WINDSCANNER.DK - a new Mobile Facility for Wind Energy and Turbulence Research

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Forskningsmæssige resultater:

In 2009 DTU Wind Energy was granted 25 M DKK in support by the Danish National Research Council to design, establishing and help initiate operation of a new Danish national research infrastructure denoted WindScanner.dk
The new Research Infrastructure (RI) was established to enhance research and technological development in collaboration with research institutes and industry in the field of renewable wind energy in Denmark. Today, five years later, the envisioned RI have been designed, constructed and established as an operational facility within the Wind Energy Department at DTU Risø Campus. Since 2011 it has serviced the wind energy research society and the wind energy industry with its spectacular and unprecedented 3D remote sensing based wind field scanning operations.

The overall scientific objective set out in 2009 for the establishment of the WindScanner.dk RI facility was to provide wind field measurements and evidence, from which theoretical hypotheses and numerical modelling of the atmospheric wind and turbulence properties, relevant for wind energy, can be experimentally evaluated.

The tangible goals with establishing a new 3D wind field scanning RI has been to provide a new RI facility to investigate and to enhance our common comprehension of the complex wind field and turbulence phenomena's in the atmospheric boundary-layers where wind energy is being harvested. In particular, the WindScanner.dk RI set out to investigate and understand how the wind fields and energy potential in particular is being influenced by terrain features, complex terrain, by other wind plants all under different atmospheric stability characteristics, e.g. by investigating the characteristic differences between boundary-layer onshore and offshore, as well as day and night time flow characteristics.

The new Windscanner.dk RI has been integrated closely with other experimental and CFD modelling activities also addressing wind flow and turbulence. For instance, detailed terrain effects and flow over a hill have been studied with respect to the influence of wind and turbulence profiles, and ongoing studies are addressing changes in the wind fields at coastal interfaces between onshore and offshore wind regimes.

Today, with the new WindScanner.dk facility now established, the wind energy research and industry community are offered the attractive and obvious advances of remote sensing-based meteorological measurement techniques. The WindScanner.dk developed sets of three by three short- and long range synchronized scanning wind lidars are aspiring for scanning and probing entire fields in two and three dimension space of wind and turbulence 3D velocity vectors in the atmospheric boundary-layer.

Design, construction and Operation of the WindScanners: Two different sets of 3D wind and turbulence wind velocity scanning lidar systems have been designed, constructed and are now deployed at DTU Wind Energy as part of the new operational RI for atmospheric boundary-layer and wind energy research in support of wind energy and wind industry technological developments:

1. A short-range (10 – 150 m range) high space/time resolution WindScanner system, consisting of three time and beam scanning synchronized continuous wave (cw) wind lidars, and

2. A long-range (0.1 - 6 km range) lower space/time resolution WindScanner system, consisting of three time and beam scanning synchronized pulsed-lidar wind lidar systems.

Phase-I: Constructing of the WindScanners 2009-2011

Figure 2 Left: First Short-range WindScanner at DTU Risø Workshop 2010; Middle: Inaugurating the first of three Short-range WindScanners, R2D1 vers. 1.0, Risø DTU 2011; Right: Improved Short-range WindScanner vers. 1.2 Sep 2014).

Figure3. Short range WindScanner R2D2 on operation at the Nenuphar vertical axis offshore prototype, Fos-sur-Mer, Fr.

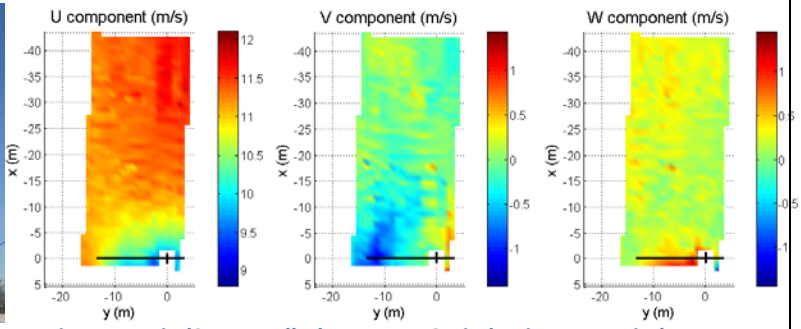

Figure 4. WindScanner.dk short-range 3D induction zone wind scanning in front of a Vestas V27 test turbine at DTU Risø campus.

