INSTITUTO UNIVERSITARIO INGENIERIA COMPUTACIONAL

WIND ENSEMBLE FORECASTING USING AN ADAPTIVE MASS-CONSISTENT MODEL

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11th World Congress on Computational Mechanics (WCCM XI)

5th European Conference on Computational Mechanics (ECCM V)

6th European Conference on Computational Fluid Dynamics (ECFD VI)

July 20-25, 2014, Barcelona, Spain

UNIVERSIDAD DE LAS PALMAS DE GRAN CANARIA

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

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Wind forecasting over complex terrain

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- Ensemble methods
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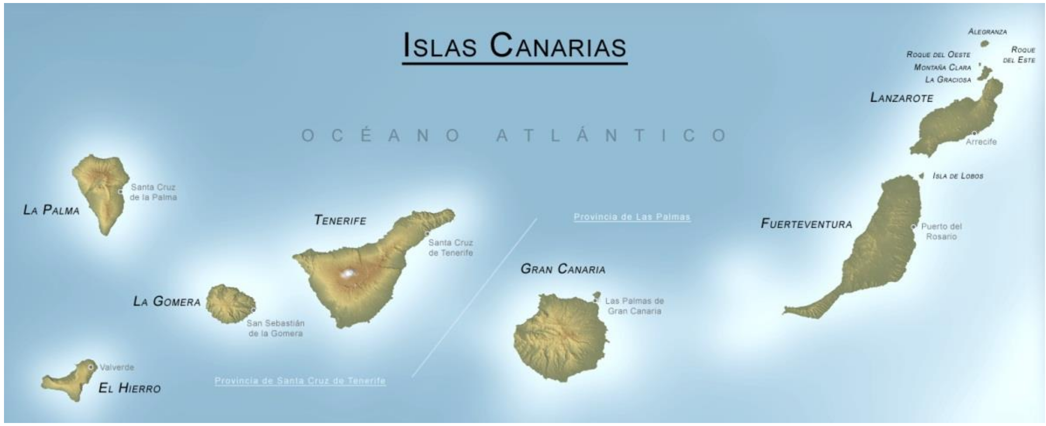
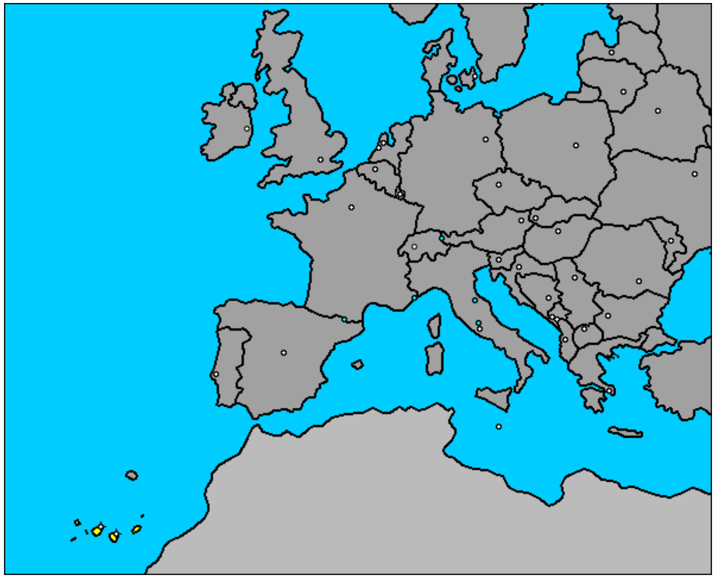
- Conclusions

Motivation

- Wind field prediction for local scale
- Ensemble methods
- Gran Canaria island (Canary Islands)





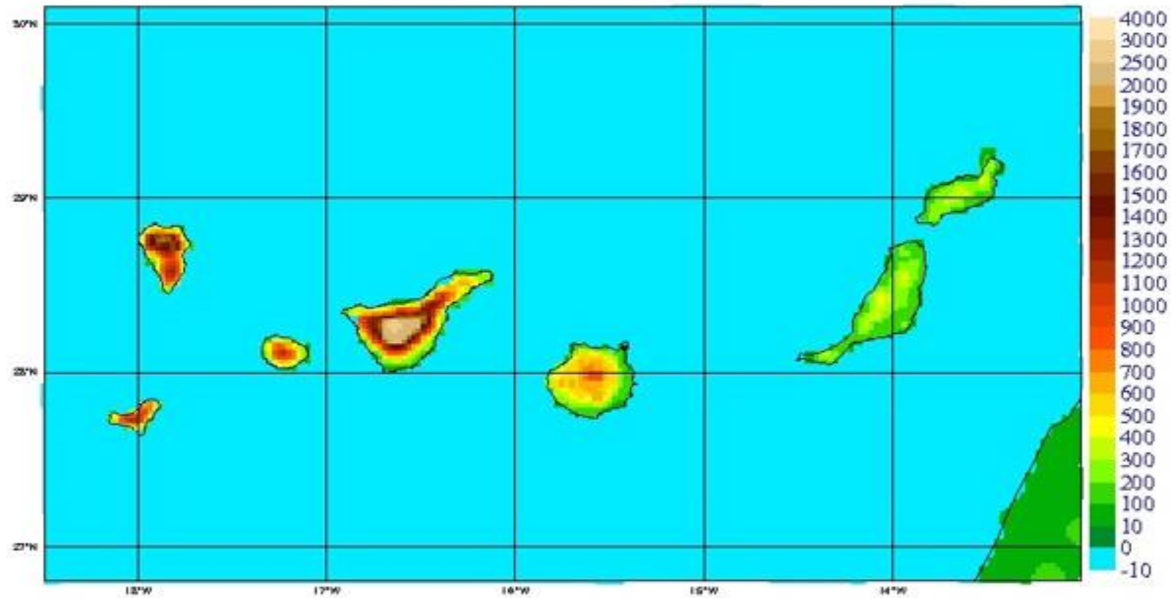
Motivation

- Wind farm energy
- Air quality
- Etc.

Motivation

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)

Motivation

Ensemble methods

- Ensemble methods are used to deal with uncertainties
- Several simulations
  - Initial/Boundary conditions perturbation
  - Physical parameters perturbation
  - Selected models

- Ensemble methods are used to deal with uncertainties
- Several simulations
  - Initial/Boundary conditions perturbation
  - Physical parameters perturbation
  - Selected models
- 80% rain probability → 80% of simulations predict rain

General algorithm

Adaptive Finite Element Model

- Construction of a tetrahedral mesh
  - Mesh adapted to the terrain using Meccano method

- Wind field modeling
  - Horizontal and vertical interpolation from HARMONIE data
  - Mass consistent computation
  - Calibration (Genetic Algorithms)

- Ensemble method

The Adaptive Mesh

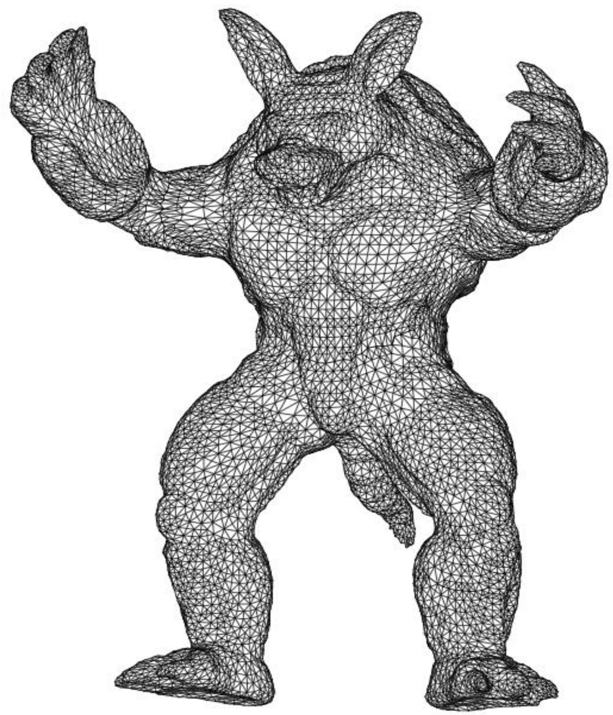
Meccano Method for Complex Solids

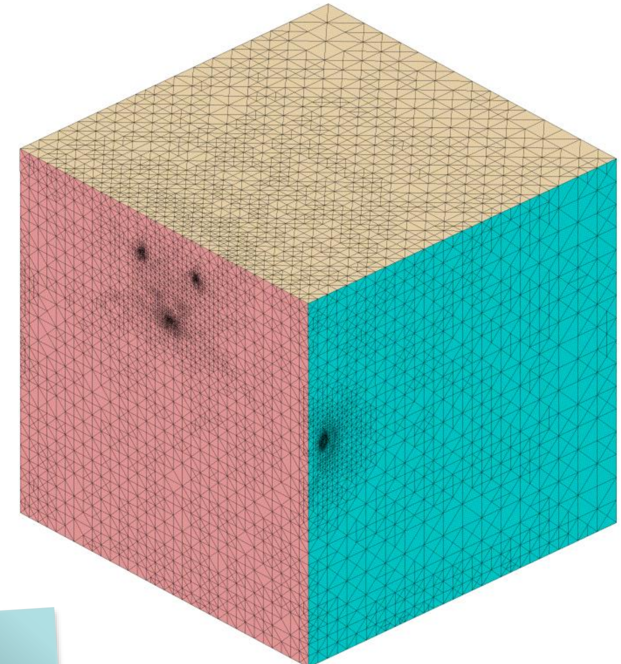
Algorithm steps

- Meccano construction
- Parameterization of the solid surface
  - Solid boundary partition
  - Floater's parameterization
- Coarse tetrahedral mesh of the meccano
  - Partition into hexahedra
  - Hexahedron subdivision into six tetrahedra
- Solid boundary approximation
  - Kossaczky's refinement
  - Distance evaluation
- Inner node relocation
  - Coons patches
- Simultaneous untangling and smoothing
  - SUS

