Minutes
of the IEA Wind Task 32 and Task 36 Workshop on

Very short-term forecasting of wind power

Date: June 12-13, 2018
Venue: Niels Bohr Auditorium, DTU Risø Campus, Roskilde, Denmark
Workshop leaders: Ines Würth (Uni Stuttgart), Laura Valldecabres (Uni Oldenburg),
Elliot Simon (DTU Wind Energy), Mike Courtney (DTU Wind Energy)

Background to the Workshop

Due to the increasing penetration of renewable energy power systems into the grid, the demand for short-term wind power forecasting increases, as grid operators need to ensure grid stability in spite of the highly fluctuating power sources. As state of the art forecasting techniques using Numerical Weather Prediction (NWP) models do not cover forecasting horizons in the minute range, different approaches have to be carried out. These techniques include statistical approaches, the use of remote sensing devices such as lidar or radar and also the use of turbine data information from surrounding wind parks. The goal of this workshop therefore was to

- Enable an exchange of experience in very short-term forecasting techniques
- Create links between the potential users and the researchers
- Come up with a definition of the forecasting horizon of "very short-term" and discuss which forecasting horizon is of interest now and in the future
- Provide a list of barriers and possible solutions to the adoption of very short term forecasting

Program

Start	Day 1
09:00	Arrival and registration

09:30	**Introduction** ● Workshop goals ● Introductions
10:00	**Where are we with very short-term forecasting?** ● David Schlipf, Uni Stuttgart: Introduction to Task 32; Presentation of State of the art lidar applications ● Gregor Giebel, DTU: Introduction to Task 36; Presentation of state of the art forecasting techniques and overview of different forecasting horizons.
11:00	**Break**
11:15	**What is the target forecasting time and on which factors does it depend?** Plenum discussion
12:00	**Experiences with very short-term forecasting Part 1 Scada Data** Presentation of different stakeholders ● Ciaran Gilbert, Uni Strathclyde, Pierre Pinson, Jakob Messner/ DTU Elektro: Very high resolution forecasts using a nested LES system ● Christopher Bay, NREL: Wind Direction Consensus and Forecasting for Improved Wind Farm Operation
12:30	**Lunch**
13:15	**Experiences with very short-term forecasting Part 1 Scada Data** Presentation of different stakeholders: ● Harley Mackenzie, HARD Software Australia: Short term forecasting of wind power plant generation for system stability and provision of ancillary services ● Bahri Uzunoğlu, Uppsala University: Maximum likelihood ensemble filter SCADA data assimilation for wind farms for very short-term forecasting
14:15	**Experiences with very short-term forecasting Part 2 Lidar & Radar** ● Anamaria Sirghie, ConWX: Lidar based short term forecast for offshore wind ● John Zack, AWS Truepower: Intra-hour wind ramp forecasting in Hawaii using scanning lidar
15:00	**Break**
15:30	**Experiences with very short-term forecasting Part 2 Lidar & Radar** ● Corinna Möhrlen, WEPROG, Can Lidars replace met masts in real-time system operation: results from a study for the Irish TSOs ● Laura Valldecabres, Uni Oldenburg: Very short-term probabilistic forecast of offshore wind power using dual-Doppler radar ● Elliot Simon, DTU: Results from a time series/online learning approach using scanning lidar inflow measurements ● Gabriel Dantas, Valentin Perruci, UFPE Brazil: An operational forecasting tool using different approaches - results from the HPC4E EU project and the EOLIPREV Brazilian project
17:00	**End of Day 1**

Start	Day 2
09:00	**Welcome and recap of Day 1**
09:15	**Looking over the horizon: Experiences with remote sensing devices** ● Thomas Schmidt, DLR, Short term solar forecasting from sky imaging, up to 30 min ● Ines Würth, Uni Stuttgart, How far can we see? Analysis of the measurement range of long-range lidar data for short-term forecasting
10:00	**World Cafe: What are the barriers and what are possible solutions** Splitting into different working groups on ● Lidar ● Radar ● Statistical Methods ● Coupling of measurements with NWP models
11:30	**Presentation of the results from each group and discussion**
12:00	**Summary of the workshop and formulation of next steps**
12:30	**End of workshop**

Minutes

Day 1:

9:30	Start of workshop

- Introduction to workshop from Ines Würth
- Round the room introductions: there was a wide range of experience and stakeholders amongst the participants
- The workshop is being recorded, the podcast can be found on youtube on the Task 36 channel: Day 1 , Day 2

10:00	David Schlipf, Uni Stuttgart

- Introduction to IEA Wind Task 32; www.ieawindtask32.org
- Short introduction to Lidar, what applications is lidar used for and what are the challenges when working with the data

10:30	Gregor Giebel, DTU

- Introduction to IEA Wind Task 36; www.ieawindforecasting.dk/

- Short introduction to state of the art forecasting techniques and overview of different forecasting horizons. Where are the gaps of NWP models?

