SIANI
INSTITUTO UNIVERSITARIO
INGENIERIA COMPUTACIONAL

Wind, Air Quality, Solar Radiation and Marine Energy Modelling

University Institute for Intelligent Systems and Numerical Applications in Engineering

PLOCAN

June 9, 2017, Las Palmas de Gran Canaria

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http://www.siani.es/

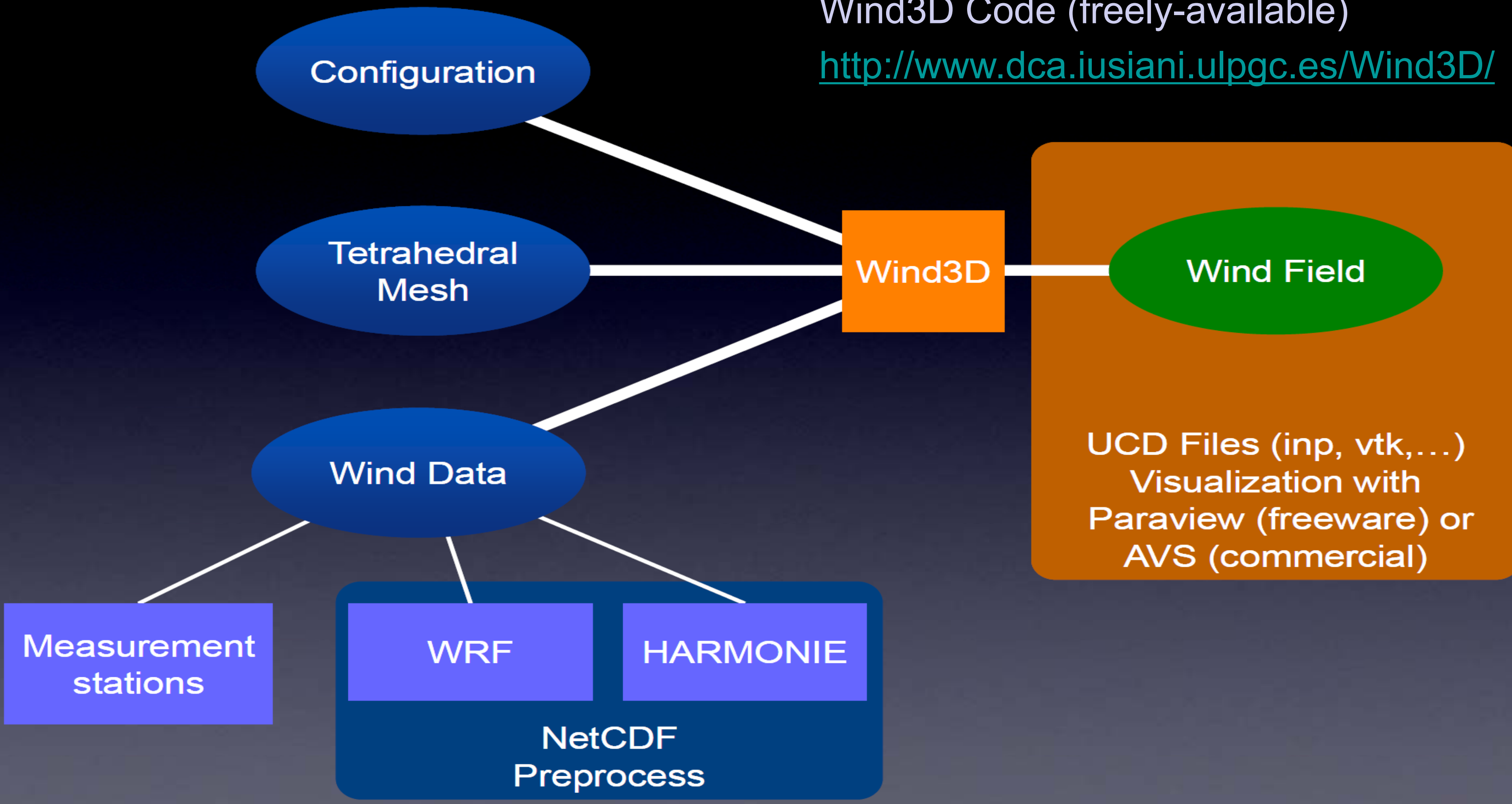
UNIVERSIDAD DE LAS PALMAS
DE GRAN CANARIA

Wind Field Modeling

Overview

Wind3D Code (freely-available)

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



Wind Field Modeling

Mass Consistent Wind Model

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Objective:

Find the velocity field $\vec{u}(\widetilde{u}, \widetilde{v}, \widetilde{w})$

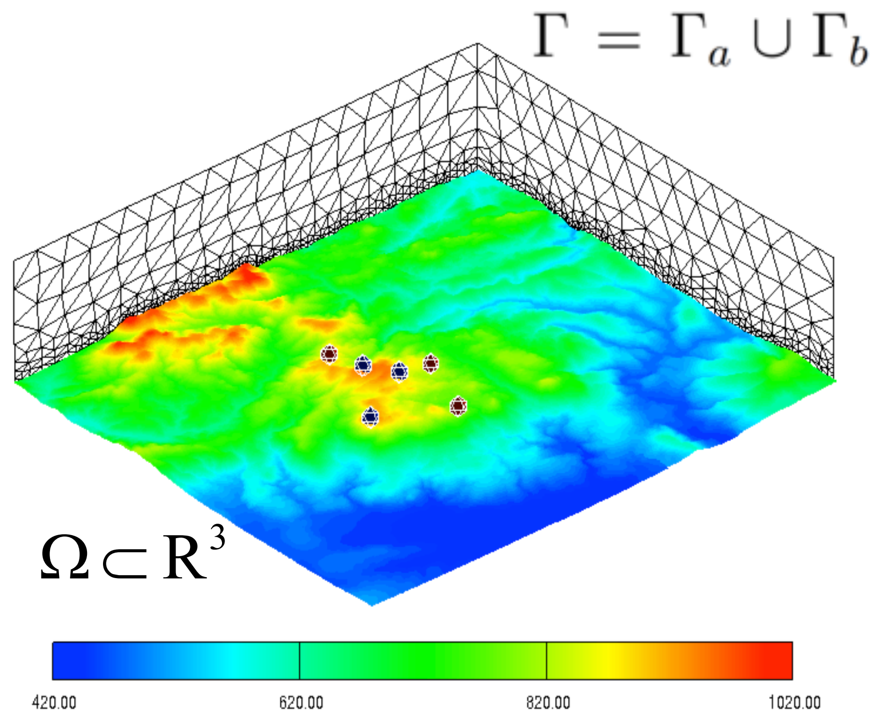
that adjusts to $\vec{v}_0(u_0, v_0, w_0)$ verifying:

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:

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

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

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If Gauss Precision Moduli are constant,

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

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

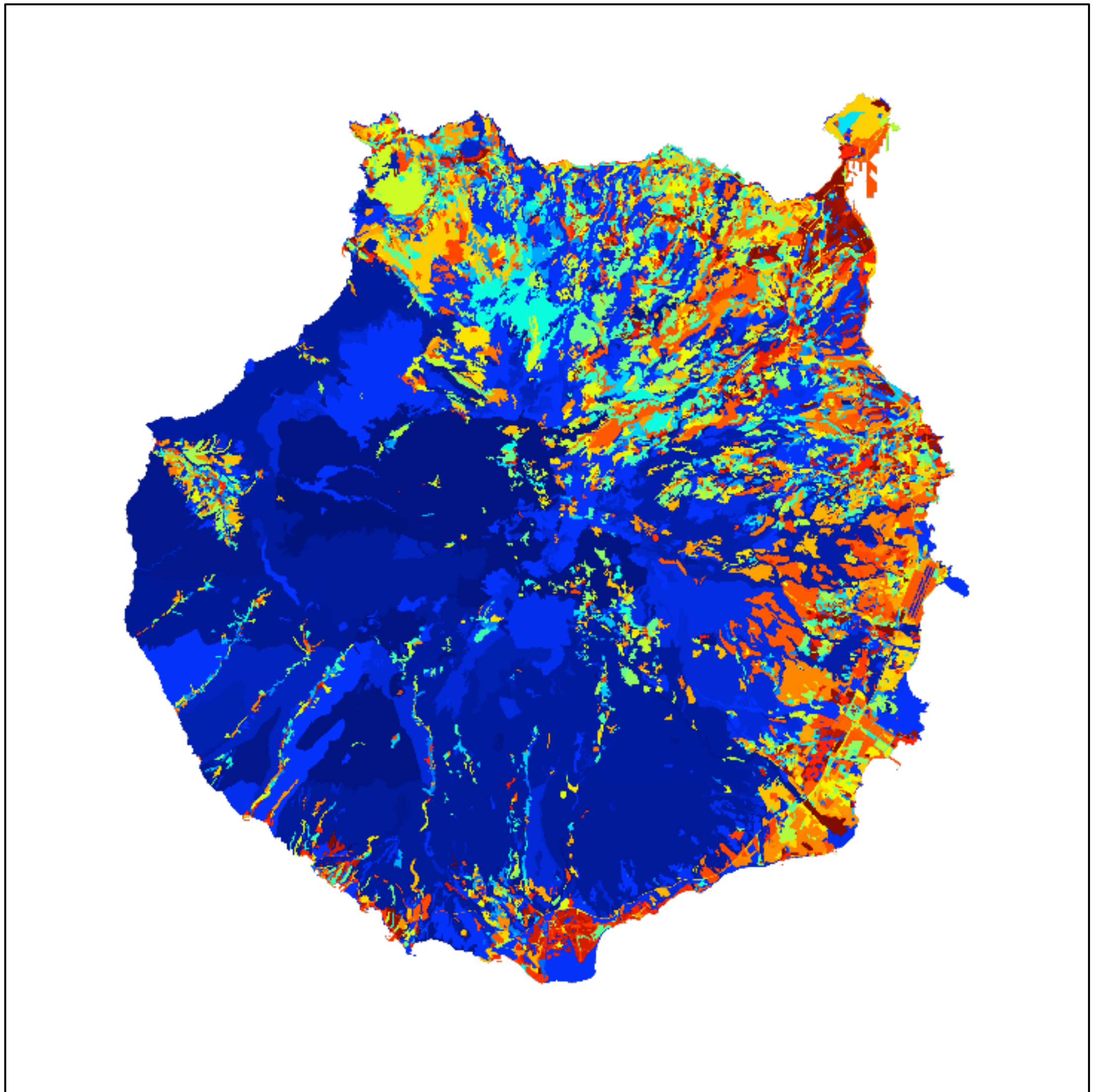
$$\vec{n}\cdot T\vec{\nabla}\phi = -\vec{n}\cdot\vec{v}_0 \quad \text{on } \Gamma_b$$

