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Local ScaleAir Quality Model with Several Pollutant Sources

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Motivation

Regional models
- Eulerian
  - CMAQ
  - Mocage

Local models
- Gaussian plume
- Lagrangian
  - Calpuff
  - Scipuff

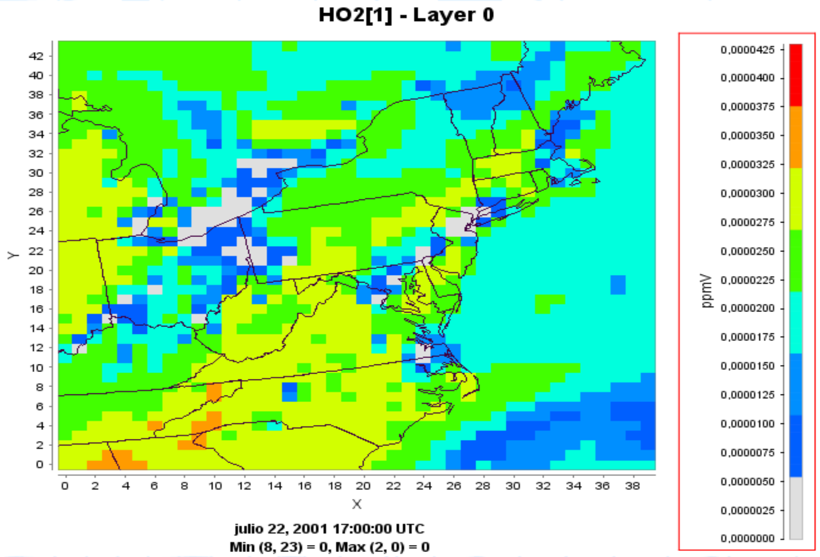
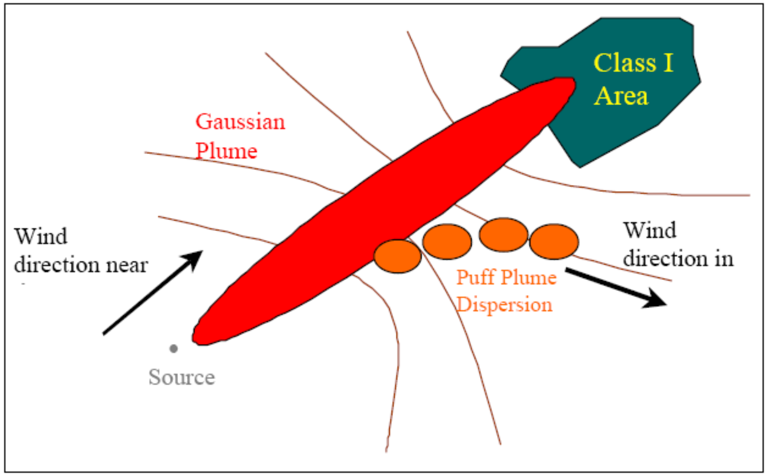


Figure 2: Comparison of Guassian and Puff Models Predicted Impacts



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Algorithm

Adaptive Finite Element Model

- Construction of a tetrahedral mesh
  - Mesh adapted to the terrain
- Wind field modeling
  - Horizontal and vertical interpolation from data (experimental/forecast)
  - Mass consistent computation
- Pollutant dispersion modeling
  - Wind field plume rise perturbation
  - Transport and reaction pollutant simulation
  - Adaptivity

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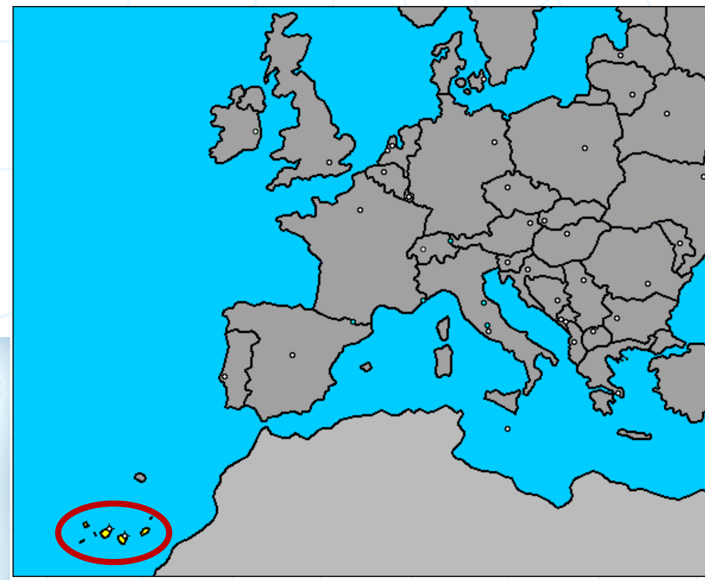
Motivation

- Air Quality modeling over complex terrains
- Range ~ 20km x 20km
- La Palma island (Canary Islands)



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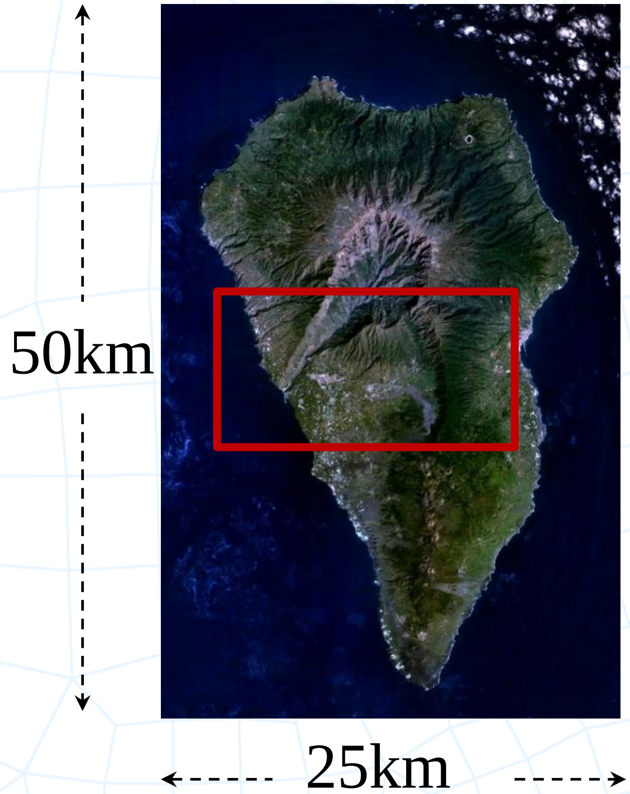
Motivation

- One of the highest horizontal-vertical ratios in the world
- Height: 2426m

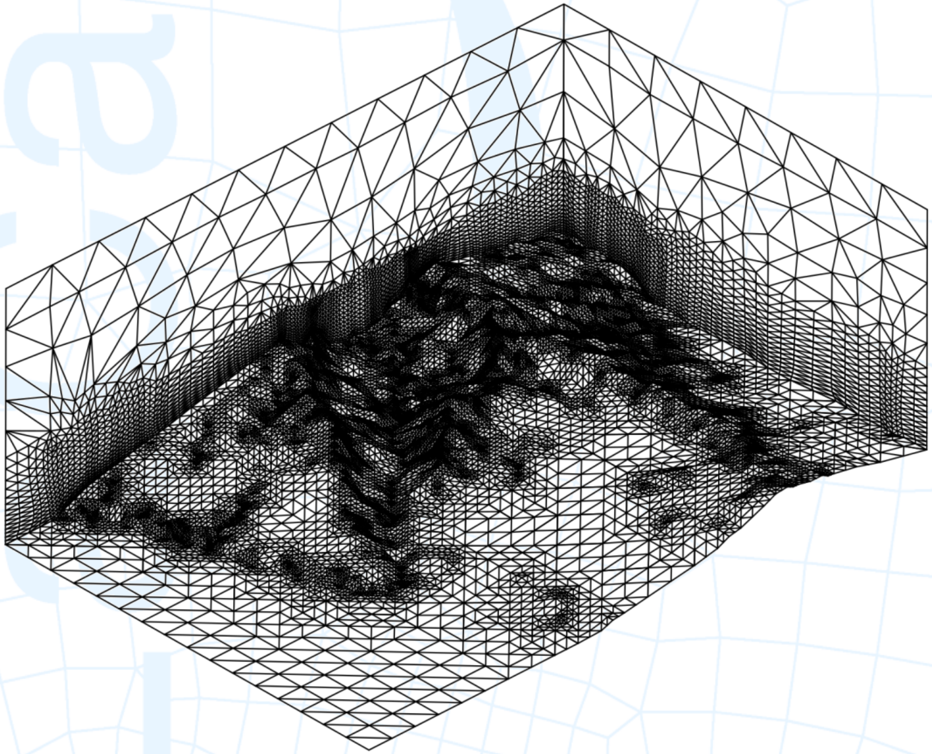


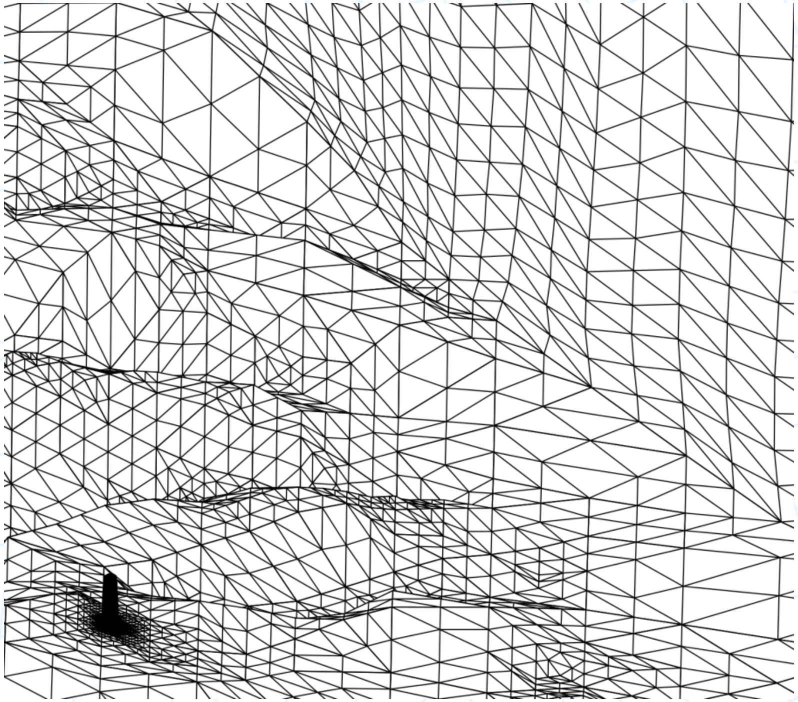
Mesh construction

- Two dimensional triangular mesh of terrain
  - Stack discretization
  - Local Refinement – coarsening process
- Vertical spacing following layers
- Three dimensional tetrahedral mesh creation
- Smoothing and untangling in order to guarantee a minimum quality

