Ensemble Wind Forecasting Based on the HARMONIE Model and Adaptive Finite Elements in Complex Orography

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http://www.dca.iusiani.ulpgc.es/proyecto2012-2014

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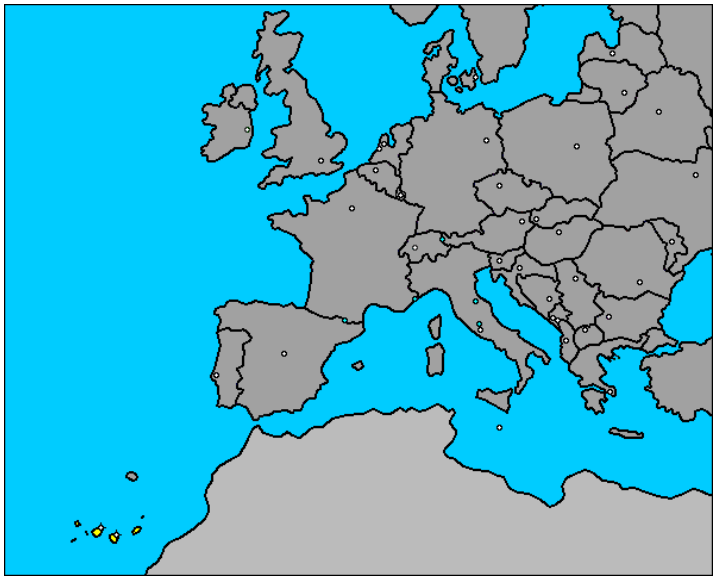
Motivation

- Wind field forecasting for complex terrain
- Ensemble methods
- Gran Canaria island (Canary Islands)



Motivation

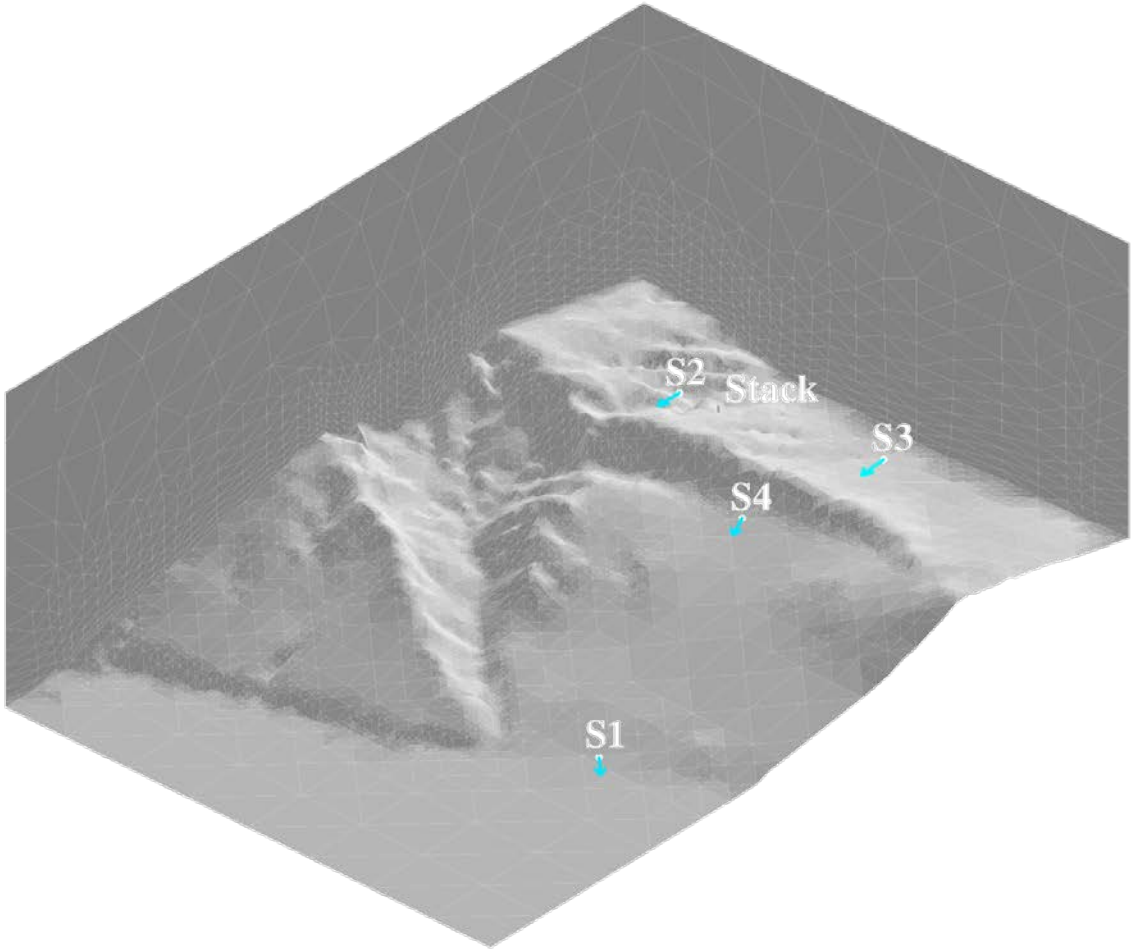
- Wind farm energy
- Air quality

The Local Scale Wind Field Model

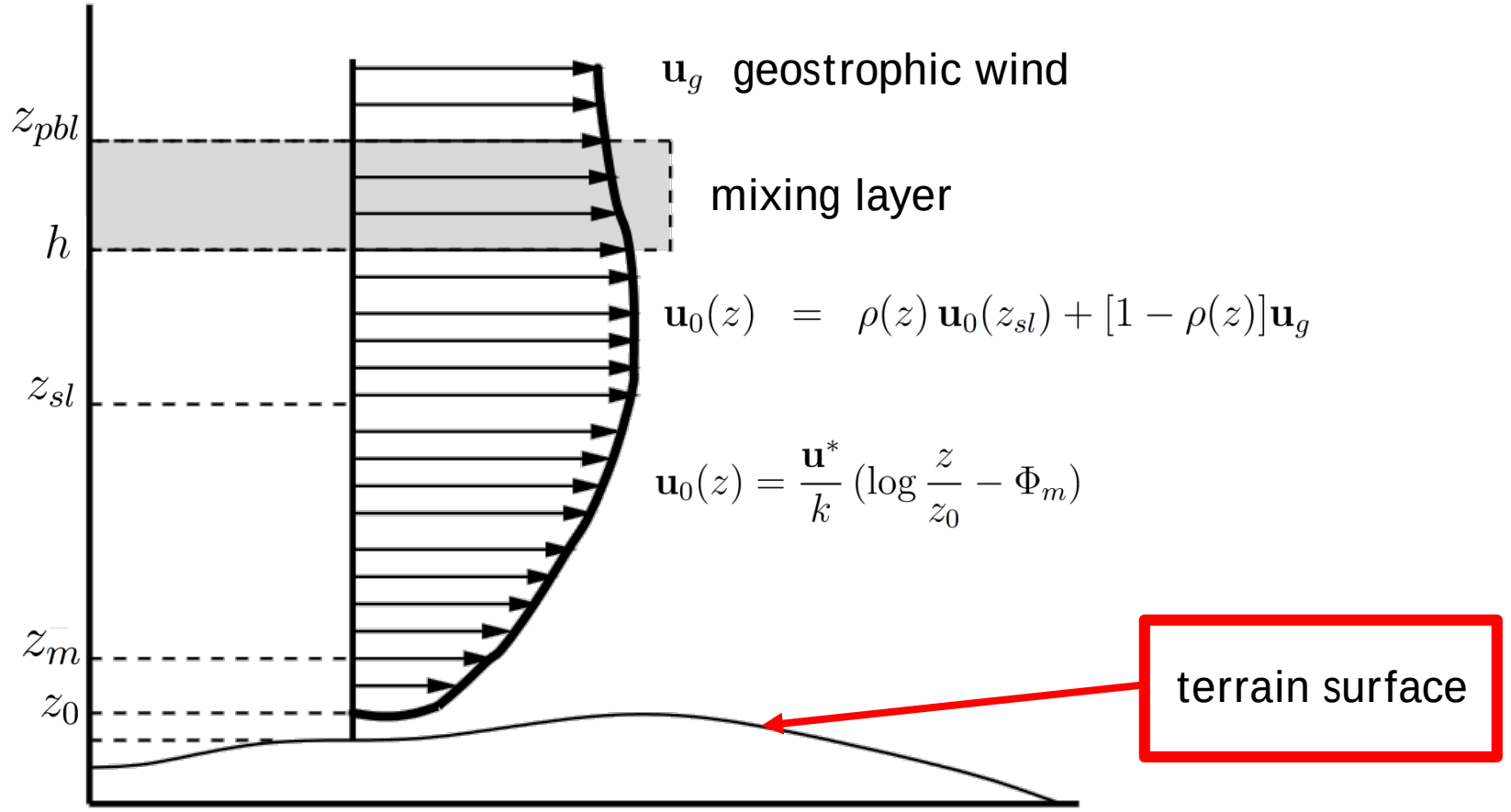
Mass Consistent Wind Model

Problem description

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



Vertical extrapolation (log-linear wind profile)



Mass Consistent Wind Model

Construction of the observed wind

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

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

  $f = 2\Omega\ \sin\phi$ **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**

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

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

Horizontal interpolation

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

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

Mass Consistent Wind Model

Mathematical aspects

- 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

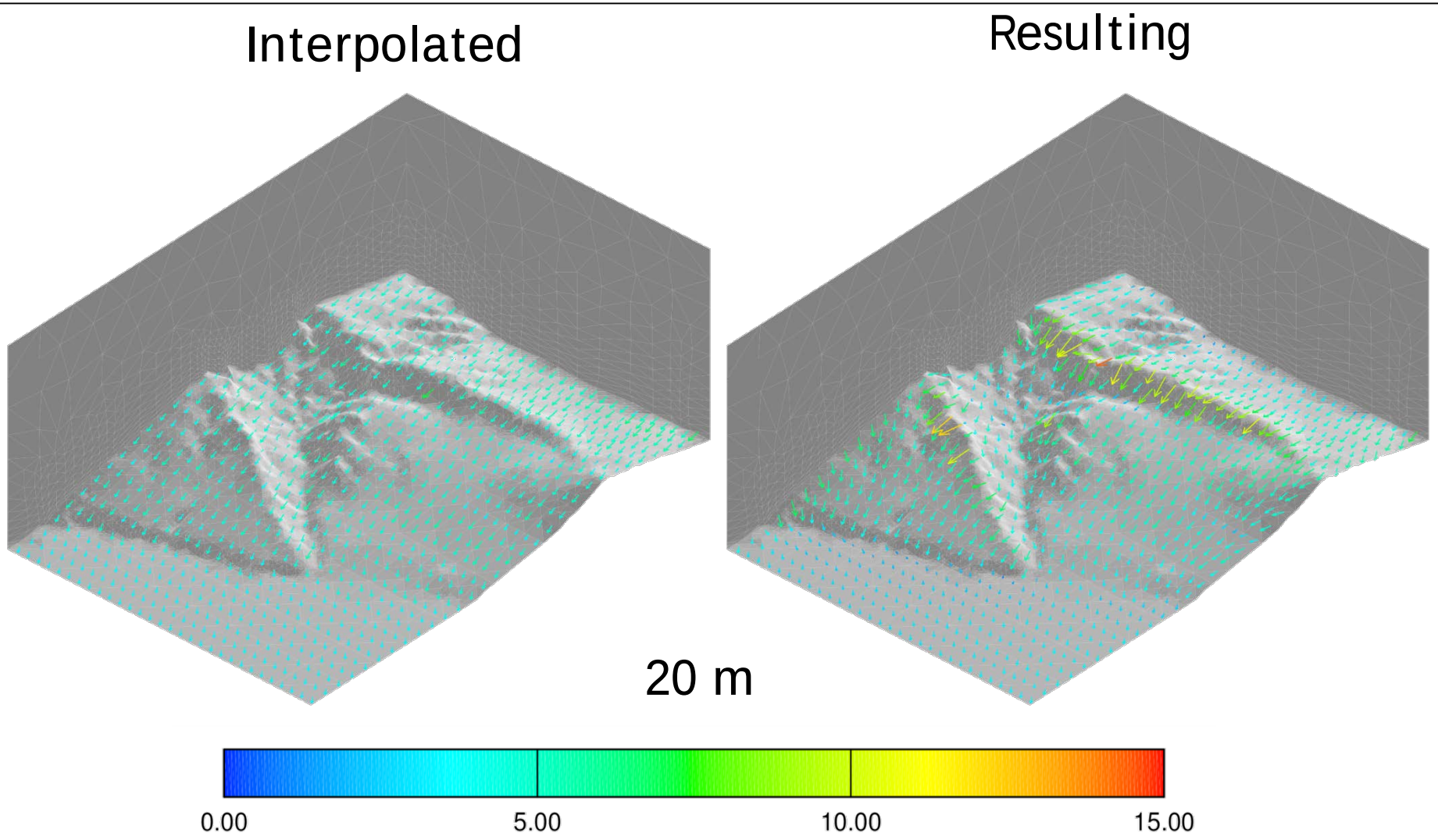
$$u = u_0 + T_h \frac{\partial \phi}{\partial x}, \quad v = v_0 + T_h \frac{\partial \phi}{\partial y}, \quad w = w_0 + T_v \frac{\partial \phi}{\partial z},$$

