The Perdigão double-hill experiment

A large scale field experiment with the cooperation of USA and European research groups

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UPORTO (Portugal)

Presented at NEWA Final Workshop
Wind Europe 2019 (Bilbao, Spain)
2-4 April 2019

Contents

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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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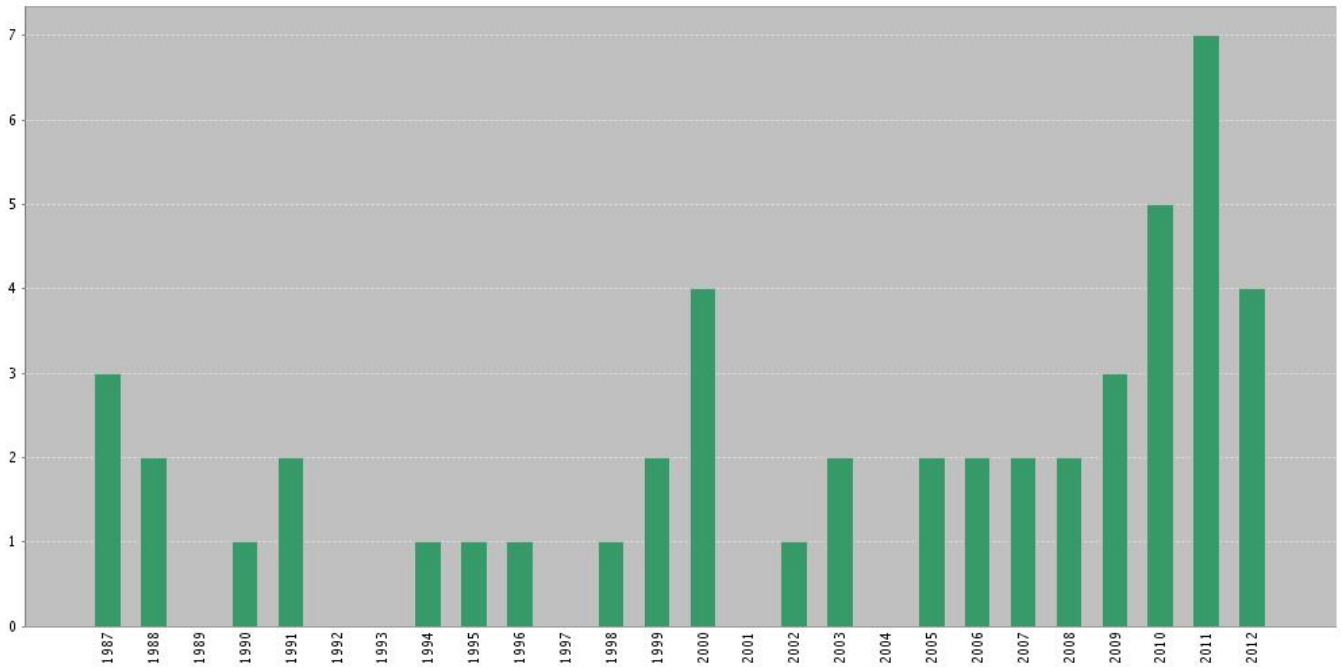
Askervein's impact (publications)



- Web of Science	
Articles:	48
Times cited:	563
Average citations per item:	11.73
- Boundary Layer Meteorology	
Articles:	68
- Google Scholar	
Times cited:	497

