Welcome
by Dag T. Breistein, Vestavind Offshore, Chair of NORCOWE executive board

NORCOWE has in 2011 continued the exciting and pioneer work, which they started in 2009/2010. Current research shows promising results and provides high expectations for future work as well as new knowledge useable for the centre’s industrial partners.

Constructions of offshore wind farms have up to date been a very costly project, and there is a need to reduce the costs considerably in order to make ‘offshore wind’ a sustainable business. Competitive energy prices must be achieved within the next 5 to 10 years to emphasise the research momentum needed to create a new long term industry. The work performed at NORCOWE can greatly contribute in identifying new concepts, discovering new solutions and new knowledge, which in the intermediate long run can make energy production from offshore wind compatible against other energy production.

In 2012, NORCOWE will start a comprehensive strategy process where the main objective will focus on specific activities within a limited number of priority areas. The strategy process is necessary to elucidate NORCOWE’s ambitions by becoming a leading research centre within selected areas.

NORCOWE has room for new partners with ambitions to enter the emerging offshore wind industry with a global market. Please feel free to contact the centre administration for more information about the research centre and our knowledge base.
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About the centre

Organization

Centre partners

Aalborg University (AAU)
Christian Michelsen Research (CMR) (host institution)
University of Agder (UoA)
University of Bergen (UoB)
University of Stavanger (UoS)
Uni Research AS (Uni)

Agder Energi AS
Aker Solutions AS
Lyse Produksjon AS
National Oilwell Varco AS
Origo Solutions AS
Statkraft Development AS
Statoil ASA
StormGeo AS
Vestavind Offshore AS

Key figures

PhD Students NORCOWE Centre: 15
Post Docs: 4
Master students: 20

Number of publications in 2011: 41
Number of Research Reports in 2011: 15
Summary

Large-scale production of offshore wind energy requires large investments, and most of the work in NORCOWE is aimed at reducing the cost per unit energy produced.

Effort is put on good integration between the work packages, and to improve the interaction between science and industry. The collaboration between the partners in the centre has increased during 2011, and a further increase in collaboration and joint projects are foreseen.

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The committee for Innovation and Commercialization (CIC) has a strong focus on how to utilize the results from NORCOWE commercially, and work is in progress to address this topic. The board of NORCOWE has decided to start a strategic process in spring 2012, in order to select the topics where NORCOWE has a special competence and where the industry sees a strong need for research and development. NORCOWE has now been in operation for more than two years, results have come and it is time for a review in order to point out the future direction for the centre.

There is a strong focus on measurements and infrastructure in NORCOWE. We have much equipment for meteorological and oceanographic measurement, including newly developed equipment like the scanning LIDAR. NORCOWE has helped building a motion laboratory at University of Agder, where there soon will be two Stewart platforms in use.

A new subtask was started in NORCOWE in 2011 in order to develop a database and an interface using netCFD in order to store the data in a proper way and make the data easily accessible for all partners in NORCOWE.

A pre-project for “Decision support system” is running in spring 2012. This is a project where we look at application of advanced measurements and forecasting in decision support for installation, operation and maintenance of wind farms. This project utilizes industrial experience in order to define the key parameters to be included in such a system.

The five work packages with subtasks (partners involved in the work package in parentheses):

WP1 - Wind and ocean conditions (StormGeo, Uni, UoB)
- Climatology of met/ocean conditions
- Modelling of the marine boundary layer

WP2 - Offshore wind technology and innovative concepts (CMR, UoS)
- Dynamic response
- Innovative concepts

WP3 - Offshore deployment and operation (AAU, CMR, Origo, UoA, UoS, Statoil, Statkraft)
- Asset management
- Single turbine control systems
- Remote operations
- Marine operations
- Decision support system

WP4 - Wind farm optimization (AAU, CMR, StormGeo, Uni)
- Nowcasting
- Power systems integration
- Wind farm modelling

WP5 - Common themes (CMR, StormGeo, UoB, Uni)
- Education
- Environmental impact assessment
- Test facilities and infrastructure
- Data storage and management

This annual report gives snapshots from the scientific work in NORCOWE. Please feel free to contact the centre management to get more information about NORCOWE.
An introduction to offshore wind energy

by Finn Gunnar Nielsen, Statoil and UoB

The world’s need for more and clean energy is closely related to the population growth and an improved standard of living. But meeting these growing energy needs in a sustainable and affordable way is not an easy task. It cannot be achieved by a single source of energy alone.

However, harnessing the power from wind is a proven technology that has been used for centuries and one that can make a significant contribution in modern times to meet our growing energy needs. Worldwide, the installed wind power capacity has been growing steadily during recent years, even in the midst of the financial crisis. According to the Global Wind Energy Council (GWEC, 2012) the growth in global installed wind power in 2011 was 21%. By the end of 2011, the accumulated installed wind power globally was 238 GW (as a comparison the total installed hydro power in Norway is about 30G). Moreover, the growth is not limited to Europe: China is now the world leader both with respect to installed capacity and rate of installing wind power.

However, a majority of the installed wind power plants are on land, while less than 2% is installed offshore. With higher and more consistent wind speeds, moving more power production offshore could unlock huge potential in meeting energy demands. Europe has been the leading region for offshore wind power, but other markets with large coastlines such as the USA are considering this option for their energy mix. Most notably, Japan has recently turned its attention to offshore wind after the Fukushima nuclear power accident. With deep waters, close to large power markets, offshore wind, and in particular floating offshore wind, could be an attractive option. So why move the wind power offshore? There are several arguments: Wind power on land requires space, which is a scarce resource in densely populated areas. Developing wind power at an industrial scale requires large turbines, and large wind farms. The visual impact and noise are key problems making large wind farms on land less desirable.

During the last 25 years, the size of a state of art wind turbines has increased by a factor 100; from 50 kW to 5 MW. Transporting and installing such big units in remote areas on land is a challenging task. However the marine industry has long experience in handling large items. There are also significantly less conflicts related to use of acreage offshore than on land, although possible conflicts with for example fishing activities, shipping routes and bird migration routes must be considered carefully during wind farm design.

The energy density in the wind is proportional to the third power of the wind velocity. Thus with a more steady and higher average wind velocity offshore than on land a significant improved power production can be expected. A striking example on this is Statoil’s Hywind demonstration project; even if this is a test unit, the capacity factor in 2011 was 50% while the average value for Norwegian wind turbines in 2011 (0.51 GW installed capacity) was 31%.

There is a vast amount of wind energy available offshore, the technically available resources varies widely depending upon the limitations related to water depth and distances to shore and electrical infra-structure used. But even conservative esti-
mates, see e.g. IPCC, SREEN (2011) concludes that the technical potential is several times the present worldwide electrical power production. The marine Board of the European Science Foundation (ESF) states the following vision: “By 2050 Europe could source up to 50% of its electricity need from Marine Renewable Energy. This would have a profound impact on the European economy and European citizens. It would contribute to energy supply and security, reduce CO₂ emissions and their impact on the oceans, improve the overall state of the environment, improve quality of life, create jobs in a range of innovative sectors and herald a new era of environmentally sustainable development.” In Marine renewable energy ESF mainly includes energy from offshore wind, waves, tide and ocean currents. Among the marine renewable energy sources, offshore wind has the greatest potential. The European Wind Energy Association (2011) expects that by 2020 and 2030 the installed offshore wind power will amount to 40GW and 150 GW respectively. This is to be compared to the 4 GW of installed offshore wind power today. The 40 GW in 2020 is mainly reflecting the ambitions of UK and Germany.

Why does Europe have such ambitions within offshore wind? The keywords are: The need for more energy, it will contribute to security of energy supply, it will create a new industrial sector with significant job creation, and it is a key factor in achieving the ambitions set for reductions in CO₂ emission. The German car industry had in 2009 about 740 000 employees. According to BMU (2011), the German wind industry had about 96 000 of a total of 367 000 employees in the renewable sector in 2010. The lifecycle greenhouse gas emissions for offshore wind power is in the range 9 - 14 gram CO₂ eq/ kWh as compared to electricity produced from conventional coal and gas fired power plants that has average lifecycle emissions of 1000 gram CO₂ eq/ kWh and 500 gram CO₂ eq/ kWh respectively (IPPC, SRREN, 2011).

However great the benefits, there are significant challenges in developing large scale offshore wind power which need to be overcome. From the numbers above it is easily realized that building up the industrial capacity to design, manufacture, install and operate all the wind turbines needed is a huge challenge, but also a great opportunity for existing as well as new industrial actors. Presently the cost of offshore wind power is too high, the cost has to come down. This must be achieved by using a number of means. The offshore wind industry is still young and much learning and development remains. Although Norway does not have any historical merits with respect to wind power, a lot of relevant competence is available from the marine industry and hydropower sector that can be utilized in realizing the European as well as global ambitions on offshore wind power during the next decades. The competence from 40 years in offshore oil and gas is of particular relevance, but needs to be refocused for use towards offshore wind.

Hywind tow from Åmøyfjorden to Karmøy
To design and operate large offshore wind farms, we need to understand the interaction between the wind field in the atmospheric boundary layer and wind turbines, both as individual turbines and turbine – turbine interaction via the wake and even interaction between wind farms. The oil and gas industry has had focus on extreme events.

For the wind power business, the normal conditions are the important from an energy yield point of view. In the operational phase also these interaction phenomena have to be addressed to achieve an optimum power off-take from each turbine.

There are limited offshore acreage in shallow water and good wind conditions, thus the industry is moving further from shore into deeper water and a more hostile environment. This puts stricter requirements to the reliability of the wind turbines than has been industry practice up to now. We need more robust wind turbine generators with fewer parts and designed for the offshore environment. The trend is to make the turbines bigger and bigger. This makes the interaction between the atmospheric boundary layer and large diameter turbines a challenge. Many recent multi MW turbines have a weight per MW that is higher than for smaller turbines. If this trend is not changed the size and costs of the support structures will be a severe challenge.

Efficient installation of heavy equipment in hostile environment is a known task for the oil and gas industry. But new challenges are faced in offshore wind industry; heavy lifts are not only a few, the offshore wind installations require hundreds of such operations to be performed within a limited time window. Here advanced logistics, advanced weather forecasts and understanding of the operations involved become essential issues that will challenge the traditional offshore marine operators.

Even if the reliability of the future turbines is improved, there will still be need for accessing the turbines. Present methods for access are developed for sheltered water and not suited for open sea. Here new and improved methods are under development, but still much work remains before safe access can be obtained in typical wave conditions during the winter months.

Common to many of the tasks above is that there need to be semi or full scale prototype testing before the technology can be implemented on an industrial level. Within EU several such prototyping and testing initiatives are proposed; see e.g. the European Wind Initiative, EWI. Such prototypes need large funding that calls for international cooperation and coordination. Such coordination may slow the decision process and involve problems related to IP rights.

Several more challenges could be mentioned, but there is one that is common to all the R&D work on offshore wind: We have to bring down the cost of energy. Thus we have to improve the present solutions, look for radical new solutions and not at least build competence. Lack of competence may put severe restrictions to the capability of reaching the ambitious goals set for the offshore wind development.

The work packages within NORCOWE contribute to the needed improvements, investigate radical and creative solutions and not at least they contribute to building competence necessary to grow the industry.
Observations efforts in the MABL
The Marine Atmospheric Boundary Layer is much less studied than the boundary layer over land. There are several reasons for that, but the most obvious one is all the difficulties of obtaining adequate observations from the harsh offshore environment.

