SIANI
INSTITUTO UNIVERSITARIO
INGENIERIA COMPUTACIONAL

A Methodology to Map Roughness Length and Displacement Height in Complex Terrain

University Institute for Intelligent Systems and Numerical Applications in Engineering

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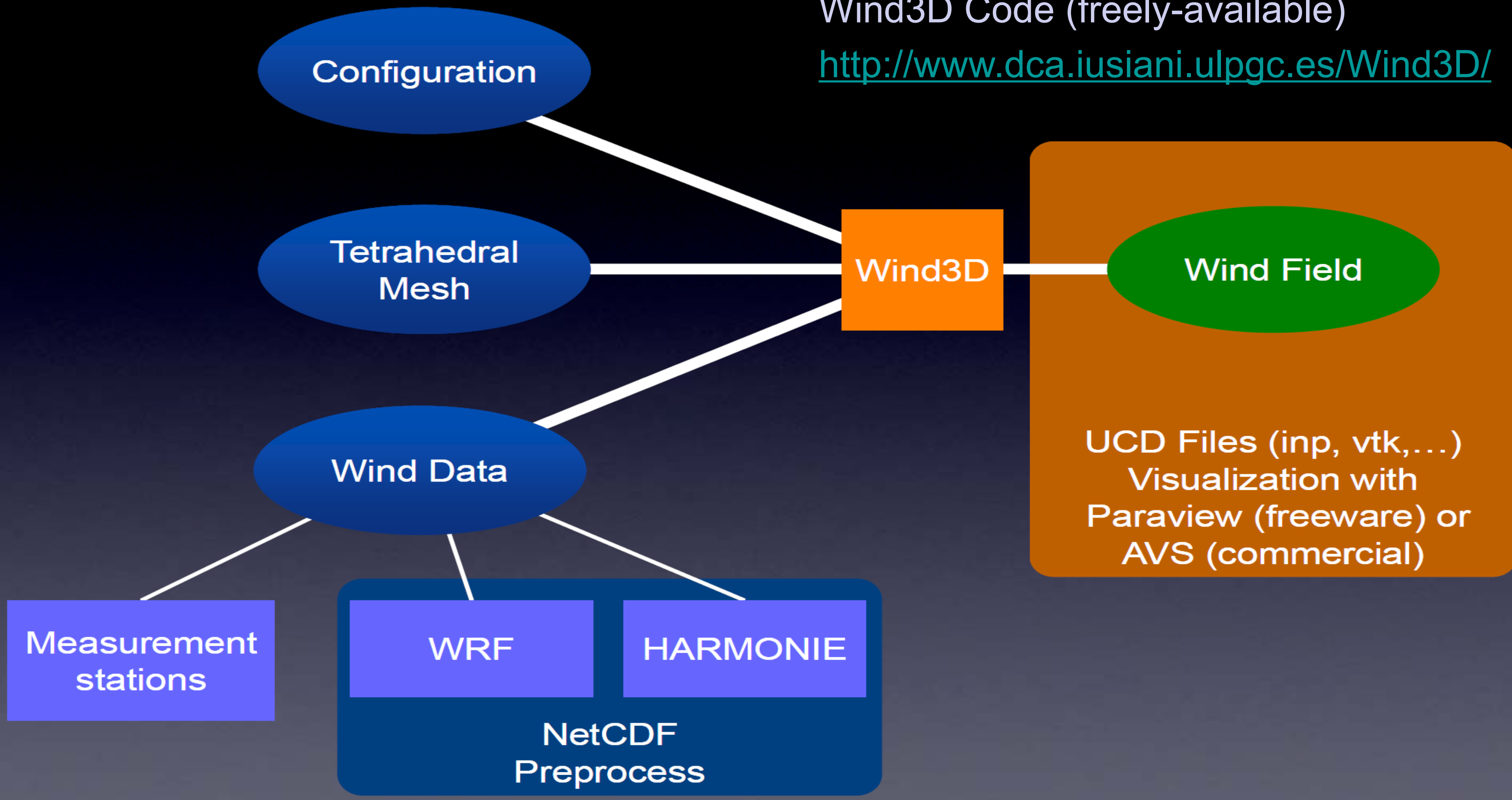
UNIVERSIDAD DE LAS PALMAS
DE GRAN CANARIA

Wind Field Modeling

Overview

Wind3D Code (freely-available)

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



Wind Field Modeling

Mass Consistent Wind Model

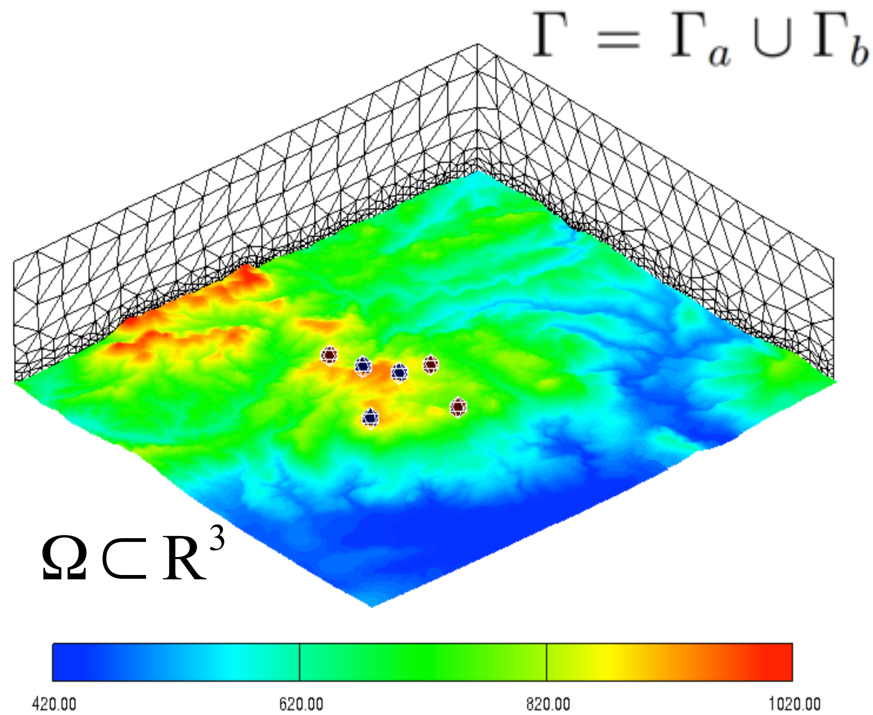
Objective:

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 and
No flow-through condition on the terrain

$$\nabla \cdot \vec{u} = 0 \quad \text{in } \Omega$$

$$\vec{n} \cdot \vec{u} = 0 \quad \text{on } \Gamma_b$$



Let state the least square problem:

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

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

Gauss Precision Moduli

They allow horizontal (α_1) and vertical (α_2) adjustment of wind velocity components

$\alpha >> 1$ adjustment in vertical direction is predominant

$\alpha << 1$ adjustment in horizontal direction is predominant

$\alpha \rightarrow \infty$ pure vertical adjustment

$\alpha \rightarrow 0$ pure horizontal adjustment

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If Gauss Precision Moduli are constant,

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

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

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

Once the Lagrange Multiplier is obtained, the wind velocity is computed with the Euler-Lagrange equations,