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

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

Wind Field Modeling

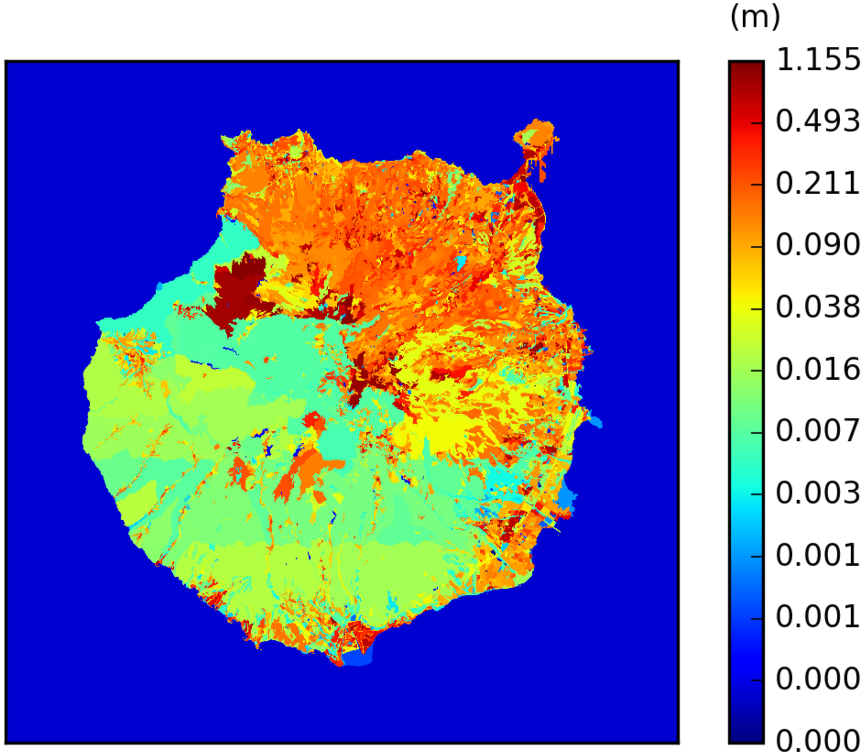
Polygons of SIOSE Land Cover



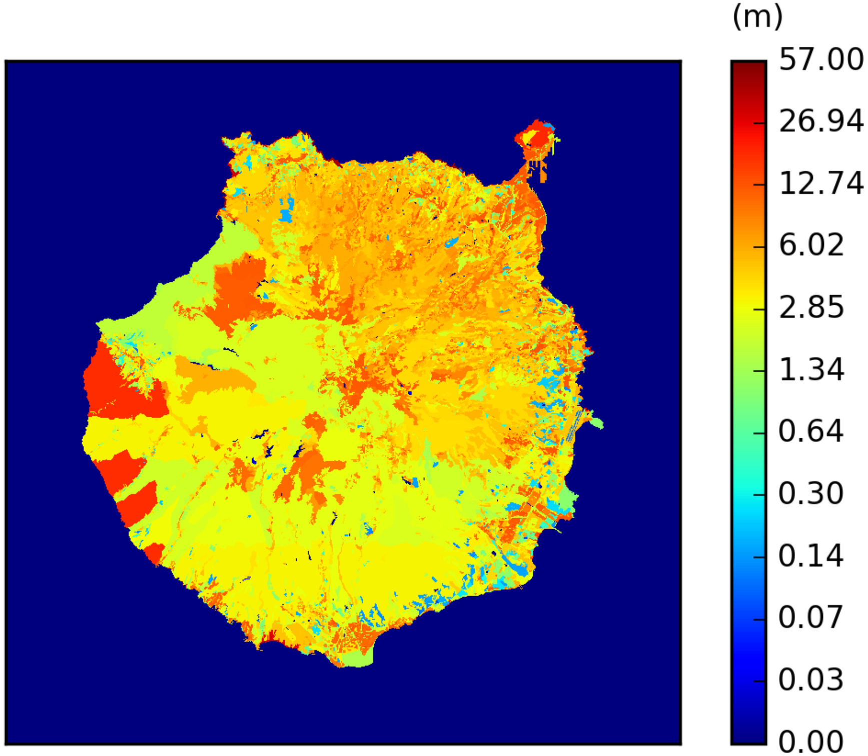
SIOSE Land Cover

SIOSE land cover polygons
in the Island of Gran Canaria

Roughness length and displacement height



Roughness length (z_0) map



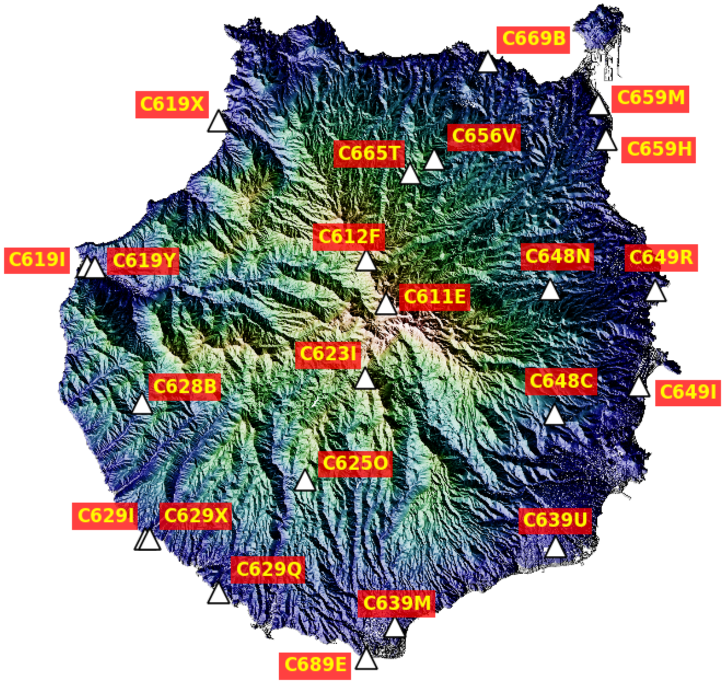
Displacement height (d) map

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

Wind Field Modeling

Measurement stations

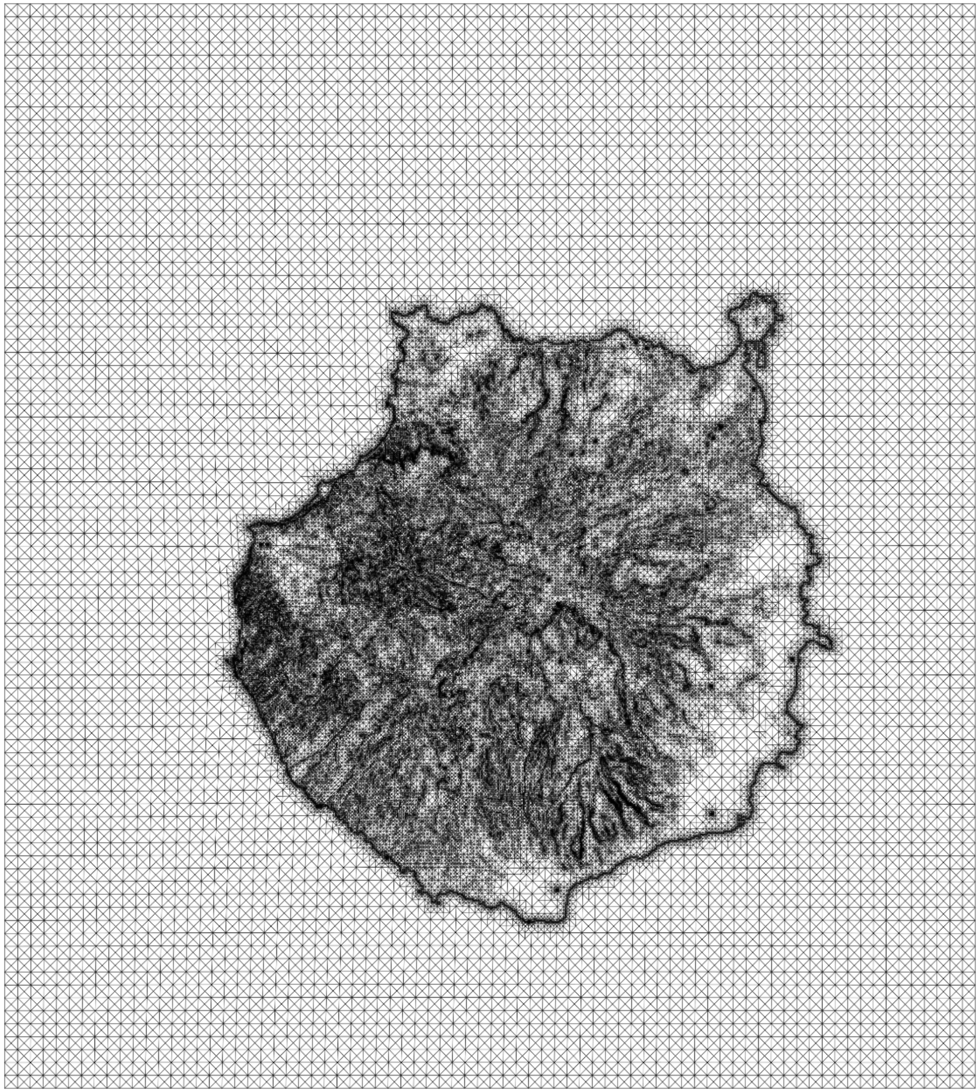
Code	Name	$x\,(m)$	$y\,(m)$	$z\,(m)$
C611E	Vega de San Mateo	442587.00	3094849.87	1712
C612F	Cruz de Tejeda	441111.20	3098128.27	1524
C619I	La Aldea de San Nicolás	420071.67	3097617.70	20
C619X	Agaete	429982.92	3108624.01	15
C619Y	La Aldea	420598.02	3097574.90	23
C623I	S. Bartolomé de Tirajana, Cuevas 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



