POW WOW A coordination Action on the prediction of Waves, Wakes and offshore wind

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Abstract

This paper describes a new project trying to harmonise approaches to wave and wind modelling offshore, helping the short-term forecasting and wake research communities by establishing virtual laboratories, offering specialised workshops, and setting up expert groups with large outreach in the mentioned fields.
Currently, a good number of research projects is underway on the European and national level in the fields of short-term forecasting of wind power, offshore wind and wave resource prediction, and offshore wakes in large wind farms. The purpose of this Action is to co-ordinate the activities in these related fields, to spread the knowledge gained from these projects among the partners and colleagues, and to start work on some roadmaps for the future. Therefore, the leaders of research projects are assuming the function of a multiplier towards the larger research and user community. Additionally, in the fields of short-term forecasting and offshore energy resource, Expert Groups will be formed to act as the central focus point for external stakeholders. The liaison with other groups will also include groups outside of Europe.
To facilitate the spread of knowledge, a number of workshops are planned, being smaller and more focused on their topics than the usual conferences.
One issue hampering the progress in our fields is the difficulty of getting access to good data. In most cases, data on offshore wind or power is strictly confidential, and also data on onshore wind power, especially in conjunction with numerical weather predictions, is not easy to come by. One example of a good testing procedure comes from the Anemos project, where in all 6 test cases were defined, to be run by all involved institutes. This idea is taken to the next level with the set-up of two Virtual Laboratories, one for offshore wake modelling, the other one for short-term forecasting.
Two guides on best practices will be written, one on short-term forecasting (bringing the experiences of high wind penetration countries to those with little wind power) and one for wake modelling.
In the end, this Coordination Action will also support preparation of next actions such as a Network of Excellence or an Integrated Project, connecting many additional partners within the European Research Area. The project is funded by the European Commission.

Introduction

Climate change is related to the way we generate electricity. As part of the Kyoto effort to reduce the emissions of greenhouse gases, the European Union has an overall target of 12% of energy (22% electricity) from renewables by 2010.
Wind energy is the fastest growing renewable energy source in the European Union. By 2005 more than 40,000 MW of wind energy capacity had been installed in Europe (600 MW offshore). The wave resource in European waters is even larger (120-190 TWh/year (offshore) and 34 - 46 TWh/year (nearshore)) than the wind resource. Yet, despite many research efforts from the 1970's onwards, relatively little installed capacity exists although prototypes have been developed in many countries. The POW'WOW project seeks to integrate further the wind and wave energy communities to maximise the research effort on resource assessment and utilise expertise from wind energy short-term forecasting, and wave energy resource assessment for optimal planning and operation of offshore energy technology.

The Situation

In many countries in Europe, most of the good wind sites on land are already taken, so the large expansion needed to reach the EU target of 12% of renewable energy has to take place offshore using both wind and wave energy. Optimal financing depends on both an accurate resource assessment and an accurate forecast several days in advance. A typical wind resource assessment is only accurate of the order ± 5%. Wind turbine wakes, and multiple wakes in particular, are the major source of uncertainty in power output once an accurate forecast of the long-term wind speed is obtained.
Energy utilities have used short-term forecasting of wind power (short-term being defined as 0 hours to a few days) for their power plant scheduling and for trading since practical tools became available, and some utilities could not keep their grid stable if not for the existing tools.
Ocean waves are generated by winds blowing over the ocean surface for long periods of time (the order of days) and long fetches. Taking as input the wind field over an ocean basin (or the whole globe), wind-wave models provide numerical solutions of the equations that describe the physical processes that govern the evolution of the wave field. As the first wave power devices are installed, the prediction of waves is getting renewed attention.
Research in short-term forecasting of wind power has traditionally been focused on the economy of wind power. Likewise, the wind and wave resource meteorology was concerned with the bankability of new installations, and therefore trying not only to give the best possible guess for the resource at a given site, but also to shrink the boundaries of uncertainty of the forecast. All these are areas where a better understanding of the offshore wind flow will translate directly into better bankability of wind and wave power projects. Therefore, this project tries to integrate the different backgrounds and approaches of researchers across various fields of offshore meteorology.
Here we focus on integrating model developments from existing and previous projects on wind and wave energy in order to maximise the benefits of this research. An innovation here is the use of the Virtual Laboratory to facilitate model comparisons based on meteorological data. We will need to consider interfacing of wind and wave models and the benefits of using an integrated model approach rather than the two quite different approaches that are currently used by these communities (wind and wave). We will also bridge the different mindsets between resource (long-term) forecasting which is used mainly for project planning and financing and short-term forecasting which is necessary is order to optimise prices obtained for electricity in the liberalised electricity