$$\vec{v} = \vec{v}_0 + T\vec{\nabla}\phi$$

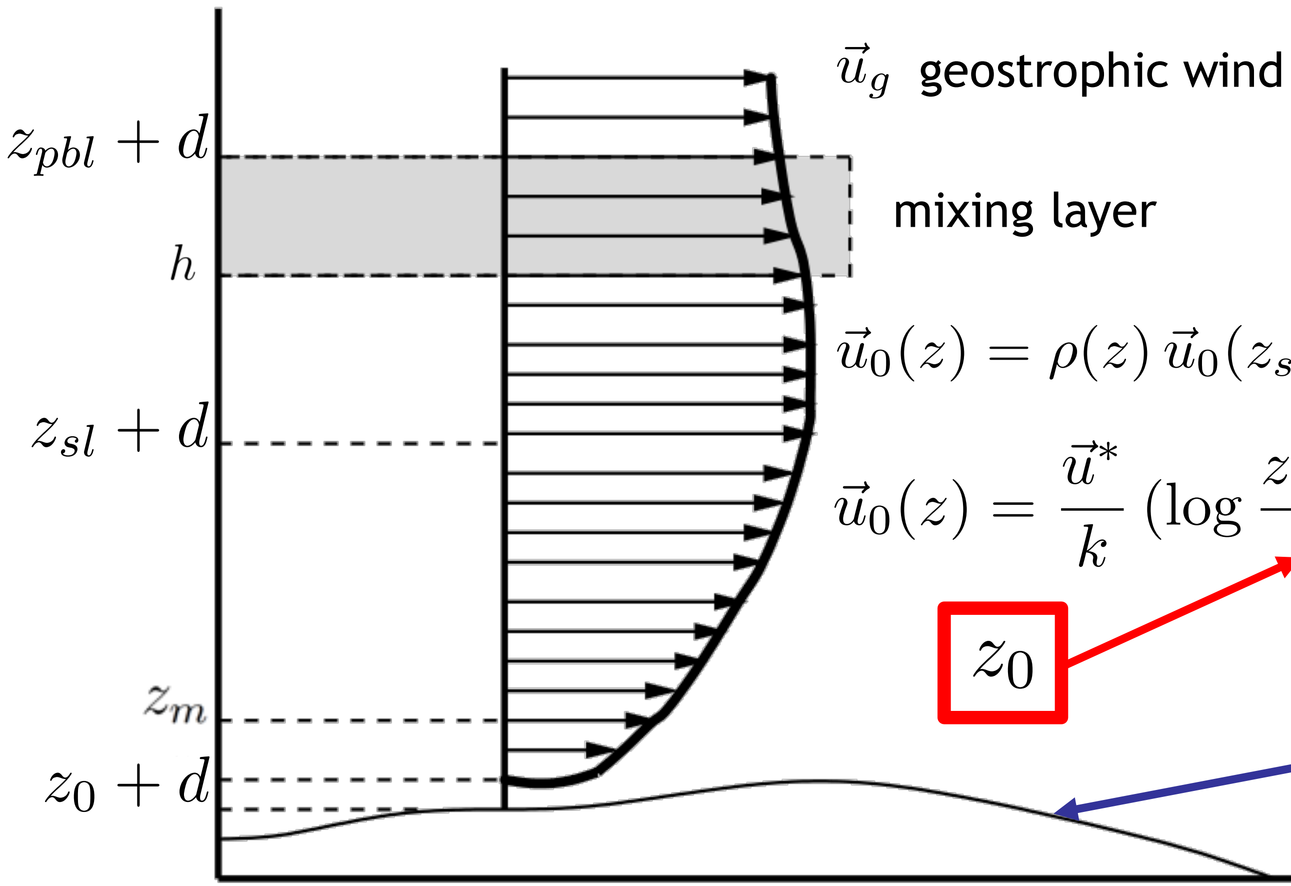
Construction of the observed wind

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)



$\vec{u}_g$ geostrophic wind

mixing layer

d

$$\vec{u}_0(z) = \rho(z)\,\vec{u}_0(z_{sl} + d) + [1 - \rho(z)]\,\vec{u}_g$$

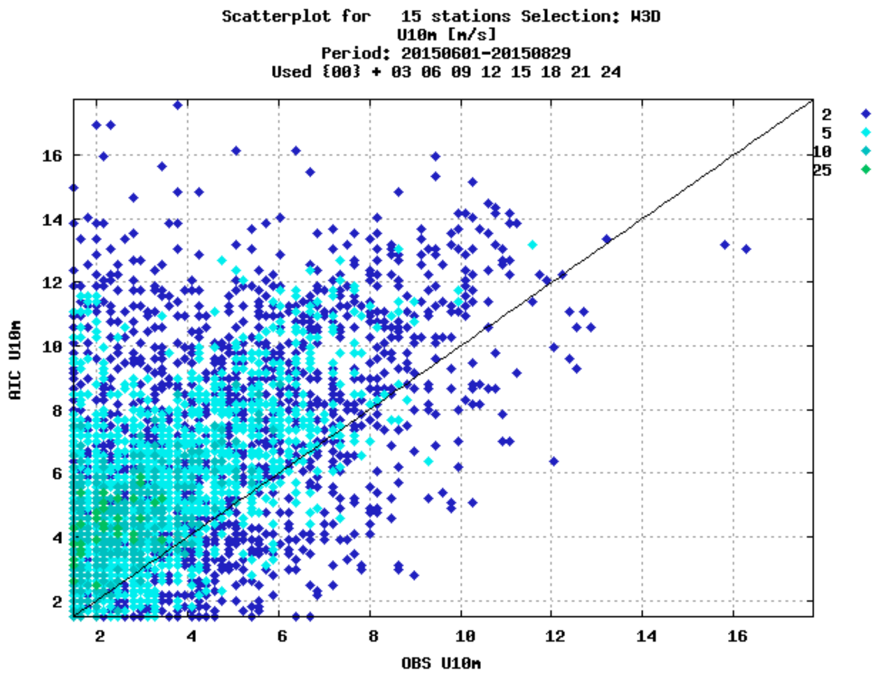
$$\vec{u}_0(z) = \frac{\vec{u}^*}{k}\left(\log\frac{z - d}{z_0} - \phi_m\right) \qquad k = 0.4$$

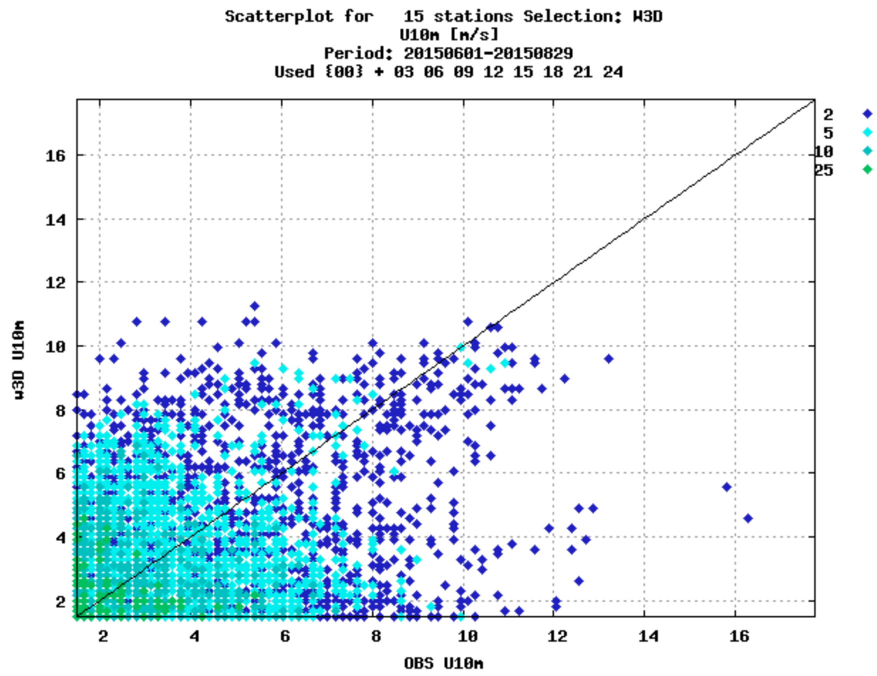
z_0

terrain surface

Wind Field Modeling

HARMONIE vs WIND3D results





HARMONIE

HARMONIE + WIND3D

SIOSE Land Cover Database — **Based on** → **CORINE Land Cover European project**

1:25.000 scale | **1:100.000 scale**

Let l_c be a $n_p \times 1$ vector containing the land cover information of all the points of the studied region, M a $n_p \times 40$ matrix which entries per row are the proportions of basic land covers at each point, and c a 40×1 vector with the basic land cover codes.

$$l_c = Mc = \begin{pmatrix} m_{1,ACM} & m_{1,ACU} & \dots & m_{1,ZQM} \\ m_{2,ACM} & m_{2,ACU} & \dots & m_{2,ZQM} \\ \dots & \dots & \dots & \dots \\ m_{n_p,ACM} & m_{n_p,ACU} & \dots & m_{n_p,ZQM} \end{pmatrix} \begin{pmatrix} ACM \\ ACU \\ \dots \\ ZQM \end{pmatrix}$$

such that, for each row i of M, it is verified,

$$\sum_{j=1}^{40} m_{i,j} = 1$$

Assume that z_0 and d in each point of study is also a weighted average of the z_0^B and d^B values assigned to each basic land cover type,

$$z_0 = Mz_0^B = M \begin{pmatrix} z_0^{ACM} \\ z_0^{ACU} \\ \dots \\ z_0^{ZQM} \end{pmatrix}$$

and similarly,

$$d = Md^B = M \begin{pmatrix} d^{ACM} \\ d^{ACU} \\ \dots \\ d^{ZQM} \end{pmatrix}$$

