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Operations & Reliability

Solution Overview

Wind Power Forecasting Pilot Project
Part A: The Forecast

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1 WEPROG's Expertise and Background

WEPROG's 75 MEMBER Multi-Scheme Ensemble Prediction System (MSEPS) is a result of many years of experience gained in weather prediction and wind power prediction. The founders of WEPROG Corinna Moehrlen and Jess Joergensen started work in year 2001 with an investigation of how to optimize weather prediction towards wind power prediction. At that time, Corinna Moehrlen carried out a PhD project on wind power forecasting at University College Cork (UCC) and Jess Joergensen was responsible for the operational weather prediction system in the Danish Meteorological Institute (DMI).

They designed 13 three month experiments and some one-year experiments to investigate the wind power prediction problem (Moehrlen, 2004). At this stage the effect of spatial resolution was unknown, because few had the computational resources to carry out such experiments with a Numerical Weather Prediction (NWP) model. The experiments used multi analysis, multi model and multiple resolutions and verification was done in Ireland using measurements of wind speed and wind power.

The results from the 13 experiments indicated that the high spatial resolution was a promising way forward, because peak values were only of the correct order in high spatial resolution. However, the timing was often not accurate enough. It appeared attractive that the high resolution runs actually performed good in windy events measured in wind speed, but the result could not be confirmed when examining the statistical scores on the wind power predictions (see also Goeber and Wilson, 2007 and Ebert and McBride, 2000). The results in fact indicated that multiple forecasts of moderate resolutions would be better than a single forecast of the extreme spatial resolution.

It was also found by subjective analysis that the high resolution forecasts captured local effects in an impressive degree, but that such events were rare. The economic value of predictions for small wind farms (5-10MW) could not justify such a forecasting system that would require super computing facilities. The 13 experiments had shown that another path forward was required and that the error level was likely to remain otherwise. It was at this stage certain that there would not be a simple solution to make accurate wind power predictions.

The conclusion from these experiments lead to the construction of experiments to simulate a short range ensemble forecasting system with the goal to predict the accuracy of the forecast and thereby increase the reliability. Details of these experiments can be found in Moehrlen (2004).

The promising results of this research were the starting point of WEPROG (Weather & wind

Energy PROGnosis), where Corinna Moehrlen and Jess Joergensen developed between 2003-2004 an operational multi-scheme ensemble prediction system based on the knowledge gained in their research projects.

1.1 The MSEPS in 2006

The 13 experiments carried out in 2001 demonstrated that a significant amount of the uncertainty (and therefore also prediction error) in wind power forecasting was generated in the integration step of the NWP model. This finding was at that time going beyond the state-of-the-art point of view in Meteorology and the wind energy community.

Therefore, it was required to develop an approach with focus on the accuracy of the model error. Even though the real time activities with the MSEPS started in summer 2003, the system has only been commercialized in year 2005 after testing and demonstration took place mainly with data from Denmark. Since then it became clear, that the customers needed customized products from the MSEPS ensemble and for this reason a general statistical tool was developed. This MSEPS tool can make optimal use of the full ensemble for any derived weather variable such as wind power.

The view point, that the NWP model error is significant, has become more common in the past years. Most recently, Peter Houtekamer from the Canadian Meteorological Center (CMC) has announced that CMC will reduce the stochastic perturbations to the state estimate and focus more on the model error. This means multiple model formulations are used and perturbations are added during the forward integration. The perturbation process at CMC is described as an approach that is simpler to maintain than multiple model formulations.

The European Center for Medium range Weather Forecast (ECMWF) has also introduced stochastic model perturbations in the past 5 years. Thus, there is an emerging acceptance that NWP model error is important for the prediction of weather forecast errors.

Another trend in the numerical weather prediction community is to exchange ensemble forecasts. The North American Ensemble Forecasting System (NAEFS) has been established to create a bigger ensemble in order to make a more realistic Probability Density Function (PDF).

However, NAEFS's strategy does not set sufficient focus on short-term predictions in comparison to WEPROG's MSEPS ensemble, because:

- * The spatial model resolution is insufficient, even though this will improve with time
- * The model formulations change as the system is not yet in a stable operational state

- * The output frequency (3-6 hourly) is not good enough for wind power
- * It is not possible to get access to the optimal set of variables for derived products
- * The short-term forecasts still have unrealistic perturbation levels
- * The ensemble size is still too small to make a smooth PDF

WEPROG can optimise the design for a particular purpose and can thereby deliver a better and more cost effective solution. No operational changes outside WEPROG can suddenly generate a side effect, as WEPROG's forecasts for the planetary boundary layer winds are entirely under the control of WEPROG's ensemble prediction system. No other mechanism than WEPROG's forecast software can change the statistical capabilities of the output variables in the boundary layer. The only exception of changes in the statistical behavior is that online measurements can with benefit be combined with forecasts 0-3hours ahead. The pure model result is best in the time horizon 4-144 hours and this is entirely carried out by WEPROG's software.

2 The Multi-Scheme Ensemble Prediction System

WEPROG's Multi-Scheme Ensemble prediction system (MSEPS) is currently predicting operationally for more than 30% of the world's wind power with delivery every 6 hours. Additionally, the system is running quasi operational for 60% of the world's wind power, where the full ensemble output is archived in one hour time resolution until 48 hours ahead for later usage.

WEPROG performs every 6 hours 75 forecasts for each continent two days ahead. This corresponds to 600 model years per calendar year. The operational systems run 6 days forward and are running duplicated on two computer systems in Europe equivalent to 1800 years of model integration.

