Welcome

Alf Holmelid, Chairman of NORCOWE, Senior Adviser, University of Agder

Last year 195 countries signed a new international climate agreement at COP21 in Paris. The Paris Agreement generated new hope for reaching a zero-carbon world. The agreement may accelerate the momentum of the renewable energy sector and thus further strengthen the foundation for investments in renewable energy. Offshore wind energy is also prioritized in the Norwegian research strategy Energii21 and in the European SET-plan.

According to the European Wind Energy Association, EWEA, Europe grid connected 584 commercial offshore wind turbines, with a capacity of 2,343 MW during the first six months of 2015. Overall, 15 commercial wind farms were under construction. Once completed, these wind farms will have a total capacity of over 4,269 MW. New offshore capacity installations during the first half of 2015 were up 200% compared to the same period the previous year. This shows a growing market for technology for offshore wind energy. We now see a recession in the oil and gas industry due to the low oil prices. Technology suppliers on the western and southern coast of Norway are forced to reduce their activity in the oil sector. Therefore some of them have shown a renewed interest in renewable energy, especially offshore wind energy. This may boost technology development for offshore wind energy, and create a new market opportunity compensating partly for the reduced market for offshore oil and gas technology.

The wind turbine itself is not part of these companies’ technology focus, but they have relevant technology for deployment, foundation, control systems, service and maintenance. This is in compliance with the core research activities within NORCOWE and shows the relevance of the research program. During 2015 NORCOWE has conducted an extensive offshore measurement campaign at the German research platform FINO1 close to the Alpha Ventus wind farm. The campaign will continue until September 2016. The key purpose of the measurement campaign is to improve knowledge of the marine boundary layer stability, air-sea interaction and offshore wake propagation effects.

Observational data from the campaign will be used to validate and improve numerical models and tools for i.e. weather forecasting, marine operations, power performance and wind farm layout. The data analysis will also give input to improved measurement techniques. Data will be exchanged with international research partners and stored for future research activities.

The Norwegian Reference Wind Farm, NRWF, was upgraded during 2015, and the website is launched. The detailed description of the NRWF baseline will be found here, as will further work involving the reference wind farm. This tool will help researchers and industry to collaborate and to improve and benchmark wind farm design.

NORCOWE will be finalized early 2017, and the board has emphasized the importance of bringing the research results to a high technology readiness level (TRL) before the program comes to an end. To achieve this and to facilitate adopting new technology, NORCOWE will arrange dedicated seminars together with industry partners. In September 2016 NORCOWE will arrange a closing conference to sum up the research activities and to present some of the results.
The Norwegian Centre for Offshore Wind Energy (NORCOWE) was officially inaugurated in October 2009. At that time, people were very interested and optimistic on behalf of offshore wind energy. Offshore wind was considered a new business opportunity for companies in the oil and gas supply chain. Then the oil prices increased significantly and most of the Norwegian oil and gas supply chain lost their interest in offshore wind energy.

Today the oil prices are low and there is an increased interest in offshore wind on the south-west coast of Norway. Many companies now include offshore wind energy in their strategy.

During NORCOWE’s lifetime, there has been a huge growth in the installed offshore wind capacity in the North Sea, and the offshore wind industry has demonstrated its importance for the shift towards a low carbon society.

Back in 2009, NORCOWE’s research partners had no specific experience from offshore wind energy with the exception of Aalborg University. User partner Statoil installed Hywind Demo in September of that year, the first full scale floating offshore wind turbine. Statoil and Statkraft had not yet started the installation of turbines in their first offshore wind farm Sheringham Shoal.

Impact is about people. It has been my main concern as centre director to maximize NORCOWE’s impact by developing a strong culture for cooperation and joint efforts. NORCOWE should be more than the individual partners. It should be a centre where we draw on the competence of the partners in order to make successful projects. The NORCOWE Reference Wind Farm and the OBLEX-F1 measurement campaign are examples of joint projects between NORCOWE partners.

I am pleased to see that we have developed a culture for cooperation during the lifetime of the centre, and that we have strengthened the cooperation between R&D partners and between R&D partners and the user partners. Strong links between research and industry are important when it comes to funding of new projects, but is even more important when it comes to the impact of NORCOWE.

The FME centres get funding from the Research Council of Norway for eight years. In NORCOWE’s case, the centre as such will end 31st of March 2017. A new application for an offshore wind centre (COWIND) has been submitted. COWIND has partners from NORCOWE and NOWITECH, and we will know if the centre will be financed on the 26th of May 2016.

The legacy of NORCOWE
NORCOWE has given the R&D partners an opportunity to build competence and a track record in offshore wind energy research. In addition, equipment has been purchased funded by infrastructure projects like OBLO and RCN’s call for infrastructure for the FME centres. A legacy of NORCOWE is also large data sets to be used for many years, e.g. as part of Horizon 2020 projects.

The annual conferences Science Meets Industry in Stavanger and Bergen have established themselves as important to the offshore wind community in Norway. These conferences are organized together with organizations like Greater Stavanger and Bergen Chamber of Commerce and Industry. The conferences will continue in cooperation with private and public organizations after NORCOWE is finished.

SFI Offshore Mechatronics hosted by University of Agder was inaugurated last year. The centre has a strong link to NORCOWE and the Norwegian Motion Lab. In my opinion, there should be 2-3 applications in the next SFI call (most likely in 2017) partly based on the legacy from the centre.

It is impossible to measure the full impact of NORCOWE and other FME centres now. Much of the impact will appear after the centre is formally finished. In many cases NORCOWE is just one of many sources for a new product, method or research project. If so, I think NORCOWE has been successful and achieved its main goals.

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In this article I will look back at my encounter with offshore wind through my work at Vestavind Offshore AS, NORCOWE and ARENA NOW and try to make a connection to where we are today and where we are going.

Six years ago we experienced great optimism in the industry and everybody followed the Havsul Offshore Wind Park development with great expectations. Government backed R&D and cluster developments like NORCOWE, NOWITECH, INTPOW, ARENA NOW and Windcluster Mid-Norway were very active. Companies from the maritime and offshore industries eyed a new market, applying our strong offshore knowledge in offshore wind. Stimulated by NORCOWE and NOWITECH many actors started researching and developing new solutions for offshore wind. INTPOW and the Arena clusters arranged meeting places to introduce Norwegian companies to the growing offshore wind markets in Denmark, Germany and the UK.

So far so good, but one thing was missing – a home market. Havsul was to be the first major step, along with some test sites such as Metcentre off Karmøy. However, as the Havsul project approached investment decision it became evident that it would not fly financially, despite newly introduced green certificates and significant support from Enova and others. Norway simply has a too weak support scheme to kick-start major offshore wind initiatives. In the same period, major actors, like GE, pulled out of the Norwegian wind industry and some of the cluster organisations started loosing members. The situation became a bit gloomy.

That was back then. In retrospect, I firmly believe that it was all well spent time and money, even if we needed to sulk a bit about the lack of public incentives to create a home market. All cluster activity between industry, government, R&D institutions and investors tends to increase the competitiveness of the actors. This is exactly what has happened, and today we are already reaping some of the fruits. Despite the lack of a home market, NORCOWE and NOWITECH have established themselves as internationally renowned offshore wind R&D institutions, and many Norwegian companies have established themselves as important suppliers to the offshore wind market in the southern part of the North Sea. As the offshore wind parks move into deeper waters, further from shore, challenges of marine operations and subsea work will become even more demanding, and this is where Norwegian companies really can excel.

We are also getting much better at cluster development. In GCE Subsea, where I currently work, we will focus on even more cluster-to-cluster cooperation and knowledge crossover between related ocean industries, and we aim to cooperate with NORCOWE and its successors in the future. As we move along, as the innovation continues and the volumes go up, the cost of energy for offshore wind will eventually come down. I am sure of that, and within the next decade or so, I am confident that we will start deploying offshore wind turbines in our waters, with a competent Norwegian supplier industry that has managed to gain a lot of experience, even without a home market.