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

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

Mass Consistent Wind Model

Construction of the observed wind



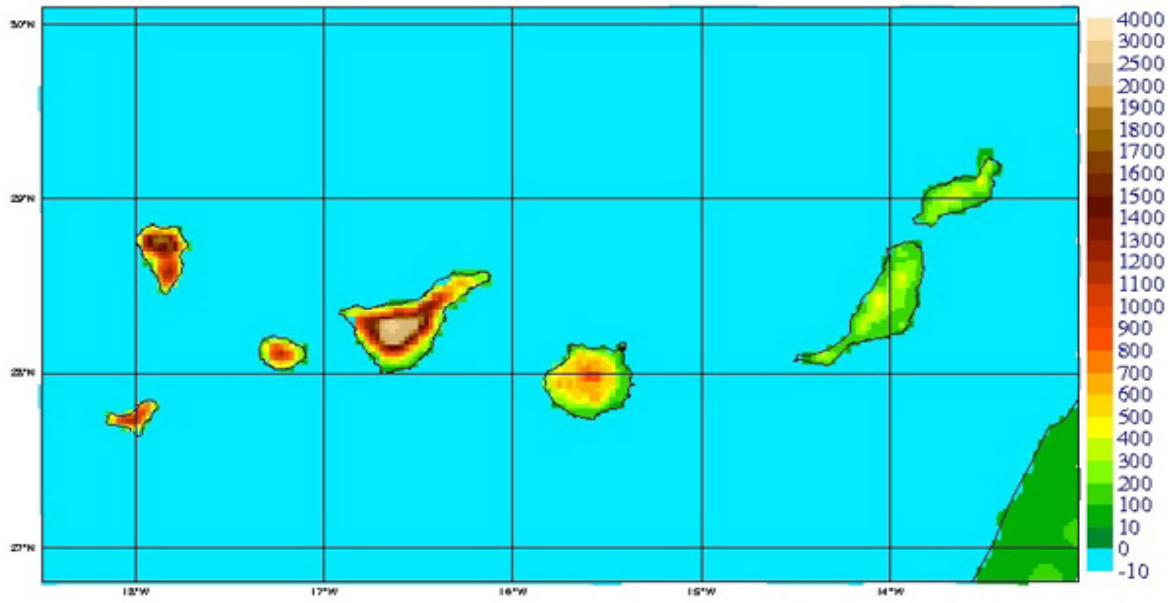
Coupling with HARMONIE

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

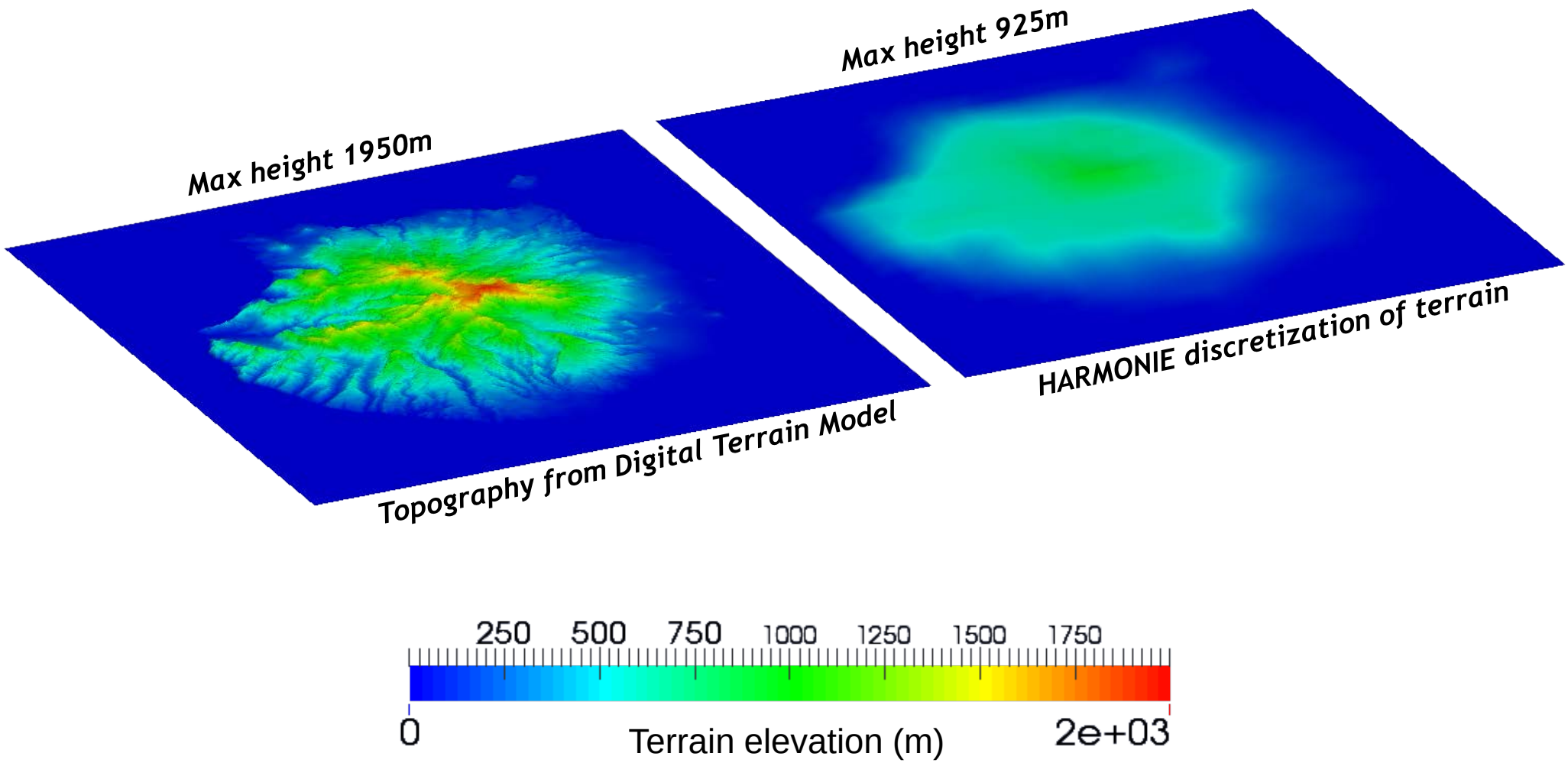
- 24 hours simulation data



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