Figur 5. Front row: DTU Wind Energy's set of three own-built prototype Long-Range WindScanners. Second row: Two Long-range WindScanners WLS200S commercially available from Leosphere, Fr

Erhvervsmæssige-samfundsmæssige resultater:

Impact: By end 2014 the WindScanner.dk RI has achieved its main goal to provide the wind energy society with a new RI for wind energy research:

The WindScanner.dk RI is established as a world first operational and mobile remote sensing-based wind and turbulence field-scanning experimental facility. The facility is mobile and can offer its services as an open access RI via collaboration institutes and industrial participants.

WindScanner.dk RI operates two different sets of multiple synchronized scanning wind lidars along user-defined trajectories: one set of three continuous wave short-range WindScanners; and also one set of three pulsed long-range WindScanners. The WindScanners, both short and long range, are capable of scanning 3D wind vectors in

horizontal and vertical planes and along arbitrary specified trajectories. Today, WindScanner.dk is a mature RI providing its open access research infrastructure "beam hole" services to Danish and European wind energy research community and the wind energy industry.

In 2013 the WindScanner.dk, both sets of 3 x3 short and long range, entered into operation mode.
The last two years they have served the Danish and the International research and technological society with 2D and 3D wind field scan measurements relevant to wind energy research, in particular, the WindScanner RI has proven useful in connection with wind energy related experimental investigations, particularly within wind energy research such as studies of induction zone flow and wake flow behind horizontal and vertical wind turbines.
Also, however, the WindScanner.dk has found use within several other inter-disciplinary uses such as 3D helicopter down wash investigations, turbulent load-structure coherence investigation on suspension bridges, effect of wind breaks, urban street canyon recirculation investigations etc.

New research Instrumentation - developments:

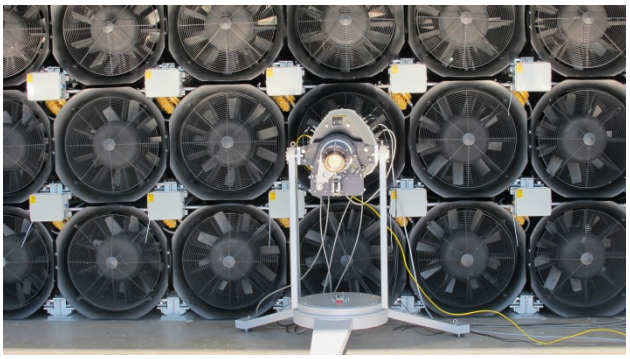

Figure 6 Short-range WindScanner v1.2 in WindEEE Wind Dome, Canada

The short-range WindScanner technology, based on a DTU invented dual axis rotating prism patented scan head, has been manufactured and user- licenses have been sold to collaborating universities (WindEEE in Canada and FORWIND Uni-Oldenburg, Germany).

The DTU Wind Energy/IPU designed new dual-mirror--based scan head for the long-range Lidars, proto-type manufactured by DTU and IPR has been transferred to Leosphere, Fr where WindScanners (WLS400S) In return DTU Wind Energy received three range-extended wind lidars (3x WLS200) from Leosphere. WLS200S scanners have meanwhile become commercial available from Leosphere.

Special developed synchronization software for steering and control of these scanners capable of synchronizing a large number of Long-range WindScanners, still remain IPR wise exclusively with DTU Wind Energy.

Small wind speed measuring telescopes (Lidics) have proven potential useful for wind tunnel inter-calibration calibration and as a new standard for absolute wind speed standards. A 2D Rotor plane scanning Spinner Lidar has also been developed. Today, the WindScanner.dk facility has now provided the Danish and international wind energy research and industry with a unique new experimental research infrastructure for wind field scanning of 3D wind and turbulence structures around wind turbines and in entire atmospheric boundary-layer.