Offshore wind farms in Norway

Havsul was the first planned offshore wind farm in Norway that obtained a license for an annual production of around 1 TWh. The license was granted in 2009, but in 2012 all work was halted due to financial motives.

Siragrunnen, situated on the south west coast, became the new hope for establishing an offshore wind farm in Norway. The planned annual production was 790 GWh but in January 2016 the Norwegian Water Resources and Energy Directorate (NVE) dismissed the application for building a wind farm here. The reasons cited were that it would be too costly as well as having a negative environmental impact.

In November 2015 the Standing Committee on Energy and the Environment invited Statoil, Statkraft, NORCOWE and NOWITECH to a meeting where offshore wind energy was discussed. The background was a proposal from the Green Party that wanted a strong Norwegian commitment to the development of offshore wind in Norwegian waters. A Norwegian pilot farm with floating wind turbines was included in the proposal.

The meeting took place immediately after Statoil had announced their investment decision for Hywind Scotland. In the aftermath of the meeting the Parliament recommended the government to include a strategy for realizing floating offshore wind pilot projects in their Energy Bill.

The Norwegian government’s Energy Bill will be released in spring 2016.

Norwegian business and R&D clusters will focus on technology and knowledge crossover in the coming years. (Photo collage: GCE Subsea)
Preparing for the OBLEX-F1 campaign

Olav Krogsæter, Scientist, Storm Geo

Prior to the OBLEX-F1 (Offshore Boundary Layer Experiment at FINO1) campaign in the south of the North Sea several new instruments for investigating the atmospheric surface and boundary layer were obtained by NORCOWE. The instruments are now installed and running at the FINO1 platform, but before the deployment a thorough training period was carried out to learn how to operate and handle the different instruments.

Scanning lidars

In January 2015 three new scanning wind lidar instruments (WindCube 100S from Leosphere, France) arrived at the Geophysical Institute, University of Bergen. This type of lidar uses infrared light to measure wind profiles in any directions. In the middle of the month one engineer from Leosphere held a three day course for key personnel in the OBLEX-F1 campaign, and for a few other interested NORCOWE partners. The focus was on how to use the software, adjustments, and how to mount and connect the instruments.

First setup and test of the instruments in front of the Geophysical Institute, Bergen.

Standing, from the left: Martin Flügge, Valerie Kumer, Mostafa Bakhoday, Joachim Reuder, Damien Ceus, Anak Bhandari and Benny Svardal. In front: Olav Krogsæter.

Humidity and temperature profiler

Just one week after the lidar course we continued with the next instruments, two RPG-HATPRO humidity and temperature profilers from Radiometer Physics in Germany. They use passive microwave technology to measure temperature/humidity profiles with high temporal and spatial resolution. The course was held at Christian Michelsen Research (CMR) and included, as for the lidar instruments, detailed instructions about the software, setups, and calibration. The calibration procedure was very interesting with the use of liquid nitrogen which held a temperature of -196 °C.

Testing of the instruments

Media March 2015 the time was coming for the pre-testing phase of the instruments. They were mounted on three different locations in Bergen: CMR at Fantoft, the Geophysical Institute close to the city centre, and on the rooftop at StormGeo at Nøstet, just a few meters from the fjord. With this setup we were able to measure the boundary layer across the whole Bergen Valley, and even further westwards to Askøy Island. In addition StormGeo also has an X-band doppler weather radar from Furuno, range ~50km, mounted on the rooftop. This radar is able to measure both precipitation and radial wind velocity during rain/snow events. The testing campaign lasted for approximately four weeks, and we learned a lot about mounting, testing, and fiddling with the software. The experience was particularly valuable since the instruments were to be deployed on the FINO1 platform, in the middle of the open ocean, with very restricted access possibilities.

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The Geophysical Institute (GFI) at the University of Bergen has been central in building up NORCOWE’s lidar expertise. Key scientists involved in the OBLEX-F1 campaign are Professor Joachim Reuder, PhD student Valerie Kumer, and Post Doc Mostafa Bakhoday (former PhD student within NORCOWE).

StormGeo was founded in Bergen in 1997 and is now a global company whose main asset and focus is operation support 24/7 for maritime activity in shipping, oil & gas and offshore wind. Key scientist involved in the testing of equipment for the measurement campaign was Olav Krogsæter.

Leosphere was founded in 2004 in France and is, together with its subsidiary Avent Lidar Technology, a world leader within ground-based and nacelle-mounted lidars. Leosphere became a NORCOWE member in 2013. Damien Ceus gave NORCOWE a course in using the WindCube 100S.

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The lidar firmly in place on the roof at StormGeo. Anak Bhandari (left) and Benny Svardal (right) are very pleased.
In May 2015 NORCOWE started up an extensive offshore measurement campaign at the German research platform FINO1 close to the Alpha Ventus wind farm. The key purpose of the campaign is to improve our knowledge of the marine boundary layer stability, air-sea interaction and offshore wake propagation effects. The collected observational data will be used to validate and improve numerical models and tools for i.e. weather forecasting, marine operations, power performance and wind farm layout.

Two scanning lidar systems (Leosphere WindCube100S) and a microwave-radiometer (RPG-HA TPRO) have been installed on the research platform. This is the first time that such a combination of instruments is installed at an offshore location. By employing microwave radiometer and long range lidar remote sensing technology together, we are able to continuously map the boundary layer conditions up to an altitude of several kilometers by simultaneous measurements of wind, temperature and humidity profiles. This provide unique datasets for the study of boundary layer stability in offshore conditions.

One scanning lidar is placed underneath the met mast, and one on top of a measurement container specifically adapted for FINO1 by ForWind Oldenburg. In this way the lidars cover different inflow and wake sectors, in addition to having overlapping field of view in key directions e.g. towards the Alpha Ventus wind farm. For ten minutes every hour, the scanning lidar on the container provides vertical wind profile measurements in parallel to the radiometric temperature and humidity profiling. The rest of the time the lidars are mapping inflow and wake behaviour in different preconfigured scanning scenarios including horizontal (PPI) and vertical (RHI) scan trajectories. The scanning patterns of both lidars can be remotely reconfigured, and we have online access for data retrieval. This means that we are also able to perform more dynamic studies adapted to actual wind conditions, such as e.g. synchronized dual doppler operation and steering mode measurements targeted towards mean wind direction for wind turbulence characterisation, as performed in a collaborative project between the University of Stavanger, University of Bergen (UiB) and Christian Michelsen Research (CMR).

For reference and validation of wind measurements, the FINO1 metmast is equipped with cup, vane and sonic wind sensors up to 100m. Additionally, a vertical lidar (Windcube VI) was installed by DEWI in September providing vertical wind profiles up to 200m altitude. Two sonic anemometers (DCF systems) were mounted under the met mast at approximately 15 and 20 m LAT (Lowest Astronomical Tide) to expand the turbulence characterisation capability at FINO1 and provide wind measurements closer to the sea surface.

The experience gained from our pilot deployment of the lidars and radiometer at the UiB, StormGeo and CMR rooftops in Bergen proved to be invaluable in preparation of the novel
In addition to the meteorological measurements from the FINO1 platform, a variety of oceanographic instruments were deployed near FINO1 early in June 2015, and recovered early in November with the help of the research vessel Håkon Mosby during cruises organized by UiB. This oceanographic instrumentation was monitoring e.g. wave statistics, surface currents and turbulence in the upper oceanic mixed layer, using amongst others ADV, ADCP and motion sensors mounted on a variety of platforms like bottom frames, submerged buoys, and the autonomous SaPiBuoy. Despite challenging biogrowth conditions in the shallow waters at FINO1, which reduced the measurement life for some of the instrumentation, the overall results and data availability from the deployed instrumentation indicates the deployment has been a success. Also this data, along with reference metocean measurements from FINO1 shared by DEWI and BSH, will be stored in NorStore and is available for the NORCOWE partners. The campaign scope also covers research on motion correction techniques for floating sensor platforms. Within the OBLEX-F1 project, AXYS executed a validation campaign for the FLiDAR 6M floating lidar buoy equipped with dual lidars at FINO1, successfully accomplishing advancement on Carbon Trust Offshore Wind Accelerator (OWA) Roadmap for commercial acceptance. In parallel to the OBLEX-F1 campaign Fraunhofer IWES made a trial deployment for two of their lidar buoys at FINO1. Improving maturity of technology and methodology to gain commercial acceptance of floating lidars is of key importance for a tool which could significantly reduce leadtime and cost for site assessments in the offshore wind industry. To support this effort, we have initiated cooperation with key partners for R&D of instruments in the offshore wind industry. To support this effort, we have initiated cooperation with key partners for R&D of integrated metocean remote sensing platforms. We have also engaged in the IEA Wind Task 32 – Wind Lidar Systems for Wind Energy Deployment, with focus on developing recommended practices in order to reduce measurement uncertainty and increase investor confidence.

