Desarrollo de un método *ensemble* para la predicción del viento a escala local usando elementos finitos

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UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA

http://www.dca.iusiani.ulpgc.es/Wind3D

Contents

- Local scale wind field model
- Coupling with HARMONIE meso-scale model
- Ensemble method
- Numerical experiments
- Conclusions

A diagnostic wind model

Governing equations

$\Omega \subset R^3$ $\qquad$ $\Gamma = \Gamma_a \cup \Gamma_b$

$\vec{u}_0(u_0, v_0, w_0)$: observed wind, which is obtained from horizontal interpolation and vertical extrapolation of experimental or forecasted data

Objective:

Find the velocity field $\vec{u}(\widetilde{u}, \widetilde{v}, \widetilde{w})$ that adjusts to $\vec{v}_0(u_0, v_0, w_0)$ verifying

- Incompressibility condition in the domain $\vec{\nabla} \cdot \vec{u} = 0 \quad \text{in } \Omega$
- Non flow-through condition on the terrain $\vec{n} \cdot \vec{u} = 0 \quad \text{on } \Gamma_b$

Let state the least square problem:

$$E(\widetilde{u}, \widetilde{v}, \widetilde{w}) = \int_\Omega \left[\alpha_1^2 \left((\widetilde{u} - u_0)^2 + (\widetilde{v} - v_0)^2 \right) + \alpha_2^2 (\widetilde{w} - w_0)^2 \right] \, d\Omega$$

$$\alpha = \frac{\alpha_1}{\alpha_2}$$

Mass Consistent Wind Model

Mathematical aspects

The solution produces the Euler-Lagrange equations

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

where $T = (T_h, T_h, T_v) \quad T_h = \dfrac{1}{2\alpha_1^2} \;, \; T_v = \dfrac{1}{2\alpha_2^2}$

it yields the governing equations,

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

$$\phi = 0 \quad \text{on } \Gamma_a$$

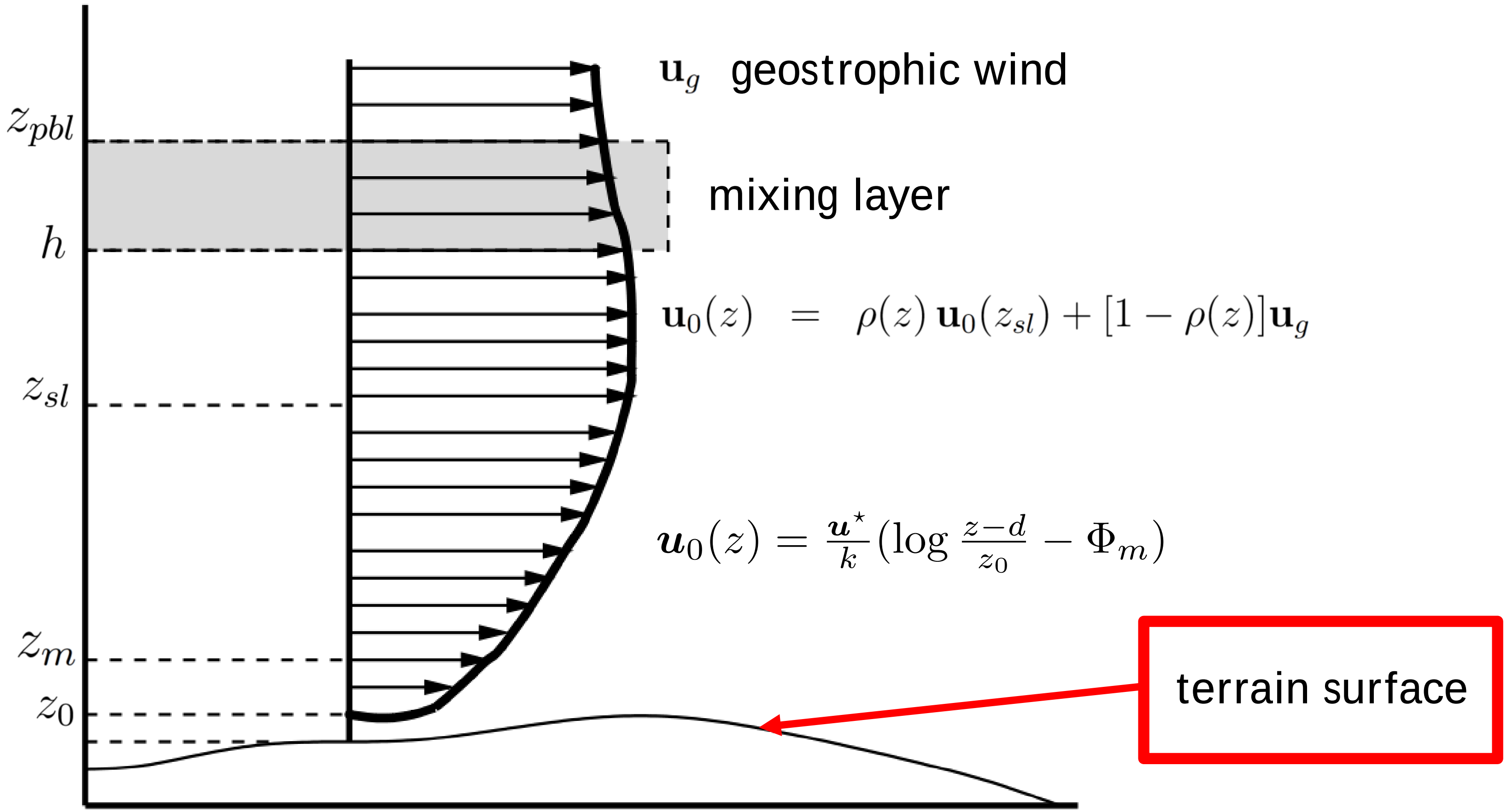
$$\vec{n} \cdot T\vec{\nabla}\phi = -\vec{n} \cdot \vec{u}_0 \quad \text{on} \quad \Gamma_b$$

Horizontal interpolation

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

$$0 \leq \xi \leq 1$$

Vertical extrapolation (log-linear wind profile)



Mass Consistent Wind Model

Construction of the observed wind

- **Friction velocity:** $$\mathbf{u}^* = \frac{k\ \mathbf{u}_0(z_m)}{\log\frac{z_m}{z_0} - \Phi_m}$$

- **Height of the planetary boundary layer:** $$z_{pbl} = \frac{\gamma\ |\mathbf{u}^*|}{f}$$

  $f = 2\Omega \sin\phi$ **is the Coriolis parameter, being** Ω **the Earth rotation and** ϕ **is the latitude**

  γ **is a parameter depending on the atmospheric stability**

- **Mixing height:**

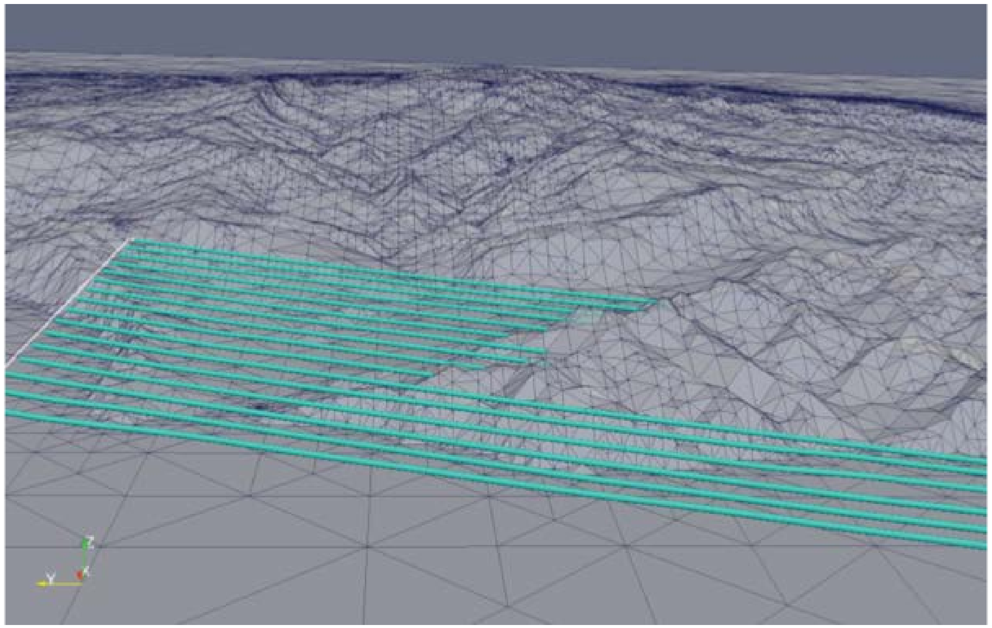
  $h = z_{pbl}$ **in neutral and unstable conditions**