market. An additional component, which is thought to be the largest single correction necessary for power forecasts from large offshore wind farms after resource prediction, is for wind turbine wakes. These are currently estimated as ~10% on average and clearly can have a significant impact on power production at both long and short timescales. Coordination of these modelling activities will be based on studies of existing models and workshops that should lead to a more harmonised approach that builds on the state of the art in the various fields. An additional study will focus on the uncertainties in the predictions, how these arise and how they can be minimised. Finally we will also consider the combined effects of wind and waves on power output and loads – likely leading to proposals for new research in topology optimisation for offshore wind farms and for wave energy devices.

A successful project would benefit renewable energies in various ways: by reducing the uncertainty in the wind or wave resource before siting of the constructions, by better distributing knowledge of wakes for the optimisation of the wind farm layouts (both within a farm and between clusters), and by helping utilities accept more wind power in their grids through better usage of the existing short-term forecasting tools. This would help wind and wave power to attain a larger percentage of the generation in Europe, thereby improving air quality, reducing dependence on foreign fossil fuel imports, and by creating employment in the offshore wind and wave sector.

Existing Projects

Large scale mapping of the offshore wind resource was addressed by a number of European Union supported projects, e.g. 'A study of offshore wind in the EC' (Garrad et al. 1993) and 'Predicting Offshore Wind Energy Resources' (Watson et al. 2000). However, for wind energy developments better methods at the site level are needed. These now have to be integrated with power losses from wakes. Although single wake models were improved during the ENDOW project (Barthelmie et al. 2002), (Rados et al. 2002), (Schlez et al. 2002) there is significant discrepancy for multiple wakes and conditions deviating from moderate wind and turbulence.

One large European research project (Anemos) (Karinokatis et al. 2004) is currently running in the short-term forecasting arena, and many previous projects addressed wind and wave resource prediction. The main research partners in Anemos would like to coordinate their actions with the other teams in Europe and world-wide. Together with non-Anemos partner ISET, they forecast operationally for a large part of the wind power capacity installed in Europe (and thereby, world-wide). The group co-ordinates a lot of national projects, and sells their forecasting systems, thereby having the direct contact and feedback from users (mainly utilities). They also work in close contact with the meteorological institutes which provide input for the models. Please note that the meteorological input is the largest source of error in most cases.

The POW'WOW project

POW'WOW will focus on improving both wind and wave predictions from short-to-resource timescales by integrating modelling approaches currently used by the communities separately. We will not undertake model development but rather coordinate results from existing and previous projects and disseminate information about state of the art in the different fields. The major issue is to try to bridge the gaps in spatial and temporal scales, which currently divide the wind and wave resource and the short-term forecasting modellers. This will happen mostly on a workshop, tentatively scheduled for winter or spring 2008 in Oldenburg.

While wind energy resource predictions are typically made at the site level with linearised models or statistical methods, wave energy predictions are more likely to be large scale based on numerical models (physical methods). Clearly though the physical links between wind and waves (heat and momentum transfer) exist and we will need to work with weather forecasters also to complete a thorough review of the methods used and how these can be better integrated. In addition to organising an offshore meteorology workshop we will establish and extend the expert group by organising a scientific session at a European conference (likely the European Geophysical Union annual conference). Uncertainty is a key factor in wind farm financing and the inventory made as part of the review will used to identify areas for future research. The major benefits will better integration of modelling approaches for resource prediction and a more harmonised approach.

The project will link between networks funded by the EU including Wavenet, WindEng and others which do not focus on the resource, such as CA Ocean Energy and COD (CA on Offshore Wind Development). It will utilize also elements from other EU funded projects like ENVIWAVE.

