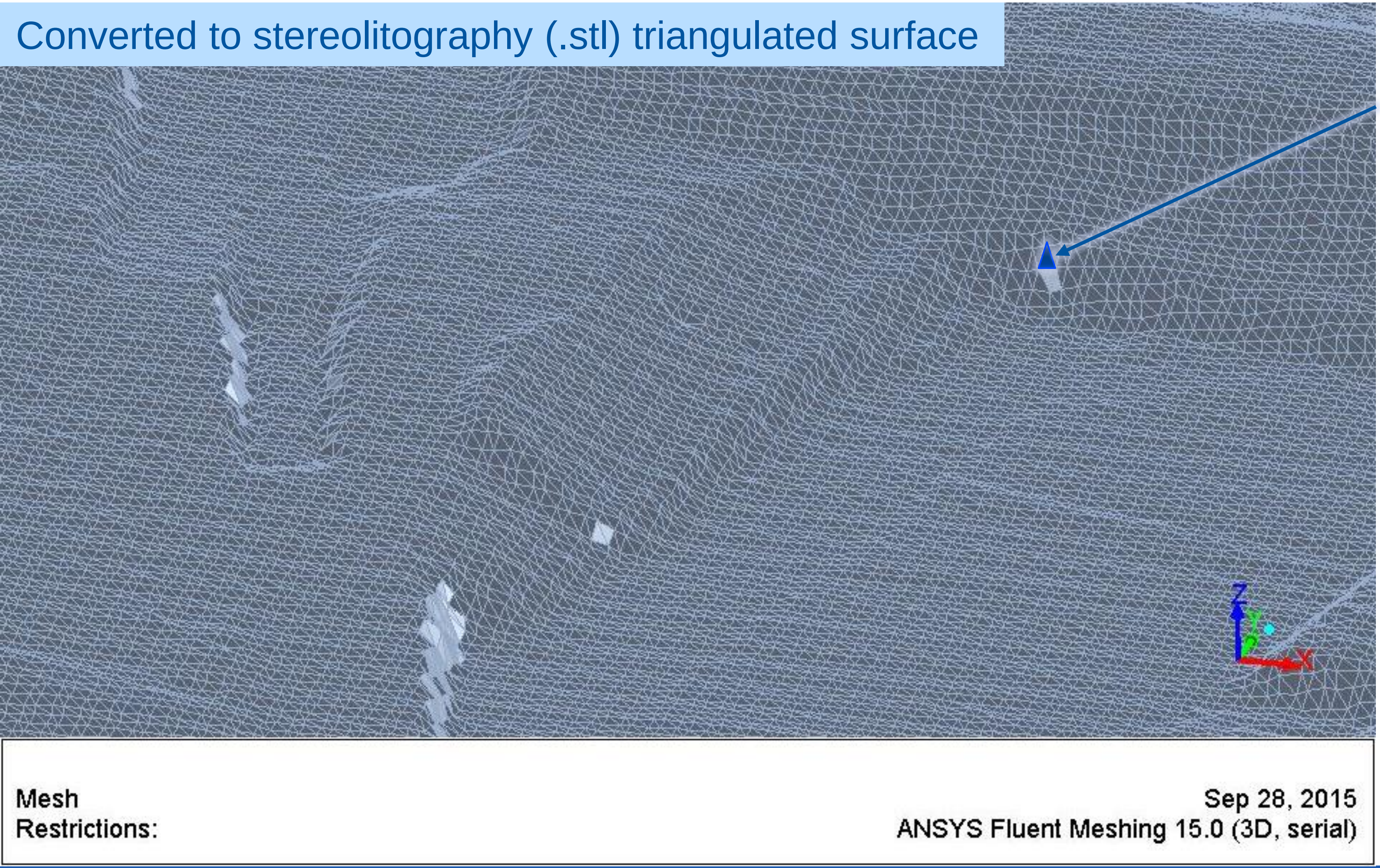
Topography

Digital terrain model (DTM) ↔ Digital surface model (DSM)



Topography

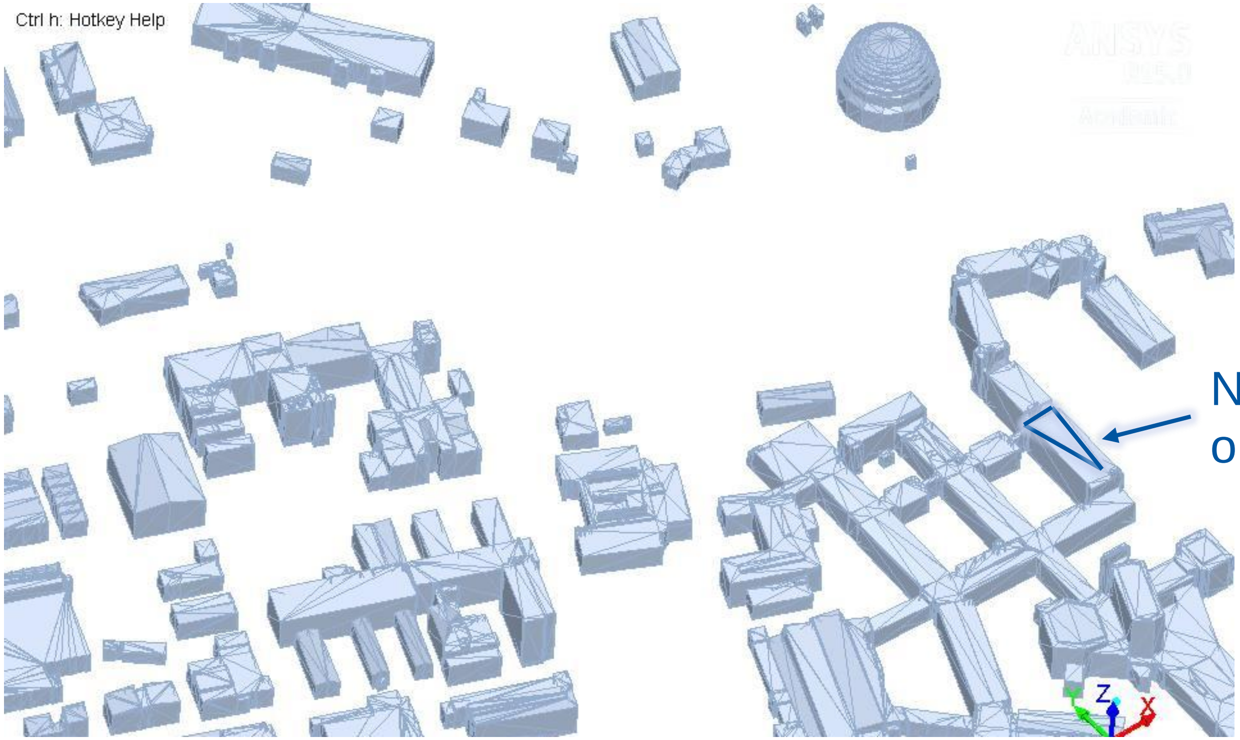
Converted to stereolitography (.stl) triangulated surface