  $h = \gamma' \sqrt{\frac{|\mathbf{u}^*|\ L}{f}}$ **in stable conditions**

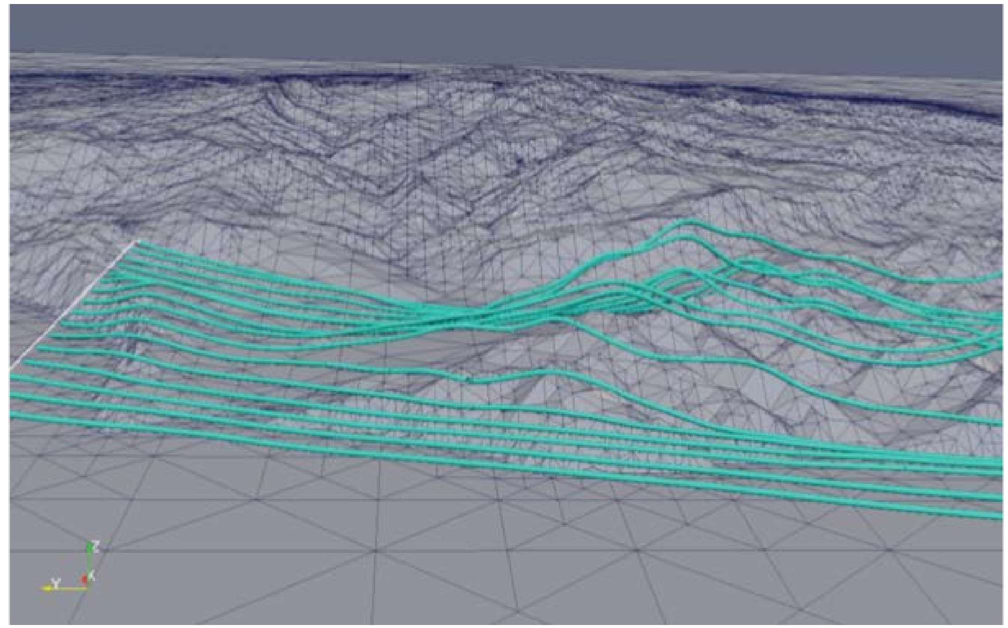
- **Height of the surface layer:** $$z_{sl} = \frac{h}{10}$$

Mass Consistent Wind Model

Interpolated and resulting wind fields



Interpolated wind field

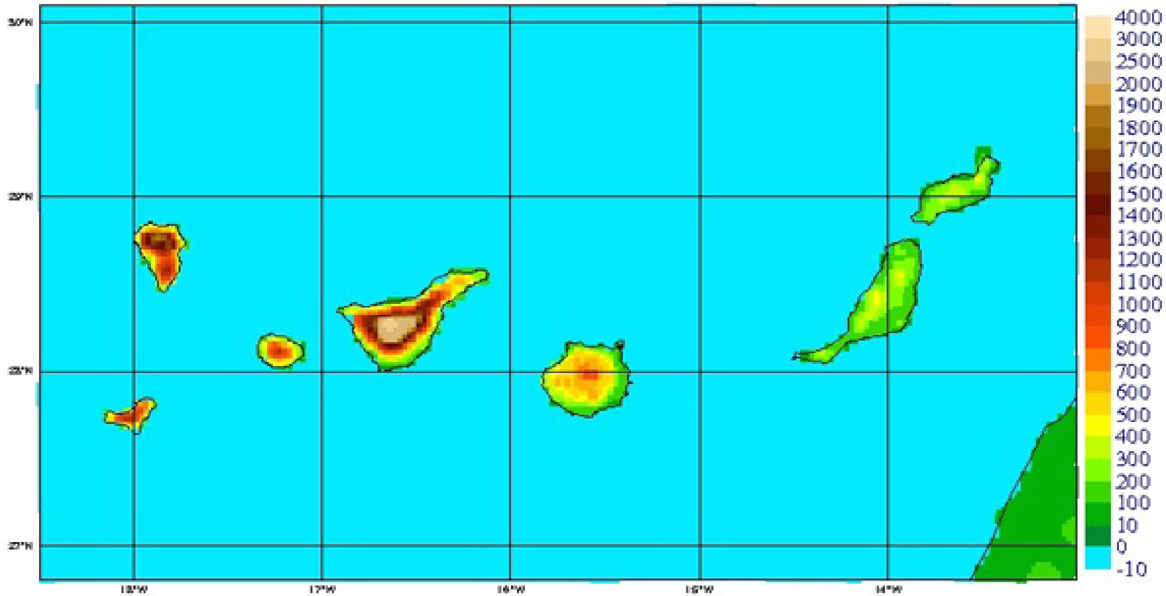


Resulting wind field

HARMONIE-FEM Wind Forecast

HARMONIE model

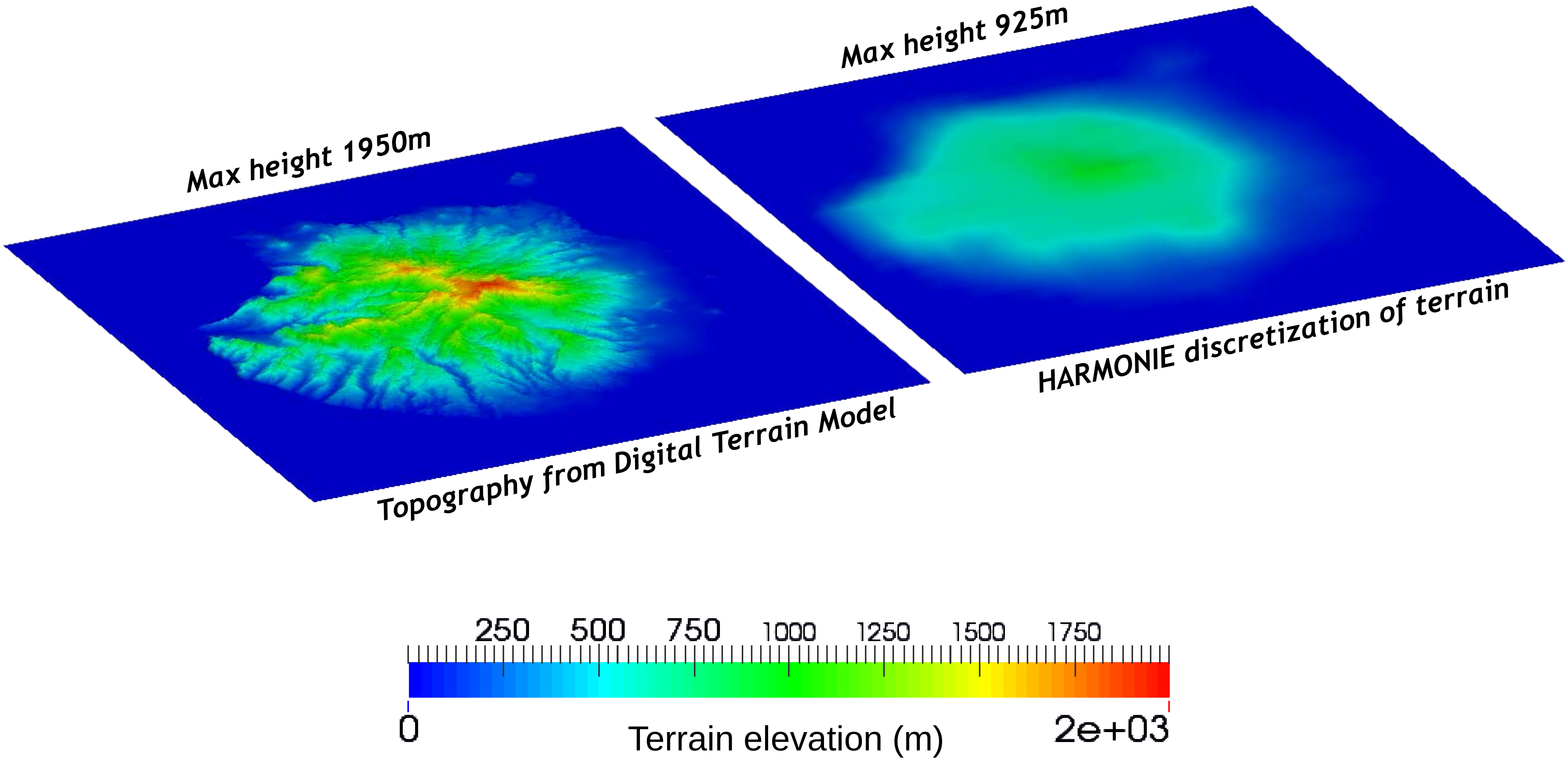
- Non-hydrostatic meteorological model
- From large scale to 1km or less scale (under developed)
- Different models in different scales
- Assimilation data system
- Run by AEMET daily
- 24 hours simulation data



HARMONIE on Canary islands
(http://www.aemet.es/ca/idi/prediccion/prediccion_numerica)