Meccano Method for Complex Solids

Simultaneous mesh generation and volumetric parameterization

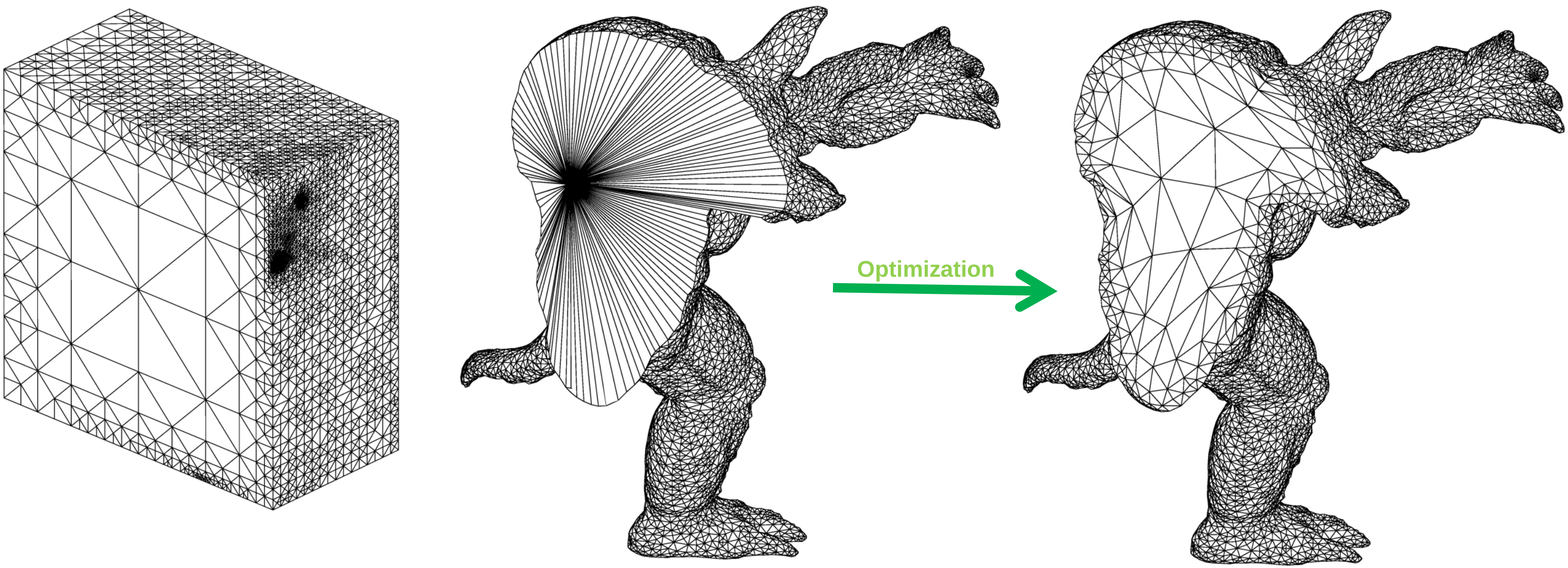




- **Parameterization**
- **Refinement**
- **Untangling & Smoothing**

Meccano Method for Complex Solids

Key of the method: SUS of tetrahedral meshes



Parameter space
(meccano mesh)

Physical space
(tangled mesh)

Physical space
(optimized mesh)

The Wind Field Model

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Adaptive Finite Element Model

- Wind field modeling
  - Horizontal and vertical interpolation from HARMONIE data
  - Mass consistent computation
  - Parameter calibration (Genetic Algorithms)

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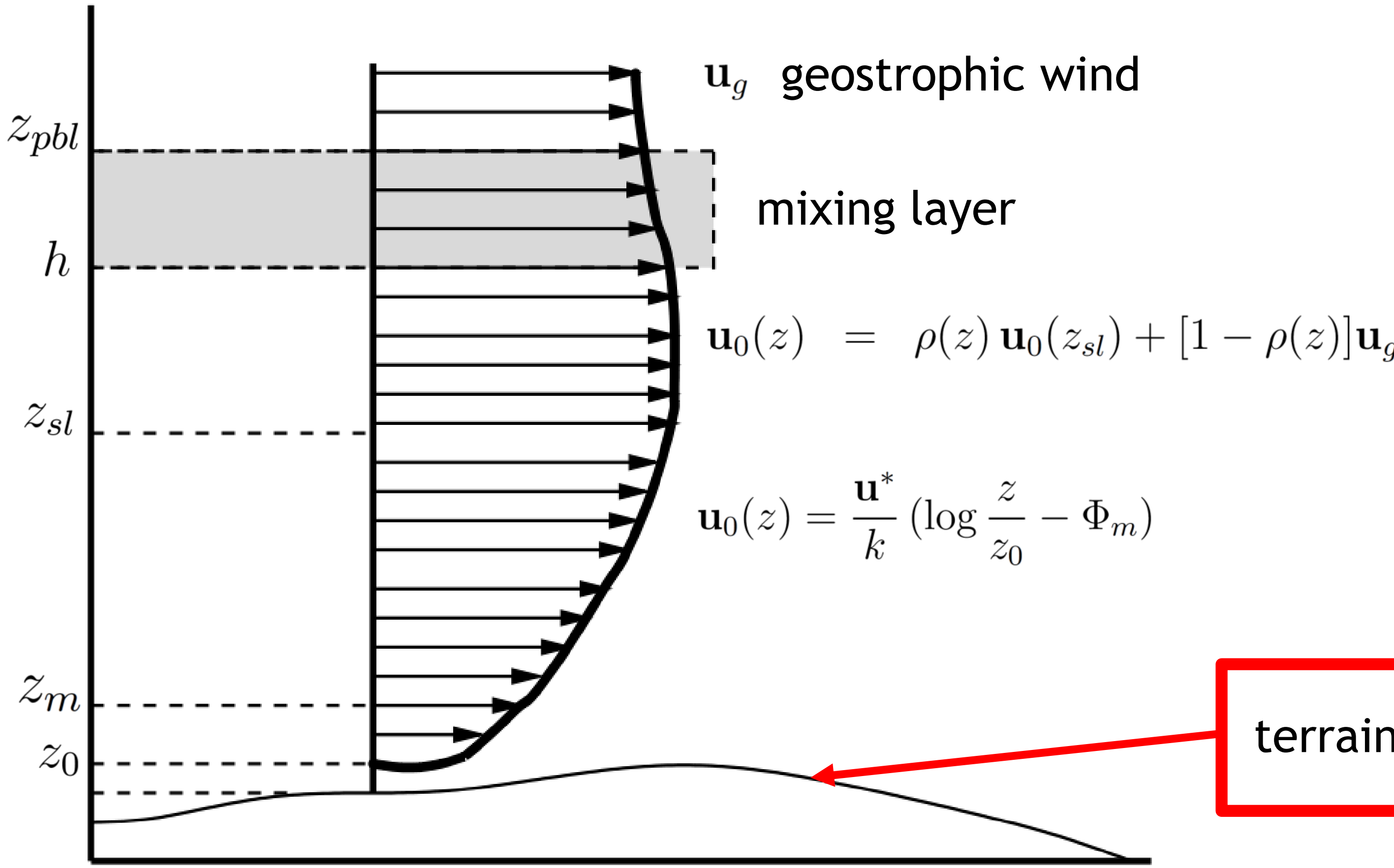
Horizontal interpolation

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

$$\boxed{0 \le \xi \le 1}$$

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:** $z_{sl} = \dfrac{h}{10}$

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- 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

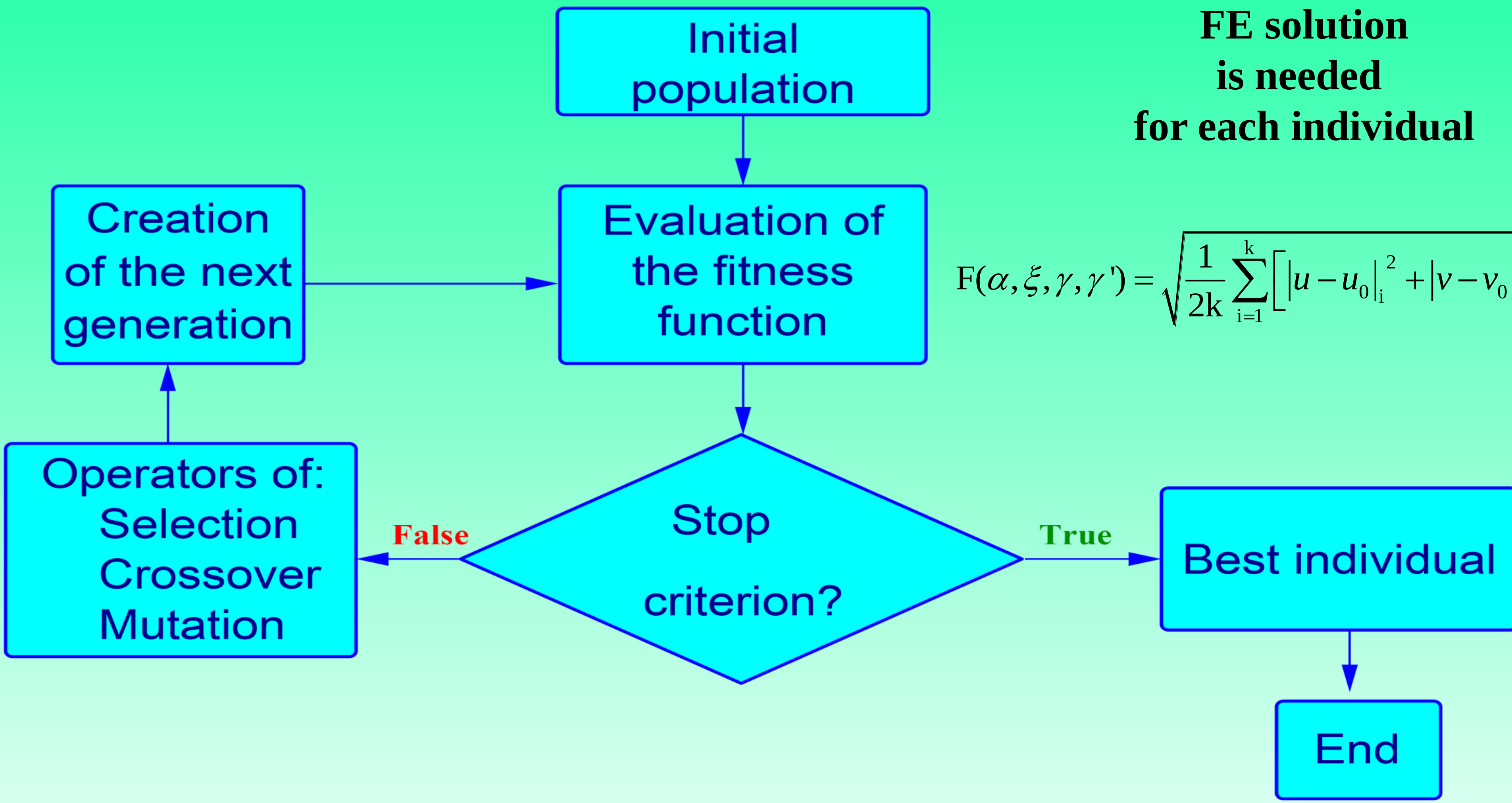
$$u = u_0 + T_h \frac{\partial \phi}{\partial x}, \quad v = v_0 + T_h \frac{\partial \phi}{\partial y}, \quad w = w_0 + T_v \frac{\partial \phi}{\partial z},$$