Despite of this, during the last decades a great effort has been made in finding formulas for the air-sea fluxes of momentum, heat and humidity, very often described by the help of bulk transfer coefficients. These coefficients are used in Numerical Weather Prediction (NWP) models, so it is highly important that they are described as correctly as possible.

Offshore measurements from the mixed layer, above the surface layer, has become more and more important during the last two decades due to the rapidly increasing activity in the offshore wind energy sector. Today the largest wind turbines have hub heights reaching over 100 meter, and together with the rotor blades, one need to know wind, turbulence and temperature profiles at least up to 200 meter above sea level (masl).

All the standards regarding wind profiles and turbulence intensity for offshore wind turbines are just using weakly modified or unmodified onshore standards, which again are only valid for the surface layer, and not the mixed layer. Therefore, several meteorological masts and measurement platforms have been erected in coastal and offshore regions with the aim of getting more knowledge about physical and dynamical processes also higher up in the MABL.
Modelling efforts in the MABL
How well today’s NWP models are simulating the 0-200 masl portion of the atmosphere over the ocean is very little studied in detail. Most efforts are done in assessment studies with the aim of estimating wind resources.

In this work Olav Krogsæter looks into more details about how different Planetary Boundary Layer (PBL) schemes affect the MABL. The WRF model is used in the experiments, together with observations from the German research platform FINO1 in the Southern North Sea.

Five one year (2005) experiments, to test five different PBL-schemes, were run on the Cray XT4 system at Uni Computing in Bergen, with the use of 384 CPUs. All together 18 TB of data were produced and appr. 700 000 CPU hours used.

Some results
The different PBL-schemes are tested against many different criteria, like 100 m level wind speed, PBL-height and different stability classifications. The experiments show large deviations among the different schemes. Some schemes are best in stable atmospheric conditions, while others are best in unstable stratifications. However, it turns out that the so-called MYJ scheme performs well or very well regardless of the atmospheric stratification. This is also supported by newly written articles at DTU in Denmark. It is also very interesting that, especially rather close to the coast, the occurrence of stable to very stable atmospheric stratification situations in the spring and early summer, shows that the hub-height of tall wind turbines is above the surface layer maybe in 15-20 % of the time. This again means that the standards used today for calculating energy outputs and fatigue loads are not valid at all for long periods of time. So it is highly important that new standards are made to reflect what the actual atmosphere looks like over open ocean conditions, and this work is a part of the efforts of obtaining a better description and understanding of what is happening in the MABL.

It must also be mentioned that the challenge with very stable atmosphere is most pronounced in coastal regions, and gradually decreases further offshore.

A new model setup with WRF and the wave model SWAN will be tested during spring 2012, and it will be very interesting to see how this coupling will influence the MABL. Very preliminary results look promising. Also more specific turbulence studies of the MABL is going on together with post.doc. Anthony Kettle at UoB.

This figure is an example from May 2005 of how long periods of time the PBL-height can stay around 100 m level, i.e. at the hub-height. It shows an almost continuously period of 12-14 days at the end of the month with very stable atmospheric stratification. When the PBL-height is only 100 m, the theory used today for estimating wind profiles are only valid up to 10 m level!

Note that the plot is showing only modelled PBL-height, but from this study it also turns out that the modelled PBL-height is slightly lower than the observed PBL-height. Despite of this bias in the model, it does not change the main conclusions.
The wind speed at hub height and along the turbine blades is determined by the interaction between the flow in the interior of the atmosphere (the geostrophic flow) and the behaviour of the turbulent boundary near the land or water surface. There is a balance between the mechanical generation of turbulence at the boundary and a suppression of the turbulence with increasing height by the rotation of the Earth. The hub height of a large wind turbine is in a transition zone between the surface turbulent boundary layer, in which the turbulent shear stress is approximately independent of height and the effect of the Earth’s rotation may be neglected, and the planetary boundary layer (PBL) or Ekman layer, where both turbulence and rotation are important.

Within the surface boundary layer, the wind speed is often assumed to have a logarithmic dependence on height:

\[ U(z) = u_* \frac{\log(z/z_0)}{k} \]  

where \( u_* \) is the so-called friction velocity, \( k \) is an empirically-determined constant (the von Kármán constant), and the roughness length \( z_0 \) depends on the physical roughness of the surface (over land, for example, \( z_0 \) is much greater over woodland than over grass-covered areas). The friction velocity is related to the surface drag \( \tau \) by

\[ \tau = \rho_o (u_*)^2, \]  

where \( \rho_o \) is the air density. (Equation 1 may be modified if the atmosphere is significantly stably or unstably stratified.)

Over the ocean, the effect of surface waves is often determined using the following relation between the friction velocity and roughness length:

\[ z_0 = \alpha (u_*)^2 / g, \]  

where \( g \) is the acceleration due to gravity and the empirically-determined constant (the Charnock parameter) \( \alpha \) lies between 0.01 and 0.02. Equation 3 is valid if the ocean waves should be close to fully developed, that is to say, that they have grown to such a height that the amount of energy and momentum they obtain from the wind is cancelled out by the energy removed by wave breaking and other processes. Waves which are still growing due to wind forcing, either because the wind has been blowing for a limited time or if the wind is blowing from the shore over a limited fetch, extract more momentum from the airflow, and, in effect, increase \( \alpha \). Computing this wind-wave feedback has been shown to improve the performance of regional and global weather and sea-state forecasts, and should also be useful for wind power applications.

Within NORCOWE we have used the WAM spectral wave prediction model to calculate the wave field and its effect on the air-sea momentum flux, and the consequent effect on the turbulent roughness and the airflow calculated by the WRF atmosphere model. We employ coupling software (MCEL) which allows us to transfer data between models, which have different computational grids. The vertical profile of the wind velocity can then be calculated using the atmosphere model wind components, extrapolated down to the surface using Equation 1.

The figures show results from a coupled test run using WRF grid of 30 km spacing and WAM grid of 22 km spacing. The run was for a period beginning 2008 February 29. The effect of waves on the surface roughness is primarily to increase the roughness under situations with relatively short, steep, waves, such as if the fetch is short or if the wind is changing rapidly, near fronts and moving depressions. A consequence of this is a moderation of the wind speed near the surface and also at hub height, with an increase in roughness length and friction velocity (see right-hand panel of Figure 2).
The Weather Research and Forecasting (WRF) model is being validated against a number of observations, to be used as a downscaling system in order to produce reliable, high-resolution meteorological data for applications in designing off-shore wind farms. The preliminary results of these validation experiments are shown here. Figure 1 shows the model domain set for the experiment, which has been nested in a ratio of 27-9-3 km in the horizontal. For the validation, three observation stations were chosen, namely Valientia, Ekofisk and Lerwick (marked A, B and C respectively in Figure 1). The test simulation period is from 2008-02-15 at 00 hrs. to 2008-03-20 at 00 hrs. The results shown in this report are from the control simulation which has a 2-way nesting, i.e., there is a 2-way information flow between the nests.

For estimating the quality of the simulation, we chose to compute the root-mean-square-error (RMSE) between the model and the observations. RMSE quantifies the deviation of a model from an observed set of values as shown below.

\[
RMSE = \sqrt{\frac{1}{n} \sum (M_i - O_i)^2}
\]  

where \(M_i\) are the set of simulated values and \(O_i\) are the set of observed values.

Figure 2 shows the evolution of RMSE for wind speed (left panel) and temperature (right panel) at individual stations during the simulation period. The RMSE has been computed in the layer up to 2 km above the ground as per equation (1). The height of each of the bar displayed on the left panel is equal to

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**Wind downscaling and its relevance for wind energy – preliminary results and future perspectives**

by Muralidhar Adakudlu and Idar Barstad, Uni Research

Fig. 2: Roughness length \(z_0\) and sample wind speed profile in WRF atmosphere model domain (after 12 hours’ simulation). LEFT: No wave model coupling; CENTRE: Calculated from data fed back from WAM wave model (within the boundaries of the WAM domain which can be seen); RIGHT: Wind speed profile from sea level to 250 metres altitude at the sample point X (58.61°N, 1.78°W): circles – no model coupling – \(u^* = 0.95\) m s\(^{-1}\) and \(z_0 = 1.7\) mm, crosses – with wave model coupling – \(u^* = 1.00\) m s\(^{-1}\) and \(z_0 = 4.5\) mm.
the RMSE of the wind speed in this 2 km layer. This layer is divided into 4 layers of 500 m depth each and the magnitudes of RMSE in these sub-layers are shown in different colours after scaling them down with respect to the RMSE in the whole of the 2 km layer. Such a measure gives an idea as to which sub-layer is contributing the most to the RMSE in the 2 km layer. The model can be said to have missed out some parameters or processes in a sub-layer that has the maximum RMSE at a particular time.

On the right panel of Figure 2, the RMSE curves for temperature are shown. High RMSE values in temperature appear to be mostly synchronous with strong temperature inversions identified in the station data (shown as bubbles), barring a few. This means that the model fails to capture the temperature inversions identified in the boundary layer. In addition, RMSE values tend to be higher when there is a sharp change in the observed wind direction and/or very strong wind speed at low levels as indicated by the wind barbs displayed on the right panel. The wind barbs have been taken at a reference height of 200 m above the ground.

Owing to the strong magnitudes of RMSE of the boundary layer wind and temperature, it is clear that the model set-up used here is not adequate to capture the wind regimes and stability structures. These parameters are very crucial in the design of wind farms in a way to optimise the power production. The present model set-up is being modified in a number of ways, such as increasing the vertical resolution in the boundary layer and coupling the atmospheric model with an ocean wave model, to name a few. These experiments are expected to improve the ability of the model to simulate small-scale boundary layer processes.
Figure 2. Magnitudes of RMSE between the model and the station data for wind speed (left panel) and temperature (right panel) in the boundary layer (up to 2 km from the ground). The wind barbs on the right panel show observed wind speed and direction at ~200 m above the ground and the coloured bubbles indicate the strength of the observed temperature inversions in the boundary layer.
The number and size of offshore wind turbines is expected to grow rapidly over the next decade. The development necessitates refined modeling of offshore wind conditions, including atmospheric stability. An important step forward to study the atmospheric conditions offshore is measurement data from the FINO platforms, located in the North and Baltic Seas (Forschung und Entwicklungszentrum, 2010). In the present study, the data from the FINO3, the latest of the measurement platforms is examined. The platform is located 80 km west of the Danish island Sylt, and has been operating since 2009. The measurement data is analysed with emphasis on the atmospheric stability conditions and their impact on the fatigue life of an offshore wind turbine.

The atmospheric stability is investigated in terms of the so-called gradient Richardson number, utilizing the temperature (29 m & 95 m) and the wind speed (50 m & 90 m) measurements at two heights, recorded from 01/10/2009 to 01/10/2011. The data was filtered to remove non-stationary conditions, and classified into six stability classes - from strongly unstable to very stable atmosphere (Golder, 1972). Further details on the data analysis and the results are given in (Obhrai, Kalvig, & Gudmestad, 2012). The most frequently observed stability class is the strongly unstable one, occurring in 52% of the cases. In such conditions, a low wind speed gradient with height is accompanied by relatively high turbulence intensity.