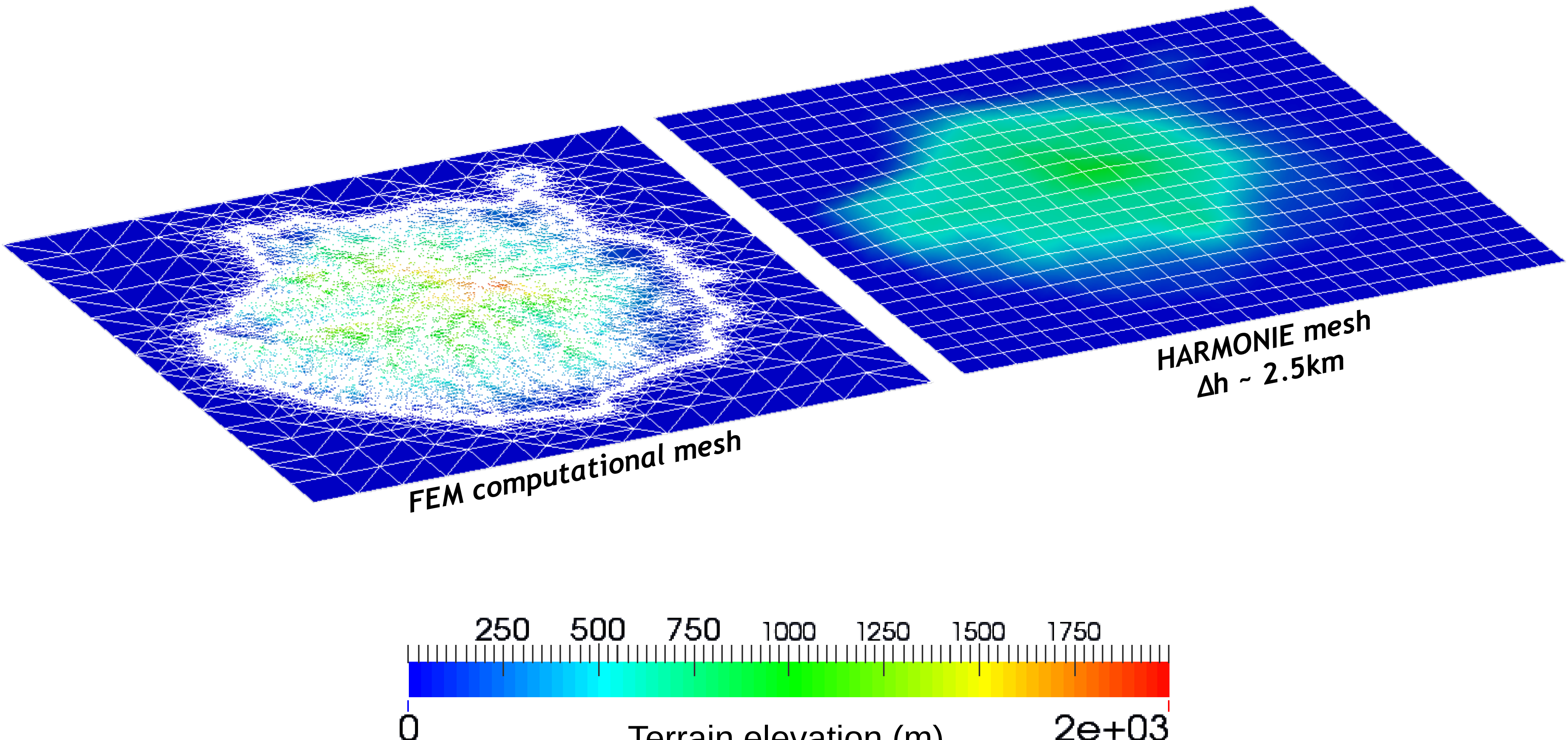
HARMONIE-FEM wind forecast

Terrain approximation



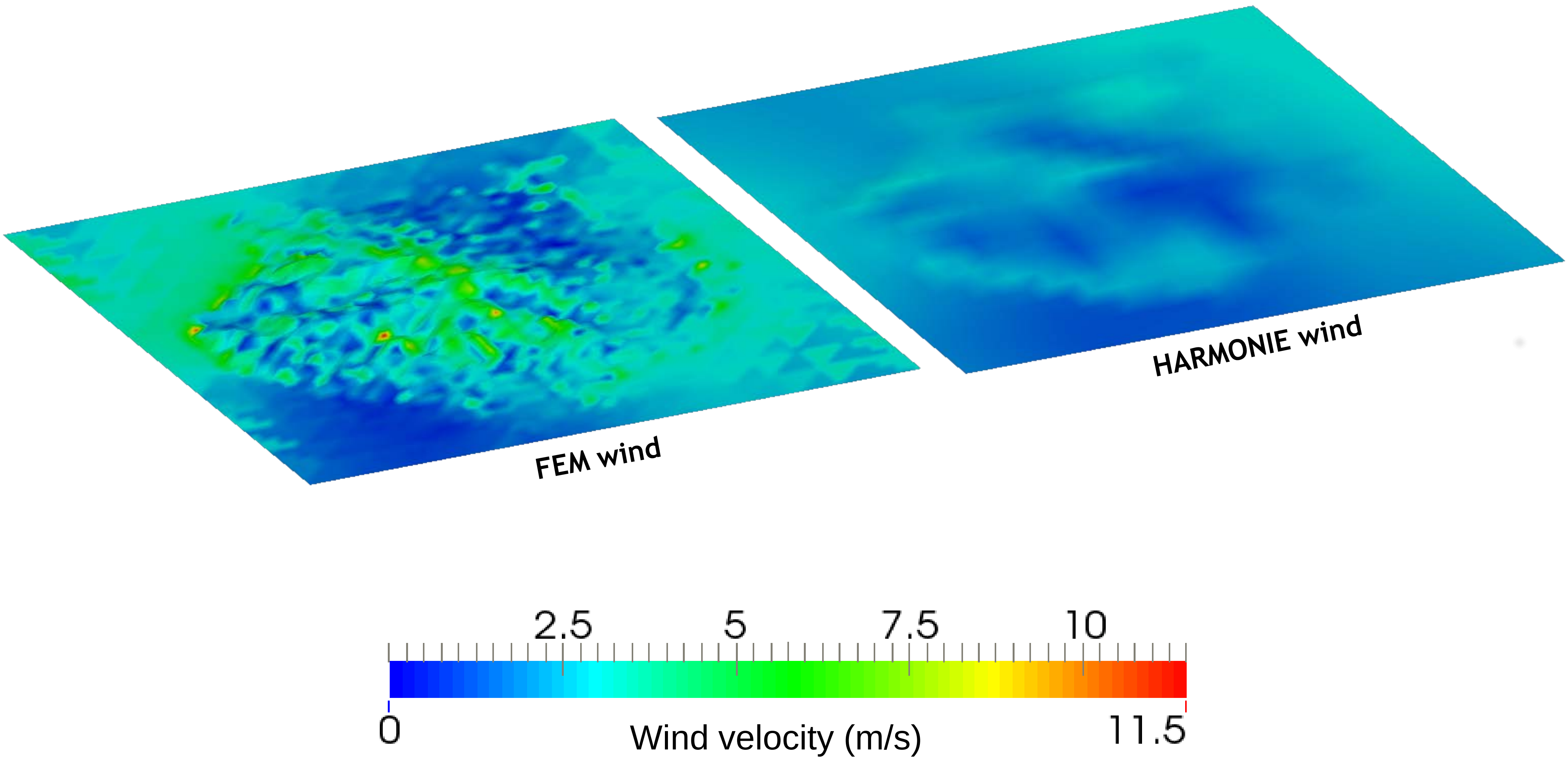
HARMONIE-FEM wind forecast

Spatial discretization



HARMONIE-FEM wind forecast

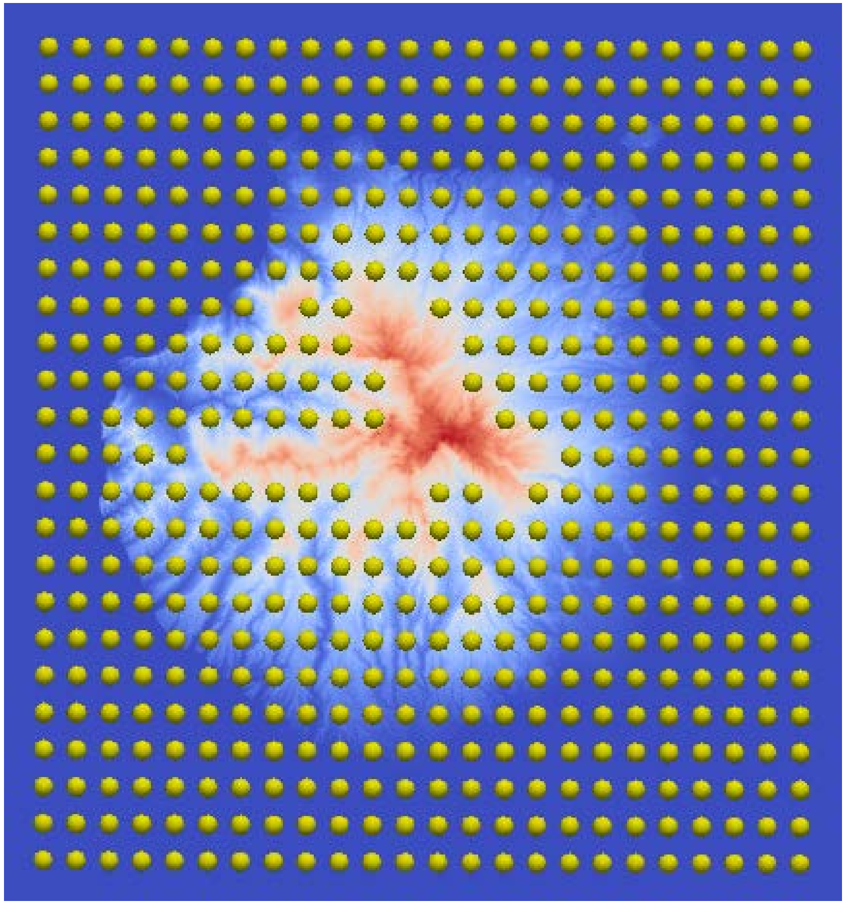