WEPROG's MSEPS forecasting systems is therefore a very robust operational forecasting system, even though it is still young. It is worthwhile to outline the difference between the MSEPS and the NAEFS system at NCEP/CMC to show, where and how the MSEPS system adds particular value to the end-user. We will use this discussion to also explain how we target the MSEPS system and minimize the risk for the end-user, while keeping the running costs reasonable and efficient.

2.1 Comparison of NAEFS and MSEPS

WEPROG is not trying to compete against NAEFS, although both carry out ensemble forecasting. This section will outline that two different methods are used to create different products, and happen to have the wording ensemble forecasting in common. The scope of this section is therefore only outlining the scientific and technical differences with no judgment of the NAEFS.

WEPROG's MSEPS system has been developed with primary focus on wind power, although the system is best described as a regular ensemble prediction system for weather forecasting with focus on the planetary boundary layer and additional features for embedding statistical processing tools.

The NAEFS system's objective is to develop the best general prediction system for the next 15 days with moderate model resolution for the entire globe. WEPROG's MSEPS is targeted to provide optimal quality from 4-144 hours on derived near-surface variables such as wind power. The forecast horizon has become a competition parameter, since the ECMWF has announced a change in November 2006 from 10 to 15 days in response to NAEFS.

NAEFS and ECMWF use an approach that may be superior to WEPROG's approach for prediction day 7-15 and their approaches are also simpler to maintain. WEPROG's method involves many more source code lines and care in the application, but is also more realistic on the short-term and the surface layer, because independent physical simulations are used in the forward integration step instead of stochastic perturbations.

NAEFS and ECMWF are governed and funded by governmental funds. There is therefore an objective reason and necessity to be reasonable good for all users. WEPROG is driven by commercial customers requirements and does not have public good service obligations.

The NAEFS and MSEPS are therefore not in competition, because WEPROG provides a solution with more detail and accuracy for specific requirements, which is opposite to NAEFS, where the focus is to give the public a good general service.

NAEFS encourages a global collaboration on ensemble forecasting, where all forecasts are assembled centrally. Such a collaboration is likely to stiffen the system and the industry might not get the optimal product for their specific needs, although there could be a significant economic benefit. WEPROG will therefore continue to provide targeted products, rather than complying to the standards defined in NAEFS.

The NAEFS is a centralized forecasting system. The service is impressive with two expensive supercomputer facilities compared to WEPROG's Linux cluster computing environment. Nevertheless, WEPROG's forecast software has a great advantage over NAEFS for the industry. Its flexibility and possibility of end-user installations makes it possible to customized even the requirements for the weather predictions. If there is a problem in a targeted end-user MSEPS installation, then this can be solved. The products from the NAEFS are for a much larger clientèle and hence improvements on one part may have positive or negative impact on other individual requirements of end-users. NAEFS software changes may therefore potentially affect the quality of a statistical end-user application in an undesirable way.

It is WEPROG's opinion, which is confirmed by WEPROG's customers, that an investment in a smaller targeted system gives the customer a better service than using a commercial data supply to a third party software product, which might not be coupled together optimal. The third party product may not be optimized further, because the input weather data are limited by the standards and procedures of the public service provider.

As WEPROG operates the entire forecasting process, changes are planned, tested and implemented without drawbacks for the end-user. WEPROG can additionally explore the entire production chain and thereby locate the weakest points and improve particular on that.

2.2 Benefits of a targeted end-user installation

WEPROG can supply a complete in-house installation, which gives several possibilities for a TSO:

- to use data in the model system that may not be made publicly available
- allow the end-user to build up own databases with weather parameters quality control of weather related measurements
- integrated demand forecasting using 75 members producing a probability density function
- modeling of intermittent generation on the entire continent
- testing grid security constraint equations with 75 members
- probabilistic price prediction
- probabilistic modeling of the flow at bottlenecks on the grid
- extra security in delivery and quality in the event serious events in the world
- the possibility to add wind farms without additional costing and licenses

As the Canadian demand and wind power generation has some correlation in regions where

household heating is electricity based, there is a special benefit of predicting "demand minus wind power" on all ensemble weather members and making use of the PDF of this deficit. WEPROG refers to this as integrated demand and wind power forecasting. This is still possible to do with an outsourced wind power prediction system, but easier to integrate, if the system is in-house. This type of integrated services requires demand and wind power forecasting on every ensemble member before subtracting the two, otherwise the PDF would not be applicable for the deficit to be delivered by the non-intermittent generation units.

The fastest 1u servers on the market in the beginning of 2007 will allow modeling of entire Alberta in 5km resolution with 75 ensemble members with a reasonable budget. This will be with a nested model system starting with 75 moderate resolution models that supply boundary values to the nested system. This will give a robust specific targeted forecasting system that is optimized for handling all weather dependent energy sources on the grid.

3 Detailed Description of the System

WEPROG's MSEPS system consist of two parts. A weather prediction system running every 6 hours and a power prediction system which is capable of using online SCADA system data and historic data in combination with the real-time forecasts. Figure 1 shows the model area of the operational AESO setup. Figure 3 shows a diagram of the meteorological component and Figure 4 shows the wind power prediction part of the system. The following sections will describe the design of the two components.