11:15	Plenum Discussion: What is the target forecasting time and on which factors does it depend?

What is the definition of “very short-term” forecasting?

- There is a technical IEC report on short-term predictions that recommends not to use terms like very short-term or ultra short-term forecasting but instead name the forecasting horizon, e.g. minute-ahead forecast, hour-ahead forecasting. The resolution of the forecast should also be stated.
- For a forecasting provider the question is which technology can provide which horizon. A definition of what is very short-term can be the horizon where the local information dominates and data sensors, e.g. lidar, radar, met masts, provide most of the value. NWP models provide better forecasts from a certain time boundary on as the local information does not matter much anymore. It is acknowledged that this boundary is moving and depends e.g. on the resolution, or update rate of the NWP model.

What is the target forecasting horizon now and in the future?

- The forecasting horizon that is needed depends on the application of the forecast. Examples are wind turbine control, mission planning for ship vessels, or the energy trade.
- Every country that has a penetration of 25-30% and more of renewable energy will have to rely on 1 minute-ahead forecasts in the future. In a country like Germany, where the power generators are well distributed, it could take longer until the 1-minute ahead horizon will have to be adopted. Especially for large offshore wind farms the minute-ahead forecasts are very relevant and Transmission System Operators (TSOs) are already asking for it.

Who will deliver the minute-ahead forecasts - TSO or wind farm operators?

- In the future, both TSOs and wind farm operators will produce forecasts as TSOs will not rely on forecasts from farm operators as the quality of the forecast of the farm operator depends on the cost of the penalty for wrong forecasts. For farm operators it is an economic decision between cost for forecasts and a possible penalty. To get good forecasts from the farm operatory, the right financial incentive has to be offered. The challenge for the TSO is that they often do not have access to the farm data.

What are the parameters that we want to forecast?

- The challenge of the NWP model is that you have to initialize the model and specify the initial state with the correct level of detail to make a minute-ahead or hour-ahead forecast. The data that you need is not a point measurement. What you need is spatial information of data that can be assimilated into the model. Parameters are three dimensional wind, temperature and pressure, which are all related to each other. The error that is made by referring from one parameter to another is translated into an error in the prediction.
- Another challenge of NPW models is that a lot of data is created when running them in a minute resolution (keyword: “very big data”). For companies this is not feasible as it is not cheap to store this data. Therefore other technologies have to be investigated to fill that gap.

- In the future, probabilistic forecasts become more important as they also include an uncertainty band and therefore provide more information compared to deterministic forecasts.
- Uncertainties in the forecasts are not only induced by errors in the wind speed forecasts but also by errors produced by the wind farm model, i.e. wake effects, setup of the wind turbines. Therefore NWP models are not further developed at the moment, as there are too many uncertainties induced by non weather related phenomena.
- Persistence is not good enough for minute-ahead forecasts, as it cannot predict events of rapidly changing wind power. But these critical events are what is of most interest and here the methods fails.

Will storage replace the need for minute-ahead forecasts?

- Currently there is no storage technology available that can compensate power drops of huge wind or solar farms. In comparison to storage, forecasts are very cheap. Therefore minute-ahead forecasts will be needed. However, storage is important to level out uncertainties from the forecasts. Storage will be needed depending on the forecast error profile which can be given as a function of the time horizon e.g. 1-minute ahead or 10-minute ahead forecasts.
- It is not clear yet what the right metric for the error function is. It is not necessarily an error profile RMSE. The right metric will interplay with the cost of storage to determine what the optimal system is going to be. On systems where it is more important to forecast ramp events, the RMSE might not be the right metric as it fails exactly for those events.