Domain dimensions:
76 km × 85 km × 4 km

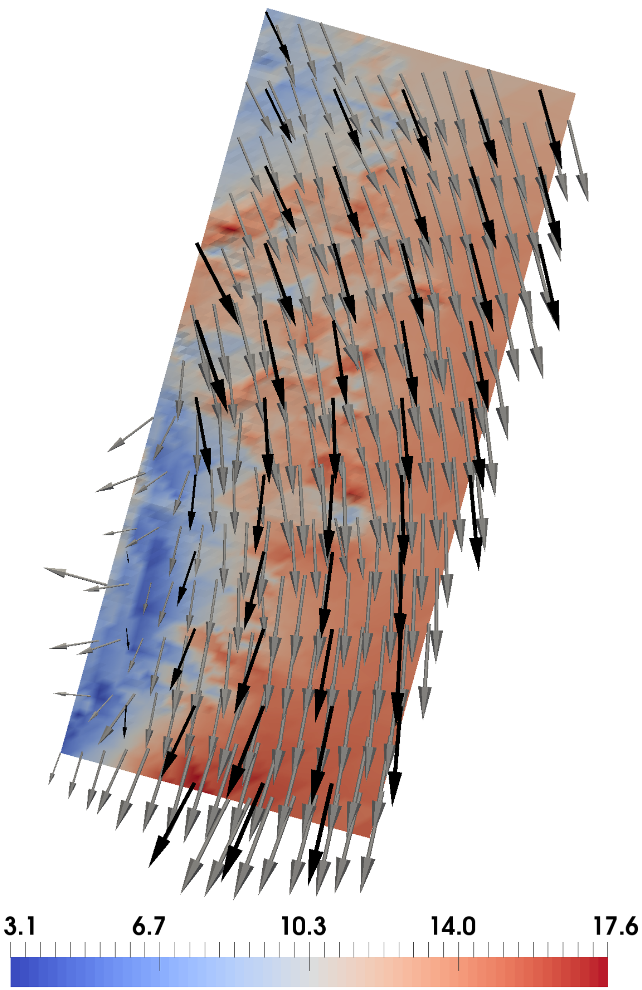
1.492.804 tetrahedra
326.101 nodes

Local refinement:
- Measurement stations
- Shoreline
- Altimetry

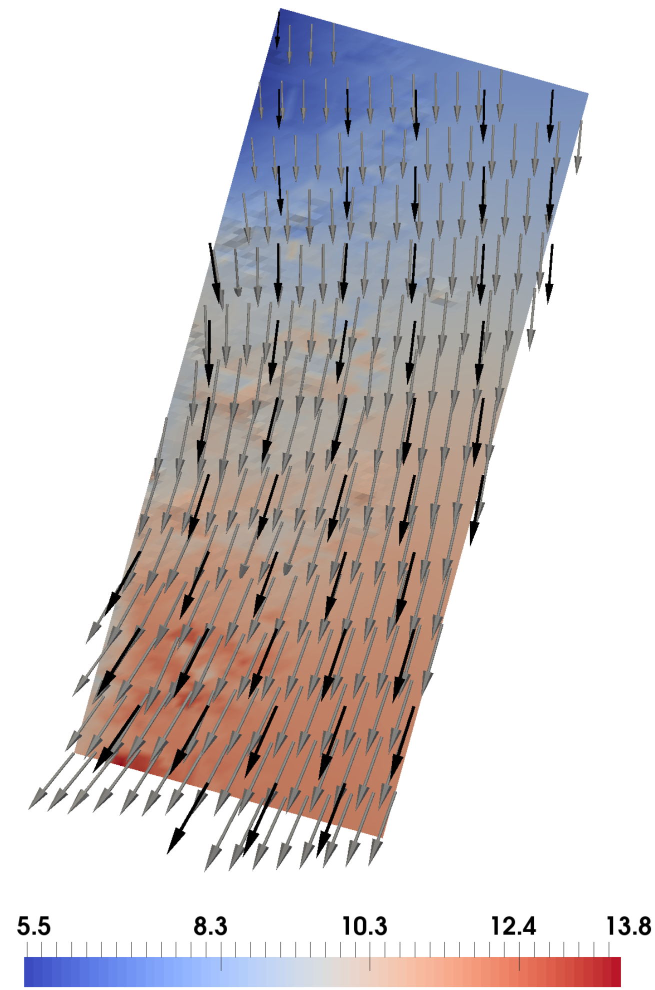
Surface triangulation

Wind Field Modeling

Wind velocities in the area of Telde



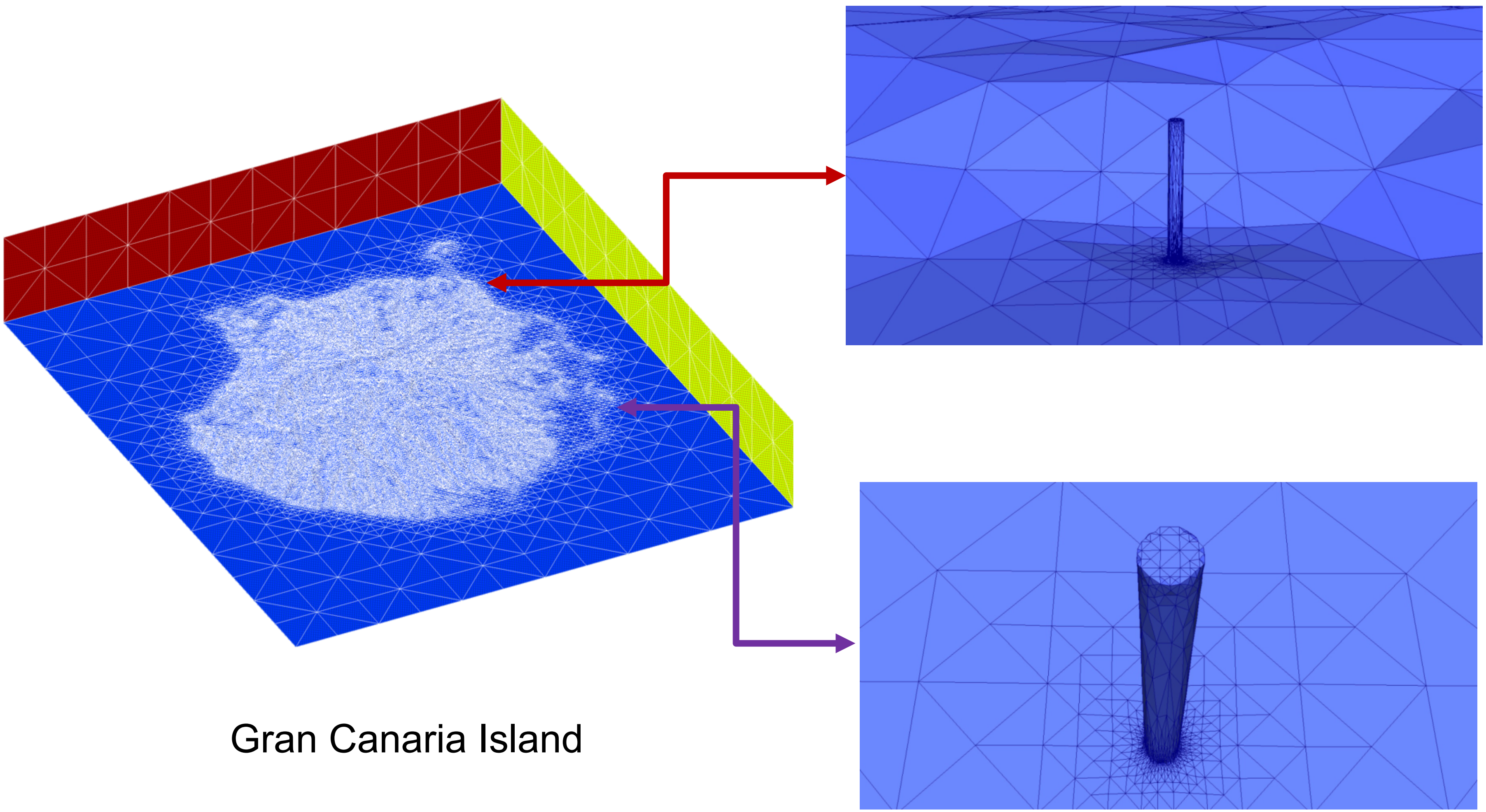
Long-lived Stable BL



Mechanically-Convective BL

Air Quality Modeling

Gran Canaria: Stacks of Jinámar and Juan Grande



Gran Canaria Island

Air Quality Modeling

Governing equations

- Convection – diffusion – reaction equation

Convection — Diffusion — Emission — Reaction

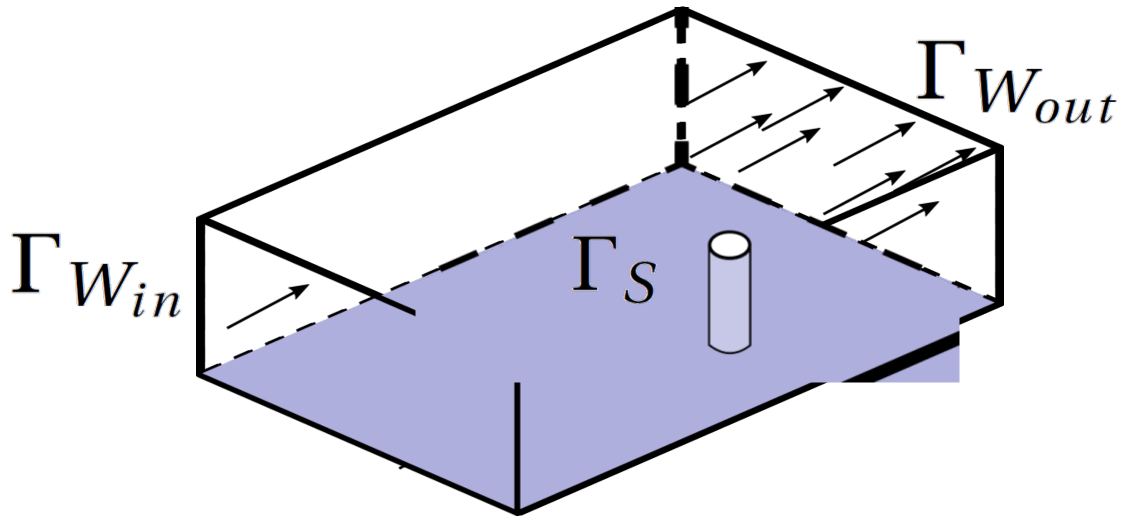
$$\frac{\partial \mathbf{c}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{c} = \nabla \cdot (\mathbf{K} \nabla \mathbf{c}) + \mathbf{e} + \mathbf{s}(\mathbf{c})$$

$$\mathbf{n} \cdot \mathbf{K} \nabla \mathbf{c} = -\mathbf{V}^d \mathbf{c} \quad \text{in } \Gamma_R$$

$$\mathbf{c}(\mathbf{x}, t) = \mathbf{c}^{out}(\mathbf{x}) \quad \text{in } \Gamma_{W_{in}}$$

$$\mathbf{n} \cdot \nabla \mathbf{c} = 0 \quad \text{in } \Gamma_{W_{out}}$$

$$\mathbf{c}(\mathbf{x}, t) = \mathbf{c}^{emi}(\mathbf{x}) \quad \text{in } \Gamma_S$$