3.1 The meteorological part of the proposed system

Meteorological measurements such as TEMP, SYNOP, AIREP, satellite etc. are transmitted on the Global Transmission System (GTS) net. The national Met-centers perform from these data and their own forecast a state estimate (analysis) and later on a forecast. A few national Met-centers perform global state estimates and forecasts. WEPROG retrieves the global state estimates as soon as they are made available by the national met-centers, which is approx. 3-4 hours after observational time 00,06,12,18 UTC.

Once the state estimate is available, WEPROG starts 75 limited area weather forecasts in parallel. Each forecast takes as input the global state estimate and combines this with the previous MSEPS forecast valid at the same time as the state estimate.

This process is optimized to produce optimal forecast uncertainty and also accuracy. The

combination of schemes in the MSEPS system is designed to simulate the uncertainty in the computation of the global state estimate. The uncertainty predictability requires that the ensemble shall be uncorrelated whenever the weather is uncertain and the accuracy optimization requires that the best model combination can be selected at any time.

Part of the weather forecast uncertainty is due to measurement errors and part might be due to model deficiencies. Since the MSEPS has 75 different states, there is a possibility to evaluate the quality of the global state estimate in a particular region and use the uncertainty to evaluate, whether the global state estimate is correct. Currently the MSEPS system uses the length scale as a measure of how certain the global state estimate actually is. The MSEPS ensemble members are all independent, but they all use the larger scales from the same global state estimate. The interaction with the smaller scales, which is different from member to member, will in uncertain weather conditions cause immediate ensemble spread. The Rocky Mountains could be an example where the weather is considerable more uncertain than in more homogeneous conditions. This may be exploited to give less weight to the state estimate in this region, if this would be beneficial for the wind power predictions.

The meso-scale weather is normally not very accurately represented in a global model's state estimate. Such weather is maybe visible as a perturbation and the MSEPS interprets this as a wave that may amplify or dampen depending on the response of the non-linear model.

As the global model has a tolerance level for deviations between forecast and measurement, it might also be that the global model discards measurements that indicate meso-scale weather activity. Therefore, the MSEPS allows the smaller scales to grow or shrink dependent of the large scale state estimate. This is in particular important for providing reliable probabilistic forecasts. Small differences in the large scale weather can either cause a growth or a decline. This uncertainty can not only arise at the beginning of the forecast, but at any time during the forecast where the atmospheric flow evolves to a potentially unstable state.

A typical pattern is that atmospheric waves at different altitudes in the troposphere may interact and thereby trigger an instability mechanism. By running an ensemble, it is possible to automatically filter out uncertain instabilities in the flow. If an event is not certain, then it will only develop in a few ensemble members.

The weaker low pressure systems cause a relative high uncertainty in wind power prediction, because the associated wind speeds are in the steep range on the power curve. They cause little uncertainty in wind, but high uncertainty in wind power.