Mesh creation

~500.000 nodes
~2.700.000 elements





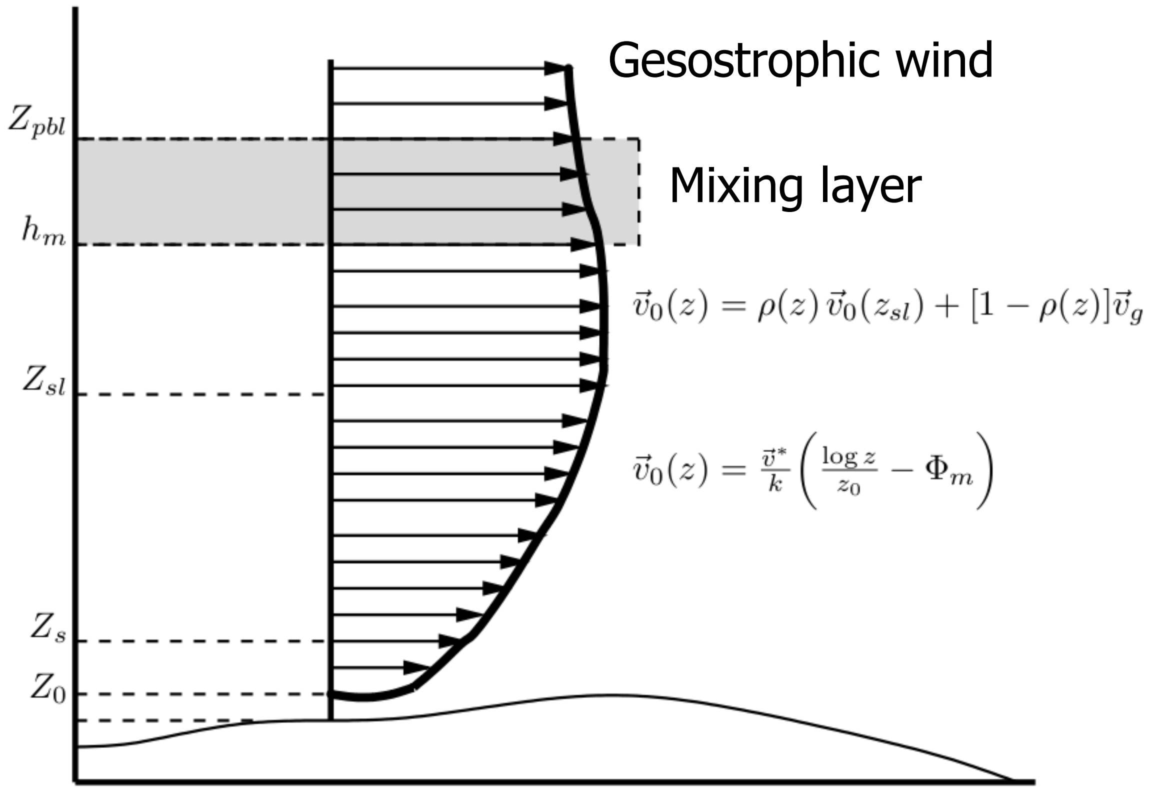
Wind field modeling

- Horizontal interpolation
  - Weighting inverse to the squared distance and inverse height differences

$$\tilde{\mathbf{v}}_0(z_m) = \varepsilon \frac{\sum_{n=1}^{N} \frac{\tilde{\mathbf{v}}_n}{d_n^2}}{\sum_{n=1}^{N} \frac{1}{d_n^2}} + (1-\varepsilon) \frac{\sum_{n=1}^{N} \frac{\tilde{\mathbf{v}}_n}{|\Delta h_n|}}{\sum_{n=1}^{N} \frac{1}{|\Delta h_n|}}$$

Wind field modeling

- Vertical interpolation
  - Log-linear wind profile



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Wind field modeling

- Mass-consistent model

$$\begin{aligned} \vec{\nabla} \cdot \vec{u} &= 0 \quad \text{in } \Omega \\ \vec{n} \cdot \vec{u} &= 0 \quad \text{on } \Gamma_b \end{aligned}$$

- Lagrange multiplier

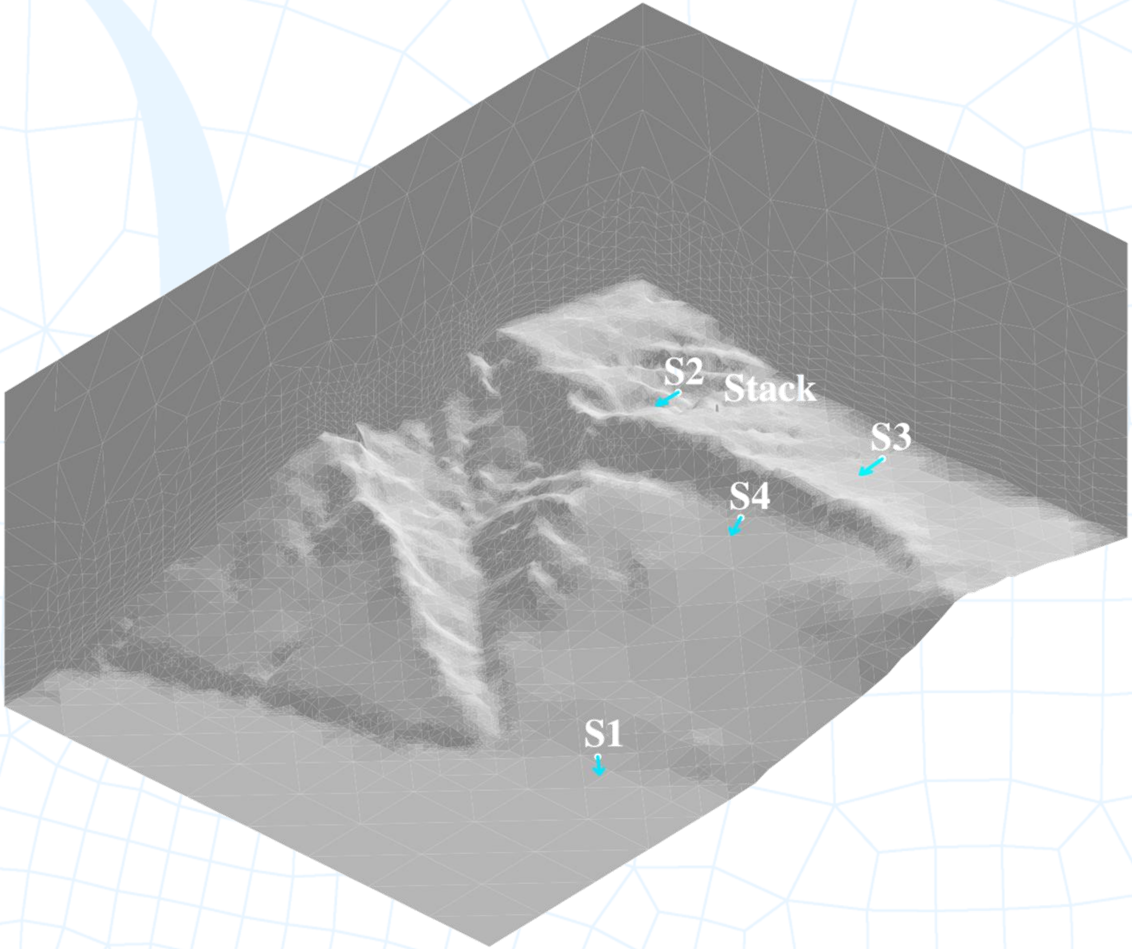
$$u = u_0 + T_h \frac{\partial \phi}{\partial x}, \quad v = v_0 + T_h \frac{\partial \phi}{\partial y}, \quad w = w_0 + T_v \frac{\partial \phi}{\partial z},$$

$$\frac{\partial^2 \phi}{\partial x^2} + \frac{\partial^2 \phi}{\partial y^2} + \frac{T_v}{T_h} \frac{\partial^2 \phi}{\partial z^2} = -\frac{1}{T_h} \left(\frac{\partial u_0}{\partial x} + \frac{\partial v_0}{\partial y} + \frac{\partial w_0}{\partial z} \right) \quad \text{in } \Omega$$