12:00	Ciaran Gilbert, Uni Strathclyde, Pierre Pinson, Jakob Messner/ DTU Elektro

- Very high resolution forecasts using a nested LES system
- Applications in day ahead wind power forecasts

13:15	Harley Mackenzie, HARD Software Australia

- Short term forecasting of wind power plant generation for system stability and provision of ancillary services

13:40	Bahri Uzunoğlu, Uppsala University

- Maximum likelihood ensemble filter SCADA data assimilation for wind farms for very short-term forecasting

14:15	Anamaria Sirghie, ConWX

- Lidar based short term forecast for offshore wind

14:40	John Zack, AWS Truepower

- Intra-hour wind ramp forecasting in Hawaii using scanning lidar

15:30	Corinna Möhrlen, WEPROG

- Can Lidars replace met masts in real-time system operation: results from a study for the Irish TSOs

15:40	Laura Valldecabres, Uni Oldenburg

- Very short-term probabilistic forecast of offshore wind power using dual-Doppler radar

16:15	Elliot Simon, DTU

- Results from a time series/online learning approach using scanning lidar inflow measurements

16:40	Gabriel Dantas, Valentin Perruci, UFPE Brazil

- An operational forecasting tool using different approaches - results from the HPC4E EU project and the EOLIPREV Brazilian project

Day 2:

9:00	Start of Day 2

- Quick recap of day 1 and introduction to Day 2 from Laura Valldecabres Sanmartin

9:15	Thomas Schmidt, DLR, Short term solar forecasting from sky imaging, up to 30 min

- Results from experiments with cloud cameras in Oldenburg

9:40	Ines Würth, Uni Stuttgart, How far can we see? Analysis of the measurement range of long-range lidar data for short-term forecasting

- Results from a range analysis of a pulsed StreamLine XR long-range lidar
- The measurement range is very site dependent and varies with filter algorithms, device settings and environmental conditions such as fog

10:00	World Cafe: What are the barriers and what are possible solutions

The participants split into rotating working groups. Each group has a host that leads the discussion. The goal is to talk about barriers and possible solution to overcome those barriers in order to apply the four different forecasting techniques:

- Lidar
- Radar

- Statistical Methods
- Coupling of measurements with NWP models

Different forecasting horizons are taken into consideration: 1min, 30min, 1h.

11:30	Presentation of the results from each group and discussion

- Each host presented the results of the discussion. Results see below.

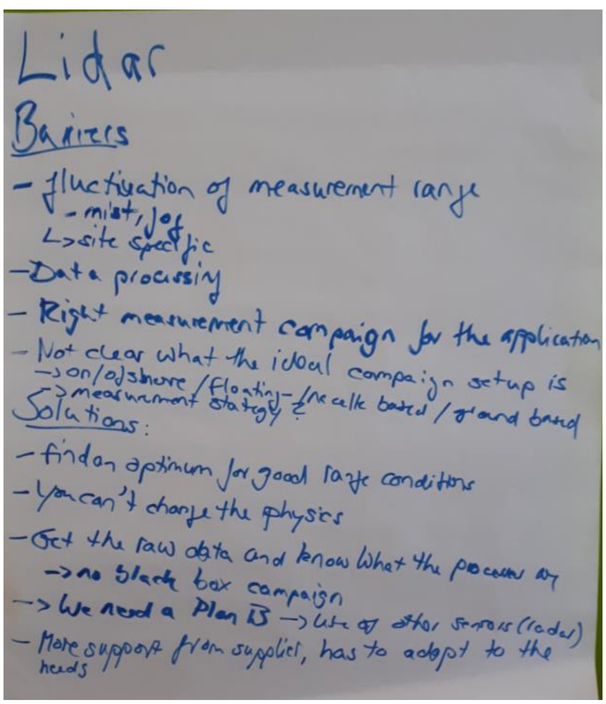
12:30	Summary of the workshop and formulation of next steps

