May 2017

Invitation
to the IEA Wind Task 32 Workshop #5 on

Elaboration of use cases in wake and complex flow measurements

Date: 19-20 June 2017
Venue: University of Glasgow, Glasgow, Scotland
Workshop leader: Peter Clive, Wood Group

Introduction to IEA Wind Task 32

The main objective of the Task 32 is to identify and mitigate barriers to the use of lidar technology in wind energy applications and topic areas such as:

- Site assessment,
- Power performance,
- Loads & control, and
- Complex flow.

One yearly workshop is organized for each of the four applications focusing on one specific problem, and with a well-defined program and tangible outcome.
More details can be found on the task website.

Objective of Workshop

Workshop #5 is concerned with the Complex Flow topic area. It continues progress made during Workshop #3 on 4th October 2016 and builds on the lidar use case framework for describing lidar applications in wind energy assessments described in "Remote Sensing of Complex Flows by Doppler Wind Lidar: Issues and Preliminary Recommendations" (the Preliminary Recommendations).

Lidars have been successfully used to investigate complex wind flow phenomena such as wind turbine wakes. The objective of this workshop is to address barriers to their more widespread adoption by improving confidence in the lidar results.

Lidar measurements represent a significant increase in sophistication commensurate with the degree of complexity of the structures they are used to characterize. The instruments themselves are used to implement a wide variety of lidar use cases to access datasets that would not otherwise be available and do not necessarily have a met mast analogue.

Barrier

A consequence of the increasing versatility and sophistication of lidar instruments and methods is the need to elaborate to a greater extent than has hitherto been the case the procedures for using these devices and the ways in which they can fulfil our data requirements. This will then support increased use of lidar to characterize complex flow.

In particular, there is a need to develop clear, complete, robust and repeatable procedures for the evaluation of the uncertainties in lidar results, when obtaining these results to fulfil the data requirements of the lidar use case being implemented.

Concept

It is necessary to increase confidence in the implementation of sophisticated lidar use cases for the fulfilment of complex data requirements. This can be achieved by ensuring the lidar use cases themselves represent a complete and valid description of the lidar application. This enables the formulation a complete uncertainty model.

There should be a one-to-one correspondence between a valid lidar use case and a complete uncertainty model, since the use case description should allow all sources of uncertainty to be identified. The way these uncertainties propagate through the calculations needed to derive the results can then be understood. Lidar methods make available new data in complex flow, however full use of these data require that the uncertainties are better understood.

The participants in the workshop will consider specific complex flow lidar use cases to formulate uncertainty models that support the development of uncertainty evaluation procedures. Examples of lidar uses cases that may be considered include (but are not limited to):

- Model validation by comparing observed and predicted radial velocities in complex flow;
- Integration of measurements and models in real time under highly constrained circumstances using fast CFD solvers;
- Convergent scan geometries / Windscanner / dual Doppler / multi-lidar techniques;
- Complex flow compensation of wind profile measurements in complex terrain;
- Wake observations and wake model validations.

Expected Outcome

Based on the results of the workshop, and building on the program detail described below, a first supplement to the Preliminary Recommendations will be compiled. This will include documentation covering the various contributions to the workshop.

Practical Arrangements

Registration

For participation in the workshop, please register by sending an email to the Operating Agent Representative David Schlipf. Your registration email should include:

- Name and institution, member country
- Please describe your stakeholder role (e.g., wind turbine manufacturer, lidar supplier, academic, consultant, developer, utility, etc.)
- A slide to be presented during the introduction round, which describes your experience with lidar measurements and/or wind models and your expectation from the workshop.

Please register before **Friday 9th June 2017**. Prior to the workshop, registered participants will receive if necessary additional workshop details and materials. Registration for the workshop is free of charge.

If you would like to present at the workshop please submit a short proposal (no more than 300 words) to the Workshop Leader, Peter Clive, or the IEA Wind Task 32 Operating Agent, David Schlipf, by **Monday 29th May 2017**.