A long lasting value of large field studies

The path towards Perdigão

- *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*: site visit (1) by prospective partners
- *26-Jan-2011*: presented at EERA Workshop on Wind Conditions
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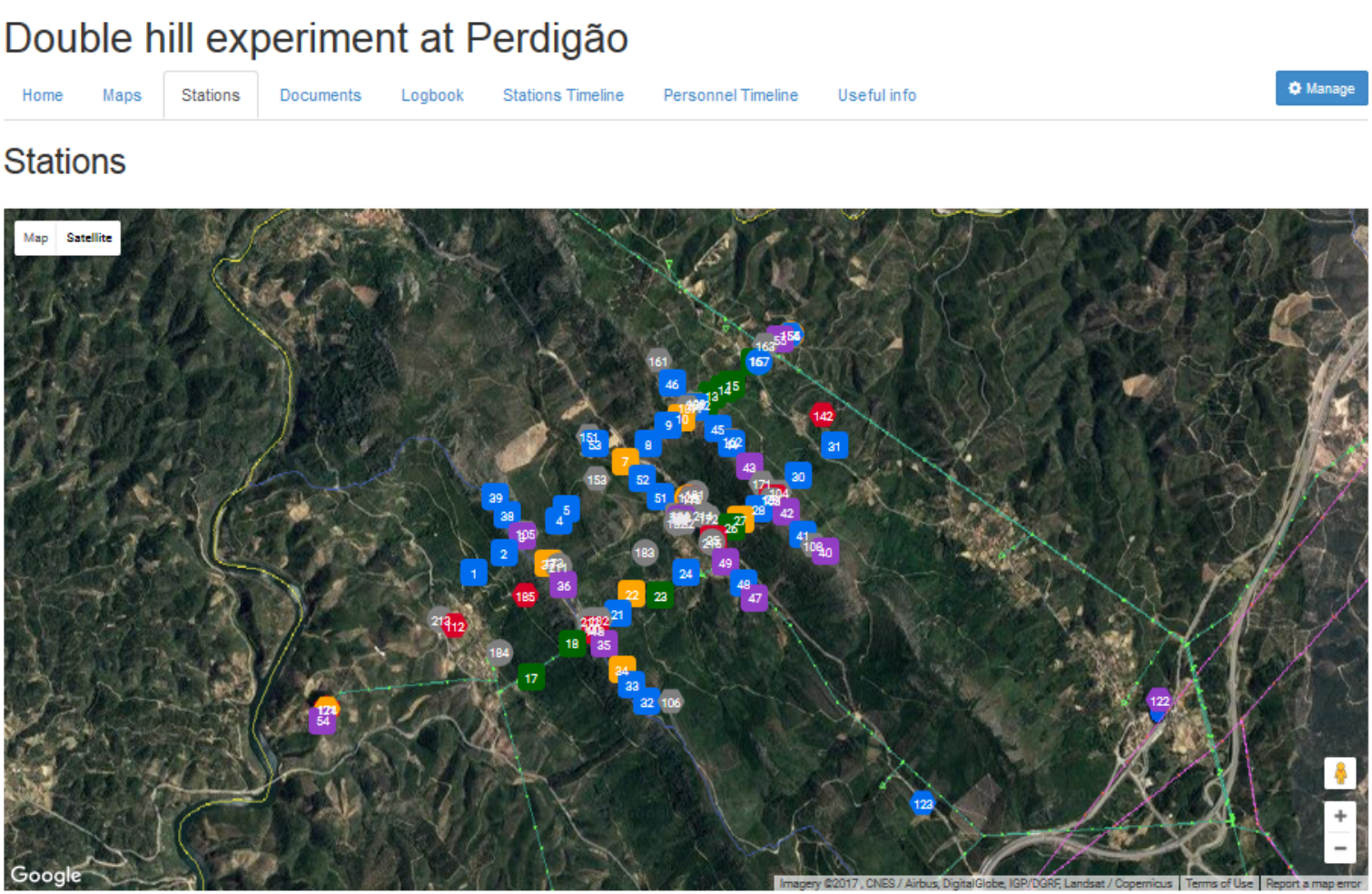
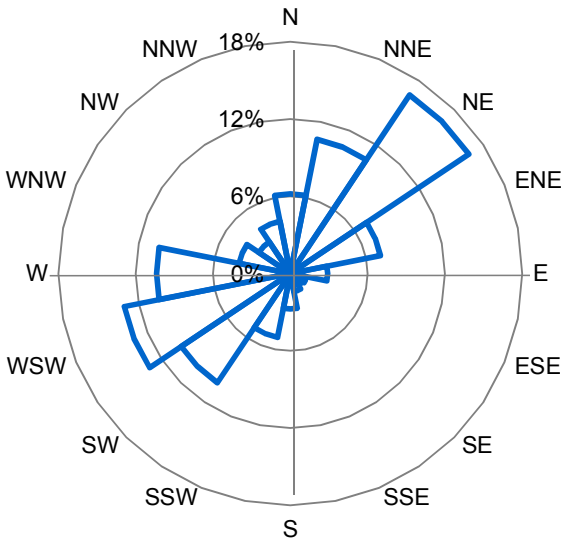
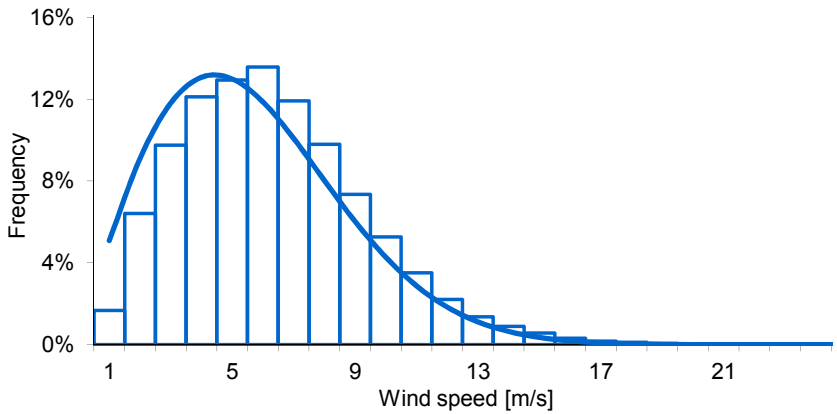
The site

