



SIANI
INSTITUTO UNIVERSITARIO
INGENIERIA COMPUTACIONAL

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

A. Oliver, E. Rodríguez, R. Montenegro, G. Montero

CMN - 2015

June 29 – July 2, 2015, Lisbon, Portugal

MINECO

PROGRAMA ESTATAL DE I+D+I ORIENTADA A LOS RETOS DE LA SOCIEDAD

Project: CTM2014-55014-C3-1-R

Contents

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



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

A diagnostic wind model

Governing equations



$$\Omega \subset \mathbf{R}^3$$

$$\Gamma = \Gamma_a \cup \Gamma_b$$

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

Objective:

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

- Incompressibility condition in the domain $\vec{\nabla} \cdot \vec{u} = 0$ in Ω
- Non flow-through condition on the terrain $\vec{n} \cdot \vec{u} = 0$ on Γ_b

Let state the least square problem:

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

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

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 $T = (T_h, T_h, T_v)$ $T_h = \frac{1}{2\alpha_1^2}$, $T_v = \frac{1}{2\alpha_2^2}$

it yields the governing equations,

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

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

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

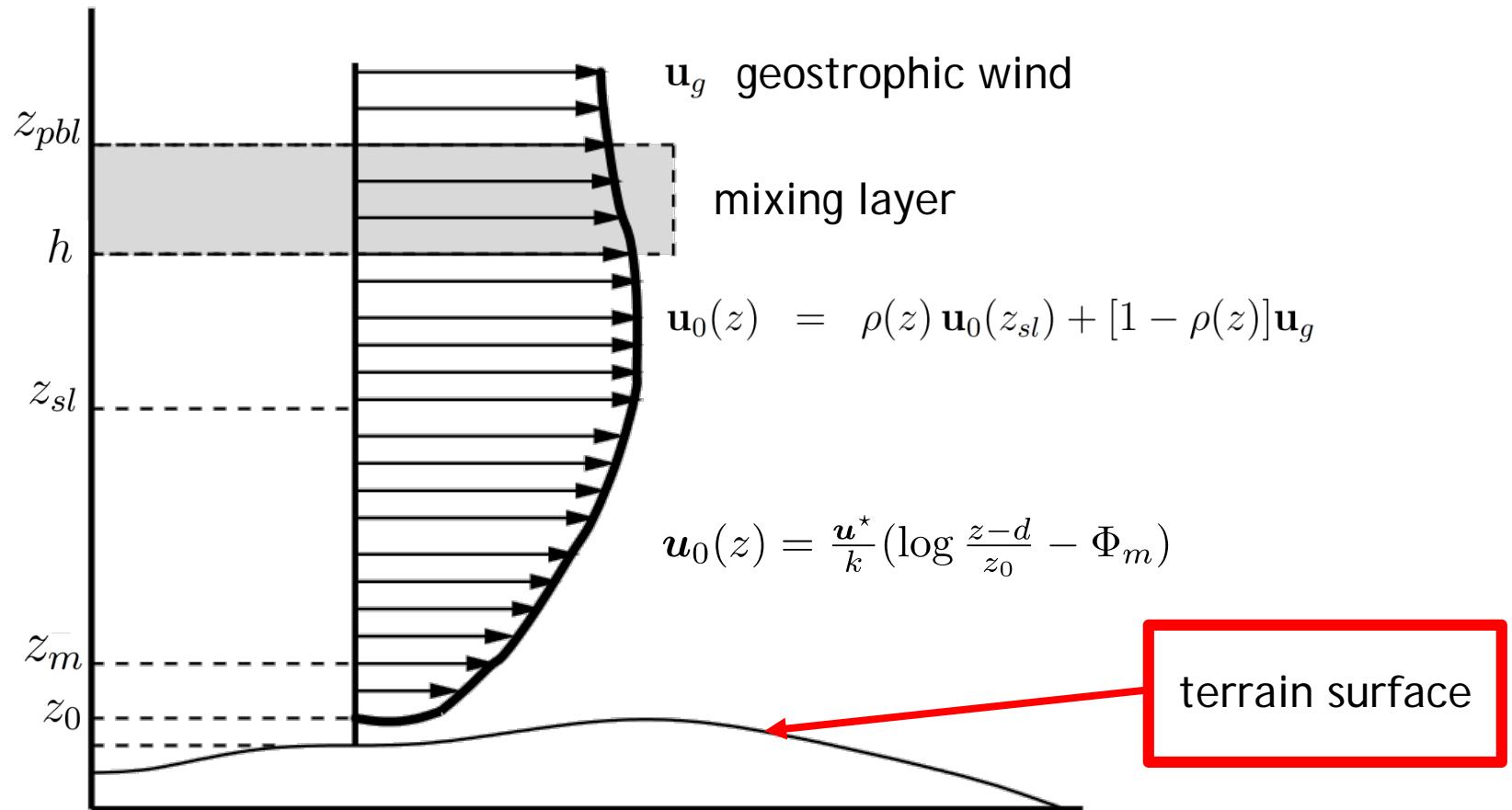
Horizontal interpolation

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



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

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:**

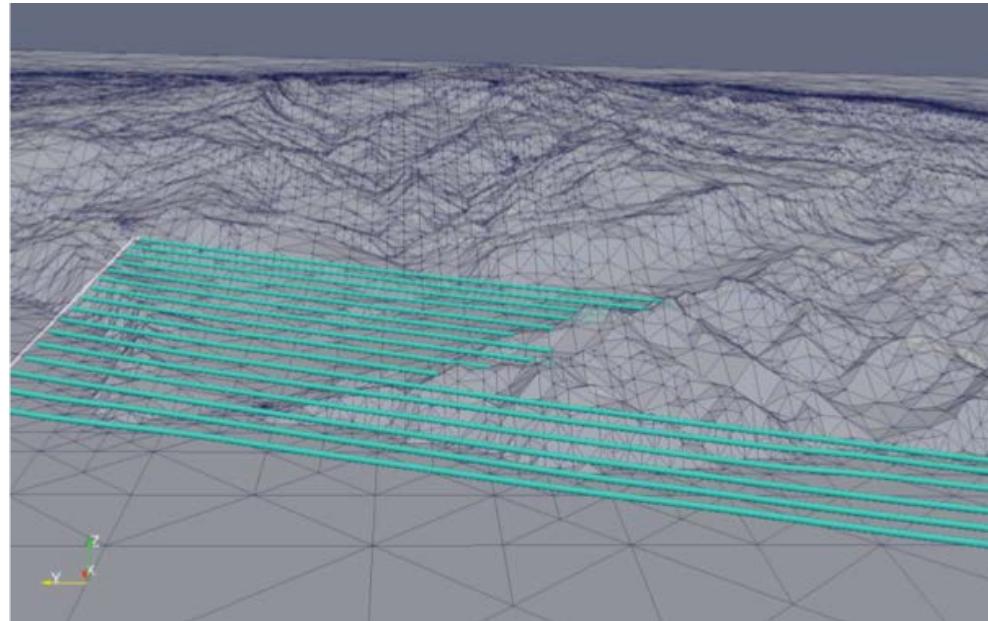
$$h = z_{pbl} \quad \text{in neutral and unstable conditions}$$

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

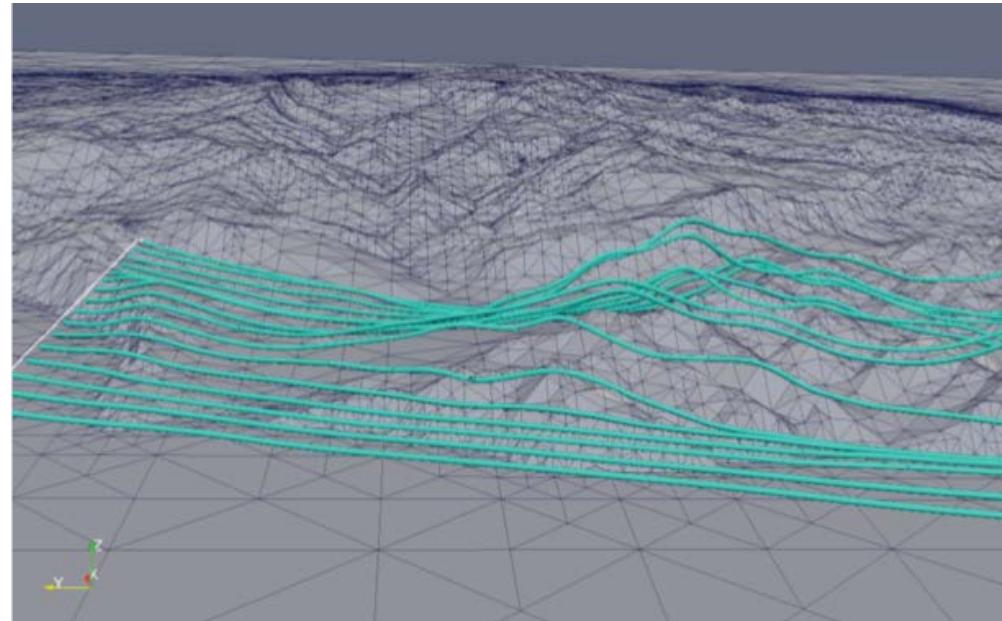
- **Height of the surface layer:** $z_{sl} = \frac{h}{10}$