The core of the short-term prediction work package is to support research by helping with development of the models by furnishing a Virtual Laboratory, where other modellers can try their models on the same footing with everyone else, using identical data. Additionally, we will enhance the outreach of the short-term forecasting community through the set-up of an Expert Group for short-term forecasting, trying to work closely together with the Commission and other European and world-wide stakeholders. Resources are earmarked for visits to interested parties to disseminate the state of the art in short-term forecasting in Europe. This group also is to co-ordinate and disseminate results obtained in national projects, to try to avoid overlap of effort, but also to make sure that all researchers in the field are aware of the latest developments and research results. This includes evaluation of the input data for models, not only trying to disseminate the latest efforts within the meteorological community to the modellers, but also by sensitising the meteorological community to the higher accuracy demand of this particular customer of their data. At the other end of the data flow, the use of short-term predictions on the clients' side can be improved upon by establishing some guidelines of best practice in their use. These practices will first be devised in close conjunction with current users of predictions, and then will be distributed to a larger audience through training courses and a separate workshop, and dissemination activities on conventional energy conferences and in power industry journals. This would have the side benefit that utilities with low exposure to wind power will be able to work constructively with wind, and not completely reject wind power on grid stability grounds.

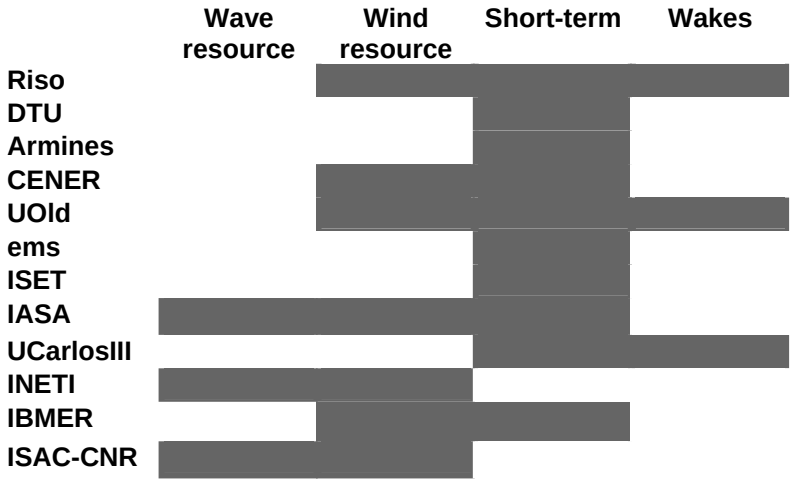
A major issue here is not just the long-term forecasting of average wakes which is used for initial estimates of power output from wind farms (mainly for planning and financing) but also the online prediction of wakes that links with short-term forecasts of power output from wind farms. The current approach is mainly a sector (wind direction)/wind speed prediction of wake losses in the form of a lookup table. However, given the complexity of wake losses within wind farms including wake turning within the wind farm this approach is likely inadequate. Introducing online wake models adds a degree of complexity and many wake models (CFD type) are likely too computationally intensive to be considered. Scientists and engineers will work together to consider how short-term forecasting and wake modelling can be operationalised. The work will take the form of wake case studies via a Virtual Laboratory, an open workshop for scientists and engineers and finally a set of guidelines for best practise in including wake models in short-term forecasts.

The Consortium

The group consists of some of Europe's major research leaders in their respective fields. The current Anemos project in the case of short-term prediction already links a substantial part together, in conjunction with utilities (*ie*, end users) and numerical weather prediction providers. Offshore wind resource is covered by partners active in this field linking research and commercial activity that gives insight into the requirements of wind resources requirements from developers together with the state of the art in the field. Two of the partners were involved in the first comparison of wind turbine wake models for use offshore and are active in the development and evaluation of wake models. Wave energy resource modelling is also covered by three partners working in different aspects of the field. However the reach of the project partners is considerably wider since they are project coordinators or partners in most of the current EU research projects covering wind, wave and short-term prediction in addition to national and international projects as listed below.
The end users are identified as wind and wave energy developers and the energy utility sector and other energy market actors. The projects being coordinated have a number of highly qualified end users integrated in them, who we will approach for relevant guidance. Also, the utilities/energy market actors will be integrated into the project through the workshops/training held specifically for them. In order to translate the project results into useable results for developers, the methods and models used have to be standardised and compared as outlined in the work packages and a major benefit will be quantification of uncertainties. All end users will be encouraged to join the workshops within the project, to learn more about the state-of-the-art in the various fields.

Since the actions identified build on and complement existing research projects, the partners have a strong commitment to consolidation of the state of the art and disseminating the results.