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- Splitting
  - Strang splitting

$$\frac{d\mathbf{c}^{\star}}{dt} = \mathbf{s}(\mathbf{c}^{\star}) \qquad \text{for } t \in \left[0, \frac{\Delta t}{2}\right] \text{ and } \mathbf{c}^{\star}(\mathbf{x}, 0) = \mathbf{c}^{n}(\mathbf{x})$$

$$\frac{\partial\mathbf{c}^{\star\star}}{\partial t} + \mathbf{u}\cdot\nabla\mathbf{c}^{\star\star} = \nabla\cdot(\mathbf{K}\nabla\mathbf{c}^{\star\star}) + \mathbf{e} \qquad \text{for } t \in [0, \Delta t] \text{ and } \mathbf{c}^{\star\star}(\mathbf{x}, 0) = \mathbf{c}^{\star}(\mathbf{x}, \frac{\Delta t}{2})$$

$$\frac{d\mathbf{c}^{\star\star\star}}{dt} = \mathbf{s}(\mathbf{c}^{\star\star\star}) \qquad \text{for } t \in \left[\frac{\Delta t}{2}, \Delta t\right] \text{ and } \mathbf{c}^{\star\star\star}(\mathbf{x}, \frac{\Delta t}{2}) = \mathbf{c}^{\star\star}(\mathbf{x}, \Delta t)$$

- **Transport equation**
  - **Temporal discretization: Crank-Nicolson**

$$\mathbf{c}^{n+1} = \mathbf{c}^n + \frac{\Delta t}{2}\left[\frac{\partial \mathbf{c}^{n+1}}{\partial t} + \frac{\partial \mathbf{c}^n}{\partial t}\right]$$

  - **Spatial discretization: Least Squares FEM**

$$\mathscr{L} = \mathbf{u}\cdot\nabla - \nabla\cdot(\mathbf{K}\nabla)$$

$$\left[\mathscr{I} + \frac{\Delta t}{2}\mathscr{L}\right]\mathbf{c}^{n+1} = \mathscr{F}$$

$$\mathscr{F} = \mathbf{c}^n - \frac{\Delta t}{2}\mathscr{L}\mathbf{c}^n + \frac{\Delta t}{2}\left[\mathbf{e}^{n+1} + \mathbf{e}^n\right]$$

$$\left(\left[\mathscr{I} + \frac{\Delta t}{2}\mathscr{L}\right]v, \left[\mathscr{I} + \frac{\Delta t}{2}\mathscr{L}\right]\mathbf{c}^{n+1}\right) = \left(\left[\mathscr{I} + \frac{\Delta t}{2}\mathscr{L}\right]v, \mathscr{F}\right)$$

  - **System solver: Conjugate gradient preconditioned with an Incomplete Cholesky Factorization**

$$\mathbf{B}\mathbf{c}^{n+1} = \mathbf{f}$$

- **Chemical equation**

  - **Rosenbrock**
    - **Ros2 (Rivad)**

$$\begin{cases} \mathbf{c}_{n+1} & = \mathbf{c}_n + \frac{3}{2}\tau k_1 + \frac{1}{2}\tau k_2 \\ ((\mathbf{I}) - \gamma\tau\mathbf{J})k_1 & = \mathbf{s}(\mathbf{c}_n) \\ ((\mathbf{I}) - \gamma\tau\mathbf{J})k_2 & = \mathbf{s}(\mathbf{c}_n + \tau k_1) - 2k_1 \end{cases}$$

$\gamma = 1 \pm 1/\sqrt{2}$

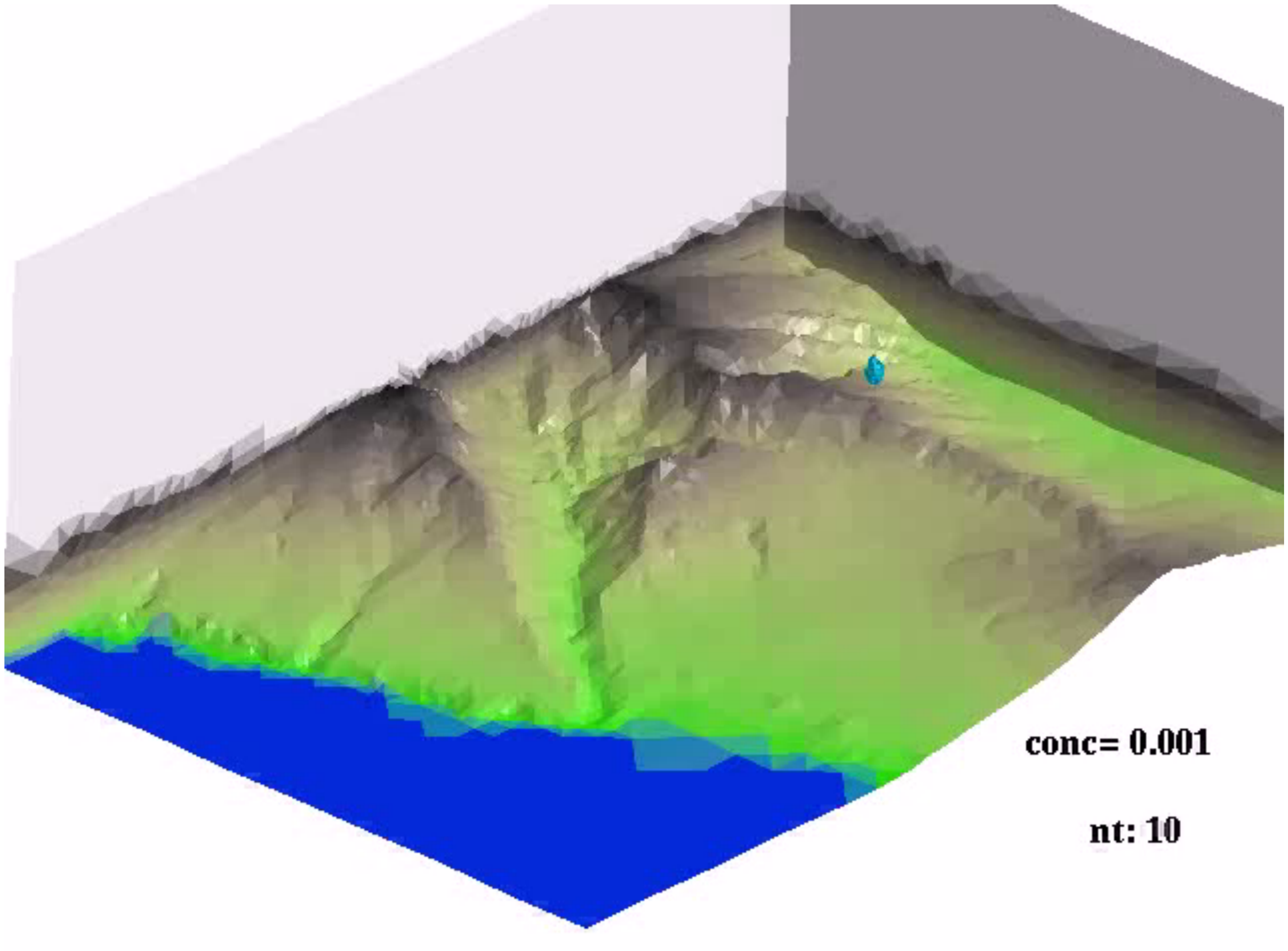
$\tau = dt$

J = Jacobian **s**(c)

    - **Ros3 (CB05)**
  - **SMVGear (CB05)**
  - **Euler Backward Iterative method (CB05)**

Air Quality Modeling

Example of realistic geometry in La Palma Island



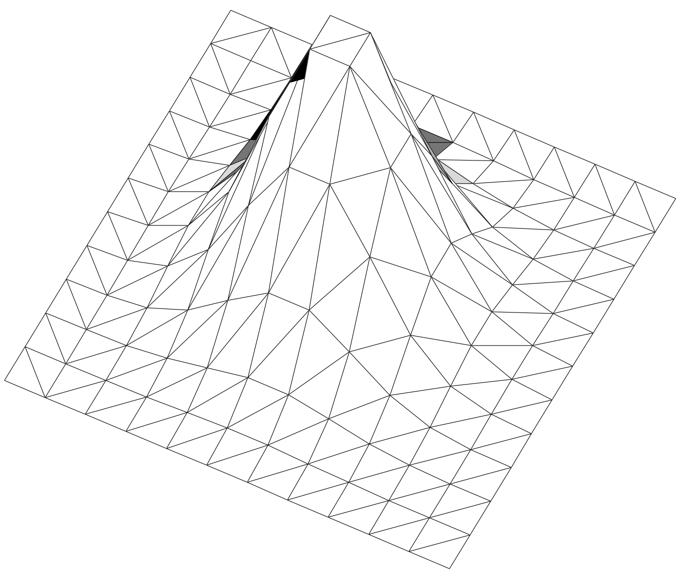
Plume evolution

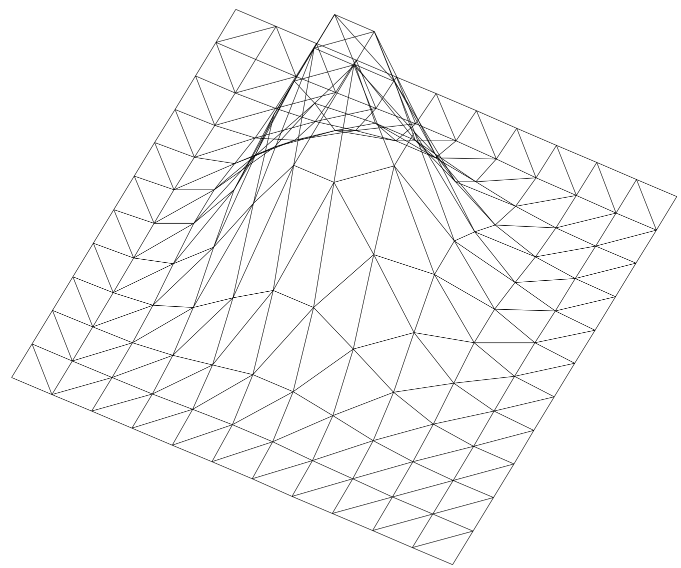
Solar Radiation Modeling

Items

1. Solar radiation estimation over a physical domain:
   -Clear Sky
   -Real Sky
   -Typical Meteorlogical Year(TMY)
2. Shadows detection
3. Satellite data an NWP
4. Forecasting models
5. Estimated and forecasted electrical production (PV or STE)

