8 December 2017

Minutes
of the IEA Wind Task 32 Workshop #7 on
Lidar Campaigns in Complex Terrain

Date: Wednesday 8th November 2017
Venue: Campus Guest, 70569 Stuttgart, Germany
Workshop leader: Andrew Clifton, WindForS
Minutes by: Andrew Clifton, Ines Würth, David Schlipf

Background to the Workshop

Participants in the 2016 IEA Wind Task 32 General Meeting in Glasgow identified three major barriers to the further deployment of wind lidar in complex terrain:

1. **Operations**. Sites may be remote, which makes setting up and operating the lidar challenging.
2. **Data**. Data may be incomplete because of power or other issues, and may be difficult to interpret because of inhomogeneous flow conditions.
3. **Guidelines**. Existing recommended practices and standards do not explain what should be done to achieve satisfactory measurements in complex terrain.

The background of many of the challenges is described in a previous IEA Wind Task 32 report[1]. However, because of the lack of common experience, there is little agreement on what the most important barriers are, how to address them, or on priorities. The goal of this workshop was to create case studies that would illustrate what the current barriers are and allow agreement on how to tackle them.

Workshop Leader's comments:

- Lidar are used effectively and reliably in complex terrain now for a range of applications.
- Users are strongly encouraged to engage with manufacturers and consultants to ensure that they use an appropriate device and analysis method for their application
- The terrain and applications used in the workshop case studies were deliberately chosen to represent future deployments in highly complex conditions, and be provocative.
- The teams were chosen by the organizer. The presence of a person or organization in a team should not be taken to mean that they use or endorse a particular approach or method.
- The results should motivate new guidelines or standards, new products, and training.

These comments were added after the workshop. Other comments have been added elsewhere using the same format.

[1] See A. Clifton, M. Boquet, E. B. D. Roziers, A. Westerhellweg, M. Hofsäß, T. Klaas, K. Vogstad, P. Clive, M. Harris, S. Wylie, E. Osler, B. Banta, A. Choukulkar, J. Lundquist, and M. Aitken, "Remote sensing of complex flows by doppler wind lidar: issues and preliminary recommendations," NREL, NREL/TP-5000-64634, 2015.

Program

Start	
09:00	Arrival and registration
09:30	**Introduction** • Workshop goals • Introductions
10:00	**Challenges and Solutions** Experience from different groups with lidar measurements in complex terrain: • **Lidar in complex terrain: validation of CFD-based Correction Tools**. Sara Koller, Meteotest • **Lidar in Complex terrain – some general consultants' views.** Detlef Stein, Multiversum
10:30	Break
10:45	• **Site Calibration using Ground Based Lidar in two flat sites with very different roughness.**. Christof Tsouknidas, Siemens Gamesa Renewable Energy • **Multi-lidar remote sensing measurements at Kassel as part of NEWA**. Doron Callies, Fraunhofer IWES
11:30	**Introduction to Case Studies** • Explanation of goals and outcomes from each cast study • Explanation of roles
12:00	Lunch
13:00	**Case Study Working Session** In groups, develop solutions to each stage of planning and executing a measurement campaign • Identify gaps in products, services, recommended practices, guidelines, and standards • Suggest solutions for gaps / prioritize required research and development • Prepare short summary for the rest of the workshop
14:45	Break
15:15	**Results** • Presentation of results with prioritized barriers (20 minutes / group)
16:15	**Next Steps** • Summary of prioritized gaps and solutions • Draft roadmap
17:00	End
18:30	Dinner

Minutes

9:30	Start of workshop – Introductions to Task 32 and workshop, introduction round

Introduction to IEA Wind Task 32 from Andrew Clifton
Round-the-room introductions:

- There was a wide range of experience and applications amongst the participants, including resource assessment, power performance, and wind energy research
- All participants expressed interest in learning best practices, challenges, and future research for onshore and offshore lidar for wind energy applications

10:15	Sara Koller, Meteotest: **LIDAR in complex terrain: Validation of CFD correction tools**

An overview of lidar measurements in complex terrain using lidar to extrapolate mast data. The following challenges were noted:

- Weather conditions in complex terrain can be bad (e.g. snow) which makes site access difficult and can reduce data availability from all measurement systems
- There is often no power locally, and so there is a need for self-contained power supplies; this was not a problem *per se* but does need to be considered.

Several specific problems were observed:

- Flow distortion which varies depending on wind direction and atmospheric stability
- Flow correction using a model and assuming neutral atmospheric conditions only lead to improvements in the agreement between a cup and lidar in one of the cases
- Highly localized issues
- The results highlight the need to fine tune the modeling approach, including the choice of model physics, the accuracy and resolution of the digital terrain model, and roughness data
- Lack of documentation or understanding of algorithms that are used for corrections

Comments

- May need to look at domain size to avoid effects from the boundaries impacting simulations

Note:

- Paul Mazoyer from Leosphere shared the background to the FCR algorithm at the IEA General Meeting on 9-10 November.

10:40	Detlef Stein, Multiversum, Bastian Schmidt DNV GL: **Lidar in Complex Terrain - some general consultant's views**

Issues:

- Complex terrain definitions are many and varied, and cover a broad spectrum; they are not aligned
- Lack of evidence in the public domain for the effectiveness of complexity corrections either from Lidar suppliers, flow modeling or others
- Lack of uncertainty definition

Gaps

- Need to understand link between complexity and performance
- Need to transfer verification results from a benign site to a complex site
- What is the impact of different correction approaches, for example (FCR or CFD modelling)?
- Need more public information

- Need a concise approach to estimate wind data uncertainty, in particular for correction approaches
- Correction methods (i.e. CFD models) need to be improved (physics, usability, and computational power)

Comments

- Don't assume that a mast is perfect; can assume good LOS measurements but the conversion to a cup-like measurement is poor. It is questioned that such RS to cup conversion, i.e. reducing volume to point measurements, actually solves the issue of understanding wind flow in complex terrain.

11:25	Christos Tsouknidas, Siemens Gamesa: **Site Calibration using Ground Based Lidar in two flat sites with very different roughness.**

- Want to understand the effect of high roughness on the wind profile, and the effect of trees on the lidar measurement.
- Measurements at a wooded site show influence of forestry on site calibration, with effects on shear and veer and TI.
- Seeing higher deviation from unity in the REWS transfer function for the high roughness site.
- Site calibration correlations are lower in the high roughness site.
- This all makes a site calibration according to IEC standards very difficult!

11:25	Doron Callies, IWES Fraunhofer: **Multi-lidar remote sensing measurements at Kassel as part of NEWA**

Series of measurement campaigns at the Rödeserberg near Kassel

- Take the time to set up devices and configure them properly
- Lots of challenges in both campaigns
    - Setting up a lidar to point at a specific direction
    - Complex technology
    - Needs well-trained personnel
    - Costs associated with personnel
    - Technical availability of windscanner is still a challenge
    - Needs back-up equipment
- Standardization and interoperability is required
- Listed lessons learned in both sets of measurements
    - Developed standardized data formats based on the campaign data

Case Studies

11:30	Andy Clifton **Introduction to Case Studies**

Case studies based on the Rodeser Berg near Kassel were introduced. The goal of the case studies was to develop a common set of open, public examples for the planning of a lidar-based measurement campaign that could be used to identify issues and solutions related to the use of lidar for wind energy applications. A key goal of the case studies was to identify both the availability and gaps in existing knowledge, for example in recommended practices, guidelines, or standards.