Mass Consistent Wind Model

Interpolated and resulting wind fields



Interpolated wind field



Resulting wind field

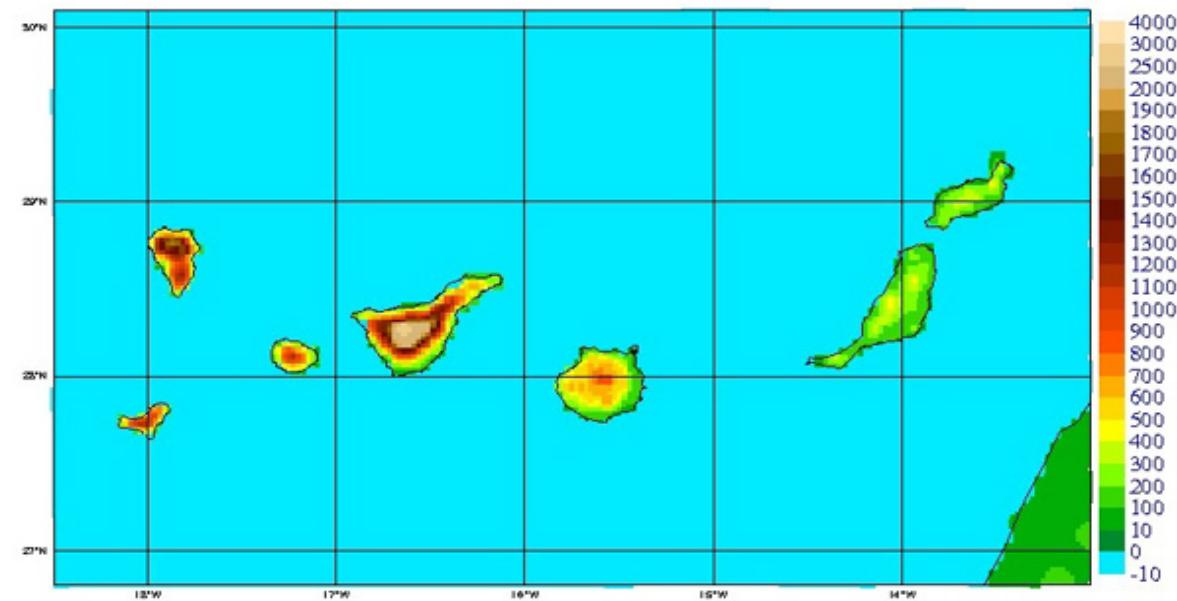
HARMONIE-FEM Wind Forecast

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

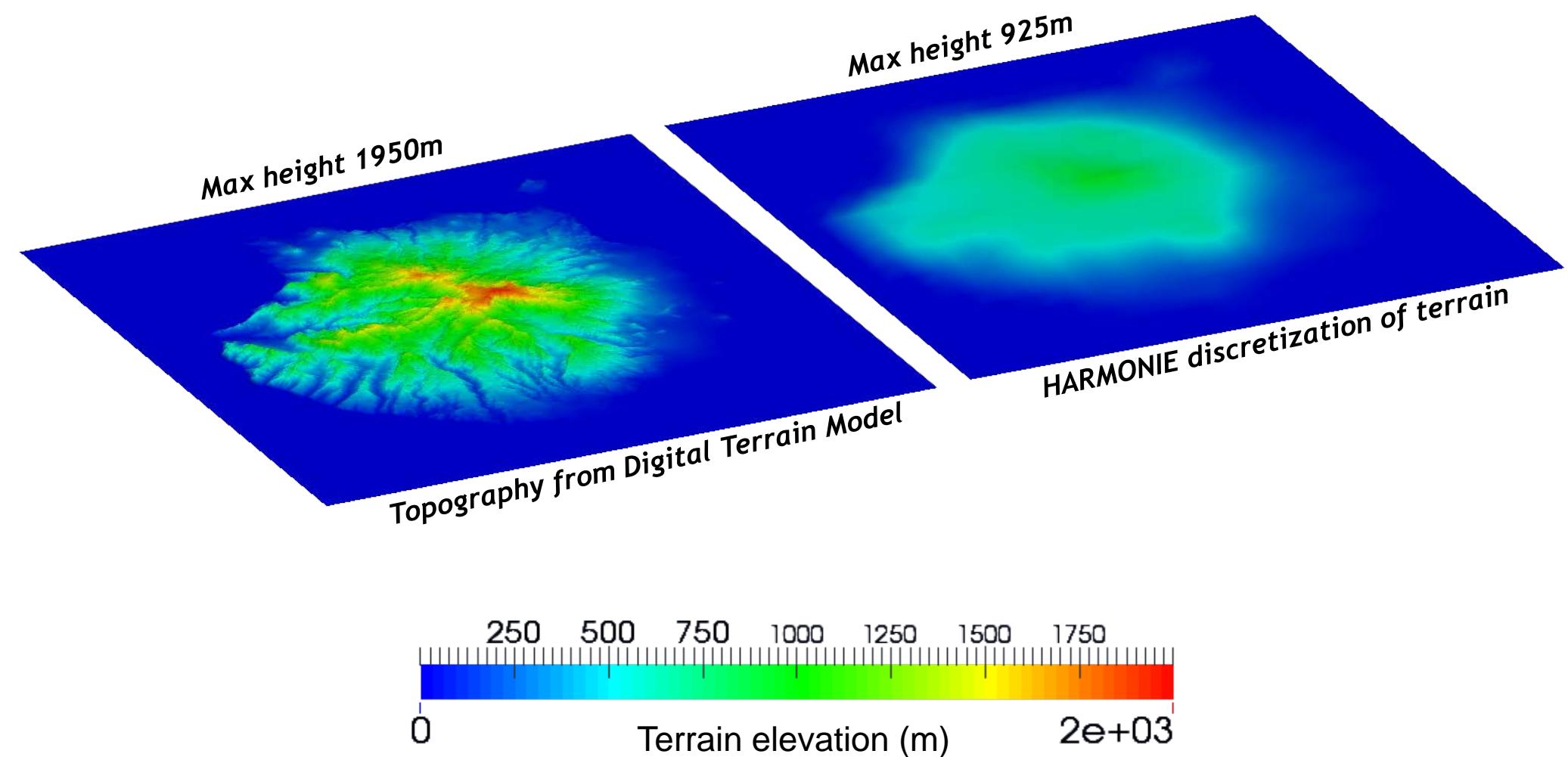