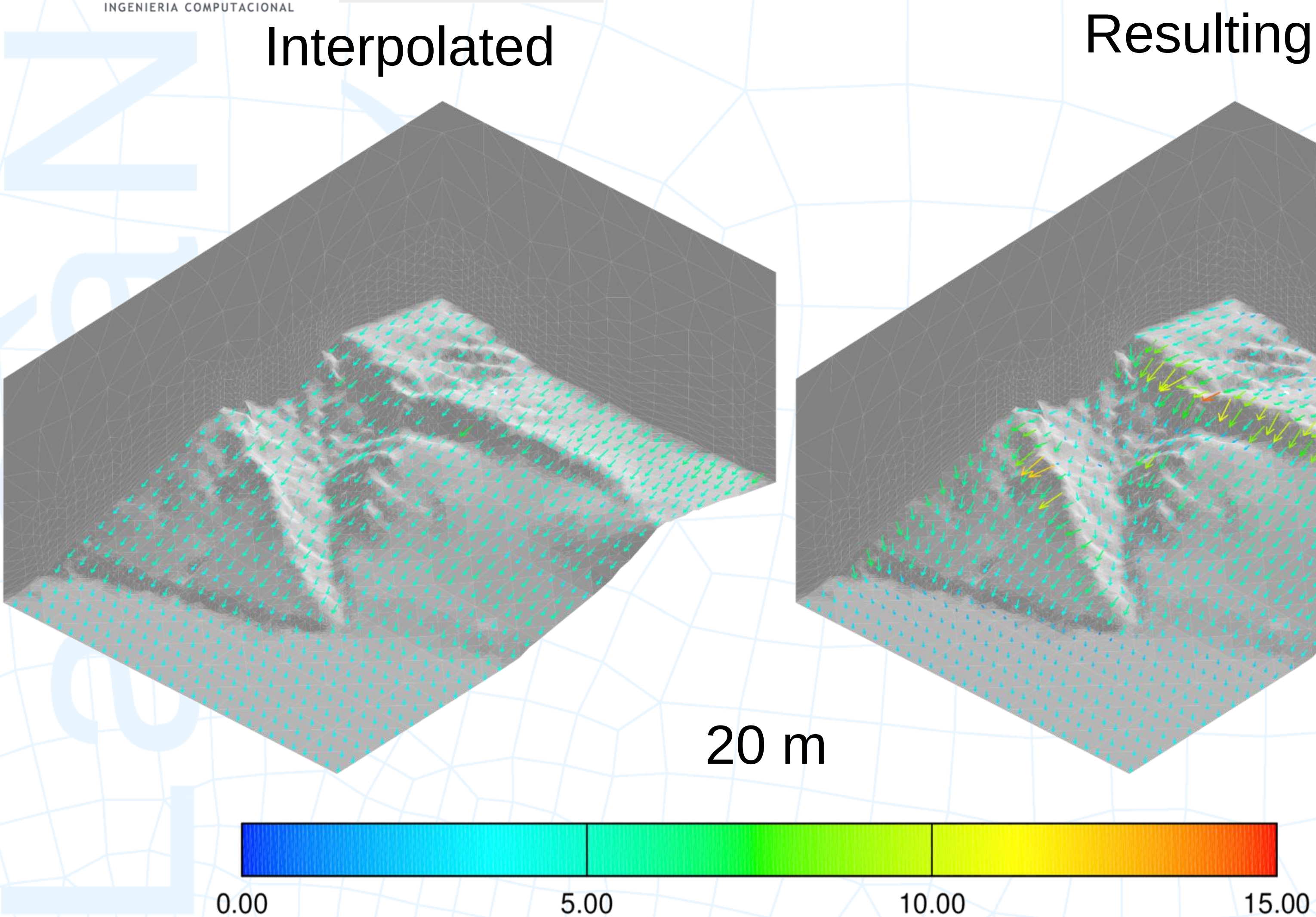
$$\begin{aligned} \phi &= 0 \quad \text{on } \Gamma_a \\ \vec{n} \cdot T \vec{\nabla} \mu &= -\vec{n} \cdot \vec{v}_0 \quad \text{on } \Gamma_b \end{aligned}$$

Wind field modeling

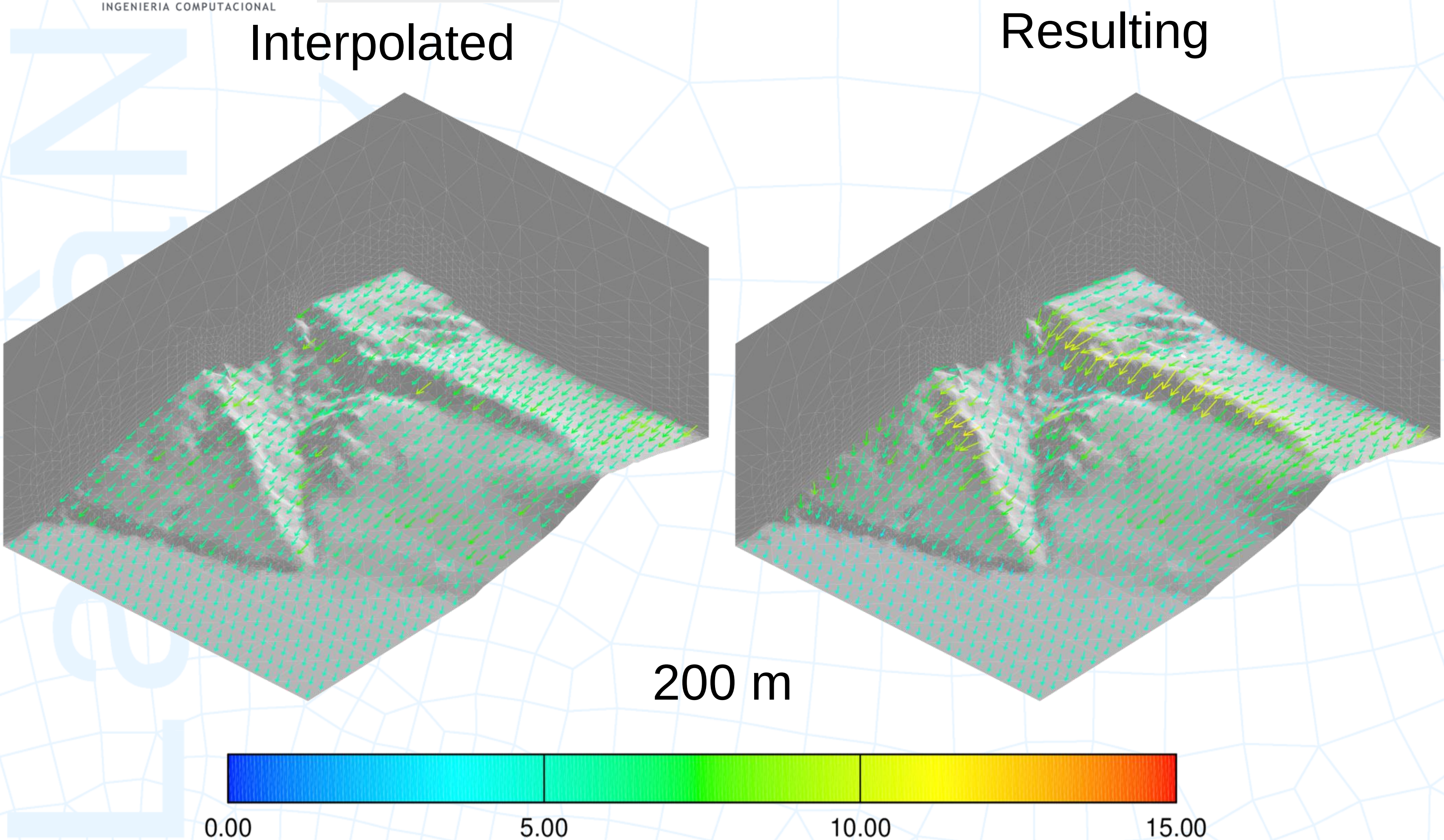
- Experimental data from 4 stations (10 m over terrain)