Wind Field Modeling

SIOSE Land Cover z_0 and d

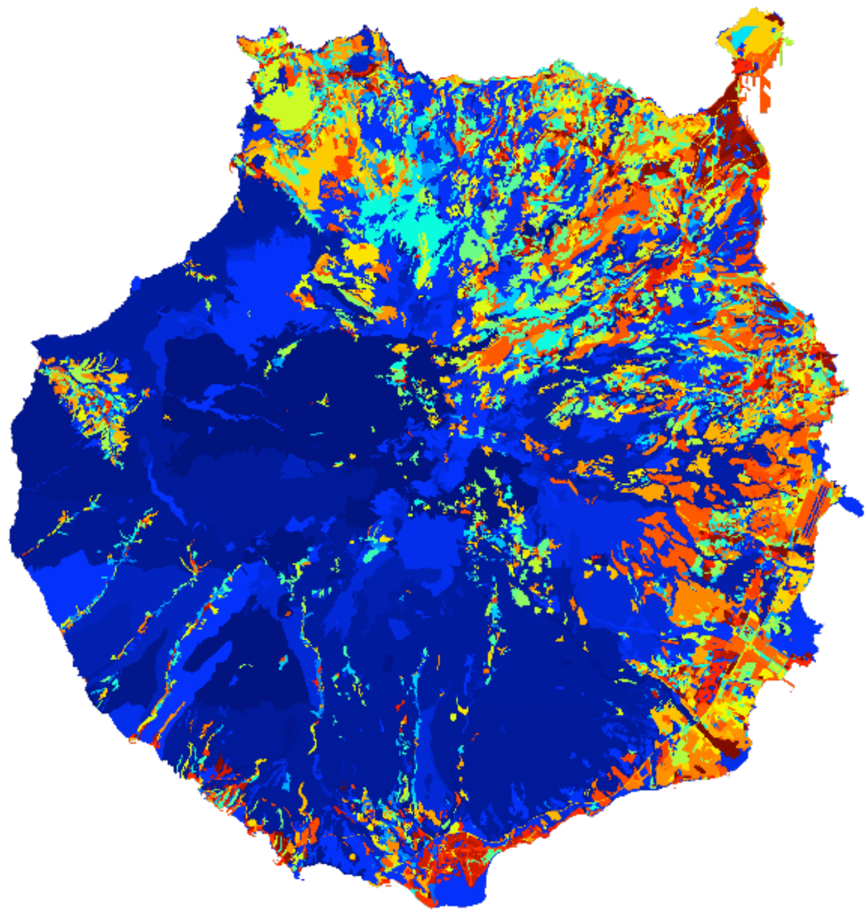
Code	Land Cover	z_0 (cm)	z_{0min}–z_{0max}	d (cm)	d_{min}–d_{max}
ACM	Sea Cliff	5[1]	5[2]–19[2]	5700[2]	330[2]–8500[2]
ACU	Water Courses	0.025[3]	0.01[4]–1[5]	0[6,47]	–
AEM	Sheet of Water. Reservoir	0.025[4]	0.01[4]–0.5[7]	0[6,47]	–
AES	Estuaries	0.02[8]	0.01[4]–1[5]	0[6,47]	–
ALC	Coastal Lagoons	0.5[7]	0.01[4]–1[5]	0[6,47]	–
ALG	Sheet of Water. Lakes and Lagoons	0.05[9]	0.01[4]–0.5[7]	0[6,47]	–
AMO	Seas y Oceans	0.02[8]	0.01[4]–3[1]	0[6,47]	–
ARR	Rocky Outcrops and Rocks	0.5[5]	0.03[10]–18[11]	3[6]	0[6]–96[6]
CCH	Screes	10[1]	5[12]–15[13]	60[14]	56[14]–66[14]
CLC	Quaternary lava flow	2.86[15]	0.13[15]–7.35[15]	15[6]	0[6]–40[6]
CNF	Forest. Conifers	128[16]	25[17]–193[18]	1310[19]	487[18]–2200[14]
CHA	Herbaceous crops. Rice	7.2[20]	0.1[21]–11[20]	85[20]	10[20]–155[20]
CHL	Herbaceous crops. Different from Rice	10[22]	0.4[23]–74[24]	25[23]	10[23]–300[35]
EDF	Artificial Coverage. Building	150[26]	70[26]–370[24]	1400[26]	700[26]–1973[6]
FDC	Forest. Leafy. Deciduous	100[28]	18[28]–140[1]	1180[29]	300[29]–2160[29]
FDP	Forest. Leafy. Evergreen	72[11]	60[3]–265[30]	970[29]	300[29]–3100[26]
GNP	No Vegetation. Glaciers and Perpetual Snow	0.1[5]	0.001[31]–1.2[26]	1[6]	0[6]–6[6]

Wind Field Modeling

SIOSE Land Cover z_0 and d

Code	Land Cover	z_0 (cm)	z_{0min}–z_{0max}	d (cm)	d_{min}–d_{max}
HMA	Salt Marshes	11[11]	0.02[10]–17[10]	60[6]	0[6]–93[6]
HPA	Wetlands	10[5	0.5[28]–55[11]	55[6]	3[6]–300[6]
HSA	Continental Salines	1[5]	0.05[5]–4[7]	5[6]	0[6]–22[6]
HSM	Salines	1[5]	0.05[5]–4[7]	5[6]	0[6]–22[6]
HTU	Peat bogs	3[5]	0.05[5]–3[5]	16[6]	0[6]–16[6]
LAA	Artificial Coverage. Artificial Sheet of Water	0.01[5]	0.01[5]–0.5[7]	0[5,47]	–
LFC	Woody Crops. Citrus Fruit Trees	31[33]	3[4]–40[34]	300[14]	0[35]–400[35]
LFN	Woody Crops. No Citrus Fruit Trees	25[5]	3[4]–100[32]	92[36]	0[35]–400[35]
LOC	Other Woody Crops	6.15[37,6]	3.69[37,6]–8.61[37,6]	33[37,6]	20[37,6]–47[37,6]
LOL	Olive Groves	48[38]	25[5]–61[38]	267[38]	200[38]–300[38]
LVI	Vineyards	20[39]	8[40]–55[39]	75[39]	31[40]–140[41]
MTR	Scrubs	16[28]	1.6[28]–100[1]	480[42]	90[26]–710[42]
OCT	Artificial Coverage. Other Buildings	50[5]	6[11]–100[5]	400[27]	200[27]–1400[26]
PDA	No Vegetation. Beaches, Dunes and Sandy Areas	0.03[5]	0.01[43]–6[10]	0[6]	0[6]–33[6]
PRD	Crops. Meadows	3[5]	0.1[31]–10[5]	1.3[26]	0.7[35]–3.5[26]
PST	Grassland	9[31]	0.1[31]–15[31]	17.1[44]	1.3[26]–66[35]
RMB	No Vegetation. Ravine	0.12[45]	0.03[4]–0.5[46]	0.5[6]	0[6]–3[6]
SDN	No Vegetation. Bare Soil	0.1[10]	0.02[46]–4[11]	0.5[6]	0[6]–22[6]
SNE	Artificial Coverage. Unbuilt Land	0.03[10]	0.02[46]–4[1]	0[6]	0[6]–22[6]
VAP	Artificial Coverage. Road, Parking or Unvegetated Pedestrian Areas	3[5]	0.35[45]–50[5]	100[47,48]	2[48]–250[48]
ZAU	Artificial Coverage. Artificial Green Area and Urban Trees	40[4]	3[10]–130[24]	350[47,48]	350[26]–1400[26]
ZEV	Artificial Coverage. Extraction or Waste Areas	10[5]	0.03[10]–18[11]	56[6]	0[6]–100[6]
ZQM	No Vegetation. Burnt Areas	60[5]	10[5]–110[10]	327[6]	54[6]–600[6]

