PERDIGÃO

Field experimental planning and how US participants can help

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Microscale Modeling of Complex Terrain Flows
University of Notre Dame, Notre Dame, Indiana (USA)
2014 September 25–26

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Contents

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The path ...

1. Developments in wind energy: larger and more powerful machines, the need for new tools or update of now old tools Wind European Atlas (1989), linear flow models)
2. Awareness of the problem (scientific community, wind energy industry, governments)
   - In Europe:
     - TPWind
     - Strategic Research Agenda: Market Deployment Strategy from 2008 to 2030
     - TPWind brochure: The way forward,
     - European Energy Research Alliance (EERA)
     - European Wind Initiative
     - *Strategic Energy Technology Plan* (SET-Plan)
   - in the US:
     - Research Needs for Wind Resource Characterization
3. 25-Jan-2012: EERA Workshop on Wind Conditions
4. Jul-2012 : Call ENERGY.2013.10.1.2 - ERA-NET Plus - European wind resources assessment
5. 19-Jul-2013: Meeting in Notre Dame

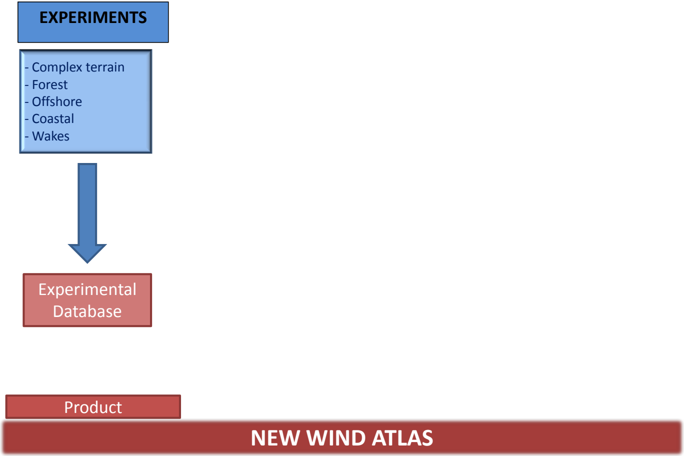
Perdigao ...

- *Oct-2005*: first attempt to locate a proper site
- *Oct-2007*: identification of the main characteristics of such site
- *Jan-Dec 2008*: analysis of 4 possible sites
- *Dec-2009*: site selection
- *24-Jan-2011*: visit Peter Taylor, Erik Petersen, Ib Troen, Michael Courtney, Hans Jorgensen.
- *26-Jan-2011*: presented at EERA Workshop on Wind Conditions
- *13 Oct-2012*: visit Ned Patton.
- *4-5 Sep-2014*: visit Steve Oncley, Joe Fernando, Julie Lundquist.

NEWA Chart

NEW WIND ATLAS

NEWA Chart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- Forest
- Offshore
- Coastal
- Wakes
Experimental Database
Product
NEW WIND ATLAS

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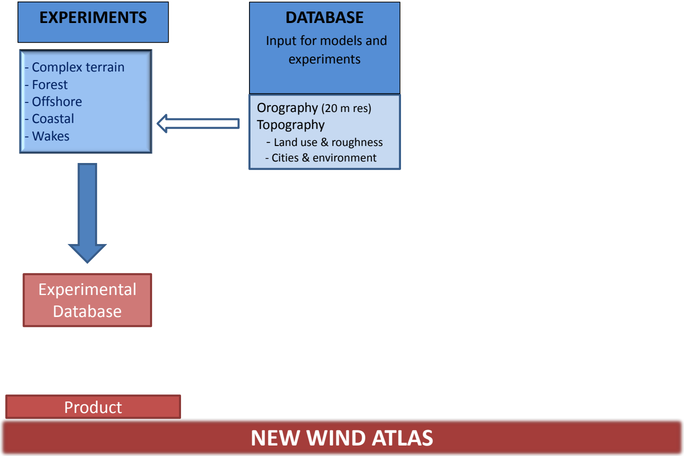

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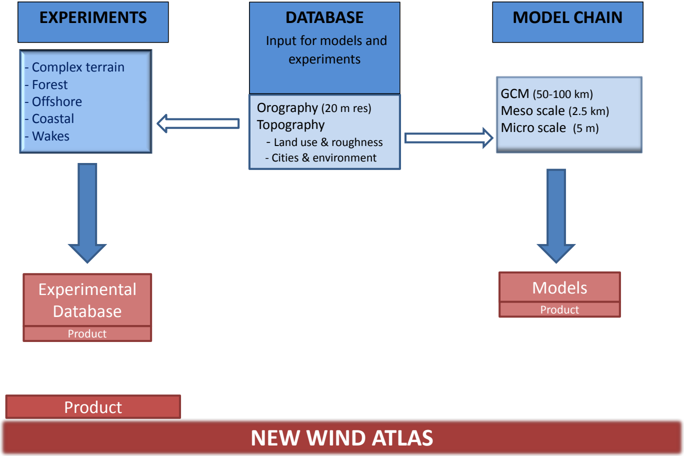

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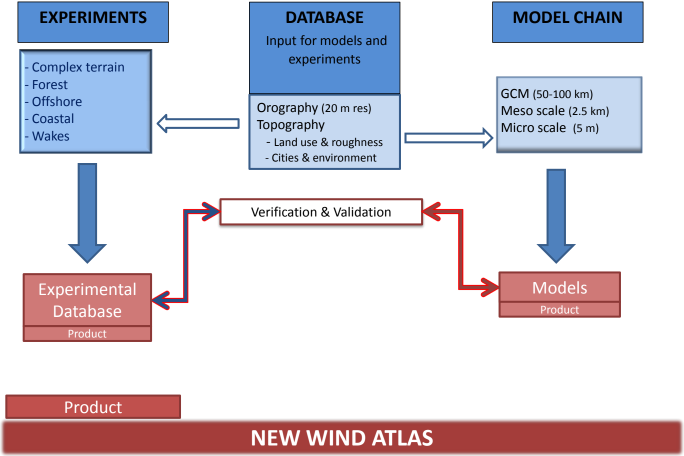
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Orography (20 m res)
Topography
- Land use & roughness
- Cities & environment
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GCM (50-100 km)
Meso scale (2.5 km)
Micro scale (5 m)
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Models
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NEW WIND ATLAS