Note triangles on the surface

Buildings

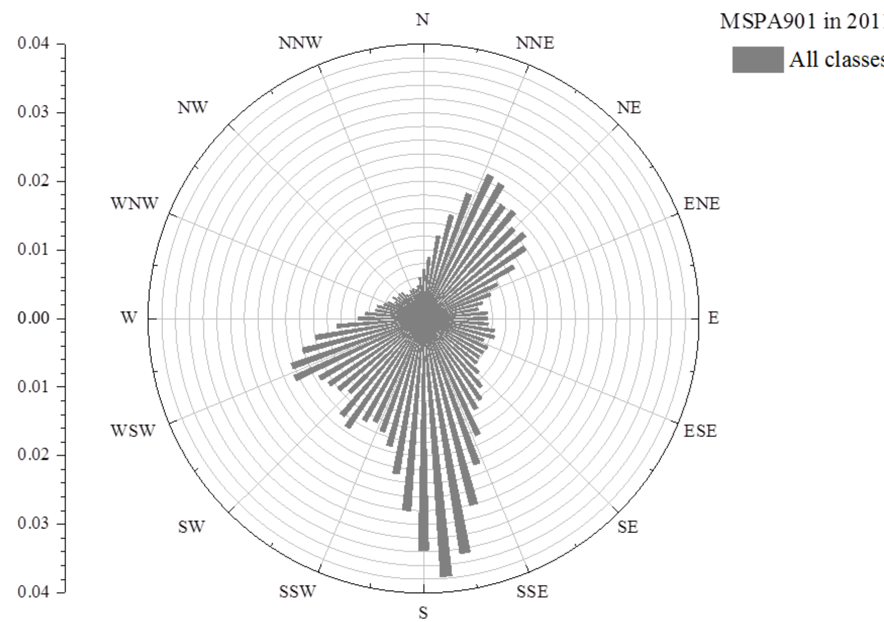
- GIS shape files
- converted to .stl as well
- more suitable for CFD meshing



Note triangles on the surface

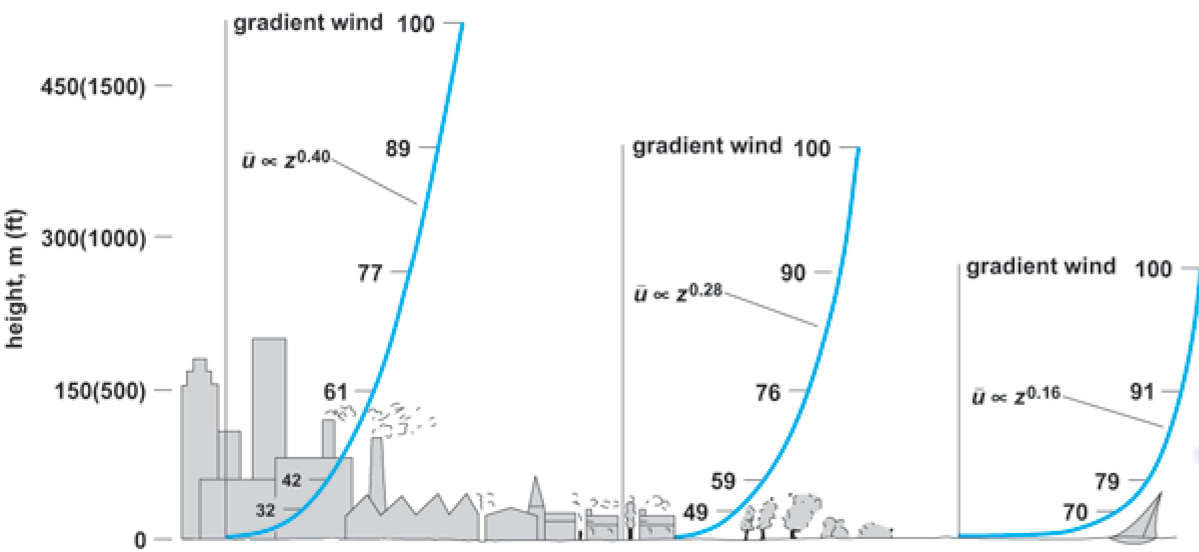
Meteorological data

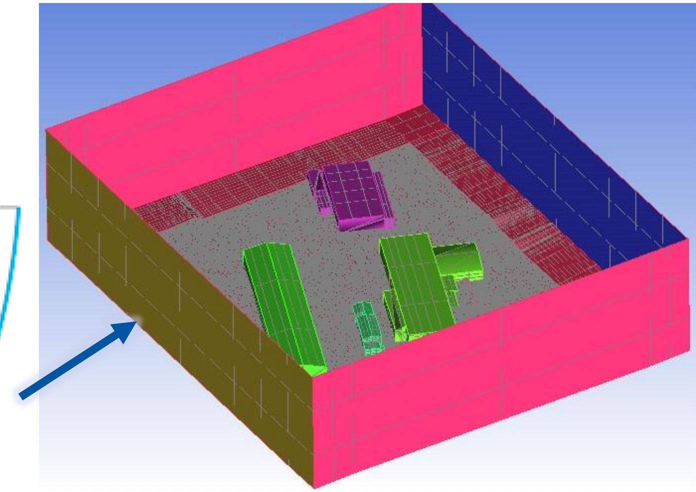
- RAMSES (Radiation Monitoring System for the Environment and Safety) data of CERN
- 3 years, 10 min resolution: Wind Atlas [8]



Boundary conditions

- Inlet: atmospheric boundary layer (ABL)
- Ground: ABL or sand roughness
- Top and sides: not really end of the domain