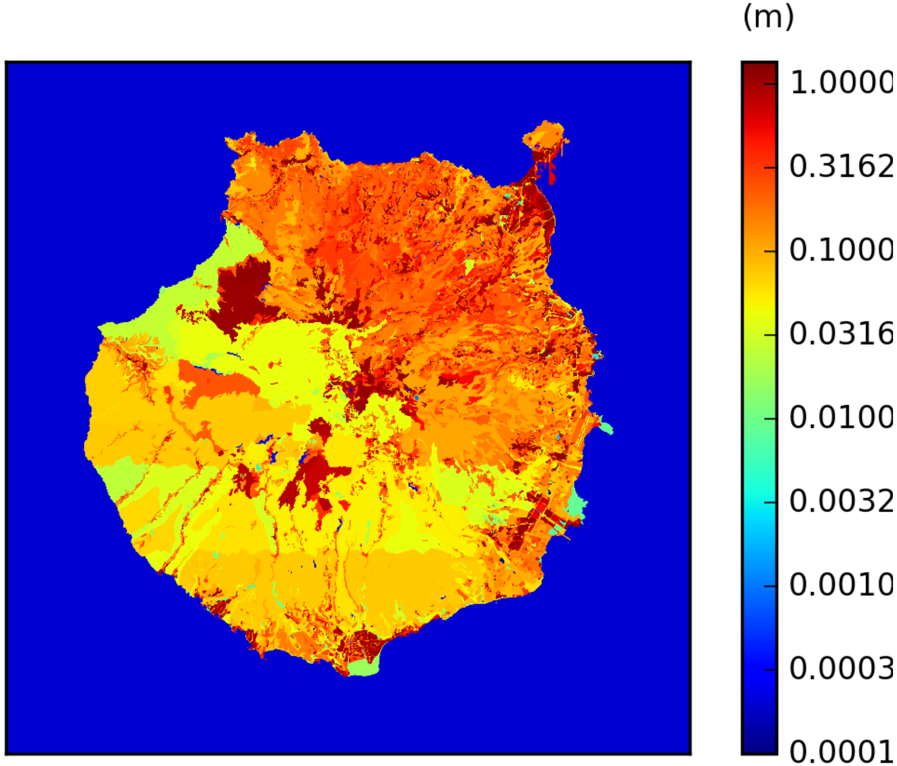
Polygons of SIOSE Land Cover



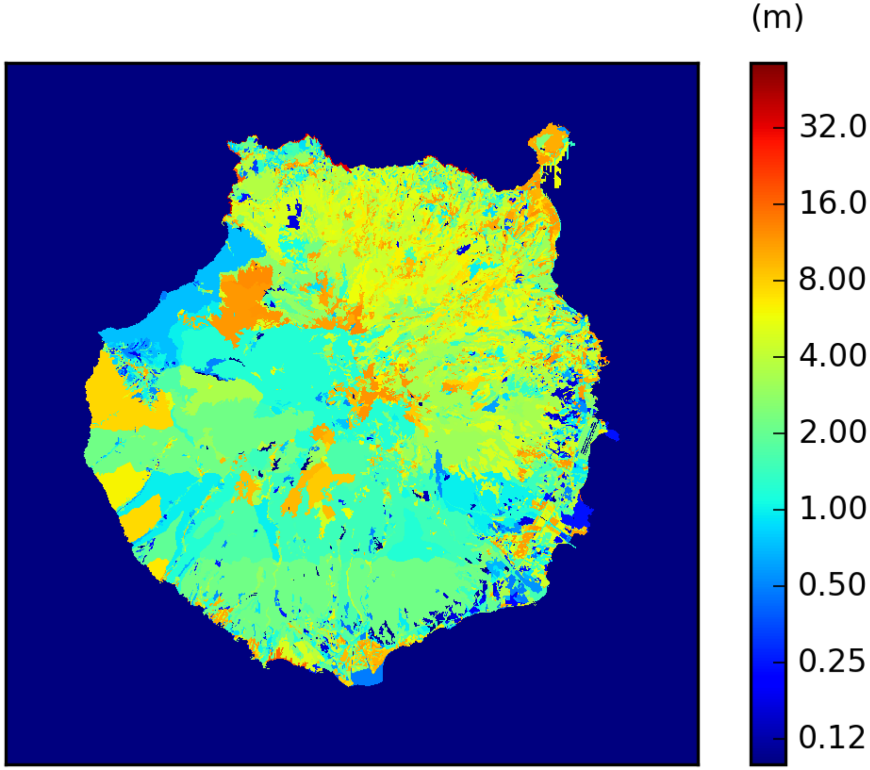
SIOSE Land Cover

SIOSE land cover polygons in the Island of Gran Canaria

Roughness length and displacement height



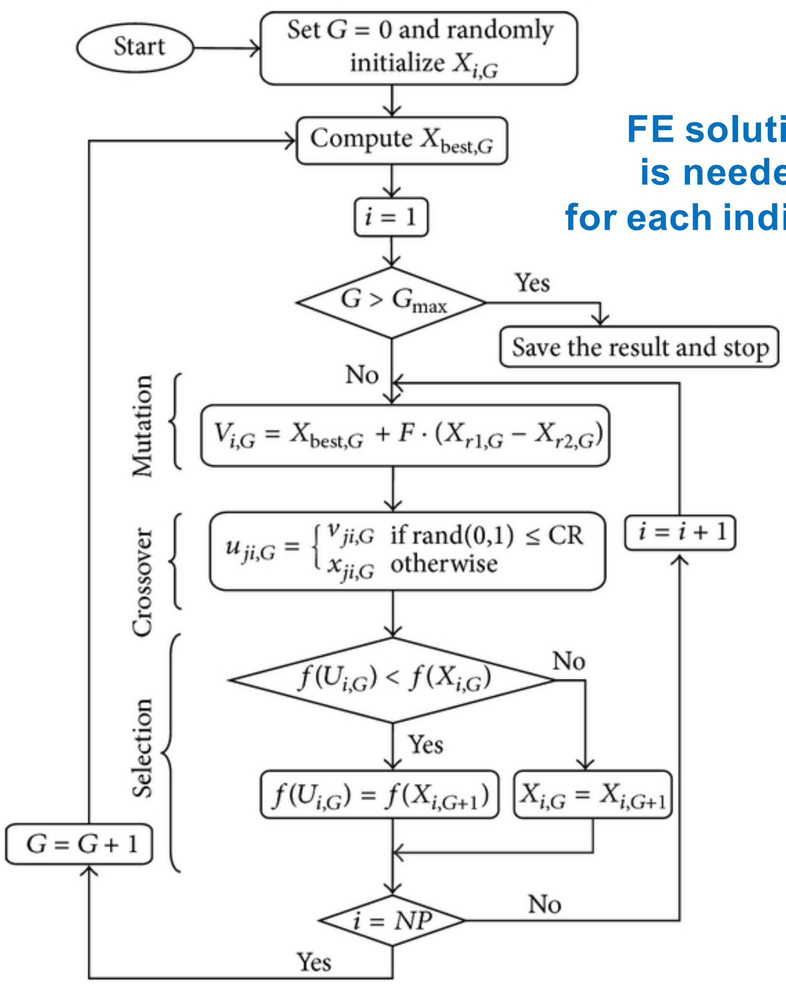
Roughness length (z_0) map



Displacement height (d) map

Roughness length and displacement height maps of Gran Canaria Island (m) corresponding to the nominal values

Differential Evolution



FE solution is needed for each individual

$$RMSE = \sqrt{\frac{1}{n_c}\sum_{i=1}^{n_c}(u_{xi} - u^c_{xi})^2 + (u_{yi} - u^c_{yi})^2 + (u_{zi} - u^c_{zi})^2}$$

NE times

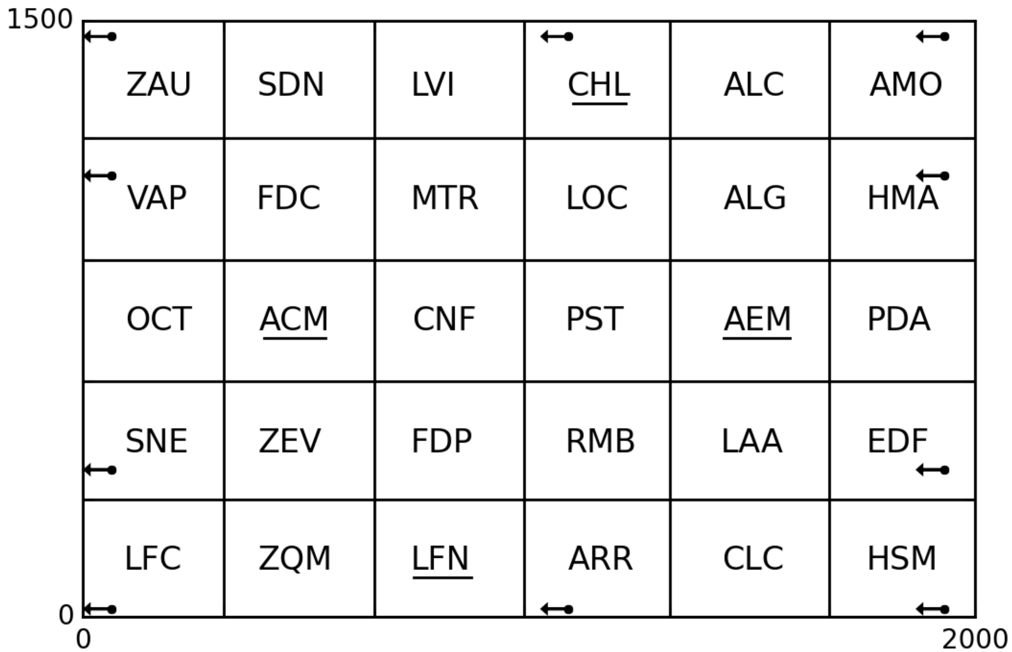
Reduction the search space: Student T distribution