The web address (*perdigao.fe.up.pt*)



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



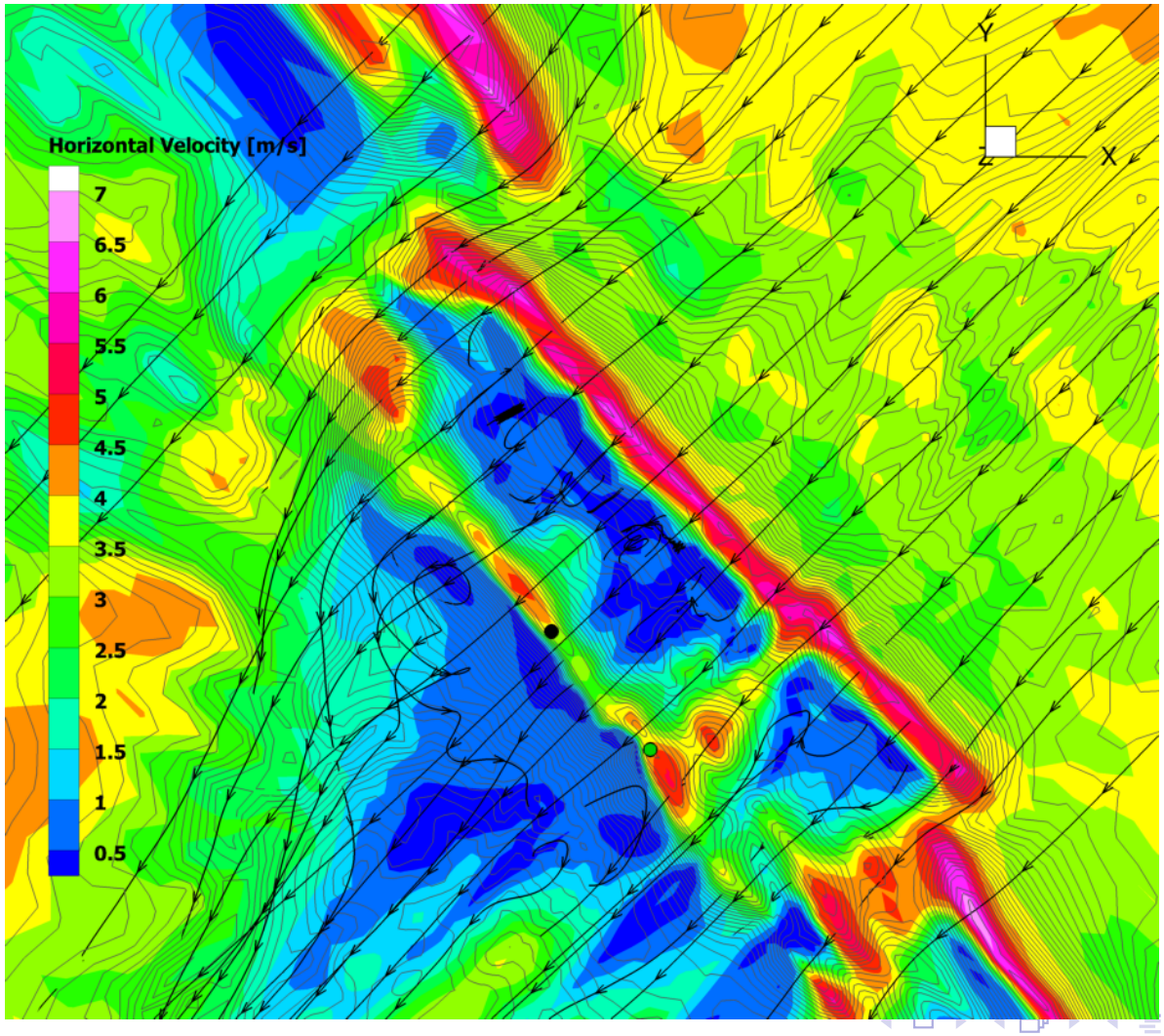


- Easting, Northing [Datum Lx IGeoE; m]: 233999,303531, at an altitude of 489 m