We are continuously gathering the meteorological measurement data for backup via a radio communication link to the Borkum island. The work on quality control and checking of availability of data has begun, and all the data will be stored in NorStore and be available to NORCOWE’s partners. So far the results indicates the instrumentation is providing measurement data as intended and fitting for the purpose, namely to establish a highly versatile data set for investigation of the offshore wind profiles, wind shear and turbulence intensity as a function of atmospheric stability in and around the wind farm.

Offshore deployment of the complex scientific instrumentation. Nevertheless, the offshore location means challenging, harsh and remote conditions, and we have faced our share of expected and unexpected issues. Due mainly to power outages and instrument failures, we have some gaps in data availability for the lidars and radiometer, especially during the summer months (when stability conditions are of special interest). The OUBLEX-F1 campaign was originally planned to be completed by June 2016, but will continue until September in order to cover as much seasonal variations as possible. The random wavelike structures of meandering could be seen in Figure 1. The figure shows “small” displacement events for three wakes of a research turbine row. In addition to higher frequency signatures as e.g. caused by periodic vortex shedding, also larger-scale turbulent eddies contained in the atmospheric boundary layer play an important role. These were included in the investigations during the Wind Turbine Wake Experiment in Wieringermeer (WINTWEX-W).

The random wavelike structures of meandering could be captured in lidar scans performed during WINTWEX-W and can be seen in Figure 1. The figure shows “small” displacements for three wakes of a research turbine row. In addition we can see wakes with longer wavelengths and amplitudes from upstream prototype turbines at ECHS wind turbine test facilities in Wieringermeer.

Exposing downstream turbines to a steady change between wake and wake-free conditions, meandering is clearly a challenge for wind park operations. These unsteady wind and turbulence conditions lead to unequal loads along the rotor disk and with that to an increase of fatigue. Additionally wakes of upstream turbines can interact with wakes of turbines positioned further downstream. Such multiple wake effects are rather complex and can even increase the power losses predicted by simpler wake models.

Another challenge, especially for offshore floating systems, could be that meandering can have a frequency signature, which is close to eigenfrequencies of the floating structure. The frequency-weighted power spectra obtained from three
Figure 2: Frequency weighted spectral energy density plots of the three wind components and the turbulent kinetic energy. Colours denote the upstream Windcube in blue and the sonic anemometer in black, and the downstream Windcubes in green and red. The dashed line indicates the Kolmogorov slope.

Windcubes v1 (one upstream, two downstream) in Wieringermeer show enhanced wind speed fluctuations downstream of one research turbine for frequencies of around 0.03 Hz (Figure 2).

If we normalise this frequency signal by the ratio between the rotor diameter D and the average upstream wind speed $u_{\text{mean}}$ ($fD/u_{\text{mean}} = 0.48$) we find a very good agreement to the frequency signal ($fD/u_{\text{mean}} = 0.5$) obtained in wind speed and wake position time series collected in wind tunnel experiments by Muller et al [4]. They found significant correlations between upstream transversal velocities and wake positions. Moreover, they also found significant correlations between the wake position and the lateral force as well as the yaw torque of downstream turbines.

These correlations highlight again the importance of a better understanding of meandering and the need for improvements in wind turbine and wind park control systems. In our future work we will focus on the stability dependency of the frequency signature related to meandering.

References:
Lidars and wind coherence estimation

Jasna Bogunovic Jakobsen, Professor, University of Stavanger

A measurement set-up tailored for observations of the wind velocity variations in a rotor plane has been developed, and explored using lidars currently installed at the FINO1 research platform in the North Sea. The platform is located some 45 km North-West off the German coast and is utilized for the OBLEX-F1 measurement campaign. The campaign was launched by NORCOWE in May 2015 and will last to September 2018. The campaign addresses various aspects of the atmospheric and the oceanic boundary layer and their interaction across the air-sea interface, including wave effects.

One of the two pulsed Doppler lidars on the Fino1 platform, WindCube100S, is positioned at the base of the 100 m high measurement mast, in the south-west corner of the approximately 20 m x 20 m large platform deck area. The second lidar is placed on the top of a container about 3.5 m above the platform deck, at about 10 m horizontal distance from the first one. The two scanning heads are located roughly 20 and 24 m above the mean sea level.

The key step in the coherence measurements is to orientate the lidars into the mean wind direction, similarly to the orientation of a wind turbine rotor. At present, this is done manually, utilizing the online access to the instruments and the available real-time data on the mean wind direction, from the sonic anemometers on the platform.

In order to observe the wind velocity fluctuations at various distances across the mean flow direction, the prime measurement set-up utilizes two lidars in the so-called LOS (Line Of Sight) scanning modes, with slightly diverging light beams. In another arrangement, the so-called PPI and the RHI measurement modes (see page 11) can be used by a single lidar to survey the sectors in the horizontal and the vertical plane. A 6° angle sector corresponds to the across-flow separations of 150 m at 1.5 km distance from the lidar, and is considered to be small enough to provide the measurements of nearly parallel wind velocity components. The PPI and the RHI scanning modes make it possible to acquire the data at several different across-flow separations for a given distance from the lidar, at a cost of a reduced sampling rate. The recording interval in this case varied between 2.5 to 3.5 s, for the lines in the middle of the sector, to 5 to 7 s, in the outer part of the sectors, in the RHI and the PPI modes respectively. Figures 1 and 2 show the preliminary results obtained utilizing data from a single lidar and provide the proof of concept of the measurement set-up [2]. The results suggest that the estimated coherence is in the overall agreement with the function based on the Kaimal spectra, provided in [3]. A more extensive data set is required in order to establish reliable estimates of the coherence. Further analysis is also planned to include wind velocity records acquired simultaneously by two lidars. A complementary study based on the sonic anemometer data from the FINO1 platform is investigating the along-wind turbulence coherence for vertical separations [4].

References

It is imperative to have an understanding of modeling of winds in order to predict wind loads on wind turbines. Different models and approaches are cited in the literature where wind engineers have the opportunity to explore the synthetic data obtained from different models (say spectral models e.g. Kaimal, von Karman etc.). For a physical understanding of winds in the atmospheric boundary layer, and in particular the spatial structure of turbulence in the atmosphere, it would be useful to test model outputs with observations as well as the synthetic data. One simpler way of doing this is via spectral analysis. We here present a small test.

We compare observed one dimensional velocity and temperature spectra and co-spectra with the Mann model [1] and a stability based spectral tensor model [2]. The measurements were taken from sonic anemometers measuring temperature and wind speeds at 20 Hz in three dimensions on an NREL’s met-mast [3]. The observed (co-)spectra were averaged over the wind speed bins of 12, 13, 14 and 15 m/s and for the winds between directions 250° - 310°.

The Mann model, which assumes neutral stability, contains three parameters which are obtained by fitting observed velocity (co-)spectra. The parameters in the model represent physical aspects of turbulence structure due to shear, namely the dissipation rate, a length scale, and turbulence anisotropy. The current IEC standards (IEC 61400-1:2005 and IEC 64100-3:2009) assume neutral stability. However, for the simulation of turbulence in the lower atmosphere and subsequent estimation of its loading effects upon structures in the lower atmosphere, it would be useful to augment the spectral tensor model of Mann to include buoyancy effects. Stable and unstable stratifications each have different effects upon the mean wind and turbulence.