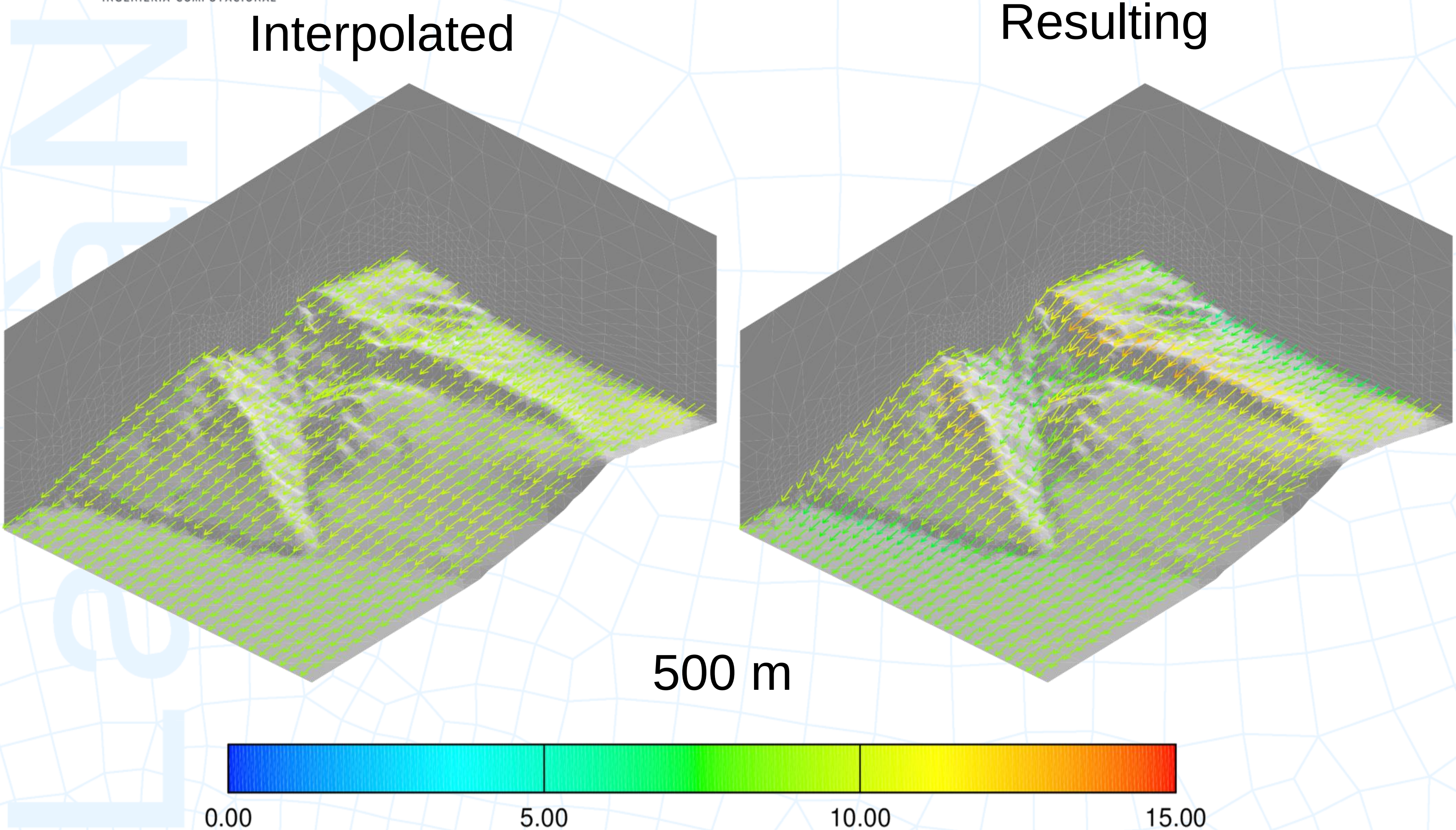
Wind field modeling



Wind field modeling

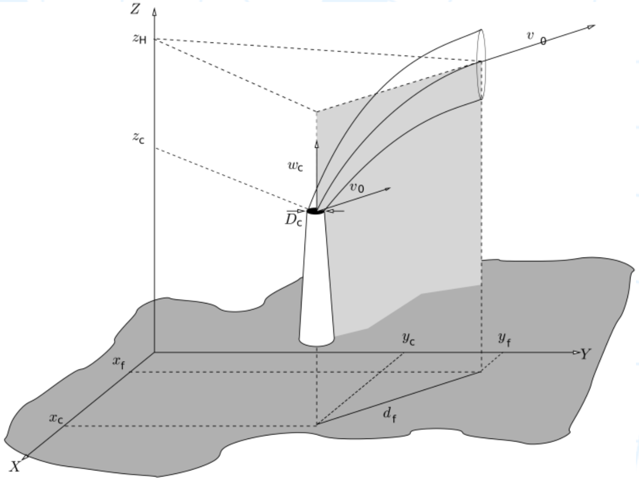


Wind field modeling

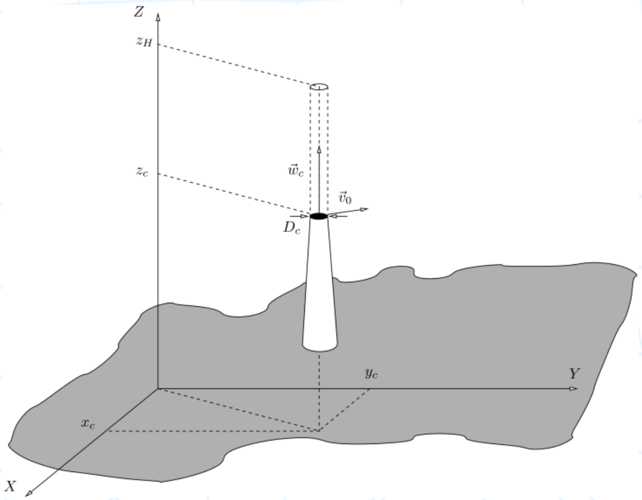


Plume rise modeling

- Briggs formula
  - Buoyant (wc < 4Vo)
    - Driving-force: gas temperature difference
    - Curved trajectory



  - Momentum (wc > 4Vo)
    - Driving-force: Gas velocity
    - Vertical straight trajectory



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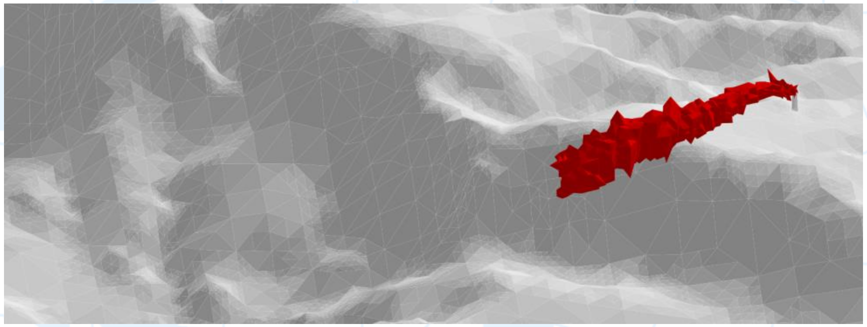
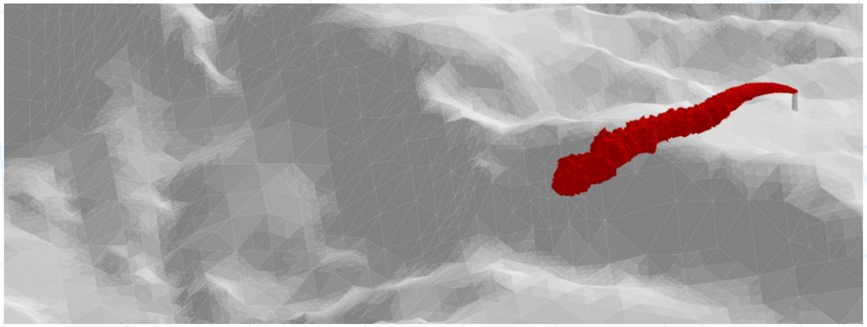
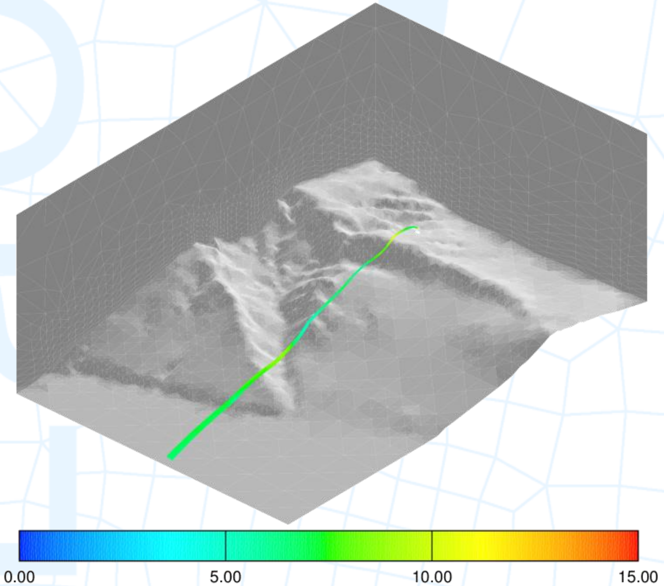
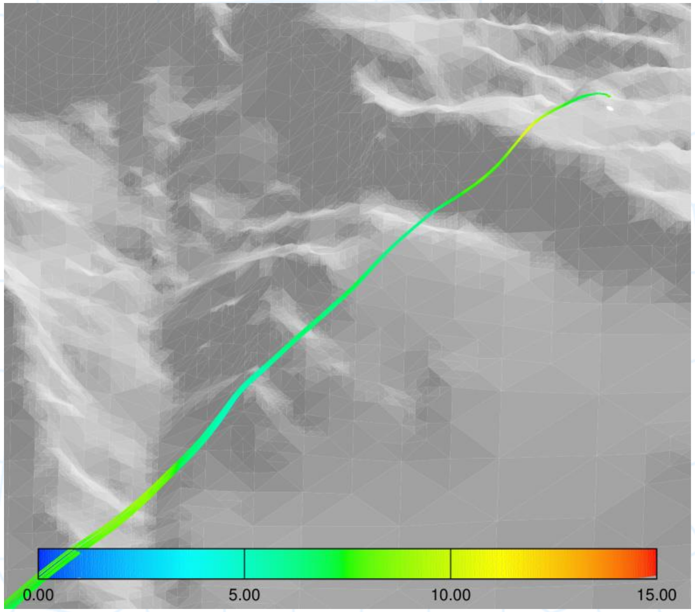
Plume rise modeling









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Air quality modeling

$$\frac{\partial \mathbf{c}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{c} = \nabla \cdot (\mathbf{K} \nabla \mathbf{c}) + \mathbf{e} + \mathbf{s}(\mathbf{c})$$

$$c(x,t) = c^{emi}$$ Stack outflow

$$c(x,t) = c^{amb}$$ Inlet wind boundaries

$$\mathbf{n} \cdot \mathbf{K} \nabla u = 0$$ Outlet wind boundaries

$$c(x,0) = c^{ini}$$ Initial condition

Air quality modeling

Splitting

Direct splitting

$$\begin{cases} \dfrac{\partial \mathbf{c}^*}{\partial t} = \mathbf{s}(\mathbf{c}^*) & [0, \Delta t], \quad \mathbf{c}^*(\mathbf{x}, 0) = \mathbf{c}^n(\mathbf{x}) \\ \dfrac{\partial \mathbf{c}^{**}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{c}^{**} = \nabla \cdot (\mathbf{K} \nabla \mathbf{c}^{**}) & [0, \Delta t], \quad \mathbf{c}^{**}(\mathbf{x}, 0) = \mathbf{c}^*(\mathbf{x}, \Delta t) \end{cases}$$

