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PREDICTION OF WAVES, WAKES AND OFFSHORE WIND – THE RESULTS OF THE POW'WOW PROJECT

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Abstract:

The POWWOW project (Prediction of Waves, Wakes and Offshore Wind, a EU Coordination Action) aimed to develop synergy in the fields of wind and wave predictions from short to resource timescales by integrating modelling approaches currently used by the communities separately. The project aimed to help these research communities by establishing virtual laboratories, offering specialised workshops, and setting up expert groups with large outreach in the mentioned fields. In this paper, the main results of POW'WOW are summarised.

Keywords: Wind resource, wave resource, offshore, short-term prediction, wakes

1 Introduction

The nearly finished EU Coordination Action POW'WOW (2005-2009) had three major tasks: to connect the mindset of researchers in the offshore energy meteorology field, working on wave and on wind modeling, to help with data for the development of models for wakes and short-term prediction, and to have a series of workshops for researchers and end users.
The two Virtual Laboratories (ViLabs) had quite opposite success: the ViLab for wakes had many users which downloaded short time series of large-scale wind farms, while the ViLab for short-term prediction of wind power did not received the attention expected despite large efforts on our part.
The workshops held by the project were largely seen as a success. There were 2 workshops on the integration of wind and wave resource calculations, 2 workshops on best practice in the use of short-term forecasting (yielding something like a wind power prediction user group), and one workshop on optimal use of information for wind power forecasting, a workshop on the special situation in short-term forecasting in Brazil and one on wake modelling. Additionally, a number of special sessions at conferences was held. The best-practice workshops actually turn into a series beyond the end of the project.
The third major activity was the position paper on wind and wave resource integration, partly an outflux of the workshops on the same topic.
The paper will shortly summarise all of those activities and deliver a list of references of the most important findings of the exercise.

2 The Virtual Laboratories

2.1 The Wakes ViLab

The aim of this task is to evaluate the state-of-the-art on wake modelling. The task emphasises models and evaluation results reported in the bibliography and from ongoing national or EU research projects. A major issue at present is that offshore resource and wake data (SCADA) is mainly commercial which can make further model development and evaluation difficult. Data from smaller wind farms such as Vindeby and Middelgrunden are available and have been provided. In order to address the problem of wake studies in large offshore wind farms the partners from the UpWind project have identified test cases and time series and data for Horns Rev have been made available. Case studies from Nysted are currently being processed. This Task will provide also documentation that is accessible through the Wake ViLab (see the dedicated paper to the topic in this conference: [1]). The availability of these data has been advertised at a number of international conferences and workshops e.g. the 2007 and 2008 European Wind Energy Conferences, the American Wind Energy Workshop on Wind

Resources 2008 (an invited presentation was given on the status of wakes research), the World Renewable Energy Congress, European Offshore Conference 2007 etc.

There are two related activities: the UpWind EC funded integrated project and the International Energy Agency Offshore Wind Energy wake model benchmarking initiative. Wake modelling is underway in UpWind. The wakes wiki will eventually be transferred to the IEA after the end of the POW'WOW project to ensure its continued growth and use. Planned joint activity has been somewhat hampered by changes in wind farm ownership. However it should be possible to provide some of the cases used in UpWind to the POW'WOW wakes wiki.

2.2 The Short-term Prediction ViLab

The idea of the Virtual Laboratory for short-term prediction is in part, to take some of the cumbersome work of data acquisition out of the research projects themselves and put it here, and in part to have common evaluation criteria and common evaluations of the work, being able to compare one's own research with a number of leading models in the field. This idea is somewhat modelled after two very successful efforts, one being winddata.com and the other one the Anemos case studies and benchmarking process.

Since October 2007, the ViLab was operational. After many discussions with the data owners, only two test cases were available: the wind farm at Klim in Denmark, and the offshore wind farm at Middelgrunden. Hopes to include a case in Spain in complex terrain did not materialise, despite otherwise good contacts with the wind farm owner. An invitation has been made to some prominent short-term prediction modellers outside the Anemos group, and an open call was published as a Cut-In Note in the journal Wind Engineering [2]. After many invitations to collaborate, only two groups eventually accepted our offer. One reported their results in a poster at this conference [3]. We expected a much larger turnout.