Teams

Participants were split into four teams. The task of each team was slightly different, and reflected common lidar-based measurement campaign goals and equipment. The teams, the goals of their campaigns, and the equipment pool they had access to, are shown in Table 1.

Table 1 Teams, goals, equipment

Team	Campaign Goal	Equipment Pool
1	Design a measurement campaign to provide the data to drive and validate a wind resource map	• Lidar wind profiler • 200-m mast
2	As team 1	• As Team 1 • Scanning lidar with 4 km range
3	Design a measurement campaign to provide the wind data required for power performance	• As Team 1
4	Design a measurement campaign to provide the wind data required for validating a mesoscale to CFD or LES turbine-scale model chain for a wind turbine on the Rödeser Berg near Kassel.	• 200-m tower • 2x 100-m tower • 2x 60-m tower • Multi-lidar system (3x long-range scanning lidar) • Other equipment appropriate to a large-scale collaborative field campaign.

The members of the four teams are shown in Table 2. Each team was assigned a facilitator who was tasked with helping teams make decisions and move forward in the case studies.

Table 2 Team members

Team	1	2	3	4
Goal	Resource assessment	Resource assessment with a scanning lidar	Power performance testing	Model validation
Facilitator	Andy Clifton	Tobias Klaas	Ines Würth	Doron Callies
Team	Liliana Del Angel Bulos Guillaume Sabiron Christoph Tiefgraber Dong-Hun Ryu Dominique Deen Bastian Schmidt Simon-Philippe Breton Mun-jong Kang	Sara Koller Shumpei Kameyama Martin Hofsäß Jens Riechert Madalina Jogararu Dominique Philipp Held David Böckler Mingyuan Jiang	Andy Scholbrock Detlef Stein CarloAlberto Ratti Julian Hieronimus Dimitri Foussekis Ioannis Antoniou Christos Tsouknidas Kyungnam Ko	Andreas Rettenmeier Robert Menke Oliver Bischoff Norman Wildmann Antoine Larvol Lei Liu

Case Study Framework

The case studies used a framework described in "Perdigão 2015: methodology for atmospheric multi-Doppler lidar experiments" by Nikola Vasiljevic et al. (2016)[2] to document the campaign plan. This framework has 10 major steps which are listed below with a short explanation.

1. Definition of objectives. What is the goal of the measurement campaign?
2. Site selection. Where can we measure to get the data required? [less relevant in this case]
3. Site characterization. What is known about the site terrain, land cover, wind field and other aspects of the site?
4. Experiment layout design. Where should devices be positioned to achieve campaign goals?
5. Infrastructure planning. What is required - such as power, data, and other services - to make the campaign a success?
6. Deployment and calibration procedures. What needs to be done to make sure that equipment arrives in the field in the best possible condition?
7. Scanning mode design. How should the lidar(s) and other devices be configured to acquire the data that are required?
8. Execution and data collection. How should the campaign be carried out day-by-day?
9. Decommissioning and post calibration procedures. What is required to retrieve equipment and confirm equipment performance?
10. Data dissemination and availability. How is data stored, protected, and given to customers?

Stakeholders

The participants were asked to consider the perspectives of all of common stakeholders in a lidar measurement campaign. Common stakeholders are listed in Table 3.

Table 3 Common stakeholders in a lidar measurement campaign

Stakeholder	Interest
Project lead	Responsible for team management and coordination, focusing on ensuring each stakeholder's needs have been established and satisfied
Field team	Preparing, deploying, maintaining, and retrieving equipment
Data analysts	Converting data into usable results
Lidar supplier	Supporting the campaign by providing information about equipment and advice on deployment strategies
Consultant	Ensuring actionable results
End users	Ensuring that the data delivered actually meet their needs, e.g. OEM, owner / operator, independent engineer, certification agency, …

[2] Nikola Vasiljevic et al., "Perdigão 2015: methodology for atmospheric multi-Doppler lidar experiments" DOI: 10.5194/amt-10-3463-2017

Case Study Working Session

13:00	Andy Clifton **Case Study Working Sessions**

Each team was provided with a poster that summarized their task, including a relief map, landuse, and satellite image. These posters are included in these minutes. The teams were also provided with another poster to collect the solutions and barriers that each team encountered at each point in the campaign planning. Photographs of the results posters are also included. To prioritize the barriers, each team member voted on the three barriers that they thought were most important. The respective votes are given in orange in the following result tables.

Team 1: Resource Assessment in Complex Terrain

This team developed a resource assessment campaign for the area of the Rödeser Berg.

The team was asked to assume that they had a 10-km^2 site with an existing 200-m tower and a vertically-profiling wind lidar (Figure 6, in the appendices). This situation is relatively common in Europe, North America, and Asia at this time, although towers are usually shorter.

> Note:
> - The goal of a resource assessment campaign is to create a grid of wind data characteristics that can then be used for site selection and energy yield assessment.
> - Vertically-profiling Lidars are frequently used in complex terrain for resource measurements with and without towers for comparison at this time
> - Differences between lidar and traditional anemometers can occur as flow becomes less homogenous and unsteady. Flow modeling tools might reduce the difference.
> - Sites are built in complex terrain worldwide using data from lidar and flow models.
> - Guidelines exist for resource assessment in such sites, such as the German TR6 guideline.

The solutions and barriers that Team 1 found are shown in Figure 1 and listed in Table 4.

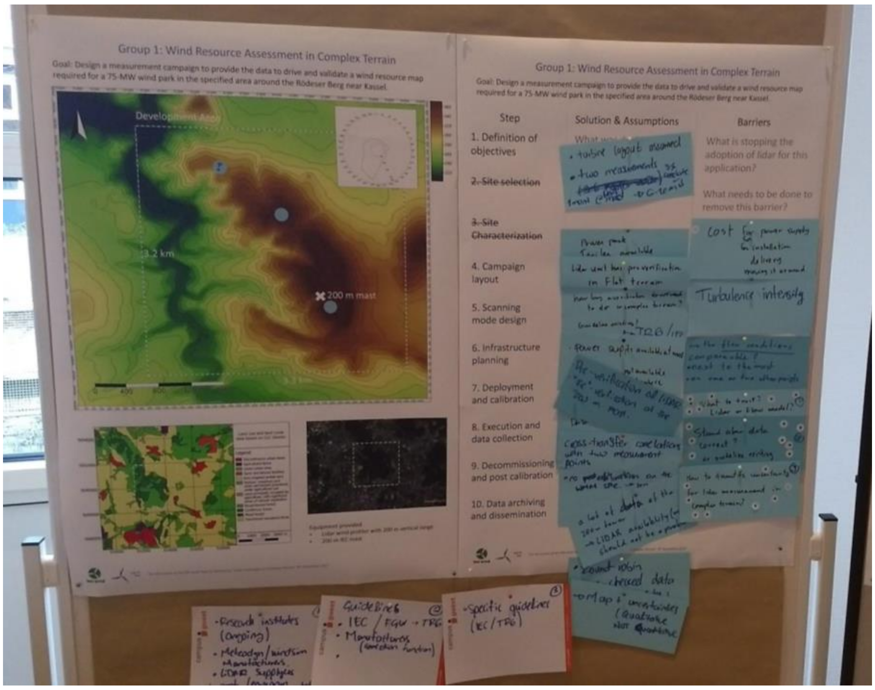


Figure 1 Planning Information and Results from Team 1

Table 4 Solutions and barriers found by Team 1 for a resource assessment campaign