Strang Splitting

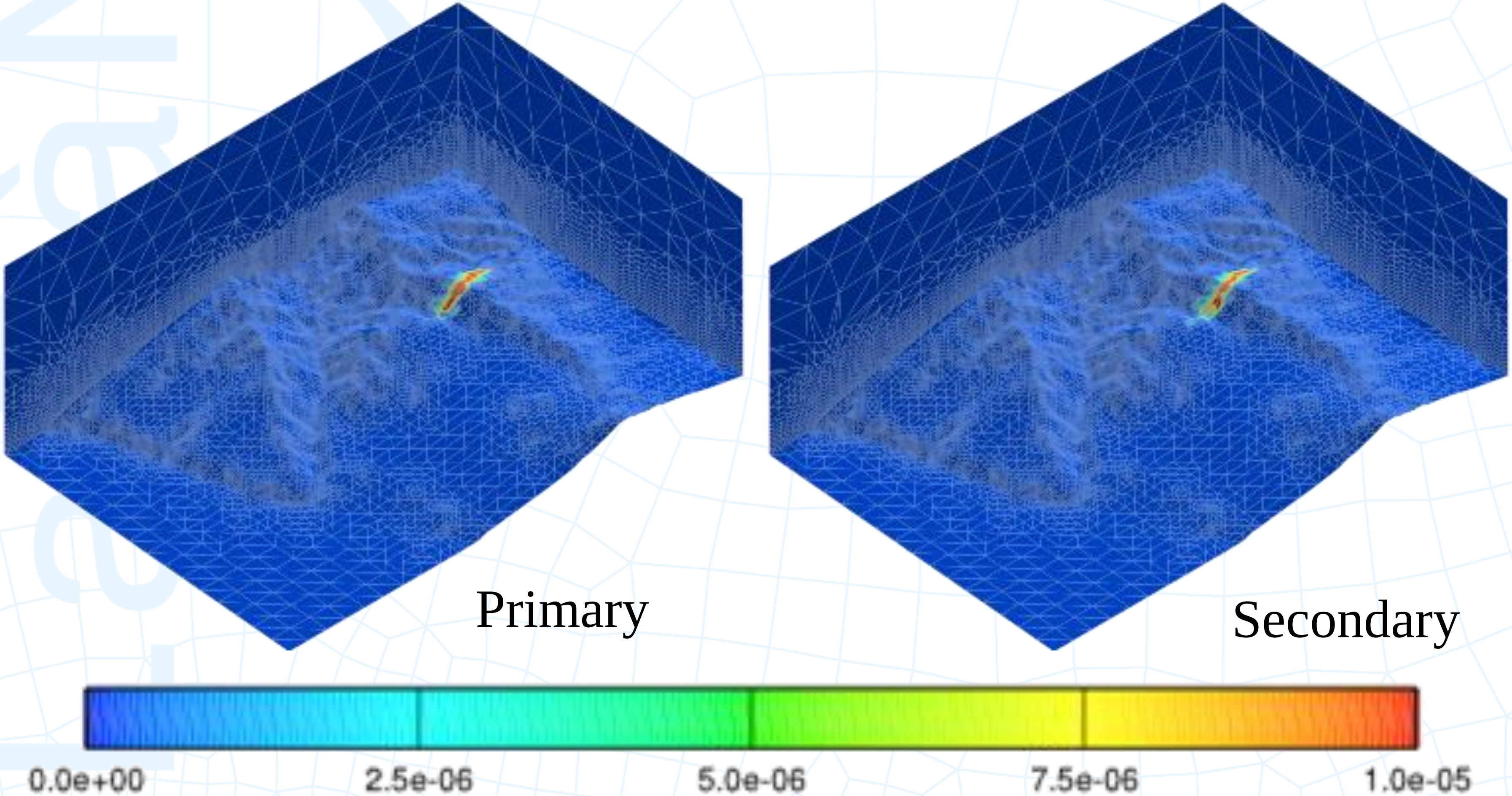
$$\begin{cases} \dfrac{\partial \mathbf{c}^*}{\partial t} = \mathbf{s}(\mathbf{c}^*) & [0, \Delta t/2], \quad \mathbf{c}^*(\mathbf{x}, 0) = \mathbf{c}^n(\mathbf{x}) \\ \dfrac{\partial \mathbf{c}^{**}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{c}^{**} = \nabla \cdot (\mathbf{K} \nabla \mathbf{c}^{**}) & [0, \Delta t], \quad \mathbf{c}^{**}(\mathbf{x}, 0) = \mathbf{c}^*(\mathbf{x}, \Delta t/2) \\ \dfrac{\partial \mathbf{c}^{***}}{\partial t} = \mathbf{s}(\mathbf{c}^{***}) & [0, \Delta t/2], \quad \mathbf{c}^{***}(\mathbf{x}, 0) = \mathbf{c}^{**}(\mathbf{x}, \Delta t) \end{cases}$$

Air quality modeling

- Temporal discretization: Cranck-Nicolson
- Spatial discretization: Least Squares FEM
- System solver: Conjugate gradient preconditioned with an Incomplete Cholesky Factorization
- Matrix storage: sparse MCS

Air quality modeling

Immission after 10 minutes



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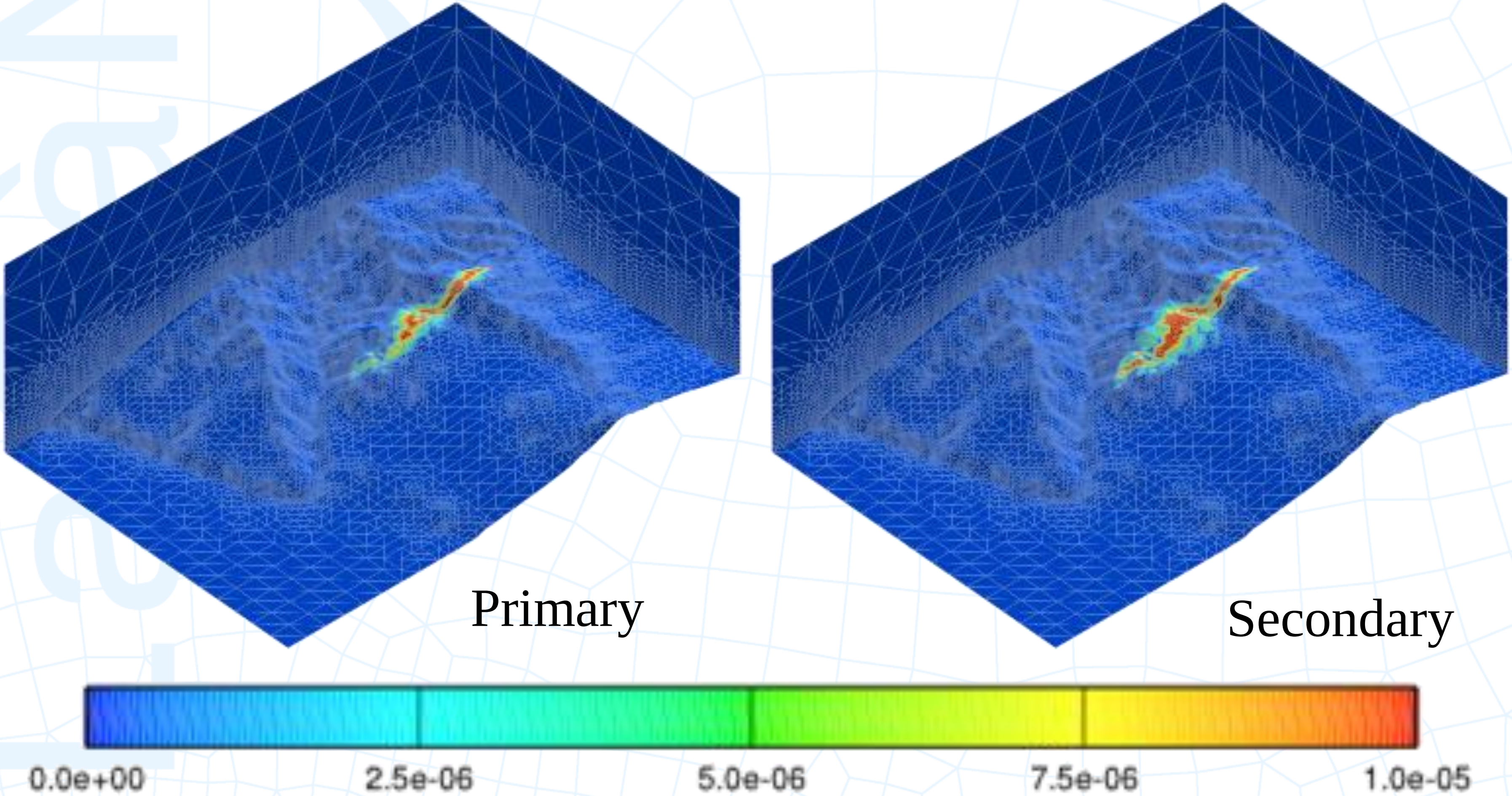
Air quality modeling