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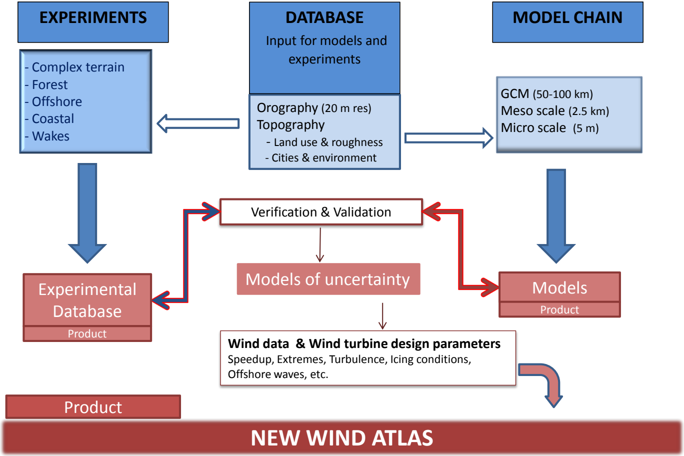
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Speedup, Extremes, Turbulence, Icing conditions, Offshore waves, etc.
Product
NEW WIND ATLAS

The 7 questions

1. Identify critical scientific issues that stymie prediction of microscale flows in complex terrain, especially focusing on wind energy resources, urban and defense applications;
2. Review novel research tools that may help improve microscale predictions in complex terrain in leaps;
3. Discuss opportunities to closely collaborate with the European **ERANET+: New European Wind Atlas (NEWA) project**;
4. **Map out research topics and instrumentation deployments that would augment ERANET+ project field studies to be conducted in Perdigão (Portugal)**, in 2016-2017;
5. Develop a science plan for field deployments in Perdigão so that the US Investigators can seek research support from national agencies, especially via NSF SPO/EDO process, to collaborate with European counterparts;
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Atmospheric boundary layer flow over hills

WHY? Triggered by scientific enquiry and designed in the framework of Jackson and Hunt (1978) [1]

Applications: pollution and dispersion studies, micro-meteorology, boundary layer parameterisation in large scale NWP, local weather and climate, wind loads in structure and wind energy (in its infancy).

FIELD EXPERIMENTS:

1979–1986 11 sites [?] : Brent Knoll, Pouzauges Hill, Black Mountain, Ailsa Craig, Kettles Hill, Bungendore Ridge, Sirhowy Valley, Blashaval, Askervein Hill and Nyland Hill (England, Scotland, France, Australia and Canada)

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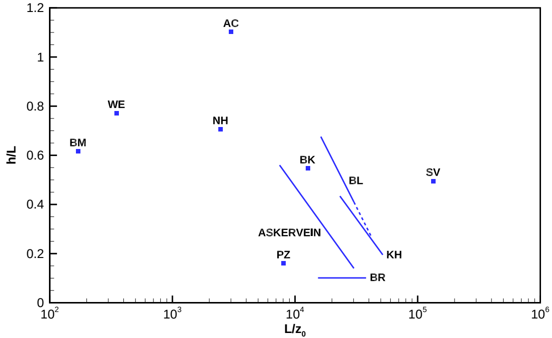
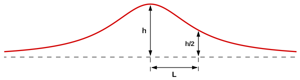
Parameter space / Hill scales





	L, h	h/L	L/z_0
Black Mount.	275, 170	0.62	2×10^2
Askervein	279, 116	0.42	1×10^4
Kettles Hill	520, 100	0.19	5×10^4
Bungendore	75, 7.5	0.10	4×10^4
Nyland Hill	100, 70	0.70	3×10^4

typically have lengths $\approx$ 1 km and heights $\approx$ 100 m
hills not mountains

KEY SENTENCES (Taylor, Mason & Bradley (1987) [7])

- if additional field studies are to be undertaken, it would be desirable that sites be chosen to extend this L/z_0 range.
  - studies with $L/Z_0 \approx 10^3$ are of particular interest as many hills are tree-covered

    Such large roughness elements generate local flows on their own scale and measurements are difficult as they must be made well above the height of the roughness elements.
  - (high end) it would be highly desirable ... to conduct a field study with $L/z_0 \approx 5 \times 10^5$.
    Note, however that as L increases, thermal, slope wind effects can begin to dominate and directional shear in the upstream profile may become important

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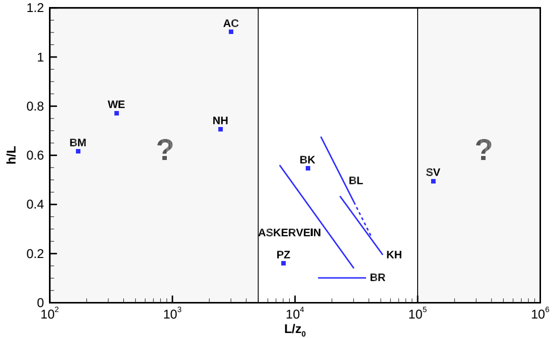

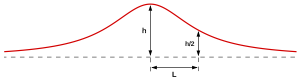

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Challenges

- Wind turbines:
  - more powerful, larger, higher and located at remote places
    $\Longrightarrow$ no (or very few) measurements
  - operate between 60 and 300 m agl $\equiv$ no man's land (or a wind turbine's land)

- limit for ground based measurements

Met towers

Height	Mast	Equip	Mast+Equip
80	30000	34000	64000 €
100	38000	40000	78000 €
120	48000	48000	96000 €
80	39000	44200	83200 $
100	49400	52000	101400 $
120	62400	62400	124800 $

- remote sensing: which Lidar type? short (Zephyr) or long range (Leosphere) sodars
- UAVs will be most useful

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Science questions

Engineering: wind turbine, wind energy, wind engineering
Large structures operating under extreme conditions, of high wind and high turbulence

$\Downarrow$

characterise both the wind and loads on structure

Atmospheric flows: flow separation, related to terrain inclination and roughness, roughness change, stratification, gravity waves, valley flows recirculation, separated flow impinging on a hill

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characterise the wind in a fine spatial mesh

Climate: energy balance, water cycle, pollution, forest fires

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Criteria

General Criteria

1. Higher and steeper than Askervein $\Longrightarrow$ flow separation
2. Surrounded by flat terrain for well defined impinging flow; i.e. boundary conditions)
3. Simple or complex ?
   - not too complex
   - mildly complex
   - a complexity that one can understand
4. Quasi two-dimensional $\Longrightarrow$ long ridge
5. Dominant winds perpendicular to ridge
6. Land cover (?)