Step	Solution	Barriers (votes)
1. Definition of objectives	turbine layout assumed two measurements 1 month@ met mast → 6-12 months total	How long a verification do we need to do in complex terrain? Guidelines existing? TR6/ IEC
2. Site selection	Not investigated; information was provided as part of the case study	
3. Site characterization		
4. Campaign layout	see poster	Are the flow conditions comparable? next to the met mast on one or two other points
5. Scanning mode design		
6. Infrastructure planning	Power pack trailer available and power supply available at mast	Cost for power supply for installation (1)
7. Deployment and calibration	Lidar unit has pre-verification in flat terrain "Reverification" at 200m mast	Turbulence intensity
8. Execution and data collection	Cross transfer correlations with two measurement points A lot of data of the 200m tower -> lidar availability should not be a problem	What to trust: Lidar or flow model? (6) → need for correction functions (from lidar manufacturers and model developers) Are stand-alone data correct? No guideline existing (8)
9. Decommissioning and post calibration		How to quantify uncertainty for lidar measurement in complex terrain? (8) → Need for specific guidelines (IEC/ TR6) → Round robin to cross check data → Map + uncertainty (qualitative NOT quantitative)
10. Data archiving and dissemination		

Note:

- This team identified a challenge in understanding the uncertainty in the resource assessment at a location where there was a meteorological tower and lidar, versus one without, because of concerns about different interactions between terrain, flows, and measurement devices (cups and lidars) and flow models at each location.
- There are tools to explain differences between lidar and met towers. Some of these models are proprietary black-box models, which has reduced their acceptance.
- It is not clear when terrain or flow is complex enough to warrant flow modeling to investigate differences between lidar measurements and cups.
- There is ongoing academic and industry research into how to quantify the uncertainty of modeling and measurements in complex terrain, and how to better describe the performance of wind turbines in complex inflow conditions.
- IEC standards are being developed for the resource assessment process.

Team 2: Advanced Resource Assessment in Complex Terrain

This team developed a resource assessment campaign for the area of the Rödeser Berg.

The team was asked to assume that they had a 10-km^2 site with an existing 200-m tower, a vertically-profiling wind lidar, and a scanning wind lidar with a nominal range of 4 km (Figure 7, in the appendices). This situation is relatively common for challenging locations in Europe, North America, and Asia at this time, especially where teams already have significant experience with wind lidar.

Note:

- Current scanning lidar are often more expensive than a profiling lidar to rent or buy
- Scanning lidar require more power than profiling lidar.
- Scanning lidar typically generate more data than profiling lidar.
- Radial velocities obtained from scanning wind lidar often need to be converted to wind vectors for use. This is called windfield reconstruction and requires assumptions about the flow. Windfield reconstruction using a single lidar (as in this case study) is inherently challenging.
- Because scanning lidar may use low elevation angles to see near hub heights at long distances, they can be blocked by trees.

The solutions and barriers that Team 2 found are shown in Figure 2 and listed in Table 5.

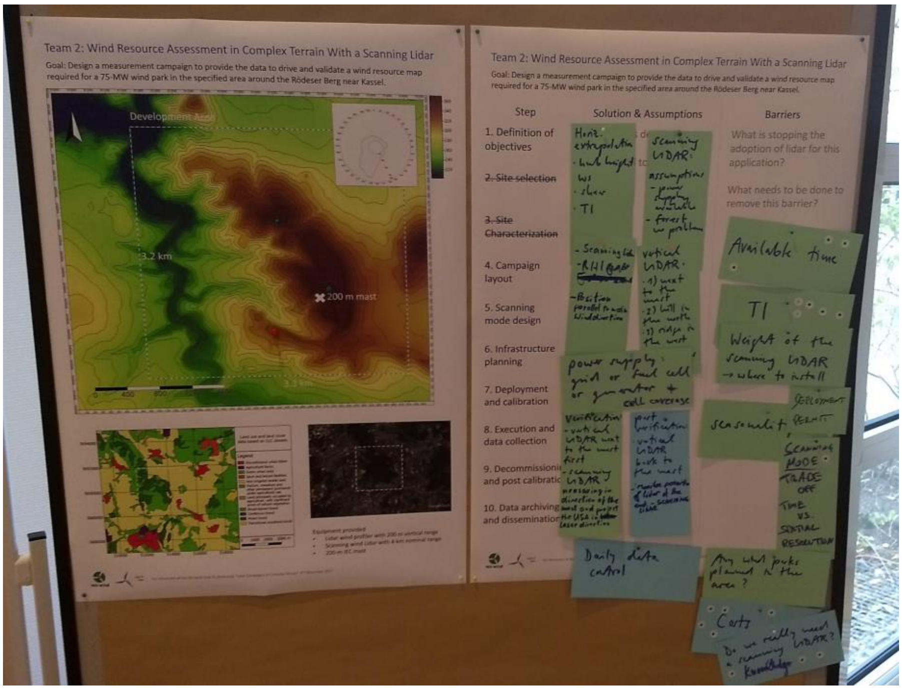


Figure 2 Planning information and results from Team 2

Table 5 Solutions and barriers found by Team 2 for a resource assessment campaign

Step	Solution	Barriers (votes)
1. Definition of objectives	Profiler: • Hub height wind speed • Shear • TI Scanning lidar: assumptions: power supply available, forest no problem	Available time (3) TI (5)
2. Site selection	Not investigated; information was provided as part of the case study	
3. Site characterization		
4. Campaign layout	Scanning lidar: • Position parallel to main wind direction Profiler: 1. Next to the the mast 2. hill in the north 3. ridge in the west	Weight of the lidar → where to install Seasonality Costs (5) Do we really need a scanning lidar? Knowledge is missing (3)
5. Scanning mode design	Scanning lidar: • RHI	Stanning mode trade off: time vs. spatial resolution (1)
6. Infrastructure planning	power supply: grid or fuel cell or generator + cell coverage	Any wind parks planned in the area?
7. Deployment and calibration	Verification: • Vertical lidar: next to mast first • Scanning lidar: measuring in direction to the mast and project the sonic data in laser direction	Deployment permit
8. Execution and data collection	Daily data control	
9. Decommissioning and post calibration	Post verification: • Vertical lidar back to teh mast Scanning lidar: • monitor position of the lidar at the end	
10. Data archiving and dissemination		

Note:

- This team found it difficult to use the scanning lidar in this case study in such a way that it added value to the overall measurement campaign.
- Reducing the cost of deploying the equipment and analyzing the data would make it easier to explain the value of the campaign to the client
- Alternatively, being able to estimate in advance the effect of more data on the uncertainty would help explain the value of the campaign to a client

Team 3: Power Performance Measurements in Complex Terrain

This team was tasked with developing a measurement campaign for power performance testing of wind turbines on the Rödeser Berg.

The team was asked to assume that they had an operating wind farm with a 200-m tower and a vertically-profiling wind lidar, and were required to carry out a power performance test on one or more turbines. This situation is likely to become common in the next few years as more wind turbines are built in complex terrain.

> Note:
> - The goal of a power performance test is to measure the undisturbed wind speed and direction to a wind turbine together with the turbine power. These data are used to check performance and may be contractually required.
> - Contractual tests often follow the IEC 61400-12-1 (2017) power performance testing standard.
> - Tests may use the hub-height wind speed or an area-averaged wind speed (rotor equivalent wind speed) to quantify the inflow wind speed.
> - A key issue in power performance testing is understanding the relationship between the measurement point and the turbine location, which is called site calibration. This was discussed in an earlier presentation at this workshop.
> - In this example, the 200-m tower was positioned approximately where the IEC 61400-12-1 (2017) standard would require it to be placed, i.e. 2.5D upwind in the direction of the prevailing winds. This may or may not represent current best practice, but the choice of location was made partly to stimulate discussion.