Immission after 20 minutes



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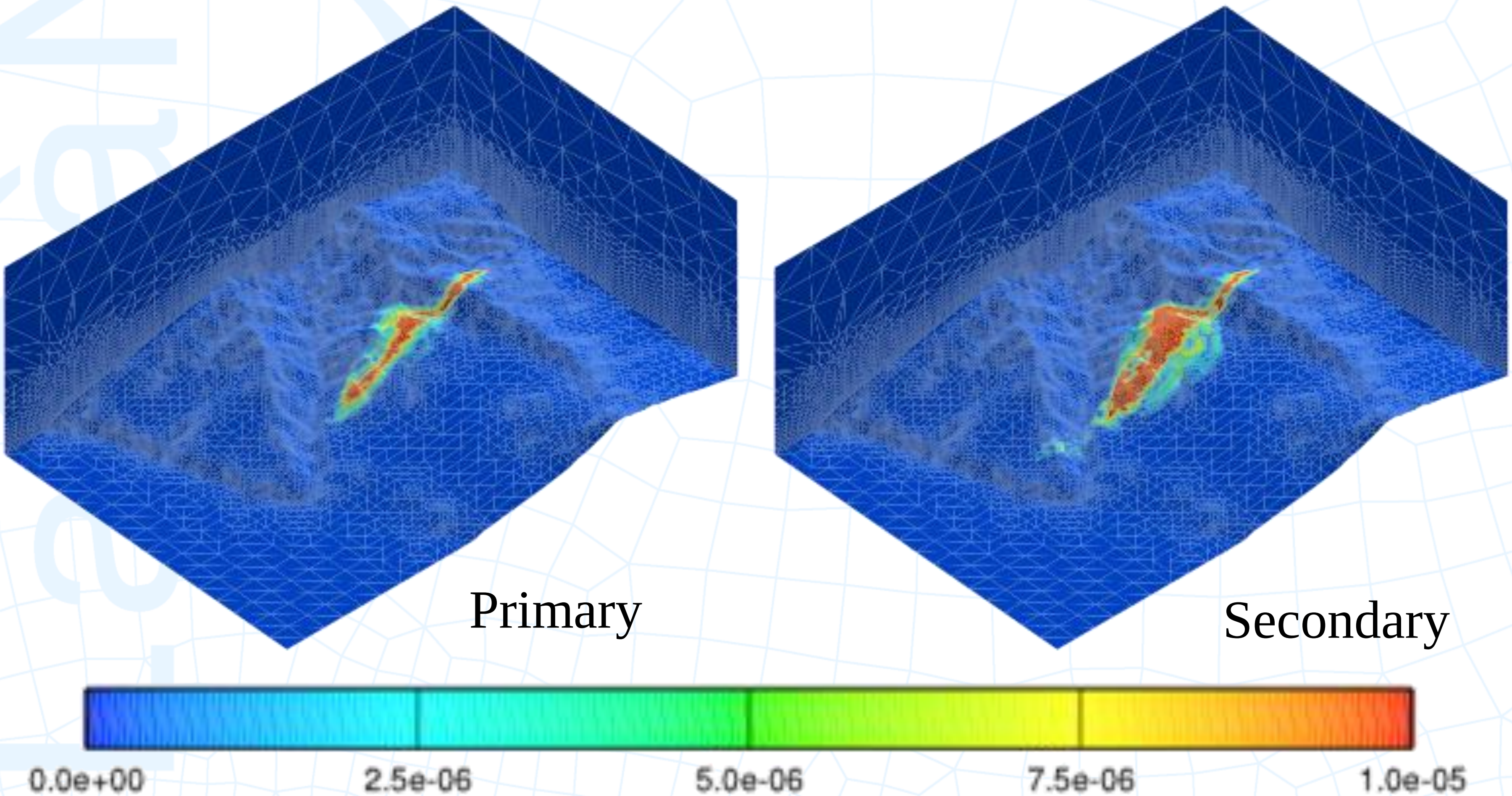
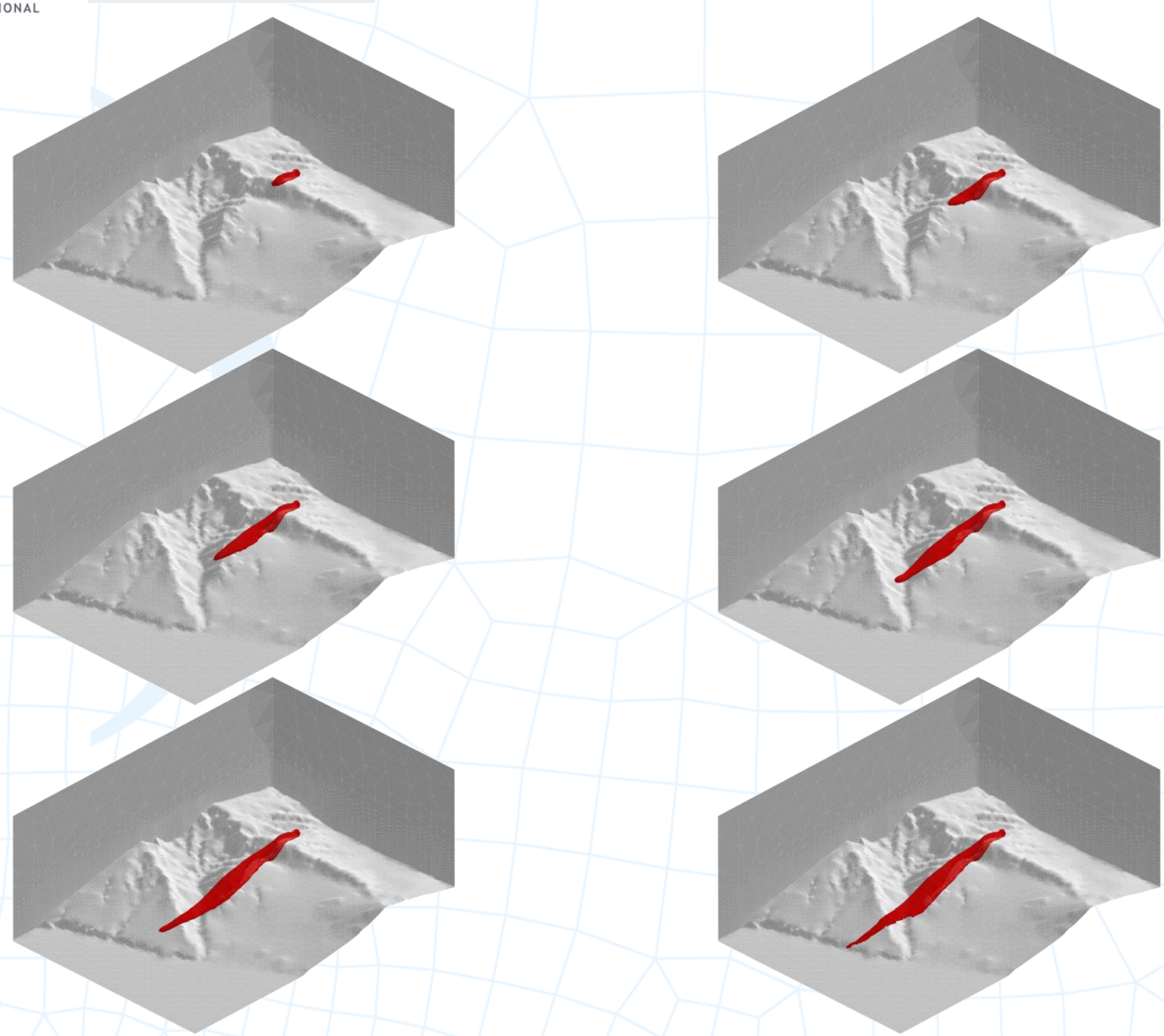
Air quality modeling

Immission after 30 minutes



Air quality modeling



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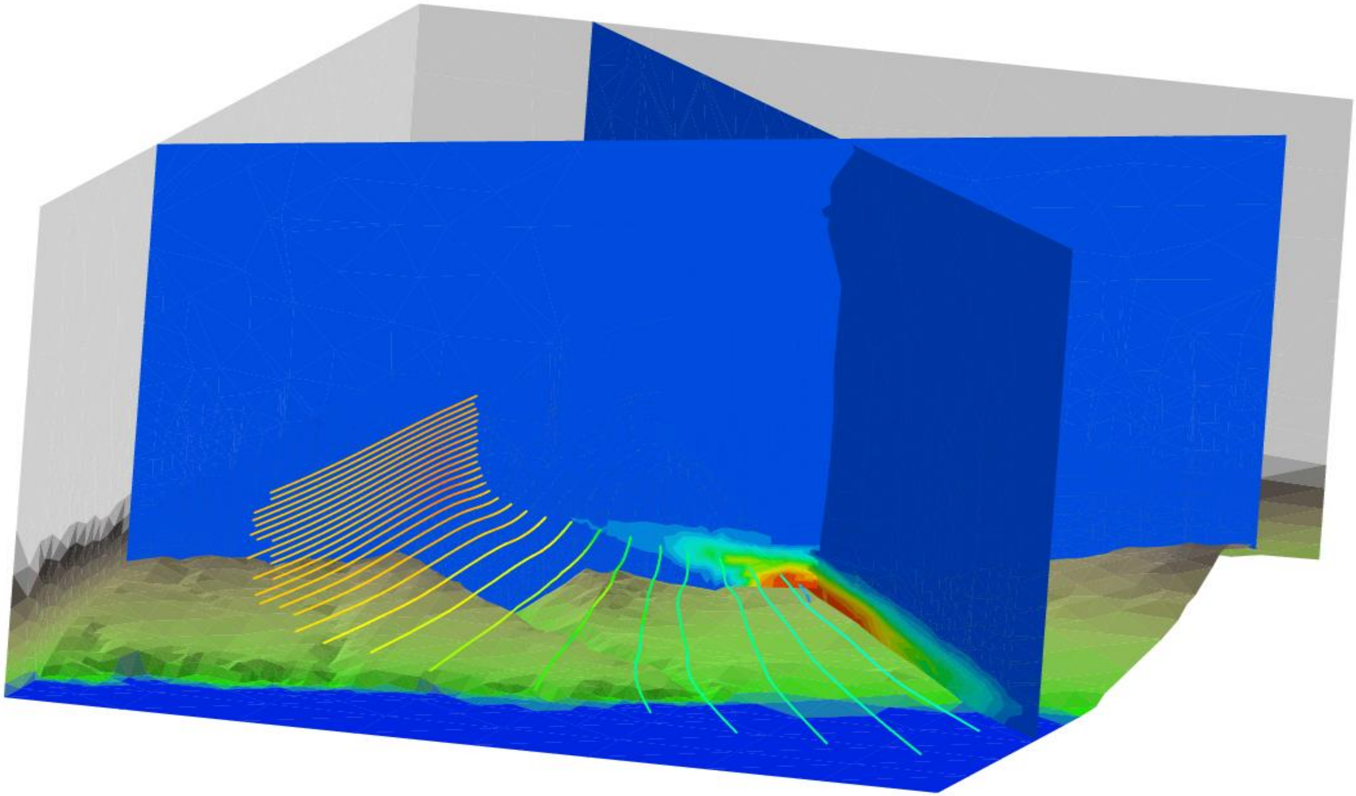
Air quality modeling



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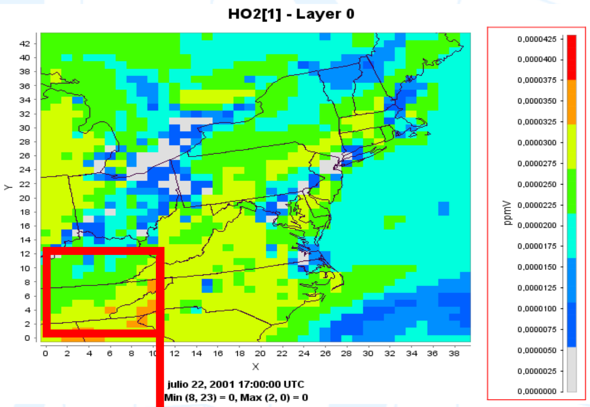
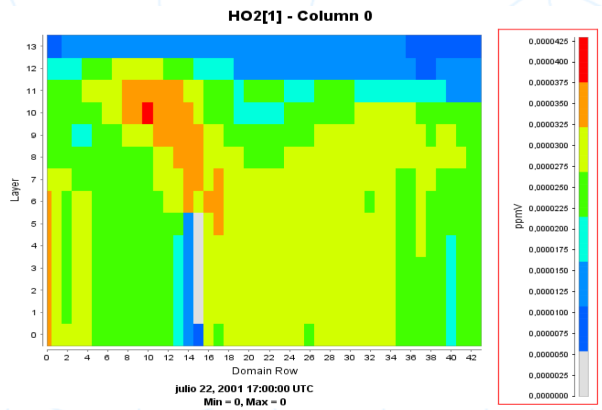
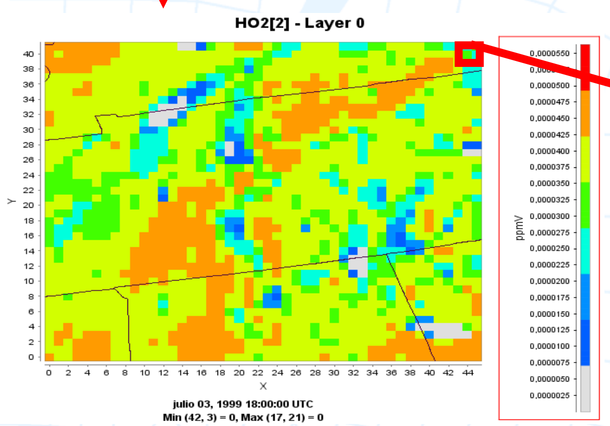
Air quality modeling