Two Ridges (Two Hills)?

- Two ridges and because two-dimensional (condition 4)
  $\Longrightarrow$ two parallel ridges.
- Two parallel ridges is the best nature can make to mimic a sequence of periodical hills, and please mathematicians.
- Full advantage of the experiment. Two parallel ridges because:
  - the lee side flow is the also the flow impinging on the second ridge (two birds with one stone)
  - the lee side of the first hill and the upwind side of the second hill, make up the valley flow (three birds with one stone)
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6. Land cover (?)

Two Ridges (Two Hills)?

- Two ridges and because two-dimensional (condition 4)
  $\Longrightarrow$ two parallel ridges.
- Two parallel ridges is the best nature can make to mimic a sequence of periodical hills, and please mathematicians.
- Full advantage of the experiment. Two parallel ridges because:
  - the lee side flow is the also the flow impinging on the second ridge (two birds with one stone)
  - the lee side of the first hill and the upwind side of the second hill, make up the valley flow (three birds with one stone)
- Where on Earth can we find it?

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Criteria

General Criteria

1. Higher and steeper than Askervein $\Longrightarrow$ flow separation
2. Surrounded by flat terrain for well defined impinging flow; i.e. boundary conditions)
3. Simple or complex ?
   - not too complex
   - mildly complex
   - a complexity that one can understand
4. Quasi two-dimensional $\Longrightarrow$ long ridge
5. Dominant winds perpendicular to ridge
6. Land cover (?)

Two Ridges (Two Hills)?

- Two ridges and because two-dimensional (condition 4)
  $\Longrightarrow$ two parallel ridges.
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- Where on Earth can we find it?

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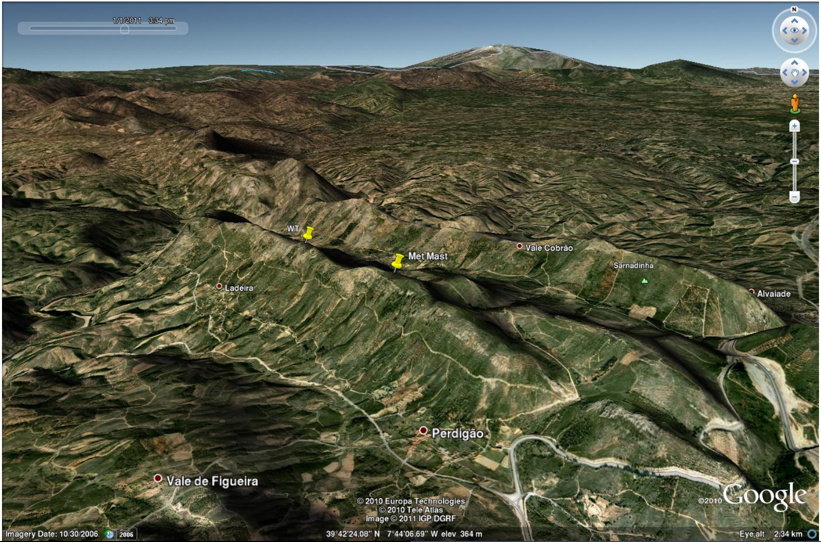
Terrain



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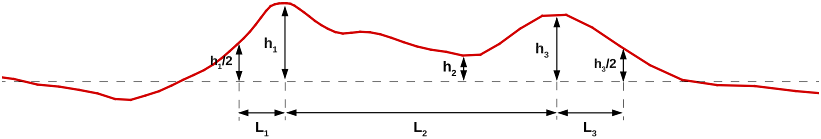
Length scales

	h_1	L_1	L_1/z_0	h_1/L_1	deg	h_3	L_3	L_1/z_0	h_1/L_3	deg	ℓ
A	200	425	4250 - 425	0.47	13	255	510	5100 - 510	0.50	14	37 - 25
B	230	308	3075 - 309	0.75	21	205	395	3950 - 395	0.52	15	29 - 19
C	215	245	2450 - 245	0.88	24	205	305	3050 - 305	0.67	19	25 - 16
D	255	360	3600 - 360	0.71	20	210	395	3950 - 395	0.53	15	33 - 22
E	265	450	4500 - 450	0.59	16	230	698	6975 - 698	0.33	9	39 - 26



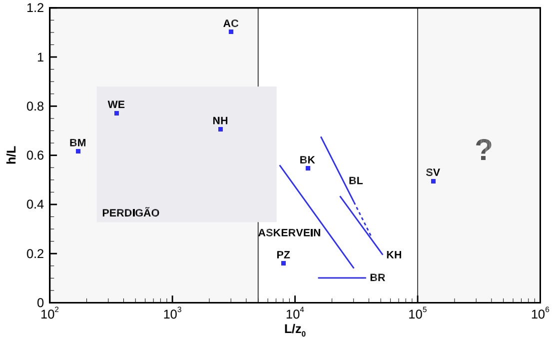
Inner layer depth

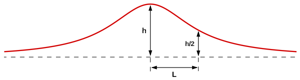
$$\frac{\ell}{L}\ln\left(\frac{\ell}{z_0}\right) = 2\kappa^2$$

	h	L	z_0	L/z_0	h/L	deg	ℓ
Black Mountain	170	275	1.140	241	0.62	17	28
Askervein	116	279	0.030	9300	0.42	12	15
Kettles Hill	100	520	0.010	52000	0.19	5	22
Bungendore Ridge	7.5	75	0.002	37500	0.10	3	3
Nyland Hill	70	100	0.004	25000	0.70	19	5

Flow separation or not ?? [8]

Parameter space / Hill scales





	L, h	h/L	L/z_0
Black Mount.	275, 170	0.62	2×10^2
Askervein	279, 116	0.42	1×10^4
Kettles Hill	520, 100	0.19	5×10^4
Bungendore	75, 7.5	0.10	4×10^4
Nyland Hill	100, 70	0.70	3×10^4

typically have lengths $\approx$ 1 km and heights $\approx$ 100 m
hills not mountains

KEY SENTENCES (Taylor, Mason & Bradley (1987) ?)