Figure 1 shows the model predictions where the one dimensional spectra are compared with the measurements. It should be noted that the model assumes homogeneity whereas the wind data measurements were taken over relatively inhomogeneous terrain. As can be observed from the plot to the left in Figure 2, the model co-spectrum of $u\theta$ falls more rapidly in the inertial sub-range as noted in the literature [4].

We also represent spectra calculated from synthetic data from NREL’s Turbsim simulator using the IEC Kaimal and IEC von Karman model, both of which assume neutral stability. The 10 min data were generated for the time step 0.05 seconds (i.e. at 20 Hz) with given random seed for each 12, 13, 14 and 15 m/s mean wind speed. The spectra are shown in Figure 3.

As mentioned earlier the area where the wind measurements were made is relatively inhomogeneous whereas both models presented here assume homogeneity. As can be observed from the plot to the left in Figure 2, the model co-spectrum of $u\theta$ falls more rapidly in the inertial sub-range as noted in the literature [4].

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Table 1: The model parameters from the spectral fits shown in Figure 1 and Figure 2.

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<th>$L$</th>
<th>$\Gamma$</th>
<th>$Ri$</th>
<th>$\eta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mann</td>
<td>0.22</td>
<td>64</td>
<td>3.15</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Stability model</td>
<td>0.20</td>
<td>67</td>
<td>3.0</td>
<td>0.15</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Table 1: The model parameters from the spectral fits shown in Figure 1 and Figure 2.
The variations of parameters in the Mann model with mean wind speeds were shown by Sathe et al. [5]. The length scale and anisotropy parameter do not vary significantly with mean wind speed in neutral stability whereas the dissipation rate does. However, the model coherence and cross-spectral phases were independent of the dissipation rate which was also supported by observations [6].

**Outlook**

In addition to the assessment of the quality of the spectral models, we will analyze synthetic wind field data generated based on the spectra. We will run simulations of turbine load data with synthetic time series as input and compare the result with simulations were we use measured wind data as input. This should give a better understanding of the requirements on the quality of the spectral information used for turbine load calculations.

References:


![Figure 3: Velocity (co-)spectra calculated from the synthetic data from FAST for Kaimal (left) and von Karman (right) spectral models which assume neutral stability.](image)
LiDARs can be used to increase the energy output from wind farms by accurately measuring wind speeds and wind turbulence. They were originally introduced in 1996, but only in the 2000s did LiDARs become widely used for wind speed measurements. Research has shown that LiDAR technology can measure averaged wind speeds accurately. This has been proven by several (validation) projects with the conclusions that there is a good fit between LiDAR and anemometry instruments regarding 10 min averaged wind speeds. Today, floating LiDAR systems are gradually gaining acceptance by the wind industry for producing accurate offshore wind data. AXYS’ floating LiDAR devices measure wind conditions up to 200 m. Two systems are available (FLiDAR 6m and FLiDAR 4m), both of which have been validated against met masts. A dual-LiDAR option is available with the FLiDAR 6m if data redundancy is required. Clients can purchase the system outright or buy data as a service. Today, floating LiDARs have proven accuracy on 10 min average (wind speed & direction) compared to cup anemometers.

The next challenge in improving the accurate picture of the wind climate in a defined region is gaining knowledge about turbulence characteristics. Turbulence is an important parameter for the performance of the wind turbine. Measurement of turbulence intensity at hub height plays a significant role in wind resource assessment through the estimation of energy losses due to turbine wakes. Besides that, it is also a key component of site classification and turbine selection studies. AXYS plans to engage more in improving these understandings since our primary business is collecting and managing real-time, reliable, high quality data offshore. This makes turbulence an important topic to investigate from our side as well.

A measure of the turbulence level is given by the so-called turbulence intensity (TI) defined as the division of the standard deviation of 1 s measurements by the measured mean wind speed. This approach is used today to have the turbulence characteristics at a predefined region offshore using floating LiDARs. The increased mobility, no flow distortion and possibility to measure at 12 heights makes this technology a cost effective and reliable alternative to a fixed offshore meteorological mast. But how valid are (floating) LiDAR devices for measuring turbulence characteristics? Up to now, no clear answer can be given since the standards do not yet address criteria for TI or other turbulence characteristics (e.g. turbulence kinetic energy). The IEC 61400 – 12.1 Annex L does not address a code for LiDARs, while in the IEA WIND task 32, measurements of turbulence and gusts using floating LiDAR systems are not within the scope.

It can be concluded that floating LiDARs are accurate devices for 10 min averages and a promising technology for TI measurements. However, a revision of the standards would be useful to push floating LiDAR further in its research capabilities to include new studies, such as turbulence. Next to that, a reflection is needed on how TI measurements can be improved offshore. Can LiDAR technology be a standalone technology for this or is a combination of different measurement devices needed? Since the vision about turbulence offshore has changed from: “offshore it’s low and doesn’t change much” into “a hot topic for improving offshore & onshore site suitability and assessment”, AXYS is very interested in contributing to this interesting field.
First wind turbine wake measurements with
the unmanned SUMO system

Joachim Reuder, Professor, and Line Błeserud, PhD student, University of Bergen

Motivation

The accurate characterization of the structure and dynamics of turbine wakes is the key to understanding the wind field inside and behind a wind farm, and therefore of major interest and vital importance for wind farm designers and operators. The general wake features, a reduction of the average wind speed combined with an enhancement of turbulence, reduce the power output and increase loads and fatigue for downstream turbines. Both effects have negative implications for the economy over the lifetime of a wind farm as they increase investments and reduce the revenue.

Full-scale wake investigations have during the last years mainly been performed in situ by mast-based wind profile and turbulence measurements, or by the means of sodar and lidar remote sensing. The in-situ measurements from a mast can provide a good temporal resolution, but are limited to point measurements at the location of an available mast. Remote sensing, in particular by scanning lidar systems, gives a high flexibility with respect to spatial probing. However, these systems provide per definition volume averages instead of point measurements. The development and fast growing systems provide per definition volume averages instead of point measurements. The development and fast growing systems provide per definition volume averages instead of point measurements. The development and fast growing systems provide per definition volume averages instead of point measurements. The development and fast growing systems provide per definition volume averages instead of point measurements. The development and fast growing systems provide per definition volume averages instead of point measurements.

In atmospheric research over the last decade has now opened up for a novel airborne measurement approach to bridge and complement existing measurement techniques.

The SUMO system

The Small Unmanned Meteorological Observer (SUMO, see Figure 1) is a micro-RPAS of about 80 cm length and wingspan and a take-off weight of around 700 g. It has been developed in collaboration between the Geophysical Institute at the University of Bergen and the Lindenberg, and Müller GmbH & Co KG in Germany. The system has since 2007 been subject to numerous improvements and is based on a slightly modified version of the commercially available model aircraft FunJet by Multiplex. Equipped with the open source autopilot system Paparazzi it is able to automatically fly preprogrammed flight missions. In addition to standard meteorological sensors for temperature, humidity and pressure, the SUMO system has also been equipped with a 5-hole flow probe for the measurements of the turbulent fluctuations of the wind with a sampling rate of 100 Hz. This allows for the calculation of relevant turbulence parameters, e.g. the turbulence kinetic energy (TKE).

Results

Figure 3 presents the measurements of the east-west wind component U along the flight track given in UTM coordinates for the positions B (ca. 1.5 rotor diameters downstream) and D (upstream). The overall length of the x-axis presented is 1 km and the ticks are labeled every 100 m. The thin gray lines show the data from the individual legs (10 in the case of B and 4 in the case of D). The individual legs show a high inter-leg variability, while the average over all legs displays a rather homogeneous behaviour. The average background level of the wind speed is around 8 m/s for both positions. In the flight legs at B the wind turbines WT6 and WT7 both create a clear wake deficit that extends over about 150 m and reaches a maximum wind reduction of close to 4 m/s. Both the dimension and the amplitude of the effect measured by SUMO compare very well with results from static and scanning lidar wind measurements at the site.