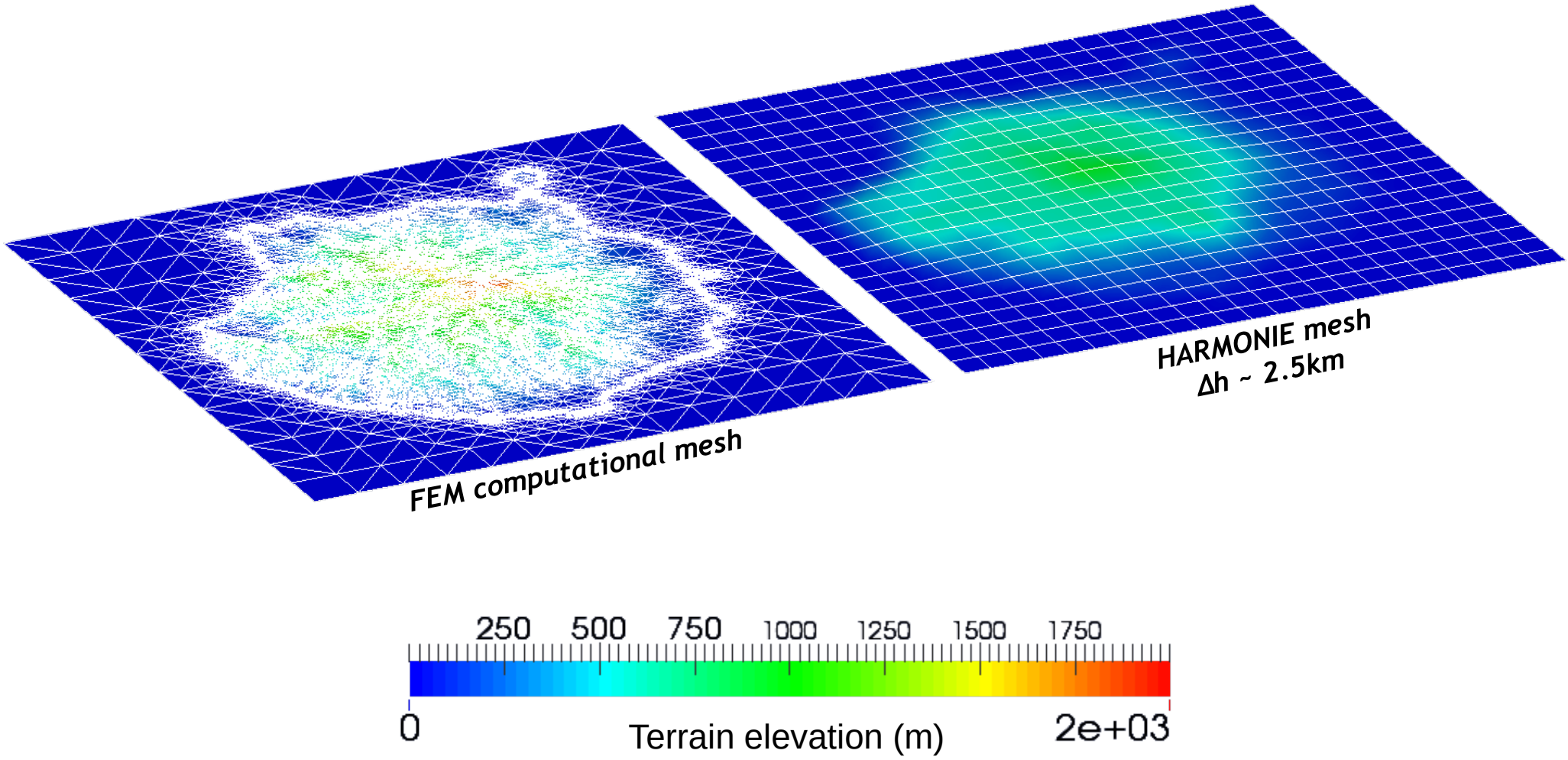
HARMONIE-FEM wind forecast

Terrain approximation



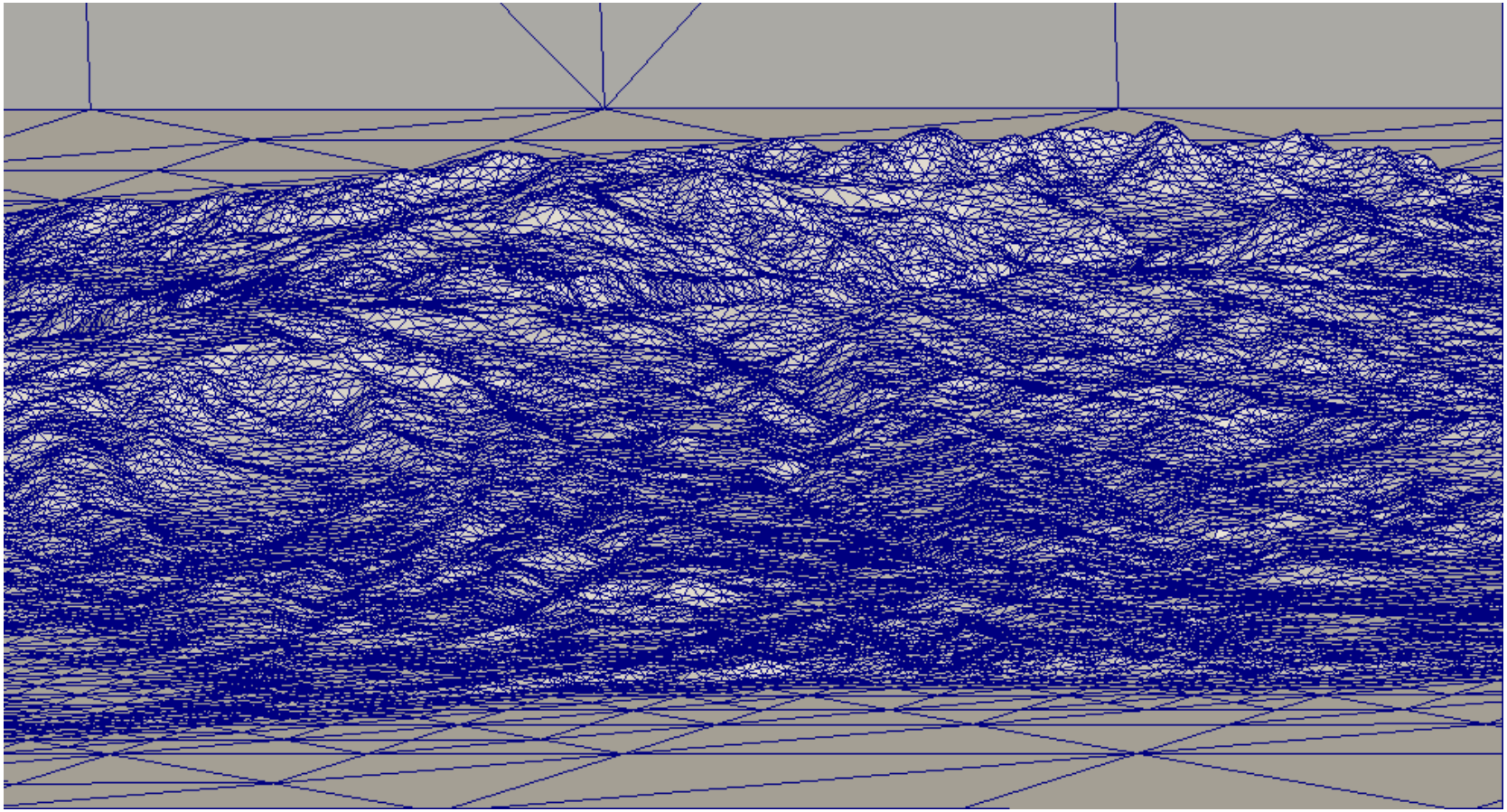
HARMONIE-FEM wind forecast

Spatial discretization



HARMONIE-FEM wind forecast

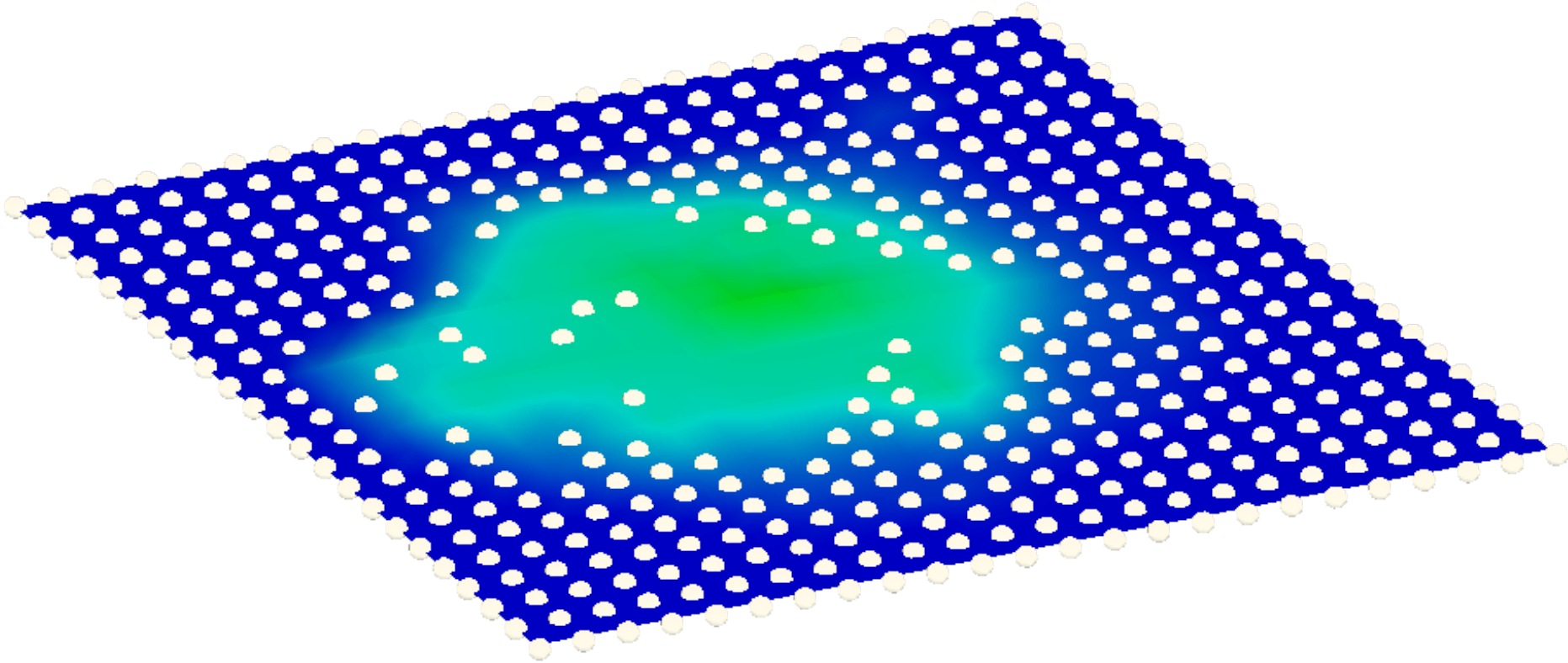
Terrain approximation



HARMONIE-FEM wind forecast

HARMONIE data

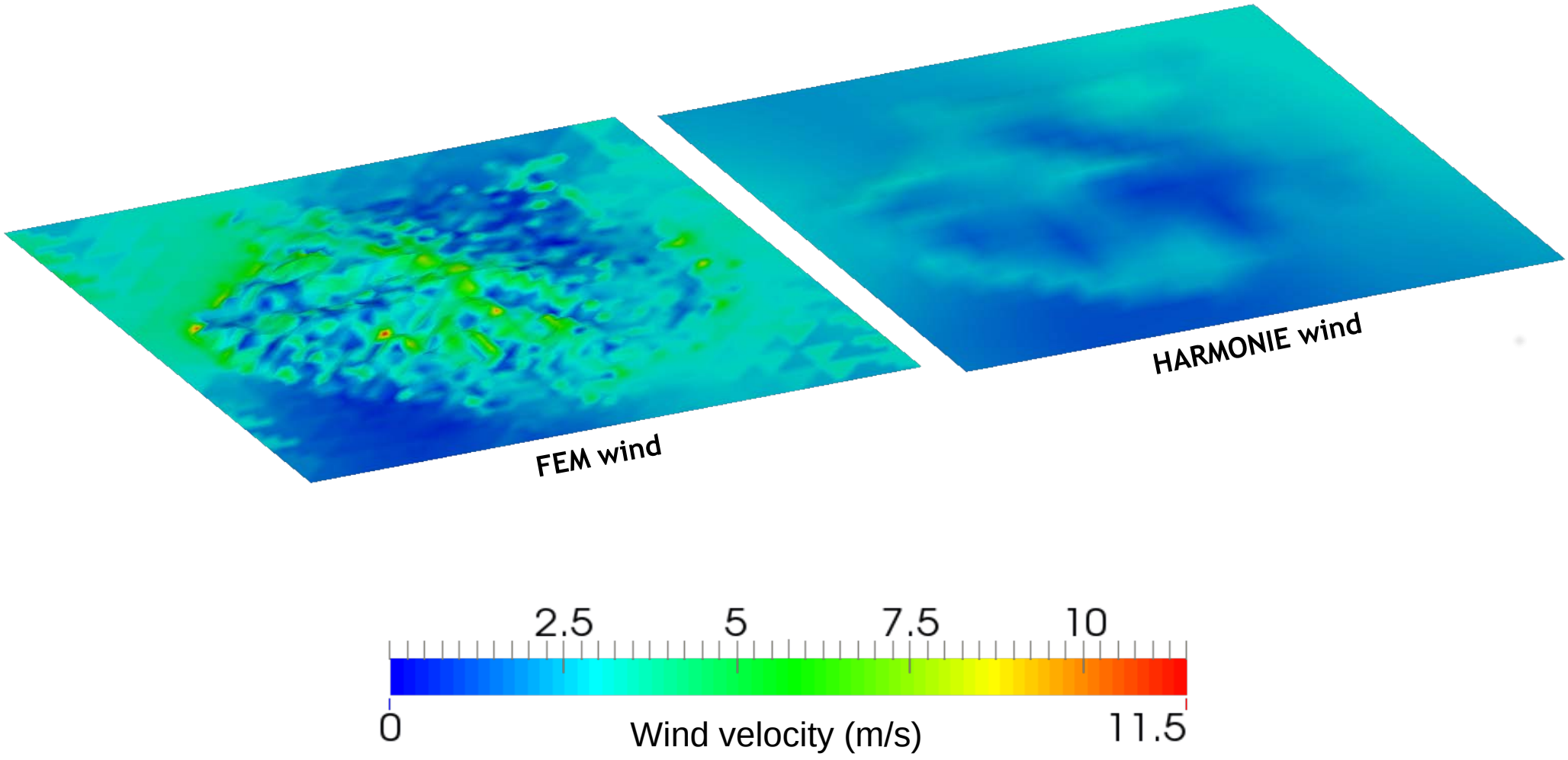
U_{10} V_{10} horizontal velocities
Geostrophic wind = (27.3, -3.9)