The solutions and barriers that Team 3 found are shown in Figure 3 and listed in Table 6.

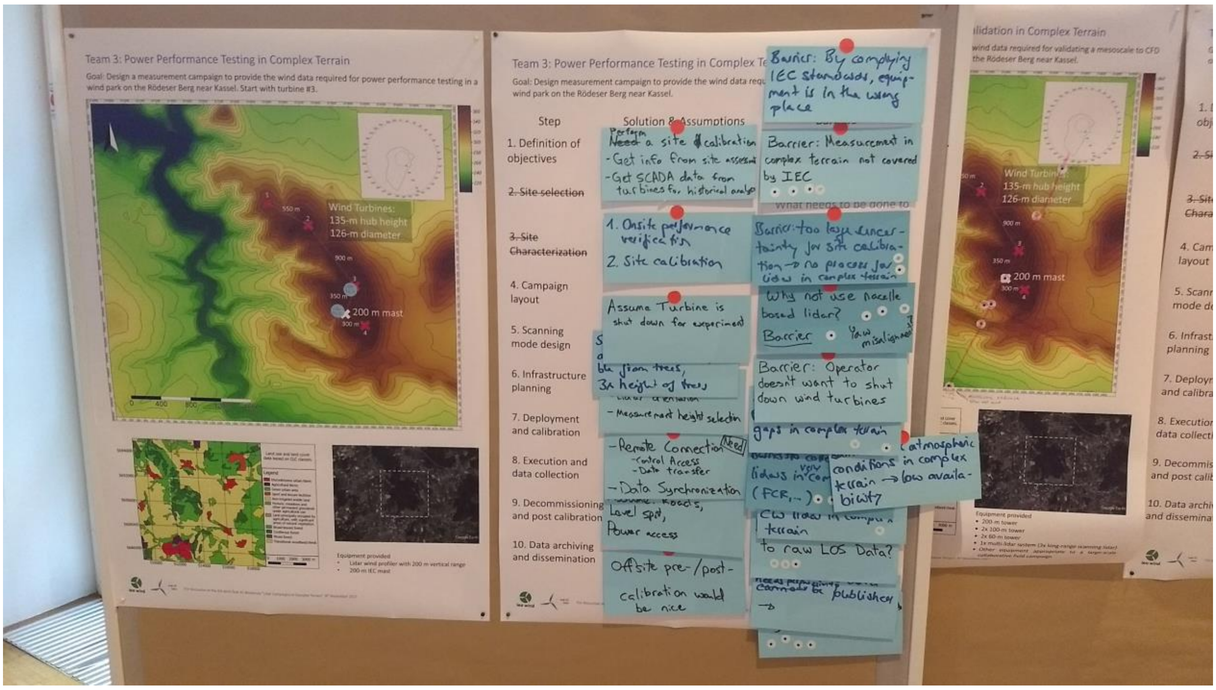


Figure 3 Planning information and results from Team 3

Table 6 Solutions and barriers found by Team 3 for a power performance test

Step	Solution	Barriers (votes)
1. Definition of objectives	Perform a site calibration Get information from site assessment Get scada data from turbines for historical analysis → onsite performance verification → site calibration	By complying IEC standards, equipment is in the wrong place (met mast below the turbine in 2.5D) Measurement in complex terrain is not covered by IEC (4) Too large uncertainty for site calibration → no process exists for lidar in complex terrain (2)
2. Site selection	Not investigated; information was provided as part of the case study	
3. Site characterization		
4. Campaign layout	1. measurement next to WMM 2. measurement at Turbine #3 3. again measurement at WMM (post calibration) Assumption: turbine is shut down for 2. measurement	Why not use nacelle based lidar? (4) Operator does not want to shut down turbines
5. Scanning mode design	Stay away as much as possible from trees (3x height of trees) → need for sector filtering Lidar orientation depending on obstacles Measurement height selection according to tree height	No studies exist on pulsed vs. cw lidar in complex terrain (1) Often no access to LOS data (3)
6. Infrastructure planning	Assumption: existing roads, level ground, power access	
7. Deployment and calibration	offsite pre/post calibration would be nice	No standard procedure to calculate gaps in complex terrain (2)
8. Execution and data collection	Need for remote connection → control access → data transfer	Worse atmospheric conditions in complex terrain → low availability of lidar data
9. Decommissioning and post calibration	offsite pre/post calibration would be nice	No correction for lidar in very complex terrain exists (4) Single lidar uncertainty high in complex terrain (4)
10. Data archiving and dissemination		Private data needs permission to be published

Note:

- Forward looking lidar mounted on the turbine nacelle or spinner can also be used to measure wind turbine inflow.
- The use of forward looking lidar for power performance testing is not yet covered by standards.
- There are several projects in industry and academia to investigate the use of forward-looking lidar, including developing best practices as the basis for standards. More information can be found at www.unitte.dk.

Team 4: Model Chain Validation in Complex Terrain

This team was tasked with developing a measurement campaign for the validation of an atmospheric model chain covering scales from the mesoscale to the micro- and turbine blade scale.

The team was asked to assume that they had an operating wind farm with a 200-m tower, a synchronized 3-scanning lidar system, and sensors appropriate to a major international project. Several comparable projects have taken place recently.

> Note:
> - This type of experiment has been tried in the USA and Europe over the last few years, e.g.:
>   - For the New European Wind Atlas (NEWA)[3]
>   - At the US-DoE Scaled Wind Facility (SWiFT)[4]
>   - Within the Wind Forecasting Improvement Project (WFIP) 2 campaigns[5].
> - Such projects usually try to resolve conditions at a range of temporal and spatial scales, "telescoping" down to the location of focus.
> - Winds are driven by a combination of regional effects (such as pressure fields) and local effects (such as buoyancy due to heating over forests and drag from trees). Therefore fluxes of momentum, heat, and moisture are also measured to understand processes in the domain of interest.

The solutions and barriers that Team 4 found are shown in Figure 4 and listed in Table 7.

