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The new generation of tools for prediction of wind power potential and site selection

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ABSTRACT

Today a number of well established models and methodologies exist for estimating resources and design parameters and in many cases they work well. This is true if good local data are available for calibrating the models or for verification. But the wind energy community is still hampered by many projects having large negative discrepancies between calculated and actual experienced resources and design conditions.

However, when such significant discrepancies are found, no well established methods exist to correct the situation. Discrepancies can be introduced at any point in the modeling chain, from insufficient input data to deficient physics and resolution in any of the models, model linking issues, insufficient resolution or errors in surface topographical data such as terrain heights, land cover data etc.

Therefore it has been decided on a European Union level to launch a project "The New European Wind Atlas" aiming at reducing overall uncertainties in determining wind conditions; standing on three legs: A data bank from a series of intensive measuring campaigns; a thorough examination and redesign of the model chain from global, mesoscale to microscale models and the creation of the wind atlas database. Although the project participants will come from the 27 member states it is envisioned that the project will be opened for global participation through test benches for model development and sharing of data – climatologically as well as experimental. Experiences from national wind atlases will be utilized, such as the Indian, the South African, the Finnish, the German, the Canadian atlases and others.

Keywords: Wind conditions, wind resource, wind design conditions, short term predictions, meteorological models, turbulence, topography (orography and land surface property).

INTRODUCTION

An important objective of the European Union's Strategic Energy Technology Plan for wind energy is to accelerate the reduction of costs of wind energy. For this purpose the wind energy technology roadmap highlights the need for more accurate mapping of wind conditions for estimating wind resources and loads for wind turbine design. It is recognized that this objective can only be accomplished by highly coordinated research and development focusing on the creation of a new EU wind atlas, including a climate database, and on the improvement of models for wind energy physics[5]. Bases on these considerations the European Commission decided to issue a call on the Wind Atlas project in their research programme FP7, July 2012. It is issued as an ERANet Plus call, which means that the Commission shares the budget for the project with interested member states. Duration of the work will be five years beginning 2014.

The wind atlas will have to be validated by onshore and offshore measurement campaigns, targeting also complex and hostile environments. The experimental campaigns will provide extended reference data, will improve spatial planning tools and will reduce the uncertainty in wind resource and load estimation and thereby in the economic assessments.

The project will therefore be structured around three areas of work, to be implemented in parallel:

- Creation and publication of a European wind atlas in electronic form, which will include the underlying data and a new EU wind climate database which will include: Wind resources and their associated uncertainty; extreme wind and uncertainty; turbulence characteristics; adverse weather conditions such as heavy icing, electrical storms and so on together with the probability of occurrence; the level of predictability for short term forecasting and assessment of uncertainties; guidelines and best practices for the use of data, such as extremes and turbulence (especially relevant for micrositing)
- Development of dynamical downscaling methodologies and open-source models (including coupling to wake models), validated through measurement campaigns, to enable the provision of accurate wind resource and external wind load climatology and short term prediction at high spatial resolution and covering Europe. The developed downscaling methodologies and models will be fully documented and made public available and will be used to produce overview maps of wind resources and other relevant data at several heights and at high horizontal resolution.
- Measurement campaigns to build and validate the EU wind atlas together with selected European wind climatologies. At least five coordinated measurement campaigns will be undertaken and will cover at least complex terrains (mountains and forests), offshore, large changes in surface characteristics (roughness change) and cold climates.

The accomplishment of the New European Wind Atlas will play a strategic role in the world wide future of wind power, because it will contribute to a reduction of the uncertainties and risks related to the design and operation of large-scale wind turbines through an enhanced knowledge of wind energy physics. The project will better quantify the European wind energy potential, and will provide data and models that can help improve operations and ensure an effective and efficient deployment of wind power world wide.

The Wind Atlas work will benefit from the accomplishments of the ongoing work with the IRENA (the International Renewable Energy Agency) project: The Global Solar and Wind Atlas, especially with regard to building the database, which most likely will use the architecture form the Global atlas.

THE NEW EUROPEAN WIND ATLAS DATABASE

The work with the existing European Wind Atlas[1] was performed 1982 – 1989 and published by Risø National Laboratory for the European omission in 1989, covering 12 of the 27 current member states. As of today, it is still the only atlas covering several EU member states in a uniform way. A number of national wind atlases exist today, but they do not provide a consistent and comprehensive coverage of the entire territory of the EU, which results in a lack of verified and publicly available data on European wind conditions. Further to this, the 1989 atlas does not cover new EU Member States and was developed using standard climatological data being less suited for wind energy purposes. The new EU wind atlas will take advantages of newly created long term datasets well suited for the purpose of the atlas and thereby contribute to the creation of an EU standard for site assessment.