Wind magnitude at 10m over terrain



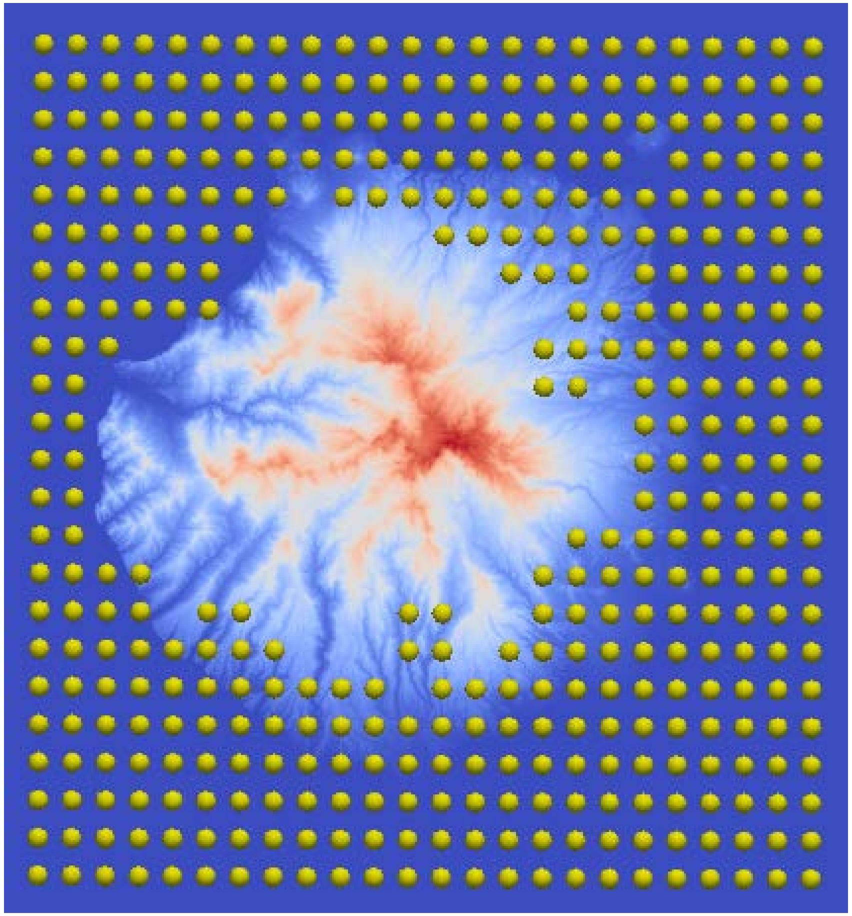
HARMONIE-FEM wind forecast

HARMONIE data

HARMONIE Grid points with U_{10} V_{10} horizontal velocities



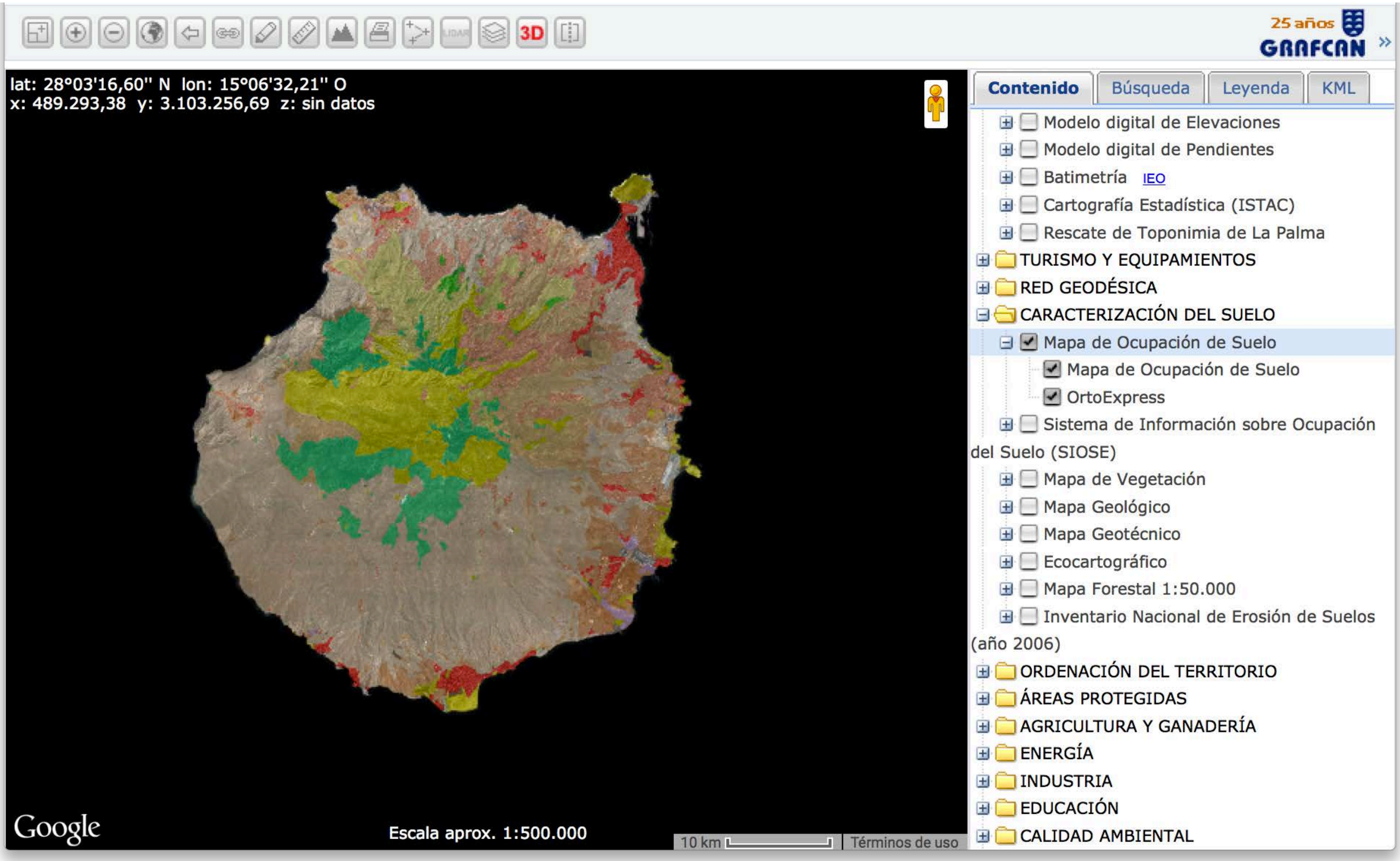
Used data (Δh < 500m)



Used data (Δh < 100m)