The wind profiles for offshore conditions described in the IEC 61400-3 standard are based on neutral stability and are formulated by a power law profile. In a previous study, the fatigue lifetime of an offshore wind turbine was found to be significantly shorter when stability was taken into account (Sathe & Bierbooms, 2007), compared to the result based on the neutral stability conditions. The study accounted for the influence of the stability on mean wind profiles, without considering turbulence. In the present work, the fatigue analysis is based on the wind field representation including turbulence. The simulated wind speed time-histories follow the above described distribution of the atmospheric stability conditions, observed at the FINO3 platform. The wind fields at different stability conditions are generated using the so-called Smooth spectrum, by the simulation tool TurbSim (Jonkman, 2009).

The offshore wind turbine studied has a hub height of 90 m and a jacket support structure, and is used in the code comparison in the OC4 project. It is modelled and analyzed in time-domain using the multi-body program FEDEM Windpower. The model of the wind turbine and its key design parameters are given in Figure 1. The wave loading on the jacket substructure is kept constant in all the simulations. The applied wave condition is a regular stream function with wave height 8 m (difference between the wave crest and the trough). The wave period is 10 seconds. No current is applied, and the sea depth is 50 m.

The dynamic response and the fatigue damage are studied in terms of the bending moments in the two principle directions, at the root of the blade and at the base of the tower. The Wöhler exponents for the blades and the tower, i.e. for com-
posite and steel, are set equal to $m=12$ and $m=4$ respectively. The ultimate load for all the stress resultants investigated is $S_u=70$ kNm. The fatigue damage is calculated for the power producing phase, disregarding the situations such as start-up, shut-downs and installation. The damage due to cyclic loading for each short term simulation run (10 minutes) is expressed indirectly, in terms of the so-called damage equivalent load (Hendriks & Bulder, 1995). The life-time equivalent loading is then established by weighing the short term damage for wind conditions simulated according to the observed probability distributions of different stability classes, as well as assuming neutral conditions only. The lifetime damage equivalent loads for the blade flapwise ($M_y$) and edgewise bending moment ($M_x$) are shown in Figure 2, together with those for the longitudinal ($M_y$) and transverse bending moments ($M_y$) of the tower. The damage equivalent loads for the analysis with different stability classes are normalized with the damage equivalent load of $R_i=0.2$, i.e. for neutral conditions. It can be clearly seen that the assumption of neutral stability is not conservative in the case studied. In particular, accounting for the variable stability conditions is important for the flapwise bending of the blades.

Figure 2: The lifetime damage equivalent load for the blade root moments and the tower bottom moments. The loads are normalized with those for neutral stability condition, $R_i=0.2$. 
The offshore wind turbines in operation today are mostly adaptations of wind turbines designed for onshore conditions. By adapting the onshore turbines the offshore technology and practice has come a long way in a short time. But although the fundamentals between the technologies are the same, it is clear that the offshore industry needs to follow its own path. The offshore environment is very different from onshore and new methods of installation, operation and maintenance are required. For the offshore wind industry to mature to the level of onshore wind, a new and dedicated offshore technology is needed.

One design that is believed to be more suited for offshore application than the traditional horizontal axis wind turbine (HAWT) is the vertical axis wind turbine (VAWT). The lower centre of gravity and simpler installation and maintenance provided by the VAWT design are benefits that might enable a more cost effective turbine system offshore. However, the VAWT was considered less optimal for onshore use compared to the HAWT in the 1970’s and 1980’s and not much development has been performed on VAWT designs since then. This makes it a challenge to develop a VAWT system that is competitive to the modern HAWT design. But the low level of development also allows for a more dedicated offshore turbine design to evolve.

In NORCOWE the VAWT turbine is being investigated with the ambition to develop a floating offshore wind turbine system. The aerodynamic design of the floating NORCOWE VAWT is divided into three subtasks. In task one, the rotor size and geometry of the VAWT are studied. In task two, studies and analysis of the possible energy capture from the VAWT are performed, and in task three the forces on the rotor of the VAWT are investigated. The design of the floating fundament is being performed in parallel. To investigate the relations between important parameters on the VAWT a two dimensional semi-analytic code is developed. The code calculates both the local angle of attack and the relative velocity on a single blade for the full rotation. Data sets containing the lift and drag coefficients for the airfoil are generated using the two dimensional panel code RFOIL. This semi-analytic code is developed to improve the understanding of the forces on a single blade of the wind turbine. To perform more accurate investigations of the energy capture and the forces acting on the VAWT a computational fluid dynamics (CFD) model is used. Measured offshore wind profiles and turbulence intensity levels will be used as design criteria. In figure to the left the NORCOWE VAWT design used as input for the calculations is shown. The development of the floating NORCOWE VAWT is now in its second year of a seven year long project. The ambition is to construct a floating offshore turbine system that is more cost effective than the traditional solutions.
WP3 Offshore deployment and operation

Research in wind energy at Aalborg University (AAU)

by John Dalsgaard Sørensen, AAU

Wind power is a central area of research and education at AAU. The research areas are

Energy planning (Department of Development and Planning). The research within the area of energy planning is centered around the technical, economic, and institutional possibilities and barriers for advancing a sustainable development of the energy systems.

Wind Power Systems and Power Electronics (Department of Energy Technology). The research programme in wind power systems combines the expertise in power systems, electrical machines and power electronic systems, operating extensively in collaboration with industry and other national and international organisations to attend the important technical issues related to the industry.

Control (Department of Electronic Systems). Due to the stochastic nature of their primary energy source, workable performance of wind energy conversion systems cannot be achieved without the contribution of automatic control. The research group explores the use of control technology in wind power systems. They aim to exploit modern control engineering methods to reduce the overall cost of the power produced by wind energy. The scientific work addresses several levels of wind power control systems, from the wind farm level to that of the single turbine, and addresses concurrent design methods and innovative floating structures.

Analysis and design of composite structures (Department of Mechanical Engineering). Research activities related to wind turbines are especially concerning analysis and design of lightweight composite and sandwich structures. Based on analytical methods within solid mechanics and finite element methods, the projects focus on the mechanical behavior of composite structures, adhesive bonded joints, micro mechanics, structural design of wind turbine blades, modelling and simulation of the moulding process for wind turbine blades.

Structural Dynamics (Department of Civil Engineering). Control of vibrations of blades, tower and rotor shaft, due to individual pitch regulation and generator moment control, or by means of different active, semi-active, passive and “smart material” strategies for vibration control, including change of aero dynamic damping properties by shape optimization of blades.

Foundation Engineering (Department of Civil Engineering). Development and verification of computational models for the load bearing capacity of different types of foundations for wind turbines, e.g. bucket, gravity and pile foundations. Especially experimental verification of constitutive models for soil exposed to dynamic loads is an important area.

Loads and Safety (Department of Civil Engineering). Stochastic modelling of environmental parameters (wind, waves, current and water level), material parameters (in blades, steel and foundation) and load bearing capacities. Reliability assessment and risk analysis of wind turbines and risk-based, life cycle based optimal planning of operation and maintenance.

Each of the above groups is internationally recognised research groups, and has a number of research projects with
the wind turbine industry both in Denmark and internationally. Some of the partners are: Energinet.dk, DTU Wind, kk-electronic, ABB, Siemens, Vestas, Gamesa, LM Glasfiber, Dong Energy and Vattenfall. The research programmes are closely associated to the European Academy Wind Energy (EAWE), European Wind Energy Association (EWEA) Technology Platform Wind (TPWind) and EERA-Wind.

**Work within NORCOWE**

**WP 3.2: Single turbine control systems – AAU contributions**

Control technology helps ensure stability, efficiency and fault tolerance of systems and is one of the enabling technologies in reducing the cost of wind power generation.

In NORCOWE, the 2011 focus was on control technology at the component level, at the single turbine level and at the wind farm level. At the component level, fault diagnosis and fault tolerant control technology were developed. This technology allows certain component faults to occur while maintaining stability of the system. The results are demonstrated on a benchmark example and compare favourably to all existing solutions for faults common to the turbine control system.

At the single turbine level, floating wind turbine structures have been studied using aeroelastic code, on a scaled version of Hywind. A single turbine model was expanded with a hydrodynamic model and new control aimed at damping the fore-aft and side-side motions demonstrated.

A PhD project was completed with focus on developing a dynamic wind farm model including the formulation of an optimal control problem that fits with a dynamical flow model. A framework for a centralized wind farm controller was proposed aimed at achieving committed production while reducing loads. To deal with the complexity of such large-scale systems, a modular distributed framework was also suggested.

**WP 4.2: Power systems integration – AAU contributions**

The following tasks have been conducted:

- Modelling of wind turbine with permanent magnet synchronous generator (PMSG)
- Study of aggregated modelling techniques for large wind farms
- Impact study of wind power on steady state voltage stability by P-V curve analysis
- Transient stability evaluation by Critical Fault Clearing Time (CCT) analysis

The above steady state voltage stability and transient stability evaluation are conducted in a modified IEEE-9 Bus test system, which contains 3 conventional synchronous generators.

As the wind energy penetration level in electrical power systems increases, grid codes are established to present more strict requirements on wind power grid integration and operation, such as Low Voltage Fault Ride-through (LVRT) capability. Large offshore wind farms, which have capacities comparable to conventional power plants, are even required to participate in grid voltage support during faults by supplying reactive power. In this project, the (LVRT) capability of variable speed wind turbines with permanent magnet synchronous generators (PMSG) is being investigated in order to make the wind farm to remain connection and at the same time produce reactive power and reduce active power injection in line with the level of voltage drop at the point of common coupling (PCC) during faults. Furthermore, for investigating the transmission systems for large offshore wind farms, a VSC-based HVDC system is also studied. The performances of the models and control strategies as well as the comparison of HVAC and HVDC will be assessed on a realistic power transmission system model.
Increasing the weather window by heave compensation

by Magnus B. Kjelland, Geir Hovland and Michael Rygaard Hansen, UoA

In offshore applications there is a wide variety of tool point control tasks related to heave compensation. This is the case in offshore areas such as wind power systems, oil & gas and ship transportation, where disturbances from sea waves represent a significant challenge for any type of payload manipulation. Machines that handle heavy objects, such as hanging loads, are greatly affected by the ocean environment, and in order to maintain an acceptable performance in as rough weather as possible active heave compensation is widely used.

For hanging loads the main objective of the heave compensation is to control the velocity of the payload mass centre relative to either an inertial or moving frame depending on the nature of the source and target of the payload transfer. This will lead to an increased weather window of operation and reduced dynamic loading on both structures and actuation system. A heave compensated crane with long reach could significantly extend the weather window for gaining access to an offshore wind turbine. A larger weather window for transferring maintenance personnel and equipment can in turn lead to higher uptime and power production for the turbines.

In NORCOWE WP3.4 Marine Operations, a Stewart platform with load carrying capacity of 1500kg has been purchased as well as a hydraulic loader crane HMF-2020-K4 with a load capacity of 1240kg at 12.4m reach. The loader crane can reach up to 20 metres, but then with a reduced load. Currently, a smaller hydraulic crane has been built and mounted on top of the Stewart platform to demonstrate the concept as shown in Figure 1. See also the video which demonstrates the Stewart platform motion.

During 2012 a larger Stewart platform with a load capacity of 8000kg will become part of the NORCOWE infrastructure. The Stewart platforms are used to simulate wave motions with up to six degrees of freedom (heave, surge, sway, roll, pitch and yaw). With two Stewart platforms available as well as a long-reach commercial loader crane, the NORCOWE partners will be able to perform experiments on a variety of scenarios in a stable and repeatable laboratory environment. For example, load transfer between two floating vessels or load transfer from a floating vessel to a bottom-fixed structure can be simulated. The control systems of the Stewart platforms are capable of replaying and simulating typical wave motions profiles from the North Sea. Hence the need for expensive offshore testing or the use of large wave tank experiments can be reduced.