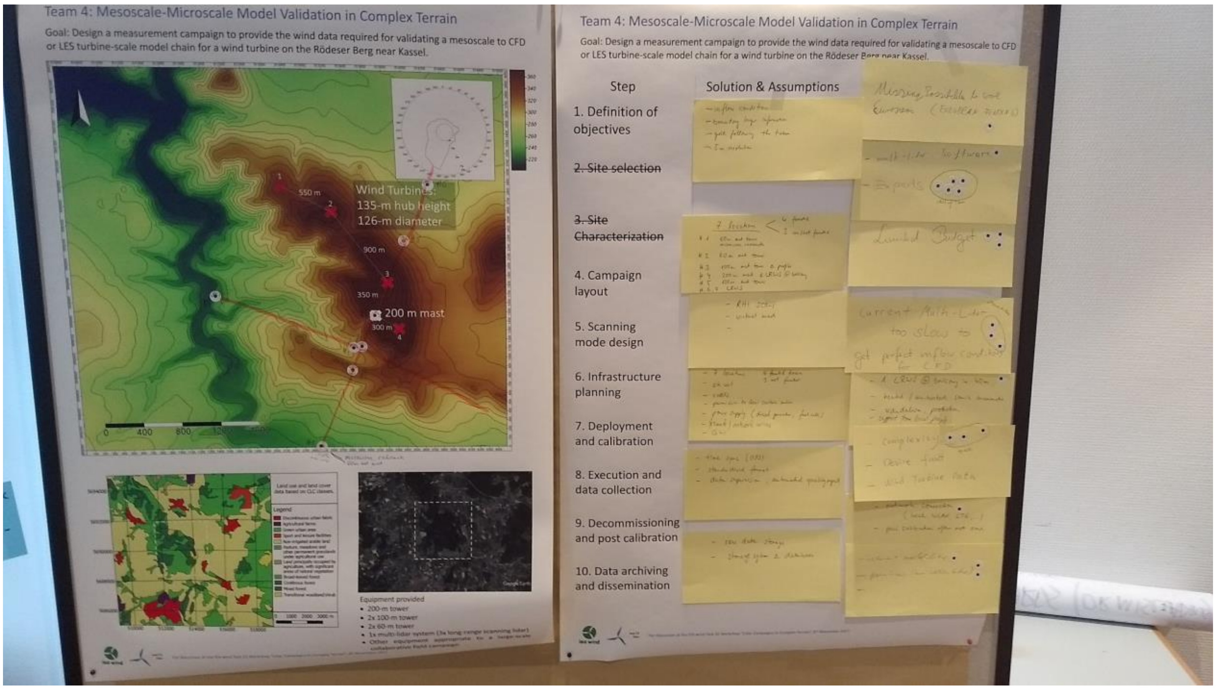


Figure 4 Planning information and results from Team 4

[3] See http://www.neweuropeanwindatlas.eu/ for details of the New European Wind Atlas

[4] See https://a2e.energy.gov/projects/wake for details of wake measurements at SWifT

[5] See https://a2e.energy.gov/projects/wfip2 for details of the Wind

Table 7 Solutions and barriers found by Team 4 for Model Chain Validation

Step	Solution	Barriers (votes)
1. Definition of objectives	Inflow condition Boundary layer information Grid following the terrain 5m resolution	Missing possibilities to work on European level (EU funding) (1) Not enough experts (5)
2. Site selection		
3. Site characterization		
4. Campaign layout	7 locations (4 forested, 3 unforested) #1 60m met tower & microwave radiometer #2 60m met tower #3 100m met tower & profiler #4 200m mt tower & LRWS@balcony #5 100m met tower #6,7 LRWS	Limited budget (3)
5. Scanning mode design	RHI scans Virtual masts	Multi lidar software Current multi-lidar too slow to get perfect inflow conditions for CFD (3)
6. Infrastructure planning	Site visit Roads Permission to clear certain areas Power supply (diesel generator, fuel cell) (Remote) network access G41 Time sync (GPS) Standardised format	1 LRWS @ balcony in 40m (1) Heated/unheated sonics Vandalism/Protection Support from local people Network connection (1) Complexity of the campaign (3) Permissions (tower installation, landuse) (2)
7. Deployment and calibration		
8. Execution and data collection	Data supervision Automatic quality report	Device faults, instrument availability (1) Availability of wind turbine data
9. Decommissioning and post calibration		Post calibration often not done
10. Data archiving and dissemination	raw data storage Storage system and database	

Note

- The solution identified by this team is similar to other campaigns.
- To ensure that equipment works and that the campaign delivers the required data, it is essential to plan personnel to prepare the experiment (stages 1-6) and support equipment once deployed (7-8), and afterwards to ensure that data are captured and used (9-10).
- There are a limited number of experts worldwide with the necessary skills and experience to support such a campaign. At this time, one person's absence can impact a campaign.
- The data sets obtained by a collaborative field project can support decades of follow-up research and have been responsible for many of the recent improvements in atmospheric science, weather forecasting, and flow modeling.
- There are synergies in this application with IEA Wind Task 31 and IEA Wind Task 36.

Case Study Results

15:30	Andy Clifton **Case Study Results**

Each team presented their measurement campaign concept to the rest of the workshop (Figure 5). There was a short question-and-answer session about each team's results.

Figure 5 Presenting results to the workshop

Summary of Issues

16:15	Next Steps and Priorities

The final stage of the workshop was a discussion of the three or four most important issues that each team identified, and how to overcome these barriers. Table 8 synthesizes the discussions.

Table 8 the most important barriers identified by each team

Team	Issues or barriers	Potential Actions
1. Resource assessment	Unclear whether to trust the mast, lidar, or a model in a complex terrain	Generalizing results and developing tools that can accurately predict differences between measurements
	Uncertainty is undefined if terrain and flow changes as you move away from a reference tower	Not clear!
2. Advanced resource assessment	Not clear how to extract value from the scanning lidar	Need to continue to demonstrate links between campaign cost, uncertainty, and the value to the project
	Lack of knowledge	• Continue developing recommended practices and share experience in IEA • Awareness of resources such as DTU-led Remote Sensing Summer School[6]
	Lack of trust in turbulence measurements; still not clear that turbulence intensity is the best metric	Continued academic and industry research needed. New metrics
3. Power performance measurements	Current IEC standards are not applicable to complex terrain, but if they are used, they are misleading or wrong	
	Not clear that ground-based lidar is the best tool in very complex terrain	Continuing to gather & share experience with forward looking lidar
	Hard to access raw line-of-sight data, which could be used in CFD comparisons	Cooperation with device manufacturers and modeling community
4. Multi-lidar	Not enough experts	• Training by consultants, academic institutions (e.g. DTU Remote Sensing Summer School) • Developing software tools to assist in campaign planning • Embed experience & expertise in tools
	Budget	• Lidar campaigns need significant and realistic funding
	Speed of devices	• Devices are not fast enough to get all of the data required for e.g. CFD validation
Common themes	Lack of national- and international-level funding to address the challenge of wind energy in complex terrain	Raising awareness of complex terrain • Communication with funding agencies • Conference presentations • A new IEA Task for Complex Terrain?
	Every measurement campaign and project is unique	Provide access to best practices by embedding experience in hardware, software, processes, standards, and tools
	Measurements in complex terrain are complex!	• Role for IEA as meeting place between researchers and users from Europe, the Americas and Asia • Is there potential for a new "Complex Terrain" IEA Task?

[6] See e.g. http://www.vindenergi.dtu.dk/english/education/phd/phd-summer-school

There was general agreement between the participants on the need to continue to investigate the use of lidar in complex terrain as part of an IEA Wind Task. Participants were also reminded that they were free to use lessons learned from today to develop new products or services, to launch research projects, or however they felt appropriate.

Closing

17:30	Andy Clifton **Closing**

The participants were thanked for their hard work!