The TKE calculated from the velocity variances measured by SUMO over the flight legs in position B (downstream) is plotted as function of the horizontal distance in Figure 4. Compared to the upstream conditions (not shown) it shows distinctly higher TKE levels as a consequence of the turbulence induced by the rotating turbine blades. At position B we can also see a clear signal from the individual wakes of the turbines WT5, WT6 and WT7 (denoted by the black arrows in the Figure). The one for WT5 is only captured partially. The fully probed wakes of WT6 and WT7 show the highest TKE levels in the flanks of the wake while the TKE in the center is only slightly enhanced compared to the background TKE. Again the wake deficit extends over a horizontal distance of about 150 m.

Future work

After the successful proof of concept of SUMO’s capability for wind turbine wake investigations, showing its potential of bridging and complementing mast and lidar measurements, a wide range of applications can be envisaged in the future. This includes the test of new flight strategies for future measurement campaigns, e.g. flying towards the wind turbine at different vertical levels and lateral displacement from the turbine centerline. This would result in rather low speed flights of SUMO over ground and therefore allowing the collection of longer time series of the 3-dimensional flow.
vector, consequently increasing the statistics and robustness of the results. A new dimension of wake measurements will in the future be opened by the combination of fixed-wing (e.g. SUMO) and rotary-wing RPAS. The latter will, due to their hovering capability, be able to perform longer time series at fixed, but freely selectable positions. Two corresponding quadcopter systems with turbulence measurement capacity have recently been purchased by the Geophysical Institute and are at the moment in the test and validation phase.

References

Background
Offshore operations like the installation of equipment, maintenance and repairs are complex and to a high degree weather sensitive. The cost of such operations is largely caused by waiting for suitable weather windows for weather-sensitive phases (transportation, mooring, crane operations, etc.) For installation of offshore wind turbines, the cost of transport and installation contributes to 15-20% of the total capital expenditure (CAPEX)[1].

In 2012, NORCOWE partners initiated a project proposal combining the joint competencies in the centre to look into reducing the cost of installing wind turbines offshore. After a successful application process, the recently finished project “Decision support for installation of offshore wind turbines” (DECOFF) started in 2013 as a 3 year knowledge building project supported by Statoil and the Research Council of Norway. A main idea in the project has been to base the decisions on the equipment responses caused by the weather.

The upper part of the figure shows a time series of the significant wave height. Each line correspond to an ensemble member of an ensemble prediction forecast. The blue line in the lower part of the figure is a time series of the computed operation failure rate, based on the output from the equipment simulator. The threshold for the failure rate is set to $10^{-4}$, which gives a weather window between 18 and 32 hours.
For day-to-day marine operations, planners use these limits together with weather forecasts to compute weather windows. As we all know, weather forecasts come with uncertainties, which varies from forecast to forecast. The standard method of incorporating uncertainties is to scale the weather limits with bulk factors called alpha-factors [2], i.e. make the limits even more conservative. DNV GL recommends alpha-factors based on analysis of weather forecasts and observed weather.

**Results of the DECOFF method**

The DECOFF method is more direct than the standard (alpha-factor) method in that it uses an equipment response simulator for each weather forecast to compute the corresponding equipment responses. We have used SIMO, which is a non-linear time domain simulator developed by Marintek. The equipment responses come as time series, which are then analysed statistically to give an estimate of the probability of exceeding critical limits within the operation period. The expertise at Aalborg University has been vital for the statistical modelling [3].

A strength of this method is that it uses all aspects of the weather forecasts. The wave period (and wave spectra if available) is for example taken into account, which is not explicitly possible with the standard method.

Ensemble forecasts provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) have a low resolution, on the scale of tens of kilometres. This is suitable for large-scale regular forecasts, but not for companies planning marine operations at a specific site, where effects of coastal or seabed terrain may be important. Uni Research has therefore worked on downscaling the forecasts to 3 km resolution for the atmosphere and 300 m for the waves. For the site selected in this project (see the fact box), downscaling gives significant changes for the wind, but for waves the differences were rather small. MET Norway has in parallel worked on site calibration of forecasts. They show that the continued rank probability score improves by 40 % for wave height and 60 % for the mean wave period. The bias was also strongly reduced [4].

Christian Michelsen Research has, in addition to managing the project, worked on combining the above tools, methods and forecasts into an online decision support tool. There are many simulations to run, and the tool was therefore designed to be highly scalable. All system states are stored in a database so that adding more web-servers and simulation servers is straightforward. The database is also scalable, making it possible to add more database servers for increased performance, redundancy and availability. The results of the simulations are presented to the user with the most important information at the top level (the computed probability of failure), while allowing the user to drill-down into the underlying data (e.g. the time-series of the critical response parameters).

The project has shown in a virtual test case that the method performs better, or at least as good as the standard method. We are now in a position to do validation of the method in a real installation case, and we hope to do that in a potential follow-up project.

**References**


The online accessible database from the German BSH (Bundesamt für Seeschifffahrt und Hydrographie) provides 10-minute averages of more than 70 meteorological and oceanographic parameters from the site.

Three years of selected data with relevance for offshore wind energy applications (wind speed and direction, temperature for stability estimations, ocean currents and wave parameters) have been quality controlled, both by a series of plausibility tests and visual inspection of the time series.
Offshore wind farms pose additional problems for maintenance compared to their onshore counterparts. Their location entails major transport costs, weather conditions limit the time for maintenance tasks and availability of personnel at the right time is also a complex problem. As the wind farms grow larger and are positioned further from the shore, a farm-level maintenance strategy becomes essential for profitable operation. As per recent studies, as much as 27% of the total wind farm operational and capital expenditures are due to maintenance activities[1]. In order to achieve profitable operation, these costs have to be lowered. Planning maintenance activities can result in significant reduction in downtimes and maintenance costs provided there exists knowledge about equipment health.

Presently, most of the maintenance in offshore wind turbines is scheduled. In addition to the scheduled maintenance, condition monitoring (CM) systems are used to detect faults at an early stage. Currently, CM systems are being used to detect faults primarily for the gearbox, generator and main bearing and are operated independent from the SCADA systems. In order to fully benefit from CM systems, they have to be used as enablers for a maintenance planning rather than indicators for reactive maintenance tasks. While condition monitoring is detecting faults prior to failure, a maintenance strategy shall be a system-level solution that includes condition assessment, maintenance planning, resource planning, inventory management and operational aspects. Many popular concepts such as reliability centered maintenance (RCM), condition based maintenance (CBM) and risk based maintenance planning (RBM) have to be utilized at different stages to identify maintenance type, priority and immediacy of attending to a particular fault condition.

Besides, detecting a fault (diagnosis) will present the maintenance personnel only with the information about the current condition. An assessment of the remaining useful life (RUL) and approximate time to failure (prognosis) will help them prioritize maintenance tasks in order to ensure high availability. In addition, we need to understand how these technologies are to be scaled across a wind farm in such a way that they’re beneficial and at the same time, economical.

<table>
<thead>
<tr>
<th>Method</th>
<th>Blades</th>
<th>Rotor</th>
<th>Gearbox</th>
<th>Generator</th>
<th>Bearing</th>
<th>Tower</th>
</tr>
</thead>
<tbody>
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<td></td>
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<td>●</td>
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</tr>
</tbody>
</table>

Table 1: CM Techniques for Wind Turbines: State-of-the-art [2]

The second question, if answered, has extended benefits, not only to the pitch and yaw systems but also to other rotating machinery that operate in offshore conditions. To this end, we are building both model-based methods for diagnostics and prognostics as well as a laboratory setup to prove their efficacy in typical operating conditions.

References
1. BVG associates “UK Offshore Wind Supply chain Capabilities and Opportunities”, 2014

Table 2: Commercially available CM Systems [3]
Wind farm layout using the NRWF - NORCOWE reference wind farm

The NORCOWE reference wind farm (NRWF) is the result of close collaboration between NORCOWE’s research and industry partners. An overview over NRWF is given in the 2014 annual report. The definition of the reference wind farm can be found at the dedicated home page. Aalborg University has amongst the first to use the reference wind farm. Below follows a description of their work on wind farm layout and how it compares with other methods, including the new WRF module on wind farms developed at Uni Research.