2.3 Comparison of the two ViLabs.

It is clear that the short-term prediction ViLab did not receive the same attention as the ViLab for the wake cases. Informal talks with some of the declining companies led us to assume that this is due to one of the following reasons (not necessarily in order of importance):

- Lack of resources for pure science. This is certainly true for the large companies, which have a hard time to justify spending time and effort on "pure science" in a competitive market environment.
- Lack of trust in the competitors in the market to administer the results according to the signed non-disclosure agreements.
- Lack of need to show that wind power forecasting is useful. This was different at the time of the AEE exercise, and at the time of writing the proposal, but the market for short-term prediction services matured very quickly after the Spanish Royal Decree mandating prediction, and after the strong commercialisation of the market in Germany.
- Lack of funding for participants. French developer Maïa Eolis had a similar exercise in parallel [4], but funded participants and promised a larger contract at the end, and eventually were able to compare six forecasting tools.
- Lack of a clear benefit for participating companies. For a large and established wind power forecaster, to be in line with the results or slightly better is just something the clients will expect, but if for some reason or other, the quality of the reference models is not achieved, the reputation could be tarnished (assuming that there would be leaks in the secrecy assured).

Those reasons are mostly valid for established forecasting companies. For universities, most of the arguments do not apply, and often, newcomers suffer from lack of available data to work with. Therefore, it is quite surprising that so few universities have taken advantage of the ViLab. The reasons for this are unclear.

In conclusion, a major reason for the lack of success of the STP ViLab is that wind energy forecasting is a relatively mature area. This implies that companies offering the services are already in the market and there was no need to demonstrate the predictions. If we compare the exercise that the Spanish Wind Energy Association (AEE) did four years ago with POW'WOW ViLab, the main difference is that in 2005 the forecasting market in Spain was not developed and there was a need to show what was possible to achieve with state of the art prediction models in order to activate commercial projects. However, nowadays experienced companies working in forecasting didn't see the benefit of comparing their products with the competence.

Wake models in contrast are still in a development phase, especially in offshore environment. This initial status of the advanced wake models makes interesting to show the benefits of the new advanced methods compared

to the traditional models. This is especially true for offshore wind farms, where experimental data show the limitations of the traditional wake models.

3 The Workshops

The idea behind the workshops was to organize dedicated platforms for exchange in very specific fields of science. Not all workshops had the same success, but most were appreciated by typically some 30 participants, mostly experts in their respective fields. One workshop, the one on Best Practice, even will survive as a series beyond the end of the project.

3.1 Integration of the Offshore Wind and Wave Resource Calculations

The calculation of the offshore wind resource is carried out along well established methodologies using all types of available data: in-situ and remote sensed data and the results of meteorological modeling. For wave energy the same data types are used, but the experience has been more limited because the technology has not entered into commercial stage yet. The first workshop was organized together with the 7EWTEC (7th European Wave and Tidal Energy Conference) in Porto, Portugal, September 9, 2007 and attracted about 30 participants, many coming from wave energy sector. The contributions focused mostly on data and methods used in the wind and wave assessments. The second workshop was organized after the EWEC 2009 (Marseille, March 20) but this conference participants did not showed so much interest as happened with the previous one. However, preliminary work on joint assessment of offshore wind and wave resource assessment was presented and discussed.