Main expertise of the partners:



As shown above the major expertise and effort is in linking short-term prediction to wakes and wave and wind resource modelling. Relatively few wake groups are needed because the project does not include model development – rather utilising state of the art models and working with short-term prediction modellers to improve wake modelling on short-term forecasts. Another major difference which will be explored is the development in wind energy resource (long-term) predictions away from atlases and similar large scale resource studies to focus on the needs of developers i.e. site specific

wind speeds and long-term power output forecasts. This results in a different approach to wind resource assessment than is typically used in wave resource work – despite the obvious links through boundary-layer meteorology in these fields. Wave modellers tend to use more physical models applied at quite low resolution in order to produce wave atlases for large areas. Wind resource modellers tend to use statistical or linearised models for site specific wind speeds. Fundamentally we understand that the processes are linked and we expect to benefit from considering how wind and wave resource modelling can be better integrated. In addition our coverage of all European seas (except the Black Sea) will allow exploration of the importance of different processes and methods. This complementarity of experience and expertise is the strength of this project.

Planned Work

The strategy of the workplan is based on:

- utilising and integrating existing experience (technical and management) from existing and former projects both EU funded and national
- drawing together experts from multi-disciplinary fields – here the focus is not the scientific content but rather that there are many approaches to the same tasks which have traditionally been utilised in different fields. This is evident from the sectors of research where weather forecasters, short-term prediction experts and wine/wave resource analysts have tended to work separately with goals based on different end-user communities. Our project will try to integrate these approaches in order that best practise from different fields is integrated and the improvements in state of the art modelling can be harmonised across these sub-sets of offshore meteorology
- activities which define best practise, integrate existing results and disseminate these across the different scientific and engineering communities
- dissemination within the project but more importantly to non-traditional end-users
- including all areas of the European Union including the new and accession states

In a practical context the work proposed is based on:

- setting up of expert groups
- reviews of existing projects and results
- integration of results across sub-sets of the same disciplines
- set-up of Virtual Laboratories to facilitate benchmarking of models
- workshops to discuss integration and to disseminate results beyond the project

Ultimately the goal of the project is to ensure successful and economic development of wind and wave energy within the European community by increasing the accuracy and reliability of power forecasts at different timescales. The success of the project relies on the integration of a group of international experts furthering their cooperation and disseminating their results both through the strategy outlined in the management and dissemination work packages, but also through existing and future projects.
In the fields treated within this project, scientists (the "middle man") connect the input from the meteorological community with the needs and requirements from the end users (investors, developers and utilities). While the end users are somewhat diverse in our case, the input is similar: meteorological data. However, the way that input is treated is quite different from case to case. Here, having different approaches and mindsets yields the potential to learn from each other. This learning process is central for the project.

Another quite important step for the project is the removal of barriers for the larger scale implementation of our techniques, and of renewable energies in general. Some of these barriers are more technical, like the relatively high uncertainty in the offshore wind resource estimation due to limited knowledge of the wind flows offshore, some are more a mindset, like the perceived lack of usefulness of short-term forecasts to utilities due to the limited accuracy obtainable. The technical barriers will benefit indirectly from the project, by connecting existing knowledge and co-ordinating the acquisition of new knowledge. The non-technical barriers can be tackled more directly, aiming for example directly at utilities with low penetration of wind power to convince them of the good experiences high-penetration utilities have made with short-term forecasting. One barrier for technical development is the lack of good quality comparison data, on which to hone the models. This will be taken care of by the establishment of two Virtual Laboratories, one for short-term forecasting, the other one for wakes. The idea here 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 the best (and worst) 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. In winddata.com, quality checked measurement campaigns (of usually short duration) were put into a central repository in a common data format, so that institutes that have signed up to it can download the data and use it. The data spans 165000 hours from 57 sites, and is used for many different purposes ranging from resource assessment (the data of the Horns Rev meteorological mast is there) to structural high-resolution measurements on actual wind turbines for load cases. The other case to model it on is the Anemos benchmarking exercise, where in all 11 different models were fed with the same NWP data for 6 wind farms in Europe. One institute (CENER) did the common evaluation, and presented the results in London on the EWEC conference in November 2004 (Marti, 2004). One important part for this was the development of a common evaluation procedure and common evaluation criteria, which IMM led. The details of access to data, the potential worries of the data owners (wind turbine data and NWP) against making their data public, and the exact demands to publication from ViLab participants will have to be decided during the set-up of the ViLab.