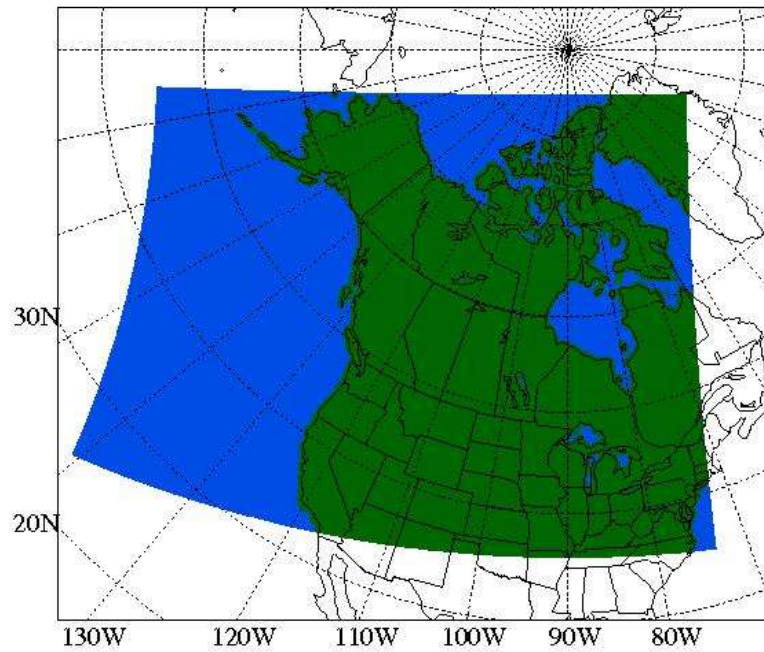


Figure 1: Large scale model area in 45km resolution

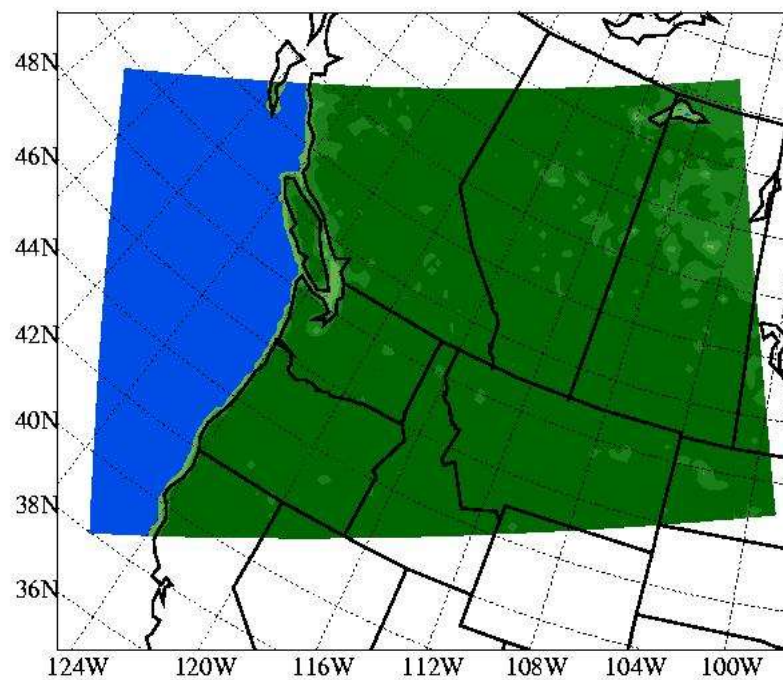


Figure 2 High resolution model area in 22km horizontal resolution

3.1.1 WEPROG’s MSEPS operational set-up for the Pilot Study

For the pilot project, the WEPROG’s MSEPS system will produce 75 forecasts of 48 hours 4 times per day. The model system will run nested with 75 outer forecasts in 45km resolution in a grid with 130x110 grid points shown on Figure 1. This will cover a fraction of the Pacific Ocean and almost all of Canada down to the very southern states of the USA with the upper boundary close to the geographical North Pole. Inside a smaller nested system in 20km resolution is running (see Figure 2). The purpose of this system is mainly to get the uncertainty effect of the Rocky Mountains simulated better. Thus 2x75 forecasts will be generated every 6 hours, but there is a one way dependency between each pair.

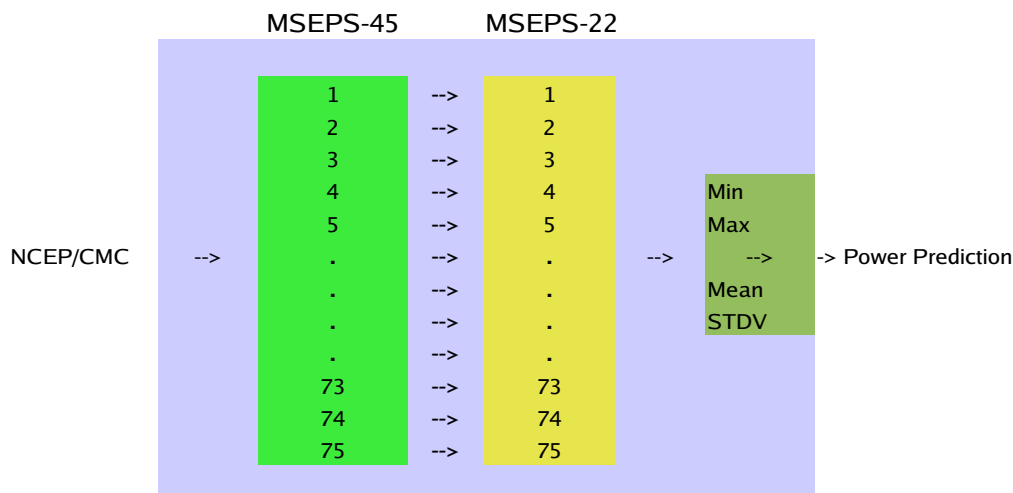


Figure 3: Schematic flow diagram of the MSEPS weather forecast process. In total 2x75 ensemble forecasts are generated. Input is take from the global NCEP/CMC model system. The power prediction has access to output from both MSEPS-45 and MSEPS-20 inclusive the basic statistical output

In recent studies (e.g. Moehrlen and Joergensen, 2006a, 2006b), it was found that the wind power prediction method has a strong effect on the prediction accuracy of the end product (wind power) and the more advanced, i.e. the more atmospheric parameters describing the weather situation at hand are used, the better the forecast quality. Four major results were drawn from from these investigations:

- Results from different continents demonstrate that the bulk of the remaining wind power forecast error is no longer the linear NWP error growth, when using the MSEPS approach
- The forecasting error is correlated to the location, the size and the production load of the wind facilities/area

- Detailed measurements are required to understand the source of and improve the prediction error

The main reason for the uncertainty in the wind power prediction step is that the 3 dimensional NWP grid only partly resembles the true state of the atmosphere. This should not be understood such that NWP model is wrong, but it is wrong when the output is compared to local measurements (see more details in e.g. Moehrlen, 2004, Mengelkamp, 2006). The real terrain is steeper and the roughness varies, while the NWP model operates with the mean values on grid point scale or waves in a spectral case. One can therefore not determine with an analytical expression, how to compute the wind power in a given NWP model grid, unless the native model resolution is very high. The cost factor of extreme high resolution is considerable. The improvement in quality are always questionable, because of the risk for phase errors as described above (Goebel et al., 2007) and each case needs to be evaluated in off-line mode.

A wind power prediction tool's most important task is to try to calculate the effective wind in the coordinate system of the wind farm given the large scale weather. This is a practically impossible task so solve with physical methods because:

- The equations that determine the NWP wind profile are not exact, but tuned according to measurements carried out in homogeneous conditions.
- Wind facilities are often located in humps in the terrain that will appear rather as roughness than mean orography in an NWP formulation. Thus the NWP has no equivalent height and roughness at the wind farm.
- The shear and direction of the wind varies uncorrelated on short timescales to any NWP model's output. There is no Earth Simulator with correct equations and correct assumptions, nor can it be calculated, how the wind turbines react on varying wind.