- if additional field studies are to be undertaken, it would be desirable that sites be chosen to extend this L/z_0 range.
  - studies with $L/Z_0 \approx 10^3$ are of particular interest as many hills are tree-covered

    Such large roughness elements generate local flows on their own scale and measurements are difficult as they must be made well above the height of the roughness elements.
  - (high end) it would be highly desirable ... to conduct a field study with $L/z_0 \approx 5 \times 10^5$.
    Note, however that as L increases, thermal, slope wind effects can begin to dominate and directional shear in the upstream profile may become important.

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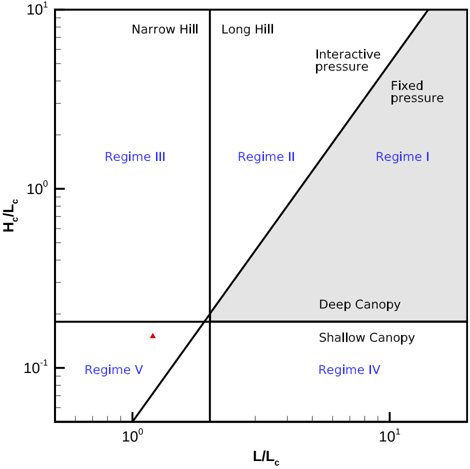
Hill and canopy scales

Poggi, Katul, Finnigan & Belcher (2008) [9]



Canopy adjustment length-scale

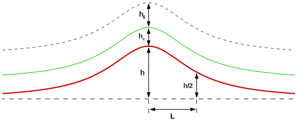
$$L_c = 1/(c_d a) \approx 4h_c/LAI$$

Eucaliptus

$$2 < LAI < 3.5$$

$$20 < h_c < 40$$

$$3 < L_c < 20$$



$$3 < L/L_c < 20$$

$$0.25 < h_c/L_c < 1.75$$

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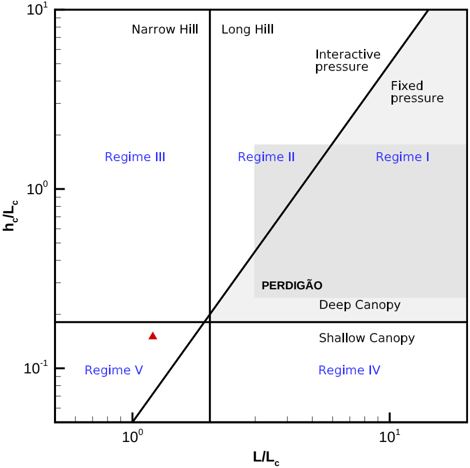
Hill and canopy scales

Poggi, Katul, Finnigan & Belcher (2008) [9]



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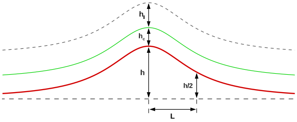

$$3 < L/L_c < 20$$
$$0.25 < h_c/L_c < 1.75$$

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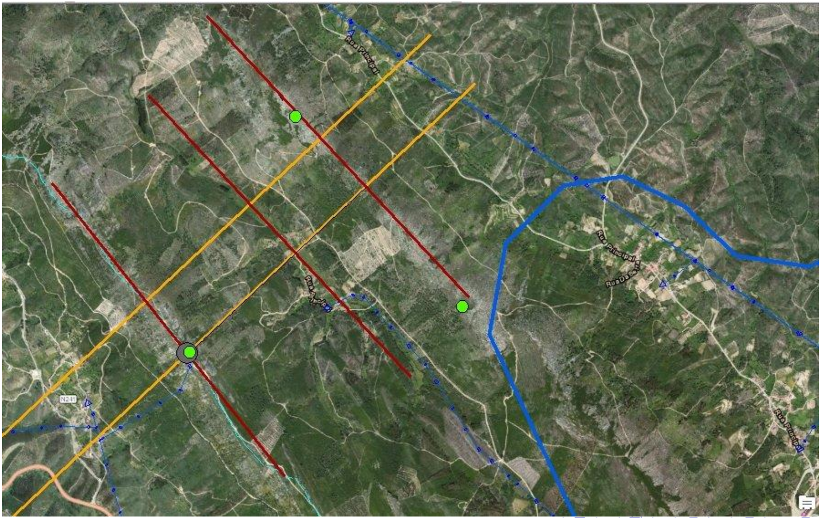
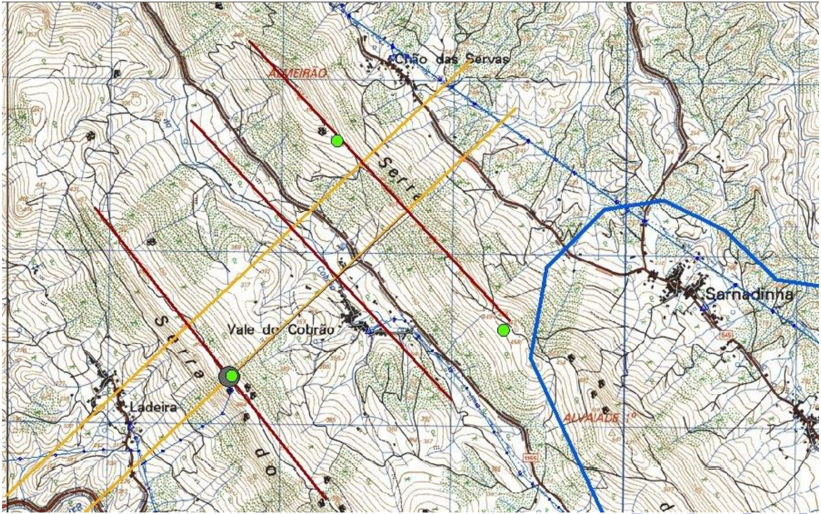
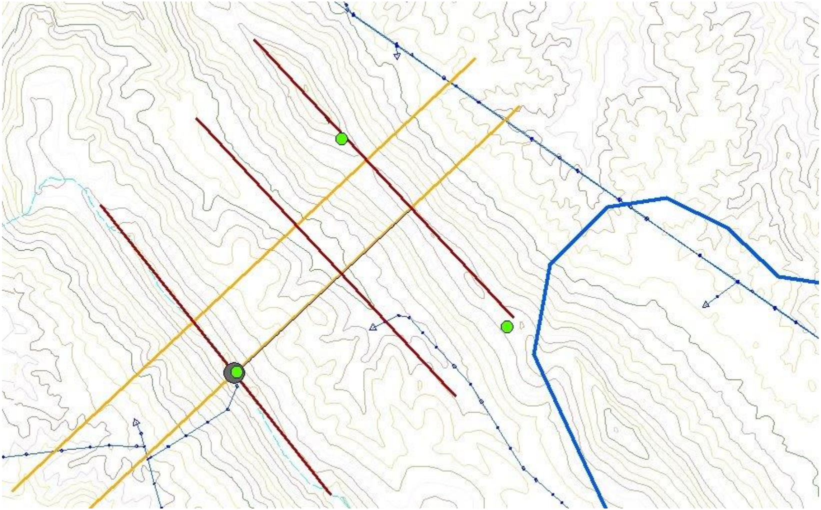
Terrain