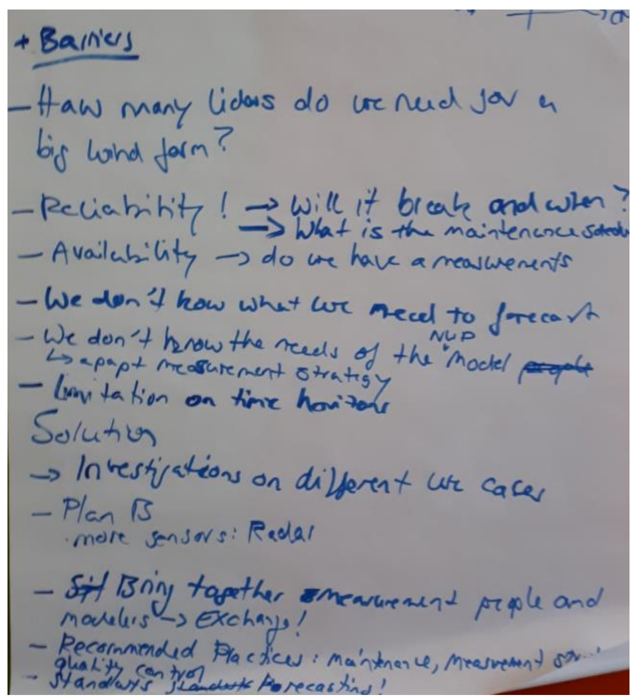
- The goals of the workshop were reached and it was a successful workshop
- Several participants indicate their interest in writing a common paper as a follow up of the workshop. The goal could be to hand it in to a journal such as the special issue “Energy Time Series Forecasting” of the Energies journal or similar. The organizers will come back to the workshop participants with a plan how to continue.
- The organizers thank all the participants and wish them safe travels back home.

Results from the World Cafe

Forecasting technique: Lidar

hosted by Ines Würth





<table>
<tr><th>Barriers</th><th>Solutions</th></tr>
<tr><td>Availability
The measurement range of the lidar fluctuates due to environmental conditions, e.g. fog, rain showers
The measurement range is site specific
You can’t change the physics → the measurement principle dictates the range and the availability
The measurement range determines the forecast horizon and if the lidar is blind, online forecasts are not possible</td><td>More investigations have to be carried out to find out what the optimum for good range conditions of lidars are
There is a need for a Plan B, i.e. a fallback solution to provide forecasts, in case the lidar does not work
Other sensors e.g. radars, drones,.. have to be investigated
Coupling of measurements with NWP models could make the forecasts more reliable</td></tr>
<tr><td>Reliability
The lidar can break and lose functionality
There is no standard that gives a maintenance schedule for lidars to ensure functionality
If the lidar does not work, online forecasts are not possible</td><td>There is a need for Recommended Practices for the application forecasting that deal with maintenance schedules of lidars
There is a need for a Plan B in case the lidar does not work (see. Solutions for availability)</td></tr>
<tr><td>Measurement campaign setup
It is not clear what the ideal campaign set-up is: how many lidars, nacelle-based, ground based,...
It is not clear what the ideal measurement strategy is: horizontal vs. vertical scan, scan opening angle, …
The needs of the NWP model are not clear and the measurement strategy might need to be adapted if data should be assimilated into the model</td><td>Different use cases of using lidars for forecasting have to be investigated to find out what the best campaign setup and measurement strategy is, e.g. for onshore/offshore/small/very large/... wind farms
There is a need for Recommended practices for the application forecasting that deal with measurement strategies
Bring together measurement and model experts and facilitate communication</td></tr>
<tr><td>Data processing
Scanning lidar systems only provide raw data that needs to be processed in order to have the data needed for forecasting. Lidar user have to create their own filtering, wind field reconstruction etc. algorithms
Sometimes only processed data is available and it is not clear how the data was processed.</td><td>Better exchange of open source methods and code to process the lidar data
More support from lidar suppliers, they have to adopt to the needs of their customers better
No black box campaigns: the raw data has to be available</td></tr>
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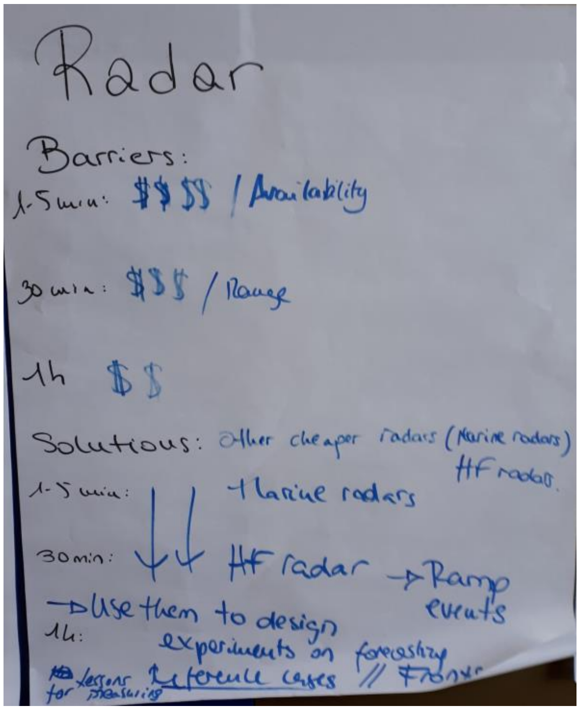
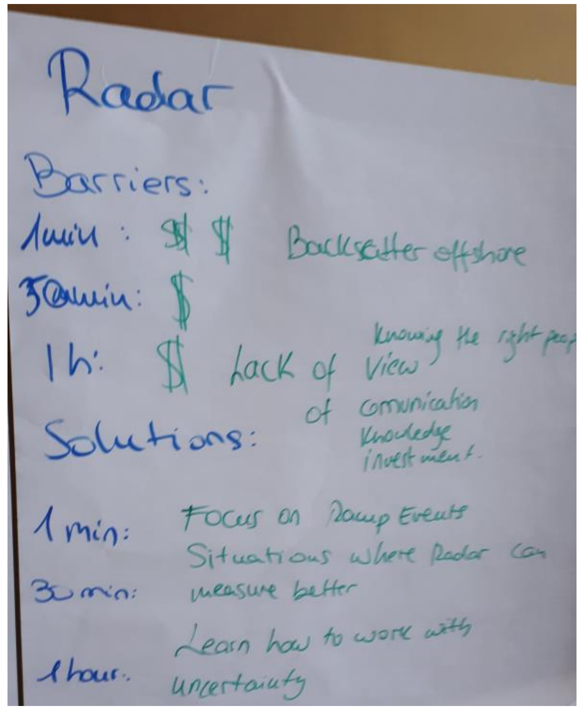
Forecasting technique Radar:

Hosted by Laura Valldecabres Sanmartin



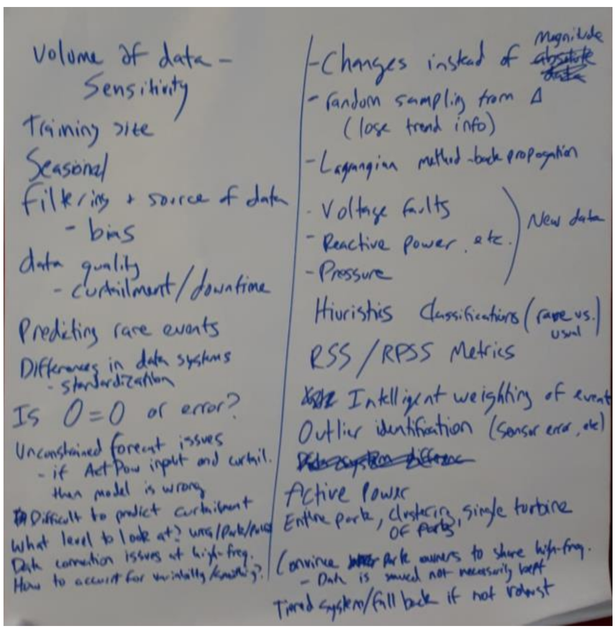


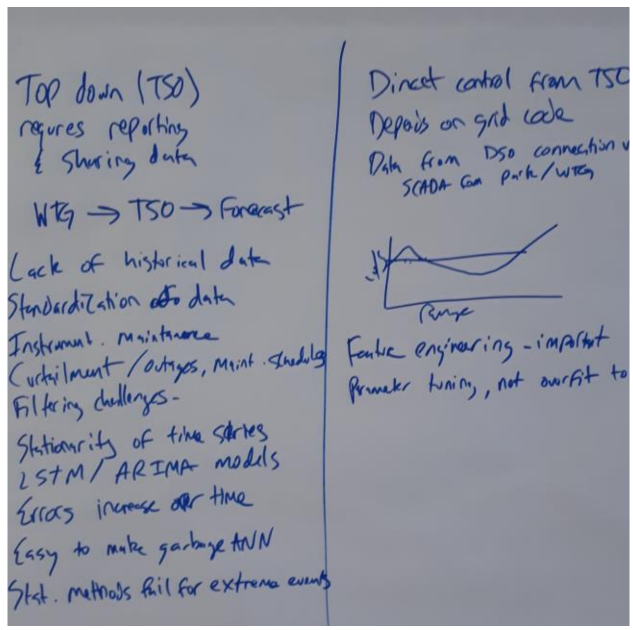
Barriers	Solutions
Reliability: ● As it happens with lidars, the quality of the radar measurements depends on the backscatter. In offshore environments, dual-Doppler radars have lower availability. ● The quality affects the range of the measurements.	● Explore deeply and define the conditions and locations for optimal measurements. Define situations where radars can add value to other forecasting techniques. ● Use hybrid modes that combine measurements with statistical analysis. Understand how to work with uncertainty.
Measurements for very short-term forecasting ● Doppler-radars have an optimal spatial/temporal resolution for very short-term forecasting of offshore wind farms. However, they are extremely expensive and improvements in the forecasting error do not pay back the	● There are other type of radars, that do not measure with the same resolution, but that are more economic: HF radars, marine radars. ● A dual-Doppler radar system could cover a cluster of wind farms and focus on