Scientific impact: The WindScanner.dk measurement technology based on 3D remote sensing-based wind vector scanning has since been disseminated to other European research institutes, in particular in collaboration with leading wind energy research institutes (EERA partners). When fully operational the European WindScanner facility, RI WindScanner.eu, is envisioned to offer open access collaboration with all wind energy engaged atmospheric boundary-layer researchers and experimentalists, including the wind energy industry throughout Europe and Overseas.

Windscanner.dk – Maturity and Impact on society: **Maturity**: The WindScanner.dk RI facility was admitted already to the European EU ESFRI Road Map for future renewable Energy research European Research Infrastructures in 2010 and also to the first established Danish road map for research infrastructure 2011. Throughout 2015 DTU Wind Energy is coordinating the EU FP7 Preparatory Phase (PP) project: "WINDSCANNER -the European WindScanner Facility" (www.windscanner.eu).

The purpose of the ongoing EU FP7PP support project is to establish the governance, the legal and the financial aspects of the ESFRI road Map supported pan-European WindScanner research infrastructure consortium, counting several EU partners. The plan is to establish the joint European research infrastructure consortium in the beginning of 2016, cf. the PP projects home pages at (www.WindScanner.eu).

Once a sufficient number of partners have obtained national infrastructure support the joint WindScanner.eu RI consortium is envisioned to form an ERIC-based consortium organization among participating partners (Denmark; Holland; Germany; Norway, Denmark; Portugal; Spain Greece. In 2016-2017, until at least three national partners have obtained national road map support, an interim, less committing WindScanner.eu consortium agreement will be established.

The already existing and by now already well-matured Danish WindScanner.dk RI, to be referred to next as "The EU ESFRI Danish WindScanner node WindScanner.dk" within the WindScanner.eu consortium, and amended in 2015 with existing and new Danish national partners, will next seek uptake on the 2015 Danish road map revision, as a RI facility matured and ready to lead the new joint European WindScanner RI facility, from a central Hub envisioned to be established at DTU Wind Energy in Denmark.

Impact on Society: The already established wWindScanner.dk, and also the forthcoming European WindScanner facility, RI WindScanner.eu, will offer open access collaboration with all wind energy engaged atmospheric boundary-layer researchers and experimentalists, including the wind energy industry throughout Europe and Overseas. Research and spin off wind lidar products will assist wind energy integration in Europe, on and offshore, and its research will assist to lowering the cost of wind energy. The WindScanner RI also secures training and education in wind lidar remote sensing.

Collaboration with Danish and European Industry:

1. The French wind lidar manufacturer Leosphere has integrated the DTU/IPU developed mirror-based scan head into their product series WLS200S marketed the long-range.
2. Collaboration with ZephIR Lidar UK regarding manufacturing and marketing of the special 2D rotor plane scanning SpinnerLidar.
3. During WindScanner.dk DTU Wind Energy has furthermore collaborated with Danish industry: LM Wind Power Blades (SpinnerLidar and Lidic lidar); Sven- Ole Hansen APS re precision Wind Tunnel calibration; Dantec Dynamics (re coherent detection lidars in wind tunnels); Dong Energy (re test of lidars for control integrated in the NM80 test Turbine at Tjæreborg Enge.
4. With European wind industry DTU Wind Energy is via WindScanner.dk RI is (ongoing) engaged in wake measurements on the Nenuphar Prototype test Vertical Axis Wind Turbine (VAWT), located at the test site Fos-sur-Mer, France. Our engagement is established via the EU FP7 MARINET, the Marine Renewables Infrastructure Network.

WindScanner.dk specific Research and Innovation activities:

1. WindScanner.dk has been engaged and supported several ongoing research activities engaging its unique 3D scanning wind field measurement technique:
2. Stavanger Lysefjordbrua. Collaboration with Uni Stavanger and NORCOWA, Norway.
3. Norwegian Ministry of Justice- The Norwegian All Weather Search and Risqué Helicopter (NAWSARH) new helicopter downwash characterization activity 2011-2013.
4. FORWIND: University Oldenburg: Long-range Lidar synchronization and 2D SpinnerLidar manufacturing.
5. WindEEE: Short-range WindScanner vers 1.2.