Contact Information

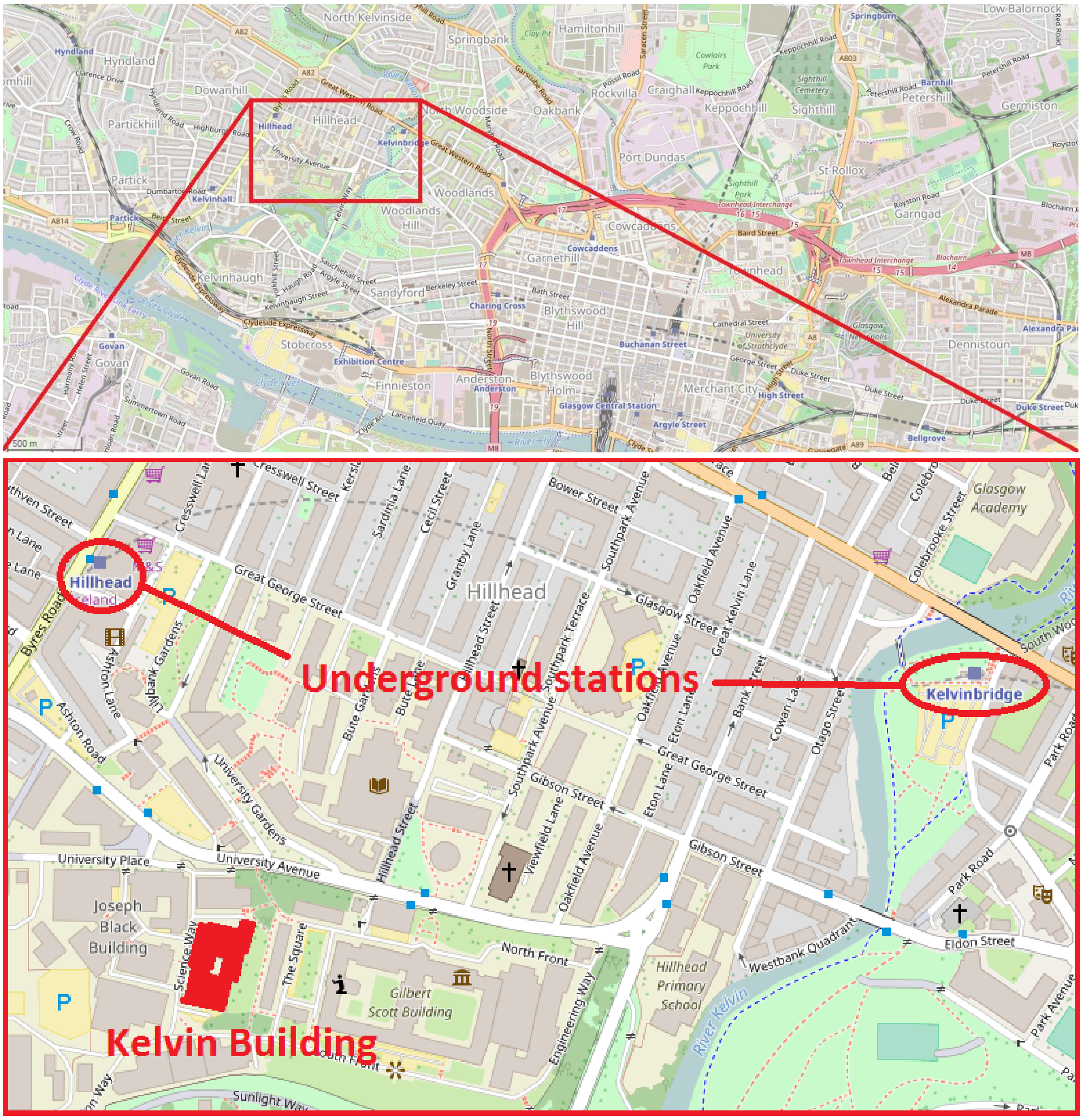
Please contact Peter Clive (workshop leader) or David Schlipf (IEA Wind Task 32 Operating Agent) with any questions you may have about the workshop.

Venue Information

The workshop will be held in Room 257 of the Kelvin Building, University of Glasgow, Glasgow G12 8QQ, in the University of Glasgow's School of Physics and Astronomy on its Gilmorehill Campus in the West End of Glasgow, just off University Avenue.