- 24 hours simulation data



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

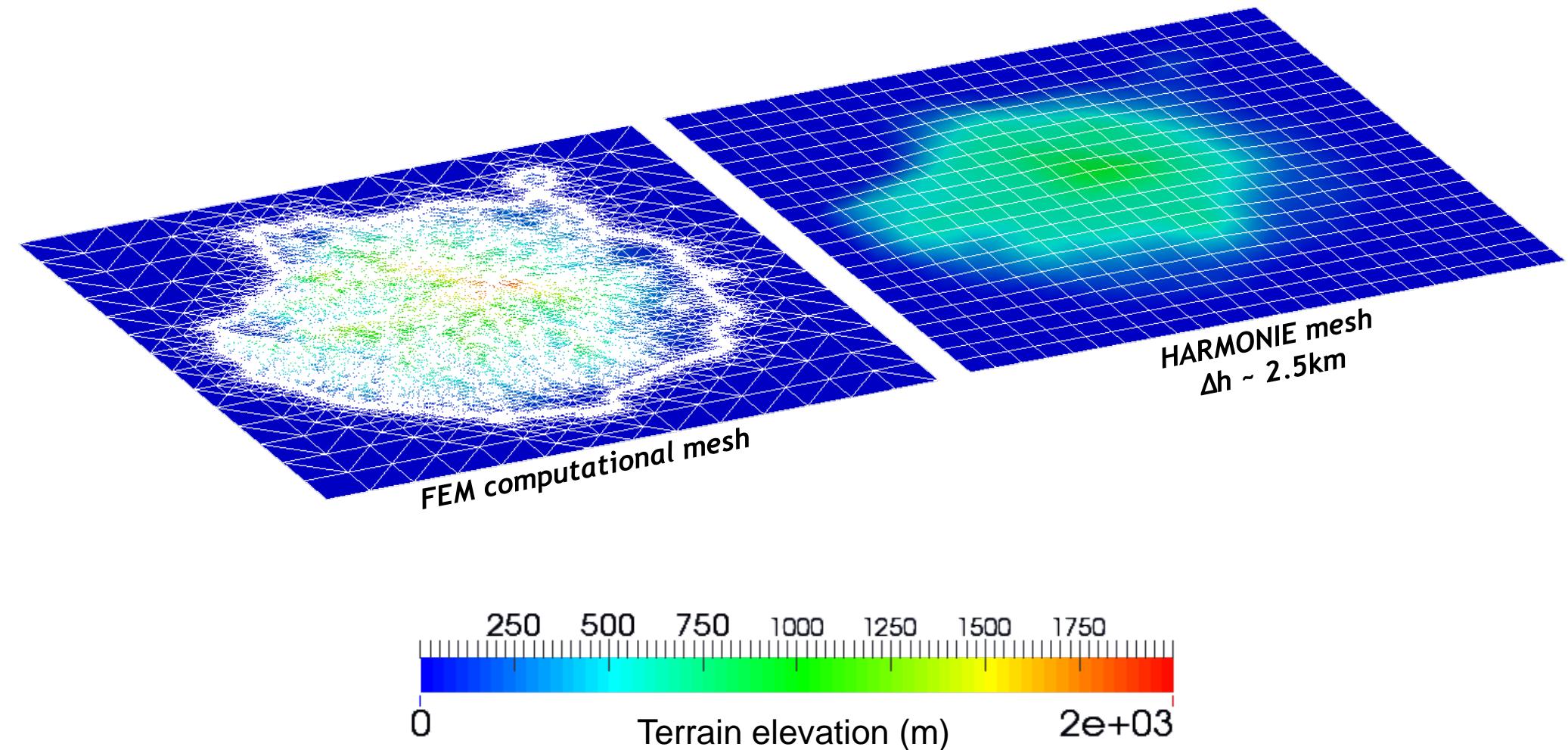
HARMONIE-FEM wind forecast

Terrain approximation



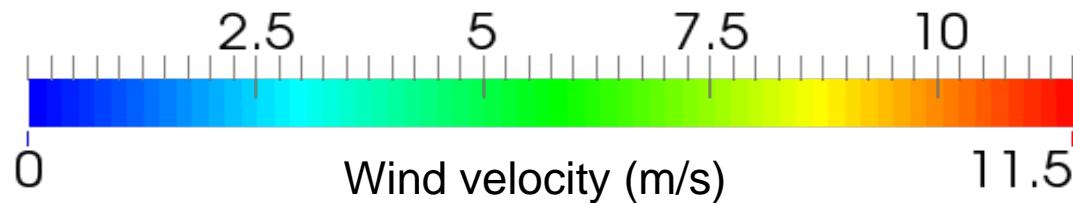
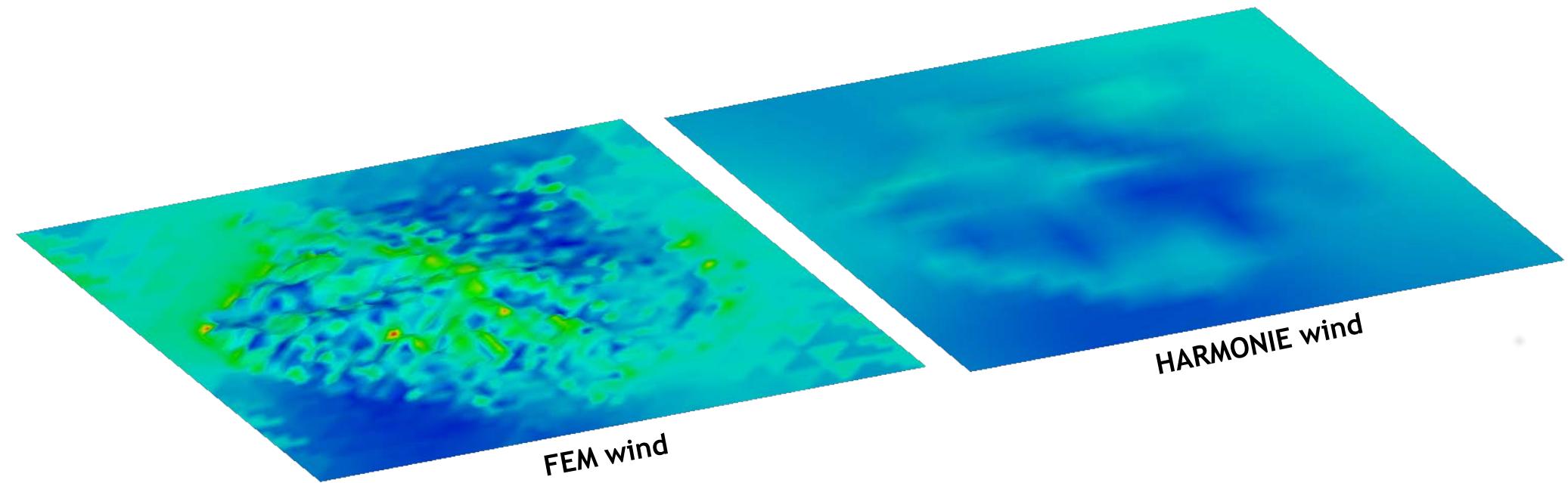
HARMONIE-FEM wind forecast