investment. ● A dual-Doppler radar system can measure the inflow of a single wind farm, covering different sectors. Again, the cost is too high.	detecting ramp events that can cause severe drops in the grid.
Other applications ● There is still no much research on how to used radar measurements for very short-term forecasting of wind power. ● There is a lack of the big picture/ knowledge transfer.	● Radar measurements can be used for validating the quality of simulations, like LES. Radar measurements can be coupled with NWP models.

Forecasting technique: Statistical Methods:

Hosted by Elliot Simon





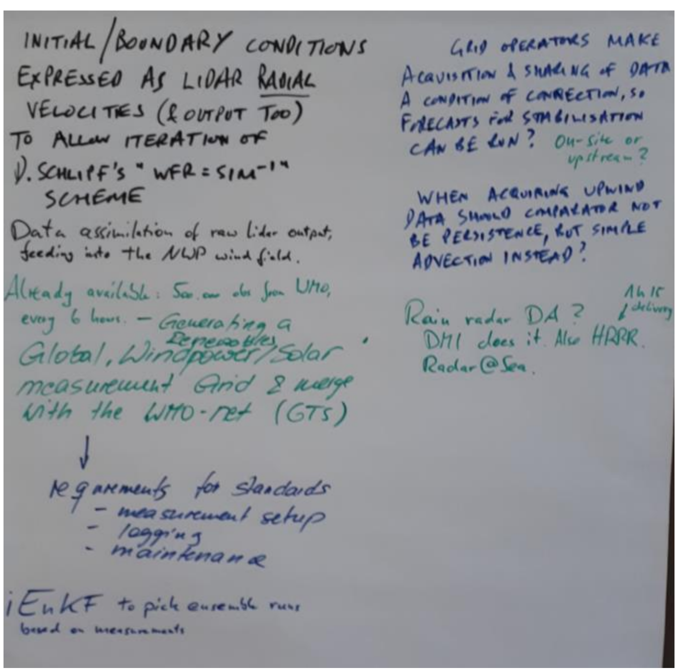
Discussion points

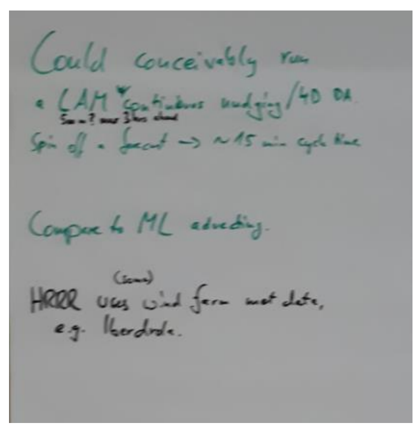
- Important for training data to be voluminous enough and contain seasonal, etc. trends.
- Care must be taken as time series are highly correlated in time. E.g. they should not be randomly shuffled around. Entire days for example can be done this way though if treated in blocks. Another approach is to use the differenced signal (instead of magnitude) which introduces a degree of independence in the samples.
- The source of the data should be quality controlled. E.g. is there curtailment or downtime? Do any filtering steps introduce bias? What are the uncertainties of the sensor and its installation? Has it been calibrated recently and properly?