- Predominant winds (NE and WSW), perpendicular to the ridges

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 $\approx 20\,\mathrm{m\,s^{-1}}$

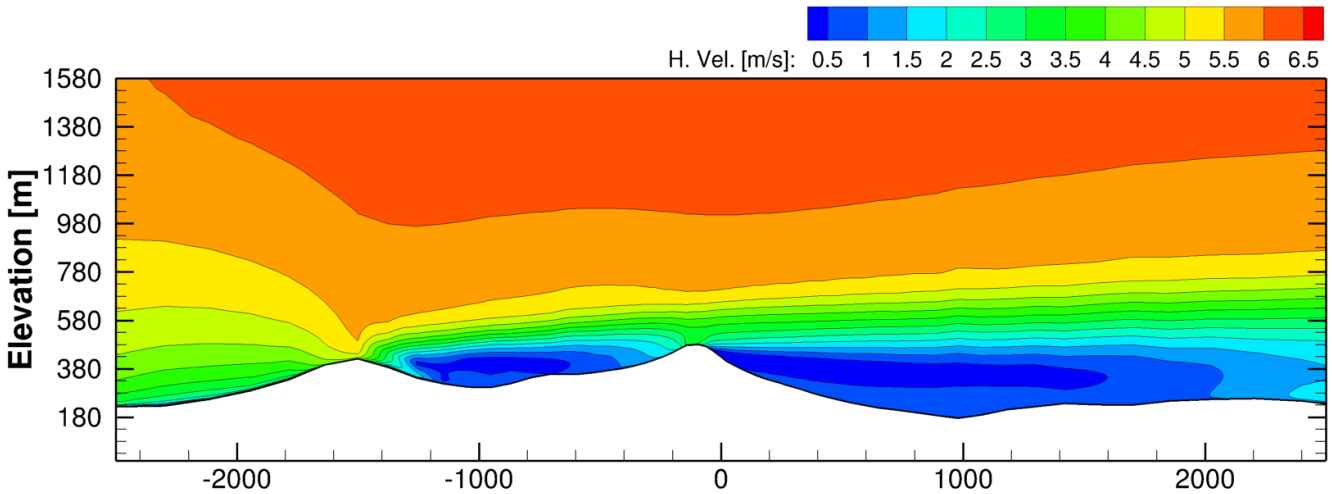
NE Winds (40 m agl)