It is therefore likely that the achievements with very high spatial resolution are that the high frequent variations will correlated poorly with the actual wind on an hourly basis, whereas the low frequent will correlate better, because they are smoother. Then it is better to filter out the high frequent variation, which is most easily done by using a moderate NWP formulation, where such motion does not exist. Using a moderate spatial resolution is therefore not only increasing the accuracy, but also saving the cost and increasing the numerical stability. The drawback is a strong need for measurements to calibrate the power prediction.

It is with moderate resolution compulsory to assume that the native NWP wind profile on local scale is incorrect. The reasons are:

- There is always some terrain not captured by the model regardless of the spatial NWP grid
- Errors in the roughness length and surface temperature details trigger errors in the wind profile
- It is not possible to estimate the effective roughness at a wind facility for a particular wind direction
- Wake effects have effect on the wind, which is equivalent to an add-on of the roughness length

WEPROG's strategy is the use a self-adaptive physical method to compute the effective height of the wind farm in the model terrain. The effective height is determined with the help of wind power measurements. The method involves computation of the wind power using the wind in 3 different altitudes and one additional 10m value computed with sea/lake as the lower boundary condition. Each altitude is calibrated separately in 16 different weather classifications. The calibration method is not using a seasonal and diurnal training like many other wind power prediction tools do. The combination of wind direction and sensible heat flux gives a sufficiently detailed calibration, because we believe that most of the wind power prediction error is triggered by errors in the friction process. This error can well have a diurnal and seasonal variation, but WEPROG believes that time of the day and time of year solutions are hiding the true error, and consider this a step in the wrong direction. There is need to understand and eliminate the errors. Secondly 2-3 years following each other may not have similar climatic conditions nor is the diurnal cycle of yesterday very correlated to the diurnal cycle of tomorrow unless the sky is clear.

We have also found that there is no need to predict the wind speed at hub height. The calibration automatically constructs the vertical integral for every entry in the weather classification scheme to take account for the slope, obstacles and heat flux in the different sectors relative to the wind facility. The 4 wind speeds are formally converted to 4 times 75 power forecasts. The vertical integral will normally be ensemble member specific. Each ensemble member will differ in the friction process and the vertical wind profile is consequently also different. There is no possibility to say which is more or less correct in the real world when there is complex terrain. Only the ability to resemble the measurements counts. The 300 values therefore need to be calibrated. The relative weight of the 300 forecasts is determined dynamically as a function of the weather from the ensemble mean. A single state estimate is uncertain. Therefore, all ensemble forecasts generated in the past 18 hours are used to determine the final forecast, which implies that 900 wind power forecasts are used for the final best wind power forecast. The maximum allowed weight of a single forecast is 7%. It is however rare that a particular model is so superior to others in a particular weather situation.

The power forecasts are independent, but the classification scheme in the current version only uses the ensemble mean. The ensemble mean is the best general approximation, if one state has to be used in the classification scheme. The ensemble mean is also the most robust forecast and

it gives the best description of the weather type. The weather of the individual ensemble members could be used and it would almost for sure increase the ensemble spread and improve risk analysis.

WEPROG is upgrading the algorithm approximately every 6 months. There are more entries in the weather classification schemes added along with other improvements. The computation of the uncalibrated wind power is also updated with physical assumptions. Currently, all wind turbines are assumed to act similar at cutoff, ice-up, extreme high and low temperatures. The longer a wind farm has been operated, the better the forecasting system will be able to learn such events via weather classification schemes for the individual wind farm.

The system will formally deliver forecasts for the next 48 hours on hourly basis as the SCADA data arrives. The SCADA data based forecasts will be generated within approximately one minute inclusive update of the graphical presentation on the aggregated wind power generation.

The generation time for the MSEPS ensemble is approximately 2 hours for the large scale model. The nested system will probably be designed with a similar run time.

3.2 The system forecasting procedure

Figure 4 shows a schematic flow diagram of the MSEPS forecast process. This process takes place with 75 different forecast model configurations. The forecasts develop different, if the weather is difficult to predict, while they develop very similar if the weather is predictable. The predictability is region and time dependent. As the atmosphere develops frontal systems, all forecasts might agree 50km northward and southward, but in between there could be a moving high uncertainty region.

The forecasts from the MSEPS is capable of identifying these regions and continuously changes uncertainty at any location according to the weather situation. Therefore, automatic objective procedures are required to deal with the data on the very local scale.

The forecast process is distributed across 10 servers referred to as compute nodes, where each compute node is running between 7 and 8 forecasts at a time. The system is designed to scale well up to at least 160 servers. The accuracy gain with 160 servers is limited and could only be justified, if the target is operation of large volumes of renewables. The best entry configuration is 10 high spec compute nodes with dual quad-core processors with two master nodes of 2x4 cores per 1u server.