Figure 1: Stewart Platform with Heave Compensated Hydraulic Crane (left). Loader Crane HMF-2020-K4 (right).
Reliable, robust and low-cost condition monitoring (CM) and structural health monitoring (SHM) systems for offshore wind turbines may reduce operating expenses significantly by providing on-line information to support optimal maintenance management. Monitoring data from CM/SHM systems can be input to turbine and wind farm control systems to reduce structural loads and optimize production both in the normal operating mode and in fault modes. Sensor technology, signal processing, and decision support systems are key factors for enabling condition-based asset management.

Damage and on-growth such as icing on wind turbine blades involve significant risk of secondary damages through load imbalance and possible impact from objects that come loose of the blades. Turbine blade damage can be a major contributor to maintenance costs, not least because demanding offshore operations are required for blade repair and replacement. Early detection and progress monitoring of blade damages and on-growth could become an important tool to prevent secondary damages and to improve maintenance planning. Several measurement technologies have been identified as possible candidates for development of reliable, robust, and inexpensive sensor solutions.

Ultrasound technology is widely used for nondestructive testing/evaluation (NDT/NDE) and for structural health monitoring. Structural health monitoring techniques based on ultrasound can be applied without intrusions or modifications in the mechanical structure. Among the relevant ultrasonic techniques, guided-wave techniques are particularly interesting for many structural health monitoring applications on components in service. Faults such as disbonding, cracking, and delamination can be detected, and their progress can be monitored. As part of their NORCOWE participation, CMR Instrumentation studies ultrasonic guided-wave monitoring of composite materials with application to structural health monitoring on wind turbine blades. The technology development work includes numerical modelling, laboratory measurements, and testing of sensor prototypes.
Scope of the project was RAMS+I (Reliability, Availability, Maintainability, Maintenance supportability, Safety and Inspectability) management in offshore wind energy sector in Nordic context. The objective was an extended concept to support RAMS+I factors identification and requirements specification especially in the early life cycle stages of offshore wind turbine development.

The results of the research work included; RAMS+I management – from single analyses to systematic approach outlines a RAMS+I management model, RAMS+I characteristics and their applications for offshore wind farm. The RAMS+I management model forms a baseline for more accurate and specific tools and approaches presented in the following publications. In this paper generic RAMS+I elements and their characteristics in offshore context were studied. Special attention was paid to inspectability issues.

Framework to assess system risks associated with offshore wind farms in Northern context presents a systematic risk management framework for offshore wind farm design in harsh Nordic conditions. In addition to the risk management framework and risk assessment process system risks associated with offshore wind farm projects were discussed and categorised.

From-design-to-operations risk mitigation in Nordic wind energy assets: a systematic RAMS+I management model concentrates on RAMS+I issues in the conceptual design phase of offshore wind turbines. RAMS+I issues were widely studied and impacts over systems up/down time and LCC-LCP were examined. The objective was to clarify and structure the fuzzy front end of the wind turbine innovation process from RAMS+I perspective and make it more manageable. As a result a basic RAMS+I information flow is illustrated and RAMS+I management model for wind turbine development in early phases is described. RAMS+I objectives, inputs, main tasks, examples of analysis methods and outputs are defined for each phase. The model is strongly influenced by the well-known stage-gate model by Cooper.

Identification and evaluation of RAMS+I factors affecting the value-added by different offshore wind turbine concepts in Nordic context present a method to compare different offshore wind turbine concepts and their critical components in the beginning of the development process from RAMS+I point of view. The suggested method divides RAMS+I issues into more detailed sectors, elements and factors in order to clarify the important variables affecting offshore wind energy system’s overall RAMS+I capability. The evaluation and comparison method called Multi Factor Risk Profiling (MFRP) is based on Multi-criteria decision analysis (MCDA) methodology. The six step approach for using the MFRP method is also proposed.

The results of the project form a strong basis to manage RAMS+I issues in offshore wind turbine development process. Reliability and safety issues have been discussed in offshore wind energy sector for many years but systematic approaches for risk management have not been published so far.

Offshore wind turbine designers are looking for the "optimal" solutions for the supporting platforms and turbine concepts that will achieve the best functionality and lowest cost. The solution is always a compromise that attempts to minimize the system costs by addressing each technical challenge. It is best to identify and assess issues affecting the value added, especially in new innovative technologies, in early conceptual design phase. The added value achieved from successful RAMS+I management throughout the offshore wind asset lifecycle comes from e.g.: high system availability; motivated and committed personnel; no accidents and negative implications to sea nature; optimal utilisation of weather windows for marine operations and maximised turbine up-time and minimised down-time.
Current development scenarios of engineering asset management involve a large number of technologies that are shifted from other industrial applications, mainly from power generation plants, hydropower, nuclear, and recently offshore oil & gas, in particularly, offshore construction and installation providers as the offshore wind energy market becomes the most competitive application. A number of systems have been transferred and utilised in building intelligent asset management systems such as data management, information systems, control and condition monitoring, tactical planning, performance measures, maintenance management, spare part and equipment management etc. These systems also transferred their ICTs’ products and solutions (i.e. hardware, software, communication, etc.) with different level of validation and adaptation to wind energy application and operational needs. However, cutting down the operation and maintenance cost is still a significant issue toward cost effectiveness and mature level of excellence.

The outcomes from this project included:
1. Review of the current commercial intelligent asset management systems, and a description of their development practices
2. Determination of the main technical pitfalls
3. Proposal of a system-oriented development model

Current EAM practice within wind energy sector significantly requires a system-oriented development model in order to avoid the current development pitfalls and enable the technologies transfer process form other industrial sectors. The developed model encourages the research and industrial partners to establish long-term partnerships in order to co-develop more robust and operate more cost effective practices.
Wind turbines generate wakes and downstream turbines will experience lower wind speeds and increased turbulence intensity compared to unobstructed turbines. Power losses from wakes in wind farms are difficult to predict. GexCon develops and validates state-of-the-art models for various physical phenomena relevant for design, optimization and operation of wind farms in the computational fluid dynamics (CFD) code FLACS-Wind (Sælen, Khalil & Melheim, 2012).

Coupling between CFD and Meso-scale models
GexCon has implemented a one-way coupling between the Weather Research and Forecasting (WRF) model (www.wrf-model.org/index.php) system and FLACS-Wind. The boundary conditions of the CFD domain are assigned by interpolating the output from the WRF meso-scale model at a given time. Uni Research, in collaboration with GexCon, identified a suitable location and time period for the WRF simulations at the prospective site for the Dogger Bank wind farm. WRF simulations were performed by Uni Research on the Cray XT4 supercomputer at Parallab (Uni Computing). The output from the WRF simulation, with 1.35 km horizontal resolution, was used to test the coupling to FLACS-Wind. Figure 2 shows wind profiles interpolated from WRF onto the CFD domain. The coupling feature will be made available in the next beta release of FLACS-Wind (June 2012).

Validation studies
GexCon organized the Second Joint NORCOWE–NOWITECH Wind & Wake Workshop on 20-21 October 2011, and participated in the wind turbine blind test organized by NTNU and GexCon. The main focus for the workshop was a blind prediction of the measurements performed in the NTNU wind tunnel.
Figure 3 (left) Picture taken at the inlet of the wind tunnel test section showing the model turbine placed 3.66 m from the inlet. (right) Result for the wake predictions of turbulent kinetic energy for tip speed ratio 6 at 3 rotor diameters downstream. Note GexCon results in red diamonds (legend Melheim, Sælen & Khalil).

for the performance and wake characteristics of a model wind turbine. Eight groups provided blind predictions for the performance and loading of the model wind turbine, and the development of the wake downstream of the turbine. The workshop covered the results from different modelling techniques including BEM models, RANS and LES CFD models and involved actuator disk, actuator line models and full rotor simulations. This was a great opportunity to exchange opinions about the different challenges in modelling wind turbine performance and wake and plan future directions.

The simulations by GexCon were performed with FLACS-Wind, using BEM and AD modelling (Figure 3). In the blind comparison, the overall performance of the simulations by GexCon was comparably well (Krogstad & Eriksen, 2011, Sælen et al., 2011).

International cooperation

GexCon participated at the kick off workshop for WakeBench (6-8 October 2011). WakeBench is an IEA initiative to perform and define benchmark cases for wind farm flow models and to develop a benchmarking standard including a database of benchmark cases and modelling tools.

Figure 2 (left) The northerly component (V) and (right) the easterly component (U) of the mean wind velocity in m/s are interpolated from the output from the WRF model simulation over the Dogger Bank area onto the CFD domain. X, Y, Z is to the east, north and zenith.
Modelling of wind energy capture

by Ivar Øyvind Sand and Anders Hallanger, CMR Instrumentation

Motivation
The flow field within a wind farm is extremely complex. Offshore wind turbines in the first line towards the wind stand in the shear flow of the marine boundary layer, while turbines further downstream may stand in a wind turbine wake or a combination of several wakes interacting with each other. Knowledge about the mean velocity profile and relatively fine details of the flow field causing dynamic loads, like wind shear, turbulence, and vortex shedding, is important for optimization of the energy production and minimization of structural vibrations. Decreasing vibrations is necessary for increasing the lifetime of the wind farm’s turbines.

In principle one can achieve a detailed picture of turbulent wind and wakes interacting with wind turbine tower, hub and moving blades using computational fluid dynamics (CFD). However, resolving the flow field around each wind turbine’s blades in a wind farm on a moving computational grid is still too costly and time consuming. Instead sub-models are made for the wind turbines representing them within the CFD code as reaction forces acting on the flow field. Depending on the computational grid resolution and the distribution functions chosen for these reaction forces, it may be necessary to include additional sub-models for turbulent kinetic energy and its rate of dissipation to achieve turbulent viscosity accurately enough to simulate the velocity- and turbulence structure of the wind turbine wakes.

There are several sub-models which can be used to approximate the reaction forces from the wind turbines. A group of these sub-models are the actuator disc models, with and without rotational forces which may be uniform or distributed over the disc. Other groups of sub-models are the actuator line method, and the actuator surface model. The latter two may be most suited for simulating the unsteady flow experienced by downstream wind turbines using transient simulations. However the increased accuracy and time dependence of these methods come at a cost in terms of computational resources, (Sanderse et al., 2011).

Work and results
The actuator disc and actuator line wind turbine models can be implemented on the basis of the generalized Blade Element Momentum (BEM) theory. CMR Instrumentation has implemented this method corrected for some of its weaknesses by including the Prandtl tip speed correction, the Glauert correction of wind turbine thrust for high loading, and Buhl’s modification of the thrust model to avoid computational oscillations in the thrust.

The implemented wind turbine model (Sand, 2011) is under testing in two different CFD codes, a version of FLACS-Wind at CMR Gexcon, and an in-house curvelinear CFD code at CMR Instrumentation. Various turbulence models, including sub-grid models, are under testing (Hallanger & Sand, 2012) comparing simulated velocity defects and turbulence intensity distributions with experimental results for wind turbine wake measurements available in (Krogstad et al., 2011).

The latest version of the wind turbine model includes a yaw model for computing turbine thrust and power when the mean wind direction is not normal to the wind turbine rotor plane. This simulation functionality may be an advantage for testing possible reducing of wind turbine loads and increased power capturing downstream of the first wind turbine line by setting an offset yaw angle. The wind turbine sub-model may be further improved by including the effect of turbulence intensity on the lift and drag coefficients used in the computational BEM procedure for turbine thrust and torque. When the wind is non-uniform in space, the forces acting on the blades change as the blades rotate. This effect of different wind profiles on turbine thrust and torque will also be studied. The computational procedure requires handling of the azimuth angle.