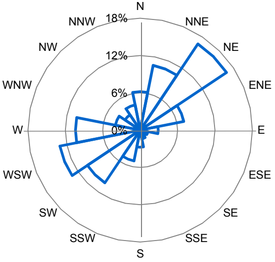
Terrain

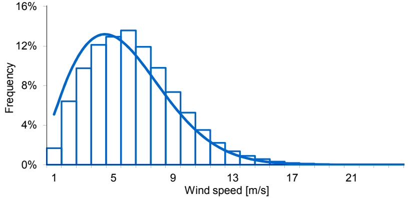

Chão das Servas
ALMEIRÃO
Serra
Vale do Cobrão
Ladeira
Sarnadinha
ALVAIADE

Terrain



Wind characteristics (mean field) [Jan 2002–Dec 2004 (3 years)]





- Easting, Northing [Datum Lx IGeoE; m]: 233999,303531, at an altitude of 489 m
- Predominant winds (NE and WSW), perpendicular to the ridges

Height (agl)	40
Wind speed (aver)	5.8
Wind speed (max)	24.8
Turb. Int.	9.1

- Mean wind speed $\approx 6\,\mathrm{m\,s^{-1}}$
- Maximum wind speed $\approx 20\,\mathrm{m\,s^{-1}}$

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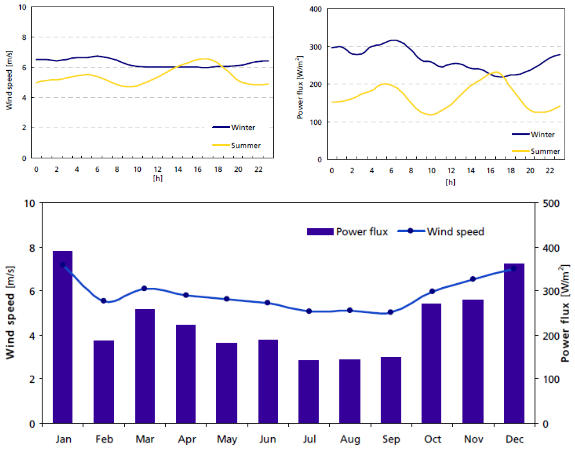
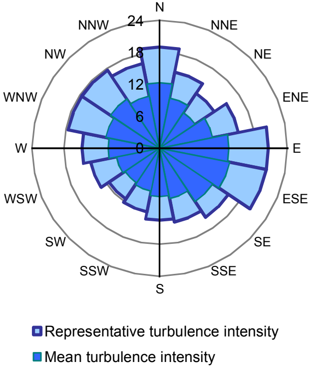
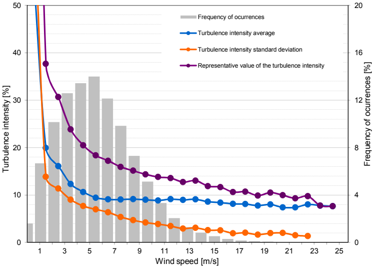
Wind characteristics (mean field) [Jan 2002–Dec 2004 (3 years)]

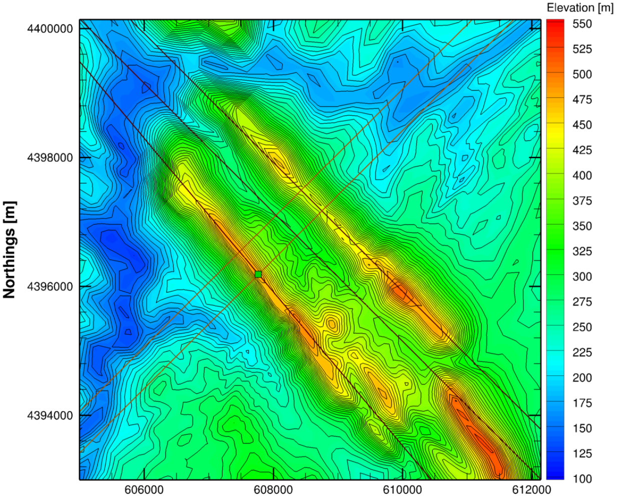


Wind characteristics (turbulent field) [Jan 2002–Dec 2004 (3 years)]