Terrain data

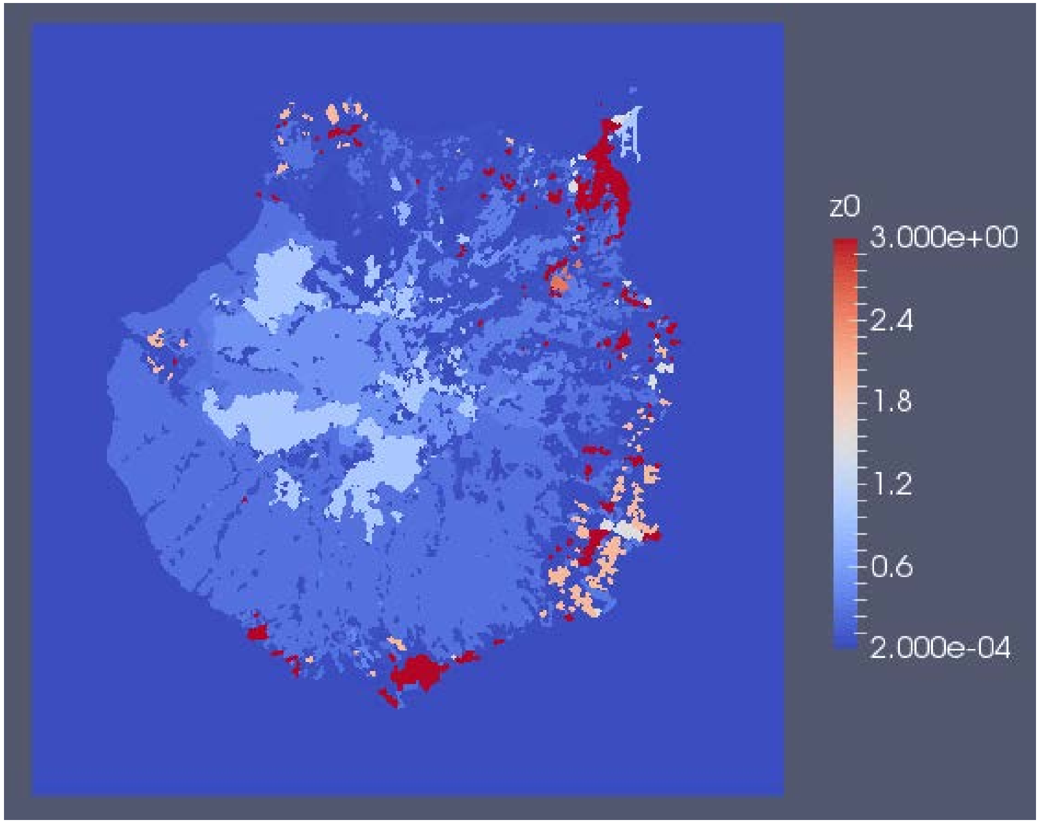
GIS image



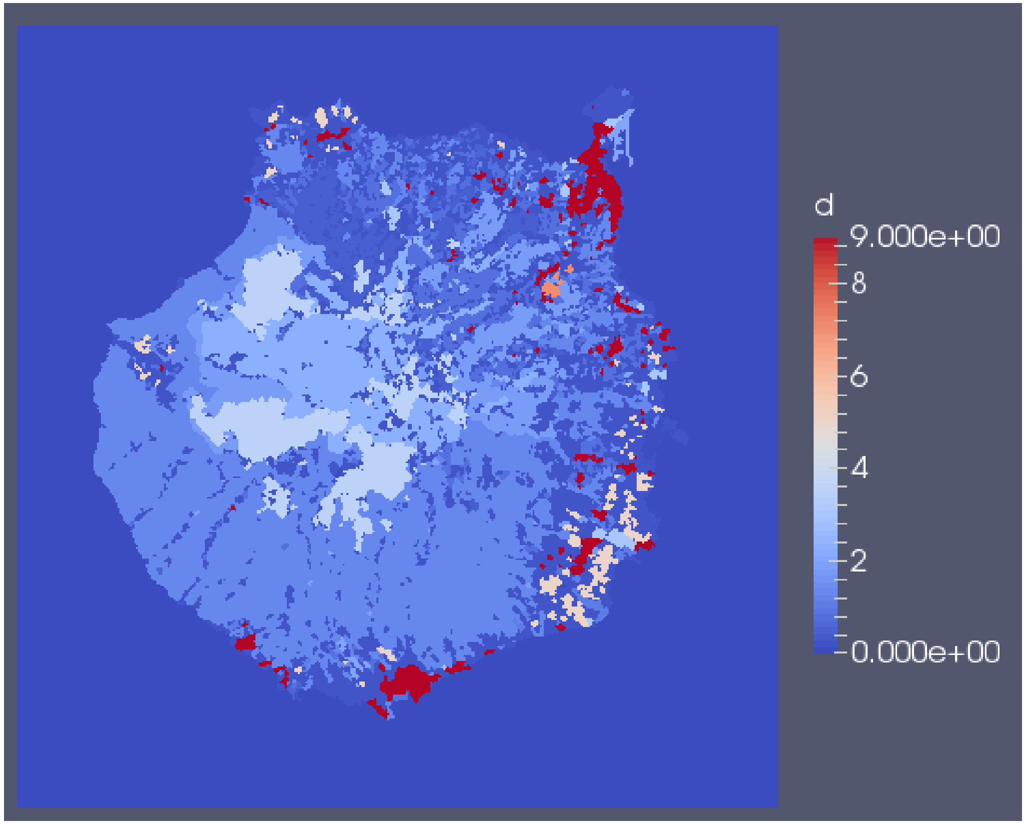
Terrain data

Image segmentation

Roughness length (z_0)

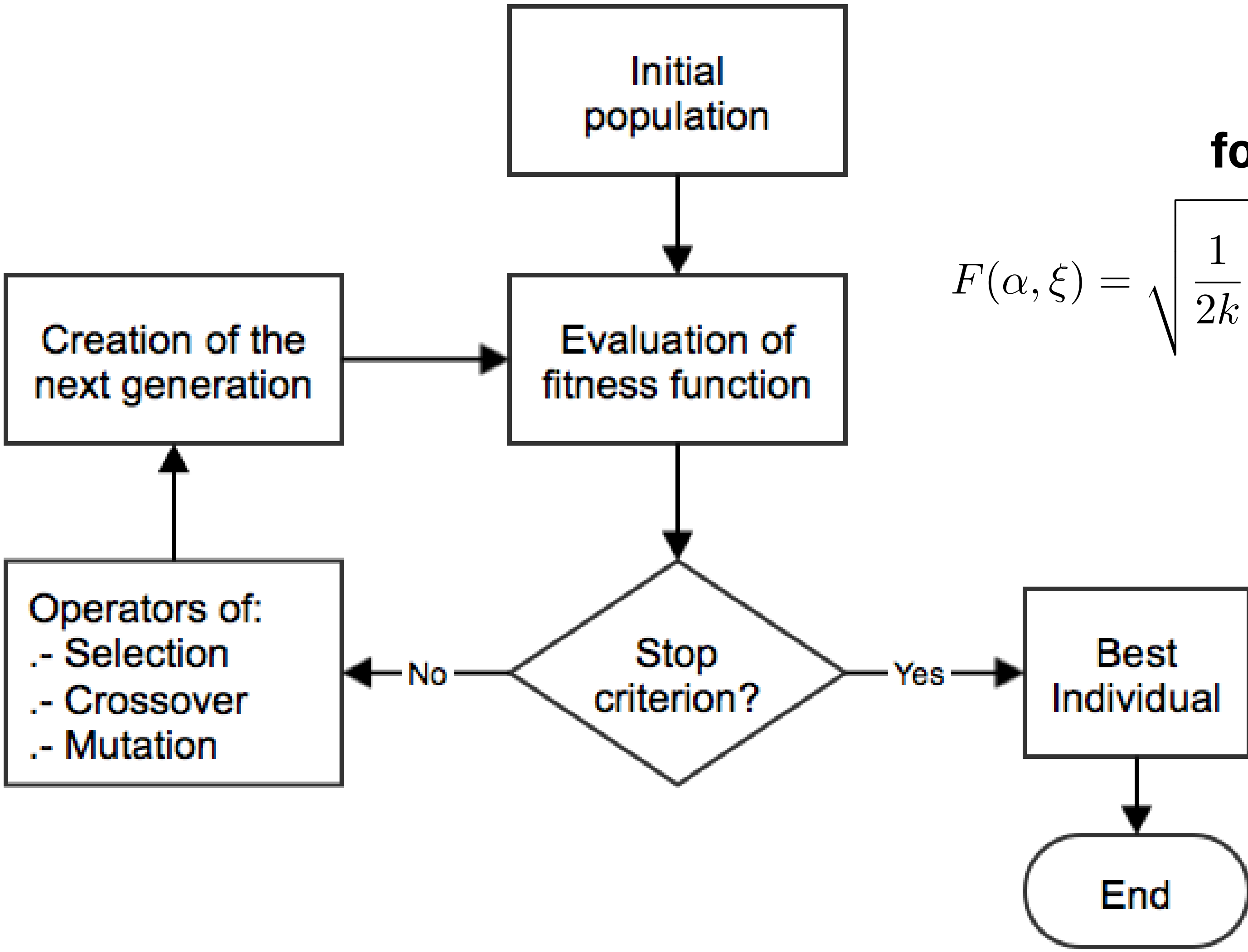


Obstacles height (d)



Estimation of Model Parameters

Genetic Algorithm

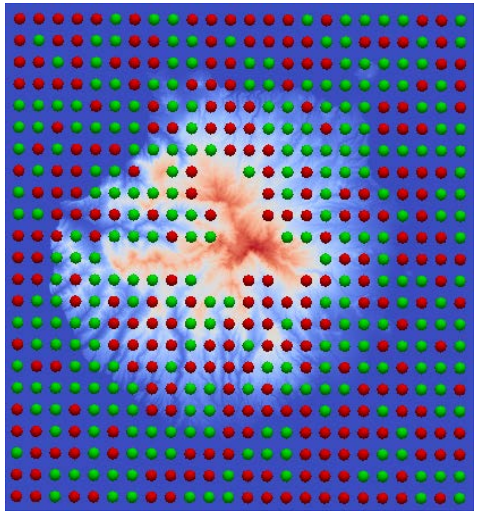


FE solution is needed for each individual

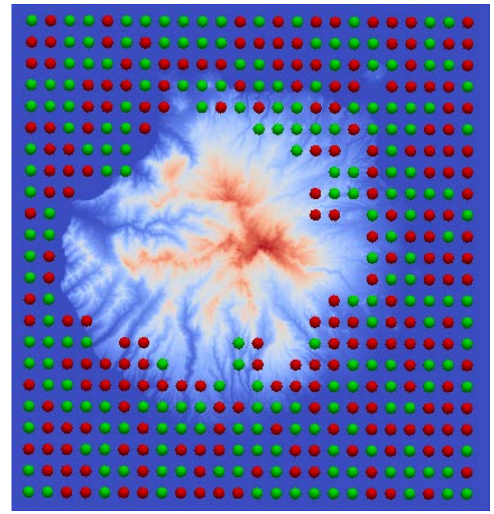
$$F(\alpha,\xi) = \sqrt{\frac{1}{2k}\sum_{i=1}^{k}\left[\,|\,u-u_0\,|_i^2 + |\,v-v_0\,|_i^2\,\right]}$$