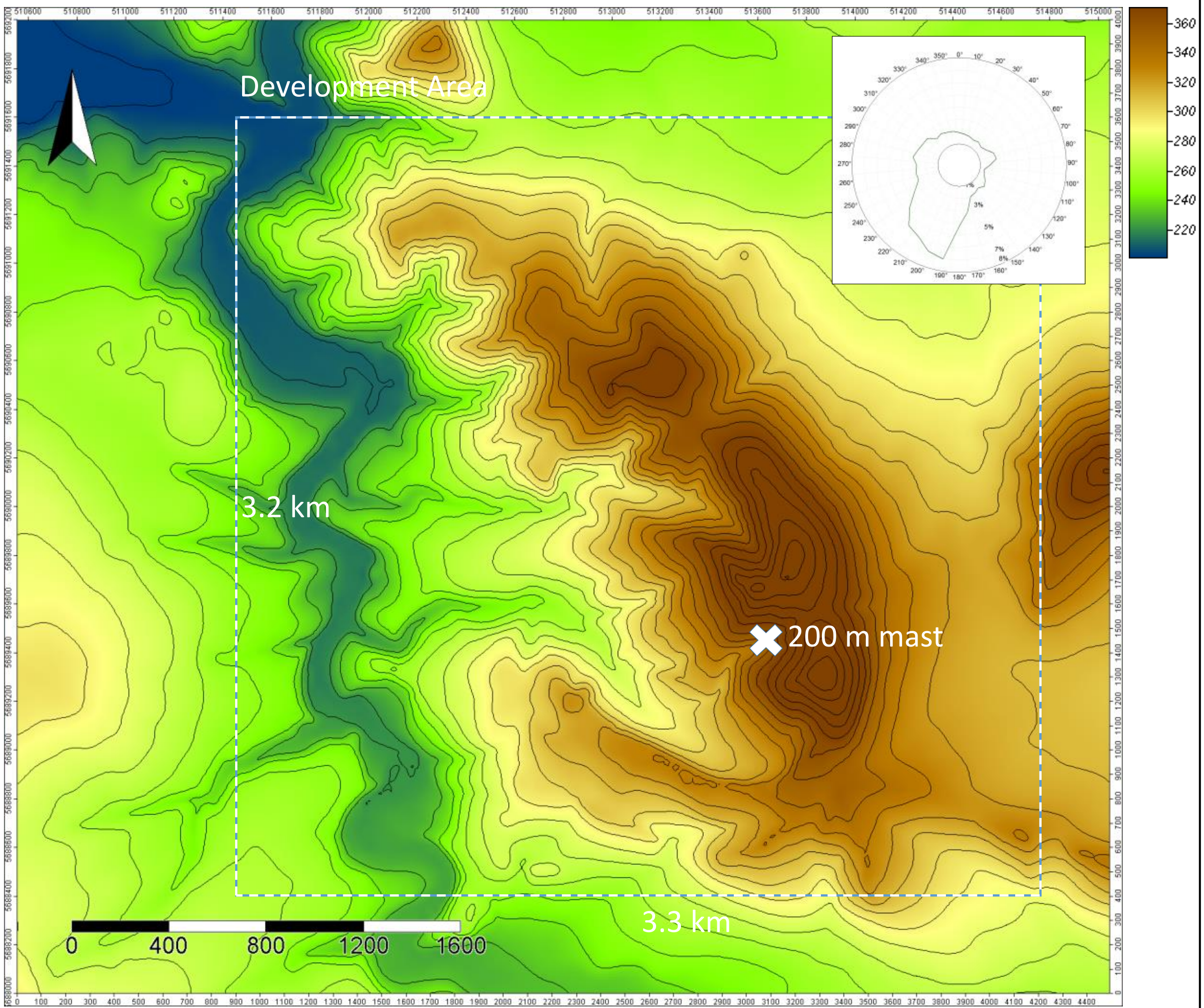
List of Participants

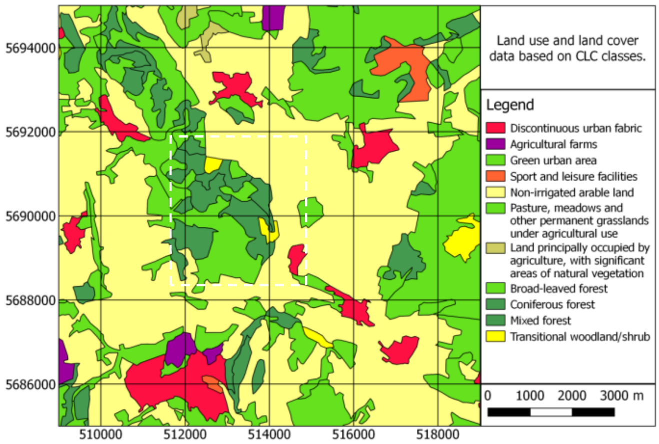
Name	Country	Representing
Andreas Rettenmeier	Germany	ZSW
Andrew Clifton	Germany	WindForS
Andrew Scholbrock	USA	NREL
Bastian Schmidt	Germany	DNV GL
Carlo Alberto Ratti	UK	ZephIR Lidar
Christoph Tiefgraber	Austria	Energiewerkstatt
Christos Tsouknidas	Denmark	Siemens
David Böckler	Germany	Enercon
David Schlipf	Germany	SWE University Stuttgart
Detlef Stein	Germany	Multiversum
Dominique Deen	Netherlands	Solidwinds
Dominique Philipp Held	Denmark	Windar Photonics
Dong-Hun Ryu	South Korea	Korea Testing Laboratory
Doron Callies	Germany	Fraunhofer IWES
Guillaume Sabiron	France	IFP Energie Nouvelles
Ines Würth	Germany	SWE University Stuttgart
Ioannis Antoniou	Denmark	Siemens Gamesa Renewable Energy
Jens Riechert	Germany	DNV GL
Julian Hieronimus	Germany	M.O.E. GmbH
Kyungnam Ko	South Korea	Jeju National University
Lei Liu	China	Goldwind
Liliana Del Angel Bulos	Germany	Windtest Grevenbroich
Madalina Marilena Jogararu	Denmark	EMD International
Martin Hofsäß	Germany	SWE University Stuttgart
Mingyuan Jiang	China	Goldwind
Mun-jong Kang	South Korea	Korean Register
Norman Wildmann	Germany	DLR
Oliver Bischoff	Germany	SWE University Stuttgart
Robert Menke	Denmark	DTU Wind Energy
Sara Koller	Switzerland	Meteotest
Shumpei Kameyama	Japan	Mitsubishi Electric Corporation
Simon-Philippe Breton	Canada	TechnoCentre Éolien
Tobias Klaas	Germany	Fraunhofer IWES

Work Sheets

Group 1: Wind Resource Assessment in Complex Terrain

Goal: Design a measurement campaign to provide the data to drive and validate a wind resource map required for a 75-MW wind park in the specified area around the Rödeser Berg near Kassel.