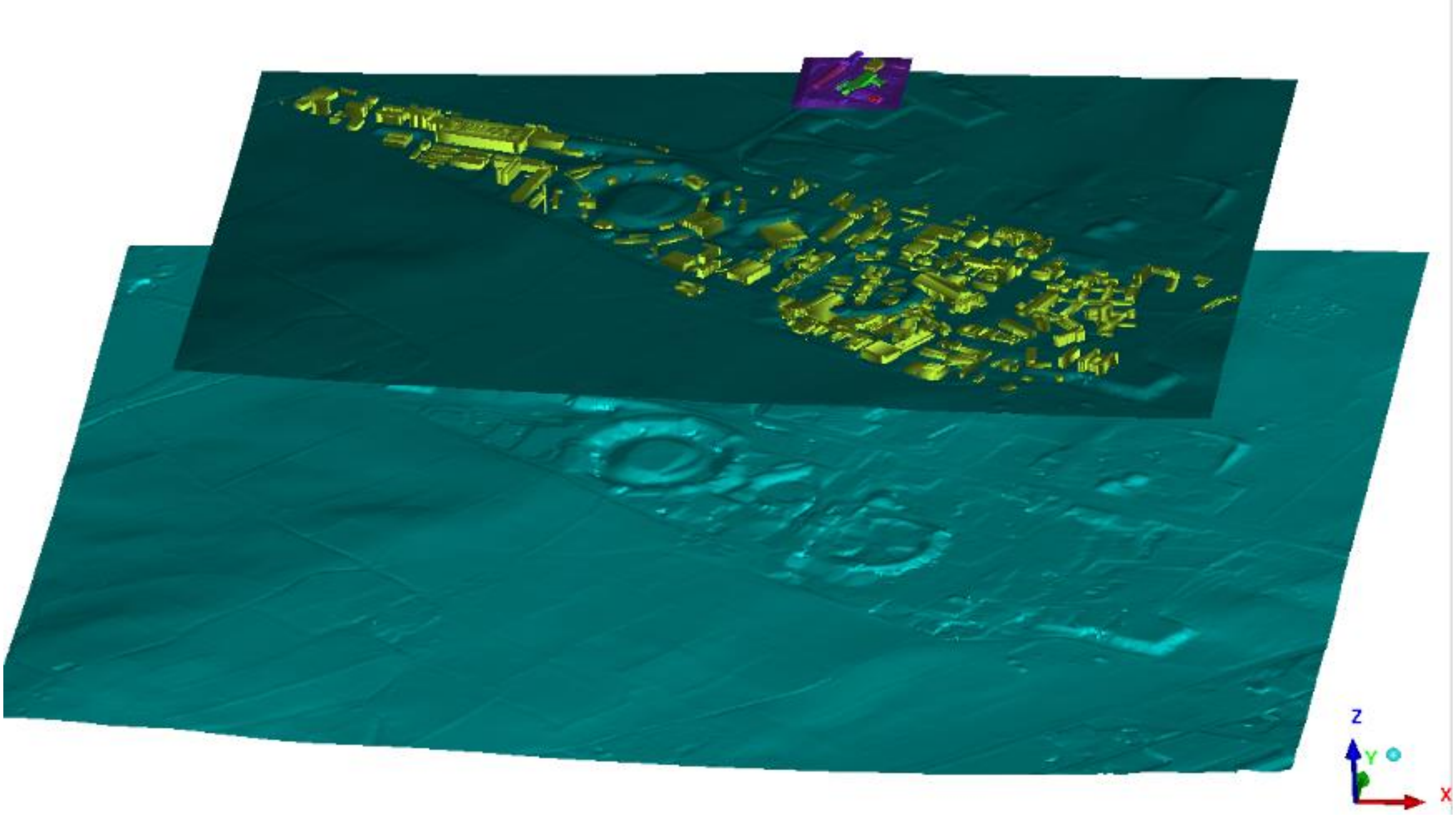




Boundary conditions - nesting

Different detail and complexity for different levels

Boundary conditions - nesting



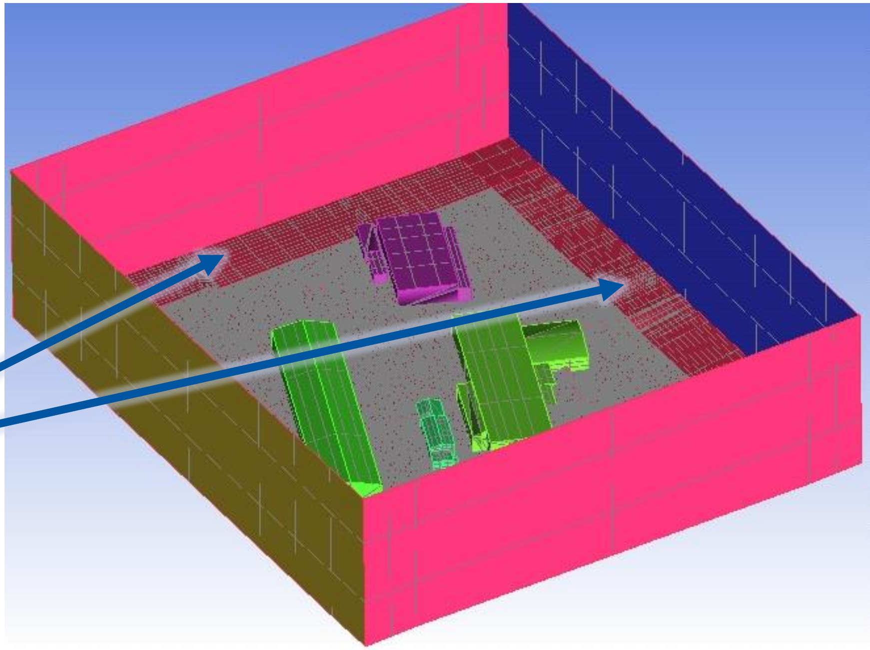
Computational mesh:

Considered software:

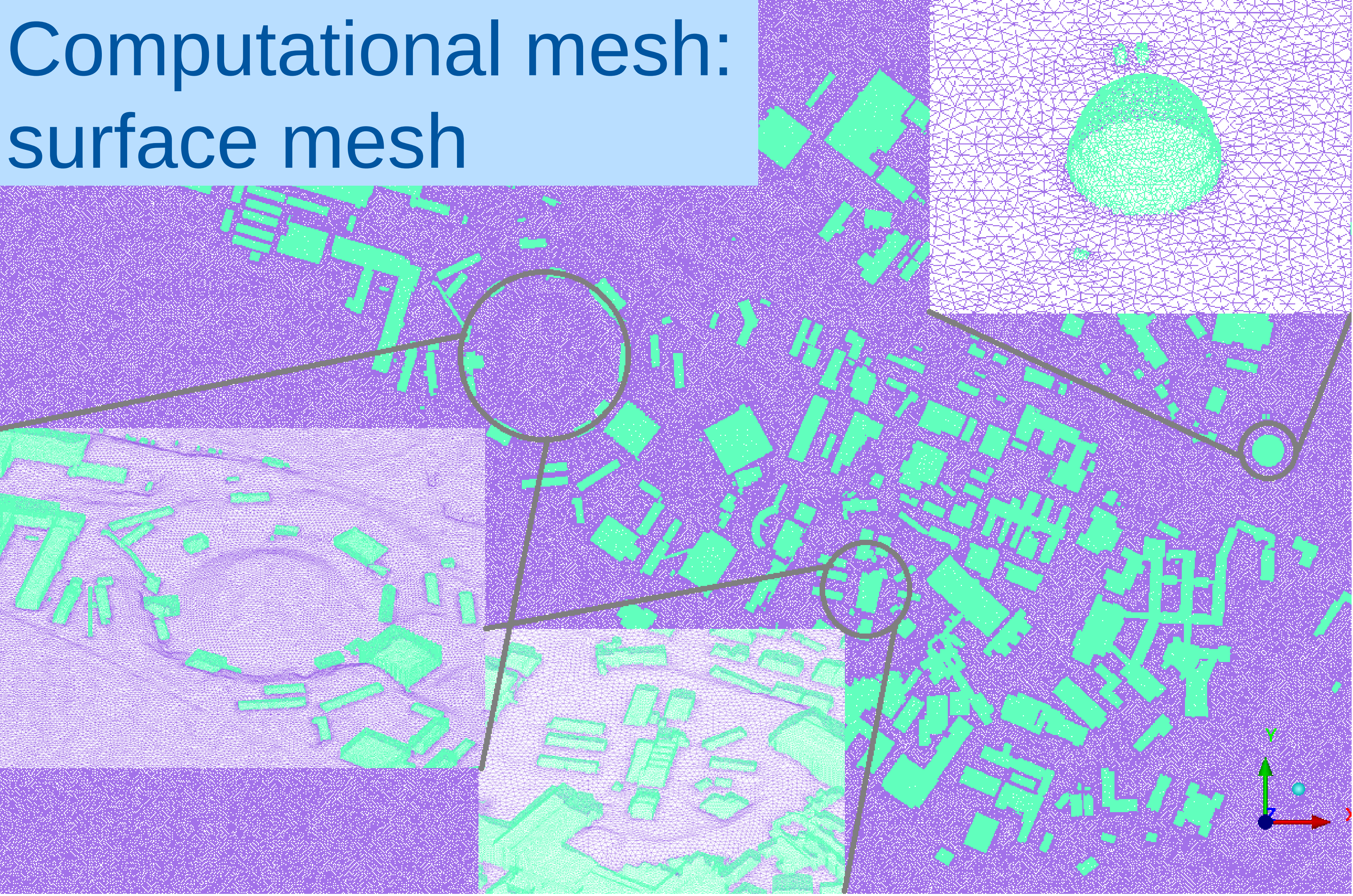
- ANSYS Meshing
- ANSYS IcemCFD
- ANSYS Fluent Mesher
- OpenFOAM snappyHexMesh