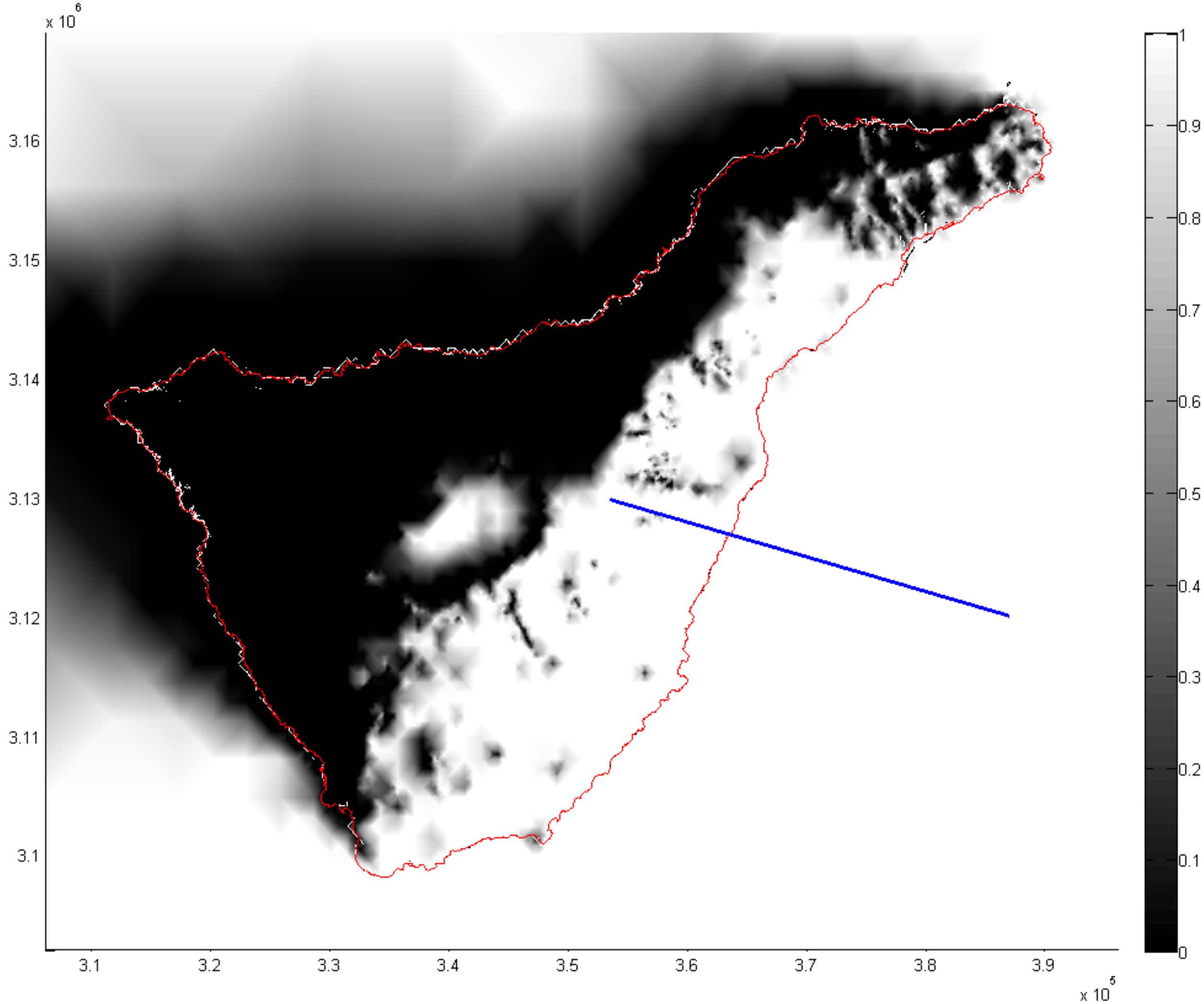
Check for each triangle Δ of the mesh, if there exists another Δ' that intersects Δ and is in front of it, i.e., the z' coordinates of the intersection points of Δ' are greater than those of Δ