1. Wind farm layout

The optimization of selecting the locations of wind turbines for a wind farm located in a specified area (land or water) and determining the connection of cables between wind turbines in the collection system of a wind farm may require a large number of calculations. The computational time will significantly increase with the number of wind turbines, as the possible combinations increase rapidly. In order to quickly assess the performance (including the wind farm power losses caused by for instance wake effects) of each possible combination, a simplified wake calculation method has been programmed in Matlab at Aalborg University for assessing the wind farm power loss.

For comparison purpose, two additional methods have also been used for assessing the wind farm power loss:
1. WASP (Wind Atlas Analysis and Application Program) is an industry-standard software package for siting of wind turbines and wind farms. Many companies use WASP worldwide for predicting wind climates, wind resources, and power productions from wind turbines and wind farms. WASP is developed and distributed by the DTU Wind, Denmark.
2. The next-generation mesoscale model WRF (www.wrf-model.org) using the new wind turbine algorithm developed at Uni Research.

2. Cases of Energy Yields Calculation Studies

Wind resource

In this study, the energy yields calculation is based on a set of time series wind data. The wind speed is recorded per hour from year 2000 to year 2010. The wind rose calculated from the time series data can be seen in Figure 1. The raw data, presented by means of the wind rose, is used for the energy production calculation of a year.

Results of Energy Yields Calculation

By using the same wind rose, the yearly energy yields with and without the inclusion of wake effects have been calculated for both the regularly and the irregularly shaped wind farms. The results are shown in Table I to Table IV.

Discussions

The following observations can be seen:

- The Matlab model produces close results in comparison with that from WASP; the errors in various cases have no uniform tendency.
- The WRF model produces reasonable close results in comparison with that from WASP. We note that extending the energy yield from year 2000 to the 10-year perspective produce a different tendency in WRF than in WASP. This suggests that projecting energy yield onto a longer period from a shorter time period, is not trivial.

Table I. Energy Yields (GWh) in year 2000- Regularly Shaped Wind Farm

<table>
<thead>
<tr>
<th></th>
<th>Energy Yields by WASP</th>
<th>Energy Yields/ Error(%) by Matlab</th>
<th>Energy Yields / Error (%) by WRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without wake effect</td>
<td>4504.25</td>
<td>4502.35/-0.042%</td>
<td>-</td>
</tr>
<tr>
<td>With wake effect</td>
<td>4086.42</td>
<td>3938.28/-5.63%</td>
<td>3870/-5.30%</td>
</tr>
</tbody>
</table>

Table II. Yearly Average Energy Yields (GWh) for a period of 10 years- Regularly Shaped Wind Farm

<table>
<thead>
<tr>
<th></th>
<th>Energy Yields by WASP</th>
<th>Energy Yields/ Error(%) by Matlab</th>
<th>Energy Yields / Error (%) by WRF</th>
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</thead>
<tbody>
<tr>
<td>Without wake effect</td>
<td>4206.87</td>
<td>4249.86/+1.02%</td>
<td>-</td>
</tr>
<tr>
<td>With wake effect</td>
<td>3773.55</td>
<td>3600.42/-5.69%</td>
<td>4590/+21.64%</td>
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</table>

Table III. Energy Yields (GWh) in year 2000- Irregularly Shaped Wind Farm

<table>
<thead>
<tr>
<th></th>
<th>Energy Yields by WASP</th>
<th>Energy Yields/ Error(%) by Matlab</th>
<th>Energy Yields / Error (%) by WRF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without wake effect</td>
<td>4504.39</td>
<td>4502.35/-0.045%</td>
<td>-</td>
</tr>
<tr>
<td>With wake effect</td>
<td>4204.03</td>
<td>4181.03/-0.55%</td>
<td>4370/-11.28%</td>
</tr>
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</table>

Table IV. Yearly Average Energy Yields (GWh) for a period of 10 years- Irregularly Shaped Wind Farm

<table>
<thead>
<tr>
<th></th>
<th>Energy Yields by WASP</th>
<th>Energy Yields/ Error(%) by Matlab</th>
<th>Energy Yields / Error (%) by WRF</th>
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<tr>
<td>Without wake effect</td>
<td>4207.06</td>
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<tr>
<td>With wake effect</td>
<td>3894.87</td>
<td>3898.33/+0.089%</td>
<td>4410/+13.23%</td>
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</table>
Artificial neural network and forecasting

Allo Sapronova, Researcher, Uni Research

Everyone relies on a prediction: the potential gain to society from accurate predictions is huge and wide-ranging — from companies thinking about managing risk, investors planning their next project, to authorities proposing new regulation policy.

Unforeseen climate change fluctuations increase requirements for spinning reserves, raise electricity system production costs, and affect electricity system reliability.

Explicit application of physical models for wind energy output prediction is not an easy task as it would require an understanding of the entire picture of complex interactions and magnitudes of variables across the range of factors that are often unique to location. On the other side, even when analytical solutions may be available, short-term predictions place a hard time limitation on the applicability of such solutions. Thus, the employment of computational intelligence, and in particular artificial neural networks (ANN), has proven to be quite effective for deriving empirical solutions from available data. ANNs are known to perform best in multi-dimensional space, mapping the input feature-vector into the solution space precisely and almost instantaneously. Therefore ANN-based models can be used in real-time operational mode and provide accurate and reliable predictions for short- to medium-time frames.

As an immediate outcome from the NORCOWE inspired and supported workshop, a collaboration between WindSim and Uni Research was established. Financed by the Research Council of Norway the joint research and development initiative aimed "to improve the wind farm performance in the operational phase by accurate predictions of wind turbine production and loading". Accurate wind characteristics on the turbine scale, the key challenge for wind power prediction, were determined by integrating ANN-corrected mesoscale predictions with fine scale CFD modelling.

The joint research activity also addressed short-term prediction of energy output for wind parks in complex terrain by developing a new model to couple Numerical Weather Prediction (NWP) at a coarse resolution of some kilometres with observations at the wind park location. In order to forecast the wind flow near the ground, where roughness and complexity affect the flow at microscale, ANN was trained against historical observations of wind speed and direction to correct the NWP forecasts of mean hourly wind characteristics. On the test data sets the model predicted the wind speed in a very satisfactory manner with mean square error (MSE) 8 m/s. Even though such accuracy is found to be superior to that based on polynomial fittings as well as auto-regressive moving average (ARMA) models, the detailed statistic on model performance shows that for some weather regimes the MSE is significantly higher.

To address the issue, the initial ANN-based model has been improved by adding categorical information. According to the physical nature of the problem the training data has been grouped into several discrete categories to allow identical category values to be treated in the same manner. One logical approach was to categorize a continuous numeric data of a wind speed to discrete categorical values similar to what is done in the Beaufort wind force scale. The Beaufort scale divides wind speeds into 13 categories, spanning from 0 (calm) to 12 (hurricane force). To design our wind force scale we followed a wind turbine power curve, so the values assigned to the categories did not correspond to the Beaufort scale. The information obtained from categorizing wind speed records was supplied back as input to ANN. The model using categorization shows MSE = 1 m/s for wind speed prediction on the test data sets, has nearly half the root mean square error (RMSPE) of a regular ANN-based model (5.4% vs 9.8%), and resolves all weather regimes at the same level of accuracy.

The learning from data concept has been successfully employed by Uni Research to improve the accuracy of wind prediction. Academically, the joint research effort between Uni Research and WindSim has led to more than 6 publications and conference presentations since 2014. Further collaboration between WindSim and Uni Research is going to address the issue of big data mining; with various large datasets collected from three-dimensional environments at high frequency (operational characteristics of multiple wind farms) the stored information is no longer possible to analyze by regular machine learning techniques. By establishing the Center for Big Data Analysis in 2015 Uni Research made it possible to utilize the new learning from data streams concept and employ the Apache Hadoop framework to use new technologies (like fast learning, deep learning, etc) for developing a model for a very short-term wind energy output prediction.