Expectation:

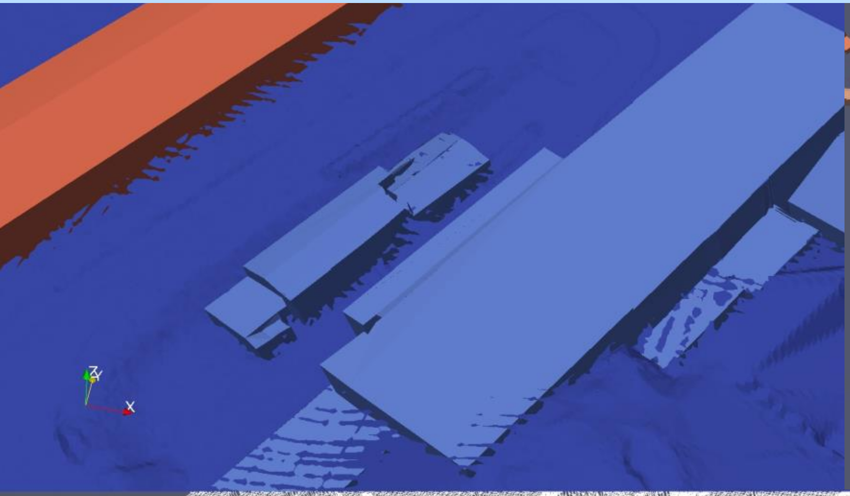
- Automatic (scriptable)
- Robust
- Relaxed at boundaries