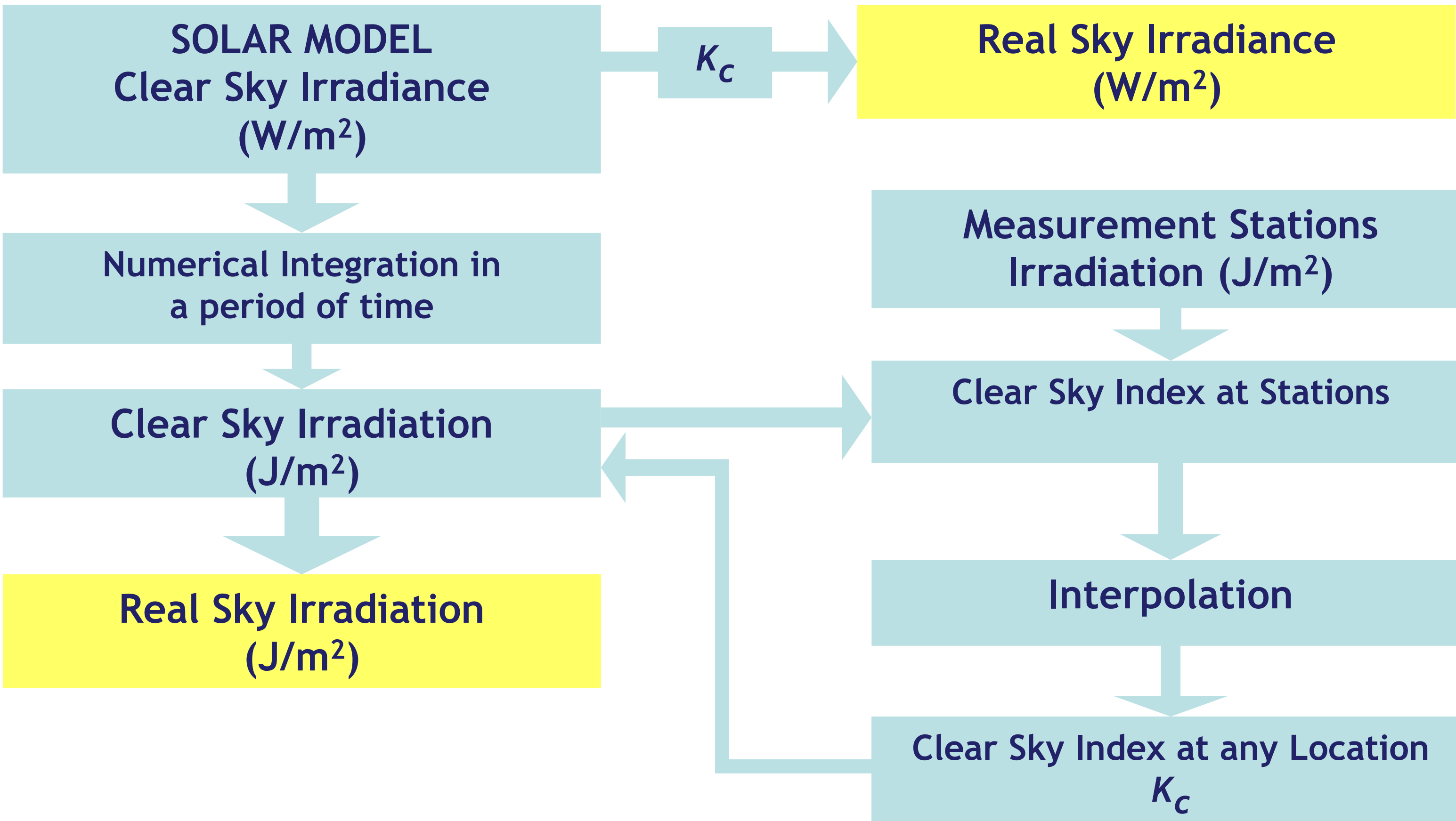
Solar Radiation Modeling

Shadows



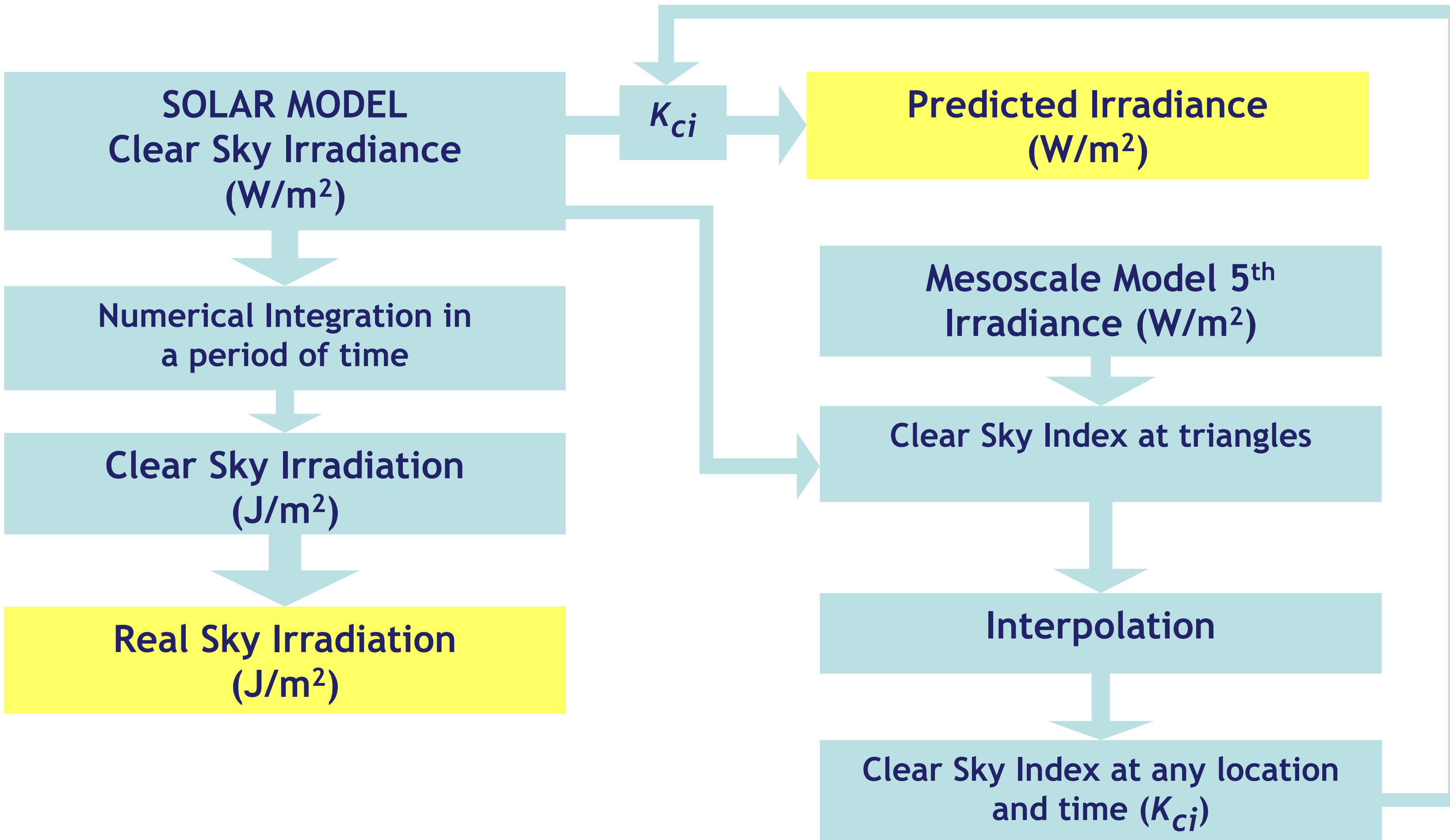
Solar Radiation Modeling

Model Summary



Solar Radiation Modeling

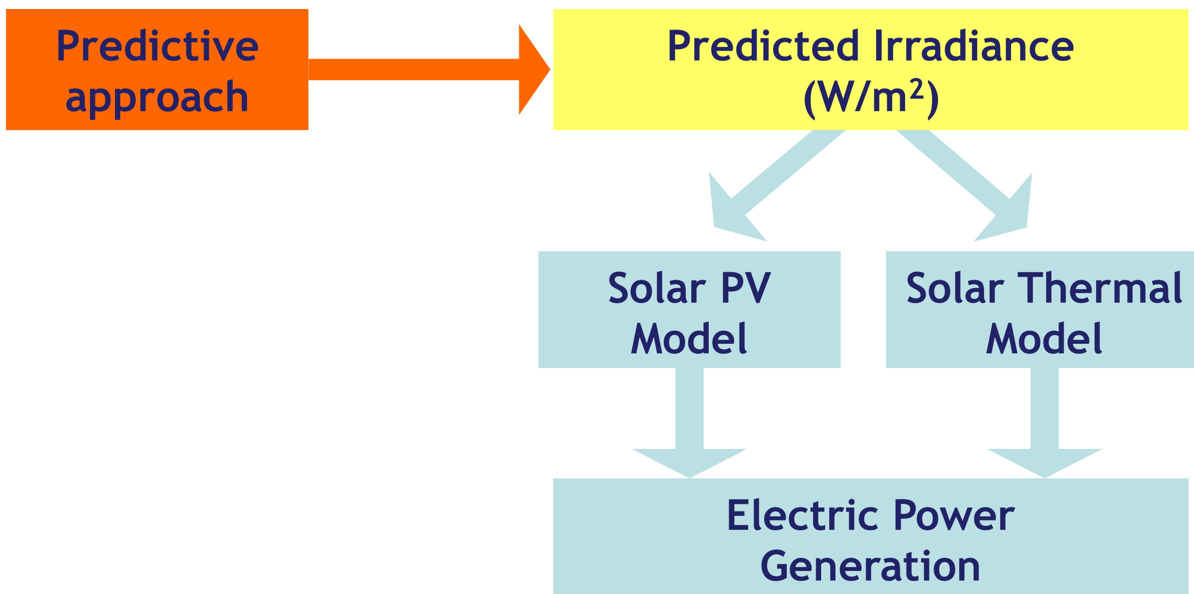
NWP Predictive Model



Solar Radiation Modeling

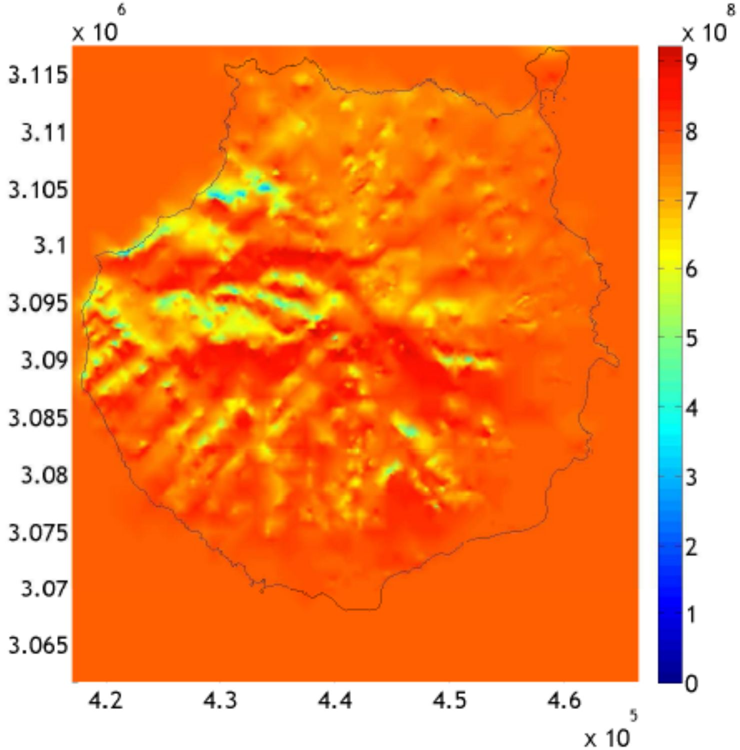
NWP Predictive Model

Solar Power Generation and Electrical Network Management:
Photovoltaic and Solar Thermal

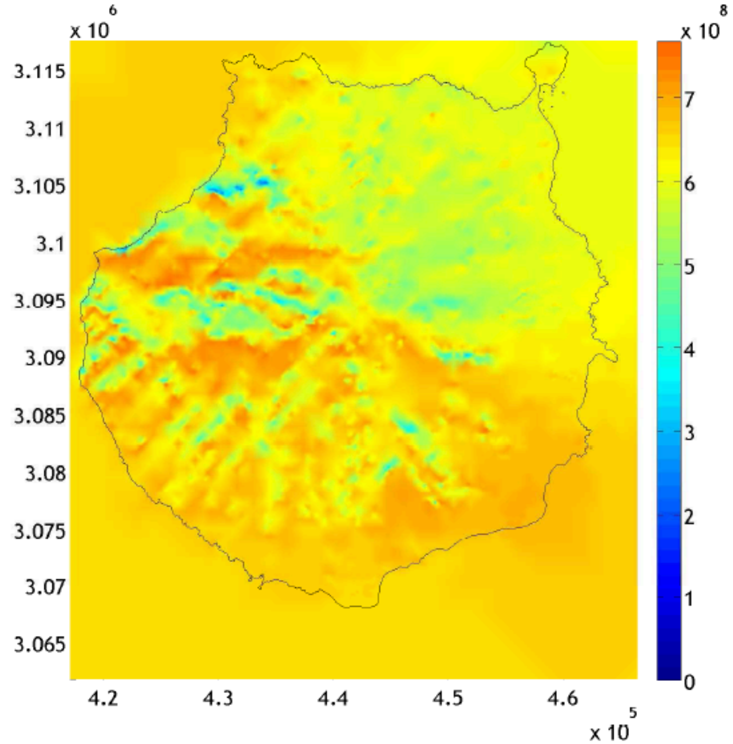


Solar Radiation Modeling

Results



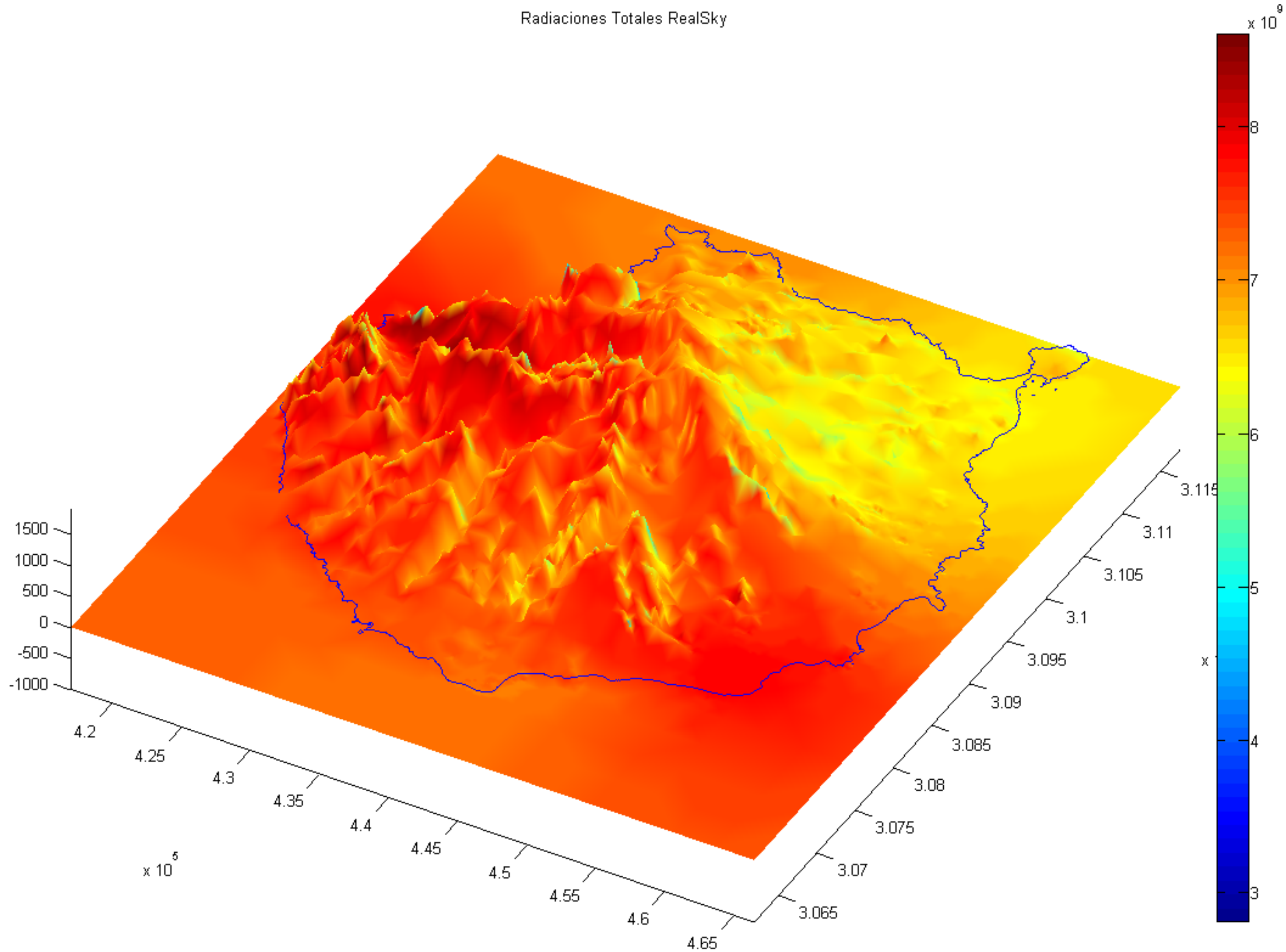
Clear sky global radiation map (J/m^2)
March TMY



