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

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

\[ \Omega \subset \mathbb{R}^3 \quad \Gamma = \Gamma_a \cup \Gamma_b \]

\[ \vec{u}_0(u_0, v_0, w_0) \]: 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 \( \vec{u}_0(u_0, v_0, w_0) \) verifying

- Incompressibility condition in the domain \( \nabla \cdot \vec{u} = 0 \) in \( \Omega \)

- Non flow-through condition on the terrain \( \vec{n} \cdot \vec{u} = 0 \) on \( \Gamma_b \)

Let state the least square problem:

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

\[ \alpha = \frac{\alpha_1}{\alpha_2} \]
The solution produces the Euler-Lagrange equations

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

where \[ T = (T_h, T_h, T_v) \quad T_h = \frac{1}{2 \alpha_1^2}, \quad T_v = \frac{1}{2 \alpha_2^2}, \]

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

\[ u_0(z_m) = \xi \sum_{n=1}^{N} \frac{u_n}{d_n^2} + (1 - \xi) \sum_{n=1}^{N} \frac{u_n}{|\Delta h_n|} \]

\[ 0 \leq \xi \leq 1 \]
Mass Consistent Wind Model
Construction of the observed wind

Vertical extrapolation (log-linear wind profile)

\[ u_0(z) = \rho(z) u_0(z_{sl}) + [1 - \rho(z)] u_g \]

\[ u_0(z) = \frac{u^*}{k} \left( \log \frac{z-d}{z_0} - \Phi_m \right) \]

terrain surface
Mass Consistent Wind Model

Construction of the observed wind

- Friction velocity: \( u^* = \frac{k \, u_0(z_m)}{\log \frac{z_m}{z_0} - \Phi_m} \)

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

\( f = 2\Omega \sin \phi \) is the Coriolis parameter, being \( \Omega \) the Earth rotation and \( \phi \) is the latitude.

\( \gamma \) is a parameter depending on the atmospheric stability.

- Mixing height:
  
  \( h = z_{pbl} \) in neutral and unstable conditions

  \( h = \gamma' \sqrt{\frac{|u^*| \, L}{f}} \) 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
Spatial discretization

FEM computational mesh

HARMONIE mesh
Δh ~ 2.5 km

Terrain elevation (m)
HARMONIE-FEM wind forecast
Wind magnitude at 10m over terrain
HARMONIE-FEM wind forecast

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

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

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

GIS image
Terrain data
Image segmentation

Roughness length ($z_0$)

Obstacles height ($d$)
FE solution is needed for each individual

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

Number of genetic experiments

<table>
<thead>
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<th>% points</th>
<th>Height tolerances</th>
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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

C635B
C656V
C639X
$d = 0, \ z_0 = 0.0025$

$d$ and $z_0$ obtained from GIS
$d = 0, \ z_0 = 0.0025$

$d$ and $z_0$ obtained from GIS
\[ d = 0, \quad z_0 = 0.0025 \]

\[ d \text{ and } z_0 \text{ obtained from GIS} \]
\[ d = 0, \ z_0 = 0.0025 \]

\[ d \] and \( z_0 \) obtained from GIS
Ensemble methods

Ensemble forecast wind along a day

\[ d = 0, \ z_0 = 0.0025 \]

\[ d \text{ and } z_0 \text{ obtained from GIS} \]
Conclusions and future research

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

- Further research on $\alpha$, $\xi$, $z_0$, $d$ definition
- Study model results under different wind conditions
Thank you for your attention