Glasgow University Kelvin Building and Room 257


Underground stations
Hillhead
Kelvinbridge
Kelvin Building
Joseph Black Building
Gilbert Scott Building
University Avenue
University Place
Great George Street
Gibson Street
Glasgow Academy
Hillhead Primary School
River Kelvin

Draft Agenda

Day 1 - Monday 19th June 2017

09:00 Welcome and introduction round
09:30 Introduction to the workshop
09:45 Lidar use cases for assessing complex flow
11:00 Coffee break
11:15 Case studies
12:30 Lunch
13:30 Integration of measurements and models
14:30 Using lidar use cases to develop complete uncertainty models
15:30 Coffee break
15:45 Group discussion
16:45 Summary and identification of next steps
17:00 End of Day 1

Day 2 - Tuesday 20th June 2017

09:00 Welcome and recap of Day 1
09:15 Wake measurement case studies
11:00 Coffee break
11:15 Discussion of lidar use cases for assessing wakes
12:30 Lunch
13:30 Discussion of wake measurement uncertainty models
15:00 Coffee break
15:15 Summary and identification of next steps
15:30 End of workshop

Program Detail

Introduction

The versatility of lidar is allowing complex wind flow to be characterized with greater detail and precision than previously possible. It is no longer necessary to invoke various simplifying assumptions when describing wind, since the limitations of the sensors historically available, which made these assumptions necessary, have been overcome by the capabilities of instruments such as lidar. Sophisticated assessments of wind conditions and their consequences for evaluations of incident wind resource, wind turbine power performance, mechanical fatigue loads, wind turbine and wind farm wake studies, and effective wind turbine control, are possible.

Wind energy assessment procedures that remain based on the limited capabilities of cup anemometry must be revised to benefit from the exploitation of the richer datasets made available by lidar. The greater degree of sophistication now possible with respect to wind measurements entails an attendant increase in the complexity of the uncertainty analyses associated with these measurements. Lidar is changing the way we do wind power.

Uncertainty

Improving wind energy assessments in general requires a more thorough approach to uncertainty assessment which considers all contributions to uncertainty, the ways they are related, and how they are propagated through the calculations on which the assessments are based. One of the main benefits of lidar, and at the same time one of its principle challenges, is the need to consider contributions that may have previously been neglected in analyses based on older measurement methods. As our picture of the wind becomes less pixelated with approximations and more detailed and precise, new features are revealed, new understanding obtained, and new challenges arise when characterizing it in a useful, and technically and scientifically rigorous, way.

The versatility of lidar has necessitated the description of its application with respect to specific use cases, as discussed in "Remote Sensing of Complex Flows by Doppler Wind Lidar: Issues and Preliminary Recommendations". These relate the data requirements that the measurements fulfil to the measurement method that is implemented and the performance of that method under the specific circumstances in which the measurements are made.

Crucially, the use case approach ensures data requirements are considered separately from the capabilities of the method that is adopted, so that the perceived limitations of a particular method do not unnecessarily restrict the data requirements that are considered. This is important because assumptions about instrument capabilities based on the limitations of met masts have restricted the data requirements addressed in established wind energy assessment procedures. This has inhibited the development of a sufficiently full and complete treatment of measurement uncertainties.

It can be seen that there is a one-to-one correspondence between the ability to describe a valid lidar use case and the ability to evaluate uncertainty using a complete uncertainty model that does not neglect any contributions and considers them in a robust and unbiased manner. This fulfils a requirement of "bankability" described in Section 1.7 of the IEA Wind Energy Recommended Practices 15.

Uncertainty contributions arise in relation to the components and subsystems used to implement the measurement method.

For example, these might include:

- The azimuth and elevation angles of the line of sight along which lidar radial velocity measurements are acquired;
- The distance along the line of sight to the probe volume where the lidar emissions interact with atmospheric aerosol particles entrained with the wind; and
- The radial velocity measurement itself.