Wind Resource Model Benchmarking

Although there is significant experience in offshore wind and wave resource modelling in the European arena, the increase in expertise has been more than matched by a demand from financing institutions for accuracy and quantified uncertainty in resource predictions for new wind and wave power plants. The work will focus on a study of methods for quantifying uncertainty and in identifying areas where increased resources for research would bring pay-back in terms of reduced uncertainties in resource/power prediction. Here, we will focus on the exchange and dissemination of good practice to reduce uncertainty in resource modelling. In wind energy there are two fundamental approaches to offshore resource modelling: one is physical modelling (e.g. linearised models such as WAsP, mesoscale models such as MC2, KAMM, MM5, WRF, SKIRON/Eta, RAMS), and the other one is stochastic/statistical, such as one of the several variants of a Measure-Correlate-Predict technique, or Kalman filtering. Although these are commonly used for prediction from onshore data to offshore resource, there are two major issues, which have not yet been addressed. One is that in the near-coastal zone (of the order <50 km to the coast where all current offshore wind farms are at present planned/installed) the underlying assumption of equilibrium conditions is violated leading to over-prediction of the resource. The second is the MCP methods tend

to under-predict the offshore wind resource because they do not account for the shift in the wind speed distribution in offshore areas. For both issues, advanced downscaling techniques in operational numerical weather prediction modelling can be applied – thanks to cheap computer power available today (RAMS modelling can be operational with grid spacing of a few hundred or tens of meters). Benchmarking will utilise the most common approaches and attempt to identify what the uncertainties are associated with each method: how they are propagated through the methods, where they are largest and where they might be reduced. The benchmarking activities will be supported technically by the Virtual Laboratory (ViLab) developed in WP-2 and 3. Wave analysis and forecasting is a must for both systems (offshore wind farming or wave energy utilization), especially in the coastal zone (<50 km). Wave modelling together with the utilization of satellite data (ASAR and RA-2) is a new technique that developed at the framework of ENVIWAVE project with promising results. The utilization of the integrated system developed at the framework of this project (SKIRON/Eta and/or RAMS atmospheric models coupled with the WAM –wave analysis and forecasting - model and the assimilation of altimeter and wave spectra data) will be exploited for energy production.
In wave energy, the accuracy of wave forecasts using data assimilation (buoys and remote sensed data) is very good. This accuracy is now limited by the quality of the input wind fields at the ocean surface; therefore, the improvement of wind fields over the ocean basins will result in better quality of the predicted offshore wave conditions. In the coastal area within the 50m+ water depth, where offshore wave power plants are deployed, the most important source of spatial variability is shelter by the coastline and/or the presence of islands. Enhanced prediction of plant performance in general requires further development of mathematical models. Short-term (wave to wave) resource time variability needs to be taken into consideration to enable better prediction of produced power.

Workshop on Integration of Wind and Wave Resource Modelling

The physical processes in the marine atmospheric boundary layer and its interaction with the wave field in the coastal zone is the underlying common background for wind and wave resource modelling. The workshop will focus on this common scientific background and will give each of the two (wind and wave) communities insight in the models used by the other one for the same processes, namely the momentum and heat transfer between air and sea. Understanding of the different perceptions and approaches taken by the two groups is a prerequisite for a successful integration of wind and wave resource modelling. We will also need to include experts from the meteorological communities to integrate the state of the art in wind and wave predictions for weather forecasting. A further linking activity, organising a session at for example the European Geophysical society meeting (we will ask for joint listing between the energy, atmosphere and hydrosphere sections) will be undertaken. This will likely precede the workshop in order to identify the state of the art and experts in the fields.
The approach taken here will try to draw the communities together by establishing a common understanding of the scientific background and harmonisation of the best practice in resource modelling. The workshop will be open to all participants. Funding is requested to provide travel grants to participants from less favoured regions from EU member states, especially NAS states, but also for others including Ph.D. students.