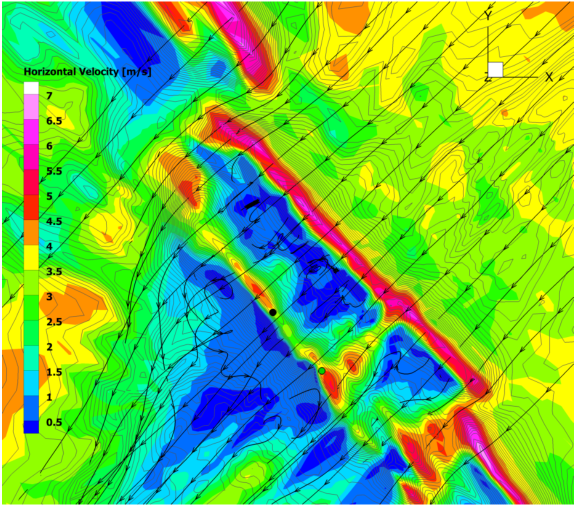




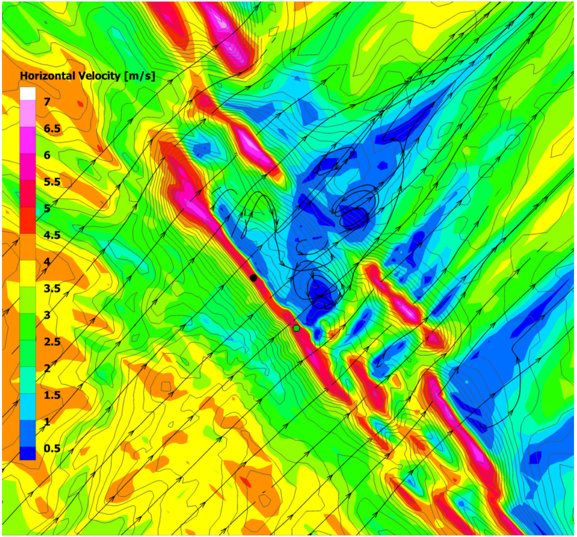
Terrain


Elevation [m]
550
525
500
475
450
425
400
375
350
325
300
275
250
225
200
175
150
125
100
Northings [m]
4400000
4398000
4396000
4394000
606000
608000
610000
612000

NE Winds (40 m agl)

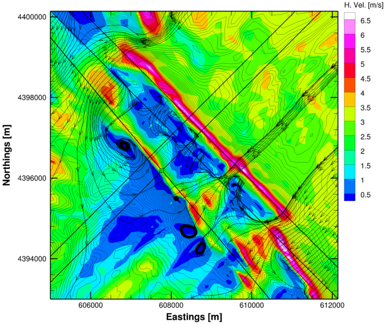


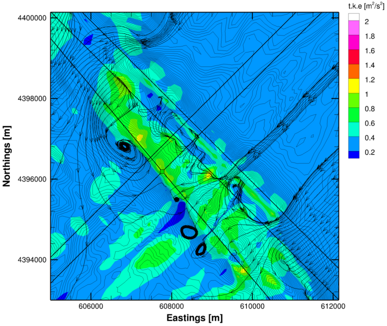
SW Winds (40 m agl)



Wind speed and turbulence (NE) 20 m agl

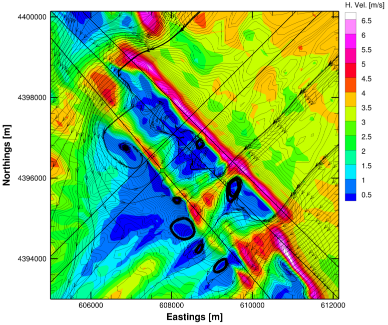
NE winds / 20 m agl ⟸





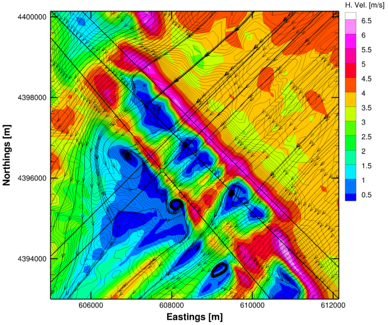
Wind speed and turbulence (NE) 40 m agl

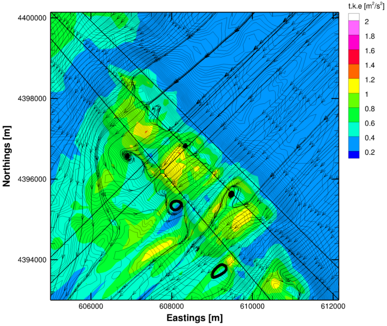
NE winds / 40 m agl ⟸



Wind speed and turbulence (NE) 80 m agl

NE winds / 80 m agl ⟸





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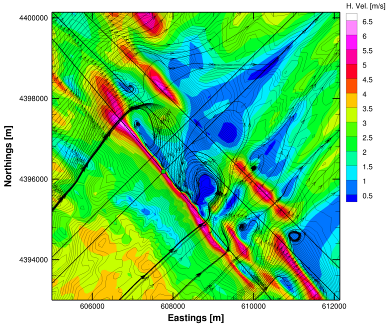
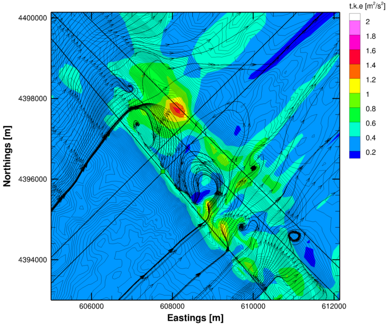
Wind speed and turbulence (SW) 20 m agl