Used data (Δh < 100m)

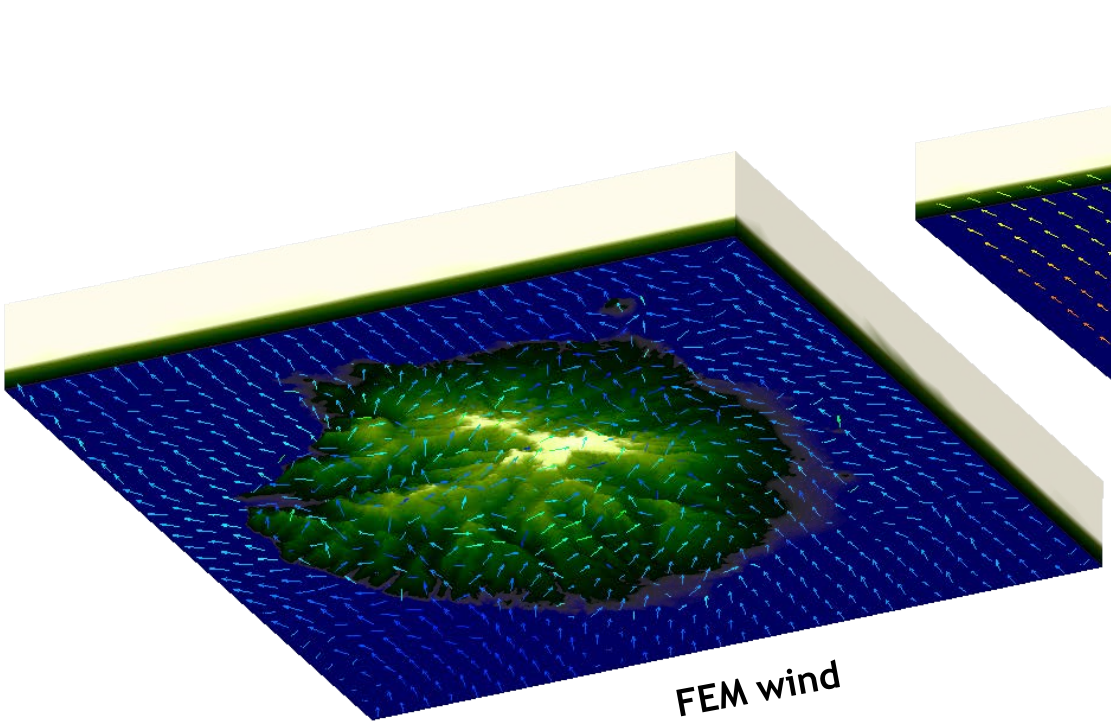
HARMONIE-FEM wind forecast

Wind magnitude at 10m over terrain

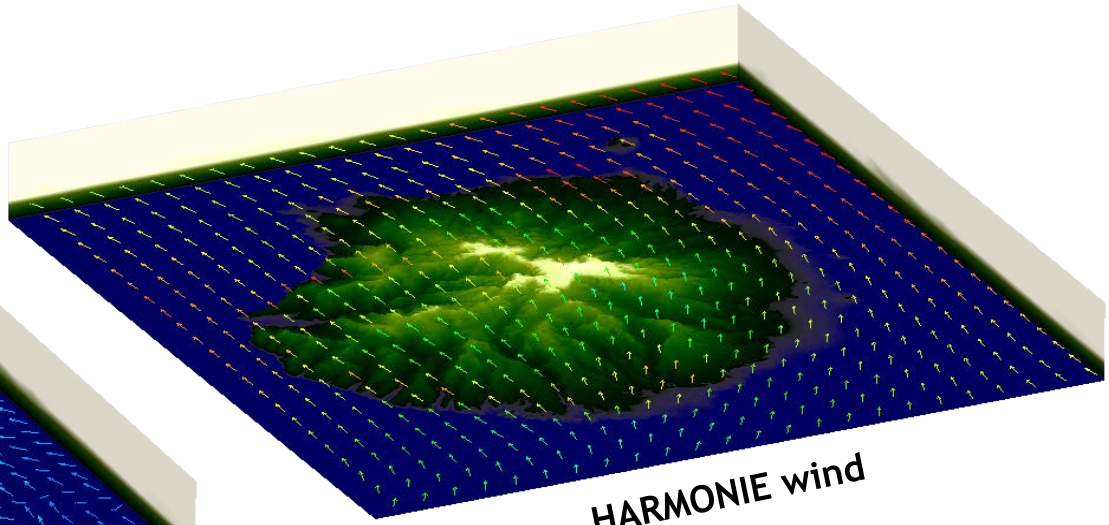


HARMONIE-FEM wind forecast

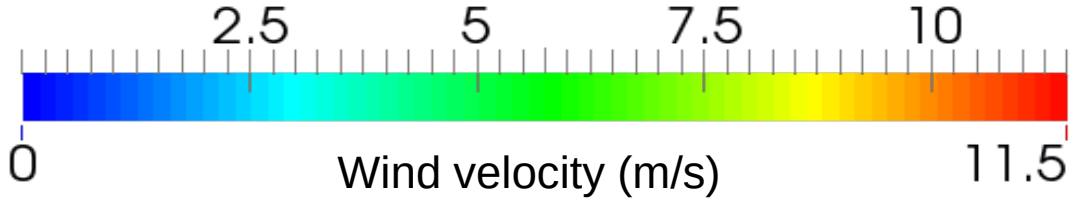
Wind field at 10m over terrain



FEM wind

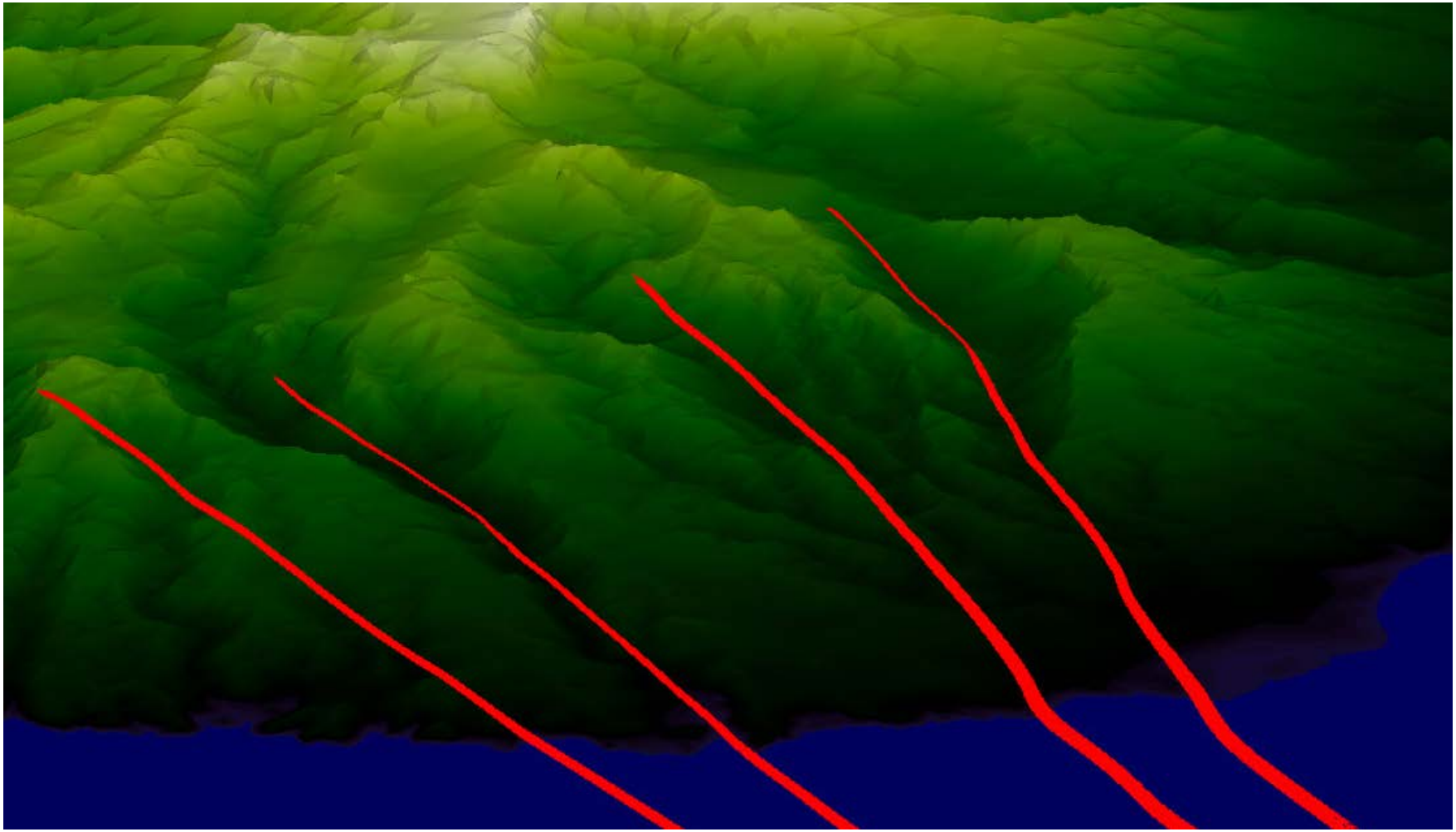


HARMONIE wind



HARMONIE-FEM wind forecast

Wind field over terrain (detail of streamlines)