Mean wind and turbulence (NE)

Transect A (wind turbine)

$\Longrightarrow$



Participants (Europe + USA)

- Europe (wind energy): 3+3 countries, 13 institutions, around 2 MEuro
- USA (atmospheric science): 8 institutions, $\approx$ 5 MUSD

- Portugal
  - FEUP
  - INEGI
  - IPMA
  - LNEG
  - CMVVR
- Denmark:
  - Technical University of Denmark
- Germany:
  - DLR
  - ENERCON
  - University of Oldenburg
  - WindForS
- USA:
  - Notre Dame
  - Cornell University
  - Univ Colorado Boulder
  - Univ Okhlahoma
  - Univ California Berkeley
  - NCAR
  - US ARL
  - NCAS
- Belgium: CENAERO and ATM-PRO
- France: Leosphere
- Spain: CENER

7 countries; 21 institutions (8 USA, 13 European); 72 field participants

Research projects

1. Multi-scale flow interactions in complex terrain (Fernando/Leo Notre Dame group)
2. Influence of terrain heterogeneity (Fernando/Leo Notre Dame group)
3. Gap flows (Fernando/Leo Notre Dame group)
4. Transitions and diurnal cycle of the atmospheric boundary layer, and interactions between valley flows and boundary layer flow above (Klein, University of Oklahoma)
5. Impacts of surface inhomogeneity (Barthelmie Cornell University)
6. Flow-turbine interactions and wake flows (Barthelmie, Cornell University)
7. Inflow, flow-turbine interaction, wake flow (Wildmann, Kigle, Hagen, Wagner, Gerz DLR)
8. Modelling (Palma U Porto)
9. Weather-dependent sound patterns around a wind turbine (Schady, Gerz DLR)
10. Intermittent turbulence and turbulence dissipation rate measurements (Lundquist/ Chow CUB/UCB)
11. Flow-turbine interactions, especially interaction of wake with coherent structures (Lundquist/ Chow CUB/UCB)
12. Mesoscale-microscale modeling (Lundquist/ Chow CUB/UCB)
13. Wind energy resource estimation by measurements and models (Mann DTU/others)

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UPORTO modelling

- Ongoing actions (1–3 year): extensive use of Perdigão data
  - Assessing the spatial resolution (DTM, digital terrain model)
  - Forest delineation (DSM, digital surface model)
  - Development and validation of our codes, VENTOS (3 versions available). Moving away from ideal conditions to real atmospheric conditions.
  - Simulation of weather episodes with a well-defined known physics, rather than over long periods; i.e., in a wind-energy application approach, either in a wind resource evaluation or turbine siting (wind farm design) or wind power forecasting (wind farm operation)
  - Sub grid models: turbulence modelling (LES) and parametrization of sub-grid physics; i.e. canopy, forested, wind turbine and wind farms.
  - Numerical approaches: RaNS, LES, IBM, downscaling (meso, WRF) to micro (VENTOS).