Sapronova, A., Meissner, C., Mana, M., "Improving an accuracy of ANN-based mesoscale-microscale coupling model by data categorization: with application to wind forecast for offshore and complex terrain onshore wind farms". Lecture Notes in Computer Science 2014 ; Volume 8817. 61-66
NORCOWE’s scientific advisory committee SAC

Finn Gunnar Nielsen has a background in engineering from NTNU, with a PhD within Marine Hydrodynamics. He has for more than 30 years worked within R&D related to dynamics of offshore structures. Presently he holds a position as senior advisor at Statoil. His main activities are presently related to R&D within offshore wind. Finn Gunnar has also had a position as adjunct Professor at NTNU teaching marine operations. Presently he is adjunct professor at University of Bergen teaching at a master programme in energy. Finn Gunnar headed the R&D project that lead to the Hywind floating offshore wind concept. He has also participated in several national and international committees related to offshore wind and marine renewable energy more generally. He is now chairing NORCOWE’s scientific committee.

In terms of wind energy meteorology offshore, Denmark and Norway share many similarities. But many aspects are quite unique to each region. My motivation for participating in the NORCOWE SAC is to be exposed to these similarities and contrasts, especially since I was educated in very different weather regimes in Brazil and the western USA. In addition, I am also interested in how such a large project is successfully managed.

Cecilie Kvamme is a scientist within fisheries biology at the Institute of Marine Research (IMR) in Bergen where she has been employed since 2005. At IMR she mainly works with fish surveys, stock assessments, advice, and is the scientist responsible for the North Sea herring and the sprat stocks. IMR has a team for giving consultative comments on wind farm plans and applications when asked, and she has led this team for three years.

“As a biologist I am predominantly interested in the environmental effects of wind parks, which was also one of the focus areas of NORCOWE when it was established back in 2009. Being a member of SAC has also given me valuable insight into the other science fields related to wind parks, like maintenance, measuring and modeling wind, and the optimal design of wind parks.”

Trond Kvamsdal is professor in Computational Mathematics at Department of Mathematical Sciences, NTNU and Chairman of the Scientific Committee (SC) of NOWITECH. His main area of interest is within the field of computational sciences and engineering, in particular the development of adaptive finite element methods for solving fluid- and structural mechanics. His focus related to offshore wind is within aerodynamics and fluid-structure interaction (wind-turbine blade interaction).

“As Chairman of the SC for NOWITECH it is of interest for me to be in dialogue with NORCOWE, and being a member of NORCOWE’s SAC facilitates information exchange. In particular, participation on the annual NORCOWE meetings is very useful in order to be updated on new research and innovations done by the NORCOWE consortium. Furthermore, our collaboration on organizing the Summer School is useful for my role at NOWITECH”.

Julie Kay Lundquist is assistant professor of boundary-layer meteorology in the Dept. of Atmospheric and Oceanic Sciences, University of Colorado Boulder, as is her M.S. degree. She studied English and Physics as an undergraduate at Trinity University, San Antonio, Texas.

Her research group uses observational and computational approaches to understand atmospheric influences on turbine productivity, turbine wake dynamics, and downwind impacts of wind energy. At present, she is involved in field campaigns to improve wind energy forecasting capabilities in complex terrain, to develop improved simulations of stable boundary layer dynamics in complex terrain, and to assess wind turbine and wind farm wake behaviour.

“...Being a member of SAC has also given me valuable insight into the other science fields related to wind parks.”

Cecilie Kvamme

Julie Kay Lundquist

Andrea Hahmann is a senior scientist in the department of wind energy at the Danish Technical University. She obtained her PhD in Meteorology from the University of Utah in 1992. She has worked with atmospheric mesoscale and climate models for nearly 30 years. Before coming to the wind energy field 8 years ago, she worked in research of the influence of land cover to climate at the University of Arizona and in forecasting and atmospheric transport & dispersion problems at NCAR. She now works on atmospheric modeling applied to wind power forecasting and in regional wind energy resource assessment.

As a member of the SAC, I enjoy learning about the cutting-edge research occurring within NORCOWE, and exchanging ideas and approaches from the US wind energy research community.

Jan Willem Wagenaar

Finn Gunnar Nielsen has a background in engineering from NTNU, with a PhD within Marine Hydrodynamics. He has for more than 30 years worked within R&D related to dynamics of offshore structures. Presently he holds a position as senior advisor at Statoil. His main activities are presently related to R&D within offshore wind. Finn Gunnar has also had a position as adjunct Professor at NTNU teaching marine operations. Presently he is adjunct professor at University of Bergen teaching at a master programme in energy. Finn Gunnar headed the R&D project that lead to the Hywind floating offshore wind concept. He has also participated in several national and international committees related to offshore wind and marine renewable energy more generally. He is now chairing NORCOWE’s scientific committee.

In terms of wind energy meteorology offshore, Denmark and Norway share many similarities. But many aspects are quite unique to each region. My motivation for participating in the NORCOWE SAC is to be exposed to these similarities and contrasts, especially since I was educated in very different weather regimes in Brazil and the western USA. In addition, I am also interested in how such a large project is successfully managed.

Cecilie Kvamme is a scientist within fisheries biology at the Institute of Marine Research (IMR) in Bergen where she has been employed since 2005. At IMR she mainly works with fish surveys, stock assessments, advice, and is the scientist responsible for the North Sea herring and the sprat stocks. IMR has a team for giving consultative comments on wind farm plans and applications when asked, and she has led this team for three years.

“As a biologist I am predominantly interested in the environmental effects of wind parks, which was also one of the focus areas of NORCOWE when it was established back in 2009. Being a member of SAC has also given me valuable insight into the other science fields related to wind parks, like maintenance, measuring and modeling wind, and the optimal design of wind parks.”

Trond Kvamsdal is professor in Computational Mathematics at Department of Mathematical Sciences, NTNU and Chairman of the Scientific Committee (SC) of NOWITECH. His main area of interest is within the field of computational sciences and engineering, in particular the development of adaptive finite element methods for solving fluid- and structural mechanics. His focus related to offshore wind is within aerodynamics and fluid-structure interaction (wind-turbine blade interaction).

“As Chairman of the SC for NOWITECH it is of interest for me to be in dialogue with NORCOWE, and being a member of NORCOWE’s SAC facilitates information exchange. In particular, participation on the annual NORCOWE meetings is very useful in order to be updated on new research and innovations done by the NORCOWE consortium. Furthermore, our collaboration on organizing the Summer School is useful for my role at NOWITECH”.

Julie Kay Lundquist is assistant professor of boundary-layer meteorology in the Dept. of Atmospheric and Oceanic Sciences, University of Colorado Boulder, as is her M.S. degree. She studied English and Physics as an undergraduate at Trinity University, San Antonio, Texas.

Her research group uses observational and computational approaches to understand atmospheric influences on turbine productivity, turbine wake dynamics, and downwind impacts of wind energy. At present, she is involved in field campaigns to improve wind energy forecasting capabilities in complex terrain, to develop improved simulations of stable boundary layer dynamics in complex terrain, and to assess wind turbine and wind farm wake behaviour.

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Lectures at the summer school:

Kari Lurås, Statoil: Early Phase Development of a wind farm
Birgitte Furevik, MET Norway: Environmental data for planning & design
Trond Kvamsdal, NTNU: Harvesting the wind energy
Jørgen Krokstad, Statkraft: The design challenges
Torben Knudsen, Aalborg University: Control of wind turbines & wind farms
Jan-Fredrik Stadaas, Statoil: Execution of a wind farm project
Jørgen Krokstad, Statkraft: The economics of wind power
Lene Eliassen, NTNU / Statkraft, assisted.

The mixture of people with different backgrounds gave fruitful interaction and discussions in both the lectures and the group work. Throughout the week, groups worked on tasks related to the lectures adding up to the main task: to make an outline of an offshore wind park addressing the different challenges covered by the lectures.