The new EU wind energy atlas will provide a unified, high resolution and public-domain dataset of wind energy resources and design condition for the entire European Union. Specifications and access through web tools will make it the best wind resource dataset for energy planners. A true estimate of EU wind resource will benefit society and the wind energy sector, by clarifying wind energy's role in the future EU energy mix.

The work with the new atlas will provide new information relevant for all life-cycle and stake holder of wind energy. It will be a new kind of wind atlas, incorporating comprehensive information about wind conditions for all stages of wind projects' life-cycle (prospecting, design, development and operation). The atlas of wind conditions will be based on newly available atmospheric and topographic data and pay particular attention to the challenges of offshore winds, coastal winds and winds induced by terrain as well as other relevant geophysical data as waves for offshore. The atlas database will give much more than resource information. It will give measures of wind variability, diurnal and seasonal variations and predictability. The work with the new atlas is required to maintain a strong position of the wind energy community in terms of wind energy knowledge, technology and deployment.

The database will be structured on several levels reaching from the need of planners for regional overview-maps to very detailed time series for technical/scientific applications. Selected important issues to be covered by the database are:

- *Wind resource*: Wind resource calculation requires frequency distributions of wind speed and direction as a function of height. For wind turbines of the future this information will be required up to 300 meters or more for accurate prediction of wind energy production. Dependent of whether the need is regional or local, this information can be acquired from the database maps or database utility programs.
- *Wind variability*: Characterization of the variability of the wind conditions on time-scales from hours to months (season and daily included). This is important for determining modes of operation for the wind farm and how the wind resource may be integrated into existing and/or alternative power supply, including other renewable energy sources.
- *Inter-annual variability*: Tools and wind conditions data that allow the placement of short-term measurement data into long term climatological perspectives is of great value for wind farm developers. This can be achieved by quantifying variation of wind conditions, relative to climate, over any arbitrary limited period of site measurements.
- *Wind power predictability*: When a farm is in operation, the ability to predict the wind power over the next hours and days is of value for operators and power grid managers. The degree of predictability will depend on the kinds of meteorological phenomena impacting a wind farm site and the ability of models to resolve and model these phenomena.
- *Uncertainty:* Throughout the wind atlas on wind conditions work flow, verification and estimation of uncertainty will be of upmost importance. The uncertainty estimations will be based on a network of in situ measurements over Europe and modeling sensitivity studies. The uncertainty estimate map makes an important statement about the confidence of the wind atlas and the intensity to which in situ measurement must be employed before development of a wind farm.

THE MODEL CHAIN

In order to achieve the objective of very high accuracy of the wind potential assessment (3-10% as long term reference) and the real conditions being faced by wind turbine generators both at the design and deployment phase, a new generation of models has to be developed: Covering all scales from synoptic to microscale; based not only in local measurements but also in global atmospheric databases (i.e. reanalysis) and new measurement techniques with much more detailed turbulence models able to give useful information for the design of wind turbines; considering extremes specifically (extreme winds, extreme shears, high wind variability, etc); models being able to simulate onshore and offshore conditions, with stability effects and large offshore wind farms with cumulative wake effects and modified atmospheric boundary layer. As a result of the project models will be developed, validated and published as open source to ensure the impact of the project, guarantee the transparency, facilitate scientific and technical progress and cooperation.

In a recent publication[3] the modelling issues are described as follows: “The assumption of large scale homogeneity of the overall wind resource, and the modelling of the indicated important local influences, was the basis of the development of the European Wind Atlas[1] and the WAsP analysis and siting programme. The methodology has since been used in a number of similar studies in other parts of the world. In this application the "correction" of local wind statistics is done by modelling the local influences (using simplified diagnostic models) to construct a "generalised" or "regional" wind climate pertaining to idealised conditions (e.g. the wind frequency distributions for 100m above a flat and open large stretch of land). Ideally (meaning if the original data are of good quality, the simplified models and the site specifications used for corrections are sufficiently accurate and that data locations are close enough to resolve the climatological variations), one can obtain maps of the variation of the (regional) resources, and by using these in reverse, introducing the necessary local corrections pertaining to any candidate wind turbine/farm site, one can estimate the actual resource and production potential for the particular site .