Spatial discretization



HARMONIE-FEM wind forecast

Wind magnitude at 10m over terrain

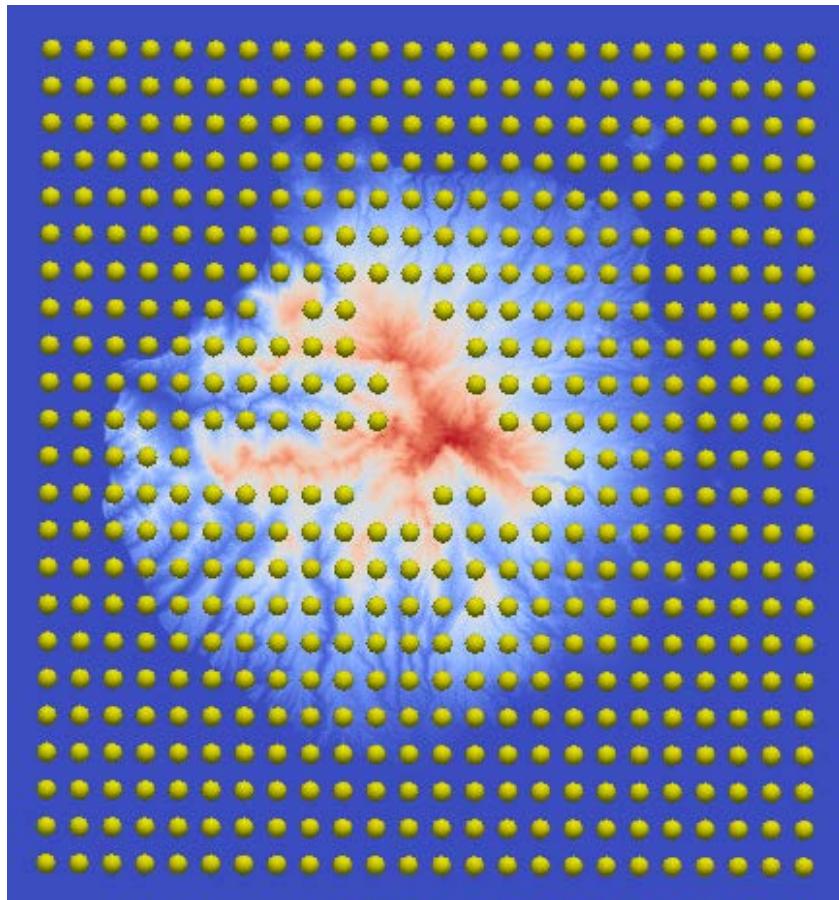


HARMONIE-FEM wind forecast

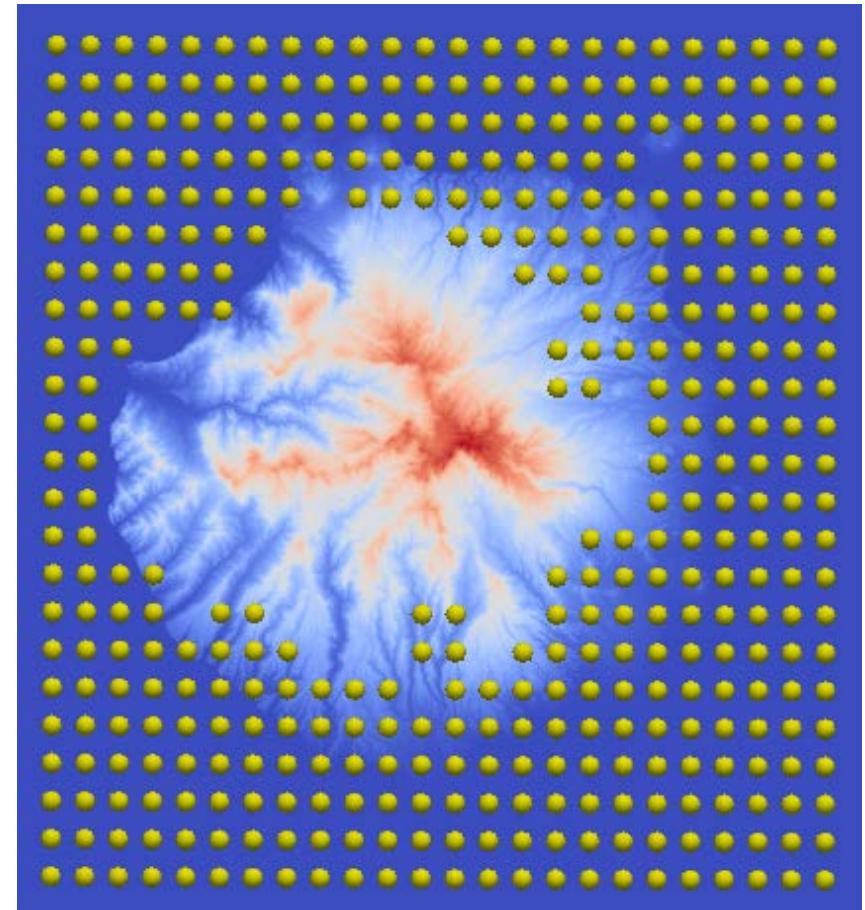
HARMONIE data



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



Used data ($\Delta h < 500m$)



Used data ($\Delta h < 100m$)

Terrain data

GIS image



lat: 28°03'16,60" N lon: 15°06'32,21" O
x: 489.293,38 y: 3.103.256,69 z: sin datos

A 3D perspective view of the island of La Palma, showing a detailed terrain model with various colors representing different land cover types. The colors range from brown and grey to green, red, and yellow, indicating different soil types, vegetation, and geological features. The model is set against a black background.

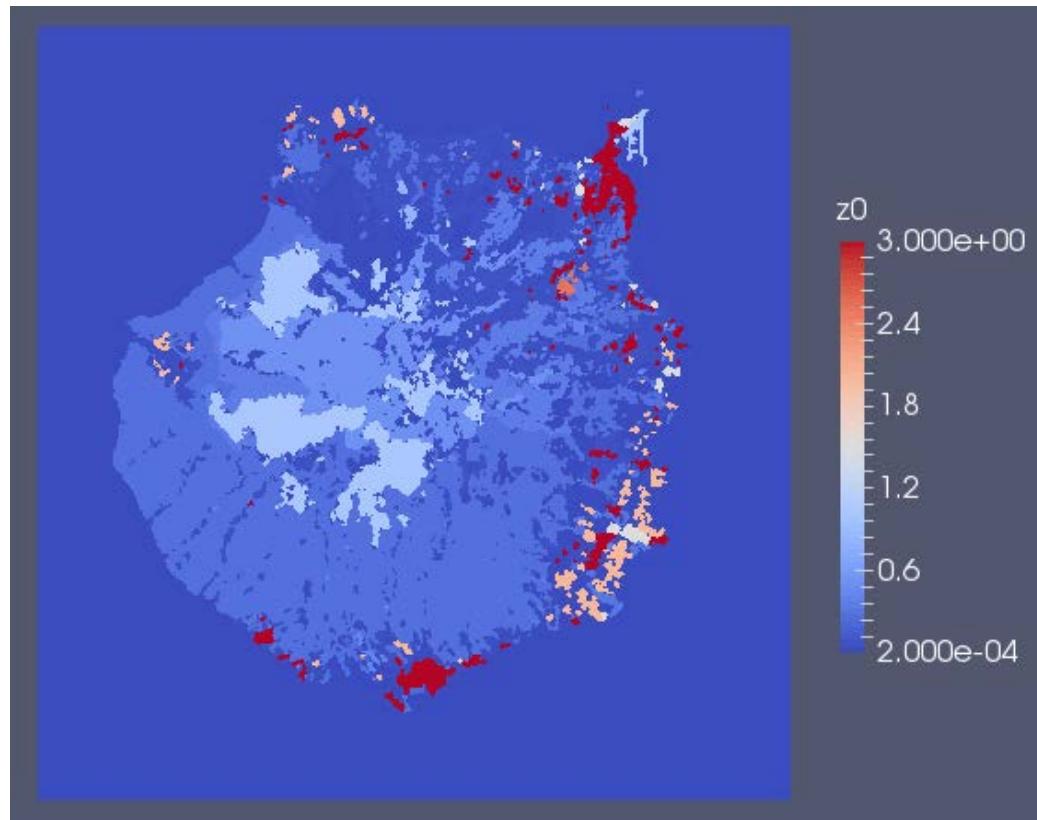
Contenido Búsqueda Leyenda KML

25 años GRAFCÁN >

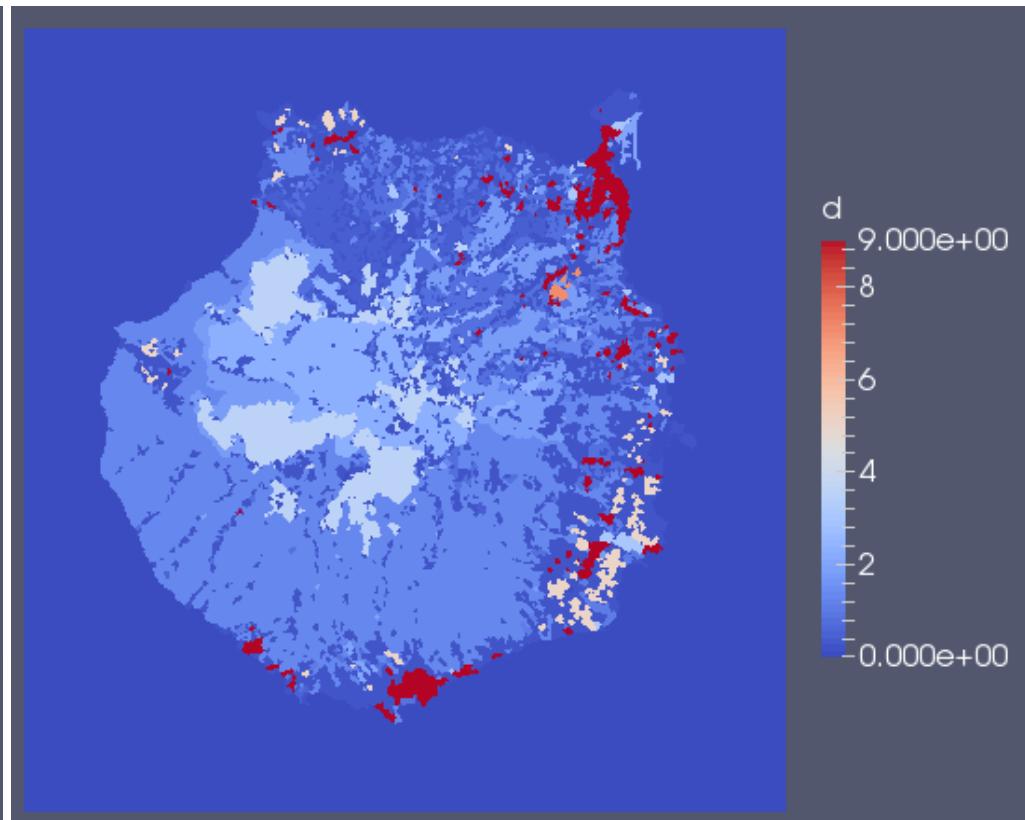
- Modelo digital de Elevaciones
- Modelo digital de Pendientes
- Batimetría [IEO](#)
- Cartografía Estadística (ISTAC)
- Rescate de Toponimia de La Palma
- TURISMO Y EQUIPAMIENTOS
- RED GEODÉSICA
- CARACTERIZACIÓN DEL SUELO
 - Mapa de Ocupación de Suelo
 - Mapa de Ocupación de Suelo
 - OrtoExpress
 - Sistema de Información sobre Ocupación del Suelo (SIOSE)
 - Mapa de Vegetación
 - Mapa Geológico
 - Mapa Geotécnico
 - Ecocartográfico
 - Mapa Forestal 1:50.000
 - Inventario Nacional de Erosión de Suelos (año 2006)
- ORDENACIÓN DEL TERRITORIO
- ÁREAS PROTEGIDAS
- AGRICULTURA Y GANADERÍA
- ENERGÍA
- INDUSTRIA
- EDUCACIÓN
- CALIDAD AMBIENTAL