- CMAQ: forecast model



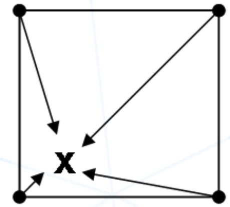




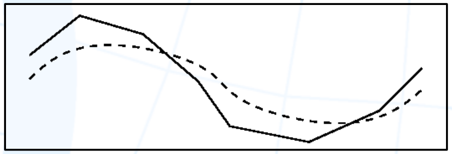
Local simulation domain: 16x16km^2

Air quality modeling

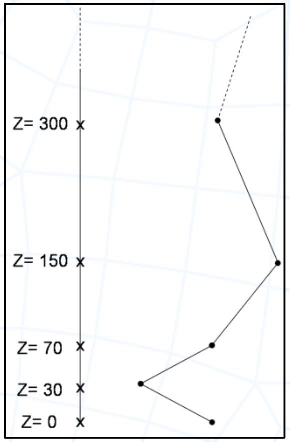
- Horizontal interpolation each CMAQ layer



- Correction height



- Vertical linear interpolation



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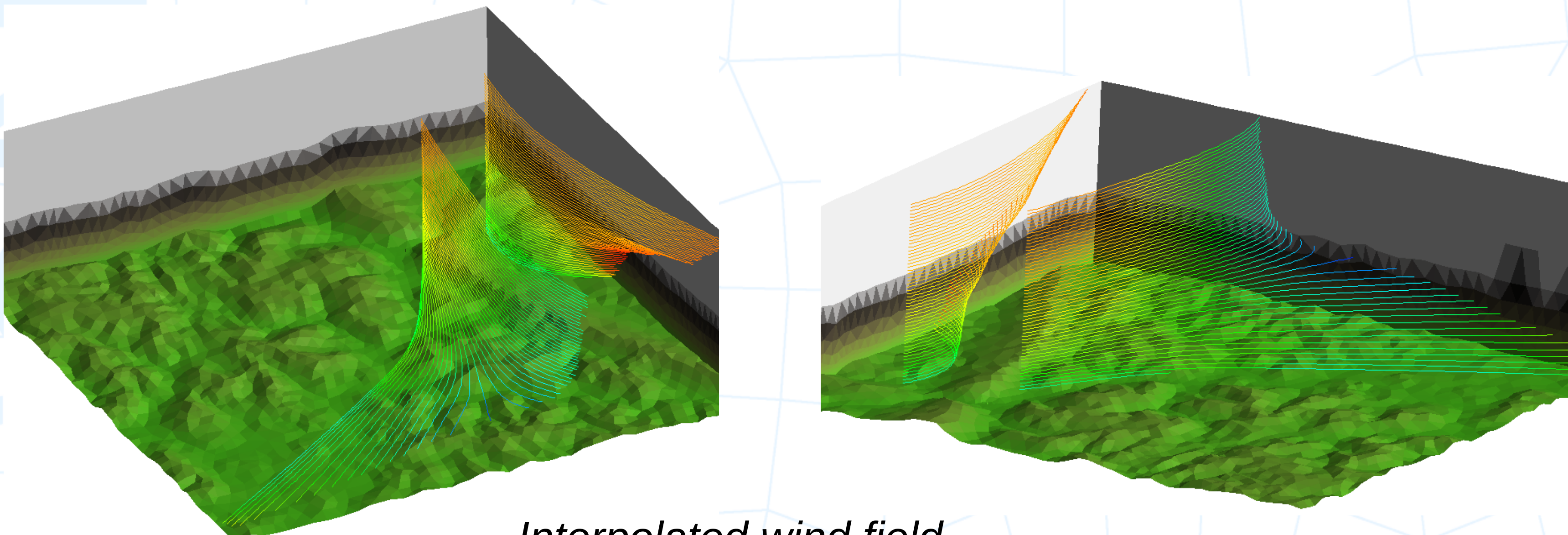
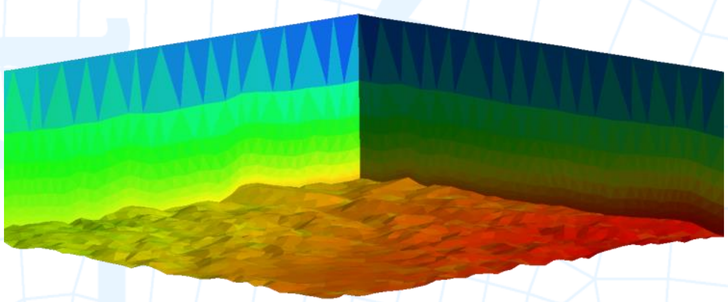
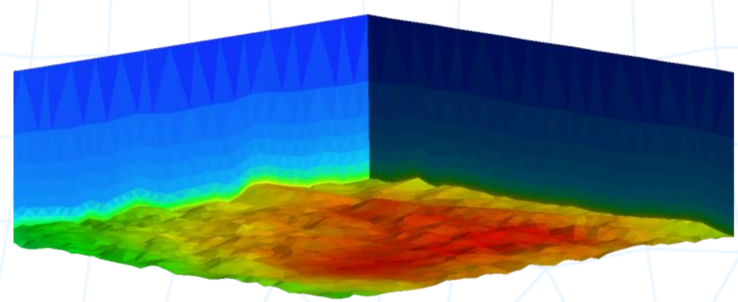
Air quality modeling