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

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

Estimation of Model Parameters

Genetic Algorithm



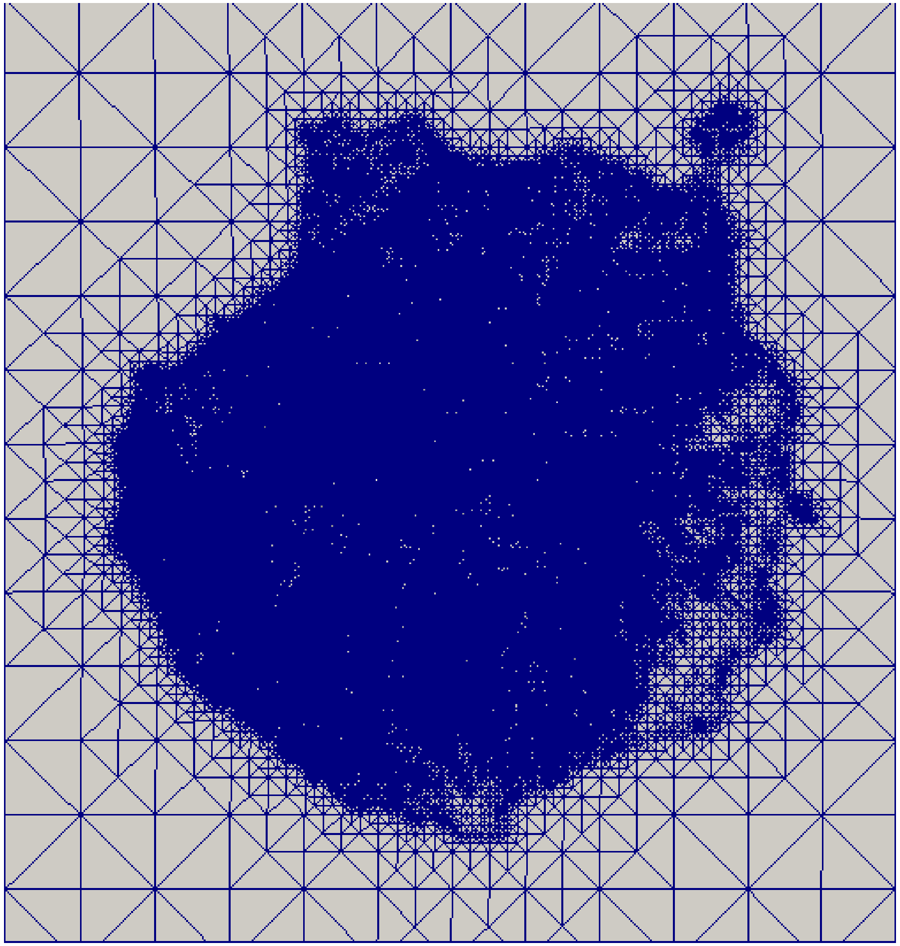
FE solution is needed for each individual