3.2 Best Practice in the Use of Short-term Forecasting

With increasing wind power penetration in a transmission system or power market, utilities and TSOs typically first try to ignore wind, then get afraid that wind might be different leading to a stop of wind power, and lastly get to grips with it. To help utilities and TSOs to get over the hurdle, a workshop was organized on October 25, 2006, in Delft (The Netherlands), with the explicit aim of delivering a platform for those in the utility world having plenty of experience with short-term forecasting to share experiences and tricks among themselves and with low penetration ones. The workshop mailing and attendance list essentially a “short-term prediction user group”. The talks are available from the event website *powwow.risoe.dk/BestPracticeWorkshop.htm*. A second workshop was held in conjunction with the *7th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Farms* in Madrid, Spain, on May 28, 2008. Among both workshop speakers were about one-third TSOs, traders or balance responsibles, and academia or meteorologists. Some travel grants, especially for researchers or utility personnel from non-OECD countries, were available, and were used by people from Tunisia and Egypt. The experiences gathered here will be used as input for a Best Practice Guide (see chapter 4.4), to be published by the POW'WOW project. A major outcome was that every countries challenges are quite specific, so every TSO or trader has to develop their own algorithms of how to deal with wind power in general and wind power predictions in specifics.

The great success of the two first workshops means that the series will continue also after the end of the project. The next workshop will be on October 13, 2009, in Bremen (Germany), in conjunction with the 8th edition of the above workshop.

Energy & meteo systems organised a one-day workshop on the “Grid integration of wind energy” in co-operation with a professional conference organizer “Haus der Technik”. The workshop was held in Hannover, Germany, on 26 Feb 2007. This workshop followed the more general topic “Best practice in wind power prediction” compared to the originally proposed dispatcher workshop. It turned out that the interest of the grid operators, energy traders and wind farm operators lies in general information on the state-of-the-art of wind energy integration and forecasting. The invited speakers came from one German TSO and the Dutch grid operator, traders and the largest wind farm operator in Germany. The workshop had more than 50 participants coming from a wide spectrum of the wind energy industry and research institutes who rated the workshop as very good and informative.

3.3 Wakes

The wakes of wind turbines markedly influence the annual wind power production of the wind farms and loads on the rotor blades. The power deficits behind single or multiple wake are observed to be of the same order of magnitude and larger for higher ambient turbulence intensity.

The wakes interaction characteristics and evolution information within wind farms is required to manage and optimize power production of large wind farms. The techniques being presently pursued to control the power production within the wind farms is through the adjustment the pitch of the blade reducing momentum transfer or yawing of the turbine to deflect the wake. The loads due to partial wakes or yawing must be well captured in the simulations for reliability of future applications.
The currently planned enormous growth of the offshore wind power will result in densely concentrated wind parks; each with a very large number of wind turbines. The wakes of wind parks are expected to strongly influence the wind parks downstream. The regional weather may be affected by large scale additional mixing in the atmospheric boundary layer. The wake measurements and models currently under development should be able to provide reasonable estimates of these effects.
At the wake workshop organised by ForWind in Oldenburg on June 30 to July 2, 2008, four open sessions discussed the demands on measurements, the demands on modelling, best practice in wake modelling and how a benchmarking exercise for wakes could look like. The slides are available from the event website (*http://www.forwind.de/events/index.php?article_id=43&clang=*).

3.4 Optimal Use of Information (with IEA)

A combined IEA/POW'WOW workshop on the Optimal Use of Information in Short-term Forecasting was held in Madrid September 11/12. It was a successful meeting with 26 participants, mainly from forecasters around the world, with a few end users in between.

The main interest of the meeting was the exchange of experiences of the participants, with different regulatory conditions for each country and different levels of application of wind energy forecasting.
During the meeting there were discussions about the topics that were identified as interesting during the first day presentations of the participants.

Wind energy forecasting has had a rapid evolution during the last years, from the technical point of view and also from the point of view of its implementation. Actually we can see that wind forecasting models are used operationally in some countries and the tendency is to increase the use of wind power forecasting to manage grids, trade in the market, maintenance, etc.

End users of the forecasts explained what their needs are and the conditions to use wind forecasts in their environment. The circumstances and needs of the users can be very different depending on the country, area of interest etc; it was mentioned that another workshop with end users should be considered in order to better understand the different scenarios and their priorities regarding the use of wind predictions. The users present at the meeting remarked the interest of focusing on extreme events and specifically on ramp forecasting.