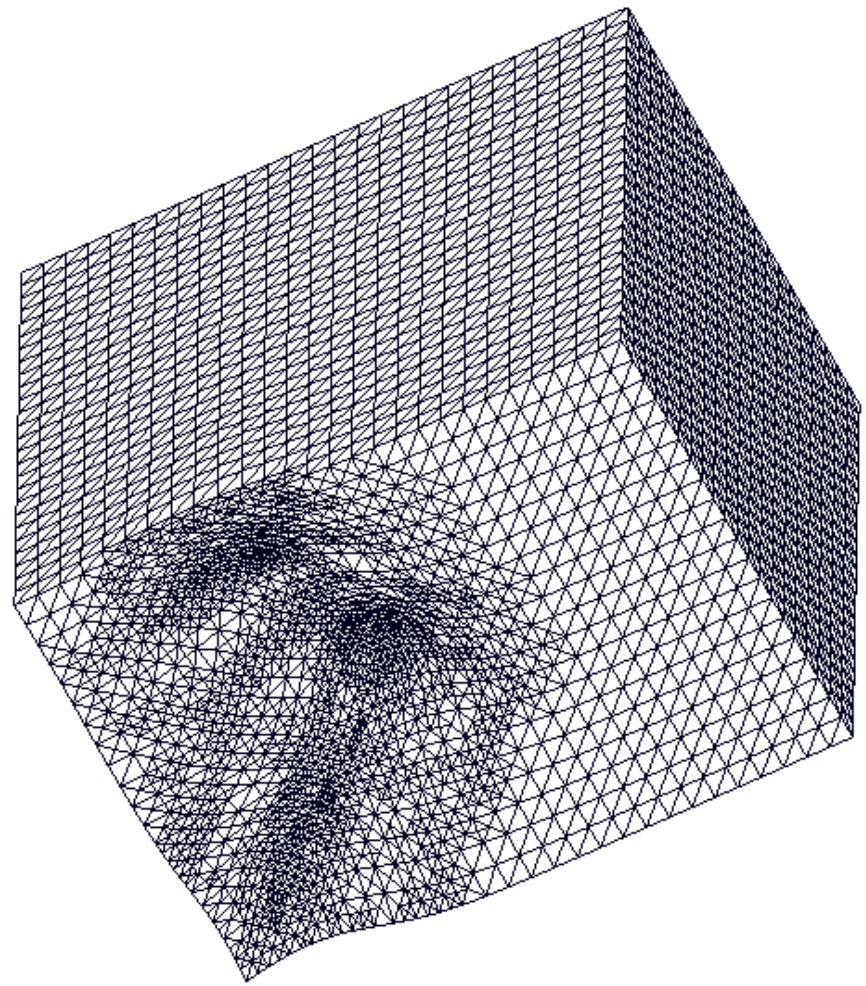
Rebirth: Differential Evolution

L-BFGS-B

Wind Field Modeling

HARMONIE-FEM wind forecast





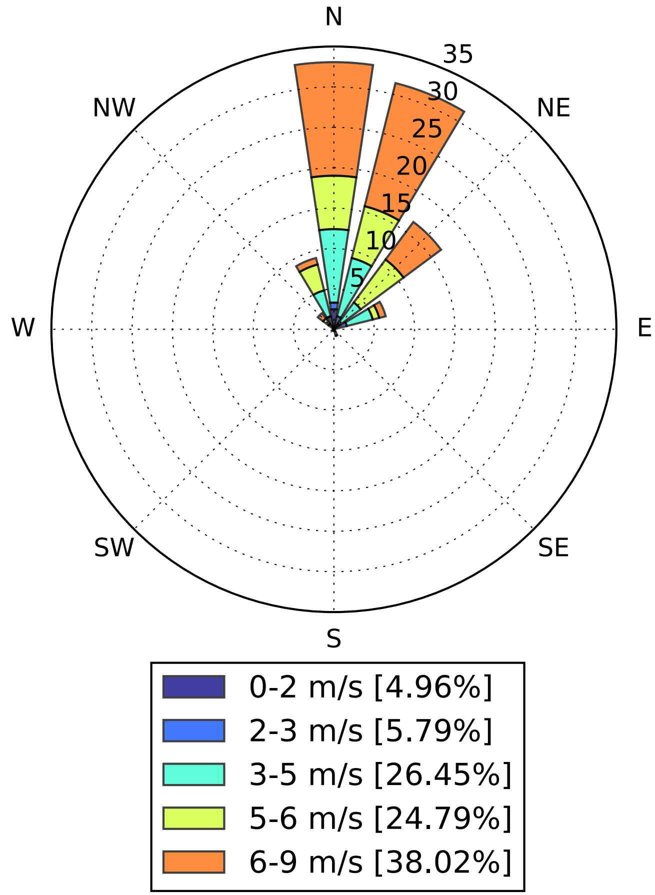
	First case		
Parameter	DE + L-BFGS-B Best error	Student T distribution Confidence Interval 99.9%	Rebirth DE + L-BFGS-B Best error
$RMSE$	1.4×10^{-4}	–	1.2×10^{-7}
α	1.1×10^{-6}	$9.99891658 \times 10^{-2}$–$1.00012716 \times 10^{-1}$	2.6×10^{-9}
ξ	1.0×10^{-2}	$1.73988332 \times 10^{-1}$–$8.27463796 \times 10^{-1}$	7.7×10^{-2}
z_0^{ACM}	2.6×10^{-6}	$5.00000000 \times 10^{-2}$–$5.00691832 \times 10^{-2}$	2.2×10^{-8}
z_0^{AEM}	1.7×10^{-8}	$2.49948364 \times 10^{-4}$–$2.50089986 \times 10^{-4}$	1.0×10^{-10}
z_0^{ALC}	1.6×10^{-7}	$4.99857962 \times 10^{-3}$–$5.00103748 \times 10^{-3}$	9.0×10^{-10}
z_0^{ALG}	5.0×10^{-8}	$4.99912109 \times 10^{-4}$–$5.00085716 \times 10^{-4}$	2.0×10^{-10}
z_0^{AMO}	1.1×10^{-8}	$1.99967466 \times 10^{-4}$–$2.00012359 \times 10^{-4}$	1.0×10^{-10}
z_0^{ARR}	1.1×10^{-6}	$4.99121953 \times 10^{-3}$–$5.00859944 \times 10^{-3}$	4.9×10^{-9}
z_0^{CLC}	1.5×10^{-5}	$2.85764791 \times 10^{-2}$–$2.86243504 \times 10^{-2}$	7.7×10^{-9}
z_0^{CNF}	1.2×10^{-4}	1.27743498–1.28228789	3.4×10^{-8}
z_0^{CHL}	1.3×10^{-5}	$9.99291955 \times 10^{-2}$–$1.00137990 \times 10^{-1}$	1.7×10^{-8}
z_0^{EDF}	8.2×10^{-4}	1.49719791–1.50218395	2.8×10^{-8}
z_0^{FDC}	6.3×10^{-6}	$9.96508723 \times 10^{-1}$–1.00198244	4.4×10^{-7}
z_0^{FDP}	4.6×10^{-4}	$7.19417726 \times 10^{-1}$–$7.21076346 \times 10^{-1}$	6.2×10^{-8}
z_0^{HMA}	7.3×10^{-5}	$1.09900104 \times 10^{-1}$–$1.10088026 \times 10^{-1}$	4.3×10^{-9}
z_0^{HSM}	4.8×10^{-6}	$9.98381363 \times 10^{-3}$–$1.00097396 \times 10^{-2}$	1.1×10^{-9}
z_0^{LAA}	1.6×10^{-8}	$9.99668434 \times 10^{-5}$–$1.00090932 \times 10^{-4}$	1.0×10^{-10}
z_0^{LFC}	1.3×10^{-5}	$3.09840527 \times 10^{-1}$–$3.10403415 \times 10^{-1}$	1.7×10^{-7}
z_0^{LFN}	3.3×10^{-5}	$2.49678372 \times 10^{-1}$–$2.50439558 \times 10^{-1}$	1.2×10^{-8}
z_0^{LOC}	1.8×10^{-6}	$6.13955515 \times 10^{-2}$–$6.16504485 \times 10^{-2}$	3.7×10^{-9}
z_0^{LVI}	3.2×10^{-5}	$1.99620082 \times 10^{-1}$–$2.00272611 \times 10^{-1}$	3.2×10^{-8}
z_0^{MTR}	9.3×10^{-5}	$1.59784202 \times 10^{-1}$–$1.60255435 \times 10^{-1}$	9.3×10^{-8}
z_0^{OCT}	1.6×10^{-4}	$4.99314831 \times 10^{-1}$–$5.01080202 \times 10^{-1}$	1.4×10^{-7}
z_0^{PDA}	3.0×10^{-7}	$2.99462452 \times 10^{-4}$–$3.00012448 \times 10^{-4}$	1.0×10^{-10}
z_0^{PST}	6.4×10^{-6}	$8.99336560 \times 10^{-2}$–$9.00573016 \times 10^{-2}$	2.9×10^{-8}
z_0^{RMB}	1.7×10^{-6}	$1.19796167 \times 10^{-3}$–$1.20251115 \times 10^{-3}$	5.0×10^{-10}
z_0^{SDN}	3.2×10^{-7}	$9.99239316 \times 10^{-4}$–$1.00074991 \times 10^{-3}$	7.0×10^{-10}
z_0^{SNE}	2.5×10^{-7}	$2.98922979 \times 10^{-4}$–$3.00247696 \times 10^{-4}$	2.0×10^{-10}

	First case		
Parameter	DE + L-BFGS-B Best error	Student T distribution Confidence Interval 99.9%	Rebirth DE + L-BFGS-B Best error
z_0^{VAP}	3.4×10^{-5}	$7.49096867 \times 10^{-2}$–$7.51352981 \times 10^{-2}$	4.1×10^{-8}
z_0^{ZAU}	6.2×10^{-5}	$3.99251685 \times 10^{-1}$–$4.00240447 \times 10^{-1}$	3.4×10^{-8}
z_0^{ZEV}	1.9×10^{-6}	$2.99902915 \times 10^{-2}$–$3.00147677 \times 10^{-2}$	1.4×10^{-8}
z_0^{ZQM}	8.1×10^{-6}	$5.98397732 \times 10^{-1}$–$6.01119602 \times 10^{-1}$	1.5×10^{-7}
d^{ACM}	1.2×10^{-5}	5.69998230×10^{1}–5.70000479×10^{1}	7.0×10^{-8}
d^{ARR}	3.6×10^{-5}	$2.98147359 \times 10^{-2}$–$3.01770648 \times 10^{-2}$	7.5×10^{-8}
d^{CLC}	8.3×10^{-5}	$1.49889938 \times 10^{-1}$–$1.50134456 \times 10^{-1}$	2.7×10^{-8}
d^{CNF}	1.5×10^{-4}	1.30971902×10^{1}–1.31033759×10^{1}	4.0×10^{-8}
d^{CHL}	9.4×10^{-6}	$2.49673215 \times 10^{-1}$–$2.50173144 \times 10^{-1}$	5.9×10^{-8}
d^{EDF}	1.1×10^{-3}	1.39971698×10^{1}–1.40035399×10^{1}	8.0×10^{-9}
d^{FDC}	6.4×10^{-5}	1.17974877×10^{1}–1.18043741×10^{1}	4.6×10^{-7}
d^{FDP}	5.9×10^{-4}	9.69852738–9.70074087	7.3×10^{-8}
d^{HMA}	1.9×10^{-4}	$5.99773010 \times 10^{-1}$–$6.00217925 \times 10^{-1}$	6.5×10^{-9}
d^{HSM}	5.9×10^{-5}	$4.98784059 \times 10^{-2}$–$5.01964508 \times 10^{-2}$	8.2×10^{-9}
d^{LFC}	1.2×10^{-5}	2.99934291–3.00033454	2.5×10^{-7}
d^{LFN}	3.5×10^{-5}	$9.19353542 \times 10^{-1}$–$9.20547522 \times 10^{-1}$	1.8×10^{-8}
d^{LOC}	1.1×10^{-5}	$3.29657441 \times 10^{-1}$–$3.30250920 \times 10^{-1}$	7.2×10^{-9}
d^{LVI}	6.3×10^{-5}	$7.49509571 \times 10^{-1}$–$7.50659495 \times 10^{-1}$	6.7×10^{-8}
d^{MTR}	1.6×10^{-4}	4.79965761–4.80027533	1.5×10^{-7}
d^{OCT}	1.6×10^{-4}	3.99872271–4.00077854	1.4×10^{-7}
d^{PDA}	6.3×10^{-5}	0.00000000–$1.32206493 \times 10^{-4}$	1.7×10^{-8}
d^{PST}	3.3×10^{-5}	$1.70875618 \times 10^{-1}$–$1.71135885 \times 10^{-1}$	3.8×10^{-8}
d^{RMB}	1.1×10^{-4}	$2.98518849 \times 10^{-2}$–$3.01158004 \times 10^{-2}$	6.2×10^{-9}
d^{SDN}	3.0×10^{-5}	$2.99515287 \times 10^{-2}$–$3.00614935 \times 10^{-2}$	4.2×10^{-8}
d^{SNE}	5.9×10^{-5}	0.00000000–$2.57881261 \times 10^{-4}$	3.3×10^{-8}
d^{VAP}	9.4×10^{-5}	$9.99736844 \times 10^{-1}$–1.00016263	7.7×10^{-8}
d^{ZAU}	1.2×10^{-4}	3.49954738–3.50122087	4.2×10^{-8}
d^{ZEV}	5.5×10^{-6}	$1.59949878 \times 10^{-1}$–$1.60018604 \times 10^{-1}$	6.5×10^{-8}
d^{ZQM}	1.1×10^{-5}	3.26873871–3.27180076	1.9×10^{-7}