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

The Results

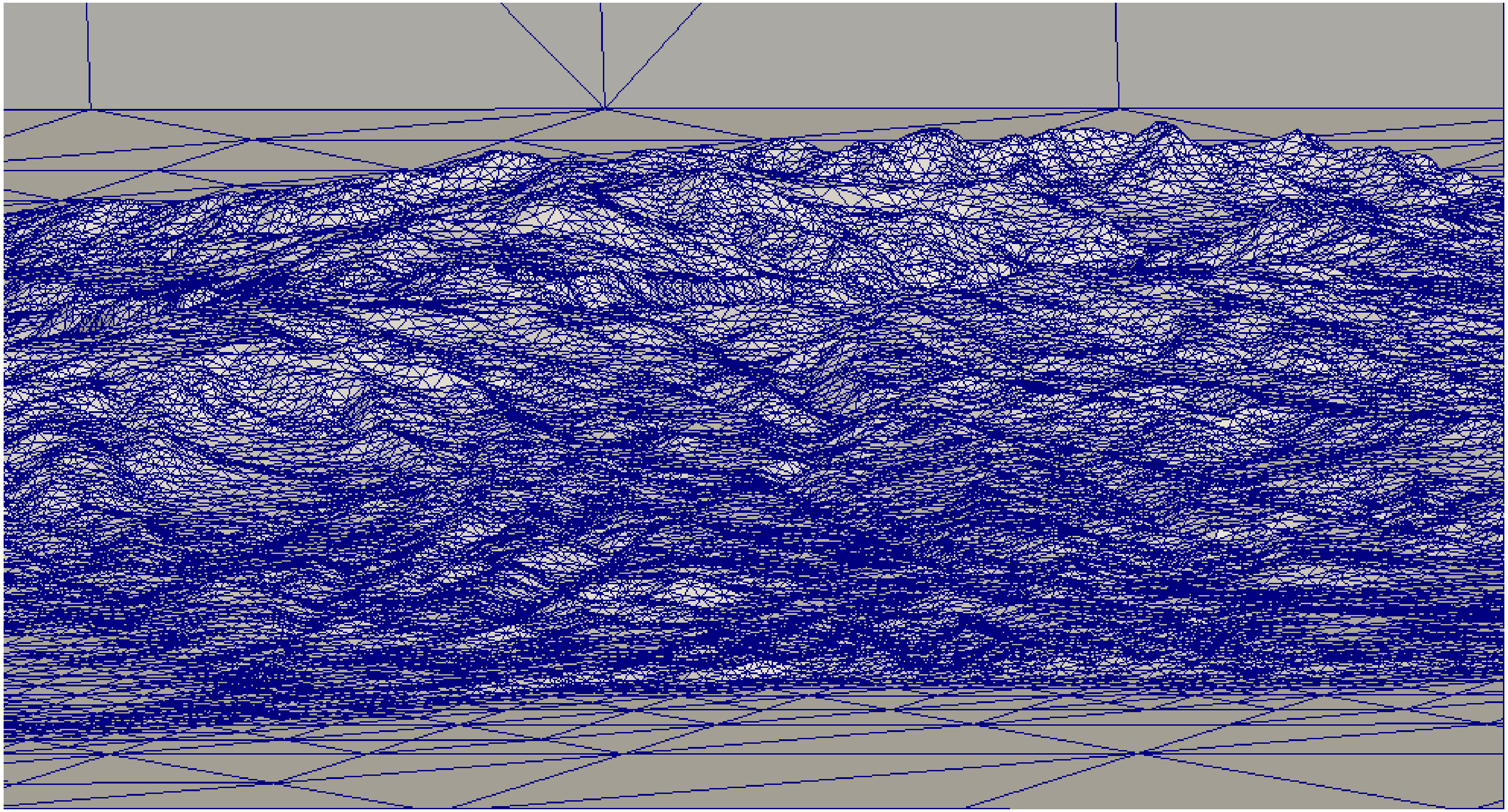
HARMONIE-FEM wind forecast

Terrain approximation



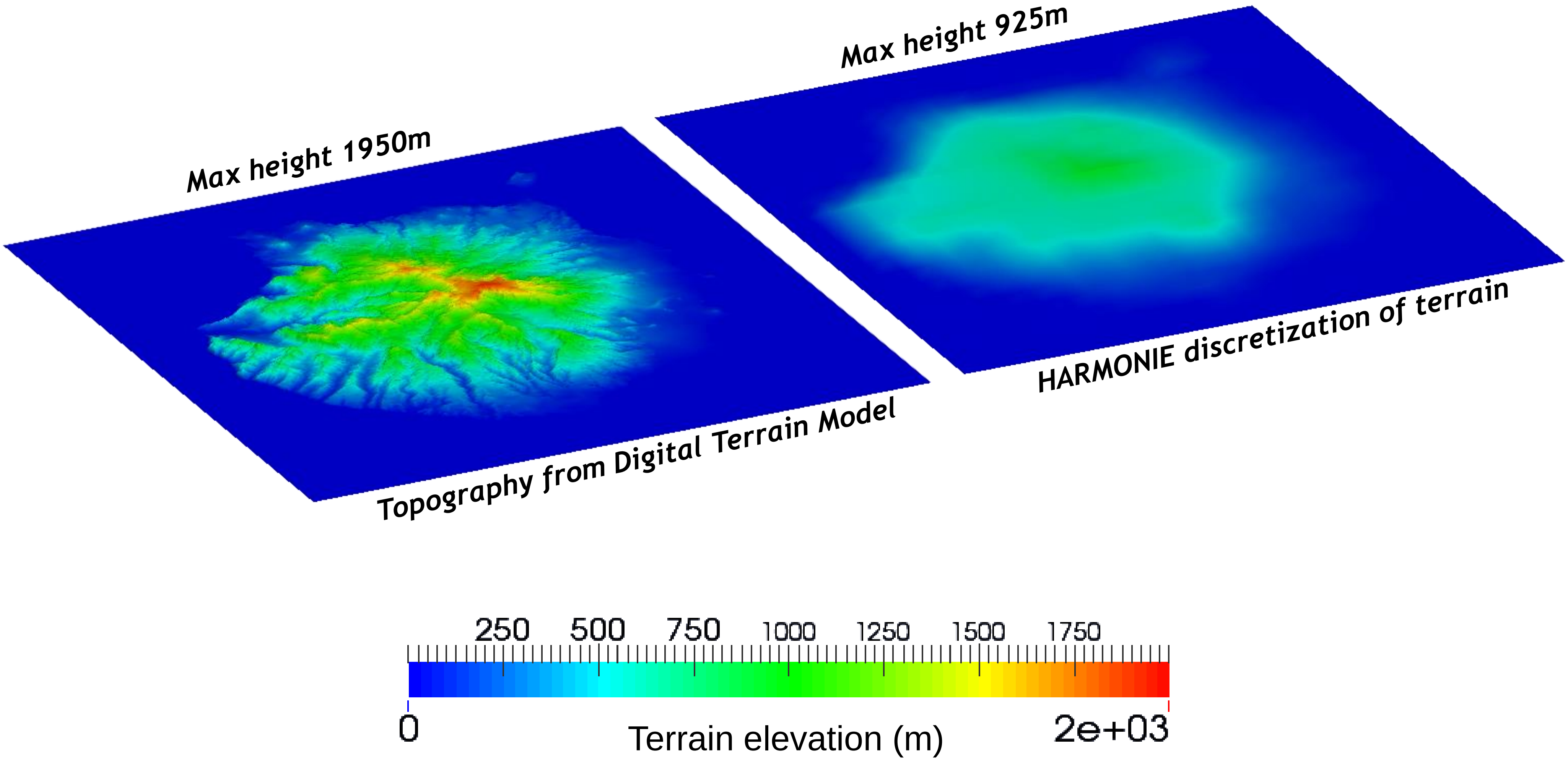
HARMONIE-FEM wind forecast

Terrain approximation



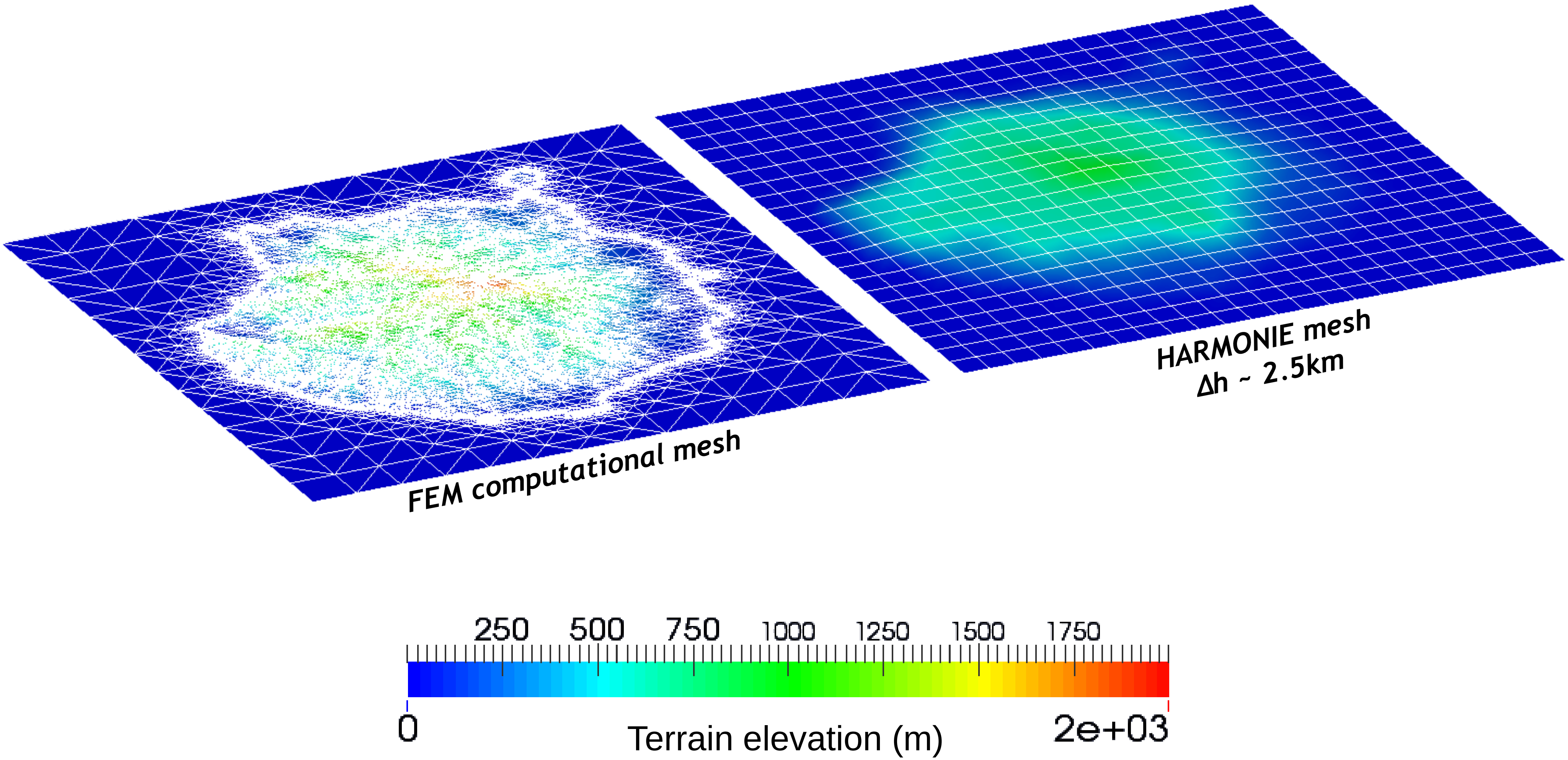
HARMONIE-FEM wind forecast

Terrain approximation



HARMONIE-FEM wind forecast

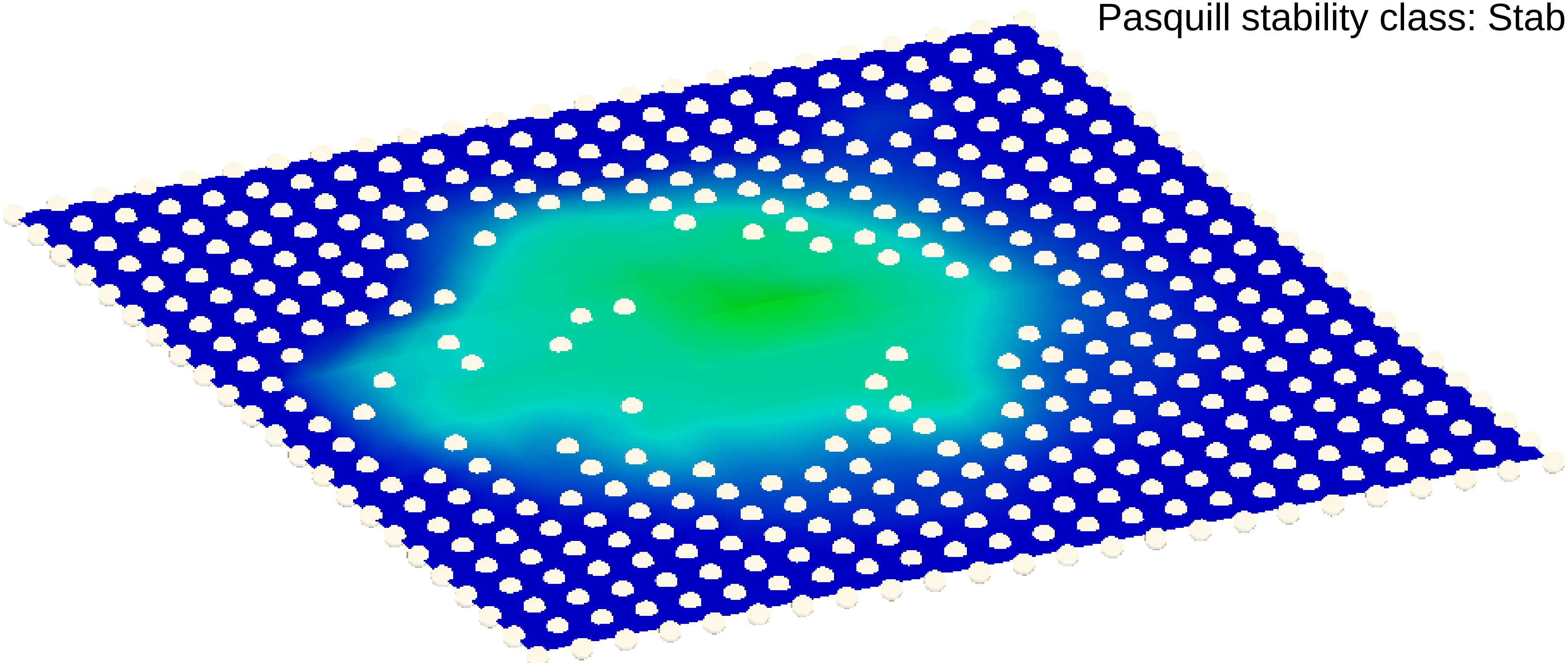
Spatial discretization



HARMONIE-FEM wind forecast

HARMONIE data

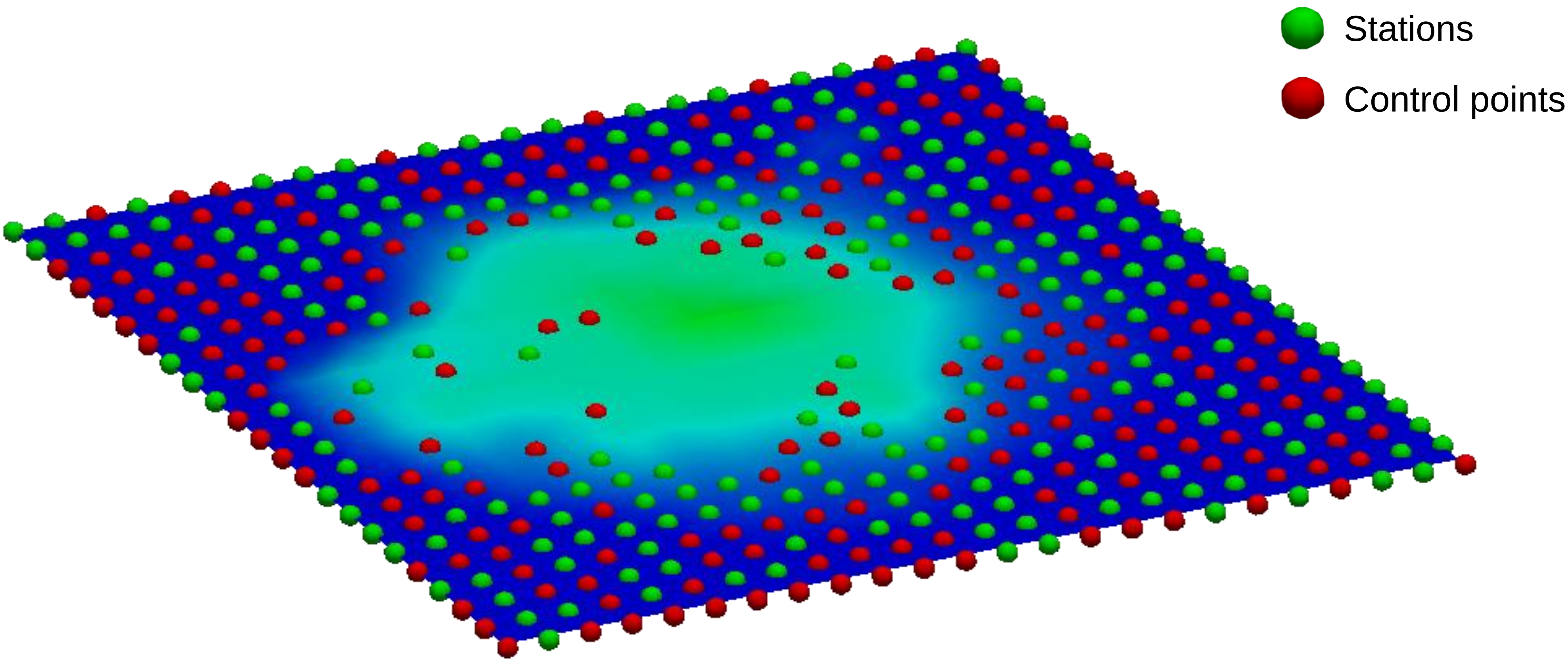
U_{10} V_{10} horizontal velocities
Geostrophic wind = (27.3, -3.9)
Pasquill stability class: Stable



Used data (Δh < 100m)