SW winds / 20 m agl ⟹





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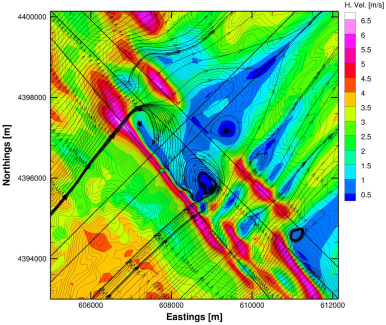
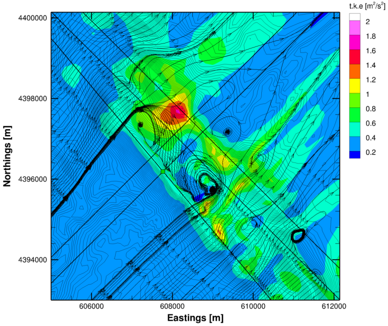
Wind speed and turbulence (SW) 40 m agl

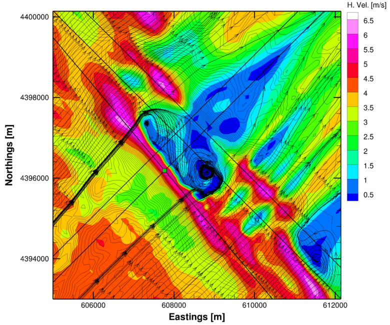
SW winds / 40 m agl $\Longrightarrow$

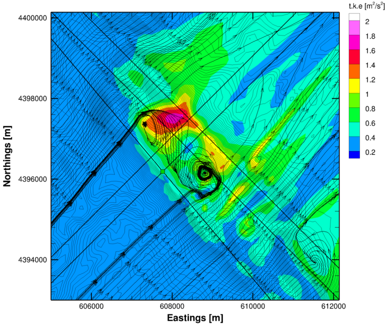




Wind speed and turbulence (SW) 80 m agl

SW winds / 80 m agl $\Longrightarrow$





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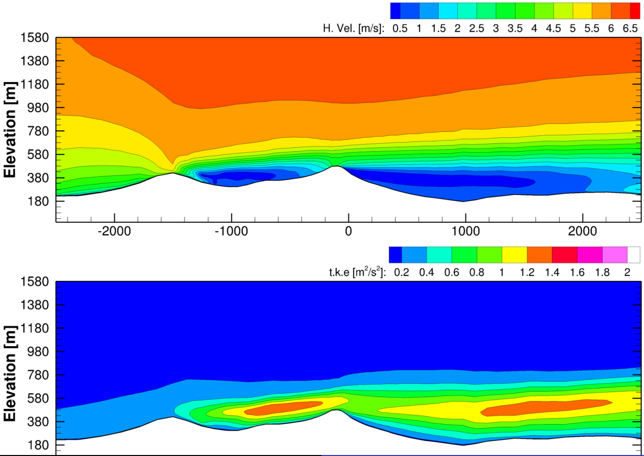
Mean wind and turbulence (NE)

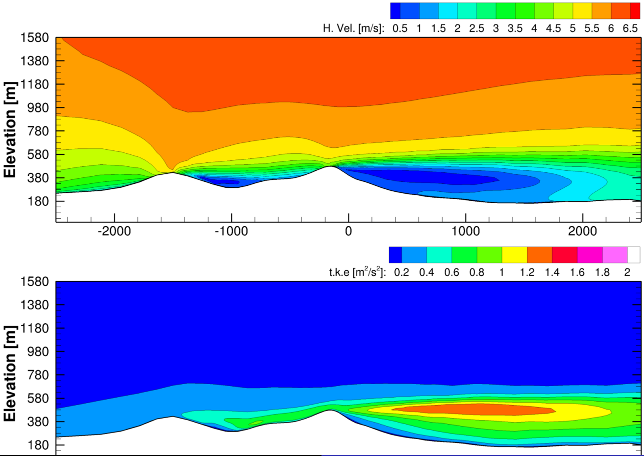
Transect A (wind turbine)



Mean wind and turbulence (NE)

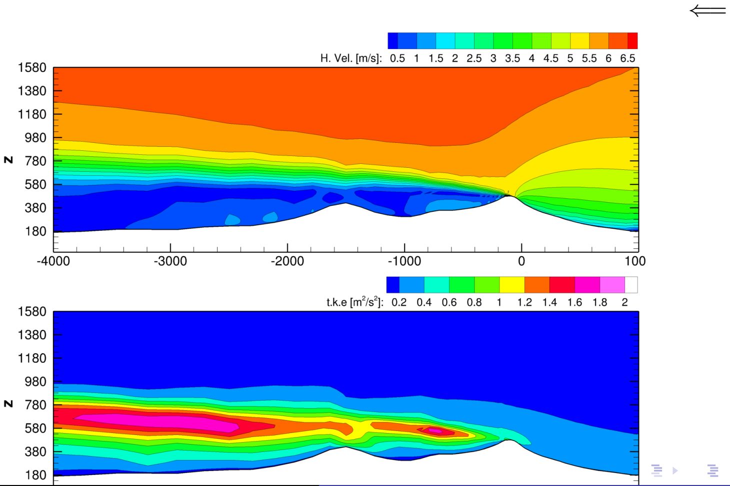
Transect A (gap)

⇐



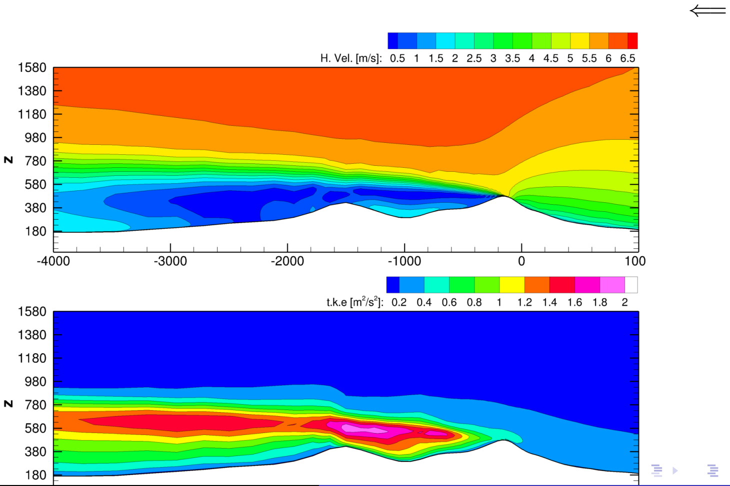
Mean wind and turbulence (SW)