The value of the wind forecasts depends on several factors like the characteristics of the system, the way the system is operated, regulations, climatic conditions, etc. Some studies points to the conclusion that improvements in the accuracy of the forecasting do not have an impact in the management of the system; this studies should be extended to extreme events (where the value of a single event can be enormous) and to other systems with different operational conditions.

The value of some extreme events can be catastrophic and would justify investing resources in good forecasts for those rare events. Security of supply is a priority for any system; this objective has to be achieved taking into account the influence of wind energy especially for high penetration situations. Up to now forecast models are usually tuned to produce the best possible forecasts in average conditions (minimising average errors), but not for extreme events. There is a clear need of better forecasts of potentially dangerous events like large and quick variations in wind power production. The information needed for extreme event forecasting and decision taking can be different than the one needed for normal conditions operation (i.e. higher temporal resolution of forecasts and warnings). A number of projects are developing now in the meteorological community to implement extreme events forecasts and warnings not specifically for wind energy but as a general service to the society; there should be a closer collaboration between meteorologists, wind energy forecasters and end users of wind predictions to take advantage of the new developments coming from the meteorology.

On the other hand the end users want to know where the limits of the predictions are. Is there a limit of the forecasts accuracy for a wind farm?

Before investing resources in improvements it should be known how far we are from the limits and, therefore, the margin for improvement that can be achieved.

Under operational conditions in system operation environment, the typical situation is that the persons taking decisions involving wind energy do not use optimally the information coming from the forecasting models. There is a gap between the forecasters and the users of the forecasts, especially when new information is produced (like probabilistic forecasting).
There is a consensus about the interest of reducing errors and uncertainties, especially under extreme conditions. A better identification of extreme events causing an important impact is needed.
Workshops having wind energy forecasters, meteorologists and the end users of the forecasts are needed to improve the quality of the forecasts, and also to improve the processes of decision, involving wind energy management and integration in the electricity system. It was also mentioned that it is difficult to attract end users to these events, especially TSOs and large utilities.

3.5 Meteorological Aspects of STP

A main issue in power production and energy management today is the accurate prediction of the local environmental conditions at the area of interest. In particular, wind speed and direction for wind power plants and wave parameters for off-shore platforms are crucial for the estimation of the corresponding energy potential.

The main tool for such predictions is the use of Numerical Weather and Wave prediction models that simulate successfully the general weather conditions providing wind and wave forecasts even for five or seven days ahead.

Such models have been successfully applied by several operational centers and research groups to different regions and for long forecasting periods. In most of the cases the forecasts describe successfully the general weather and wave conditions. However, discrepancies emerge when focusing on very local weather characteristics.

These activities as well as the general issue of forecast improvement for power applications were one of the main subjects of the POW'WOW project. Within this framework the Institute of Accelerating Systems and Applications of the University of Athens organized a workshop in Athens on February 2009. The main objective was to review and discuss the best methodologies for utilizing Numerical Weather and Wave Prediction on Energy Prediction - Short and Long Range - as well as to bring together researchers from Universities and Institutes with people from the Industry.

A number of participants from different countries and institutes (CEZ Obnovitelné, Czech Republic; Risø-DTU, Denmark; IASA-University of Athens, Greece; CENER, Spain; Met Office, U.K.; Atmospheric, Meteorological, and Environmental Technologies, Boulder, Colorado, U.S.A.) contributed with new ideas as well as operational experience that cover the subject in study by different points of view.

3.6 Short-term Prediction in Brazil

After the integration of the Universidade Federal de Pernambuco as Brazilian partner, it was deemed useful to hold a workshop in Brazil on the specific situation there in the field of short-term forecasting. Gregor Giebel of DTU.Risoe and Pierre Pinson of DTU.IMM were reporting of the European experience on June 12/13, Natal. There were about 30 attendants from various sectors of the Brazilian academia and electrical utilities. As a main result, a letter was drafted to the ministry, explaining that the current situation was untenable in the longer run and that forecasting would need to be handled at a different level. The slides are on the event homepage (*http://powwow.risoe.dk/STPWorkshopBrazil.htm*).