Uncertainty contributions also arise in relation to the circumstances of the measurement and the way in which the complex flow structures themselves interact with the lidar probe being deployed to assess them. This might include, for example:

- Variations in wind velocity vector components within the probe volume itself; and
- Variations in wind velocity vector components between individual probe volumes in which radial velocities are acquired, and the implications these variations have for the validity of any assumptions inherent in the way wind vector fields are reconstructed from radial velocity measurements.

Lidar system categories

When describing lidar use cases, it is useful to categorize the available systems themselves. This may be done with reference to three generations of device:

- First generation systems emulate the capabilities of predecessor instruments such as cup anemometry mounted on temporary meteorological masts (met masts). This involves a characterization of wind conditions in one location in a way that is intuitively straightforward (for example, a wind speed and direction measurement), and the extrapolation of these measurements to other locations using models of varying sophistication.
- Second generation techniques acquire measurements throughout the region of interest. However, these are not intuitively simple (for example, radial components of the wind velocity vector in the measurement location relative to the location of the lidar). In addition, trade-offs are incurred between, for example, time- and space resolution, as the region of interest is scanned. Greater spatial detail will require a longer period of time to acquire the necessary rays of data, impacting time resolution. Conversely, high frequency measurements necessary for characterizing turbulence are only possible in a small number of locations. In general, a process of inference is required to determine the wind velocity vector field from the observations of the line of sight radial velocities acquired in different locations at different times.
- Third generation techniques restore the intuitive aspect of first generation measurements, but provide them throughout the region of interest rather than in a single location, without incurring any trade-offs between time- and space resolution. A third-generation technique provides a full characterization of complex wind conditions. No systems currently exist that fulfil this requirement.

Integration of models and measurements

However, there are approaches that are beginning to bridge the gap between the second and third generation. For example, convergent scan geometries in which synchronized beams from multiple devices are used to survey a region of interest allow wind velocity vector fields to be mapped, albeit with measurements in a sequence of locations rather than simultaneously in all points of interest. Alternatively, if the measurement circumstances are sufficiently restricted, it may be possible to run a fast solver of a suitably simplified model that allows lidar measurements and model predictions to be seamlessly integrated so that wind conditions throughout the region of interest can be fully characterized without compromising either time- or space-resolution.

With respect to uncertainty, the increasing degree with which measurements and models are integrated requires careful attention to the origins of uncertainty in both measurements and models and the way these are propagated through the systems used to integrate them.

Currently the ways in which lidar measurements and wind flow models are integrated include (but are not limited to):

- Complex flow compensation techniques, in which the influence of terrain is modelled to enable first generation lidar wind resource measurements to be adjusted to compensate for flow heterogeneity within the measurement volume;
- Model validation, in which radial velocities observed in complex forested terrain are compared to predicted radial velocities offline; and
- Fast solver methods, in which the region of interest is highly constrained to allow the use of a simplified or linearized model which can be fitted to observed radial velocities in order to characterize the entire region in real time.

Each of these approaches must be described as a use case and the corresponding uncertainty model developed to allow realistic uncertainty values to be derived for output parameters used in subsequent wind energy assessments.

Eolics

The integration of measurements and models in the characterization of complex flow is a key strategy for accelerating progress towards third generation understanding of the wind. The objective is that predicted and measured radial velocities become essentially equivalent as our understanding of the physics, as embodied in the equations solved by our models, satisfies the tests provided by the lidar data against which it is compared to any meaningful and useful degree of granularity, and the time overhead associated with running the models and acquiring the data is reduced to become less than the timescales associated with the phenomena being observed.

Workshop program

This workshop will be concerned with reviewing and elaborating the basis on which we approach the development of a complex flow measurement campaign uncertainty model. As well as general principles, particular lidar use cases will be considered. Particular attention will be given to use cases adopted in wind turbine and wind farm wake assessments. The first day will consider the general problems associated with the development of useful uncertainty models, using the description of use cases as a means to trace the relationships and dependencies of uncertainty contributions, and to ensure important contributions are not neglected. The second day will consider use cases adopted in wind turbine wake investigations, reviewing measurement campaigns previously undertaken to identify areas in which practice can be improved.