Transect A (wind turbine)

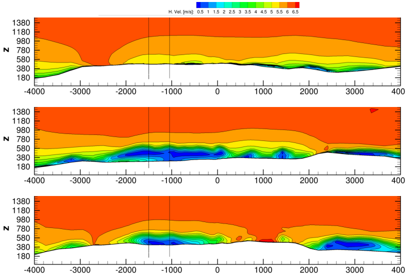


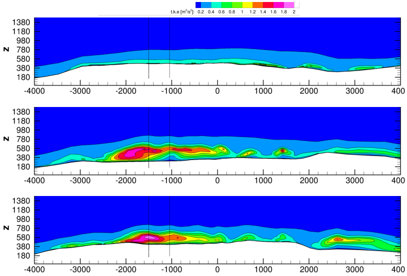
Mean wind and turbulence (SW)

Transect A (gap)



Wind speed and turbulence (SW)





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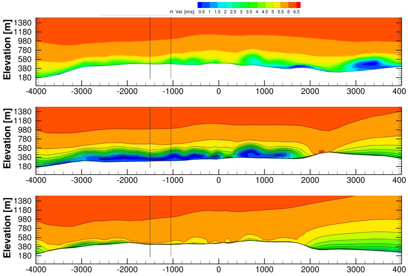

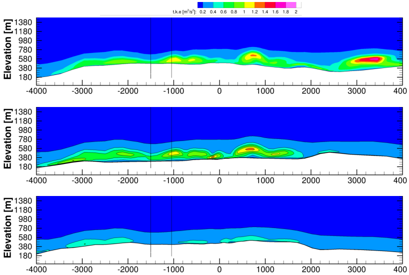

Logistics

BEFORE (12 months)

1. Identify land parcels and owners
2. Contact and negotiate land use and access
3. Terrain and land coverage mapping
4. Determine met masts location, based on 2, 3 and 8
5. Needs and availability of scientific equipment(?)
6. Transport and purchase of scientific equipment
7. Secure storage of equipment
8. Flow predictions to assist met mast location and variables to be measured
9. Met mast: construction and installation, installation of scientific equipment

DURING (12 months)

- Support visitors, during short intensive campaigns:
  - summer
  - winter
  - rainy days
  - high and low winds
  - ...
- Daily forecasts
- ...

AFTER (4 months)

- Dismantle and ship equipment

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  - high and low winds
  - ...
- Daily forecasts
- ...

AFTER (4 months)

- Dismantle and ship equipment

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Timeplan

	1 (2015)				2 (2016)				3 (2017)				4 (2018)				5 (2018)			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1 Management																				
2 Field experiment and data collection																				
3 Model chain																				
Coastal Experiment					Denmark & Germany															
Forest experiment						Kassel (Germany)														
Double hill									Perdigão (Portugal)											
Complex terrain										Alaiz (Spain)										
High Altitude												To be defined (Turquey)								
Simulations for ...																				
4 NEWA Database																				
5 Communication, outreach and exploitation																				

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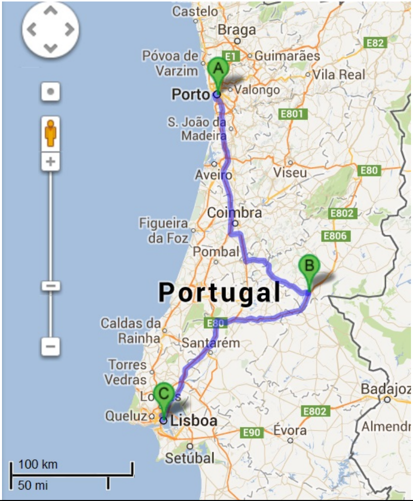
Location: travel and and accommodation



	Distance	Time	Road
Two Portuguese main cities			
Lisbon /airport	200	01:48	A1 / A23
Porto /airport	250	02:29	A1 / IC8
Nearest main cities			
Castelo Branco	29	00:22	A23
Portalegre	53	00:47	IP2 / N18
Coimbra	125	01:29	IC8
Aveiro	180	01:58	A1 / IC8
Évora	154	02:00	IP2
Faro	441	03:53	A2
Madrid (Spain)	424	04:32	A-5
London	1986	18:27	
Copenhagen	2761	26:00	
Nearest villages			
Proença a Nova	32	00:27	IC8
Castelo de Vide	45	00:44	N246 / N18
Nisa	18	00:18	N18

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1. Jackson, P. S. and Hunt, J. C. R. *Quarterly Journal of the Royal Meteorological Society* **101**(430), 929–955 (1975).
2. Walmsley, J. L. and Taylor, P. A. *Boundary-Layer Meteorology* **78**, 291–320 (1996).
3. Coppin, P. A., Bradley, E. F., and Finnigan, J. J. *Boundary Layer Meteorology* **69**, 173–199 (1994).
4. Lewis, H. W., Mobbs, S. D., and Lehning, M. *Quarterly Journal of Royal Meteorological Society* **134**(633), 801–816 (2008).
5. Berg, J., Mann, J., Bechmann, A., Courtney, M. S., and Jörgensen, H. E. *Boundary-Layer Meteorology* **141**(2), 219–243 July (2011).
6. Koblitz, T. *CFD Modeling of Non-Neutral Atmospheric Boundary Layer Conditions*. PhD thesis, Danisch Technical University (DTU), July (2013). DTU Wind Energy PhD-0019 (EN).
7. Taylor, P., Mason, P., and Bradley, E. *Boundary-Layer Meteorology* **39**, 107–132 (1987).
8. Wood, N. *Boundary-Layer Meteorology* **76**(1-2), 137–164 (1995).
9. Poggi, D., Katul, G. G., Finnigan, J. J., and Belcher, S. E. *Quarterly Journal of Royal Meteorological Society* **134**(634), 1095–1112 (2008).

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