- In the examples of curtailment or maintenance, if simply using turbine Active Power signal as the predictand, then the model will learn outputs which do not correlate to the inputs (e.g. a factor of wind speed). Predicting curtailment periods is difficult and highly dependent on the local power system, but labelling or classifying this during model training is possible and necessary.
- Need to decide between building a general forecasting system and focusing on getting rare events correct when designing the model. This drives the error metric you are minimizing and how everything is implemented.
- Much discussion surrounded which level to forecast at: turbine/turbine clusters/entire windfarm/entire geographic area of windfarms. No consensus was reached on this.
- Measures of variability are useful and should be included with each forecast delivery. This could be compared against e.g. a smoothed version of the same forecast
- A suggestion to data 'creators' is to keep and share valuable high-frequency measurements which can be used to improve forecast models and classify periods. This includes: Voltage faults, active & reactive power (perhaps from the grid connection point), air pressure and other met-info, etc.). This data is usually already recorded.
- A suggestion to promote (enforce?) data sharing is a top-down approach where reporting is regulated by the TSO. Some countries have implemented this, but not with high-frequency data.
- Some approaches we discussed: AR(I)MA models, LSTM (deep) neural networks, other ANNs
- Feature engineering, exploratory data analysis, parameter tuning (while avoiding overfitting) are stages where more attention can drastically improve model performance.

Forecasting technique: Coupling of measurements with NWP models

Hosted by Gregor Giebel





Discussion points
How can remote sensing data be used in NWP models? ● WMO already collects 500.000 observations world-wide, the additional measurements would only rarely contribute significantly. ● The data needs to be timely, and delivered quickly and with a quality flag to the NWP models. ● However, collection of a "Global Renewables Measurement Grid" might get very many data points as well. ● The NWP model needs to have a constant analysis, from which forecasts are spawned every hour or quicker, the way that Rapid Refresh or Rapid Update Cycle models work. Conceivably, this could get down to about 15 min cycle time. ● It might be beneficial to directly use raw lidar data and use the compatibility with the NWP wind field. A data assimilation operator needs to be developed. ● Rain radar data assimilation is already used in Denmark or the US (HRRR, the High Resolution Rapid Refresh model of NOAA). There was a project in Denmark some years ago on using a rain radar for very short term forecasting, Radar@Sea. ● HRRR already uses meteorological data from Iberdrola wind farms. Are there requirements for standards, either from the standardisation bodies or the grid codes? Standards are lacking for the measurement setup, logging, and for calibration and maintenance. For the grid connection, provision of (to be defined) data could become a requirement. When acquiring upstream data, should it be compared to some advection scheme instead of persistence? The iEnKF, the inverted Ensemble Kalman Filter can be used to connect ensemble models with measurements, finding the most fitting model run from recent measurements.

List of Participants

	First Name	Last Name	Company
1	Markus	Abel	4cast
2	John	Zack	AWS Truepower
4	Gabriel	Dantas	CER-UFPE
5	Valentin	Perruci	CER-UFPE
6	Anamaria	Sirghie	ConWX
7	Mikkel	Hansen	ConWX
8	Thomas	Schmidt	DLR
10	Henrik	Stang	DTU
11	Pedro	Santos	DTU Wind Energy
12	Elliot	Simon	DTU Wind Energy
13	Gregor	Giebel	DTU Wind Energy
14	Ignacio	Marti	DTU Wind Energy

15	Mike	Courtney	DTU Wind Energy
17	Marie-Sophie	Briem	Enercon
18	Anders	Lindfors	FMI
19	Laura	Sanmartin	ForWind – Oldenburg
20	Frauke	Theuer	ForWind - Oldenburg
21	Shigang	Yao	Goldwind
22	Xuefu	Jin	Goldwind
23	Harley	Mackenzie	Hardsoftware
24	Sebastian	Gaidi	KTH
25	John	Bremnes	met.no
26	Christopher	Bay	NREL
27	David	Schlipf	Stuttgart Wind Energy (SWE), University of Stuttgart
28	Ines	Würth	Stuttgart Wind Energy (SWE), University of Stuttgart
29	Ciaran	Gilbert	University of Strathclyde
30	Benjamin	Baier	Vattenfall
31	Corinna	Möhrlen	WEPROG
32	Antoine	Larvol	Windar Photonics A/S
33	Guillermo	Rilova	Windar Photonics A/S
34	Nikolaos	Kouris	Windar Photonics A/S
35	Scott	Wylie	ZephIR Lidar
36	Tingting	Jiang	Zhejiang Windey Co., Ltd.
37	Nicolai	Nygaard	Ørsted
38	Bahri	Uzunoğlu	Uppsala University
39	Anton	Kaifel	Center for Solar Energy and Hydrogen Research (ZSW)