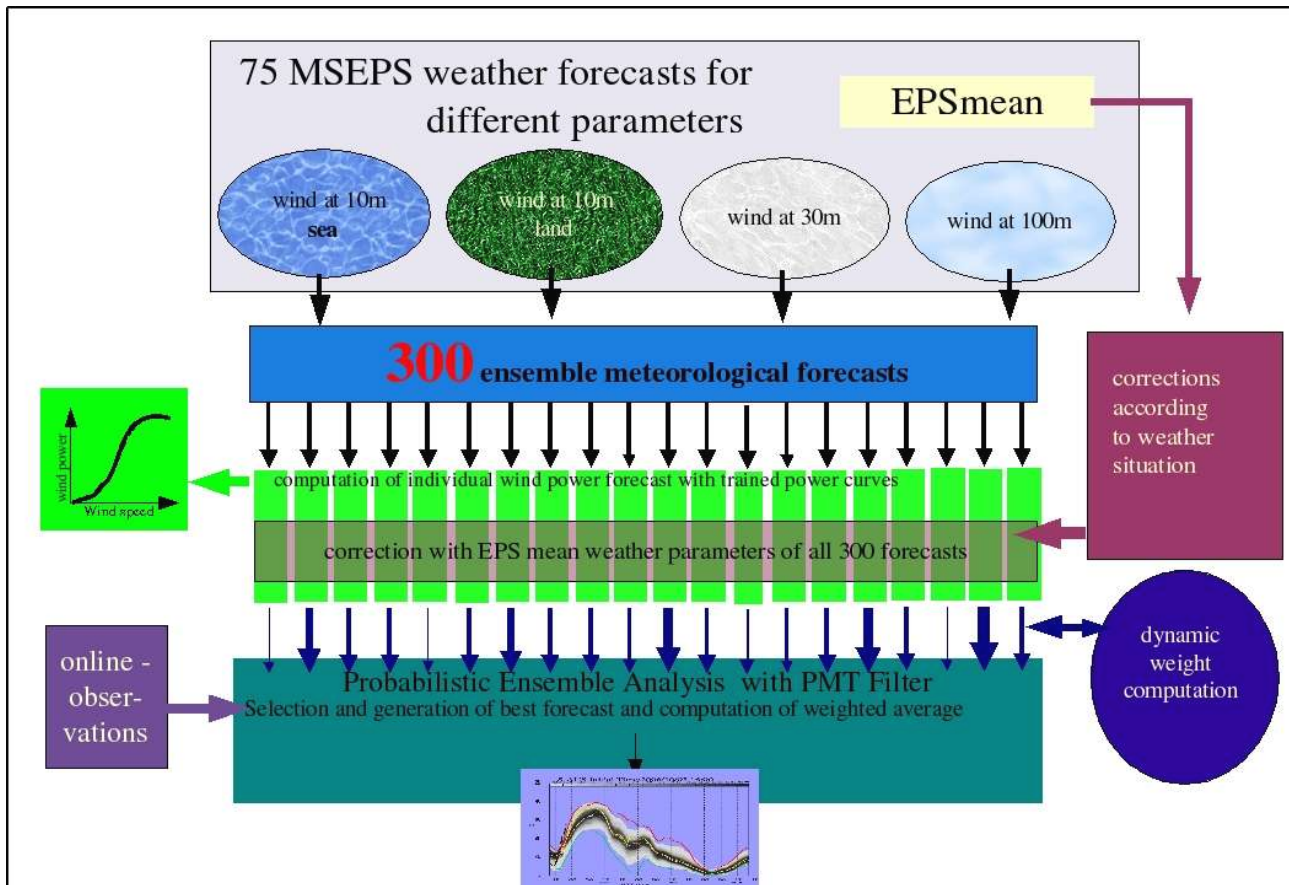


Figure 4: Schematic flow diagram of the MSEPS forecast process. The PMT filter step uses a window of 18 hours, which allows to use up to 900 forecasts depending on the level of uncertainty in the forecast. The EPSmean refers to the average of all 75 weather Ensemble members.

The two master nodes assemble all forecasts from the compute nodes and perform a multi step statistical analysis first in model space and later on at each wind farm site. This involves calibration according to the predicted weather and the performance of the forecasts in the specific weather pattern. The next step is to compute the best forecast combination given the error statistics of the weather in the ensemble mean forecast.

Until this stage all wind power computation has taken place with a load factor. Therefore, an upscaling with the current installed capacity of the wind farm is carried out in the last step. The current capacity is defined as the rated capacity at the time. If there are limitations that have been announced in advance of the forecast, the rated power is adjusted in this step.

Finally the master nodes deliver the data to the final destination servers.

3.3 Other benefits of the MSEPS approach

Wind energy started in Denmark and Germany as small single turbines dispersed over the countries and grew slowly in the 1980'ies. This pattern is very different from the way wind energy has been installed after year 2000, where large wind facilities bring economy of scale, but also new challenges to solve. The major issues are the stability of the electrical grid in periods with low consumption and high levels of wind. WEPROG has on the basis of measurements from and ensemble predictions for a number of countries the possibility to give advice and compare the technical difficulties to be expected.

3.3.1 Calculation of Return Periods

WEPROG will by March 2008 have in the excess of 1500 model years data over Alberta. This can be used to give a good estimate of the frequency of extreme conditions with a given distribution of wind farms. The past is the best choice to estimate the future, as the future climate is unknown. Even though the 1500 model years are more correlated than 1500 calendar years, wind power is sensitive and may behave very different in apparently similar conditions. The MSEPS data set is therefore expected to be suitable for studies of risk assessment. The MSEPS ensemble has not been used for this kind of study before, because focus has been on real time forecasting.

A possible strategy is set up a number of physical limits, which may trigger a wind farm to stop operation. Such limits could be related to cut-off wind speeds, extreme temperatures, ice-up on the blades, reduced farm efficiency and turbulence at sudden wind direction changes. The MSEPS dataset can then be used to estimate the frequency of such events and the correlation with the demand extremes. The MSEPS data set can therefore be used to answer the questions:

- which extreme conditions can occur
- how frequent extreme conditions occur
- how fast does such conditions develop
- how predictable are such conditions
- what would curtailment in such conditions cost

WEPROG's subjective experience is that 3 years MSEPS model simulation will give a trust- worthy probability distribution and return period calculation on the various events. The weather has shown recently abnormal behavior for a period of almost 2 years in a row. Europe had hardly any storm events from January 2005 to November 2006 and far less wind than normal in nearly all months. However, November 2006 was a very windy month. However, each windy event is with north westerly flow, whereas January 2005 was with south westerly flow. Therefore, WEPROG

recommends to use 3 years of MSEPS simulation for risk assessment.