Interpolated wind field

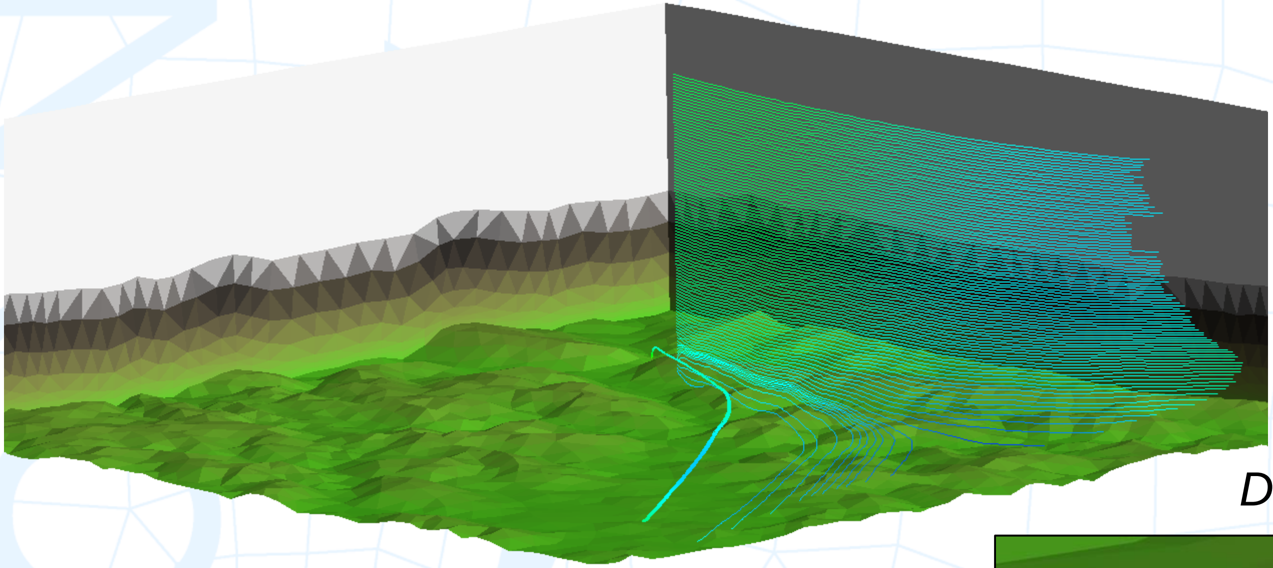


SO_2 Interpolated concentration



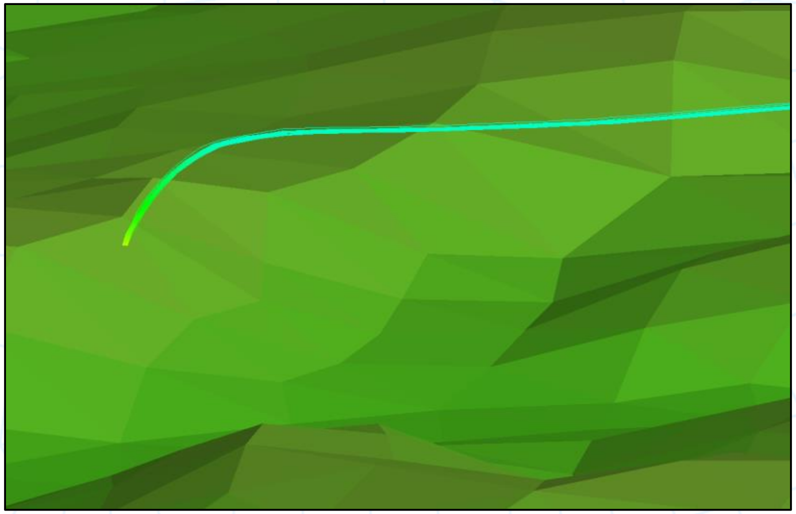
SO_4 Interpolated concentration

Air quality modeling

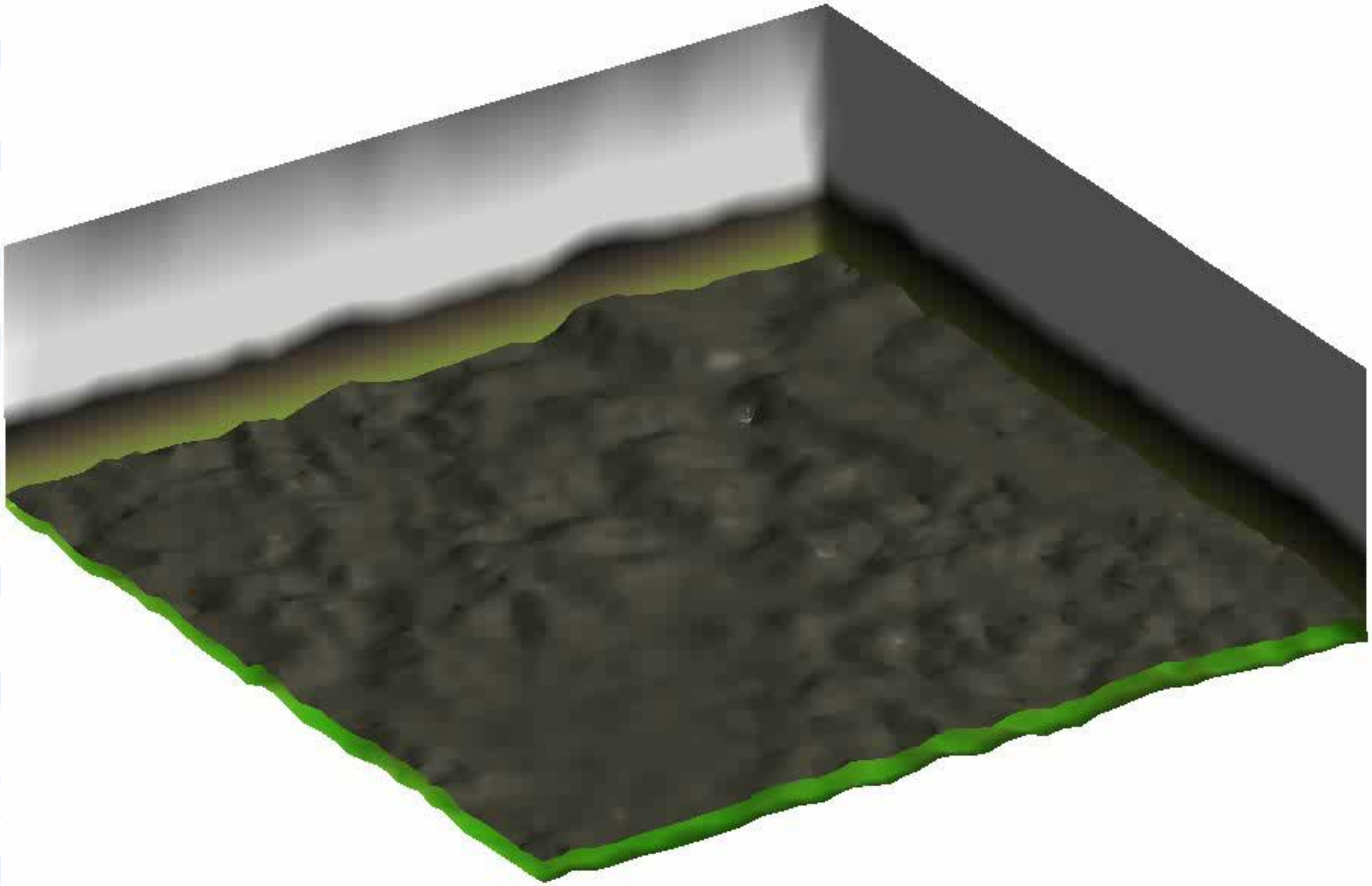


Plume and wind streamlines

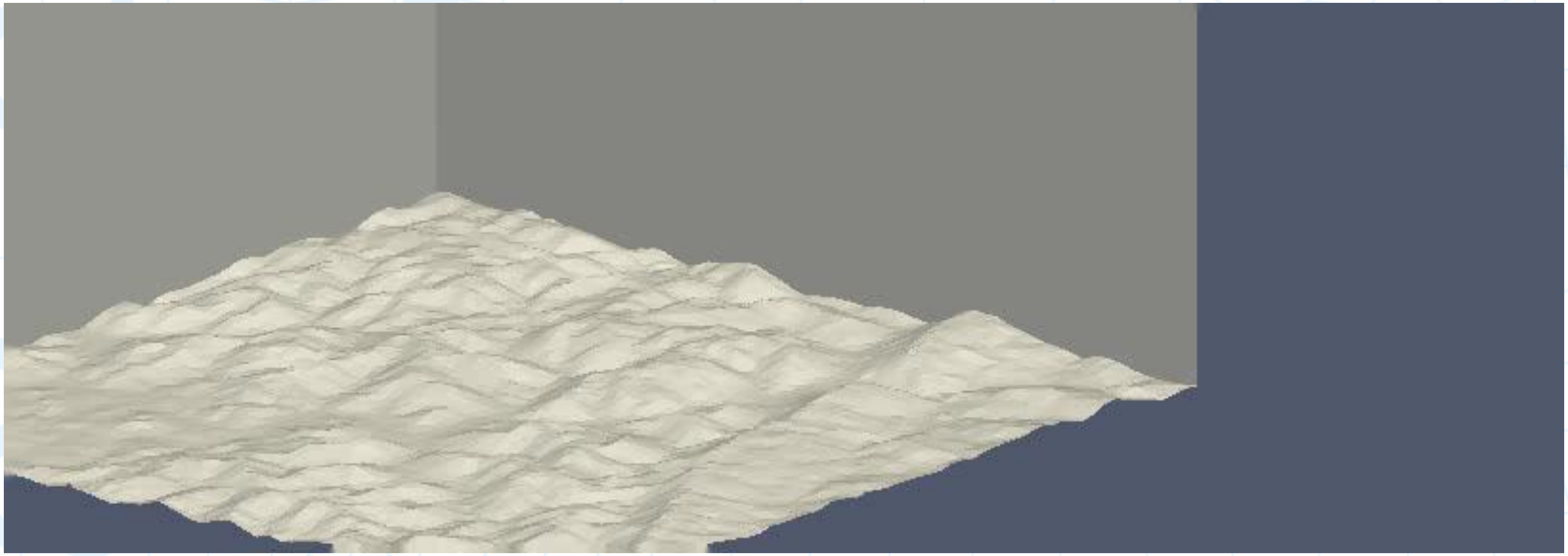
Detail of plume rise



Air quality modeling



Air quality modeling



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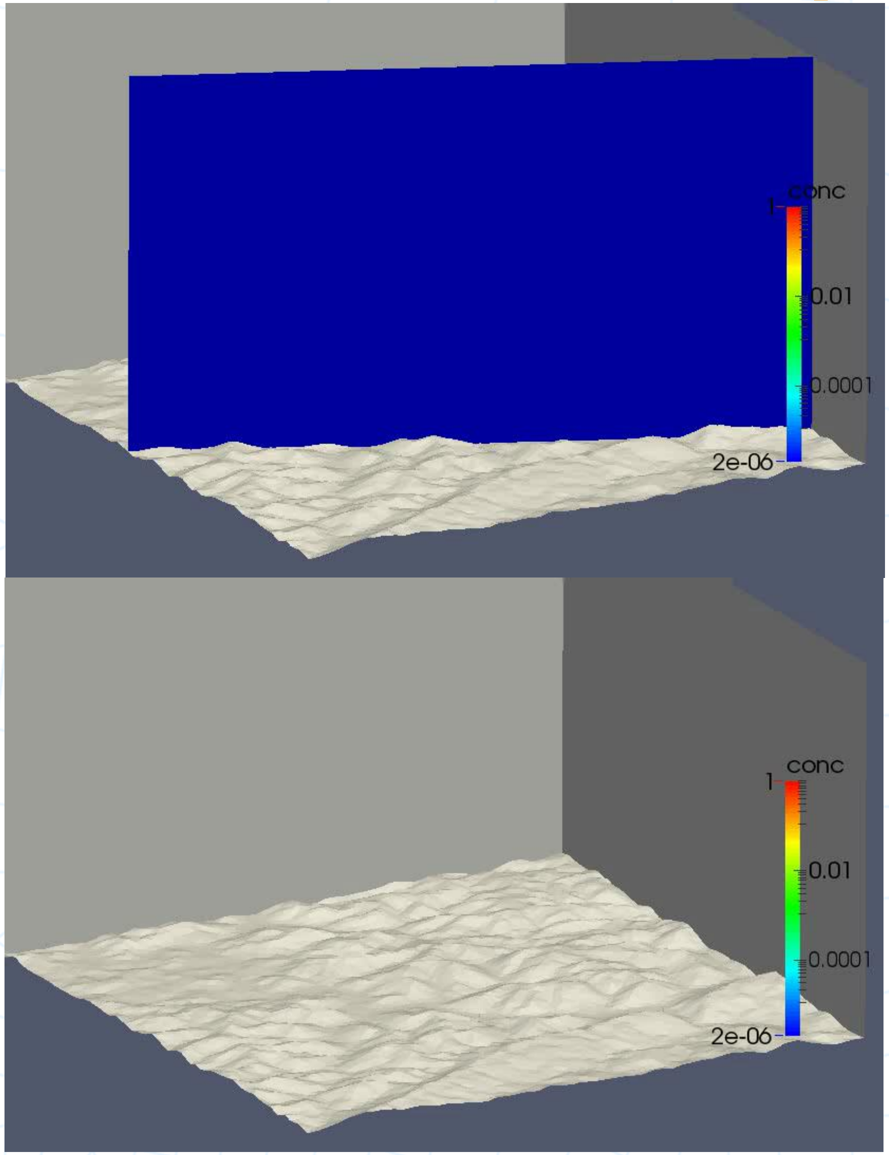

Conclusions

- Suitable approach for modeling air transport and reaction over complex terrains
- The air quality model is transport dominant
- Splitting and FEM resolution is an efficient technique to solve the problem
- Model can assess problems with coupling plumes