Google Escala aprox. 1:500.000 10 km Términos de uso

Roughness length(z_0)

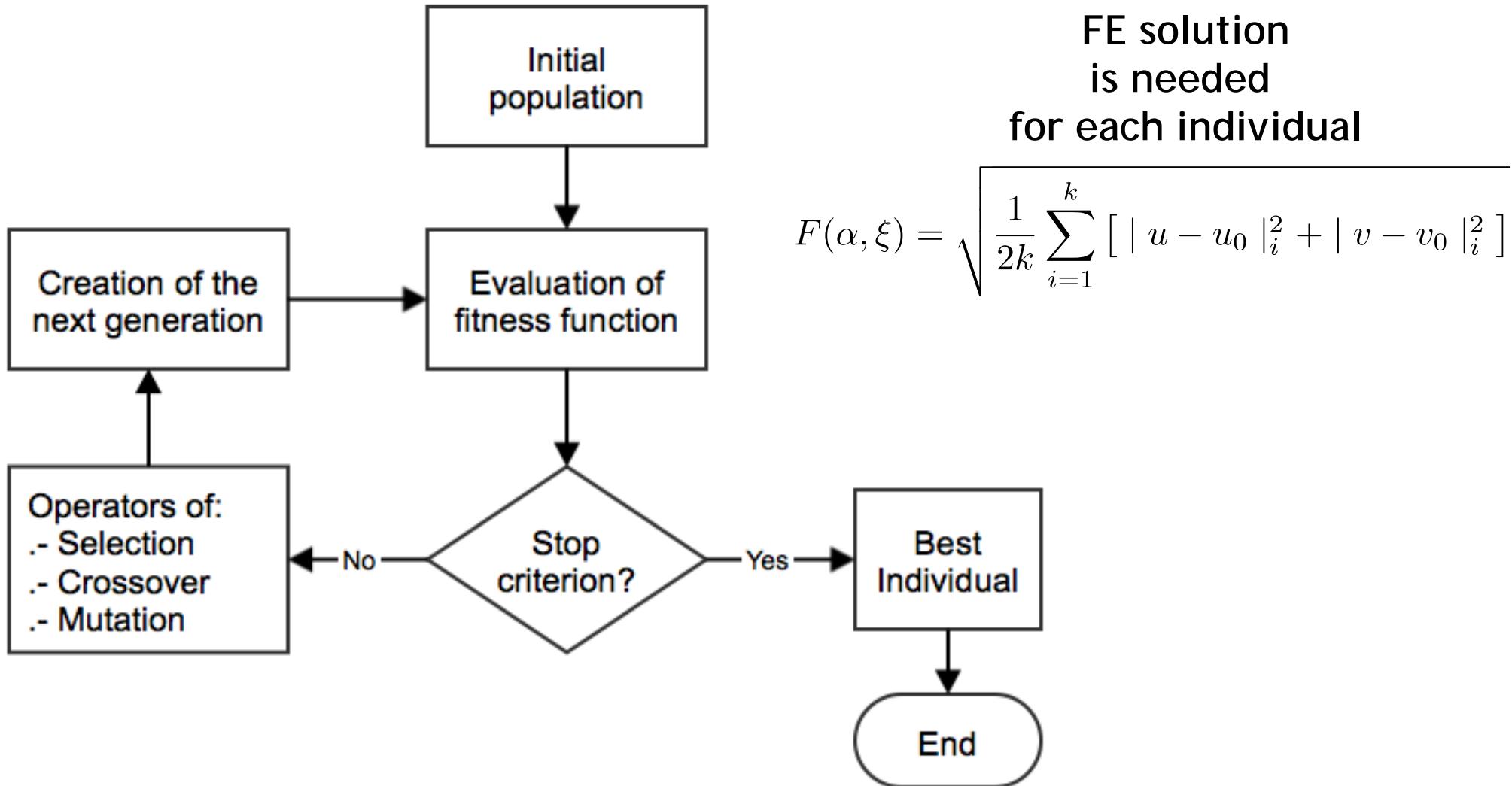


Obstacles height(d)



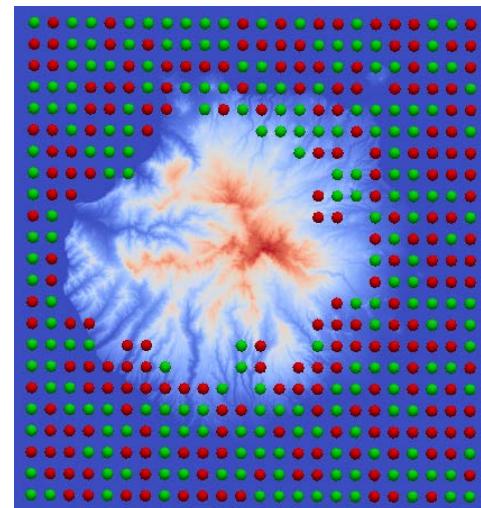
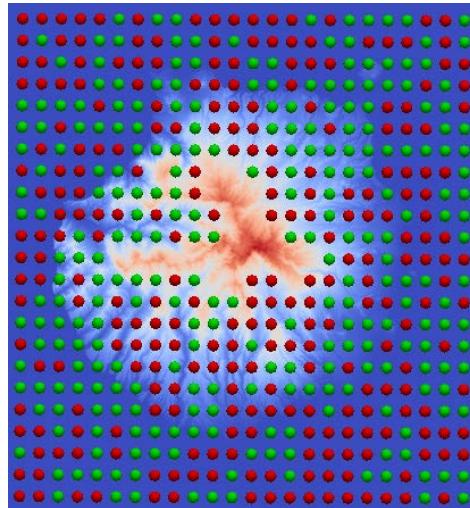
Estimation of Model Parameters