HARMONIE-FEM wind forecast

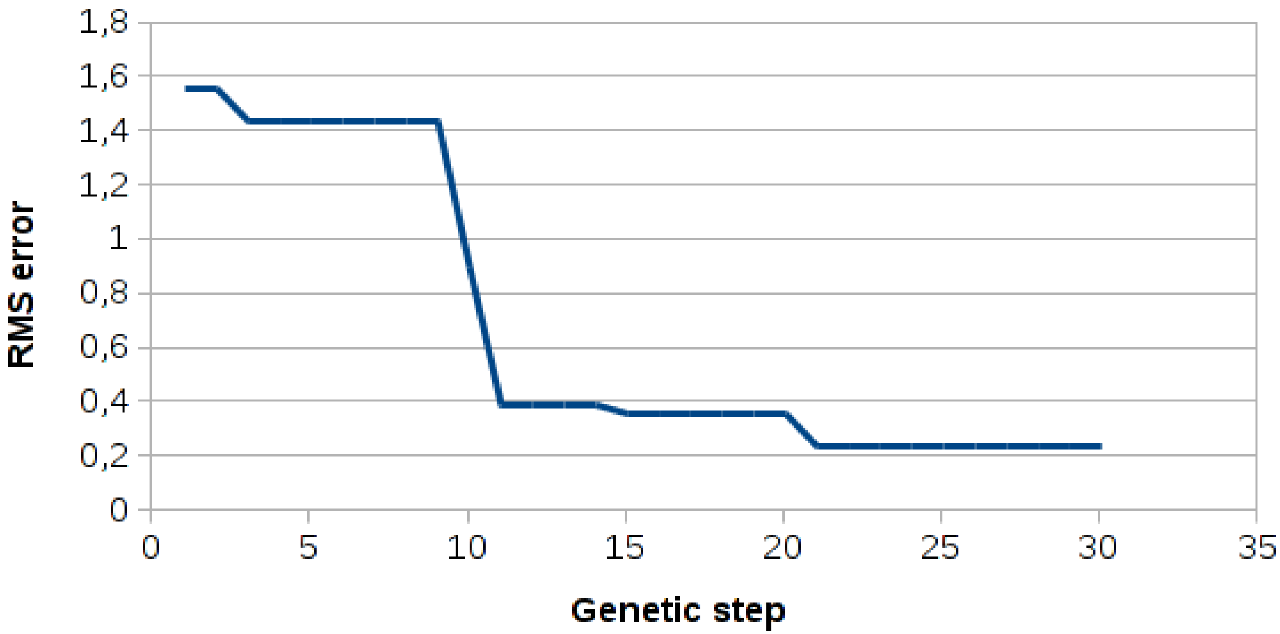
Stations election



Stations and control points

HARMONIE-FEM wind forecast

Genetic algorithm results

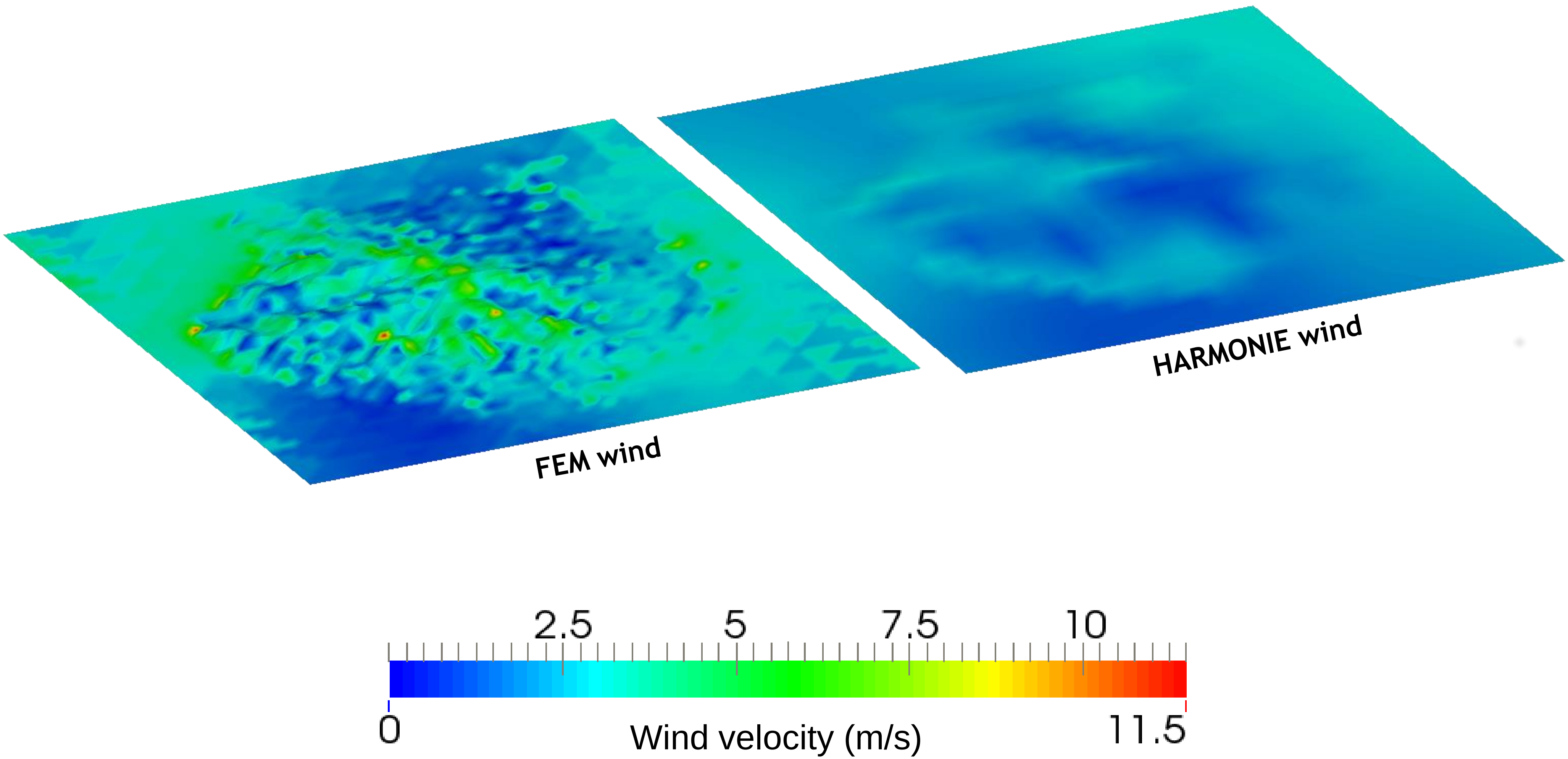


Optimal parameter values

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

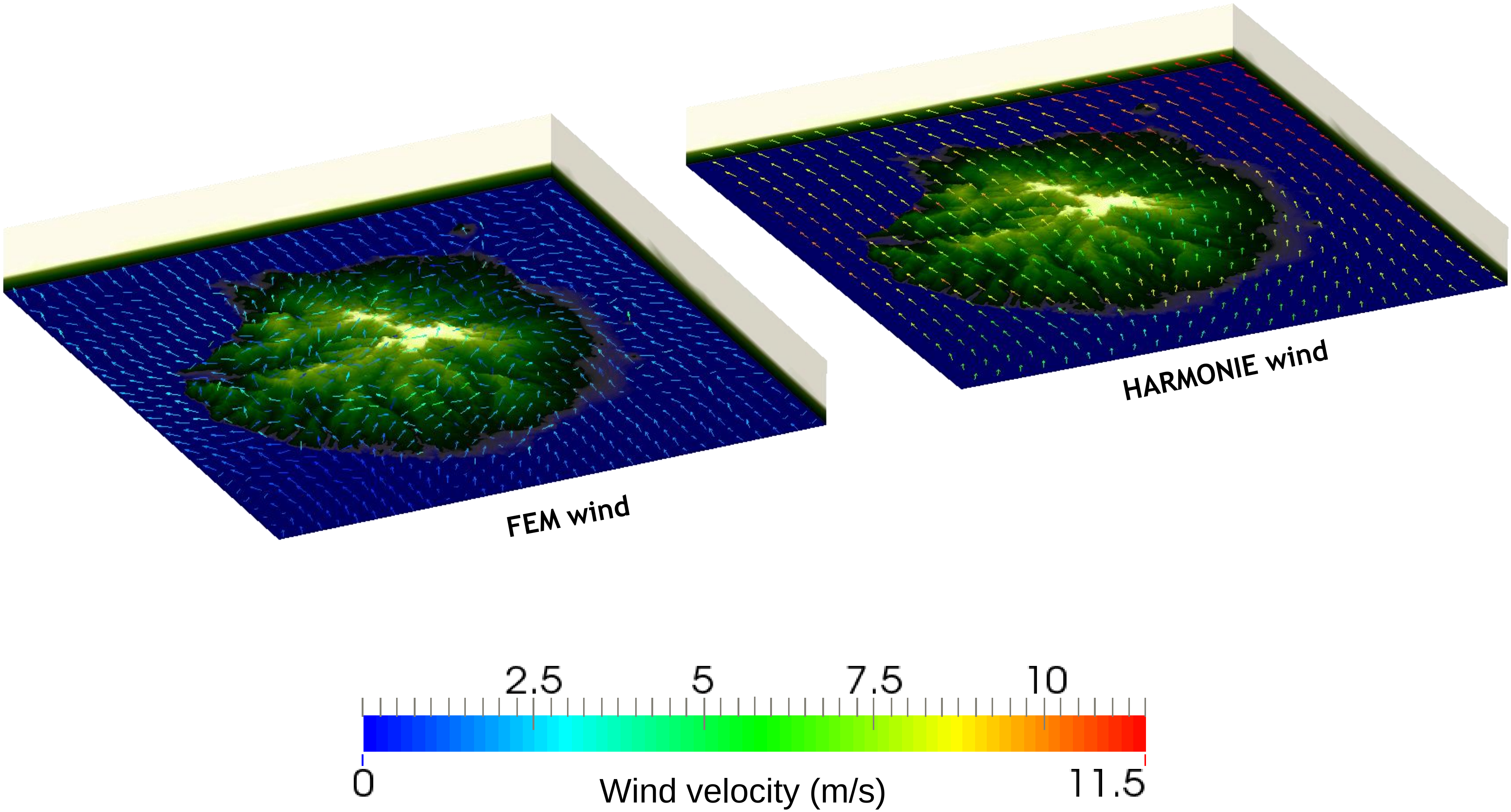
HARMONIE-FEM wind forecast