Ensemble methods

Stations election



Δh < 500m



Δh < 100m

Stations

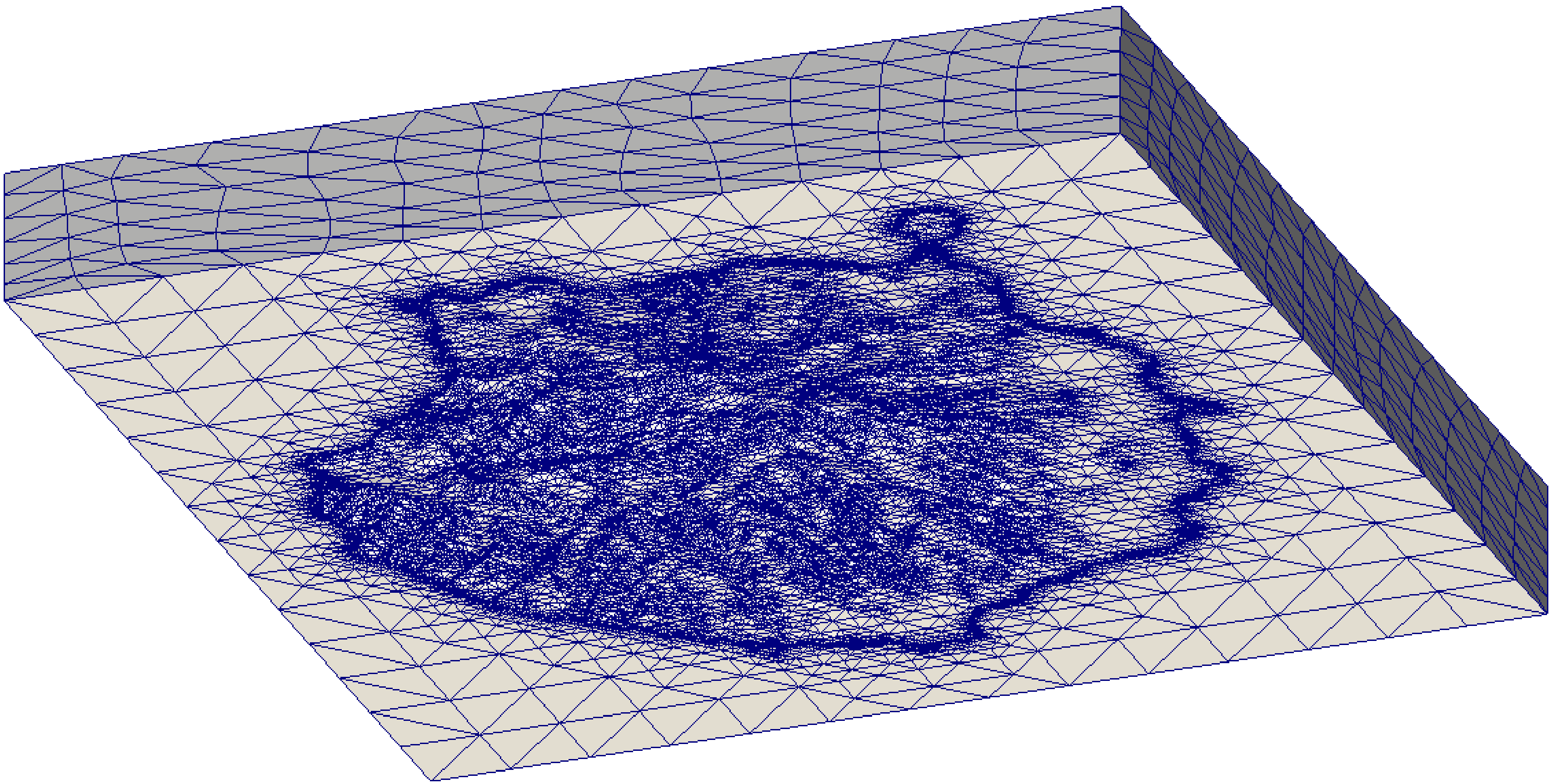
Control points

Number of genetic experiments			
% points	Height tolerances		
	Infinite	500 m	100 m
100 %	1	1	1
50 %	10	10	10

33 experiments x 24 hours = 792 genetic experiments

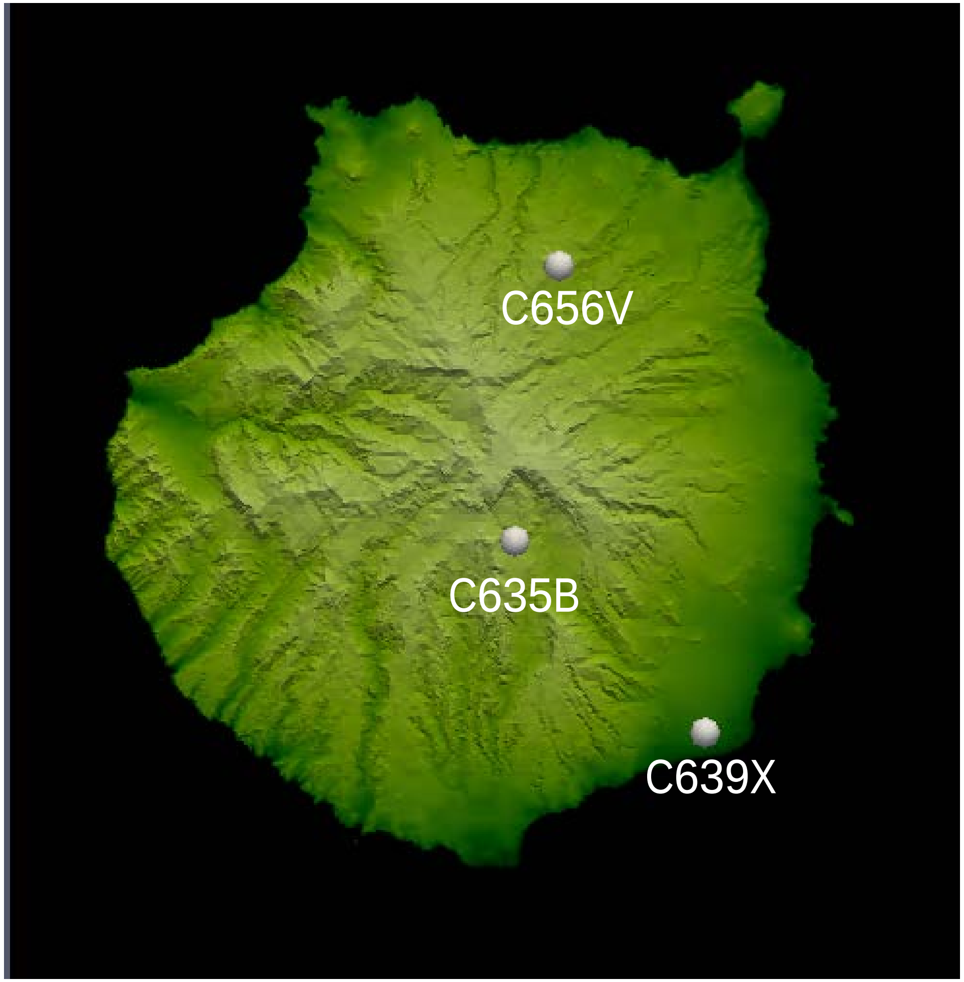
Domain: Gran Canaria Island (60 Km x 60 Km)