CMR Instrumentation has also carried out work on controlling the energy catching from a model wind turbine in stochastic wind with time varying strength and direction. The wind turbine is modelled quasi steadily (Sand, 2012).

Simulated horizontal cut through the wake of the wind turbine model of Krogstad & Eriksen (2011). Inlet velocity is 10m/s, and the tip speed ratio of the wind turbine is 6. The figure is taken from Hallanger & Sand (2012).
In this period, the following tasks have been conducted:

- Modelling of wind turbine with permanent magnet synchronous generator (PMSG)
- Study of aggregated modelling techniques for large wind farms
- Impact study of wind power on steady state voltage stability by P-V curve analysis
- Transient stability evaluation by Critical Fault Clearing Time (CCT) analysis

The above steady state voltage stability and transient stability evaluation are conducted in a modified IEEE-9 Bus test system, which contains 3 conventional synchronous generators. As the wind energy penetration level in electrical power systems increases, grid codes are established to present more strict requirements on wind power grid integration and operation, such as Low Voltage Fault Ride-through (LVRT) capability. Large offshore wind farms, which have capacities comparable to conventional power plants, are even required to participate in grid voltage support by supplying reactive power during...
faults. In this project, the LVRT capability of variable speed wind turbines with PMSG is being investigated. The modelled wind farm is able to output reactive power to support voltage, and reduce active power injection in line with the level of voltage drop at the point of common coupling (PCC) during faults. A network implemented in DlgSILENT is used to test the voltage support capability of the proposed PMSG-based wind farm as shown in Fig. 1. Fig. 2 shows the comparison of the performance of a PMSG-based wind farm with and without voltage support when a three phase short circuit occurs on the PCC (HV Bus). Furthermore, for investigating the transmission systems for large offshore wind farm, a VSC-based HVDC system is also studied. The configuration of the PMSG-based wind farm connected to AC network through VSC-HVDC link is shown in Fig. 3. The performances of the models and control strategies as well as the comparison of HVAC and HVDC will be assessed on a test power transmission system model.

Figure 2: Responses of a PMSG-based wind farm with three-phase short circuit occurred. Left-without voltage support; Right-with voltage support

Figure 3: Configuration and control concepts of PMSG-based wind turbine with VSC-HVDC transmission
In this work we consider design of offshore wind farms, using the power production as the layout design parameter. Other parameters could also be considered, such as sea bed conditions and the electrical system, but the power production is the dominant layout design parameter. Even a 1% gain in energy production from improved wind farm layout is worthwhile, as it may be achieved at no increase in capital cost. The cause of variation in the power production for different wind farm layouts is the wake generated by each turbine in the wind farm influencing the power production of downstream turbines. Such power losses from wakes are difficult to predict, but the effect is important and is estimated to be in the region of 5-10%. Therefore, there is a need for fast and accurate methods for evaluation of power production to enable interactive design and optimization of wind farm layouts.

The state-of-the-art in wind farm design is using explicit models for the turbine wakes. The current status on explicit wake modelling is that significant work has to be done to develop an understanding of why different models do not predict the wake losses well. Computational Fluid Dynamics (CFD) is a technique that has the potential to resolve the complex flow in a wind farm with multiple wake interactions. CFD tools are however computationally expensive, which makes them unsuitable in an interactive design tool where the user expects almost immediate response. The approach investigated here is a simplified CFD approach using a model reduction technique of the steady state Reynolds Averaged Navier-Stokes (RANS) equations and the method of snapshots to generate Proper Orthogonal Decomposition (POD) modes. A tiling approach is used, where the tiles capture the localized flow behavior close to a turbine. A basis is generated from snapshots of FLACS-Wind simulations with 3 and 6 turbines. Figure 1 shows the singular values and the first six POD modes of the basis. Once the basis is established, the solution is computed within seconds and the wind farm designer can move turbines interactively. Figure 2 shows the estimated U-component of the flow for a 21-turbine wind farm. This example shows that the model reduction approach allows constructing solutions of flow fields for large wind farms by using CFD simulations from smaller wind farms.
Offshore wind farms consist of large wind turbines placed on extensive areas of seabed on the continental shelf. Together with transformation towers and connecting cable tranches, the turbines have an impact on marine ecosystems from installation to decommission of the wind farm. A wind farm investment is made with a calculated life of about 25 years, but a wind farm site can be re-developed using new technology, which increase both lifetime and energy production per turbine.

The development of offshore wind energy at sites such as the Norwegian coast that is dominated by a rocky seabed, very large waves, and strong currents, is unique at a global scale. The experiences drawn here can be used where such development is under consideration, for example on the Scottish west coast and off Japan. High-energy sites like these are inaccessible and effectively “remote”. Hence are these ecosystems not well studied and, as for example coastal areas in polar regions, poorly known.

The environmental research within NORCOWE focus on developing monitoring methods that are cost effective and suitable for Norwegian sites where exploitation of offshore wind energy is being considered. The impact and expected effect on the marine ecosystem will be different in different habitats, and while monitoring has been conducted at developed sites in the southern Baltic and North Sea we currently lack methods that would work at rocky seabeds, typical of the Norwegian coast. The common challenge for this work is to fully understand the variation in the studied variables that are caused by natural fluctuations and human activities such as fishing, offshore oil and gas exploitation and shipping. Long term trends in eutrophication, harmful chemical load and climate can also have a confounding effect. Any impacts from the future wind farm need to be analysed, taking full account for the existing variation. We use a standard before-after-control-impact, or BACI, design for our monitoring work. A BACI design needs baseline data collected before any impact generating activity start. To exclude concurring effects, data is also collected in control areas where no impact from the studied activity is expected.

Marine life at the seabed
Also known as the benthic flora and fauna, this component of the marine ecosystem is very species rich and fundamental for fish, marine mammals and birds. Small but significant effects on benthic species composition, diversity and biomass have been shown at other wind farm sites and are therefore important to monitor. We study the possibility to detect the effects that wind farms can cause at three major types of seabed habitats; kelp forests, deep rocky seabeds, and deep soft sediments. None one of these habitats has been studied in conjunction with wind farms before. Most work is needed to develop methods for the deep rocky habitats. In contrast to other types of seabed, we can’t take a quantitative sample of a rock surface and bring it to the lab for analyses. The method that we develop in collaboration with an international group of scientists relies on video footage collected by remotely operated vehicles. To facilitate computational analyses of this kind of samples the footage is turned into picture files by a mosaicing algorithm. This picture file is in turn analysed for rate of occurrence of different biological and sediment features by other computer algorithms detecting specific colours, shapes and patterns. In this way the habitat can be mapped and changes assessed over the life-time of the wind farm. We also compare the performance of this method with a standard method to analyse the video data using manual observations.

Fish
Monitoring of fish occurrence, diversity and distribution is notoriously difficult due to large natural fluctuation and con-
founding effects from synchronous changes in fishery efforts. Nevertheless, some effects on the fish community at offshore wind farms has been described in the recent community. These effects are in all cases limited to an increase of fish around the turbines, probably caused by reef effects. To assess changes in the fish community we use a set of fishing methods that are traditionally used in the area. Any impact on commercially important fish stocks may also be assessed using landing data collected by local fisheries authorities.

NORCOWE is also active in a separate research project that aim to understand the long term effects on fish and changed distribution of fish and shellfish at wind farms. In collaboration with Norwegian and international scientists we collect data for the model fish species viviparous eelpout (Zoarces viviparus) and the shore crab (Carcinus maenas) at the Lillgrund wind farm in Sweden. Lillgrund wind farm has 48 turbines and has been in the production phase since 2007. Extensive base line data collected at this site allow for rigorous analyses of impact from the wind turbines.

Marine mammals
The most negative effects from offshore wind farms are caused by the impact from the insertion of mono-pile foundations in the seabed by hammering. The noise can reach lethal levels at close range. Mono-piles cannot be used at rocky seabed and our monitoring work focus on the long-term effects during the production phase, on small cetaceans and seal. Recent results from Belgian waters indicate that the red listed harbor porpoises (Phocoena phocoena) are attracted to wind farms. Because of the difficulties to estimate porpoise and dolphin populations in the open sea, little is known about the porpoise occurrence outside of the calmer Norwegian fjords. For the first time in Norway we assess the use of C-pods in rough seas with a chaotic sea shape. This instrument logs the specific clicks from toothed whales (not sperm whales). Rather surprisingly, the preliminary results from the first year of background data collection suggest that porpoises are as common in the choppy Norwegian Sea as in the calmer waters in the southern North Sea. It has been suggested that disturbance from increased boat traffic during the construction phase can have an impact on seals, but previous studies have not been able to detect any effect on seal occurrence or behaviour. Harbor seal (Phoca vitulina) are known to be common along the Norwegian coast and the population is culled by hunting to protect fishing interest. Several seal haul-out sites are monitored by flight observations in collaboration with a bird monitoring program. Impact on sea bird populations is not part of the NORCOWE research centre.

Future work
Other environmental issues that are of interest to investigate for offshore wind farm development include the potential for the foundations to act as stepping stones for invasive species. By providing a hard intertidal substrate in the middle of the sea turbine foundation can facilitate spread to otherwise unaffected areas. More than half of the fouling species found at the foundations at Belgian and Dutch wind farms, are indigenous invasive species such as the pacific oyster (Crassostrea gigas). While this issue has been acknowledged for some time, mitigation methods are still to be developed and assessed, a future research topic that would fit the interdisciplinary work within NORCOWE.
Transport of heat and momentum across the air-sea boundary affects the stability of the lower 150 meters in the atmosphere and will affect the structural loads and fatigue of wind turbines. Direct turbulence flux measurements in the Marine Atmospheric Boundary Layer (MABL) are important to improve the understanding of the exchange processes between the atmosphere and the ocean. Flux measurements can be conducted from three types of platforms: an offshore tower, a ship or a buoy. Except from the German FINO platforms most offshore towers are mostly placed in shallow waters (up to 20m depth) close to the coast to ensure continuous energy supplies and easy access. Nowadays, there are only a few sites in the world where offshore turbulence flux measurements are conducted from fixed towers. In contrast to ships and buoys, one of the major advantages of tower measurements is that the collected data is not contaminated by any motion of the instrument platform. Nevertheless, tower instrumentation is vulnerable to flow distortion from the tower structure and useful turbulence measurements can often only be obtained when the wind is blowing from predetermined directions. Turbulent flux measurements over deep water require the use of a ship or buoy. The main advantage of ships is that turbulent fluxes of heat, momentum and CO₂ can be assessed over a large ocean area. The ships engines ensure continuously power supply for the instruments and researchers have the opportunity to adjust and reconfigure the scientific instrumentation whenever necessary. In contrast, flow distortion around the ship’s bow is a major contamination source of direct turbulence flux measurements. In order to minimize the ship induced flow distortion (i.e. measuring the turbulence induced by the ship instead of the “real” turbulence in the MABL), the instrumentation has to be placed as high as possible on the foremast and the ship’s bow has to be turned into the mean wind direction. In addition, it is required to avoid any ship maneuvers during the measurements. Recently, researchers have started to investigate the use of buoys for turbulent flux measurements. This platform is so small that flow distortion is almost eliminated, thus giving the researchers the opportunity to measure uncontaminated turbulent air-sea fluxes. As with ships, buoy measurements will still be contaminated by the platforms attitude (i.e. tilting.