Real sky global radiation map (J/m^2)
March TMY

Solar Radiation Modeling

Results



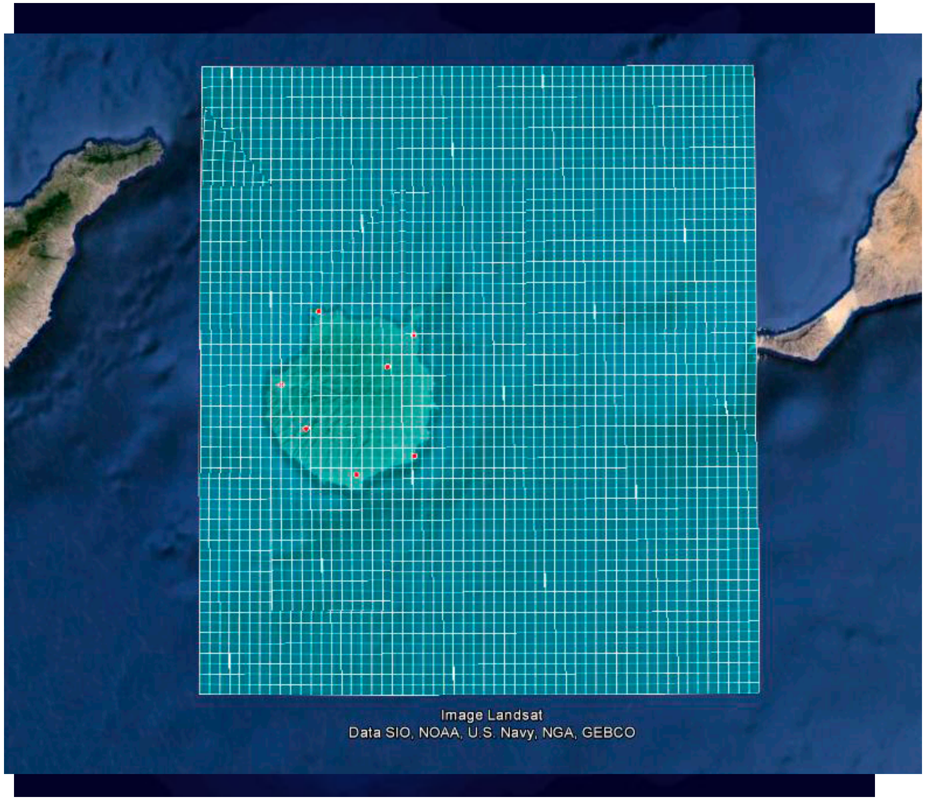
Solar Radiation Forecasting

Satellite Data

Global solar irradiation data (2010 - 2012) from six measurement stations on the Island were used.

- **CLEAR SKY,** validation of different clear sky models as Bird, ESRA or McClear (based on satellite observation of aerosols).

- **CMSAF and HELIOCLIM**, validation of different satellite data and calibrate comparing with ground data.



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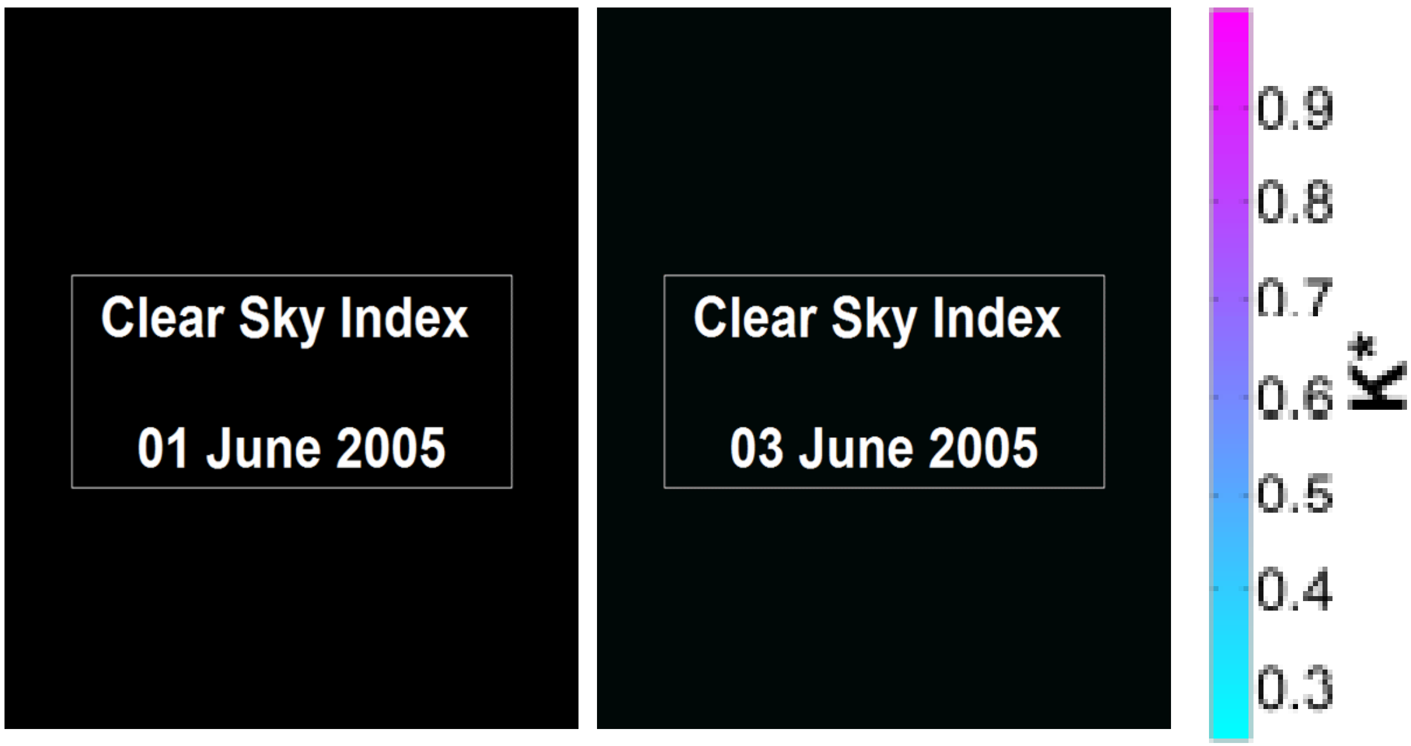
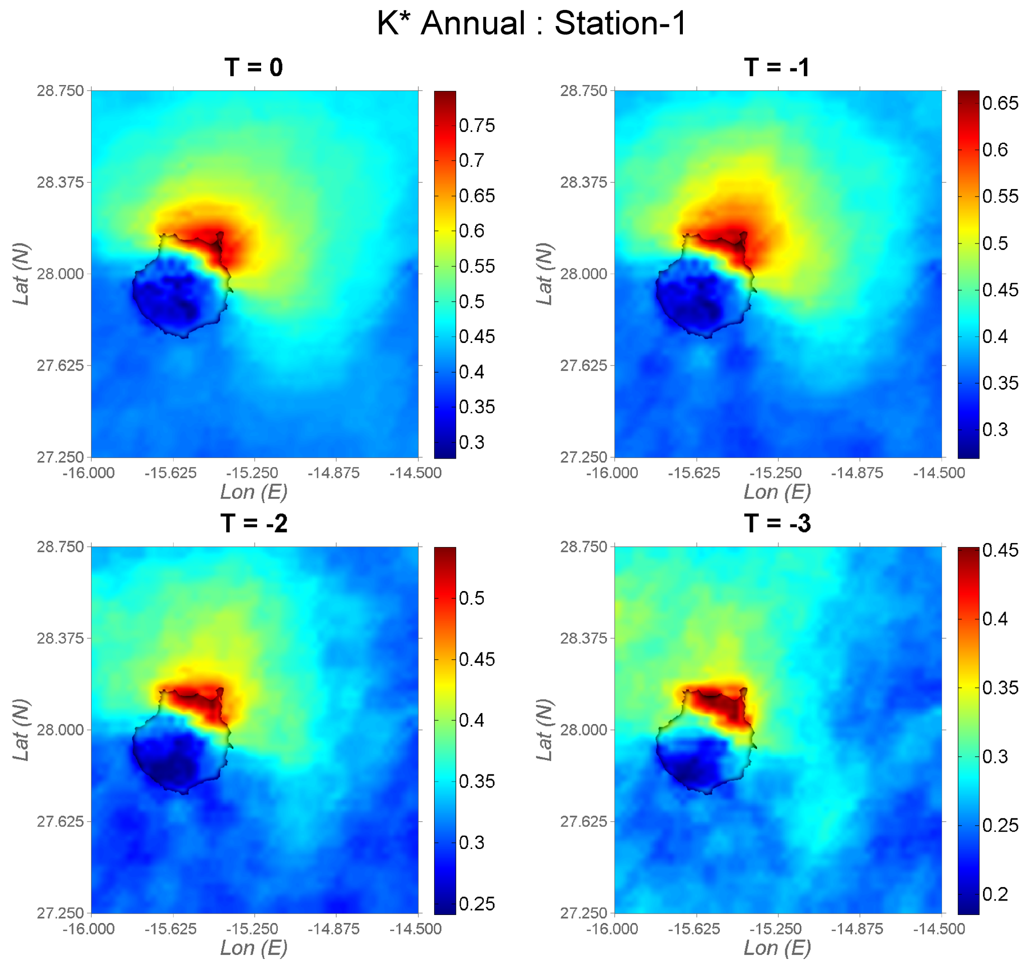
Satellite data visualize - Local thermal inversion