Wind magnitude at 10m over terrain



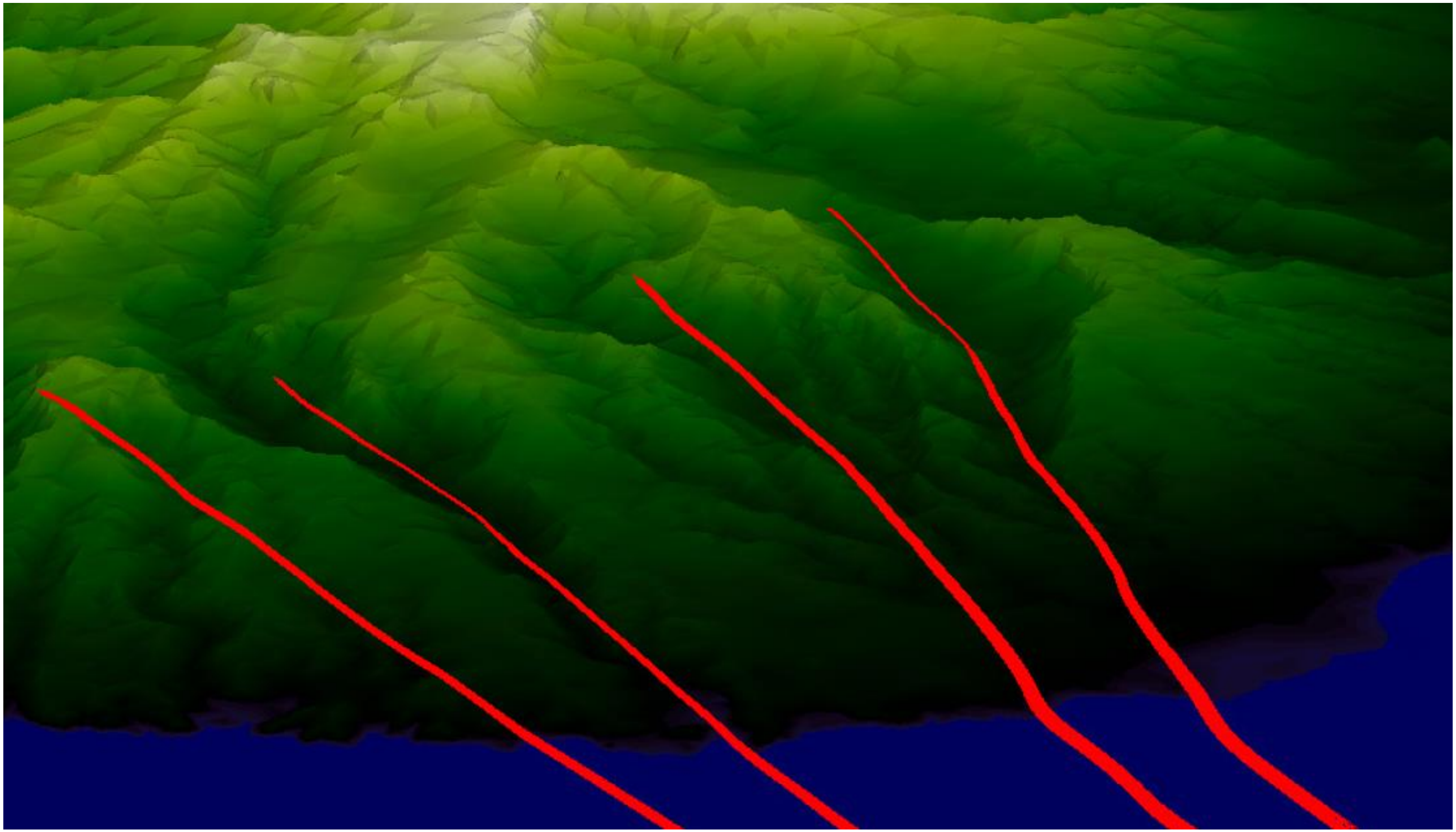
HARMONIE-FEM wind forecast

Wind field at 10m over terrain



HARMONIE-FEM wind forecast

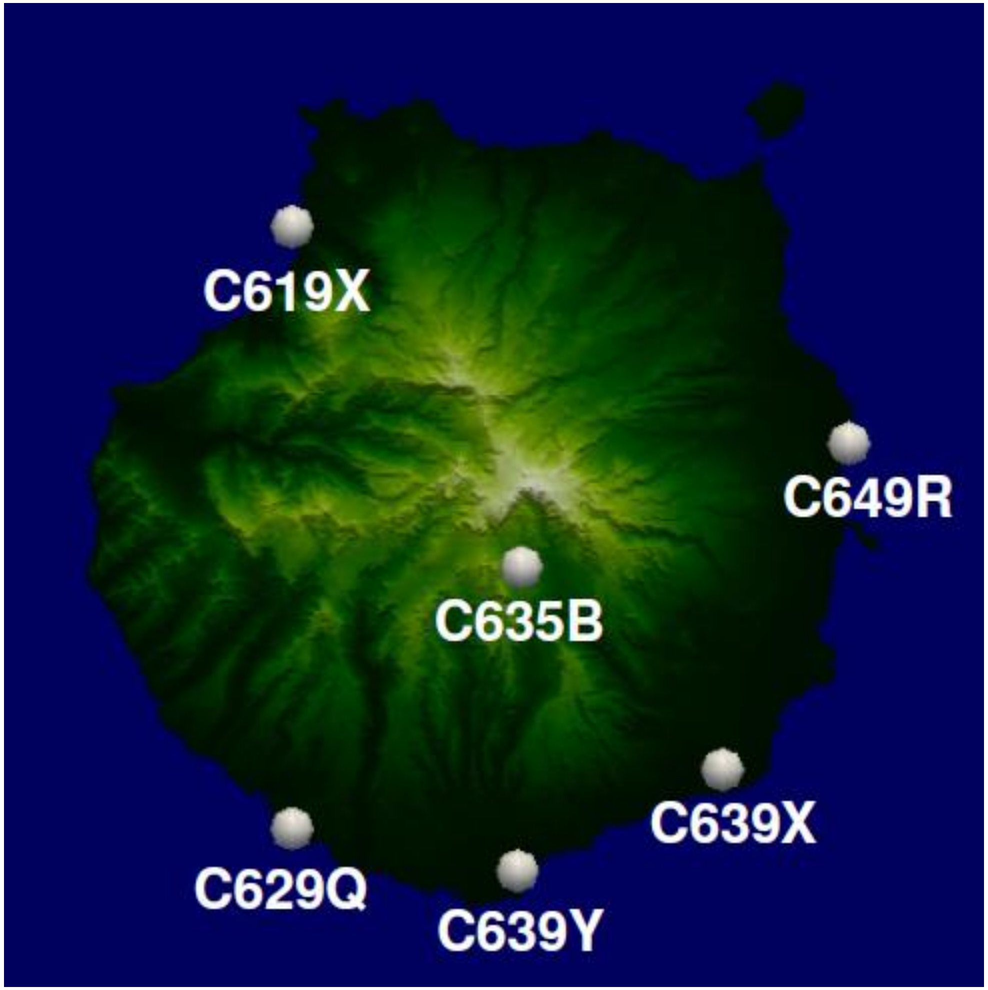
Wind field over terrain (detail of streamlines)



Zoom

HARMONIE-FEM wind forecast

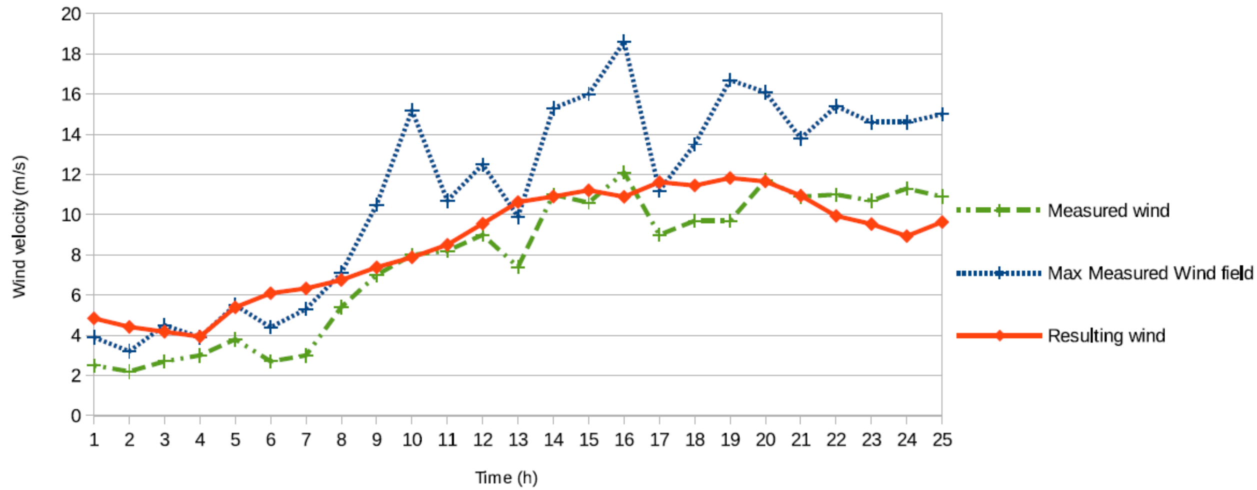
Forecast wind validation (location of measurement stations)