Genetic Algorithm



Ensemble methods

Stations election



- 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

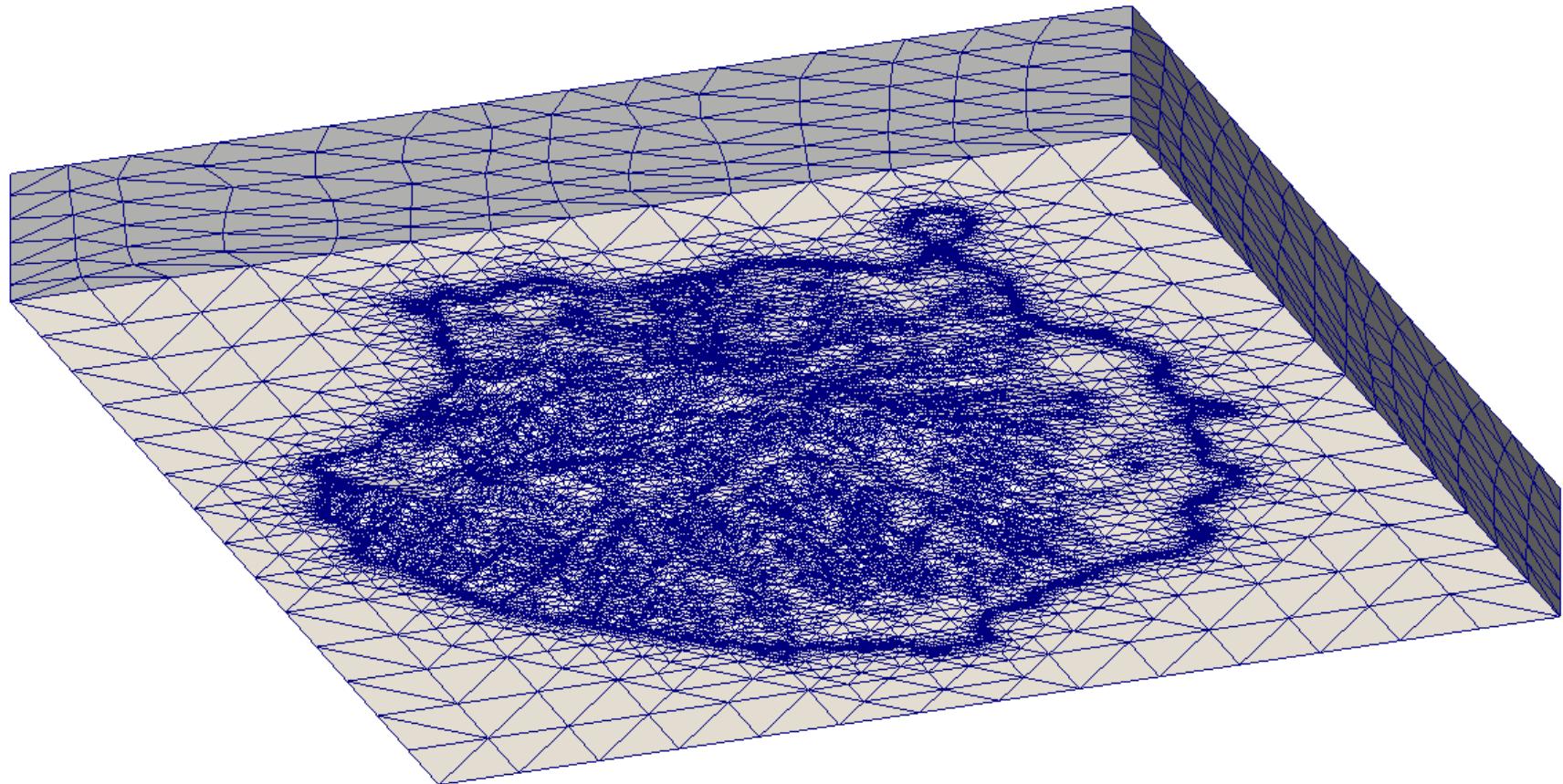
Mass Consistent Wind Model

Problem description



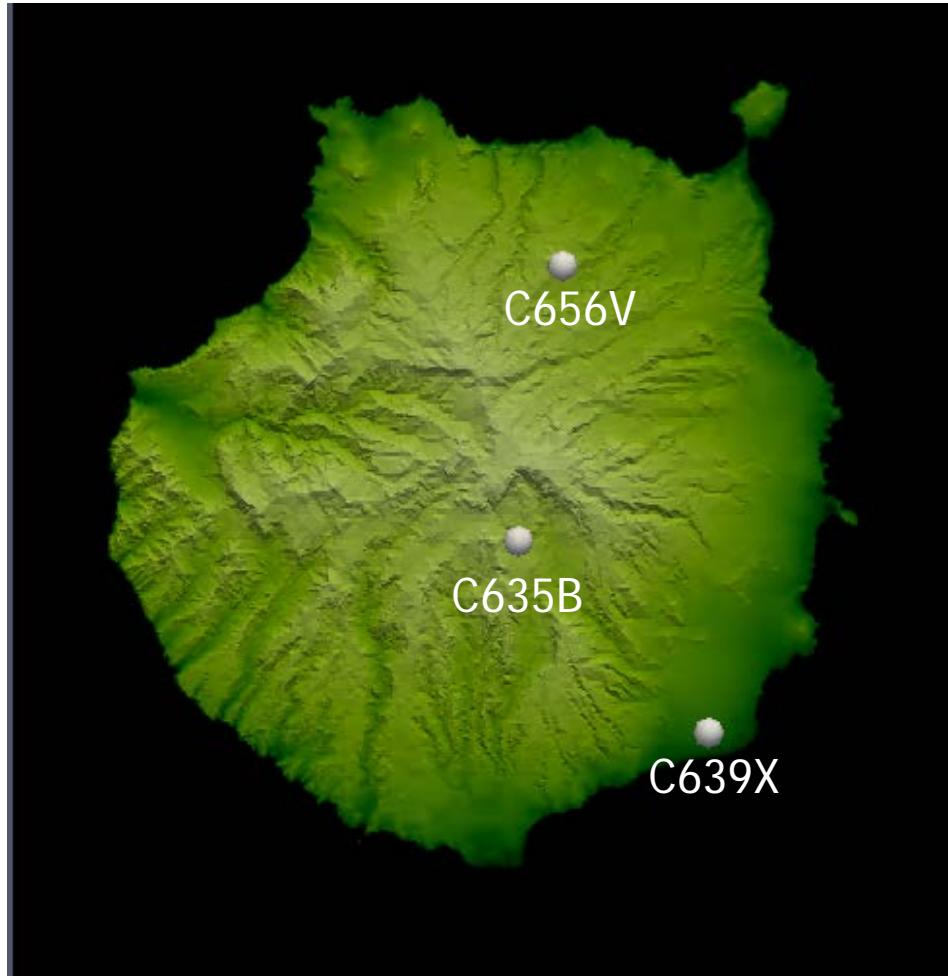
Domain: Gran Canaria Island (60 Km x 60 Km)