Mesh: 84325 nodes, 437261 tetrahedra



HARMONIE-FEM wind forecast

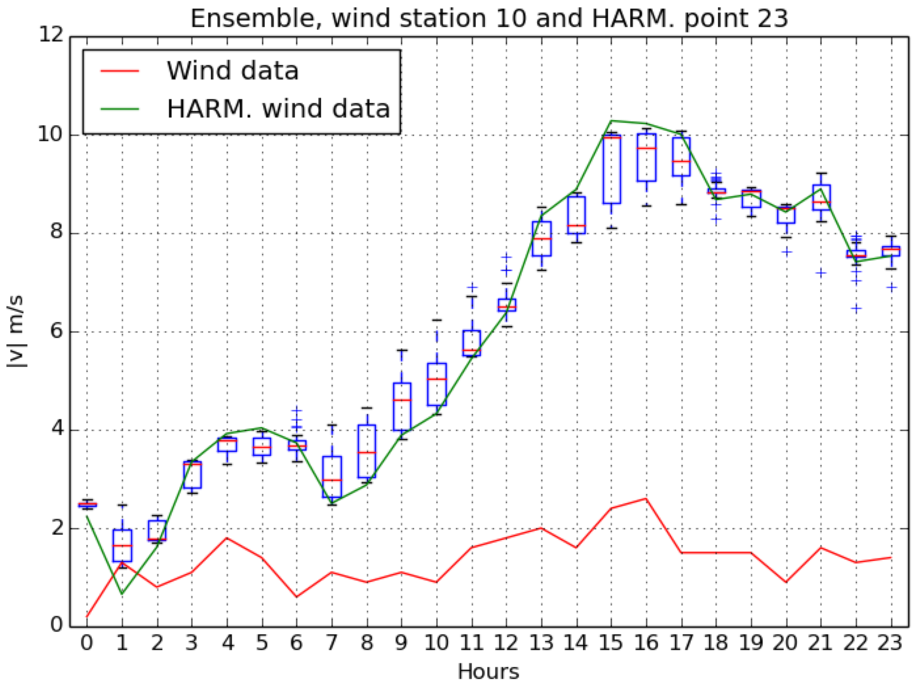
Location of measurement stations



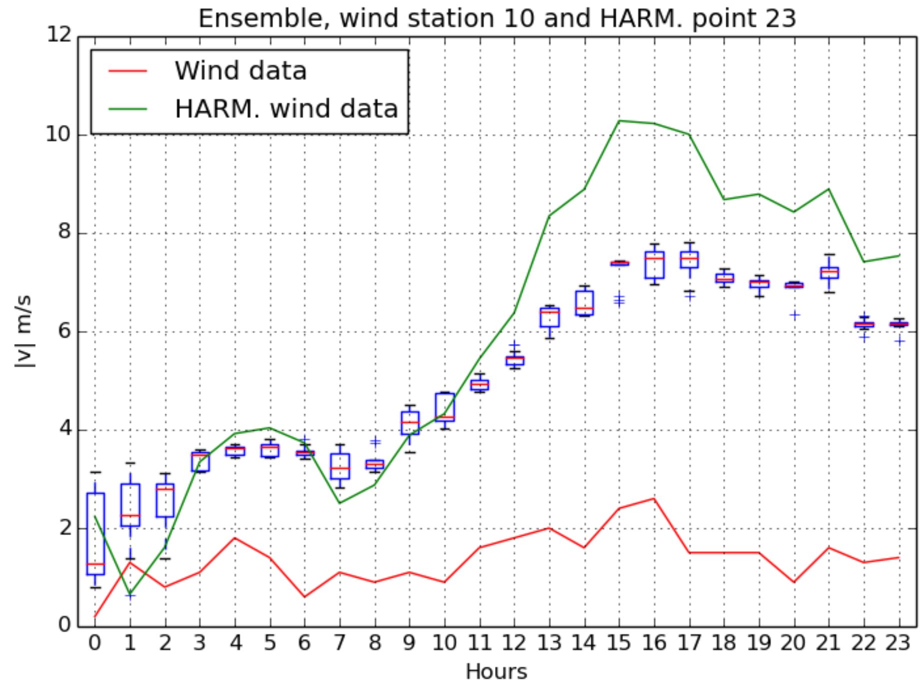
Ensemble methods

Ensemble forecast wind along a day

$d = 0,\ z_0 = 0.0025$



d and z_0 obtained from GIS



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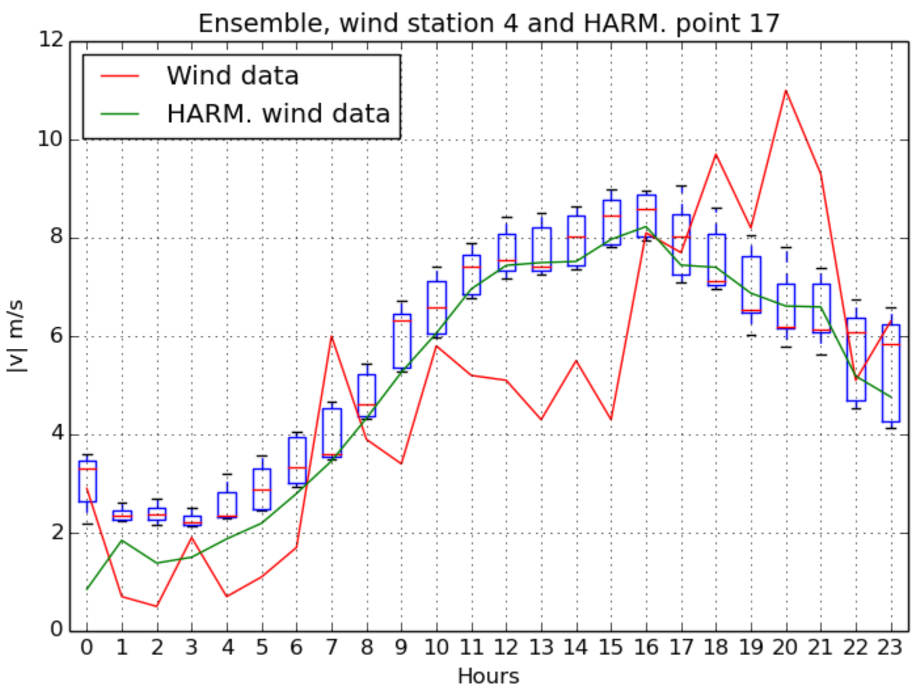

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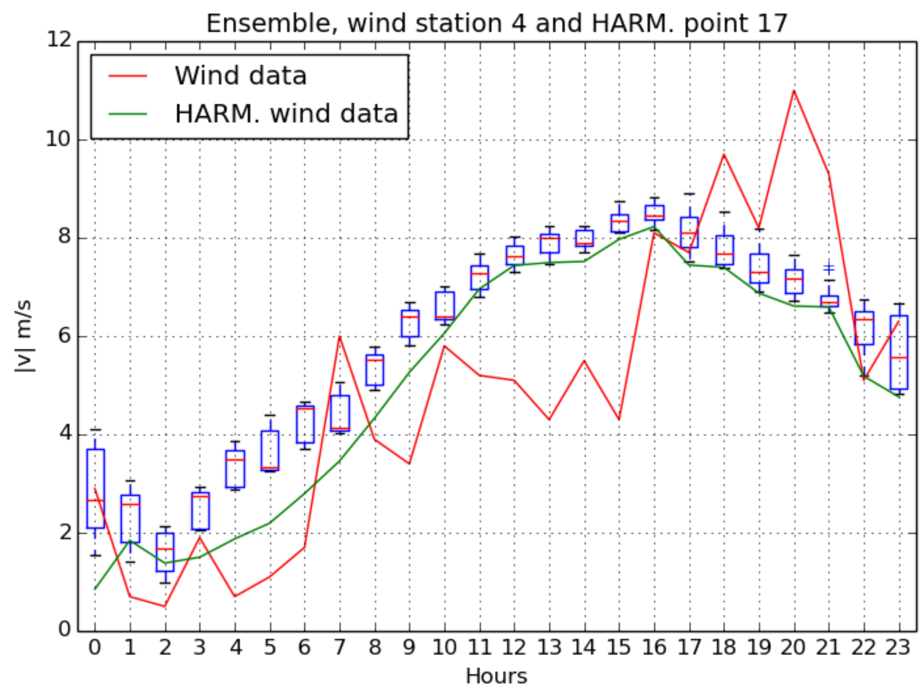

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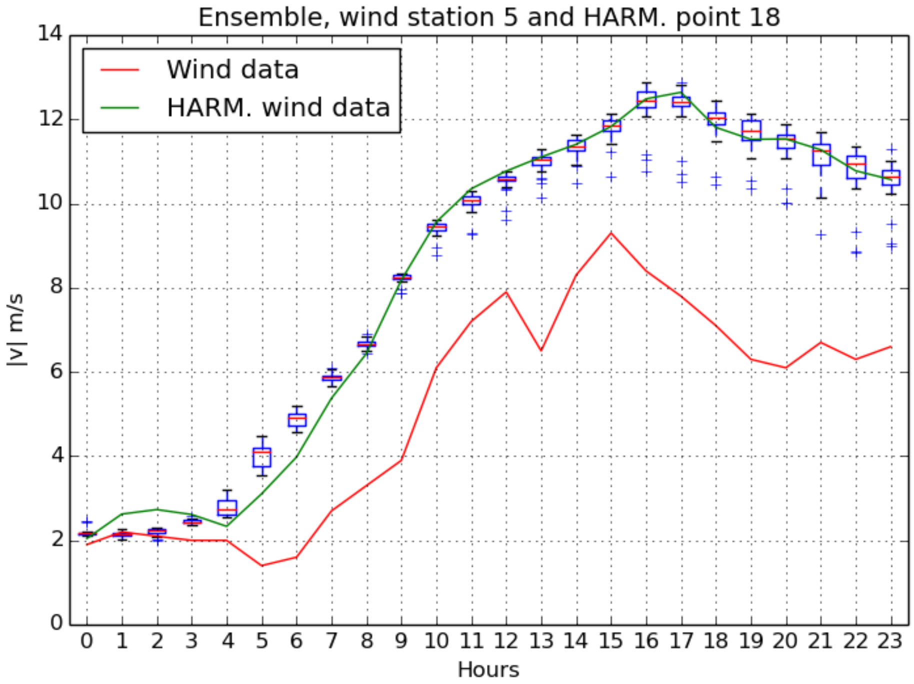

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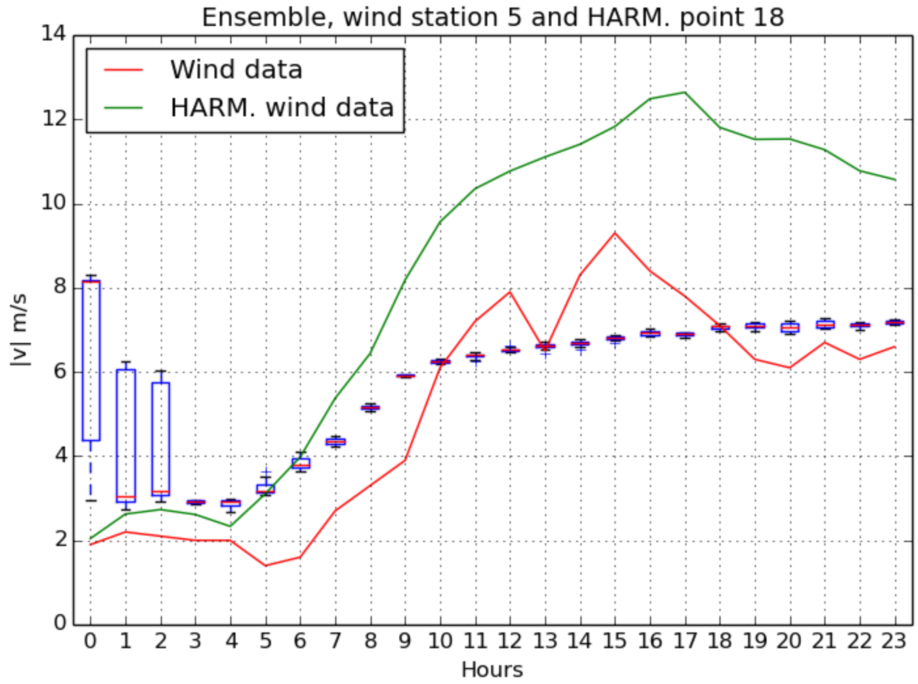