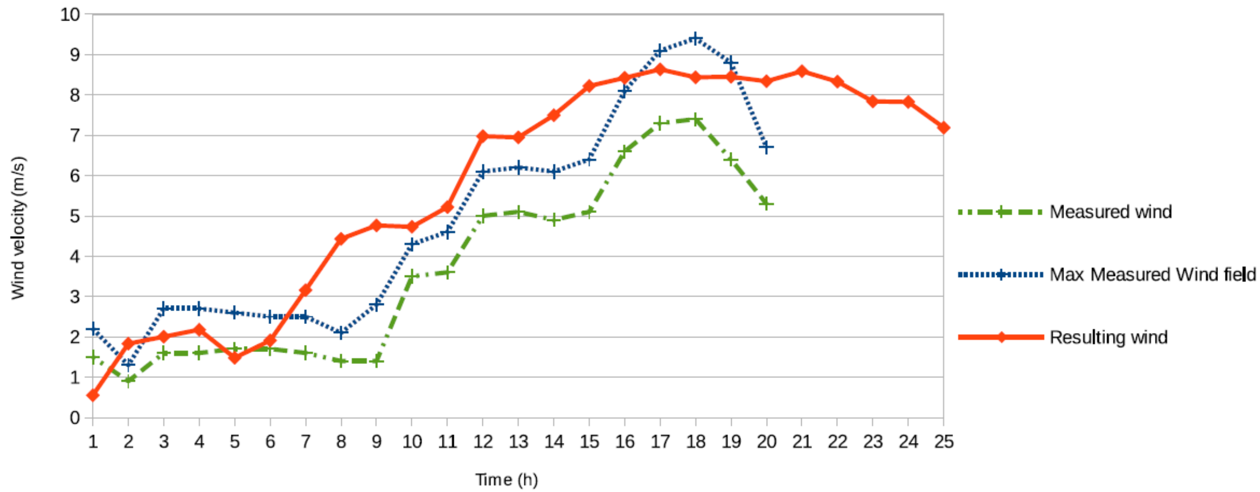
HARMONIE-FEM wind forecast

Forecast wind along a day

C619X measurement station



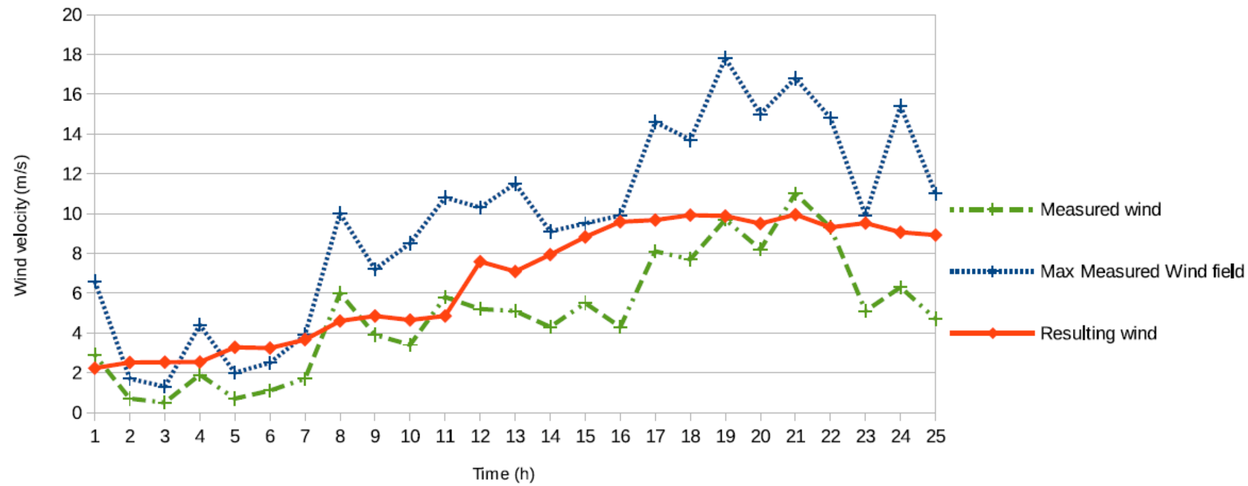
C629Q measurement station



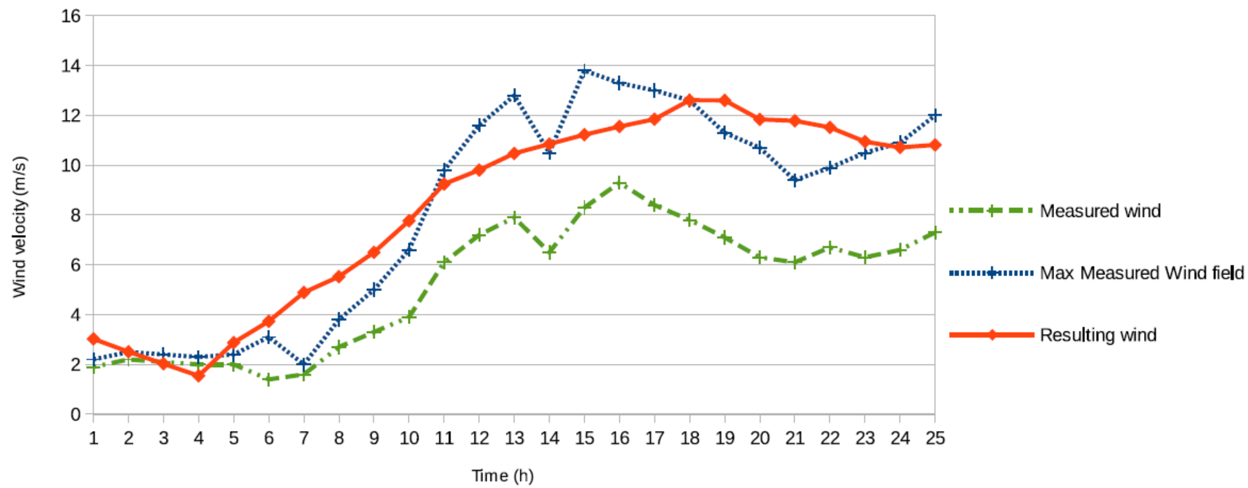
HARMONIE-FEM wind forecast

Forecast wind along a day

C635B measurement station



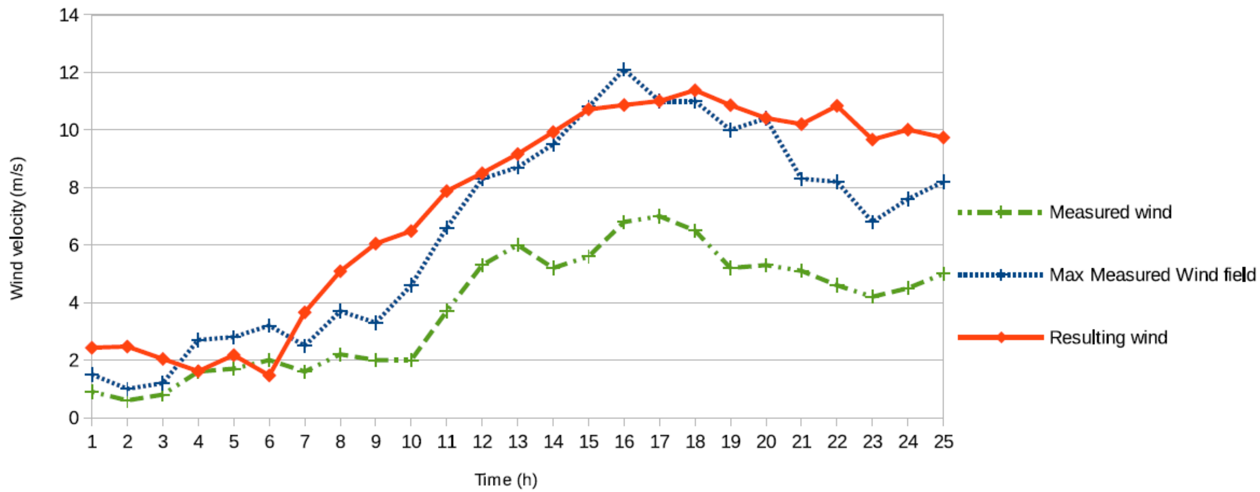
C639X measurement station



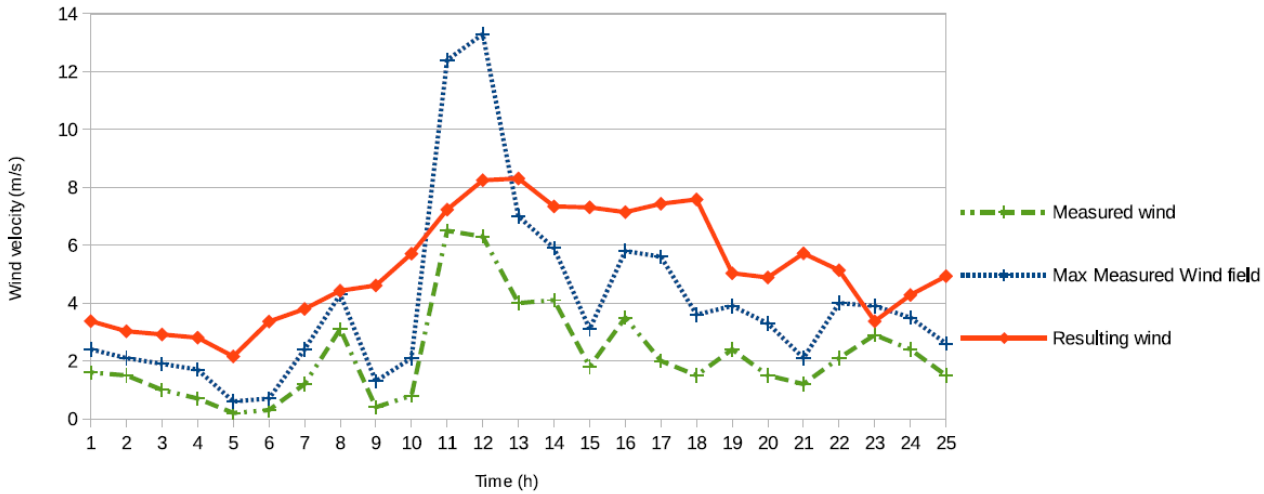
HARMONIE-FEM wind forecast

Forecast wind along a day

C639Y measurement station



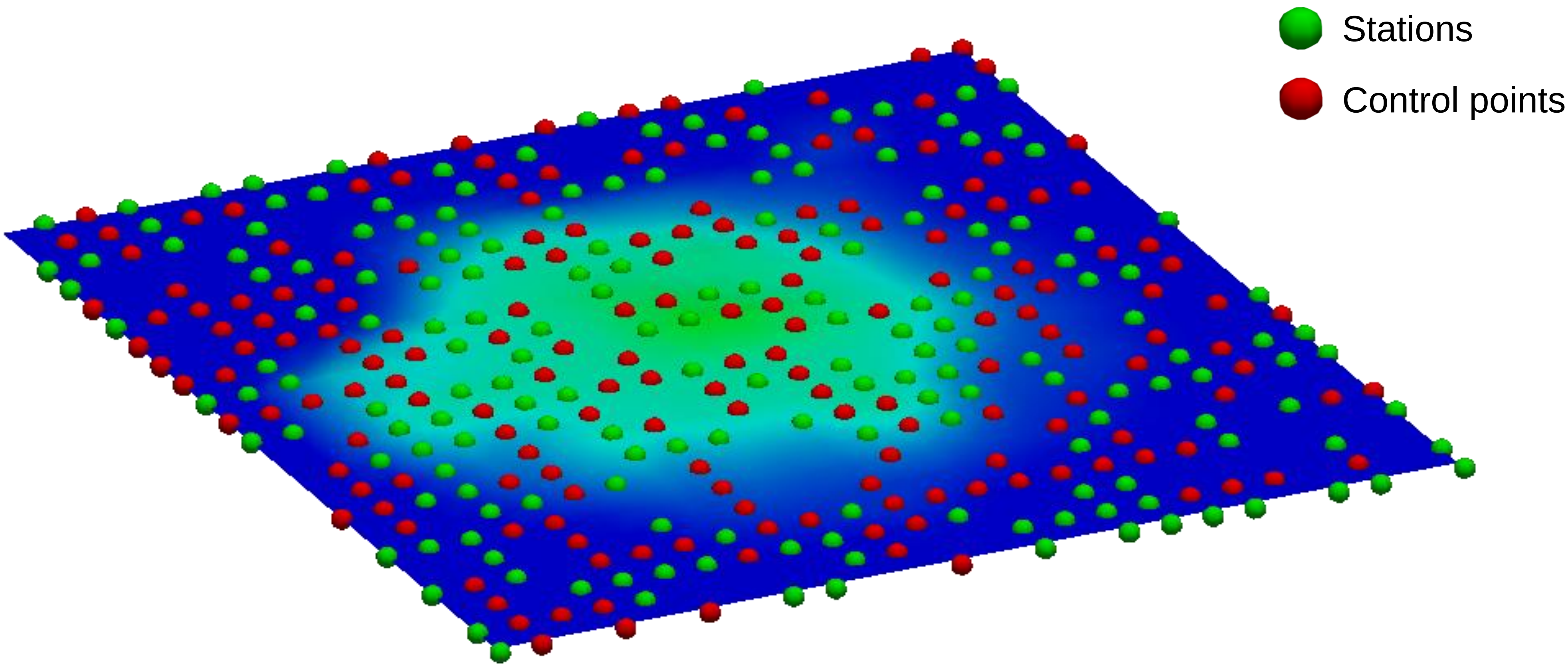
C649R measurement station



Ensemble method

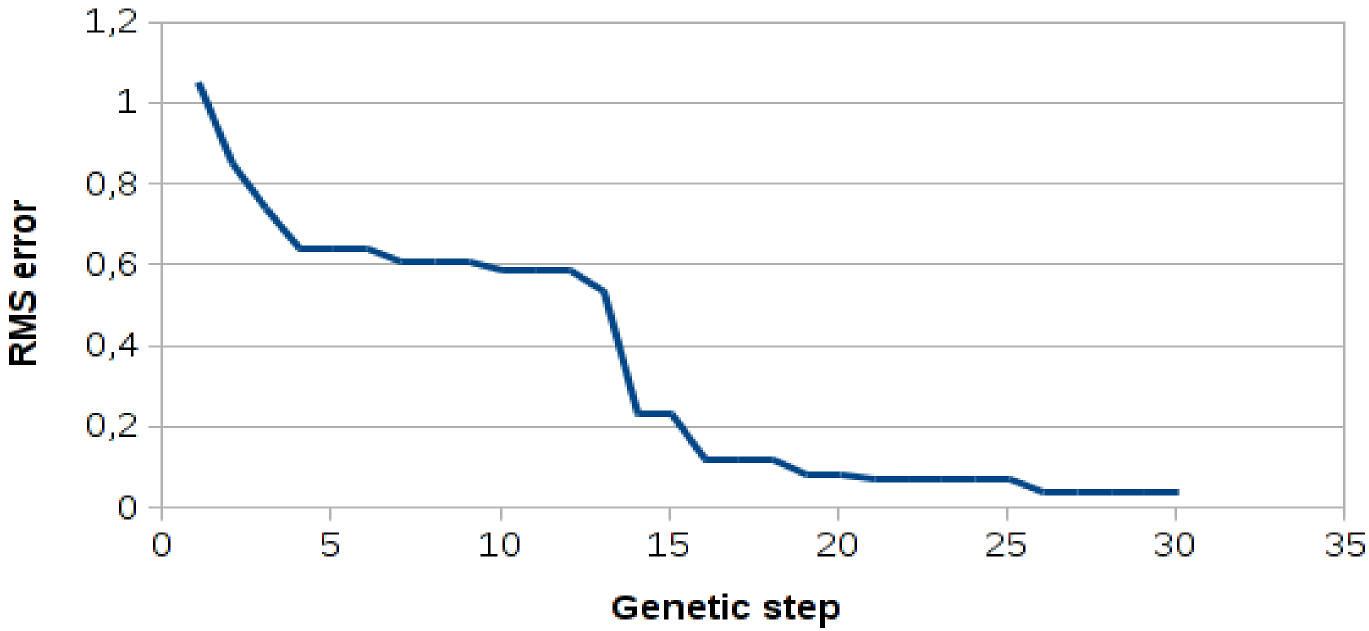
Ensemble methods

Stations election



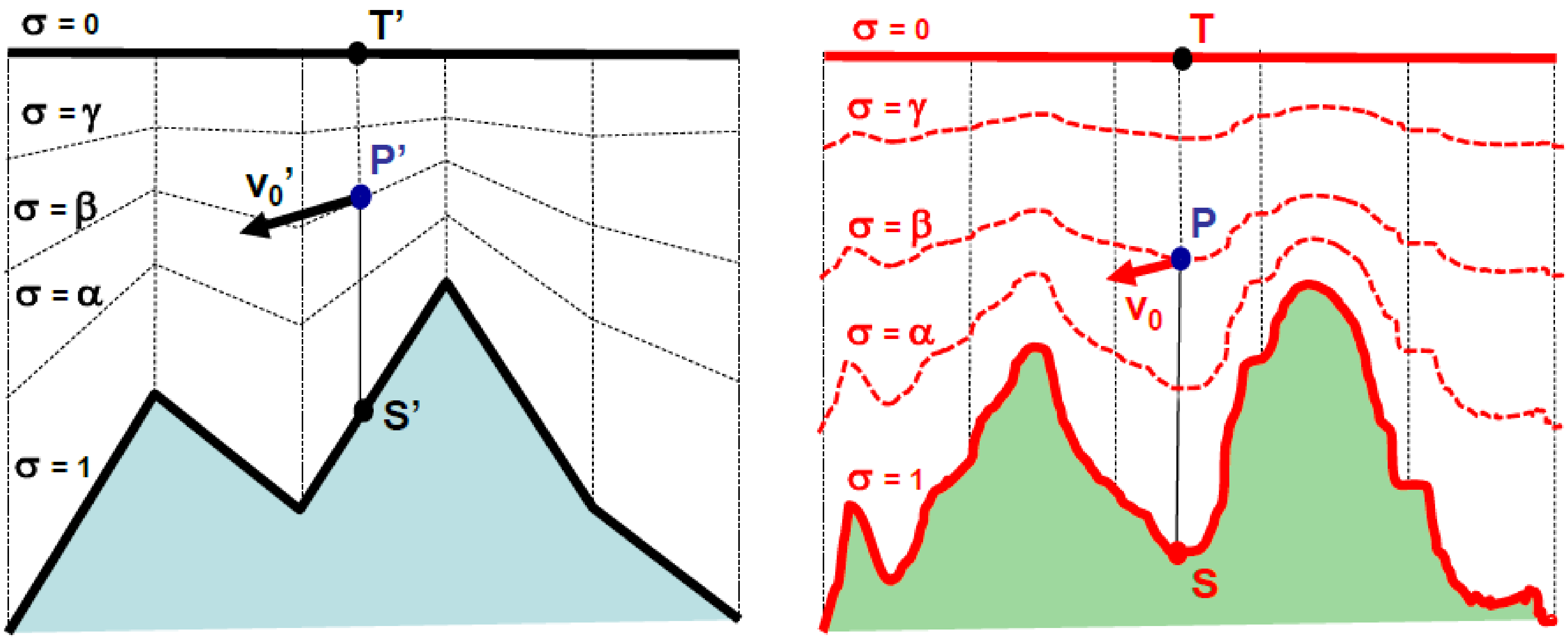
Stations (1/3) and control points (1/3)

Ensemble methods



New		**Previous**
Alpha = 2.057920		Alpha = 2.302731