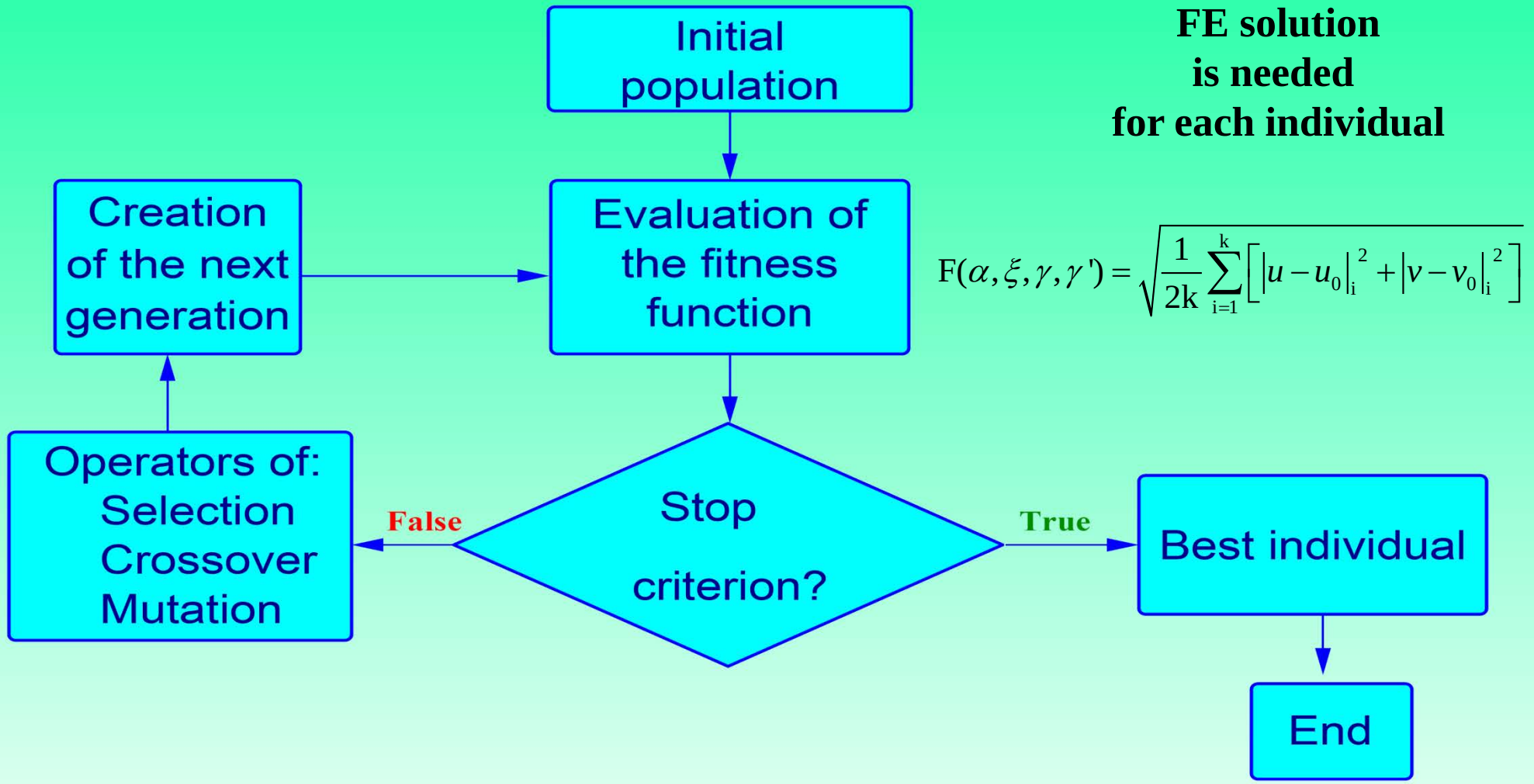


Zoom

Calibration

Estimation of Model Parameters

Genetic Algorithm

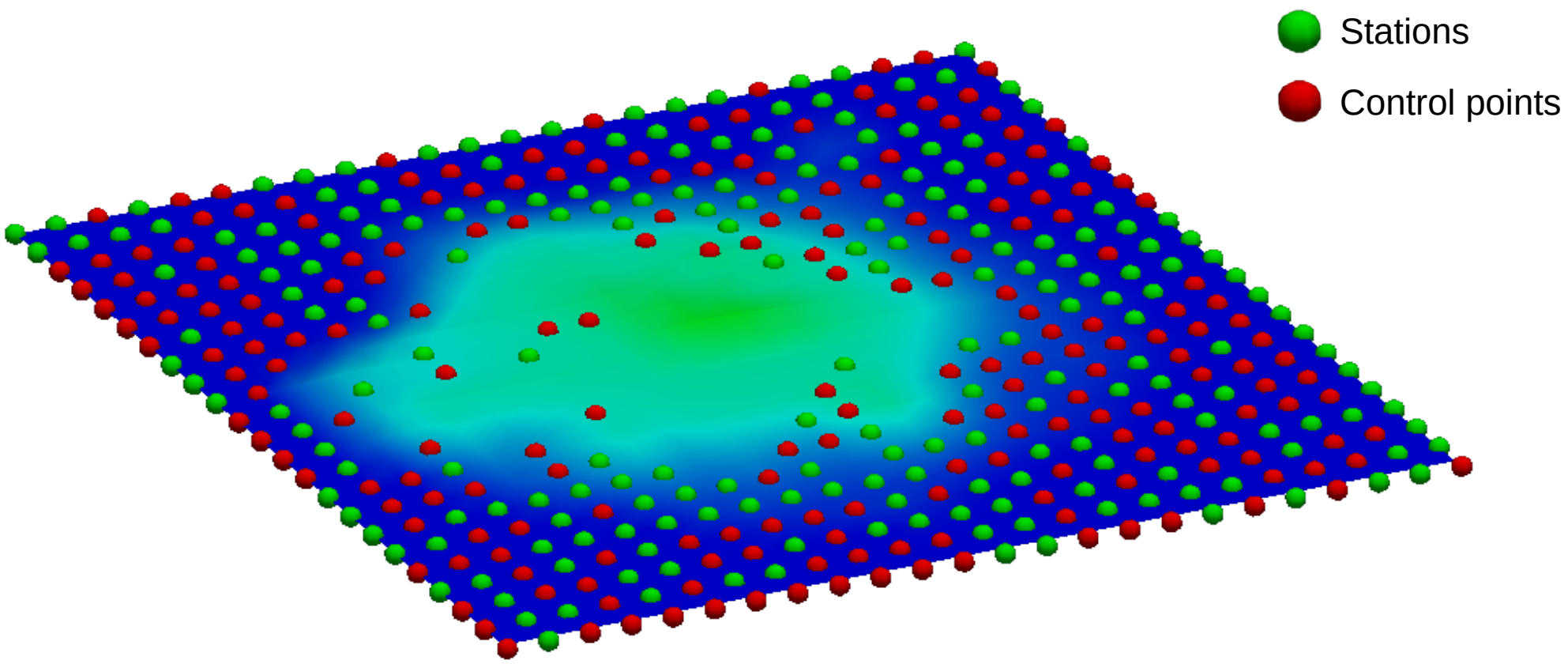


FE solution is needed for each individual

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

HARMONIE-FEM wind forecast

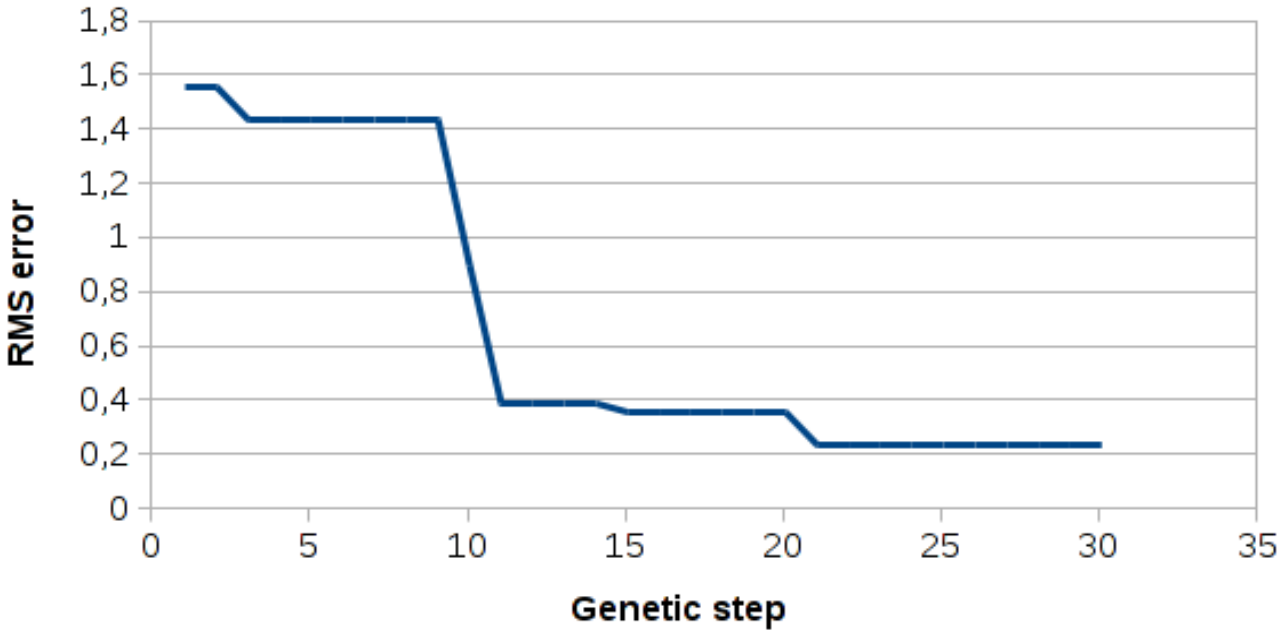
Stations election



Stations and control points

HARMONIE-FEM wind forecast

Genetic algorithm results

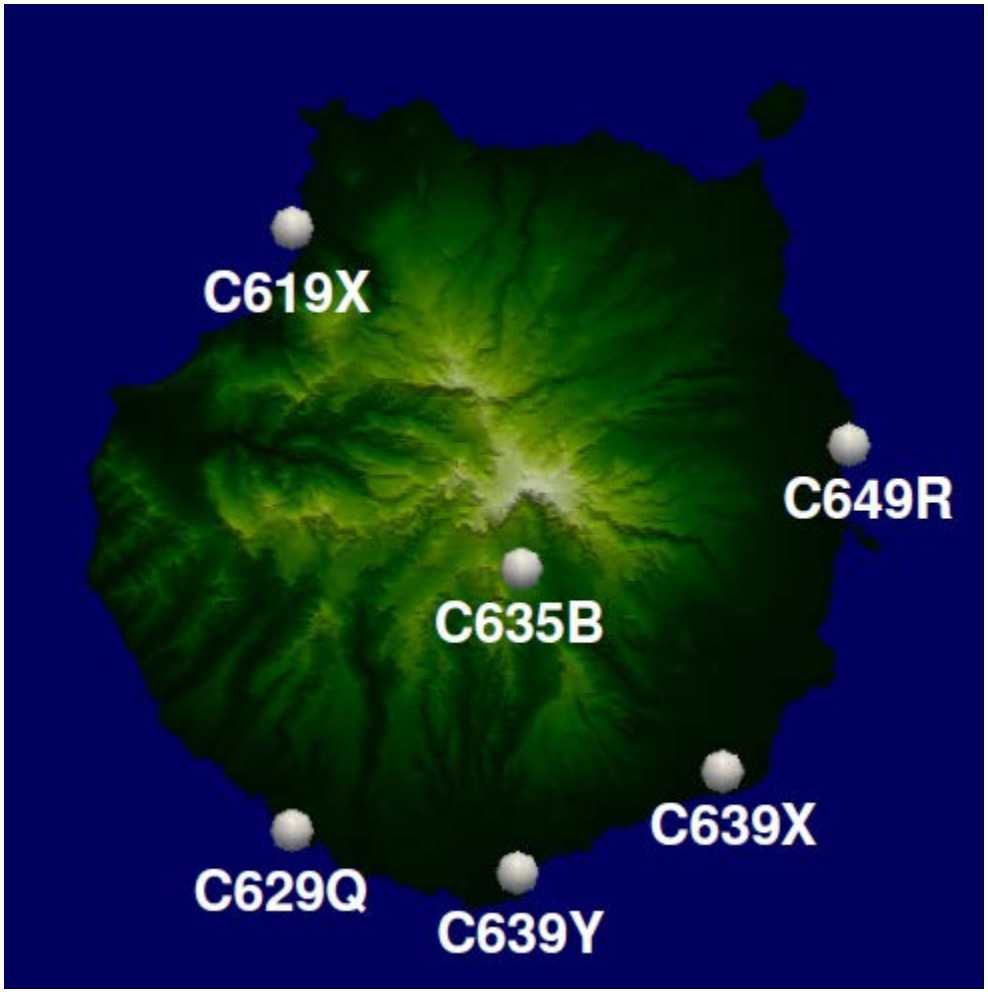


Optimal parameter values

Alpha = 2.302731
Epsilon = 0.938761
Gamma = 0.279533
Gamma‘ = 0.432957

HARMONIE-FEM wind forecast

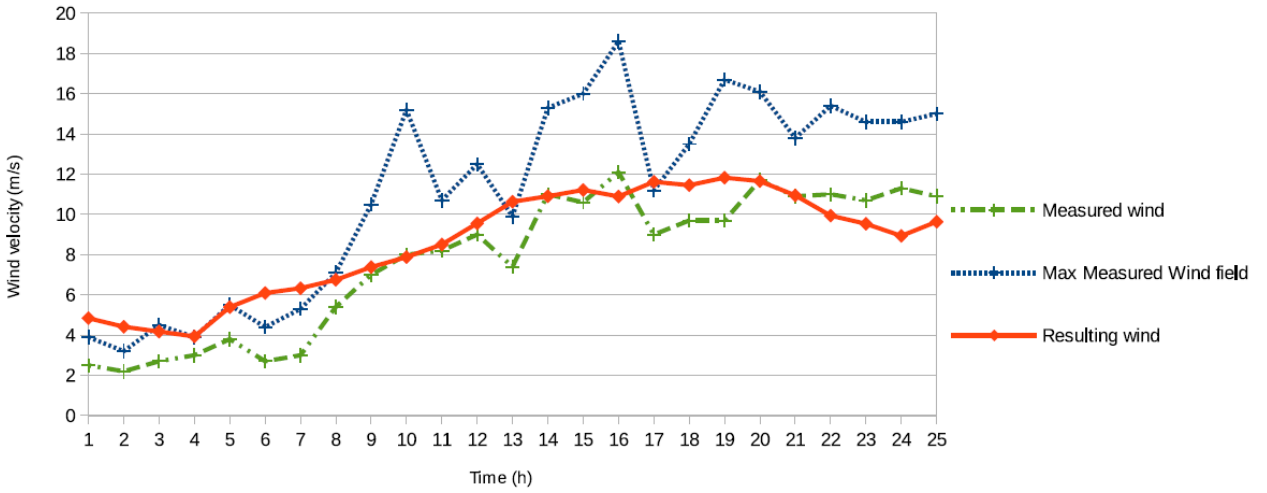
Forecast wind validation (location of measurement stations)