3.7 Special sessions at EGU

The European Geosciences Union General Assembly is a yearly major event aiming to present the activity of basic and applied research in Europe in all geo-related fields. EGU has a large participation of scientist usually also attending sessions beyond their research activity or willing to explore field for application of their research. One of the group programme Energy, Resources and the Environment (ERE) includes the ERE1 Wind Power Meteorology session. In 2007 and 2008 special sessions for the POW'WOW project were organised, addressing offshore wind resources and three member of POW'WOW acted as Co-conveners. The sessions were well attended with respect to the previous years. The contributions to the sessions in 2007 and 2008 included a POW'WOW Poster. In 2007, the lecture "Offshore wind resource assessment in European Seas, state-of-the-art. A survey within the FP6 POWWOW Coordination Action Project" opened the ERE1 session.

4 The Position Papers

4.1 Integration of Offshore Wind and Wake Resource Calculation

A position paper [6] was produced after comments by the Expert Group on Offshore Meteorology set up within POW'WOW. This paper will be updated and the revised version is planned to be submitted for publication in a scientific journal.

4.2 Wake estimation in Short-Term Prediction

Historically, wake losses in wind farms were estimated on-land for small wind farms comprising few turbines. On land, the turbulence brought into the atmosphere by the surface is much larger than offshore, which is why wakes persist much longer behind offshore turbines. Those wakes and wake decay are predicted with reasonable accuracy for small wind farms both on- and offshore. However, offshore the potential farm size is much larger, and turbine generated turbulence also has to be accounted for. Current models appear to under-predict wake losses in large offshore wind farms. New models have been proposed recently to address those problems: STORPARK, which links the wake model to the overlying boundary-layer and in GarradHassan's commercial software Windfarmer additional roughness has been proposed as a modification. First simulations are being undertaken for offshore wind farms using CFD within the UPWIND project.

Wake models usually are used for resource estimation, not for short-term forecasting. The report [7] should outline the current state-of-the-art in offshore wake modeling, assess the potential to use those models in short-term prediction models, and outline future research directions to address the deficiencies in the current wake descriptions.

4.3 Methodologies for Offshore Wind Energy Assessment in European Seas

This paper [1] has been solicited by the journal Survey in Geophysics that has education and outreach policy. Wind resource assessment process has been conceptualized as a two-phase activity, *i)* an evaluation of wind resources at the regional scale to locate promising wind farm sites and *ii)* a site specific evaluation of wind climatology and vertical profiles of wind and atmospheric turbulence together with an assessment of historical and possibly future changes due to climate non-stationarity. Pros and cons of different methodologies have also been indicated. Current methodologies for undertaking all aspects of the resource assessment procedures have been reviewed.

4.4 Best Practice in the Use of STP

Based on the experiences of the first workshop on Best Practice, a paper was shown at the EWEC in Milano [8]. The Best Practice in the use of short-term forecasting of wind power can be summarised as:

•Get a model

•Get another model (NWP and / or short-term forecasting model)

•Balance all errors together, not just wind

•Use the uncertainty / pdf

•Use intraday trading

•Use longer forecasts for maintenance planning

•Meteorological training for the operators

•Meteorological hotline for special cases

The paper will be updated with the results of the second workshop before the end of the project.

6 Conclusions

The POW'WOW project improved or tried to improve the life of researchers in offshore energy, wakes, and short-term prediction of wind power. Most of the activities were received well, some were not as much sought after as initially envisaged (the short-term prediction ViLab comes to mind here). Some reviews have been produced, and some workshops held. The results of the workshops are usually referenced on the project website, powwow.risoe.dk.

In addition to the fields mentioned above, two expert groups for waves and for short-term prediction were formed, mainly from within the consortium, and an effort for the extension of the IEC standard for wind turbine communication (IEC 61400-25 and the similar IEC 61850 for distributed energy resources) with forecast data is underway.

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