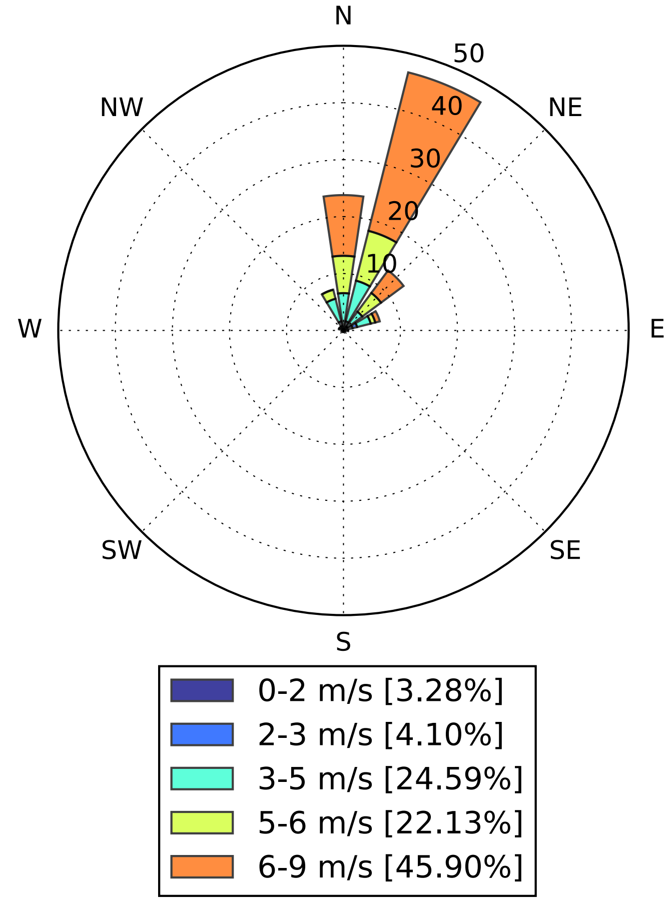
Wind Field Modeling

Summer wind rose of Gran Canaria

Daytime



Nighttime



Wind Rose of Gran Canaria at 10 m relating to the period from June 1 to September 30 of the year 2015.

Wind Field Modeling

Selected cases

Cases		Daytime			
Surface wind direction	**Surface wind speed range (m/s)**	**HARMONIE 10 m wind speed**	**HARMONIE 10 m wind direction**	**Incoming solar radiation**	**Pasquill stability class**
NNE	> 6	7,61	32,89	530,85	D
NE	> 6	9,01	37,29	583,39	D
N	> 6	7,11	349,53	494,75	D
NE	$5-6$	5,57	40,50	665,60	C
N	$3-5$	4,16	4,26	797,14	B
NNE	$5-6$	5,88	12,76	771,82	C
NNE	$3-5$	3,54	12,70	586,43	C
N	$5-6$	5,39	350,28	695,26	C

0,0019-0,0043

Cases		Nighttime			
Surface wind direction	**Surface wind speed range (m/s)**	**HARMONIE 10 m wind speed**	**HARMONIE 10 m wind direction**	**Cloud amount (oktas)**	**Pasquill stability class**
NNE	> 6	9,87	25,75	4,59	D
NE	> 6	8,07	34,16	3,39	D
N	> 6	6,82	355,35	7,04	D
NE	$5-6$	5,10	42,58	2,24	D
N	$3-5$	4,99	359,27	6,45	D
NNE	$5-6$	5,13	19,94	0,61	D
NNE	$3-5$	4,90	12,56	0,00	E
N	$5-6$	5,62	353,72	1,86	D

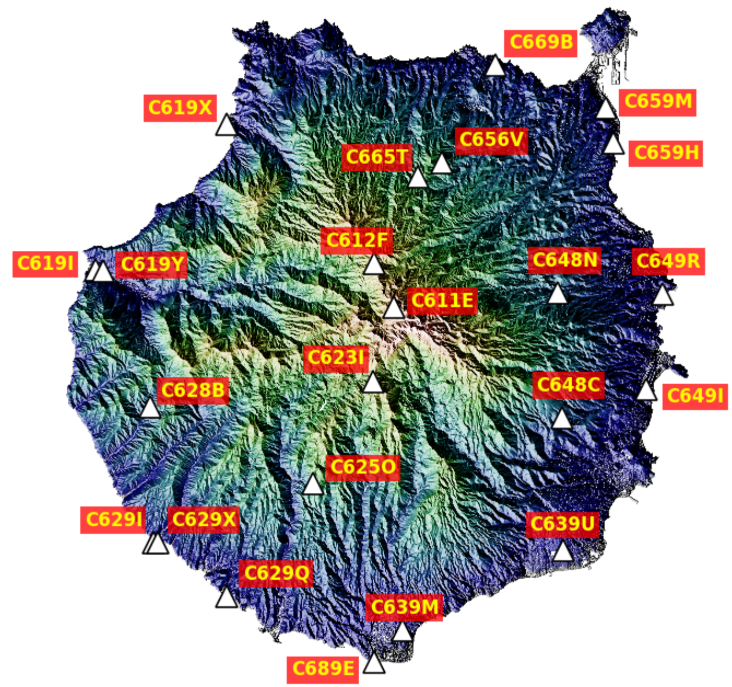
0,00-0,00

Table 1: Most frequent wind speeds and directions in the island of Gran Canaria during the summer months.

Wind Field Modeling

Measurement stations

Code	Name	$x\,(m)$	$y\,(m)$	$z\,(m)$
C611E	Vega de San Mateo	442587.00	3094849.87	1712
C612F	Cruz de Tejeda	441111.20	3098128.27	1524
C619I	La Aldea de San Nicolás	420071.67	3097617.70	20
C619X	Agaete	429982.92	3108624.01	15
C619Y	La Aldea	420598.02	3097574.90	23
C623I	S. Bartolomé de Tirajana, Cuevas del Pinar	440978.20	3089240.95	1230
C625O	S. Bartolomé de Tirajana, Lomo Pedro Alfonso	436499.77	3081522.42	816
C628B	La Aldea de San Nicolás, Tasarte	424210.25	3087335.04	328
C629I	Mogán, Puerto	424469.50	3077087.00	22
C629Q	Mogán, Puerto Rico	429927.60	3073056.56	20
C629X	Puerto de Mogán	424751.35	3077101.81	20
C639M	Maspalomas, C. Insular Turismo	443238.31	3070506.07	55
C639U	S. Bartolomé de Tirajana, El Matorral	455345.47	3076502.74	51
C648C	Agüimes	455325.70	3086483.97	316
C648N	Telde, Centro Forestal Doramas	454970.89	3095890.75	354
C649I	Gran Canaria, Aeropuerto	461658.52	3088640.43	34
C649R	Telde, Melenara	462854.84	3095804.64	19
C656V	Teror	446227.23	3105674.70	693
C659H	Polígono de San Cristobal	459130.00	3107201.82	65
C659M	Plaza de la Feria	458627.05	3109809.55	25
C665T	Valleseco	444392.38	3104643.66	910
C669B	Arucas	450225.76	3113015.52	96
C689E	Maspalomas	441057.23	3068075.14	35