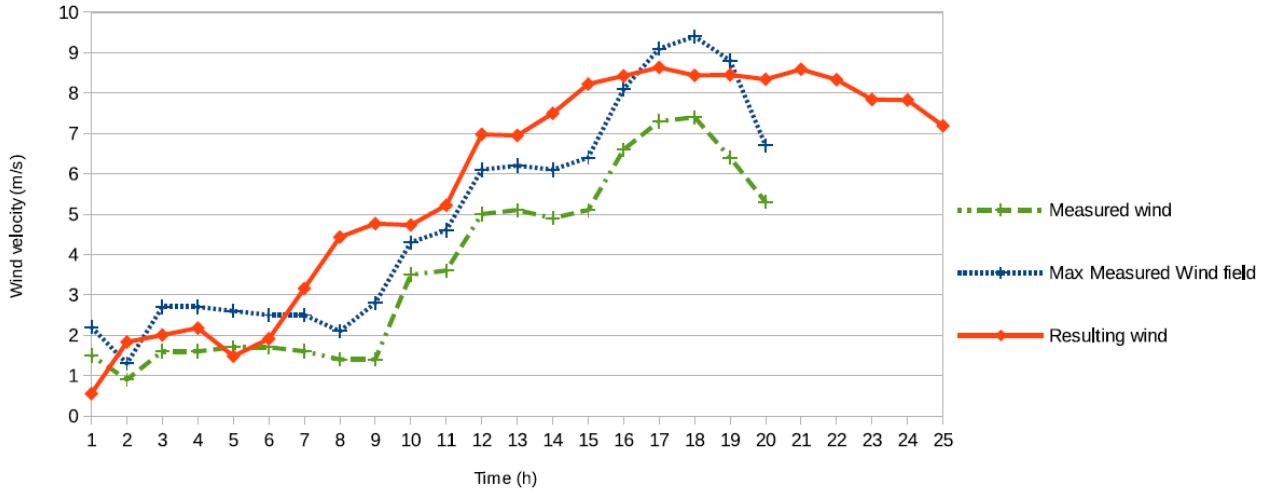
HARMONIE-FEM wind forecast

Forecast wind along a day

C619X measurement station



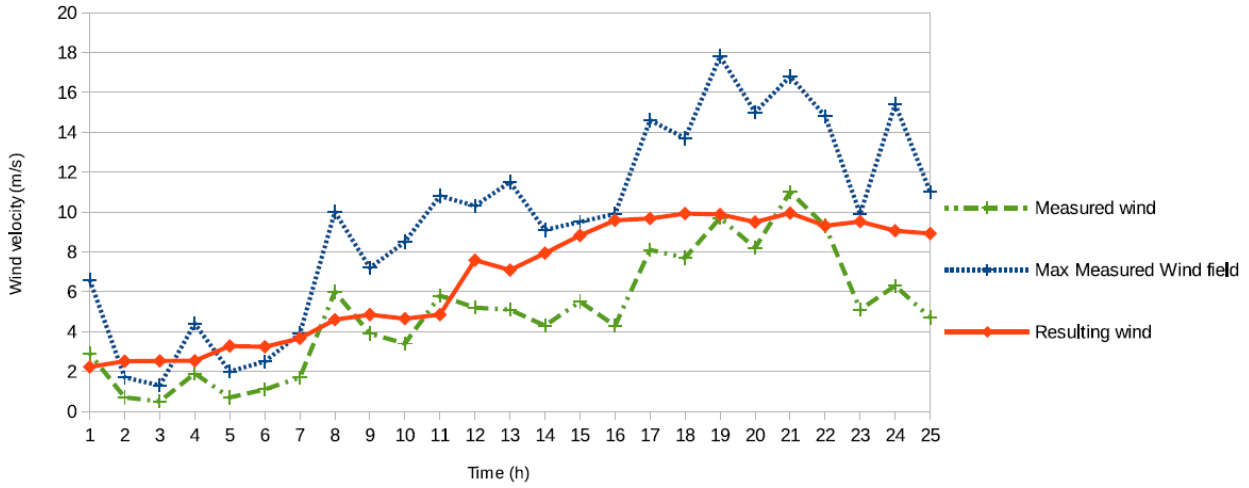
C629Q measurement station



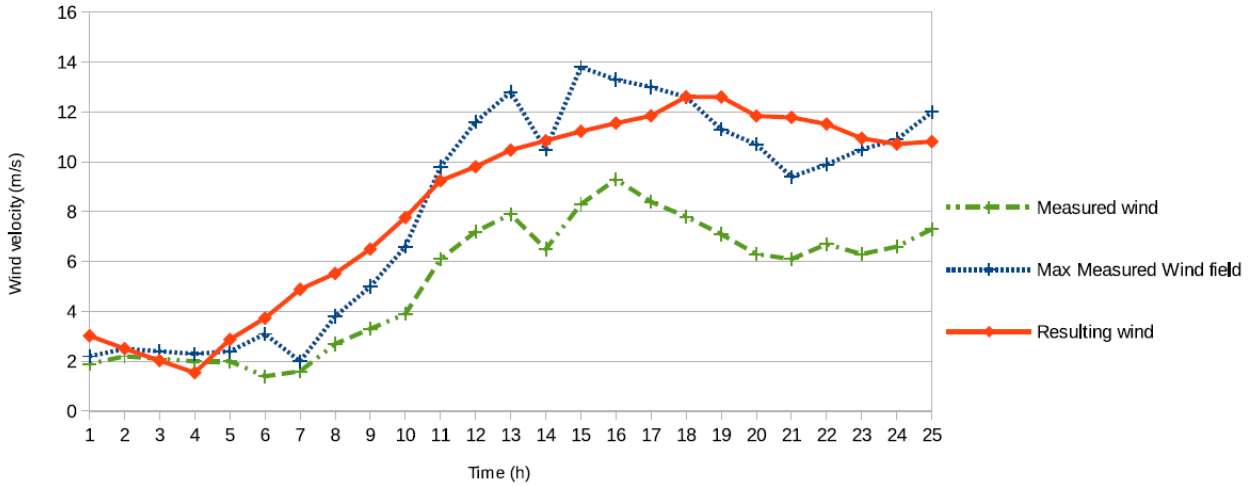
HARMONIE-FEM wind forecast

Forecast wind along a day

C635B measurement station



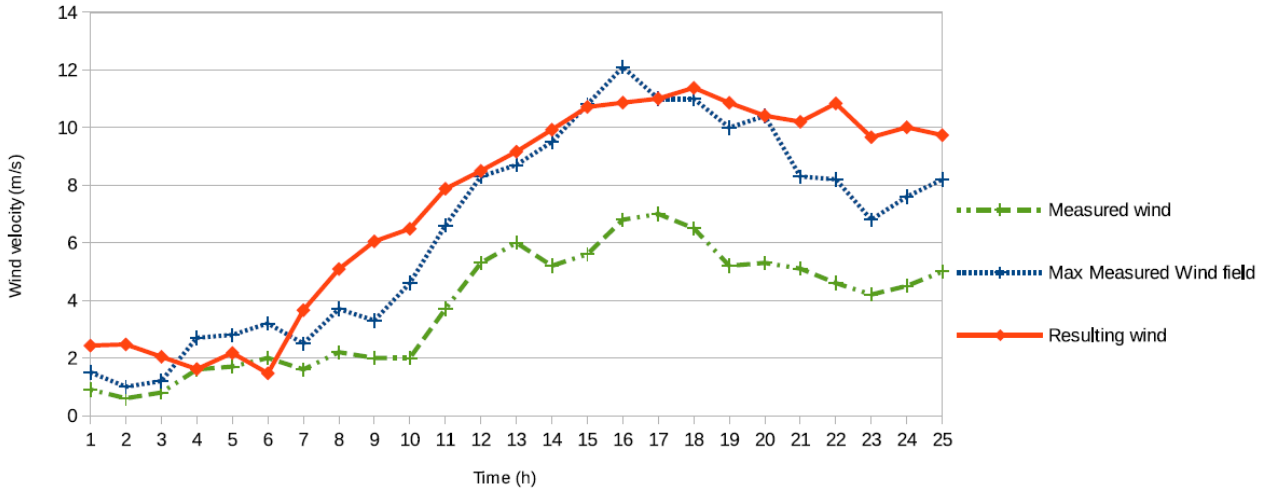