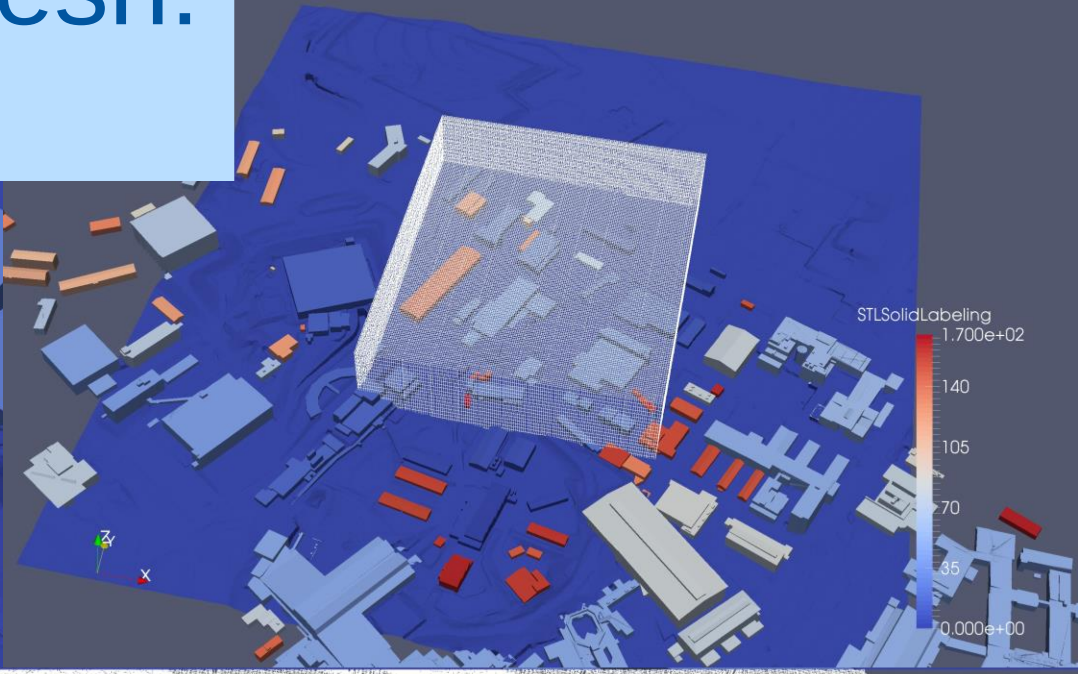


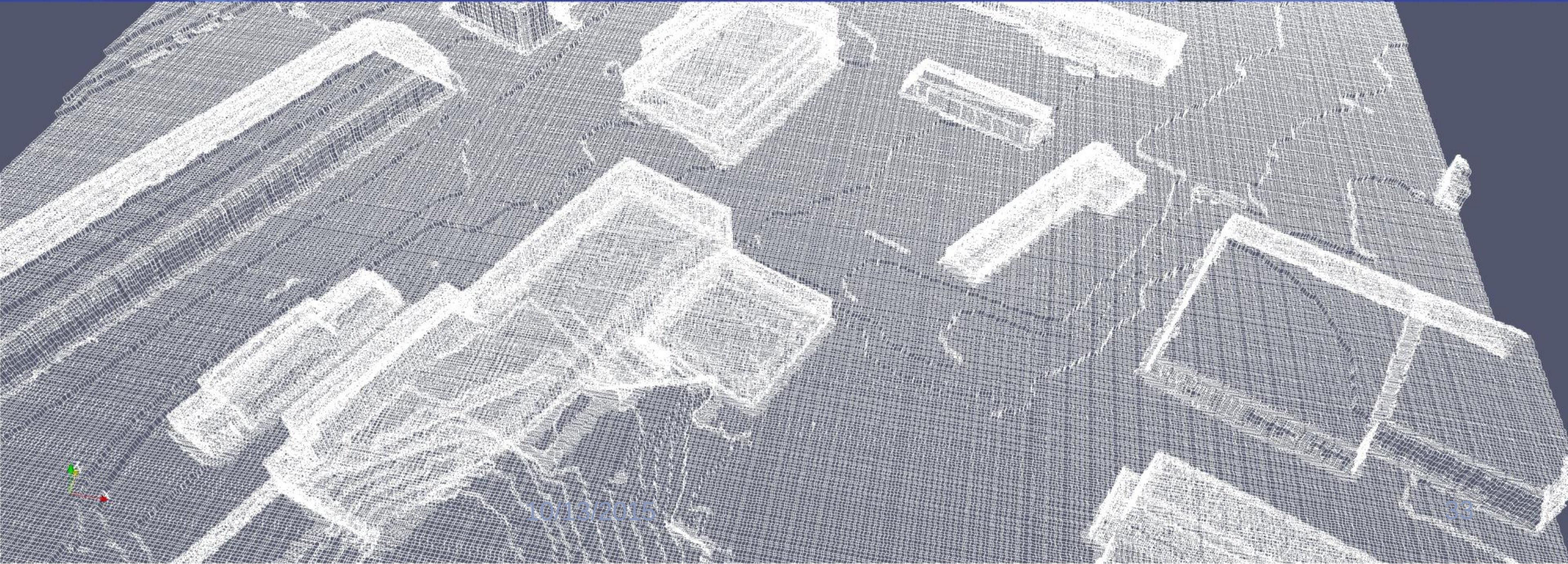
Computational mesh: surface mesh



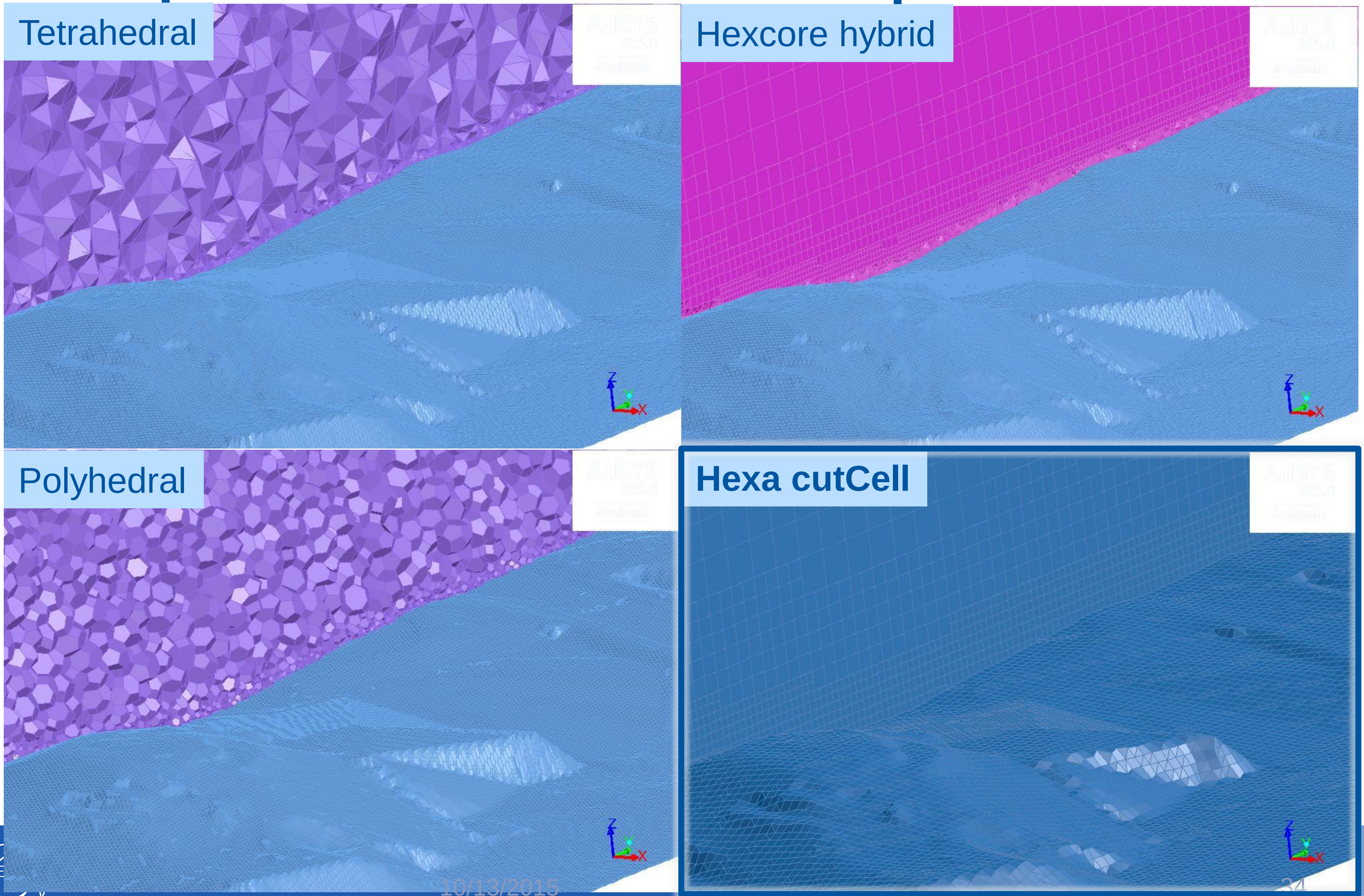
Computational mesh: snappyHexMesh





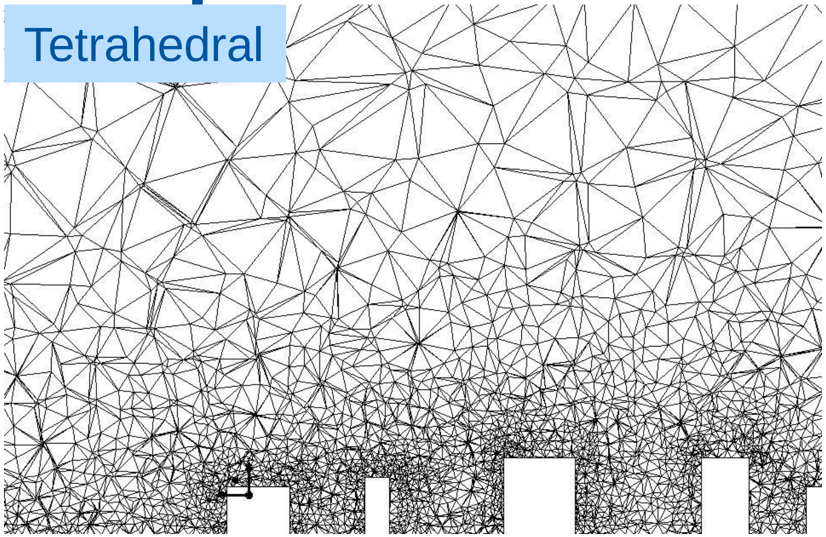


Computational mesh: options

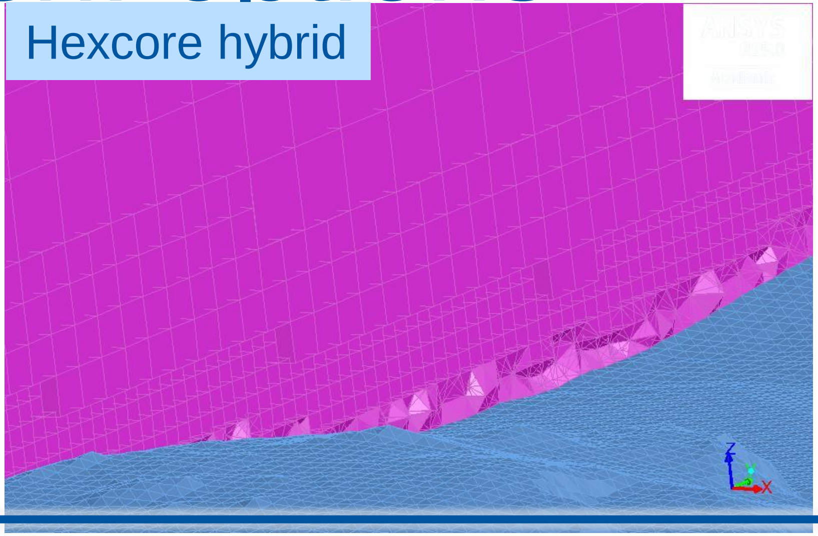


Computational mesh: options

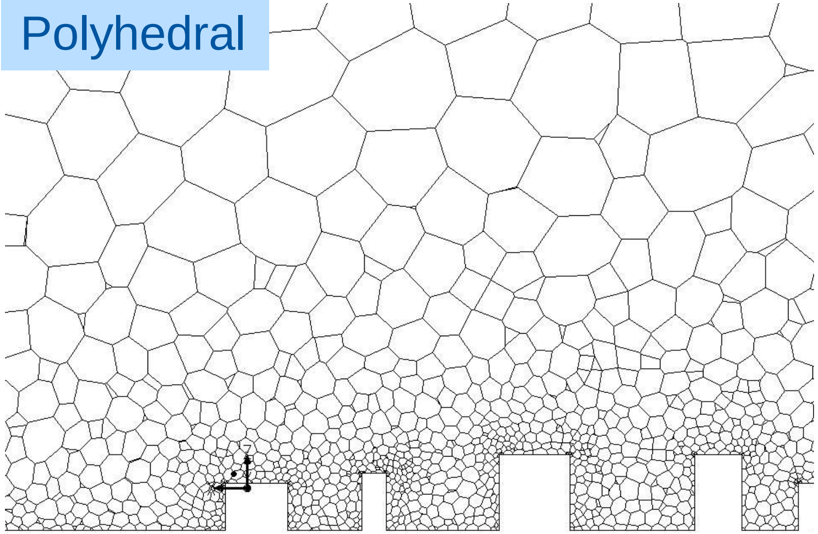
Tetrahedral



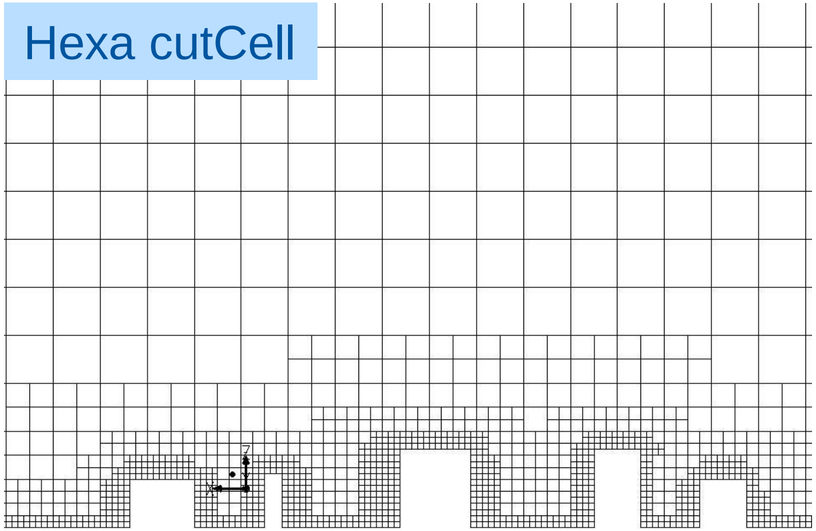
Hexcore hybrid



Polyhedral



Hexa cutCell



Current modelling strategy

- Small test site
- Meyrin site
- Automatize modelling and nesting process.

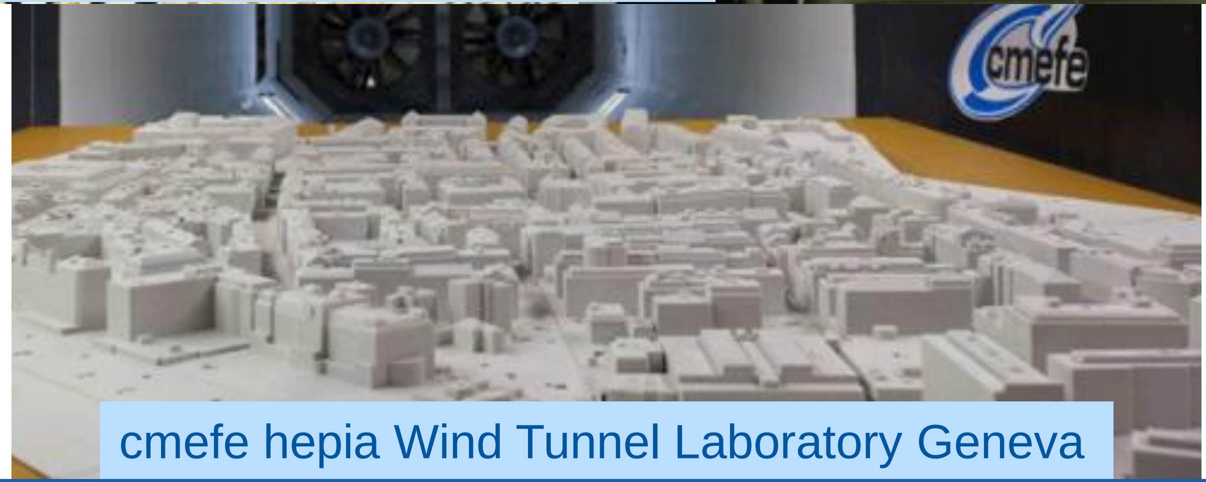
<table>
<tr><th colspan="3">2015</th><th colspan="8">2016</th></tr>
<tr><th>october</th><th>november</th><th>december</th><th>january</th><th>february</th><th>march</th><th>april</th><th>may</th><th>june</th><th>july</th><th>august</th></tr>