There is no guarantee on the prediction of the future climate. The 3-year ensemble approach is designed to estimate the return period of given events with today's climate. This is not very accurate for events with a 100 year return period, because the climate will change over that many years. Wind generation units may have a lifetime of 25 years, thus the return periods that would be of interest would be 1, 5, 10 and 20 years, which would be very well estimated from 600-1800 model years.

3.3.2 Reserve Prediction

WEPROG is also doing prediction of reserve for wind power. This prediction can be optimized for grid security and for trading. The ensemble is used to predict the forecast error and with additional constraints this prediction is converted into a dynamic reserve calculation. Results of this prediction has been provided along with a description of the approach in Moehrlen et al. (2006). The reserve prediction is currently optimized for the wind power uncertain on timescales larger than 15 minutes. The system can also be used to predict reserve for the shorter time scale, but the higher frequencies are mostly balanced with ancillary services as perturbations on the demand forecast and are currently not requested by the market. There are however a number of wind farms in the world with a quite extreme variability in the output on the short time scale. Their output cannot only be regarded as a perturbation on the demand as the amplitude exceed realistic uncertainty values. The most significant variability is observed in events where cold air is blowing over relatively warm water at places with large wind farms.

3.3.3 A Long-term Statistical wind power forecasting approach

The predictability of the weather after day 7 is very low, but the energy market needs forecasts ranging much further ahead. There are two components to consider in this forecasting. This is diurnal cycle and the seasonal effects. These two effects can efficiently be simulated with the large MSEPS ensemble, because only a few weeks simulations give statistically robust result for the time of the year. All the normalized calibrated $300 \times 6 \times 4 \times 365$ power forecasts in the year are accumulated in a 2 dimensional matrix with 26 fortnight bins of the year and 24 hours of the day. Interpolation in this 2 dimensional matrix will then give the forecast valid far ahead. The forecast is scaled with the expected rated capacity at times, where the forecast is valid. The robustness of the method will increase once the system has been running a few more years. The system is very simple to maintain because of the strong data reduction factor. The prediction can easily be expanded to a 3 dimensional matrix, which would give the possibility to predict the probability of

the level of wind generation at any time.

A statistical prediction tool using the MSEPS ensemble for this purpose will be developed by WEPROG unless third parties undertake the task.

3.3.4 Severe Weather and System Security

Severe weather can also have impact on the safety of the electricity grid. Sweden experienced in January 2005 serious damages on the electrical grid. A system operator would naturally need to consider import and export of energy in such events and evaluate the risks. MSEPS is ideal for this purpose also in North America, because the total generation from wind is computed as well on local scale as on region basis in North America and WEPROG keeps an up-to-date list of all North American wind facilities. The probability density function will not only show the uncertainty, but also the uncertainty in the market expectations.

The prediction of the North American wind generation production is not calibrated with measurements, but the farm specific biases will probably level out well. The 20GW wind power in Germany is known to be predicted with approximately 3.5% normalized absolute error day ahead. The American farms are larger, but they are also more geographically dispersed, thus similar error levels can be expected.

The MSEPS system gives the possibility to model the entire grid with each ensemble member and check for constraints. The MSEPS system does therefore increase the overall system security and this is not only done by dealing with the local net.

3.3.5 WEPROG's Independence

WEPROG has a wide range of expertise in providing guidance on how to manage wind power cost effective and secure. WEPROG is a corporation and is run by the owners. This enables WEPROG to give quality the focus it needs.

WEPROG does not have commercial interests on the planner site despite the MSEPS ensemble would give planners more security in their decision making. WEPROG's focus is entirely on the forecasting with special emphasis on system security.

System security extends across national borders as energy is going to be exported over long distances in the future.

4 Reference Implementations and Customers

WEPROG's main customers to date have been in the electricity area, with real-time forecast delivery to TSO's such as Energinet.dk (former ELTRA) in Denmark (3000 MW), RWE Transportnetz Strom GmbH in Germany (20.000 MW), ESB National Grid in Ireland (500MW) and NEMMCO in Australia (600MW).

Data delivery to research projects and institutions as well as active participation and coordination in research projects are also ongoing. Research with WEPROG's ensemble data is ongoing at e.g. University College Cork (IRL), Ruhr-University Bochum (DE), ISET, Germany, Joint Research Center Ispra (IT), Espace Eolien Development (Fr), Bolding-Burchard Hydrodynamics (Dk), Institute of Mathematical Modelling at the Danish Technical University, Risø National Laboratory (DK).

Apart from wind energy research, the WEPROG's MSEPS data is also used for work on weather parameters such as precipitation for flood warning and storm surge.

Recommended contactable reference customers for AESO:

EirGrid plc., Ireland, Philip O'Donnell, <philip.odonnell@eirgrid.ie>

NEMMCO, Australia, Steve Trollope, <Steve_Trollope@nemmco.com.au>

5 Conclusions

WEPROG's MSEPS system is targeted to produce primarily wind power forecast, but is not limited to this topic. The system provides the worlds largest ensemble of weather forecasts, which particular suited for the energy market. The system allows modeling of weather dependent generation units, consumption, reserve requirements and risks.