C639X measurement station



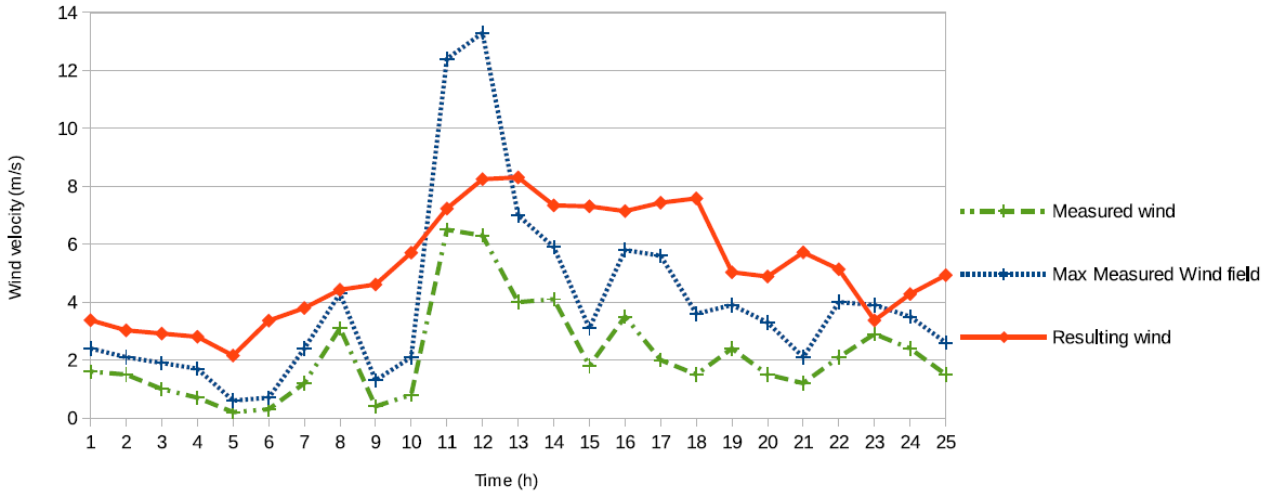
HARMONIE-FEM wind forecast

Forecast wind along a day

C639Y measurement station



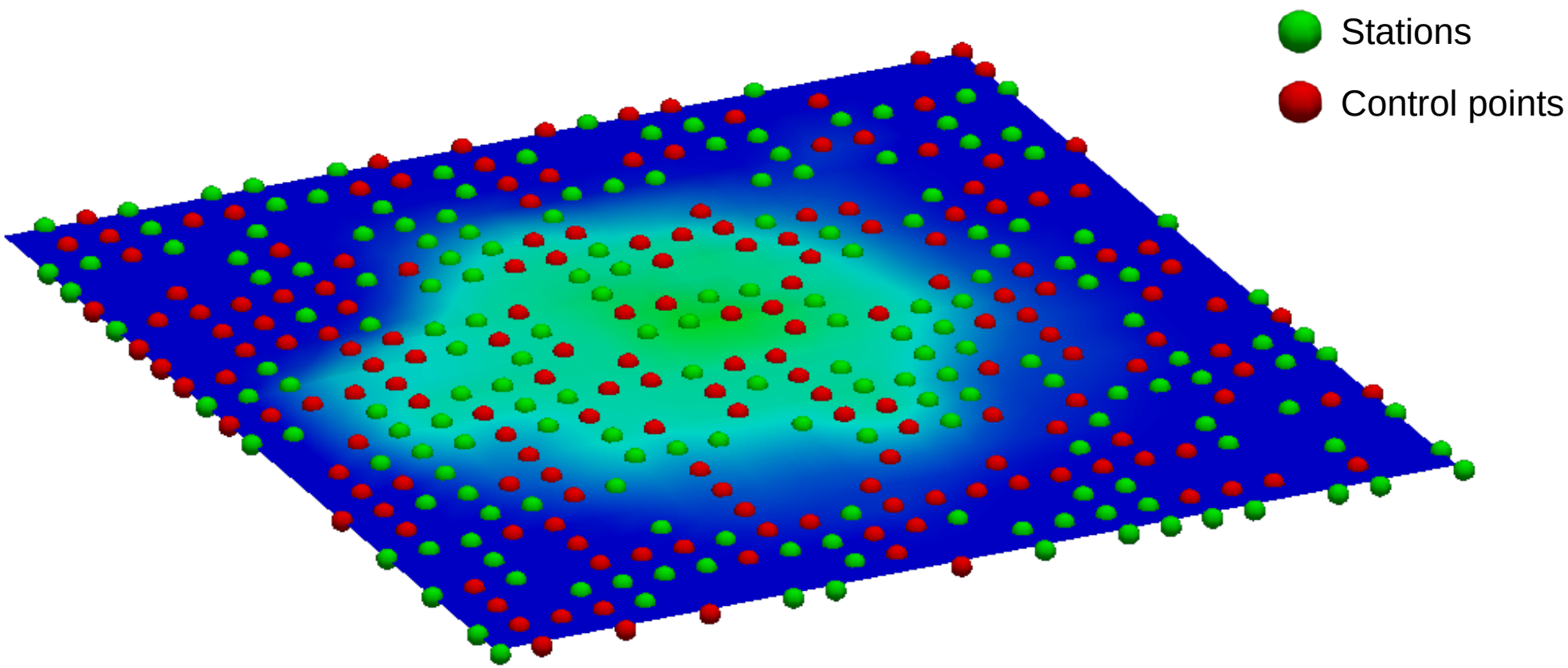
C649R measurement station



Ensemble method

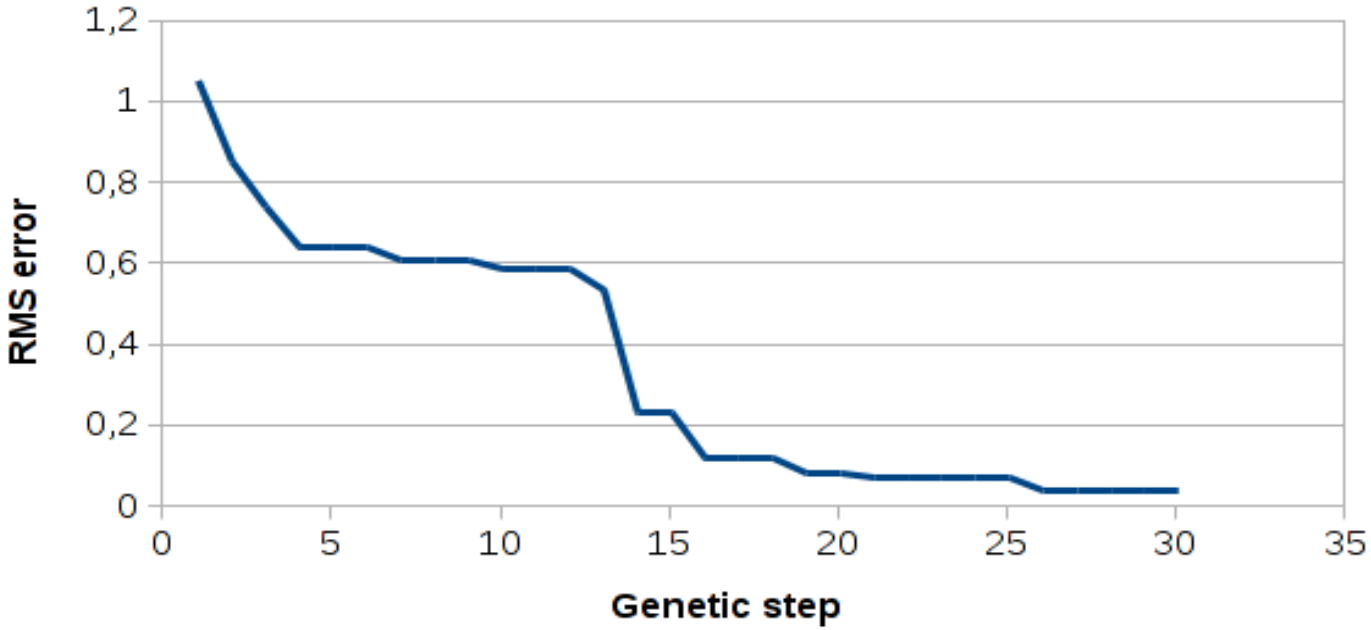
Ensemble methods

Stations election



Stations (1/3) and control points (1/3)