Virtual Laboratory for Short-Term Prediction

The aim of this Task is to continue evaluation of the state-of-the-art on short-term forecasting technology based on work initiated in the ANEMOS project. The Task will give emphasis to evaluation results reported in the bibliography and from ongoing

national or EU research projects. Then, it will prepare a common benchmarking framework that will be implemented as a ViLab (Virtual Laboratory). This Task will provide documentation that will be accessible through the ViLab.
Nowadays, a number of research institutes or companies develop models for short-term wind power forecasting. However, evaluation of such models depends on the test-case and its characteristics such as complexity of the terrain, spatial and temporal resolution of Numerical Weather Predictions, Measurements etc. A high number of approaches are reported today also from the side of Weather Prediction Systems. As a consequence it is very difficult to make cross-comparisons by different prediction systems and take decisions on the optimal ones to implement operationally.

In the area of short-term prediction (STP-ViLab) it is aimed :

- To permit exchange of data and common work in the area
- To compare NWPs for wind speed prediction purposes. For this purpose, a limited number of sites will be defined having available measurements. Then, NWPs providers will be requested to submit predictions for these sites covering a specific period.
- To evaluate the accuracy of various wind power prediction approaches. For this purpose, data will be made available to research teams working in wind power forecasting which will be then able to calibrate their models and produce prediction results that will be submitted for evaluation by the ViLab). Definition of test cases and agreement with data owners (utilities, NWP providers) for making the measurements public.
- Set-up of a web site for supporting the ViLab. This site will give possibilities to upload/download the data and the predictions. The site will be password protected and external entities will have the possibility to register for accessing to the service provided by the Laboratory.

An appropriate procedure will be defined for objective evaluation of the prediction approaches. The evaluation protocol developed in Anemos project will be used together with the evaluation functions.

Best Practice for the Use of Short-Term Prediction

Risø and partners are currently producing a document for the Anemos project on best practices for short-term predictions, using input from utilities, meteorological institutes and the short-term forecasters themselves. This document, along with the experiences from the first dispatcher training, will form the basis for a workshop bringing together high-penetration and low-penetration utilities, in order to reduce the perception of risk of wind power for grid stability among utilities with low experience. This workshop is planned to be on 7 September 2006 in Dublin (powwow.risoe.dk).
With the major results of the workshop, the best practice document will be updated and distributed to utilities. Researchers from the consortium will spread the word on some of the "standard" energy industry gatherings, liaising with the world outside the "wind energy cocoon". The results will also be used in a dispatcher training course.

Virtual Laboratory with Cases of Offshore Wakes

Initially, the aim of this Task is to evaluate the state-of-the-art on wake modelling. The Task will give emphasis on 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 will be provided. In order to address the problem of wake studies in large offshore wind farms the partners will identify test cases and request data for Horns Rev, Nysted and any other wind farms which are erected during the project. The data will be converted to common formats. The form of the Virtual Laboratory will be based on input from modellers in order that the input data and the results are displayed and available for all partners. The partners of the Task will assess then the outcome from the ViLab activities related to wakes. This Task will provide also documentation that will be accessible through the ViLab.

Workshop on Integrating Wake Models into Short-Term Forecasting Models

Wake modellers have tended to work mainly either within the CFD/aeroelastic design fields or in resource modelling leaving a gap at the short-term forecasting time scale. We will open the workshop to participants from all EU countries and offer travel grants with a preference to NAS researchers. The workshop will focus on the test cases from the virtual laboratory and drawing up guidelines for good practice for integrating wake and short-term forecasts. The workshop is intended to be the major dissemination forum for these results (beyond the virtual laboratory web site) and we will solicit a special issue of Wind Engineering for the papers presented.
This activity will also lead to a definition of the best practice guidelines for the integration of wake models into short-term prediction models. Since we intend a major result of this WP to be an improvement in the state of the art in wake modelling in short-term forecasts we will need to demonstrate that on-line wake models give better results than the 'look-up table' approach currently used. The guidelines will outline approaches that can be used with both physical and statistical methods of short-term forecasting and describe conditions under which the largest errors in wake prediction are to be expected. The guidelines will be made publicly available for comment before being finalised.

Conclusions

The expected results of this new coordinated action project are:

- Increased cooperation and streamlining of methodology for resource and short-term prediction of wind and wave energy through the establishment of expert groups.
- New opportunities for model evaluation through virtual laboratories for short-term forecasting and wake models.
- Better training possibilities and input from both data suppliers and end-users through workshops. These will be open to third countries, with supplemental funding for NAS and developing countries.
- Development of new opportunities through further proposal development.

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