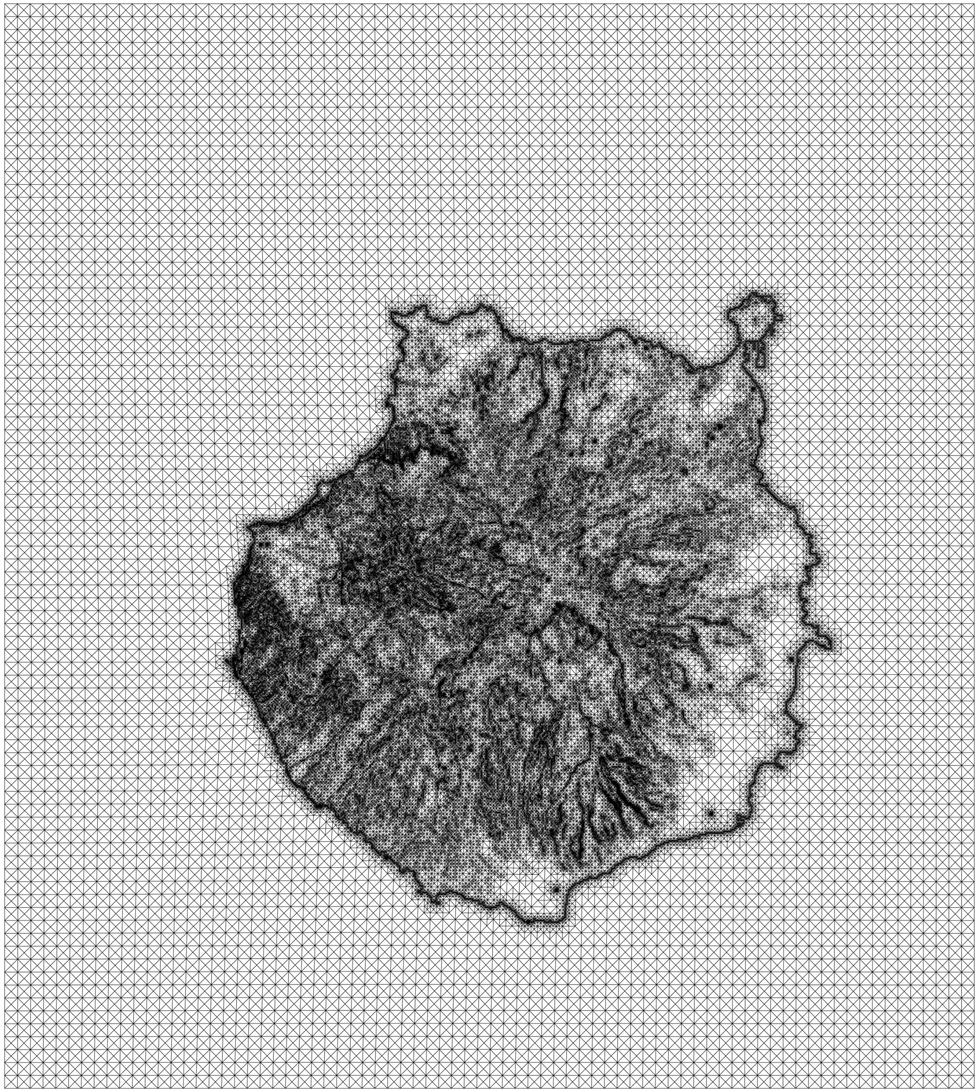


Location in UTM zone 28N coordinates and height over the sea level of the 23 anemometers available in Gran Canaria.

Wind Field Modeling

Adaptive mesh

SIANI



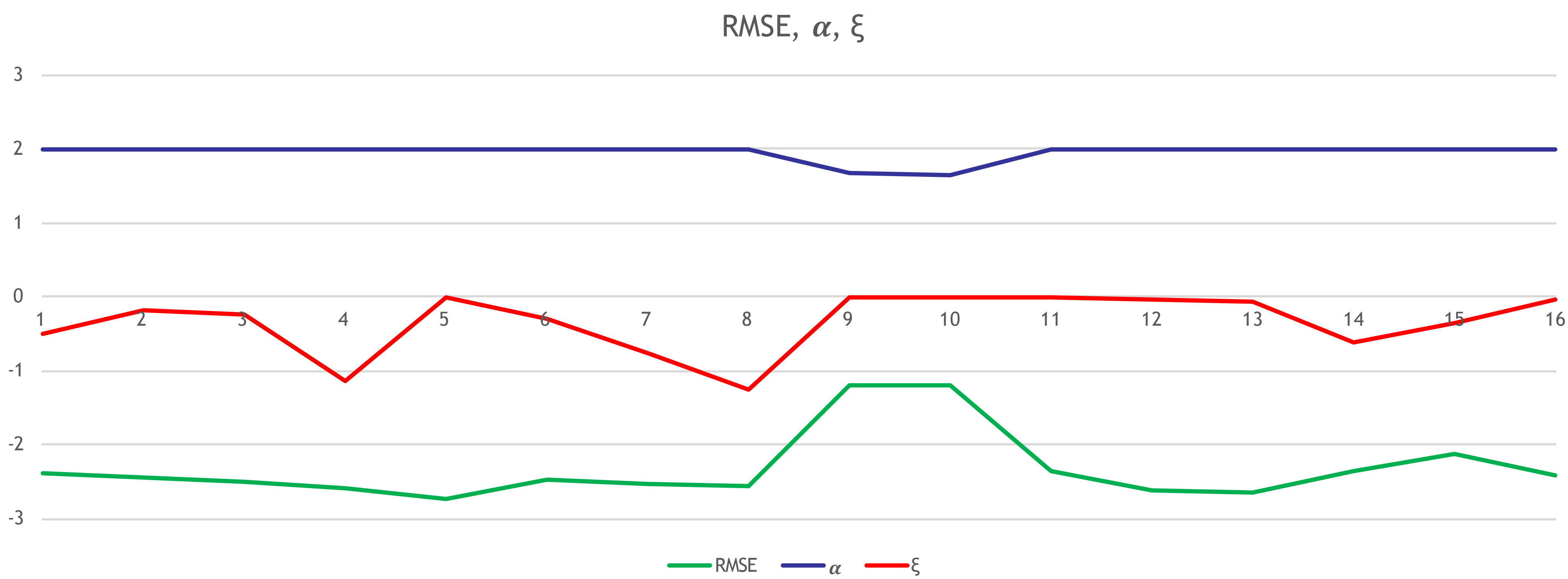
Domain dimensions:
76 km × 85 km × 4 km

1.492.804 tetrahedra
326.101 nodes

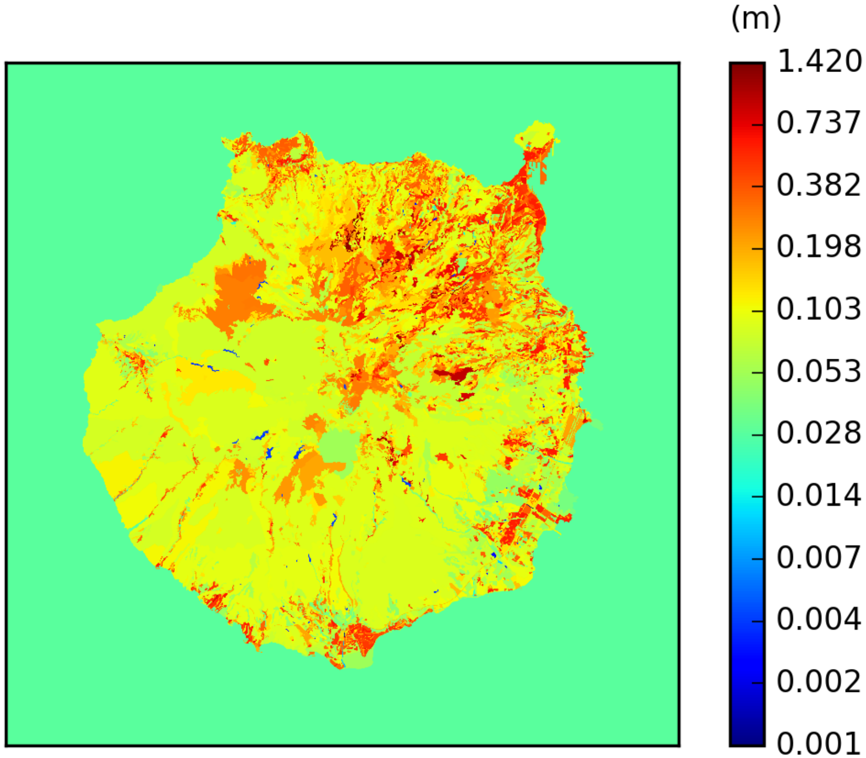
Local refinement:
- **Measurement stations**
- **Shoreline**
- **Altimetry**

Surface triangulation

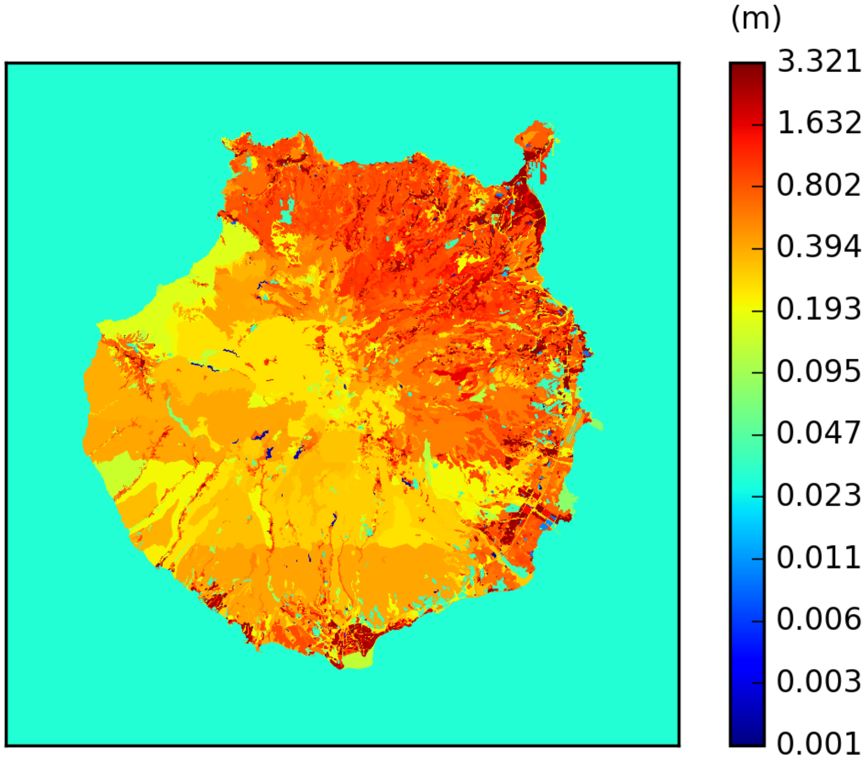
Results of α and ξ with respect to the $RMSE$ in log scale