Ensemble methods



New

Alpha = 2.057920
Epsilon = 0.950898
Gamma = 0.224911
Gamma' = 0.311286

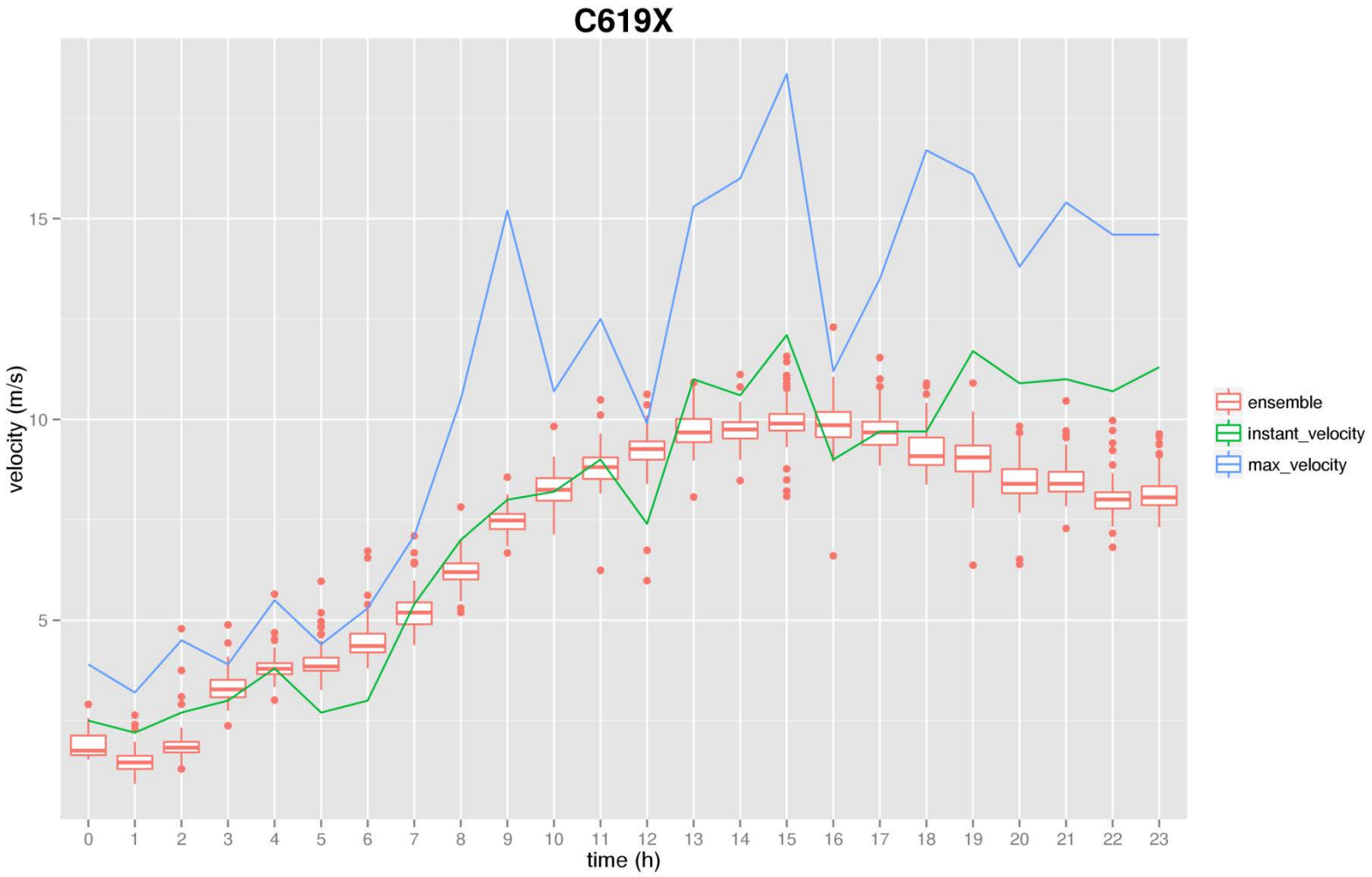
Small changes

Previous

Alpha = 2.302731
Epsilon = 0.938761
Gamma = 0.279533
Gamma' = 0.432957

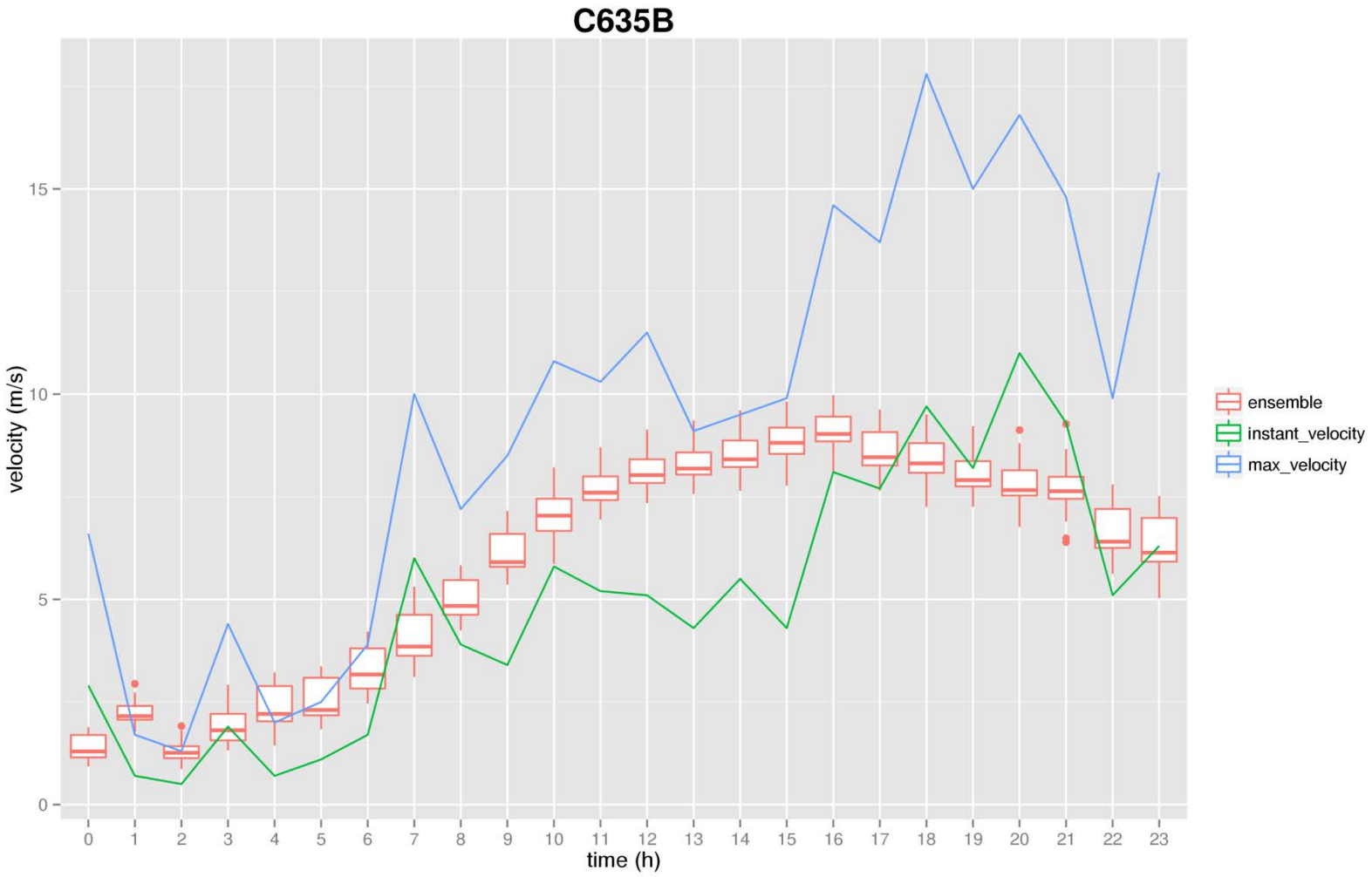
Ensemble mthods

Ensemble forecast wind along a day



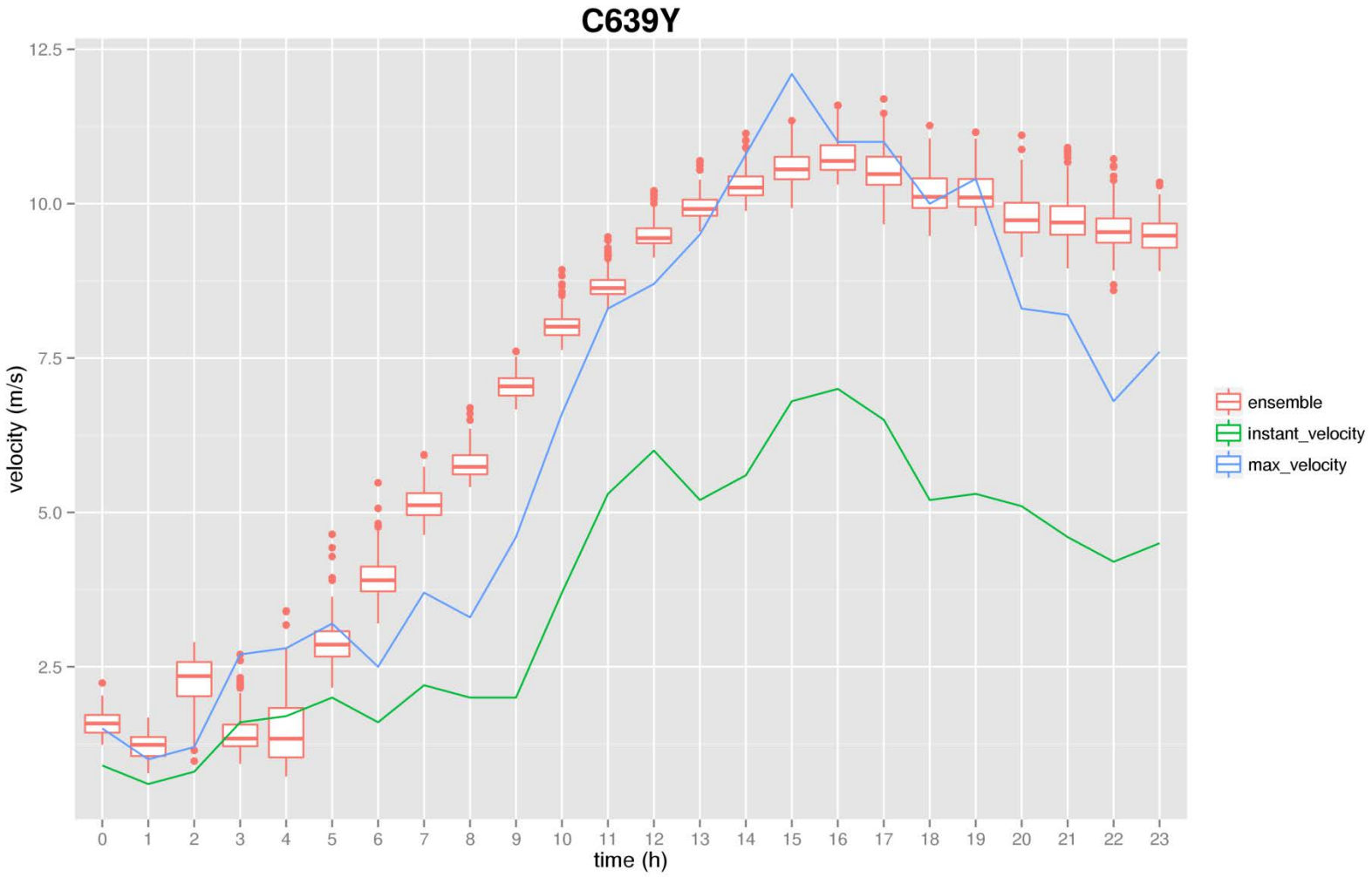
Ensemble mthods

Ensemble forecast wind along a day



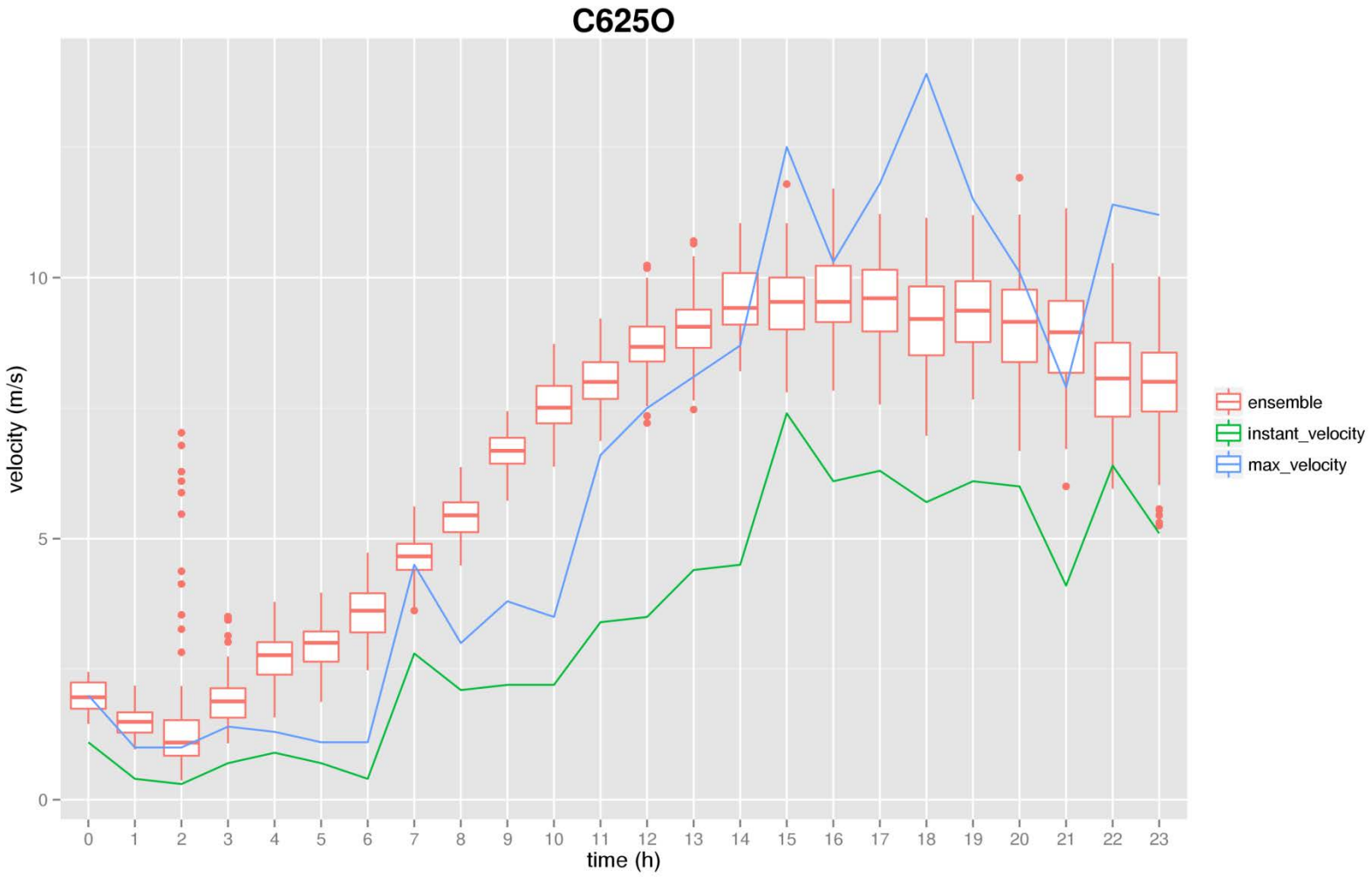
Ensemble mthods

Ensemble forecast wind along a day



Ensemble mthods

Ensemble forecast wind along a day



Conclusions

Conclusions

- Local Scale wind field model is suitable for complex orographies http://www.dca.iusiani.ulpgc.es/Wind3D

- Local wind field in conjunction with HARMONIE 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.

- The proposed method is a work in progress that looks promising

- Ensemble methods provide a promising framework to deal with uncertainties

Thank you for your attention