The sensor head of the NORCOWE covariance flux system (in front of the two LIDAR systems) integrated into the wave motion field test at UoA in Grimstad.

by Martin Flügge, UoB
of the platform due to the waves and its horizontal motion) and several motion correction algorithms have been developed to eliminate the contamination in the gathered data. Buoy systems are autonomous and therefore cost efficient and can be deployed almost everywhere, especially inside wind farms where ship access is limited. The major issue with buoy systems remains the power supply due to the limited battery capacity. Nevertheless, in addition to energy efficient battery packages modern buoy systems are equipped with solar panels that increase the operation period. As of today, autonomous buoy systems are becoming increasingly more popular platforms for direct covariance flux measurements.

Up to today, our knowledge of the atmospheric boundary layer is based on observations over land. Recent studies have shown that the wind profiles in coastal areas cannot be predicted with the established theories that have been developed from measurements over land. In fact, little is known about air-sea exchange processes that govern the wind profiles in the MABL. Numerical studies have shown that these exchange processes can influence the lower 150 meters of the boundary layer and thus affect offshore wind turbines. For the characterization of the Marine Atmospheric Boundary Layer NORCOWE has purchased two identical covariance flux systems. The systems have been developed and assembled in collaboration with the turbulence group at University of Ireland in Galway. In addition, the NORCOWE turbulence group led by professor Joachim Reuder has established a collaboration with Dr. James Edson from the University of Connecticut, one of the leading researchers on offshore direct covariance flux measurements. The sensor head of the turbulence system consists of a Gill-R3 sonic anemometer and a Crossbow NAV440 Inertial Measuring Unit (IMU) with GPS antenna, housed in a watertight box. A MOXA UC-7420 Plus is used as the data acquisition unit and provides the possibility of sending the recorded data to an external PC by WLAN. The entire system can be powered by either 230V AC or 15V DC. After completing extensively tests the systems will be mounted on a moored buoy in the Havsul area in middle Norway, one of the regions dedicated to the development of offshore wind farms by the Norwegian authorities. Combined with measurements from a nearby tower placed on an islet, the system will provide valuable information about turbulent exchange processes in the Norwegian Sea. Due to its small size, the turbulence system is able to measure air-sea fluxes directly a few meters above the seas surface where the turbulent exchange processes are taking place. These near surface measurements cannot be easily achieved from offshore towers or ships. The data collected from the system will be transferred into the NORCOWE database and will be available for all NORCOWE members.
At NORCOWE the oceanographic studies are three-fold: i) measurements of surface waves, and currents, temperature and salinity in the water column to define the background conditions and variability at a site of interest, for example, a planned offshore wind farm, ii) studies to increase our understanding of the dynamics of the upper ocean using measurements, theory and numerical modelling, and iii) investigating the influence of the presence of a large offshore wind farm on ocean circulation, surface wave field and ecosystem. The ocean surface is a complex boundary across which gas, matter and energy are exchanged between air and sea. The processes at this complex interface and the coupling between surface waves, winds and currents are of crucial importance for ocean circulation and ecosystems in general, and for the structural behavior and fatigue of offshore wind turbines in particular. To properly describe and model the upper ocean, the turbulence and mixing induced by wind and waves must be accounted for. We can only then provide the proper forcing fields for the detailed modelling of an individual wind turbine or a large wind farm, and evaluate its influence on the regional ocean circulation with confidence.

At NORCOWE dedicated oceanic measurements were made covering small turbulent scales, larger scale background properties and surface wave forcing. A platform has been developed to sample turbulent properties at a fixed level in the wave-influenced upper boundary layer for duration of several months. The data set collected from this instrument covers periods of energetic storms with wave heights in excess of 10 m. Because this platform is not fixed and responds to strong currents and wave motions, motion correction algorithms have been developed: both the currents and the wave field have been successfully recovered.

The link between wind and wave forcing and turbulent mixing in the surface boundary layer needs to be described in terms of available, calculated variables in numerical models (so called parameterization). At NORCOWE a milestone toward this goal has been achieved by modifying a widely-used ocean model by including the wave forcing effects. Applications to case studies show that the skill of the modified model in capturing the observations is significantly better than when wave forcing is ignored.

**Upper-ocean boundary layer studies at NORCOWE**

by Ilker Fer and Mostafa Bakhoday Paskyabi, UoB and Alastair D. Jenkins ,Uni Research

**Turbulence mooring being recovered from the deployment during the BIOWAVE cruise in Vestfjorden, Lofoten.**
It is already well-known that the presence of a large offshore wind farm significantly alters the ocean circulation pattern at the site as a result of changing the wind field at its wake. By harvesting the wind energy, a wind farm reduces the amount of energy transferred to the sea. The variable pattern of wind forcing at the regional scale leads to vertical circulations. At NORCOWE, we have shown that the additional effect due to the change in the wave field significantly increases the perturbation induced by the wind farm.

Turbulence mooring

Turbulence mooring (Figure 1) is an ocean near-surface turbulence measurement system designed to collect time series at a fixed level. The platform is a low-drag buoy, StableMoor 400, custom modified by Flotation Technologies to fit the turbulence instruments. All turbulence sensors protrude horizontally from the nose of the flotation pointing to the mean flow. The buoy is equipped with a MicroRider (Rockland Scientific) turbulence instrument package consisting of two air-foil shear probes, two fast response thermistors, a pressure transducer, a 2-axis vibration sensor, a precision pitch and roll sensor, and a three-axis magnetometer. Additionally a low-power 6-axis motion sensor, Gyrocube 3F (O-Navi), is fitted into the MicroRider. A three component acoustic Doppler velocimeter, Nortek Vector, is interfaced with the MicroRider. The sensor head of the Vector is rigidly fixed to the buoy, as close as possible to the MicroRider sensors such that the temperature and 3D velocity are sampled at approximately the same measurement volume. The entire system is powered by two rechargeable Lithium-Ion battery packs of 40Ah each, giving an estimated operating time of 500 h. With a 25% duty cycle, this instrument can sample 20 GB of data for about 85 days. The buoy is the upper element of a bottom-anchored mooring line, allowed to align with the current. The system allows for measurements using two independent methods sampling different parts of the turbulence spectrum: eddy correlation measurements of turbulent momentum flux and heat flux sampled in the energy containing and near-inertial subrange, and dissipation rate measurements in the dissipation subrange. Records from the accelerometers and the 6-D motion sensor allow for applying necessary corrections for the platform motion.

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Figure 1: Design of the turbulence mooring in collaboration with Rockland Scientific. The flotation element is the uppermost element of a line anchored to the bottom. A swivel will allow it to rotate freely, pointing the sensors toward the flow.
The NORCOWE activities include acquisition and processing of data from climate measurement campaigns over time, by multiple data providers. These are large data quantities, and thus qualified metadata and efficient tools are required. It is essential that the participating data providers and data users have efficient access to these datasets in a consistent way.

NORCOWE’s solution to these challenges is to establish a central, unified data repository, open to access for all participants. Users can apply a set of tools to convert, process, and tag datasets with metadata. The datasets can then be uploaded to the central repository, instantly making them searchable and available to other participants. To be able to search and find the measurement data one need for a project, known search criteria like campaign location, time, and type can be applied. This information is stored in metadata, and we ensure that all converted data is tagged according to a specific standard.

The data server is an instance of the MET (The Norwegian Meteorological Institute) METAMOD server, specially hosted for NORCOWE. Access to the server is administered by NORCOWE.

CMR activities in this respect include development of software for converting instrument data into standard data files, and applying metadata to the datasets. These software tools will be available to NORCOWE data providers. At this stage, conversion software for LiDAR, MAST, and buoy instrument data has been developed and adapted, producing standard netCDF datasets with metadata. Working closely with the data producers and work package participants we will support other formats as they become available.
In ICEWIND (Improved forecast of wind, waves and icing), a project under the Top-level Research Initiative (TRI) of the Nordic Council of Ministers, Bjørn Egil Nygaard at the Norwegian Meteorological Institute (associate partner in NORCOWE) is working on the problem of in-cloud icing as part of his PhD study. In-cloud icing on aircrafts and ground structures can be observed every winter in many countries. In extreme cases ice can cause accidents and damage to infrastructure such as power transmission lines, telecommunication towers, wind turbines, ski lifts, etc. Nygaard’s study investigates the potential for predicting episodes of in-cloud icing at ground level using a state-of-the-art numerical weather prediction model. The Weather Research and Forecasting (WRF) model is applied, with attention paid to the model’s skill to explicitly predict the amount of supercooled cloud liquid water content (SLWC) at the ground level at different horizontal resolutions and with different cloud microphysics schemes. The paper also discusses how well the median volume droplet diameter (MVD) can be diagnosed from the model output. A unique dataset of direct measurements of SLWC and MVD at ground level on a hilltop in northern Finland is used for validation. With the highest model resolution, very good results can be obtained in terms of mean absolute error (grid spacing equal to 0.333 km). The quality of the SLWC predictions decreases dramatically with decreasing model resolution, and a systematic difference in predictive skill is found between the cloud microphysics schemes applied. A comparison between measured and predicted MVD shows that when prescribing the droplet concentration equal to 250 cm\(^{-3}\) the model predicts MVDs ranging from 12 to 20 mm, which corresponds well to the measured range. However, the variation from case to case is not captured by the current cloud microphysics schemes. The results are published in Kringlebotn Nygaard, Bjørn Egil, Jón Egill Kristjánsson, Lasse Makkonen, 2011: Prediction of In-Cloud Icing Conditions at Ground Level Using the WRF Model. J. Appl. Meteor. Climatol., 50, 2445–2459.

ICEWIND is coordinated by Risø National Laboratory for Sustainable Energy, Risø DTU with partners from Finland (VTT), Iceland (Icelandic Meteorological Office, University of Iceland, Landsvirkjun, Landsvirkjun Power), Norway (Norwegian Meteorological Office, Kjeller Vindteknikk, AGR Field Operations, Statoil, Offshore Windservice Aps), Sweden (Gotland University) and Denmark (Vestas Wind Systems). The project lasts until August 2014 and in addition to icing and icing atlas, it also deals with wind atlas methods, offshore operation and maintenance and energy aspects.
Minimization of the total length of windfarm infield cable

by Joanna Bauer, UoB

At the Optimization Group at the Department of Informatics, University of Bergen, we have taken on a challenge reported by Troll Windpower (now Goodtech) in “Power system optimization and challenges” (NORCOWE-RR-C-11-WP4-004) (emphasis ours):

When planning the inter-array system [the electrical system connecting the turbines to the offshore transformer station] of a wind farm, an important part of the work is to reduce the total cable length, as this will both reduce the initial investments costs, the cable laying costs and the power losses during wind farm operation. However, due to the large number of variables affecting the solution, there is no straightforward answer to the problem.

Minimization of the total length of windfarm infield cable

The cable pattern optimization process can be divided into the following:
1. Decide cable layout philosophy(ies)
2. Decide substation(s) location(s)
3. Optimize cable pattern and total length for each case
4. Use the different cases as input to further load flow analyses and economic analyses

The most common cable layout philosophy is the radial configuration, where turbines are “strung” on a cable one after another. Every cable ends at a substation. The number of turbines per cable is bounded. Cable branches are not allowed.

If the locations of the turbines and substation(s) are given, a simple optimization model enables standard commercial optimization software to find the optimal cable pattern within a few minutes.