In areas, where resources are more determined by or dominated by smaller (than synoptic scale) flow phenomena (mesoscale flows) the methodology is still applicable, but the distance to which one can use the generalised or cleaned statistics may be much reduced. For Europe parts of the Mediterranean area poses such challenges to the wind atlas methodology. In such circumstances improved resource assessment can be obtained using mesoscale modelling.

Using global reanalyses as boundary conditions decades long timeseries and/or wind climatologies can be modelled at nominal resolution (grid cell length in mesoscale model) down to a few kilometres and covering areas with side lengths of some thousands of kilometres is becoming possible.

The application of mesoscale models for resource calculation is by no means a simple matter. The large scale reanalyses are performed in only a few global weather prediction centres using models that have been developed over many years, and which are still being developed and validated and are being used in operational services. Mesoscale models are more diverse, but nowadays quite a number have a proven track record in applications such as for regional weather prediction and also for wind resource assessment. There are still some issues, and use of model results without proper validation may lead to gross errors. It is important to realise that large scale and mesoscale models are extremely complex and that published validation studies in general focus on detail other than low level boundary layer winds. For resource assessment it is therefore highly advisable to include direct validation with in situ observed wind data over sufficient long periods. In doing so, however, the mesoscale model output must be downscaled using some microscale physical or empirical/statistical model. The linking from the global scale datasets to the mesoscale model is most often done by "nesting" the mesoscale model, that is selecting its domain over the region of interest and using the large scale data as initial data and as lateral (time varying) boundary conditions for the model. Since, however, mesoscale models are fully dynamical (unlike microscale models, which in general can be used as "diagnostic" downscaling tools) they need some integration time after initialisation to "spin-up" the mesoscale features not resolved in the initial large scale field. Depending on domain size this necessary spin-up time can be days. At the same time the mesoscale model may start deviating from the large scale fields (the large scale "truth" from the reanalysis) over the domain over similar time spans and therefore need to be reinitialised regularly or some "nudging" or relaxation technique needs to be applied to keep the system on track. The difference in resolution and model details tend to give rise to model artefacts near the lateral boundaries, therefore they need to be sufficient far from the area of interest to have negligible influence on the results. All these "technical" details and choices (not to mention the model formulation itself, the numerical schemes used and the physical parameterizations) can have significant impact on the results. A particular issue often misunderstood is the actual model resolution. This is most often quoted as the grid cell size in the model grid, but the actual physical resolution, the size of features that are well represented and modelled, is always larger. This "real" resolution depends on model details, not only the grid size and numerical methods used, but also on the physical formulation[2, 5]

In conclusion, the necessary "model-chain" for the downscaling from the available climatological data to local wind resource estimates (the "top-down" approach) consists of the large scale reanalysis model giving dynamical consistent large scale time resolved data at some spatial and temporal resolution, a mesoscale dynamical model to provide data at higher spatial resolution, and a microscale model. Data from the experimental campaigns and available wind observations of good quality at the specific sites of interest will be used for validation and accuracy/error estimation.

The developed downscaling methodologies and models will be fully documented and made public available and will be used to produce overview maps of wind resources and other relevant data at several heights and at high horizontal resolution. However, it should be brought in mind that use of mesoscale models for resource assessment is quite computer intensive if one want to resolve all (or almost all) relevant scales and produce climatology covering several years.

THE EXPERIMENTAL PROGRAM

The experiments will be designed to targeting the main outstanding problem in the Wind Atlas work: To develop or re-develop the essential models so they are specifically tailored to the Wind Atlas use and can provide results with an accuracy unseen today. A model issue which is crucial is the development of a robust protocol for linking the local micro scale wind conditions via meso-scale phenomena to larger scale climatologies.

The outcome of the experimental program is a comprehensive dataset of flow conditions in a range of topographic and climatological settings. Each dataset will document a specific setting, but the working assumption is that the data shall be detailed enough and cover a sufficient range of spatial scales from micro- to mesoscale and with sufficient temporal resolution and length to give a reference climatology.

The initial activities will comprise an examination of a number of possible experimental sites and a suggested selection of at least five sites, which are found to best cover the climatological and topographic conditions in the European Union: From Arctic to Subtropics and from sea to mountains (called "The Experimental Matrix). The selection will be based on the quality of the site with respect to the target outcome and will be guided by detailed flow modeling and will also consider logistics and costs.

For each of the sites a plan will be developed for the setting up of instrumentation and other logistics for a long term (3 years or more) backbone climatology program. The intention is to ensure a maximum of commonality of this program between sites (the selected and future sites). This will include a partial standardization of instrumentation, time and spatial resolution. A set of guidelines will be developed to ensure standardization while taking into account site specific considerations in the interest of maximization of the value of the data.