Mesh: 84325 nodes, 437261 tetrahedra



HARMONIE-FEM wind forecast

Location of measurement stations

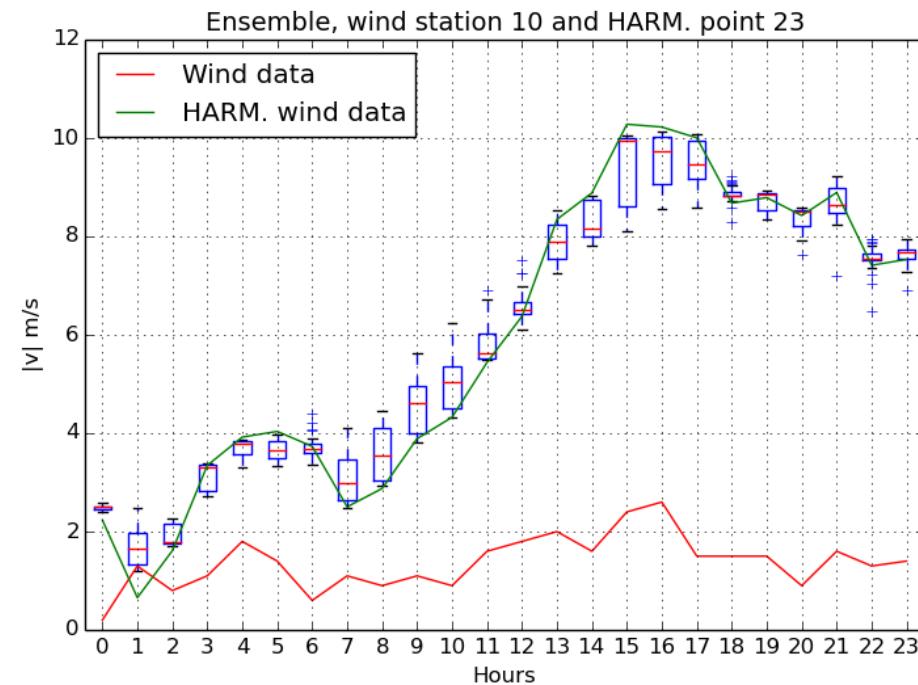


Ensemble methods

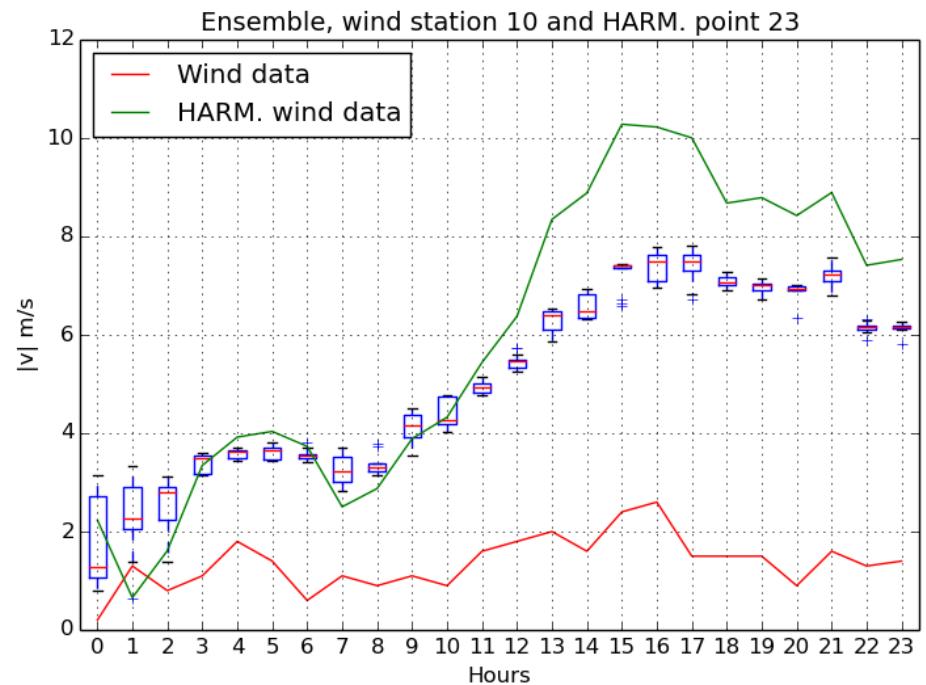
Ensemble forecast wind along a day



$$d = 0, z_0 = 0.0025$$



d and z_0 obtained from GIS

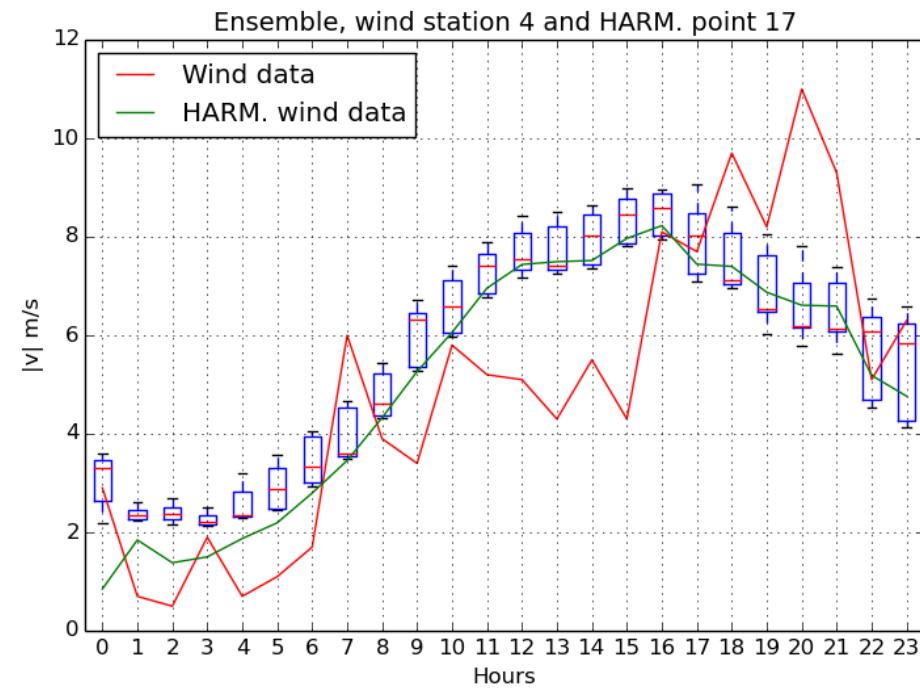


Ensemble methods

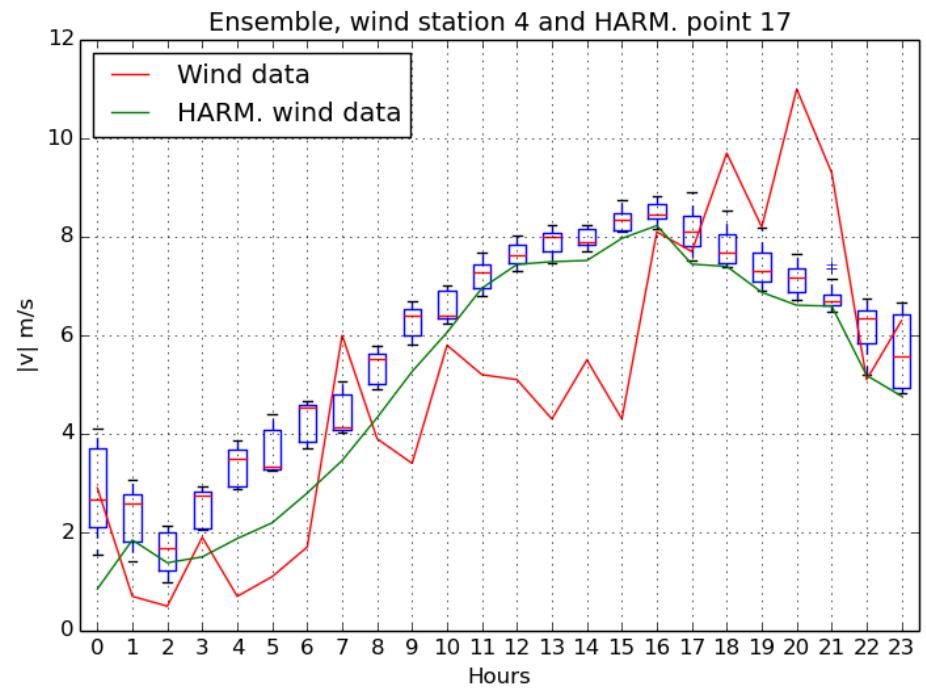
Ensemble forecast wind along a day



$$d = 0, z_0 = 0.0025$$



d and z_0 obtained from GIS

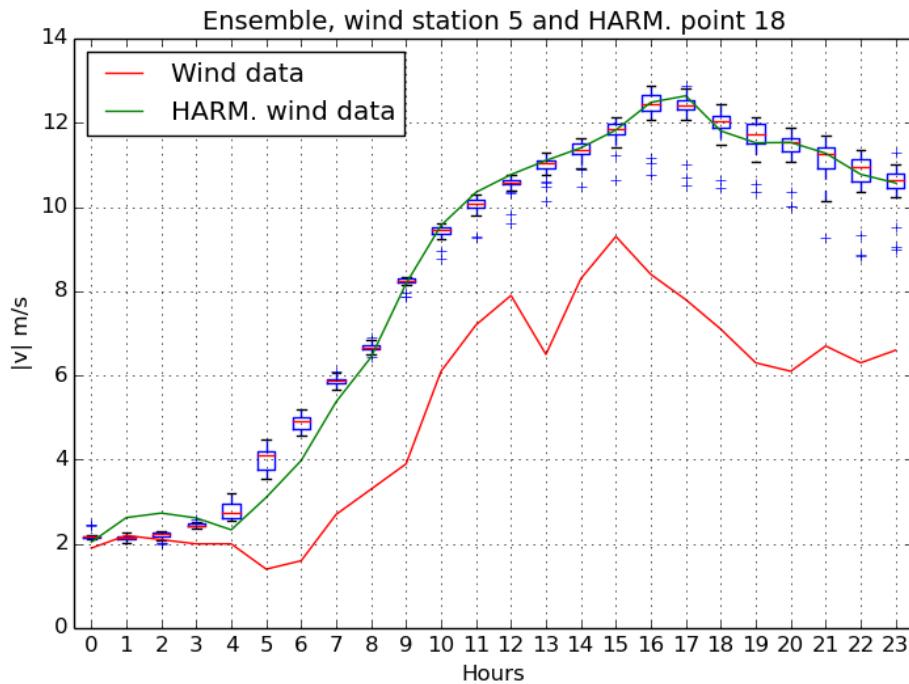


Ensemble methods

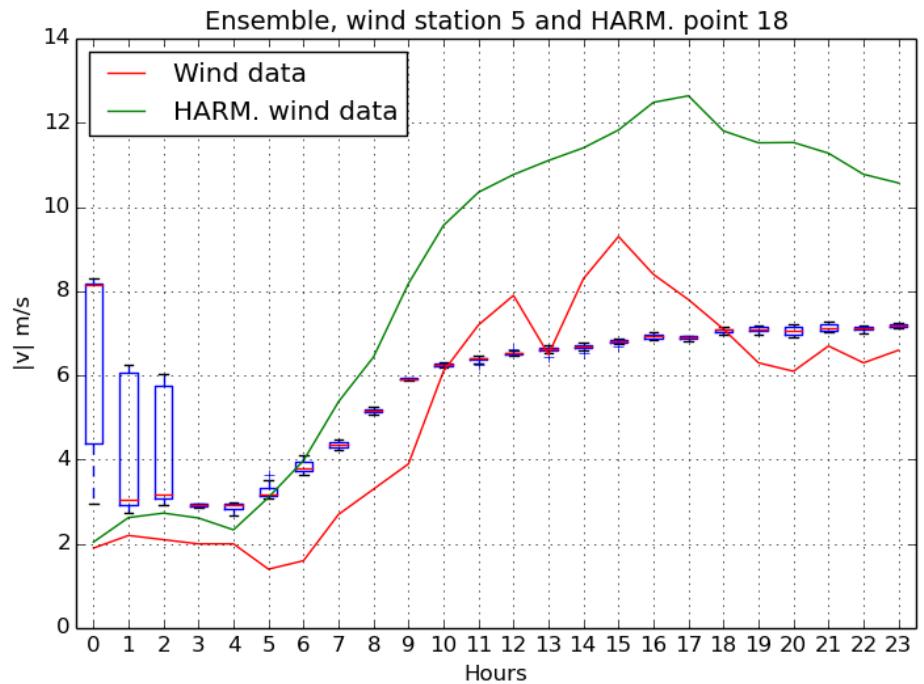
Ensemble forecast wind along a day