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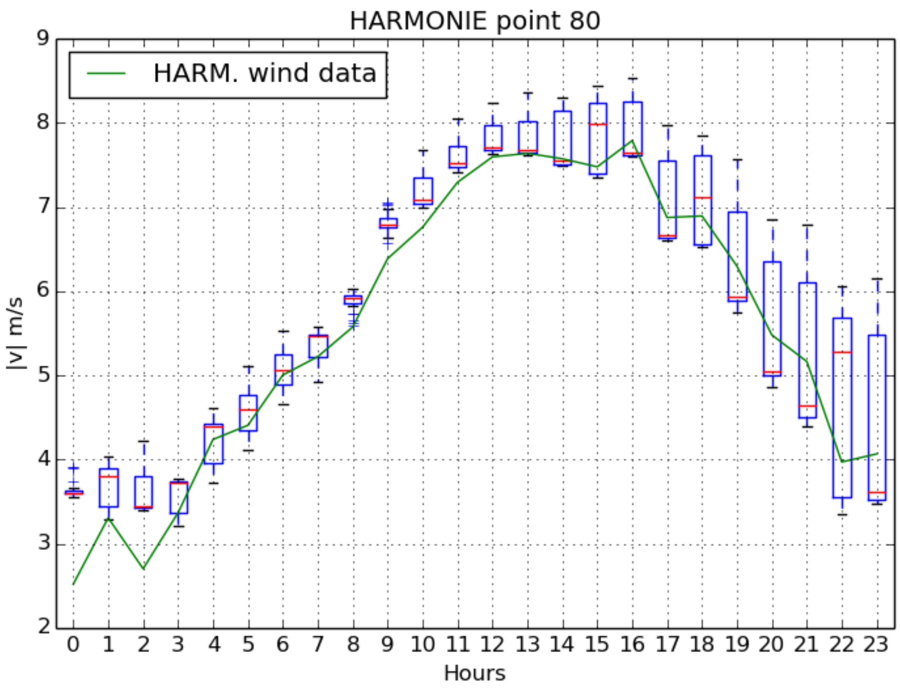

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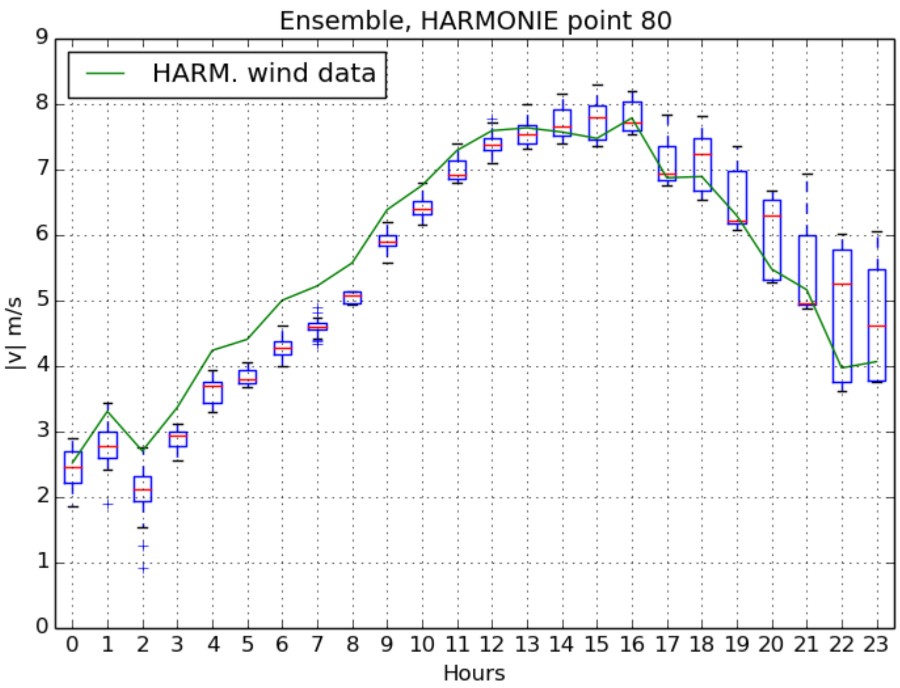

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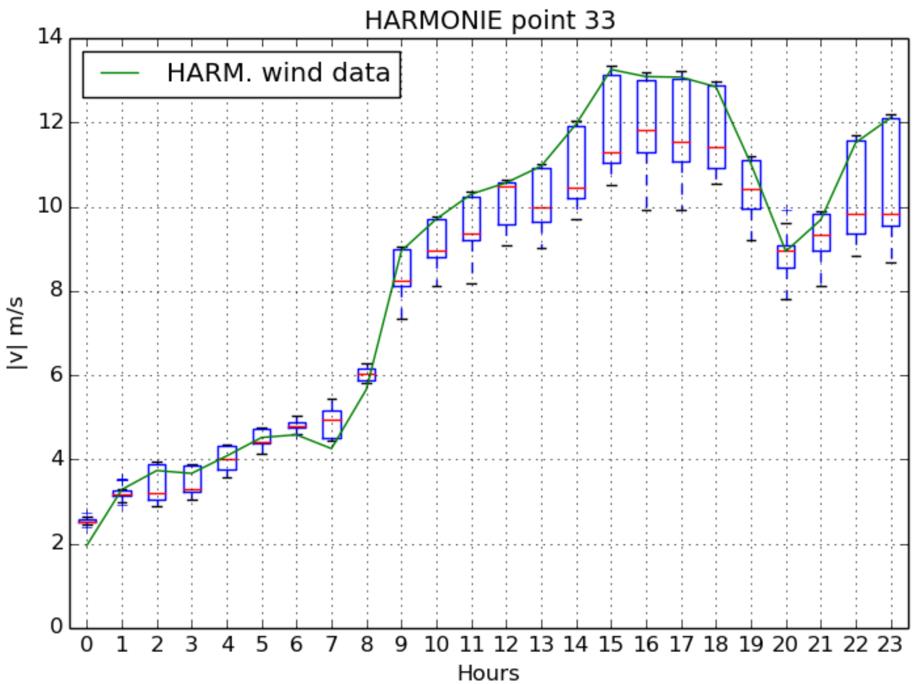

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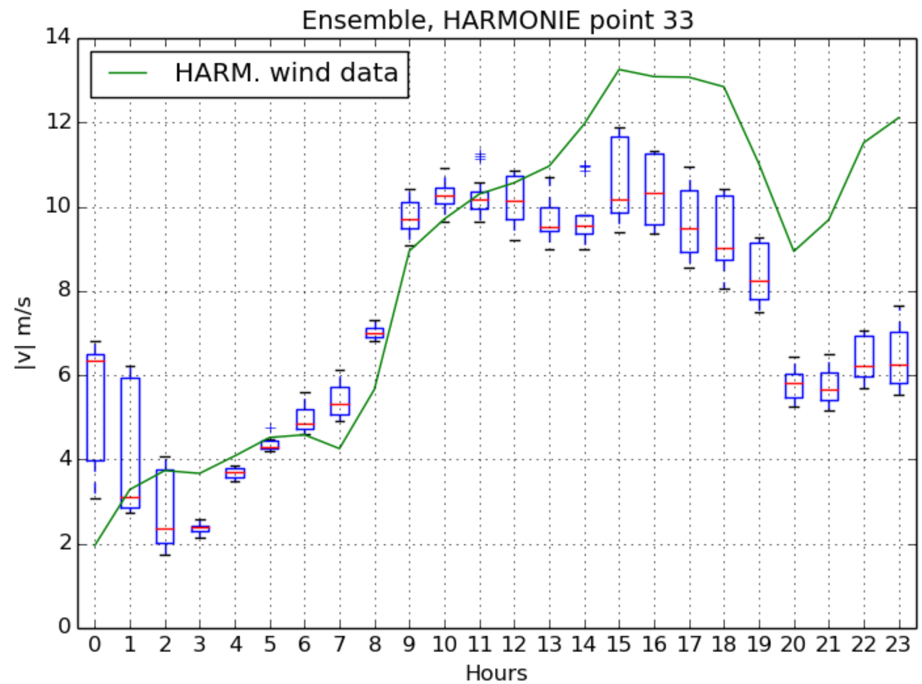

Conclusions and future research

- Local Scale wind field model is suitable for complex orographies
  http://www.dca.iusiani.ulpgc.es/Wind3D
- Adaptive meshes improve results from HARMONIE
- Local wind field in conjunction with HARMONIE and ensemble method is valid to forecast wind velocities
  A. Oliver, E. Rodríguez, J. M. Escobar, G. Montero, M. Hortal, J. Calvo, J. M. Cascón, and R. Montenegro. "Wind Forecasting Based on the HARMONIE Model and Adaptive Finite Elements." Pure Appl. Geophys. (Online). doi:10.1007/s00024-014-0913-9.

- Futher research on α, ξ, z_0, d definition
- Study model results under different wind conditions

Thank you for your attention