Equipment provided

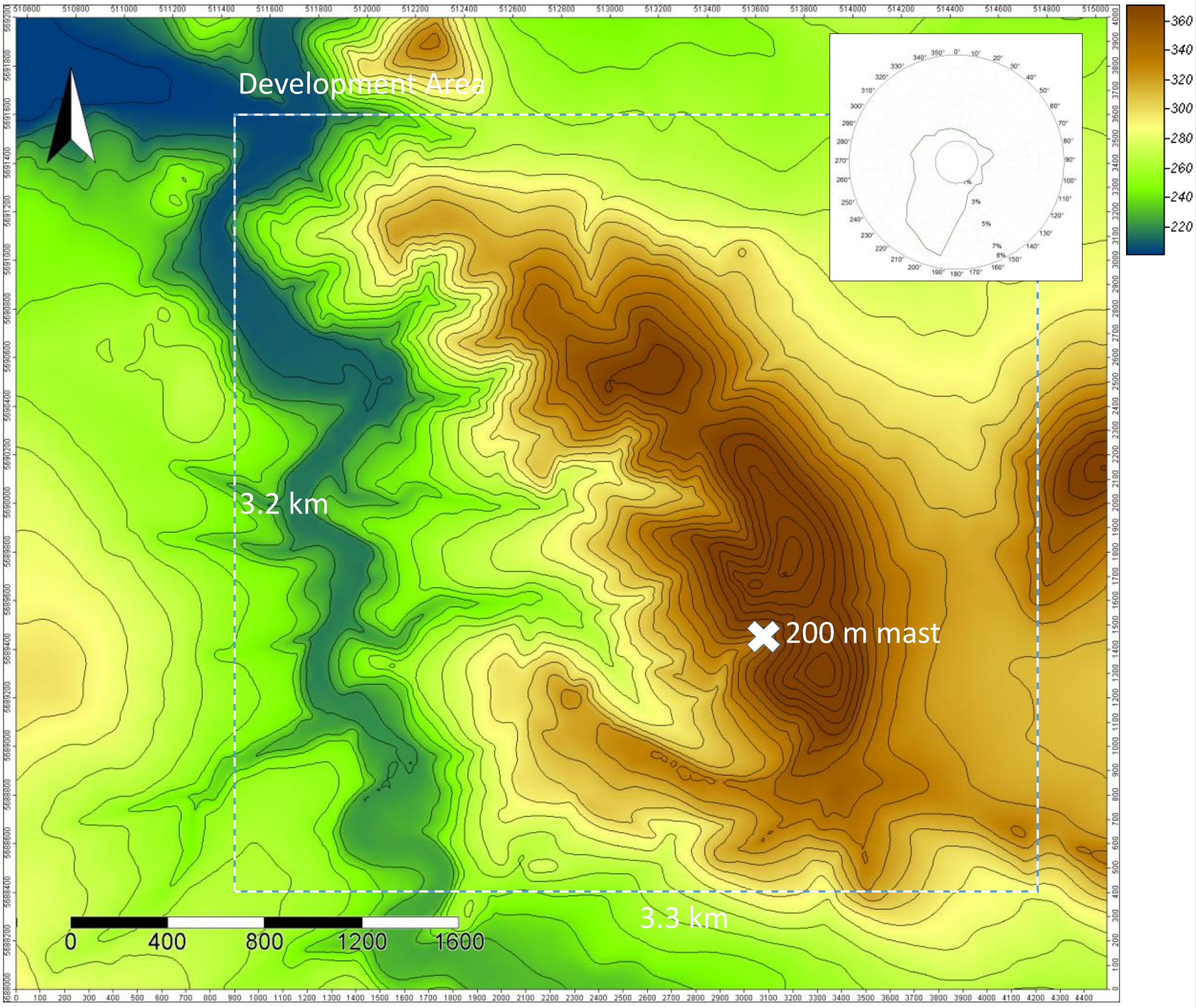
- Lidar wind profiler with 200 m vertical range
- 200-m IEC mast

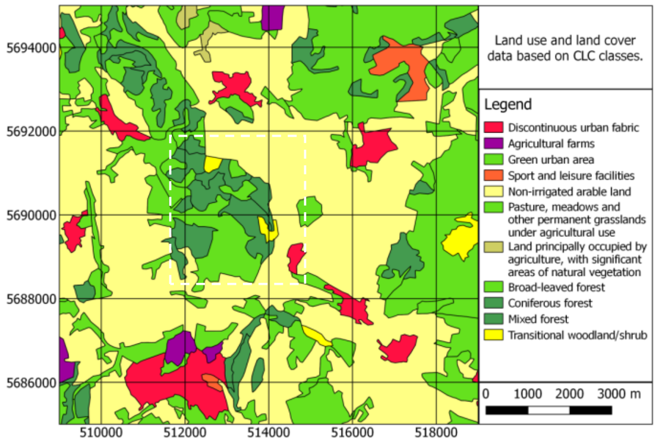
For discussion at the IEA wind Task 32 Workshop "Lidar Campaigns in Complex Terrain", 8th November 2017

Figure 6 Worksheet for Team 1

Team 2: Wind Resource Assessment in Complex Terrain With a Scanning Lidar

Goal: Design a measurement campaign to provide the data to drive and validate a wind resource map required for a 75-MW wind park in the specified area around the Rödeser Berg near Kassel.





Equipment provided

- Lidar wind profiler with 200 m vertical range
- Scanning wind Lidar with 4-km nominal range
- 200-m IEC mast