A plan for a series of shorter term intensive measurement campaigns (a few weeks to several months duration) to investigate specific flow phenomena in high temporal and spatial resolution (turbulence and gusts, wind shear, flow separation, local circulation systems...). Also for these measurement campaigns a maximum standardization will be sought in the interest of consistency and quality of the final database.

The new the European Research Infrastructure "3D wind scanner" facility will be engaged to supplement and strengthening the experimental activities. See the presentation on the WindScanner elsewhere in this volume. The measuring campaigns will not solely ensure proper modeling validation, uncertainty estimation but will also provide extensive and high value data to be used by a broader community of private and public partners to develop models and engineering tools or data sets to be used as design input, standardization of design codes or certification schemes. As an example of this aerodynamics and aeroelastics codes as well as remote sensing techniques will definitely benefit from this data. Intensive, scientifically designed and with public databases, they will allow present and future generations of researchers and designers access to detailed wind conditions in some of the most representative geographic conditions.

CONCLUSIONS

According to the European Wind Energy Technology Platform[7] the Atlas will have the following beneficiaries:

- The wind atlas database together with the web-based open source models will facilitate wind farms siting, wind turbines design and wind energy forecasts, hence contributing to reduce the cost of wind energy. For this reason, the new EU Wind Energy Atlas will be beneficial to developers, manufacturers and decision-makers.
- The new EU wind energy atlas database will be developed on maps based on the "CORINE land cover" exercise, in order to transform it into a useful spatial planning tool. The atlas will therefore indicate restricted areas (e.g. Natura 2000 sites, military areas and so on) and will include wind data for these areas. Thanks to this approach, the new atlas will be a key tool not only for manufacturers and developers, but also for public authorities and decision-makers.

- The new EU wind energy atlas will contribute to the preparation of a global wind energy atlas, to be developed under the coordination and supervision of IRENA (the International Renewable Energy Agency). IRENA together with leading international institutions (NREL, NCAR, DLR, CENER and the DTU Wind Energy) is already preparing the ground for this exercise and, through this project, Europe has the chance of making a key contribution to the development of wind power at global level.
- Finally, the development of a new EU wind energy atlas represents a clear priority not only of the European Wind Initiative (EWI) and of European Wind Energy Technology Platform (TPWind), but also of the European Energy Research Alliance (EERA). It is therefore a key goal of the entire EU wind energy sector, which confirms its importance for the future of wind power in Europe.

Further the added value and benefits as viewed from the manufactures, developers, utilities etc. can be expressed as follows: The development of a new generation of flow models as part of the EU Wind Atlas will significantly contribute to the reduction of technical and financial uncertainties. The increased security for investors and thus easier financing will in turn result in more investments in wind energy. This accelerated penetration of wind energy in the EU will be of benefit for the local industry having a geographically near-by prosperous and healthy market. The new models can thus contribute to increased employment in the EU wind energy sector and significantly reduced cost of energy while at the same time help to achieve the CO2 targets. The reduced costs of energy will - also on a global level - increase competitiveness of the European wind industry.

Benefits from the financer’s/insurer’s/owner’s view: The most significant implication of the new EU Wind Atlas is the significant reduction of uncertainties related to the wind climate for a given site. As a direct consequence the financial risk for investors decreases, making wind energy a more attractive investment. This will affect financers as well as insurers and owners.

Benefits from developer’s view: The new EU Wind Atlas will accelerate development in the EU by offering a qualified overview of the wind resources. The hereby reduced development time of projects together with the possibility of a more focused use of on-site measurements lead to reduced development costs. At the same time the decreased uncertainty will add significantly to the value of projects. Additionally more efficient layouts can be developed through improved park models.

Benefits from manufacturer’s view: The reduced uncertainty of the wind climate and the wind load parameters will contribute to a revised set of safety factors which will be reflected in more optimized wind turbine design. Value engineering will be accelerated and will find a reflection in reduced cost of wind turbines. With a more in-depth knowledge and understanding of sites, tailoring of products to match specific markets becomes feasible. Additionally the reduced uncertainty in energy prediction opens possibilities for warranties of energy production.

Benefits from utility’s view: The EU Wind Atlas will enable the utilities to plan grid capacities in a medium- to long-term time frame. Additionally the improved tools developed as part of the EU Wind Atlas will allow a significant improvement with regards to feed-in both in terms of precision and forecasting horizon.

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