A sample of events and publications

- "Unprecedented Observations of Complex Terrain impacts on Wind Resources and Wind Turbine Wakes: An Overview of the Perdigão Field Campaign"
  Invited talk, delivered by Julie Lundquist, at WindTech2017, Oct 24–26, 2017, Boulder, Colorado (USA).
- *Complex-Terrain Meteorological Studies Relevant to Wind Energy Forecasting*
  session (10 oral and 16 poster presentations) at the *2017 Fall Meeting* of AGU (American Geophysical Union), in New Orleans (USA), 11–15 Dec 2017.
- *AS1.22 Multiscale Flow in Complex terrain: The Perdigão Experiment*
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- Forthcoming publications, in special issues :
- "The Perdigão: Peering into Microscale Details of Mountain Winds".
  To appear in *Bulletin of the American Meteorological Society*. Manuscript number BAMS-D-17-0227. (In press, May 2019)
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To know more about Perdigão

- **World's largest wind-mapping project spins up in Portugal: International team seeks better picture of wind as it moves over rugged terrain.** Nature (online version):
  http://www.nature.com/news/world-s-largest-wind-mapping-project-spins-up-in-portugal-1.21481
  Huge wind-flow study spins up: International team seeks better picture of wind as it moves over rugged terrain. Nature (printed version)
  http://feupload.fe.up.pt/get/aWwUc4VuHExx5zd
- **Monitoring wind in Portugal's mountains down to microscales**
  EOS: Earth and Space Science News (online version, May 31 2017)
  http://eos.org/project-updates/monitoring-wind-in-portugals-mountains-down-to-microscales
  Monitoring wind in Portugal's mountains down to microscales. EOS, 98 (printed version)
  http://doi.org/10.1029/2017EO074745, published on 31 May 2017.
- **Capturing a detailed portrait of wind: Project in Portugal will observe wind at unprecedented resolution**
  National Centre for Atmospheric Research (EUA)
  https://www2.ucar.edu/atmosnews/in-brief/126732/capturing-detailed-portrait-wind
- **Atmospheric scientists conduct field experiment to study wind flow over complex mountain terrain**
  National Science Foundation (NSF)
  https://www.nsf.gov/news/news_summ.jsp?cntn_id=241994&org=NSF&from=news

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Lessons learned

- I found hard to contribute to the list.
  - There are so many lessons!
  - Why the lessons? Are we going for another like this?
- The practical difficulties that were overcome during the field work (many teams, different experience, countries and cultures) were a challenge.
- This work could only be possible with a large amount of common sense, ingenuity and understanding that we were working for a common good and great benefits of all.

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The future

1. A large set of data is available; a source for exploring the wind flow in all its richness (three dimensionality and time dependency), uncovering many flow details not measured before.
2. Data processing, processing ... and processing,
3. We have to look at the wind under new perspectives.
4. For efficient use of the wind resources, we must go beyond the usual annual average patterns and consider the whole panoply of atmospheric phenomena at the many scales of time and space.
5. This is the path towards:
   - higher efficiency of wind turbines under all conditions, and
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Acknowledgments

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2. We are grateful to the municipality of Vila Velha de Ródão, landowners who authorized installation of scientific equipment in their properties, the residents of Vale do Cobrão, Foz do Cobrão, Alvaiade, Chão das Servas and local businesses who kindly contributed to the success of the campaign.

3. The campaign would not have been possible without the alliance of many persons and entities, too many to be listed here and to whom we are also grateful.

1. Walmsley, J. L. and Taylor, P. A. *Boundary-Layer Meteorology* **78**, 291–320 (1996).
2. Coppin, P. A., Bradley, E. F., and Finnigan, J. *Boundary Layer Meteorology* **69**, 173–199 (1994).
3. Lewis, H. W., Mobbs, S. D., and Lehning, M. *Quarterly Journal of Royal Meteorological Society* **134**(633), 801–816 (2008).
4. Berg, J., Mann, J., Bechmann, A., Courtney, M. S., and Jörgensen, H. E. *Boundary-Layer Meteorology* **141**(2), 219–243 July (2011).
5. 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).

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