<tr><td colspan="2">meshing</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td colspan="3">test calculations</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td colspan="3">identifying all scenarios</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="4">calculations</td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="3">evaluation</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td colspan="4">report and user guide</td></tr>
</table>

Wind tunnel modelling possibilities

Von Karman Wind Tunnel Laboratory Budapest

Environmental Wind Tunnel Laboratory Hamburg

-
Limited number of measurement points



cmefe hepia Wind Tunnel Laboratory Geneva

+
Validation of the CFD model

Conclusion: feasible outcomes

Simulation of some typical/extreme situation:

- “La bise”, strong wind
- Heat waves, weak wind
- Most frequent wind direction

Find regions of:

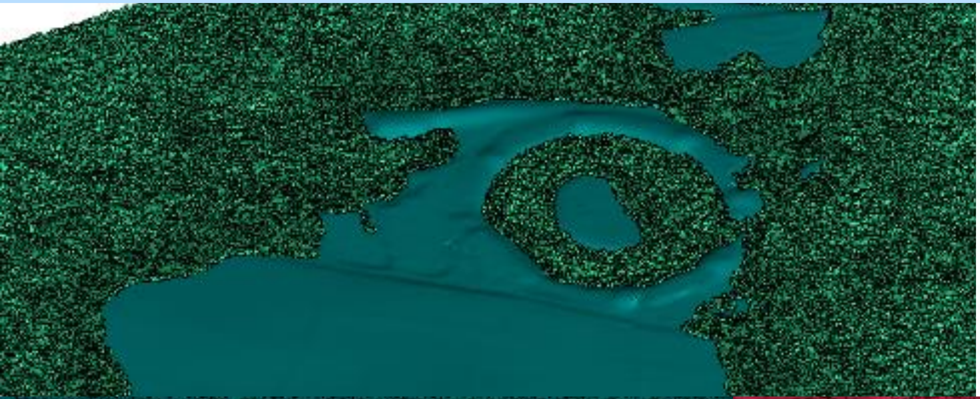
- **Accumulated pollutant, high concentration zones**
- Highest wind speeds
- Worst thermal comfort

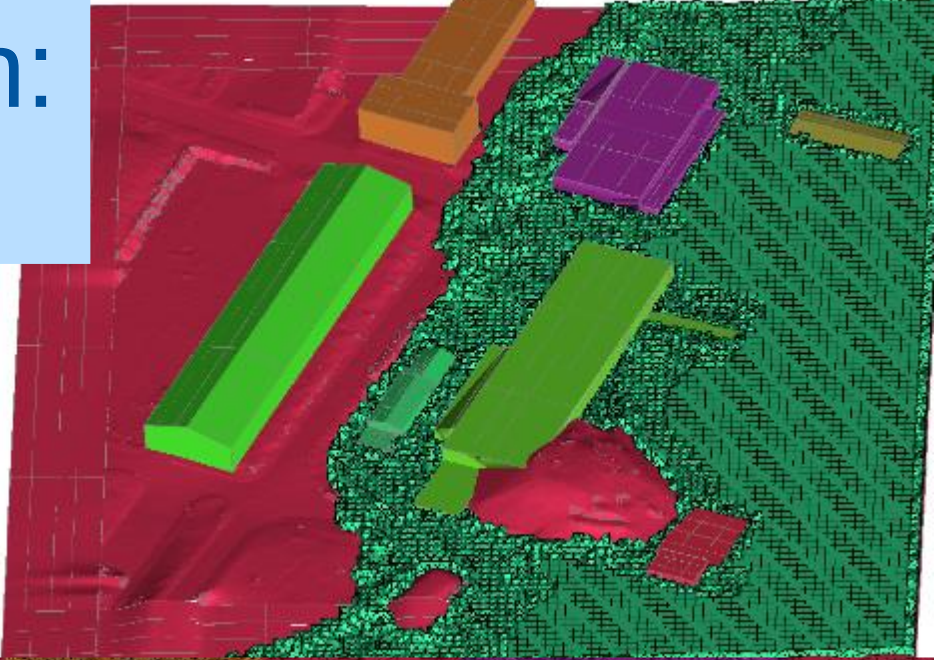
Thank you for your attention!