Minimizing the total cable length becomes much more complex if the location of the substation(s) can be determined as part of the minimization, and for other layout philosophies, especially those allowing cable branching. We are currently working on solution methods in order to minimize the total cable length in these complex scenarios.

We illustrate the problem for a wind farm with 88 turbines on a regular 8-by-11-grid. The maximum number of turbines per cable is 8.

Illustration 1 shows an optimal layout for a fixed substation location.
Illustration 2 shows a near-optimal layout if we are allowed to move the substation.
Table 1 shows the total inter-array cable length and the total length of the infield export cable (not depicted in Illustrations 1 and 2).

Table 1

<table>
<thead>
<tr>
<th></th>
<th>Inter-array cable</th>
<th>Infield export cable</th>
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<tbody>
<tr>
<td>Layout by Goodtech</td>
<td>92.8 km</td>
<td>8.4 km</td>
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<tr>
<td>Optimal layout, substation fixed</td>
<td>92.3 km</td>
<td>8.4 km</td>
</tr>
<tr>
<td>Near-optimal layout, substation variable</td>
<td>92.2 km</td>
<td>5.0 km</td>
</tr>
</tbody>
</table>

Array with branch (upper) and array without branch (below).
Meet scientist Jasna Bogunović Jakobsen

**What is your scientific background?**
PhD in Structural Engineering from the Norwegian Institute of Technology (now NTNU) and M.Sc. in Structural Engineering from the University of Novi Sad, Serbia. My research is within structural dynamics, with emphasis on wind loads and wind-induced vibrations of slender structures.

**Why have you selected that topic?**
Wind loads are among the key design factors for many long-span structures such as bridges, tall buildings, masts, flare towers, wind turbine blades, long-span roofs etc. Because of a great slenderness of these structures and their low damping, wind loads can potentially either cause their immediate collapse or a long-term, accumulated damage.

Modern, span record breaking structures often give rise to new wind engineering problems. This is for instance the case with several types of wind-induced vibrations of cables in the modern cable-stayed bridges. The University of Stavanger is part of a larger international research team working on understanding and mitigating the cable vibrations.

Another interesting aspect of wind engineering is that it is a very multidisciplinary field. It combines topics from meteorology, fluid dynamics, statistics, aeronautics, structural engineering, numerical mathematics, laboratory and field testing etc.

**What issue within offshore wind energy is addressed by your work?**
Together with other researchers at the University of Stavanger, I am currently studying the importance of the atmospheric stability, i.e. the refined offshore wind conditions, on the fatigue life of wind turbines. We are also looking into numerical tools for improved modelling of the aerodynamic loads on the wind turbine blades.

**How do you think NORCOWE can contribute to the development of offshore wind energy?**
NORCOWE addresses the whole chain of the topics relevant to the offshore wind energy – from the met/ocean modelling to the wind turbine installation, operation and maintenance. In this way, each segment of the work is put into a broader perspective, and synergy effects between the various activities can be further exploited by the researchers and the industry partners. Also, the educational activities under NORCOWE are very important for the wind energy industry in Norway.
What is your scientific background?
I obtained a bachelor’s degree in meteorology and oceanography in 2007 and a master’s degree in geophysics – climate in 2009. Currently, I am taking my PhD at the University of Bergen and work in the research field of boundary layer meteorology.

Please give a brief description of your main research topic
My main research is on the characterization of the Marine Atmospheric Boundary Layer (MABL). The project focus is to investigate the turbulent exchange processes of momentum and heat between the ocean and the atmosphere. These processes govern the stability of the MABL and thus the winds that will affect offshore wind turbines. I use the NORCOWE turbulence system mounted on a buoy in order to quantify the turbulent exchange processes. This measurement technique is still under development and my research project will also contribute to improve it.

Why have you selected that topic?
I have worked with a climate model during my master’s thesis and spent most of my time behind my PC. My PhD project is of a more practical “nature” and gives me the opportunity to work in the lab and outdoor. The main reason why I choose my PhD project is that only a few people have tried to characterize the MABL from a scientific point of view. For example, you find thousands of studies concerning climate change but how many studies do you find about the MABL? I also believe that my work in this project will contribute to mitigate climate change.

What issue within offshore wind energy is addressed by your work?
Most of our knowledge about the wind in the atmospheric boundary layer comes from field campaigns that have been performed over land. One of the major issues for offshore wind energy is that the present boundary layer theory is not applicable over the ocean. Today, little is known about the wind profiles over the ocean. My work is to contribute to a new boundary layer theory that describes offshore wind profiles.

How do you think NORCOWE can contribute to the development of offshore wind energy?
NORCOWE brings together researchers from various disciplines with the industrial partners. This gives a unique opportunity for all of the NORCOWE partners to exchange knowledge and experiences across different research areas. I think the collaborations between the different partners will highly contribute to the development of offshore wind energy!
Meet scientist Magnus B. Kjelland

**What is your scientific background?**
I have a master degree in mechatronics from the University of Agder as well as two years work experience in the company TTS Energy in Kristiansand. Currently, I am doing a PhD at the University of Agder on heave compensation techniques for offshore wind energy. In addition to the PhD position at UoA, I have a 20% position at Aker Solutions in Kristiansand in the hydraulics development department.

**Why have you selected that topic?**
I have always been interested in large mechatronic systems and the opportunity to work in the area of renewable energy appealed to me.

**What issue within offshore wind energy is addressed by your work?**
My work will contribute to an extension of the weather window for service personnel to gain access to bottom-fixed or floating offshore wind turbines.

**How do you think NORCOWE can contribute to the development of offshore wind energy?**
NORCOWE is a multi-disciplinary research centre with a wide range of expertise from meteorology to engineering. I think NORCOWE could make new contributions in the boundaries between these disciplines.

**Please give a brief description of your main research topic**
In order to increase the weather window for gaining access to an offshore wind turbine, new solutions and control structures for compensating the wave motion are developed. When a service vessel heaves several metres with the waves, a mechatronic machine using advanced control, hydraulics and mechanical structures can reduce the heave motion to within a few centimetres which will allow the service personnel to gain access to the turbine.
What is your scientific background?
In June 2011, I completed my master degree in meteorology at the University of Bergen. I have a bachelor degree in geography with minors in physics and atmospheric sciences from the University of Zurich, Switzerland.

Please give a brief description of your main research topic.
My master thesis, titled "Onshore Lidar Wind Profile Measurements at Utsira and their Benefit for Offshore Wind Turbine Design and Operation," was written in collaboration with Statoil as part of the NORSEWInD project. The study was aimed to support and extend the knowledge about the behavior of the marine atmospheric boundary layer and implement it in terms of wind energy relevant considerations. The study site was located on the Norwegian coast, close to Haugesund, where Statoil is testing the first floating offshore wind turbine, Hywind. In the study, a data set consisting of LIDAR wind profiles and meteorological mast measurements from onshore masts, an offshore buoy and the Hywind turbine itself has been analyzed.

Currently, I am working for Vestavind Offshore, who is building Norway’s first offshore wind park. It is my job to coordinate wind resource analyses and wind park simulation studies.

Why have you selected this topic?
I have always been fascinated by renewable energy sources and wind energy especially. Through my master studies at the Geophysical Institute in Bergen and due to the fact that the institute was a member of NORCOWE, I got the possibility to learn more about offshore wind energy. Offshore wind energy is a relatively young field with a great capacity to bring about change and development to the world’s increasing energy needs. It is very appealing to me being a part of this future oriented research and industry branch.

What issues within offshore wind energy is addressed by your work?
My current work addresses mainly challenges related to wind site assessment based on both measurement and model data. The results are used as inputs to the wind park design basis for Havsul and for energy estimation purposes. Coordinating projects run by external consultants is also a part of my work. I am also monitoring a project related to wind park simulations and subsequent power forecasting. Wind park simulations are essential in order to find an optimal park layout with purpose to reduce the cost of energy. A comprehensive and integrative power forecasting system is indispensable for wind parks in operational phase.

How do you think NORCOWE can contribute to the development of offshore wind energy?
During the last years, NORCOWE has built a very wide knowledge base within the field of offshore wind energy. The incorporation of research institutions and industrial partners allows combining industrial needs with research activities. The cooperation of the two parties contributes to an innovative way towards the realization of offshore wind energy projects in Norway and other countries.
Communication and public outreach

A communication plan for NORCOWE was made fall 2010 and implemented during 2011.

**Internal communication**
There has been a strong focus in NORCOWE in 2011 on improving the internal communication in the NORCOWE consortium. It has been an important goal to get all NORCOWE partners to participate in NORCOWE on a broad basis. **ProjectPlace** (online project tool) has been important to improve the internal communication and make it easy to share knowledge. More than 200 persons from the NORCOWE partners have now access to NORCOWE administrative and scientific information via ProjectPlace.

**Scientific meetings**
There have been three general scientific meetings in NORCOWE during 2011. Two of the meetings took place in Bergen (May and October) and one at Aalborg University in Ålborg. Between 60 and 100 persons from science and industry took part in the meetings.

**Public outreach**
Much work has been done in order to present scientific work from NORCOWE to the scientific community, the industry and to students. NORCOWE scientists have presented results from the centre at scientific meetings and conferences. NORCOWE organized a joint meeting with Arena NOW in Bergen 4th October 2011, in order to bridge the gap between science and industry. 100 persons attended the meeting, and two similar meetings are set up in Stavanger (25th April) and Bergen (19th September) this year. NORCOWE has also been presented to students at various occasions.

General public outreach has mostly been done via the website (www.norcowe.no) and presentations at exhibitions and conferences with a more general scope. NORCOWE’s website has been visited by more than 350 unique visitors a month. We see that NORCOWE become more known in the offshore community in Europe and North America.

There is a great interest among students and young people for offshore wind energy and more could be done in order to provide more information to students and pupils.

Work has been done to inform Norwegian governmental bodies like ministries and authorities and Norwegian political bodies.
International cooperation

It has been a goal to build up a good international network within the key topics of NORCOWE. We have focused on the North Sea Basin and USA so far.

The international cooperation is based on the researchers’ current network together with strategic work from the centre management in order to get formal collaboration agreements with selected institutions abroad.

Cooperation with Germany
NORCOWE has established good collaboration with leading offshore wind energy groups in Germany such as RAVE, ForWind and FINO. Scientists from NORCOWE have visited Germany during 2011. NORCOWE has established good contact with the operators of the German FINO platforms (Germanischer Lloyd, Forschungs und Entwicklungszentrum, Fachhochschule Kiel GmbH). Data from FINO 1 has been used by NORCOWE scientists in WP1 and WP5.

Professor Heinemann from University of Oldenburg is member of the NORCOWE’s external scientific committee. NORCOWE bought a scanning LIDAR from Leosphere in 2011, and cooperation is established with Universität Stuttgart on use of such LIDARs in wind farms.

CMR signed a MoU on behalf of NORCOWE with Fraunhofer IWES in November 2011.

Uni Research has got data from Fraunhofer IWES to be used in nowcasting tools, and increased exchange of data is a result of this agreement.

Cooperation with Denmark
Aalborg University (AAU) is partner in NORCOWE. AAU contributes to WP3 and WP4, and has a broad competence within wind energy that NORCOWE benefits from. Scientists from AAU have been speakers at Norwegian conferences and AAU has been involved in project proposals with NORCOWE partners. The board meeting in May and the work package meetings in December 2011 took place at AAU.