$$d = 0, z_0 = 0.0025$$



d and z_0 obtained from GIS

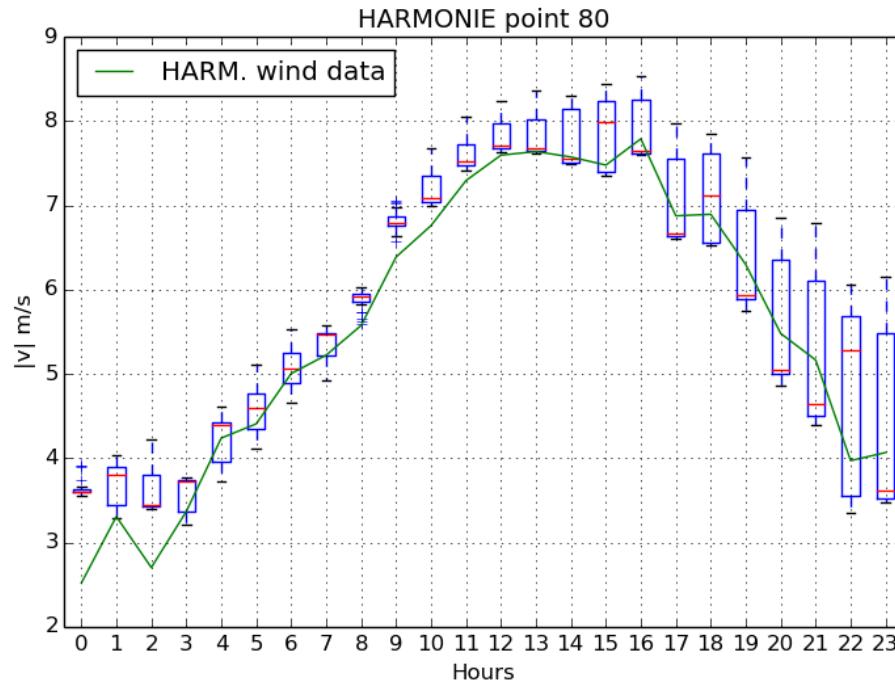


Ensemble methods

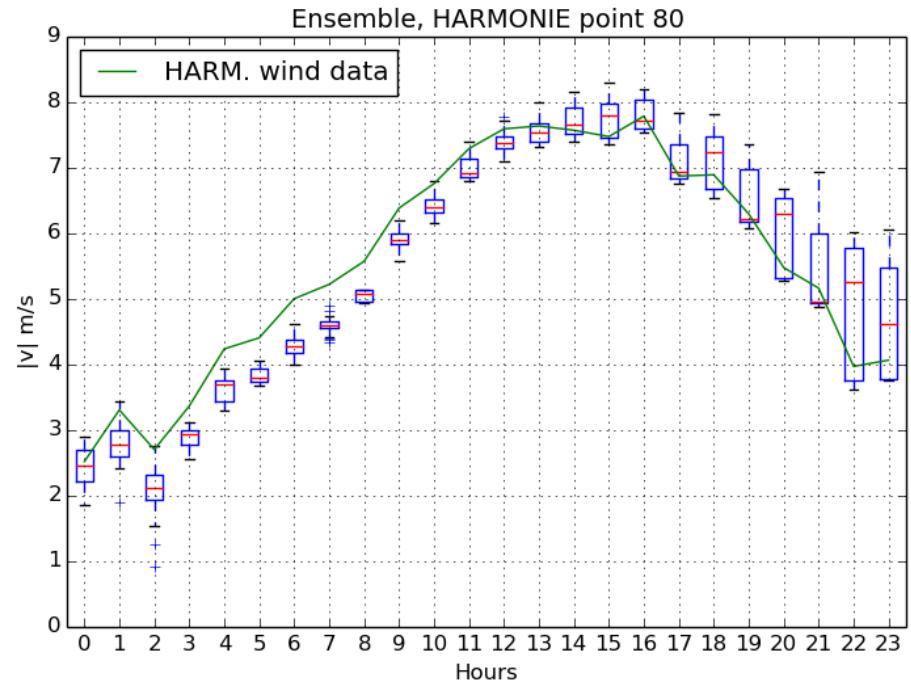
Ensemble forecast wind along a day



$$d = 0, z_0 = 0.0025$$



d and z_0 obtained from GIS

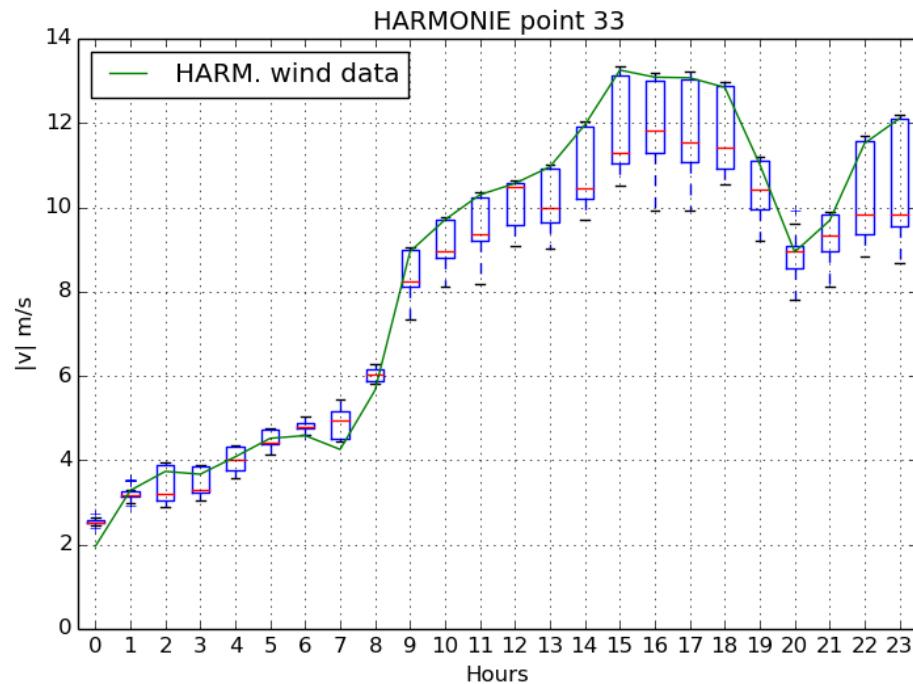


Ensemble methods

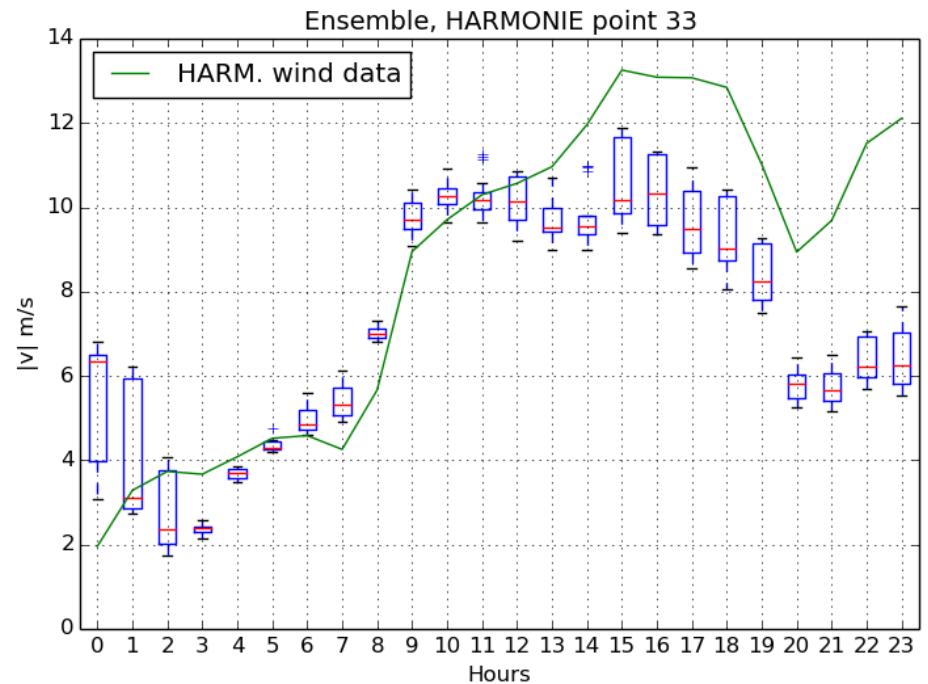
Ensemble forecast wind along a day



$$d = 0, z_0 = 0.0025$$



d and z_0 obtained from GIS



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.

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

Thanks

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



Thank you for your attention