Patents: During the project period three DTU Wind Energy owned patents has been generated: 1) a Dual prism scanning methodology, 2) a continuous wave open air precision calibration facility; 3) a new all-fibre directional sensing In-phase and quadrature detection scheme. Patent user licenses re 1) has been sold to: WindEEE, Canada and to FORWIND, Germany.

Forskeruddannelse:

The following students have during the WindScanner.dk project period either collected or otherwise obtained WindScanner.dk measurements for their PhD' work:

1. PhD candidate Anders Sig Olesen; PhD degree achieved (2014)
2. PhD candidate Nikolas Vasiljecics; PhD Degree achieved 2014
3. PhD candidate Chougule Abhijit; PhD Degree achieved 2013
4. PhD candidate Farzad Abari Foroughi (PhD degree anticipated in 2015)
5. US Fulbright fellow Eric Simley, NREL& CU; Boulder, Colorado; (2013-2014)

6. PhD candidate Julie Lange
7. PhD Ewan Machefaux

In addition, the WindScanner.dk RI project has provided two post doc training positions: Anders Tegtmeier Pedersen (1yr); Mikael Sjöholm (½yr).

Special wind Lidar course at the Masters level: A 5 ECTS Special Lidar Course for DTU's M. Sc. Students with special interest in the WindScanner.dk RI has so far been read to four DTU Wind Energy students and one from DTU BYG).
PhD Summer school: The WindScanner.dk RI staff contributes yearly to the DTU Wind Energy PhD Summer School (2009-2011; 2013-2014) in Remote Sensing at DTU and Colorado University (2012). Each year 20-25 students from universities and Industry Worldwide attens.

Samarbejde, herunder tværinstitutionelt, tværdisciplinært og internationalt samarbejde:

National: During the course 2009-2014 The WindScanner.dk RI has close collaboration with the WindScanner.dk project partners AAU; DTU Fotonik; DTU Mekanik. In addition with DTU BYG and external Danish institutes AU and DMI. The collaboration has been interdisciplinary I several fields: Air pollution (AU); Extreme wind load on buildings (AAU); Wind Breaks (DTU BYG).

The activities undertaken have demonstrated much external interest in the WindScanner remote sensing wind measurement methodology also outside the core Wind Energy field of interest.

International: EU: The ESFRI WindScanner Road map consortium formed in 2010 from 9 European Energy Research Alliance EERA partners from SINTEF in Norway; FORWIND and Fraunhofer IWES in Germany; CENER in Spain, ECN in Holland; CRES in Greece, Uni Porto and LNEG in Portugal and IPU and DTU from Denmark. Participants from FORWIND Fraunhofer IWES; Uni-Porto and DTU Wind Energy performed a joint first European field measurement campaign at Röderseberg Kassel field test of long-range space and time synchronized scanning lidars 2014.

Overseas: NREL; NOAA; NCAR; WindEEE I collaboration with National Renewable Energy Laboratory, NREL, Golden Colorado, USA DTU wind Energy have collaborated regarding wind turbine integrating testing of the DTU Wind energy developed SpinnerLidar. The SpinnerLidar has since 2013 been installed into the US wind test sites CART 3 test turbine re feed-forward control.

DTU Wind energy have also ongoing overseas collaboration with NOAA, Boulder, USA re joint development of wind lidar advanced data acquisition systems and long-range precision steerable scan heads.
Furthermore, WindScanner.dk has collaborated with National Center for Atmospheric research (NCAR) and also with Colorado University and School of Mines, Golden regarding preparation of a large joint meteorological field Experiments (Perdigão; Portugal)

Finally, collaboration continues with personnel at the new Canadian research wind tunnel facility WindEEE, located at University of London, Ontario, Canada regarding operation and data quality assurance of measurements obtained in Canada with the DTU/IPU manufactured and 2014 delivered short-range WindScanner vers 1.2.