The computer code is highly optimized and supports two level parallelism and scales therefore to far over 1000 processor cores. The entry levels starts at 80 processor cores and less for smaller projects non-operational research projects. The increase in the performance of enterprise servers makes the ensemble approach more and more attractive.

WEPROG's employees have a long history in numerical weather prediction and wind energy and started what developed to the MSEPS system in 2002 after some years of studying the error pattern. It took 4 years to reach a stage, where the system could win the first internationally announced tender in Australia.

The performance of the MSEPS system will be increasing with time as the relative performance measure of the 300 power forecasts becomes more robust. The maximum performance is only achieved after 2-3 years.

It has been tradition in Meteorology to update NWP systems 6 monthly. Such a high update frequency is against the principles of the MSEPS concept. There is a need for diversity in the model system to be able to predict the uncertainty of the weather correct. Once the correct level of diversity is found, then the need for code modifications reduces. The development of next generation systems shall be a completely non-operational process. This process will ensure that a new consistent 3 year historic forecast database will be ready with the next generation to be installed on new computer hardware. The expectation is that the core model system has reached a sufficiently robust level to run without patching for the lifetime of a computer system.

The power prediction part can be updated with any frequency as this uses relatively little CPU time and can take advantage of more variables with time. This part of the MSEPS system is therefore a separate optional package. It is also expected that wind power forecasting developers will use ensembles and therefore provide solutions in competition with WEPROG's power prediction.

WEPROG will continue to support wind power prediction until day 6 with the MSEPS system, but with emphasis on the first 2 days. Global ensembles seem to be a better choice for day 6-14 as they now focus on this forecast horizon.

The system has become ready at a time where wind energy has the highest growth rate. Therefore it is expected that the MSEPS system is going to be of great help around the world for the reason that wind energy is a difficult quantity to predict .

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Appendix A: “About us”

WEPROG was established in early 2003 with the aim of developing a real-time ensemble prediction system for the electricity market and those companies that deal with weather sensitive goods or services.

WEPROG's founders and directors Jess U. Jørgensen and Corinna Möhrle have developed a Multi-Scheme Ensemble Prediction System (MSEPS) in order to provide a solution to a problem that has been researched extensively over the past two decades, both in meteorology and wind engineering.

The MSEPS approach provides information about a crucial parameter: physical uncertainty of the weather.

WEPROG was first established as a privately owned company, with its main objectives being to transfer an approach that was until then only used in experimental research into a fully operational prediction system.

The first operational system was started in summer 2003 and consisted of 75 ensembles of forecasts, to produce physical uncertainty parameters of the weather situation for forecast horizons of 3-4 days. The operational MSEPS system has been developed by a team of scientists with over 20 years experience in meteorology, engineering and super-computing.

WEPROG ApS (GmbH/Ltd) was established in spring 2005 in order to coordinate real-time services and to expand the services internationally by establishing extended computing resources.

WEPROG's Board of directors

1. Jess U. Jørgensen
2. Corinna Möhrle

WEPROG's Business Risks

WEPROG's major risks are in the correct functioning of the computing facilities to produce its forecast products. To ensure timely delivery, WEPROG has a risk management and disaster plan in place, which ensures that WEPROG's computing resources are spread over 3 places, physically separated 500-1000 kilometers and that all Computer systems are installed with safe power and high speed networks on Linux Clusters.

At present the computer systems are installed in Denmark (1) and in Germany (2).

WEPROG risk management plan lead to a grid computing system, that ensures timely and secure delivery to customers, because all forecast suits are performed independently of each other at different locations and on different electricity grids and network points.

WEPROG also holds an appropriate professional indemnity insurance for services in the IT, network, telecommunication, Online-Services, internet, intranet and extranet.

WEPROG's operational system, customers and hardware

The first demonstration system covering Europe and the Atlantic started in operation in summer 2003 after an extensive programming period. One year later WEPROG started to produce forecasts 4 times per day in three different horizontal resolutions (45km, 15km and 5km), as 75 forecasts of the expected wind power load for the next 72 hours. In 2005 WEPROG began generating weather forecasts for all continents in limited (60km) resolution. This has ensured that the model system is capable of coping with all types of weather and that the service is available internationally. In 2006 the success of the global forecasts lead to the introduction of hemispheric models for the northern hemisphere as well as the southern hemisphere, which enabled WEPROG to producing 6-day forecasts every 6 hours (since July 2006).

WEPROG's main customers to date have been in the electricity area, with real-time forecast delivery to TSO's such as Energinet.dk (former ELTRA) in Denmark (3000 MW), RWE Transportnetz Strom GmbH in Germany (19.000 MW), ESB National Grid in Ireland (600MW) and NEMMCO in Australia (600MW), electricity traders (e.g. Shell Trading UK), power generators (e.g. E.ON (UK), Airtricity Ltd.(IRL), E2Energi (DK)).

Data delivery to research projects and institutions as well as active participation and coordination in research projects are also ongoing. Research with WEPROG's ensemble data is ongoing at e.g. University College Cork (IRL), Ruhr-University Bochum (DE), ISET, Germany, Joint Research Center Ispra (IT), Espace Eolien Development (Fr), Bolding-Burchard Hydrodynamics (Dk), Institute of Mathematical Modelling at the Danish Technical University, Risø National Laboratory (DK).

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