5-6 m/s NNE C

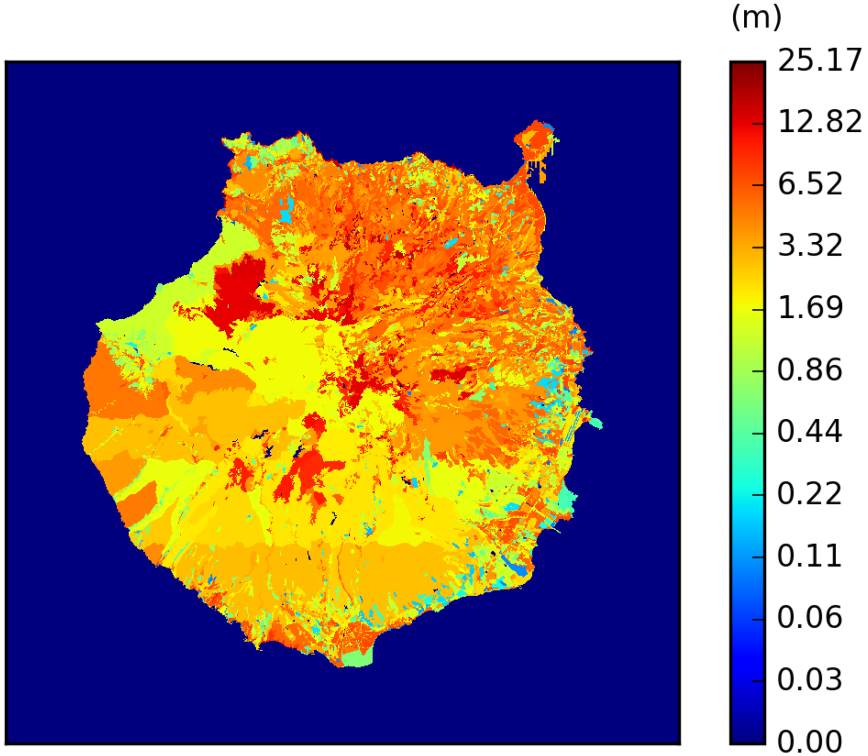


3-5 m/s NNE E

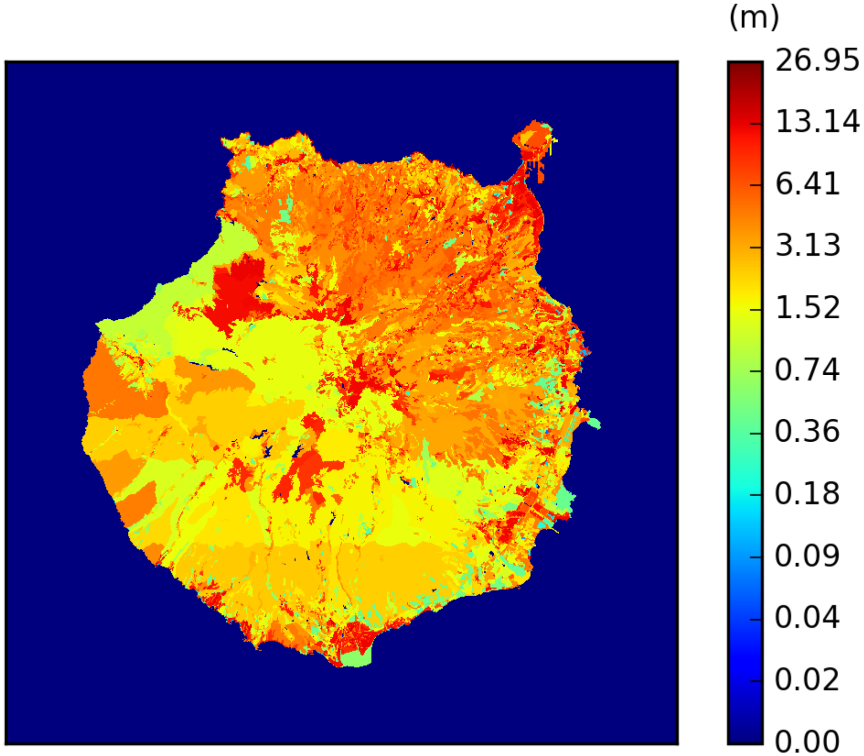


Roughness length (z_0) map

>6 m/s NNE D



5-6 m/s NNE D



Displacement height (d) map

Conclusions

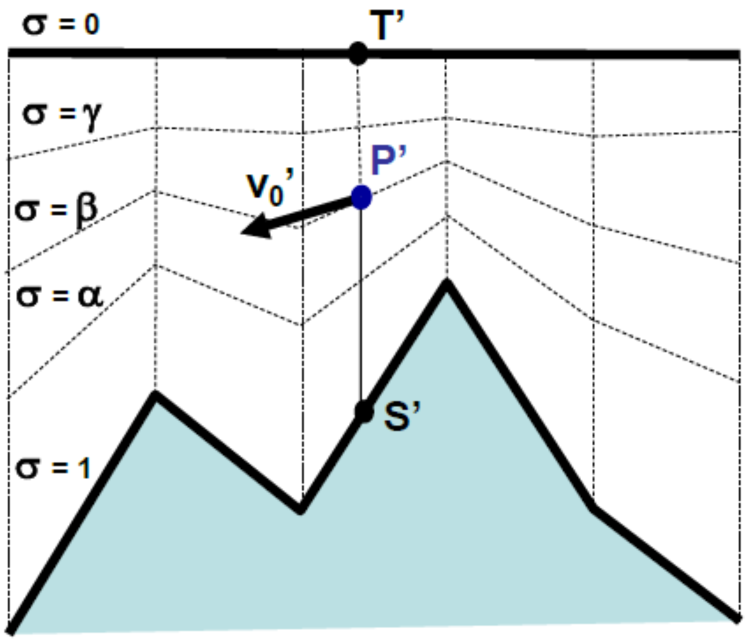
- Mass Consistent models (MCM) can improve the forecasting results of Mesoscale models
- The studied parameters involved in MCM depend on the wind velocity (speed and direction), and the atmospheric stability. Also daytime and nighttime results are different.
- The mimetic algorithm proposed is a robust tool for solving this type of parameter estimation problems.

Future Research

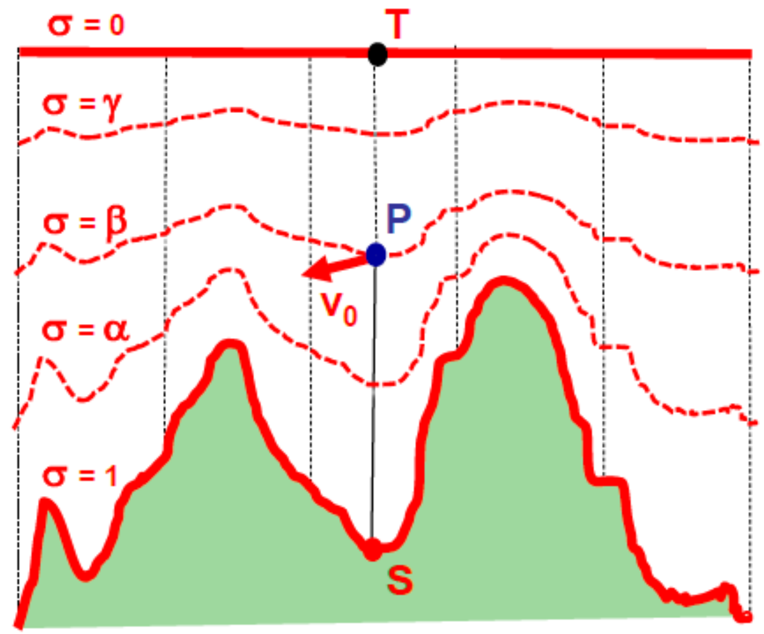
- Construct a reduced basis of those parameters for solving wind episodes (different locations). Only forecasting values as input data.
- Apply this methodology to the results of different mesoscale models (HARMONIE, ECMWF)

Wind Field Modeling

Data interpolation in FE domain



HARMONIE FD domain



WIND3D FE domain

HARMONIE data interpolation in the FE domain:

- Use U10 and V10 supposing it is 10m over the FE surface + height displacement

Statement of the problem

To find $\vec{v} \in K$ such that,

$$E(\vec{v}) = \min_{\vec{u}\in K} E(\vec{u}), \quad K = \left\{ \vec{u}; \vec{\nabla}\cdot\vec{u} = 0,\ \vec{n}\cdot\vec{u}|_{\Gamma_b} = 0 \right\}$$

This is equivalent to find the saddle point $(\vec{v}, \phi)$ of the Lagrangian

$$L(\vec{u}, \lambda) = E(\vec{u}) + \int_\Omega \lambda \vec{\nabla}\cdot\vec{u}\, d\Omega$$

with $L(\vec{v}, \lambda) \leq L(\vec{v}, \phi) \leq L(\vec{u}, \phi)$

The solution produces the Euler-Lagrange equations

$\vec{v} = \vec{v}_0 + T\vec{\nabla}\phi$ where $T = (T_h, T_h, T_v)$ $\quad T_h = \dfrac{1}{2\alpha_1^2}$, $T_v = \dfrac{1}{2\alpha_2^2}$

Substituting the Euler-Lagrange equation in,

$$\vec{\nabla} \cdot \vec{u} = 0 \quad \text{in } \Omega$$

$$\vec{n} \cdot \vec{u} = 0 \quad \text{on } \Gamma_b$$

it yields the governing equations,

$$-\vec{\nabla} \cdot (T\vec{\nabla}\phi) = \vec{\nabla} \cdot \vec{v}_0 \quad \text{in } \Omega$$

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

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

Atmospheric Stratification

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

$0.15 < \gamma < 0.45$

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

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

$\gamma' \cong 0.4$

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

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