Solar Radiation Forecasting

Satellite Data

- **Annual data - C1 Las Palmas**



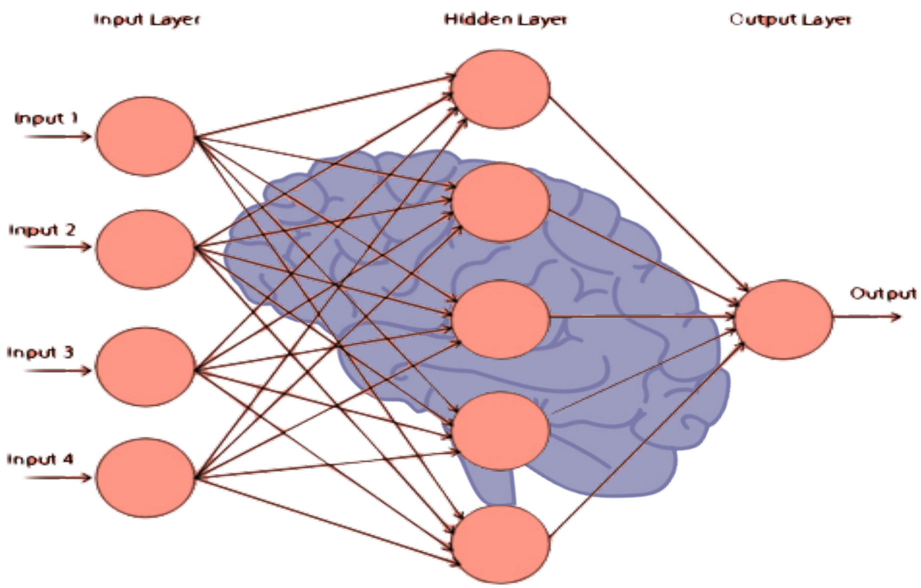
Annual Correlation

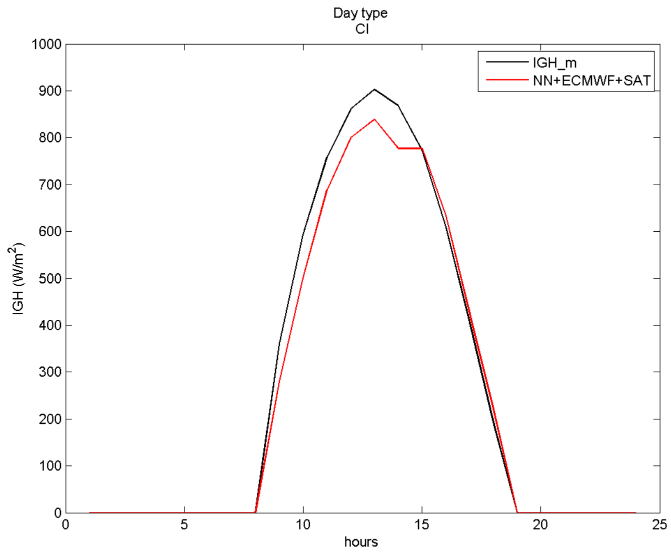
Solar Radiation Forecasting

Models

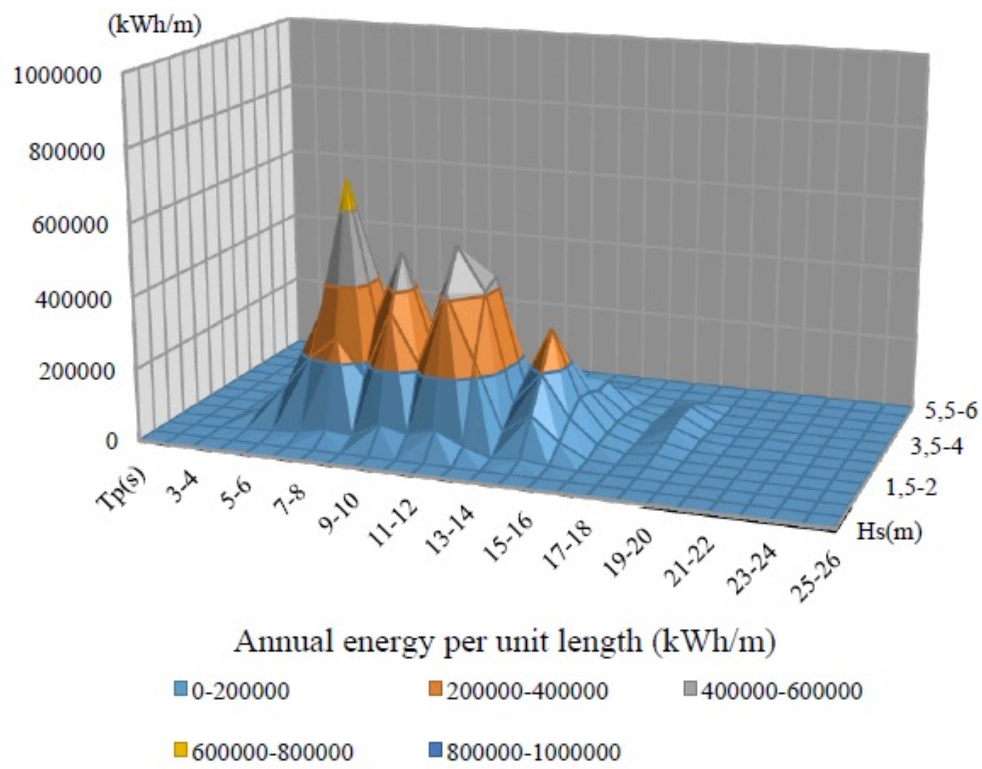
- **Solar Irradiance forecasting with different time horizons ahead (i.e. 1 to 6 hours) using ground measurement data, NWP data and satellite data as inputs.**

- **Deterministic forecasting using statistical models:**
  - **Bayesian Neural Networks**
  - **ARMA model**





- Coastal Management
  1. Harbour Agitation
  2. Spills Simulation
- Power Generation
- Pollution Problems



- Generation Tecnologies
    1. WECs
    2. Design and Modeling of Devices (W1: WEDGE & CIEMAT)
- Grid Integration: PhD Thesis

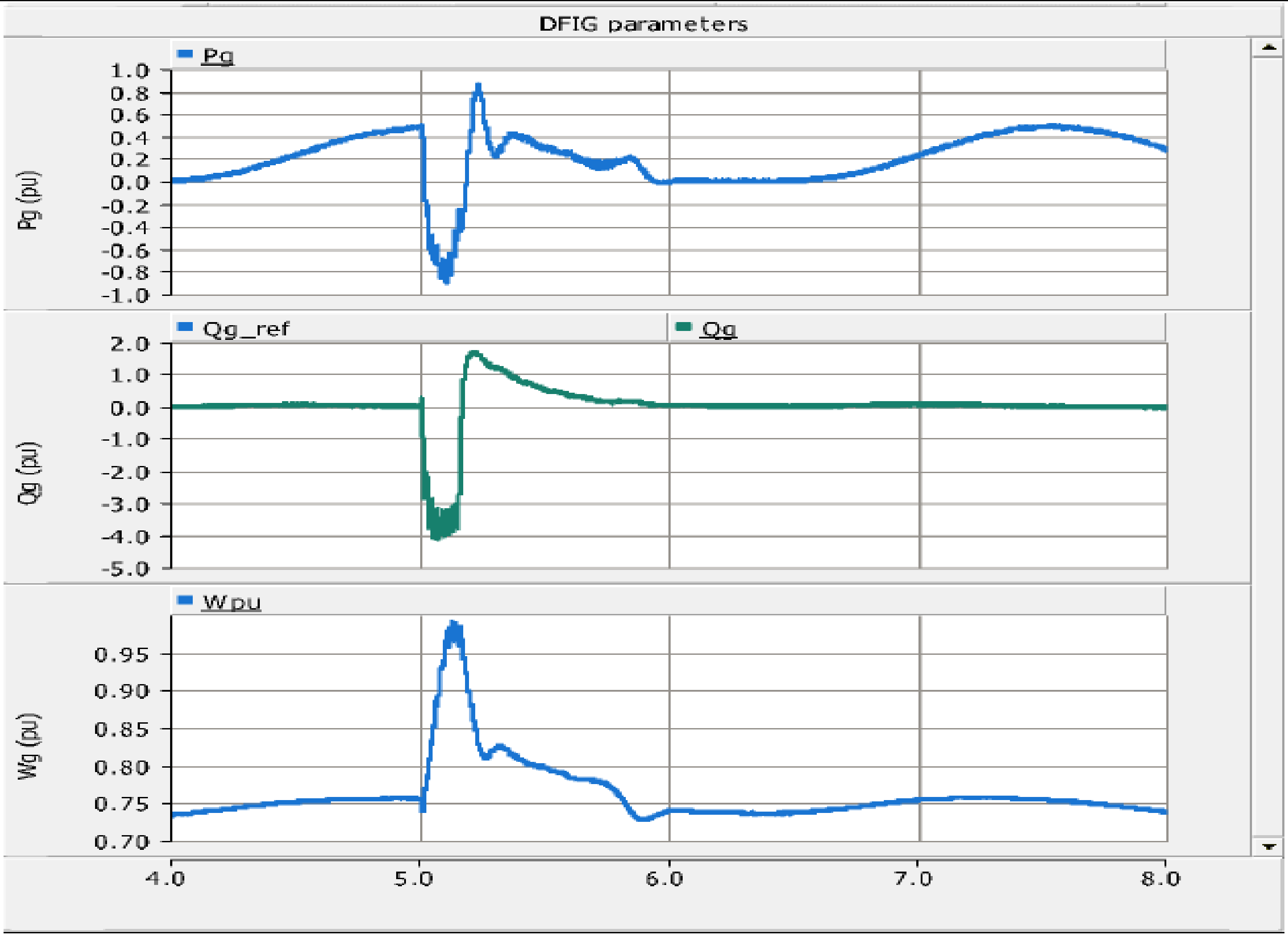


Fig. 16 OWC and DFIG parameters with 1-P SC, θ=90°