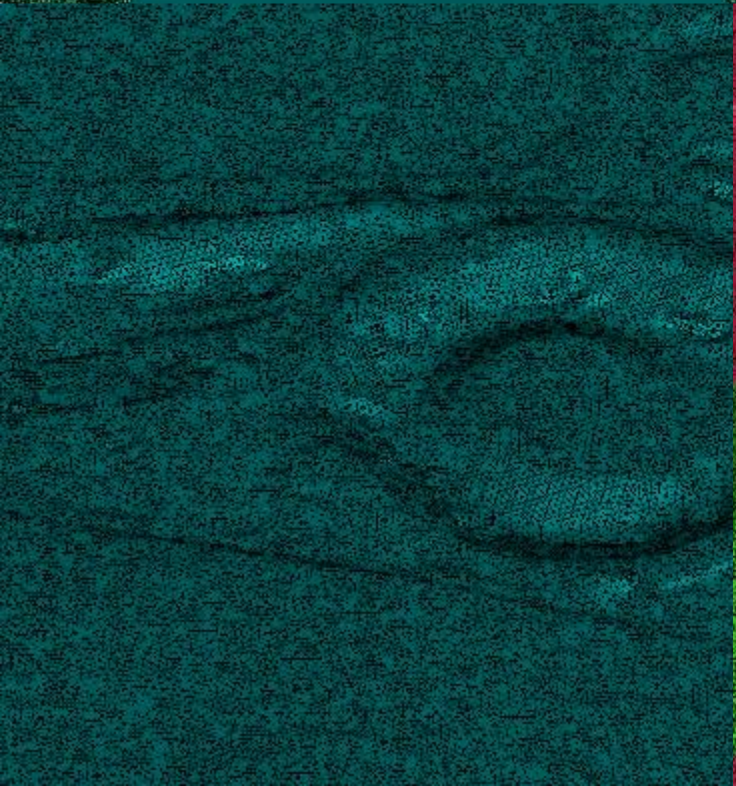
Bibliography I

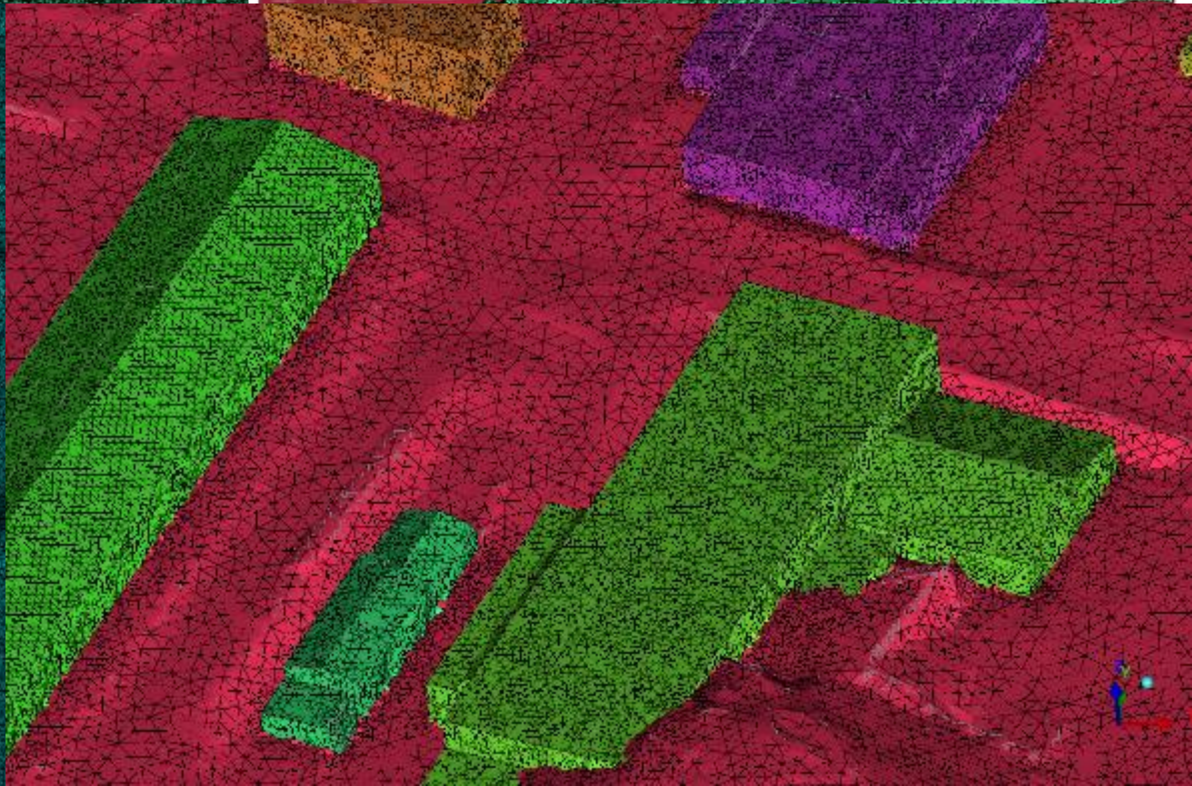
1. F. R. Menter – *Best Practice: Scale-Resolving Simulations in ANSYS CFD*, ANSYS Germany Gmbh. 2012
2. G. Triscone. *Clean city - mesures de qualité de l'air et ventilation des quartiers*. HES-SO, 2015.
3. P. Vojtyla – *Models for Assessment of the Environmental Impact of Radioactive Releases from CERN facilities* Technical Report EDMS 355483, CERN, 2002.
4. B. Blocken – *Computational Fluid Dynamics for urban physics: Importance, scales, possibilities, limitations and ten tips and tricks towards accurate and reliable simulations*, Building and Environment 91 (2015) 219-245
5. ERCOFTAC Special Interest Group on "Quality and Trust in Industrial CFD" *Best Practice Guidelines* Editors: M. Casey and T. Wintergerste Fluid Dynamics Laboratory Sulzer Innotec, Version 1, ERCOFTAC 2000
6. J. Franke, A. Hellsten, H. Schlünzen, and B. Carissimo. *Best Practice Guideline for the CFD Simulation of Flows in the Urban Environment*. COST Action 732: Quality Assurance and Improvement of Microscale Meteorological Models, 2007.
7. Y. Tominagaa,, A. Mochidab, R. Yoshiec, H. Kataokad, T. Nozue, M. Yoshikawaf, T. Shirasawac – *AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings*, Journal of Wind Engineering and Industrial Aerodynamics 96 (2008) 1749–1761
8. P. Vojtyla – *CERN's Wind Atlas 2011, 2012 and 2014* (https://edms.cern.ch/document/1503169/1/TAB3)