DTU Wind Energy (former Risø DTU) has been visited by staff from NORCOWE during 2011 and there are contacts with various research groups at DTU Wind Energy. There are several topics where it is beneficial to have collaboration between NORCOWE and DTU Wind Energy. A MoU between Risø DTU and NORCOWE was signed in June 2011.

Other European cooperation
The University of Agder (UoA) is a member of the “CBM network Europe” and has research collaborations with “Modal and Control Engineering, University of Girona, Spain and Department of Applied Mathematics, Polytechnical University of Catalonia, Spain.

UoA also cooperates with TU Delft in mechatronics. Research cooperation is established between UoS and VTT
Research, Finland, regarding work in WP3 in NORCOWE. NORCOWE has started to strengthen its network in UK. Professor Bill Leithead from University of Strathclyde is member of NORCOWE external scientific committee. UoS is currently in touch with a British company on potential cooperation on their VAWT activities.

Uni Research collaborates with Klaipeda University, Lithuania; Center for Coastal and Ocean Mapping, New Hampshire, USA; and Stockholm University, Sweden on environmental issues.

NORCOWE and NOWITECH were invited to participate at an informal “Workshop on national offshore R&D on offshore wind energy” 1st December in Amsterdam. The network of national research program is very useful, and a new informal meeting is scheduled in connection with the RAVE meeting in Bremerhaven in May.

**Cooperation with the United States of America**

There is cooperation with the National Center for Atmospheric Research (NCAR) and National Renewable Energy Laboratory (NREL). It is particularly focused on strengthening cooperation in the development of integrated mesoscale system. PhD student Anna Fitch stayed at NCAR for a long period in 2011. A MoU between NREL and NORCOWE was signed in March 2012.

It is established cooperation between the University of Bergen and Woods Hole Oceanographic Institution (WHOI) and University of Connecticut.

**Cooperation with the Japan**

Professor Tomoaki Utsunomiya from Kyoto University visited NORCOWE in October. He gave a presentation on “Current Status on Development of Floating Offshore Wind Turbine in Japan” on NORCOWE day 5th October.
Recruitment and education

All four universities within NORCOWE offer courses and master programs where offshore wind energy is in focus. A wide range of topics are covered by these universities, and new courses are being developed to meet the needs from the offshore wind industry.

There is a great interest among the students in renewable energy, and it is a goal to provide the offshore wind industry with skilled persons on master and PhD level. It is encouraging to see examples of good recruitment on master level, e.g. University of Stavanger has 11 students doing a master thesis on offshore wind topics this spring!

There are currently (March 2012) 15 PhD students and four post docs in NORCOWE. Recruitment of PhD students is difficult, and there is still an issue with gender equality. There are three women among the 19 PhD students and post docs.

From autumn term 2010 the Geophysical Institute, University of Bergen, is regularly offering a new 5 ECTS course in “Geophysics of Renewable Energy”. The main focus of the course has been set on sun (photovoltaics), wind and waves. The lectures are given in concentrated blocks, typically one week covering each of the addressed topics. The course is intended both for master and PhD students and interested employees from the industrial partners in NORCOWE.

Starting with the autumn term 2011 the corresponding course offer is extended by a module on offshore wind energy.
Appendix

Board and Committees

NORCOWE Executive Board (March 2012)

Dag T. Breistein (Vestavind Offshore), Chair
Frank Reichert (University of Agder)
Gudmund Olsen (Statoil)
Hans-Roar Sørheim (Christian Michelsen Research)
John Dalsgaard Sørensen (Aalborg University)
Jørgen Krokstad (Statkraft)
Lars Føsker (Aker Solutions)
Odd Henning Abrahamsen (Lyse Produksjon)
Per Skjerpe (University of Stavanger)
Svein Winther (Uni Research)
Øyvind Ottersen (Agder Energi)
Tone Ibenholt (Norges Forskningsråd), observer

Internal Scientific Committee

All research partners have one representative in the Internal Scientific Committee. In addition The Norwegian Meteorological Institute, as a sub vendor to Uni, and Statoil, as an industrial partner, has one representative each.

Peter M. Haugan (University of Bergen), Chair
Angus Graham (Uni Research)
Birgitte Furevik (The Norwegian Meteorological Institute)
Finn Gunnar Nielsen (Statoil)
Gard Hauge (StormGeo)
Geir Hovland (University of Agder)
Jasna Bogunovic Jakobsen (University of Stavanger)
Thomas Bak (Aalborg University)

Activity leaders in 2011 (above)

Trygve Skjold, WP4, (CMR GexCon)
Ivar Langen, WP3, (UoS)
Arnfinn Nergaard, WP2, (UoS)
Idar Barstad, WP1, (Uni Research)
Joachim Reuder, WP5, (UoB)

Committee for Innovation and Commercialization

Jan Pedersen (Agder Energi), Chair
Anne Marie Seterlund (Statkraft)
Gunnar Buvik (Vestavind Offshore)
Ivar Singstad (Innovasjon Norge)
Jostein Mælan (StormGeo)
Lars Føsker (Aker Solutions)
Ove T. Gudmestad (University of Stavanger)
Pia Pernille Weider (Lyse Produksjon)
Rolf Harsdal (National Oilwell Varco)
Steinar W. Tverlid (Statoil)
Trond Friisø (Origo Solutions)

International Scientific Committee (left picture)

Bill Leithead (University of Strathclyde, UK)
Peter M. Haugan (University of Bergen, Norway), Chair
Line Gulstad (Vestas, Denmark)
Trond Kvamsdal (SINTEF, Norway)
Solfrid Sætre Hjøllo (Institute of Marine Research, Norway)
Detlev Heinemann (University of Oldenburg, Germany)
## Scientific staff

### Key Researchers

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Main research area</th>
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<tr>
<td>Bak</td>
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<td>CFD Turbulence modelling, Atmospheric flow, High-performance computing</td>
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<td>Jenkins</td>
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<td>Air-sea interaction</td>
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<td>Environment assessment</td>
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<td>Beyer</td>
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<td>Energy meterology</td>
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<td>Hansen</td>
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<td>Marine Operations, Heave compensation and hydraulic systems</td>
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<td>Hovland</td>
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<td>Karimi</td>
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<td>Turbine control</td>
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<tr>
<td>Prinz</td>
<td>Univ of Agder</td>
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<tr>
<td>Tyapin</td>
<td>Ilya Russia/Australia</td>
<td>2011-2013</td>
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<td>Severson</td>
<td>Henning Norwegian</td>
<td>2011-2012</td>
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<tr>
<td>Kettle</td>
<td>Anthony British</td>
<td>2011-2015</td>
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<tr>
<td>Tabatabaipour</td>
<td>Seyedmojtaba Iranian</td>
<td>2011-2012</td>
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<td>Kostandyan</td>
<td>Erik Armenian</td>
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**Postdoctoral researchers**

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<tr>
<td>Fer</td>
<td>Ilker</td>
<td>Univ of Bergen, Geophysical Institute</td>
<td>Oceanic turbulence</td>
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<td>Haugan</td>
<td>Peter M.</td>
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<td>Oceanography and offshore wind energy</td>
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<td>Nielsen</td>
<td>Finn Gunnar</td>
<td>Univ of Bergen, Geophysical Institute</td>
<td>Offshore wind turbines, dynamic response</td>
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<td>Reuder</td>
<td>Joachim</td>
<td>Univ of Bergen, Geophysical Institute</td>
<td>Atmospheric boundary layer research</td>
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<td>Gudmestad</td>
<td>Ove T.</td>
<td>Univ of Stavanger</td>
<td>Marine operations, marine technology</td>
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<tr>
<td>Jakobsen</td>
<td>Jasna Bogunovic</td>
<td>Univ of Stavanger</td>
<td>Dynamic analysis of OWT, offshore structures</td>
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<tr>
<td>Langen</td>
<td>Ivar</td>
<td>Univ of Stavanger</td>
<td>Work package management, engineering mechanics</td>
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<td>Liyanage</td>
<td>Jayantha P.</td>
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<td>Asset management, operations and maintenance</td>
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<tr>
<td>Nergaard</td>
<td>Arnfinn</td>
<td>Univ of Stavanger</td>
<td>Design optimization, new concepts, design of floating OWT, subsea technology</td>
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<td>Snaebjornsson</td>
<td>Jonas Thor</td>
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**PhD students with financial support from the Centre budget**

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<td>Aarnes</td>
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<td>Oceanography</td>
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<tr>
<td>Paskyabi</td>
<td>Mostafa Bakhoday Iranian</td>
<td>Experimental characterization of turbulence in the the oceanic mixed layer</td>
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<tr>
<td>Christiansen</td>
<td>Sorens Danish</td>
<td>Control of floating wind turbine installation</td>
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### PhD students working on projects in the Centre with financial support from other sources

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<td>Bakka</td>
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<td>Norway</td>
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<td>Lene</td>
<td>UoS</td>
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<td>Flügge</td>
<td>Martin</td>
<td>UoB</td>
<td>German</td>
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<td>Kalvig</td>
<td>Siri M</td>
<td>NFR/StormGeo</td>
<td>Norwegian</td>
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<td>Krogseter</td>
<td>Olav</td>
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<td>Soleimanzadeh</td>
<td>Maryam</td>
<td>AAU</td>
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<td>Liu</td>
<td>Hongzhi</td>
<td>AAU/NORCOWE</td>
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### Master students, completed 2011

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<tr>
<td>Eugster</td>
<td>Andrea</td>
<td>Evaluation and interpretation of one year of lidar wind profiles from Utsira</td>
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<tr>
<td>Brusnet</td>
<td>Simon</td>
<td>Floating OWT concepts</td>
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<tr>
<td>Devold</td>
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<td>Hummel</td>
<td>Markus</td>
<td>Installation of OWT foundations</td>
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<tr>
<td>Mohamed</td>
<td>Abdisamed Abdillahi</td>
<td>FEM modelling of rotor blade</td>
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<td>Stølsmark</td>
<td>Rasmus</td>
<td>Dynamics of floating OWT</td>
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<tr>
<td>Ølund Byre</td>
<td>Andreas</td>
<td>Aerodynamics of wind turbine rotor</td>
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<tr>
<td>Myhre</td>
<td>André</td>
<td>Towing and installation of OWT</td>
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<tr>
<td>Andersen</td>
<td>Sarah Skovgaard</td>
<td>Probabilistic site characterisation based in Cone Penetration Tests</td>
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<tr>
<td>Lauridsen</td>
<td>Kristoffer</td>
<td>Probabilistic site characterisation based in Cone Penetration Tests</td>
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<tr>
<td>Diaz</td>
<td>Jose Luis Troya</td>
<td>Investigations of offshore mono piles subjected to long-term cyclic loading</td>
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### New master students 2011

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<tr>
<td>Haugland</td>
<td>Jan Kristian</td>
<td>University of Bergen</td>
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<td>Skauge</td>
<td>Stian Sanden</td>
<td>University of Bergen</td>
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<td>Amland</td>
<td>Thomas</td>
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<td>Gudmundsen</td>
<td>Gunnar-Martin</td>
<td>Univ of Stavanger</td>
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<td>Mirza</td>
<td>Delsher</td>
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<td>Stava</td>
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Publications and Reports

Journal Papers


Published/Accepted Conference Papers


Reports


Presentations and Posters

Presentations


Jenkins, A. D., Ocean wave effects on wind power production, EWEA OFFSHORE November 2011, Amsterdam.


**Posters**


Some of close to 50 participants who attended the Second Joint NORCOWE-NOWITECH Workshop on Wind and Wake Modelling, organized by GexCon on 20-21 October 2011.