Epsilon = 0.950898	Small changes	Epsilon = 0.938761
Gamma = 0.224911		Gamma = 0.279533
Gamma' = 0.311286		Gamma' = 0.432957

Ensemble methods



HARMONIE FD domain

FE domain

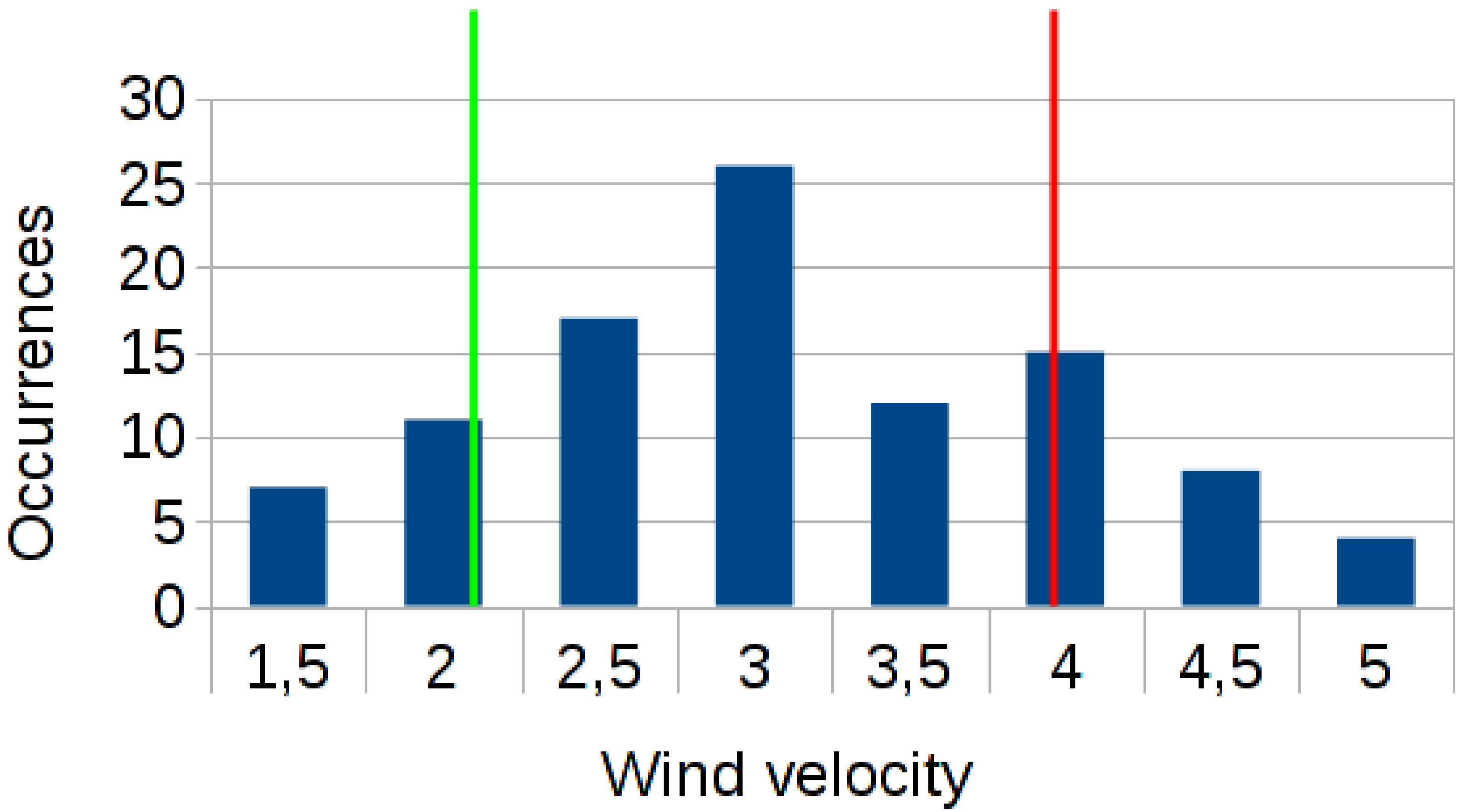
Possible solutions for a suitable data interpolation in the FE domain:

- Given a point of FE domain, find the closest one in HARMONIE domain grid
- Other possibilities can be considered

Ensemble method proposal

- Perturbation
  - Calibrated parameters
  - HARMONIE forecast velocity
- Models
  - Log-linear interpolation
  - HARMONIE-FEM interpolation

Ensemble methods



Conclusions

- Necessity of a terrain adapted mesh
- Local wind field in conjunction with HARMONIE is valid to predict wind velocities
- Ensemble methods provide a promising framework to deal with uncertainties

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Thank you for your attention