Computational mesh: ANSYS IcemCFD









Available computational resources

Linux CFD cluster: 20*8 cores

Windows HPC cluster: around 1000 cores

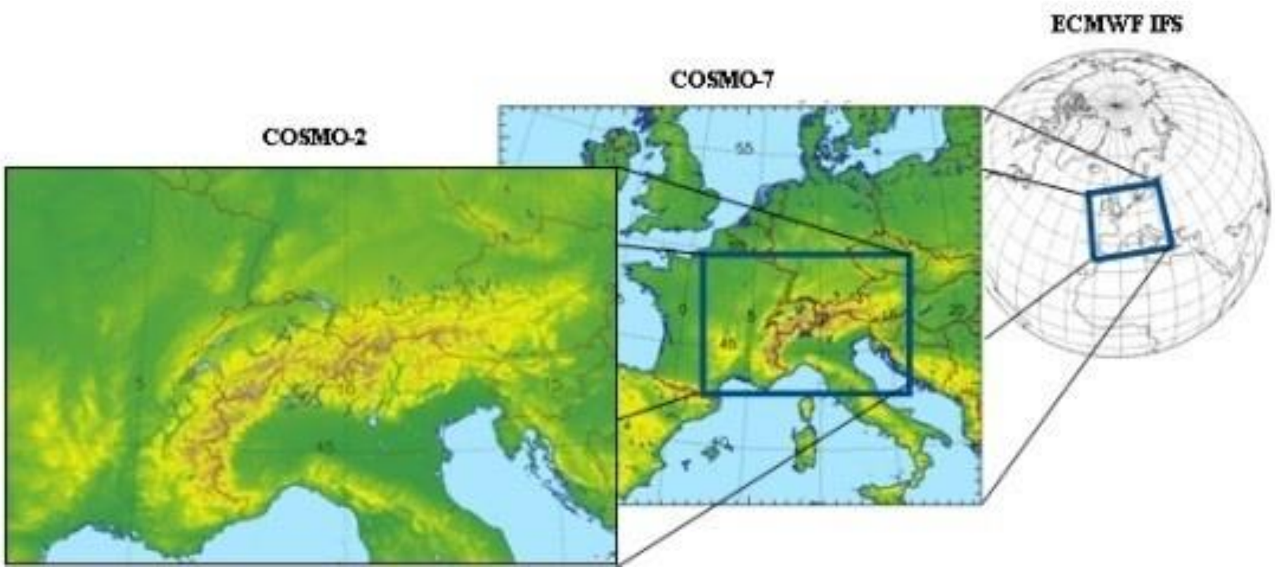
Software to be used for simulations:

- Ansys Fluent
- 10 CFD licences
- 400 Ansys HPC licences (total at CERN)

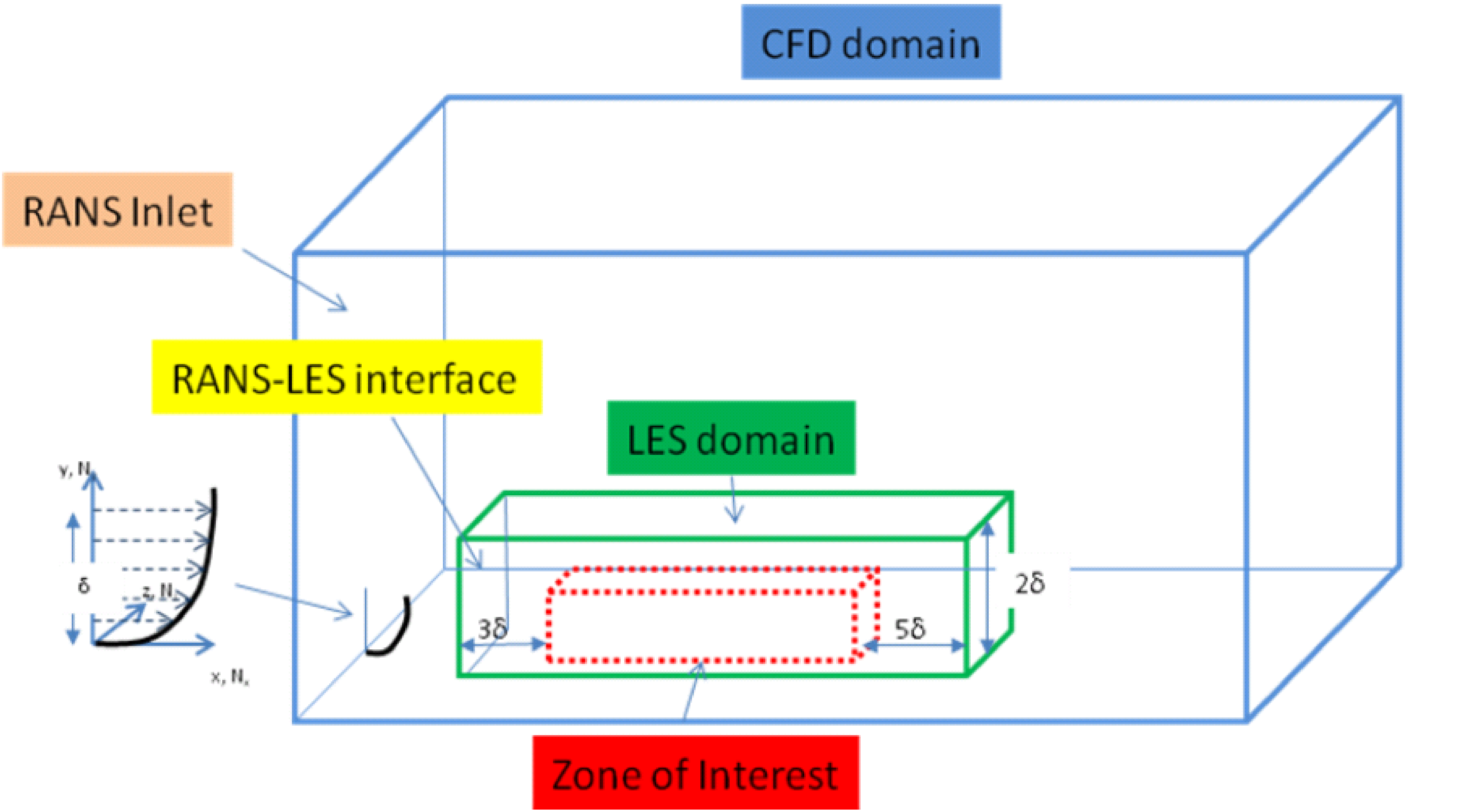
Test run: ~9 million cells, 1000 iterations, 64 cores, 0.5 hour

Swiss example of nesting

- Meteosuisse's COSMO model for weather forecasting
- 7km and 2km resolution
- FLEXPART dispersion model on top of prediction for emergency preparedness and response (Lagrangian)



Embedded LES like nesting



Boundary conditions - nesting

Downscaling literature and methods:

- From mesoscale meteorological models
- Schlünzen et al – Joint modelling of obstacle induced and mesoscale changes – Current limits and challenges, JWEIA 99 (2011)
- Time-slice approach ↔ Nesting
- Yamada and Koike – Downscaling mesoscale meteorological models for computational wind engineering applications, JWEIA 99 (2011)
- Mochida et al – Up-scaling CWE models to include mesoscale meteorological influences, JWEIA 99 (2011)