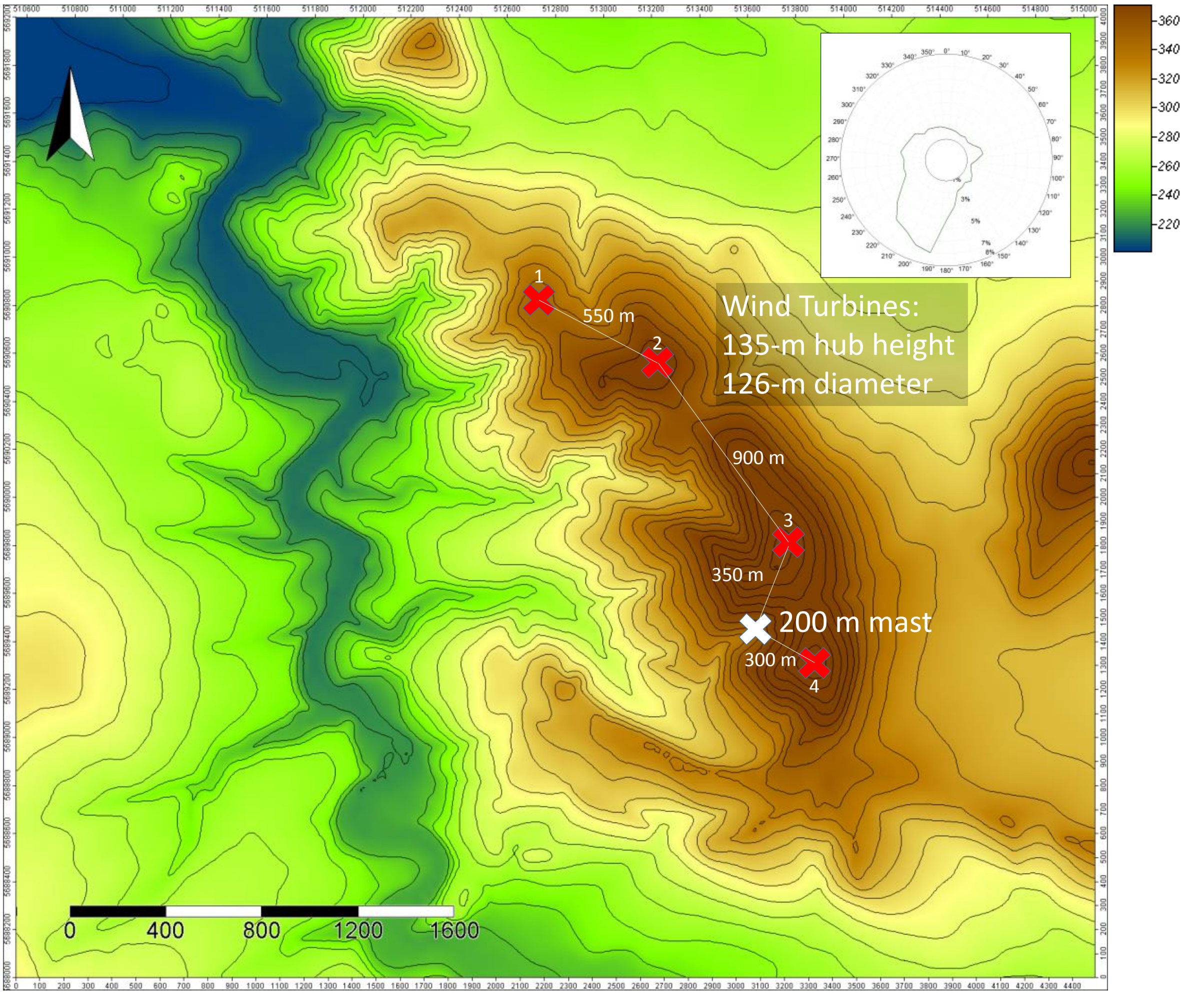
iea wind task 32 lidar

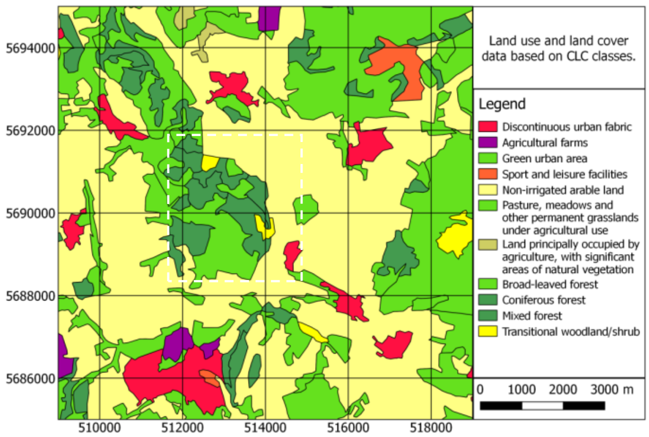
For discussion at the IEA wind Task 32 Workshop “Lidar Campaigns in Complex Terrain”, 8th November 2017

Figure 7 Worksheet for Team 2

Team 3: Power Performance Testing in Complex Terrain

Goal: Design a measurement campaign to provide the wind data required for power performance testing in a wind park on the Rödeser Berg near Kassel. Start with turbine #3.





Equipment provided

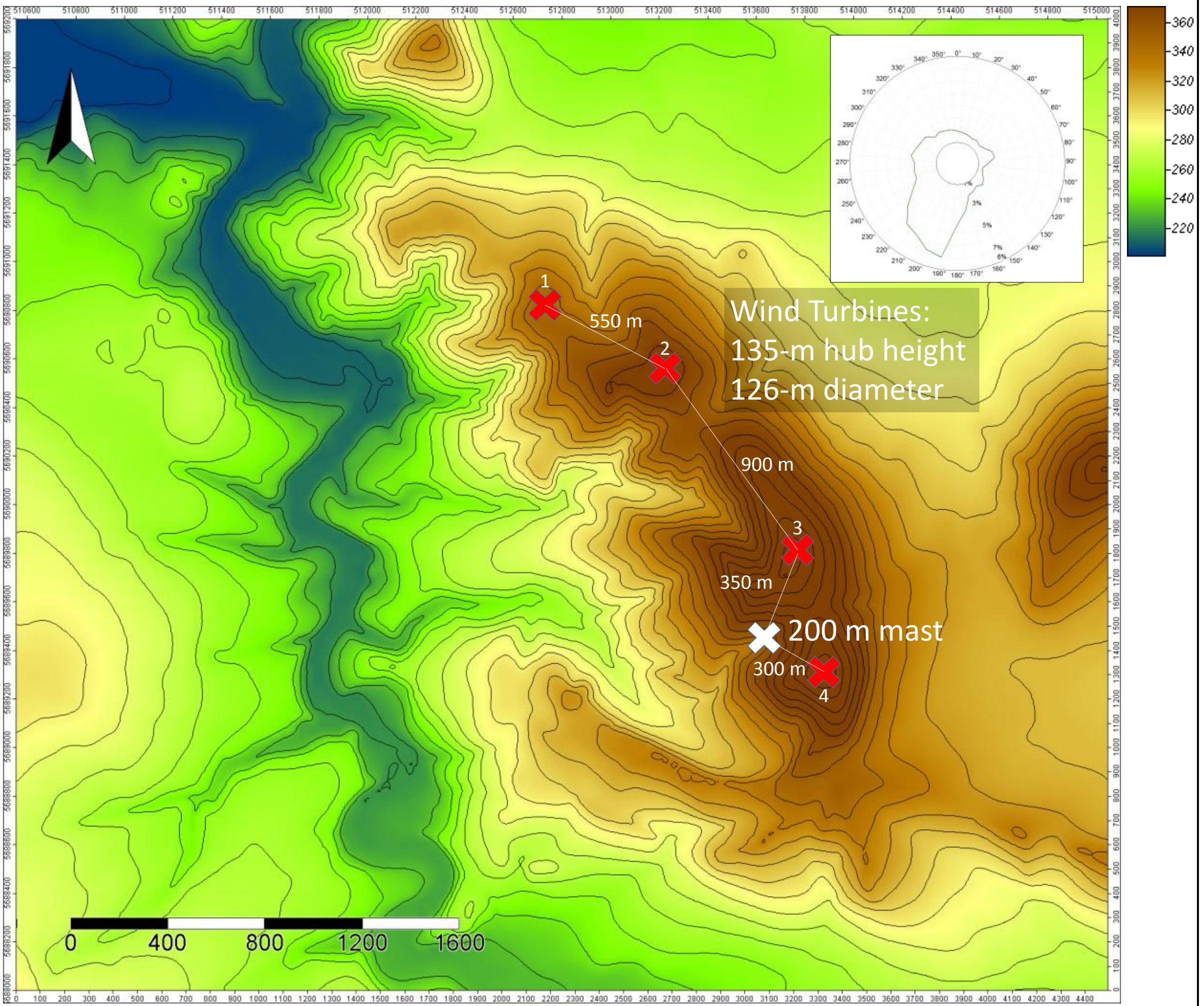
- Lidar wind profiler with 200 m vertical range
- 200-m IEC mast

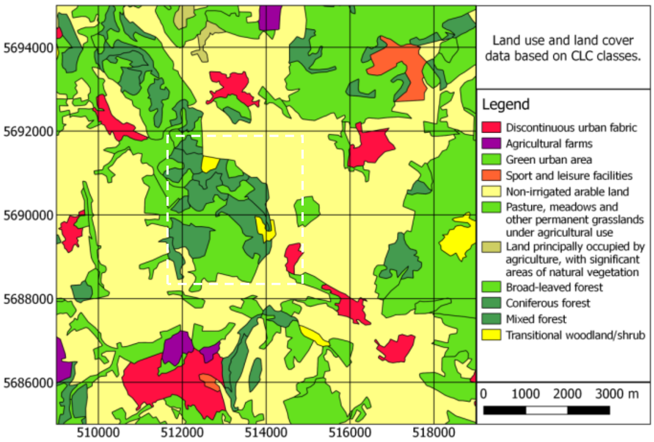
For discussion at the IEA wind Task 32 Workshop "Lidar Campaigns in Complex Terrain", 8th November 2017

Figure 8 Worksheet for Team 3

Team 4: Mesoscale-Microscale Model Validation in Complex Terrain

Goal: Design a measurement campaign to provide the wind data required for validating a mesoscale to CFD or LES turbine-scale model chain for a wind turbine on the Rödeser Berg near Kassel.





Equipment provided

- 200-m tower
- 2x 100-m tower
- 2x 60-m tower
- 1x multi-lidar system (3x long-range scanning lidar)
- Other equipment appropriate to a large-scale collaborative field campaign

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For discussion at the IEA wind Task 32 Workshop "Lidar Campaigns in Complex Terrain", 8th November 2017

Figure 9 Worksheet for Team 4