During the week, the participants were introduced to a broader perspective of the challenges related to offshore wind. We believe this is an important task in helping the PhD students to put their work into a wider context. Besides lectures and group work the participants got new acquaintances and shared their knowledge and experiences with each other. In addition, many of the lecturers stayed most of the week, which gave an opportunity to the participants to exchange knowledge and experiences in a smaller setting. The group as a whole had a great time together during both lectures and discussions, as well as enjoying the magnificent weather at the pier in the evening.

On behalf of the NORCOWE administration, we want to say thanks to our hosts, all participants and lecturers for a great summer school! Particularly we want to thank Finn Gunnar Nielsen for chairing the summer school committee and for arranging the lectures and the group work.

The presentations from the summer school are available at NORCOWE.
To successfully run a project with a large number of partners spread over a large geographical area takes some effort. NORCOWE’s Center Management Group has monthly video meetings in order to discuss and plan upcoming events and activities as well as to provide a regular forum for sharing ideas.

Talking with the teachers from the industry gives a perspective we do not experience very often in academia. In addition, it is valuable to get acquainted with scientists working with other topics than yourself.

Kasper Sandal, PhD student, DTU Wind

The aim of the summer school has been to enable the PhD student to put their own research into a wider perspective. I don’t think anyone has learned anything about their own field of research, but they have got a better understanding of wind power in general.

Organizer Finn Gunnar Nilsen, Statoil and University of Bergen
Dissemination and public outreach

Internal dissemination
The annual work package meetings in NORCOWE take place in May. The 2015 meetings were hosted by University of Stavanger and more than 50 persons were present. A major goal is to coordinate the work between the subtasks and to pave the ground for new joint projects among the partners. Thus long coffee breaks and informal meals are important ingredients besides the scientific presentations and discussions!

NORCOWE day takes place in September and serves as a preparation for the board meeting the following day. At NORCOWE day the current status of the centre is presented and major challenges to be addressed by NORCOWE are identified. The board and SAC attend the NORCOWE day together with the centre management committee, the PhD students and senior scientists.

In 2015 the workshop “Development of wind-farm power-prediction tools - Prospects from Uni Research’s work and use of data from Sheringham Shoal” was held at Statkraft in Oslo. The workshop was fully booked and the presentations made available to the NORCOWE partners.

NORCOWE collaborates with the Centre for Science Education at the University of Bergen, giving a yearly lecture for their students who are teachers in science and mathematics.

Public outreach
The annual report, our newsletter and our website are the main channels for information to the general public. The yearly conference SMI Stavanger is held in collaboration with Greater Stavanger. Last year the number of participants were 65 with presentations from both NORCOWE and external companies, national and international. Presentations and posters can be found on NORCOWE’s homepage. The 2016 SMI Stavanger conference will be held on April 8th.

The yearly conference SMI Bergen gathered in 2015 more than a hundred persons from research institutions and the industry. Presentations from the conference can be found on NORCOWE’s homepage. The 2016 SMI Bergen conference will be held on November 8th.

NORCOWE collaborates with the Centre for Science Education at the University of Bergen, giving a yearly lecture for their students who are teachers in science and mathematics.

The online magazine Sysla Grønn (Green Business in Norwegian) has had several stories and articles from NORCOWE in 2015.
National and international cooperation

International cooperation
The NORCOWE brand has been strengthened during 2015 and the brand is now recognized in the Norwegian and international offshore wind energy community.

Two large joint projects have been carried out in NORCOWE last year, namely the OBLEX-F1 campaign and the definition of the NORCOWE Reference Wind Farm (NRWF). Several NORCOWE partners have been involved in OBLEX-F1 together with German governmental institutions and research institutions. The first preliminary analyses have been done. We foresee that these data will be used by the international offshore wind community for many years.

The NRWF has been set up by Aalborg University and Uni Research. The effort to define baseline versions of the NRWF, up to the point at which annualised costs of energy were obtained, took place within Uni Research and Aalborg University during 2014-15. A website is set up, where you find information about site characterisation, layouts, wakes & loads, farm management, operations and costs.

NORCOWE is a member of IEA Wind task 32 (Wind Lidar Systems for Wind Energy Deployment), task 36 (Forecasting for Wind Energy) and task 37 (Wind Energy Systems Engineering: Integrated RD&D).

NRWF will be used in the development of IEA Wind task 37 “Wind Energy Systems Engineering: Integrated RD&D”. Using NRWF as one of the reference wind farms is a good way of enhancing cooperation between NORCOWE partners and major players in the international wind energy community. It is an efficient way to disseminate results from the centre. Taking part in the IEA Wind tasks, EERA JP Wind, Horizon 2020 and international standardization committees is an important aspect of NORCOWE’s international commitment.

We have MoUs with DTU Wind (Denmark), Fraunhofer IWES (Germany), ECN (the Netherlands) and NREL (USA). The majority of our international partners come from Europe, but we have also cooperation with institutions in the USA, South Africa and Japan.

National cooperation
NORCOWE has cooperated with NOWITECH on the 2015 summer school. NORCOWE and NOWITECH have also appointed a member to the sister center’s scientific advisory committee. Finn Gunnar Nielsen is representing NORCOWE in NOWITECH’s committee.

A new FME application (COWIND) was submitted in November 2015 with partners from the two current FME centres.

NORCOWE has also worked together with local public and private bodies like Greater Stavanger, NODE and Bergen Chamber of Commerce and Industry in order to promote offshore wind energy.
**Organization**

**List of partners and committees**

**Partners**
- Christian Michelsen Research (host)
- Uni Research
- University of Agder
- University of Bergen
- University of Stavanger
- Aalborg University
- Acona Flow Technology
- Aquiloz
- AXYS Technologies
- Leosphere
- MET Norway
- Statoil
- StormGeo

**Internal Scientific Committee**
- Finn Gunnar Nielsen, University of Bergen (chair)
- Hans-Georg Beyer, University of Agder
- Kristin Guldbrandsen Frøysa, Christian Michelsen Research
- Birgitte Rugaard Furevik, MET Norway
- Angus Graham, Uni Research
- Jasna Bogunovic Jakobsen, University of Stavanger

**International Scientific Committee**
- Finn Gunnar Nielsen, University of Bergen (chair)
- William Leithhead, University of Strathclyde
- Line Storelvmo Holmberg, Vestas
- Cecilia Kvamme, Institute of Marine Research Norway
- Trond Kvamsdal, Norwegian University of Science and Technology (NTNU)
- Andrea Hahnmann, DTU
- Julie Kay Lundquist, University of Colorado/NREL
- Jan Willem Wagenaar, ECN

**Executive Board (EB)**
- 9 representatives
  - Alf Holmelid, University of Agder (chair)
  - Nils Gunnar Kvamme, University of Bergen
  - John Dalsgaard Sørensen, Aalborg University
  - Bjørn Hyltanger, University of Stavanger
  - Gudmund Olsen, Statoil
  - Anne Marie M. Seterlund, Statkraft
  - Jostein Malto, StormGeo
  - Birgitte Rugaard Furevik, MET Norway
  - Marit Kleven, Acona Flow Technology

**Observer:**
- Harald Rikheim, RCN

**Centre Administration**
- Hosted by Christian Michelsen Research
- Centre Director Kristin Guldbrandsen Frøysa
- Centre Coordinator Annette F. Stephansen

**Scientific Committee**
- Lead: Finn Gunnar Nielsen, University of Bergen / Statoil

**Work Package 1**
- Wind and ocean conditions
  - Lead: Joachim Reuder, University of Bergen

**Work Package 2**
- Wind energy estimation
  - Lead: Angus Graham, Uni Research

**Work Package 3**
- Offshore deployment and operations
  - Lead: Thomas Bøk, Aalborg University

**Key figures 2015**

- PhD students: 12
- Completed PhDs in NORCOWE: 12, of which 1 in 2015
- Post Docs: 4
- Master students: 8
- Number of publications: 21
- Posters and presentations: 33
- Reports: 15
Contact info

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