

Using combined prediction systems for wind energy applications

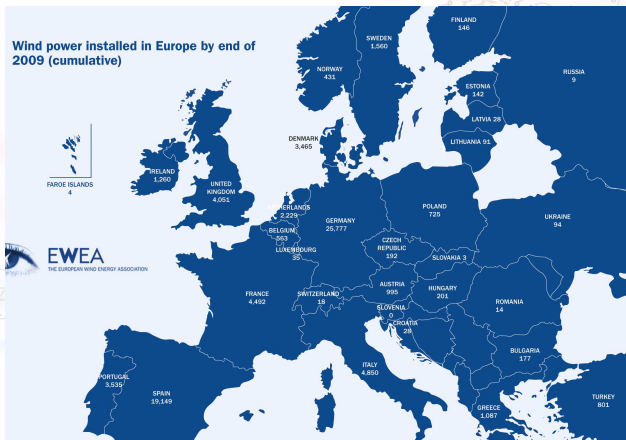
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ECMWF Training Course
Predictability, Diagnostics and Extended-range Forecasting
18-27 October 2010

Wind power in Europe

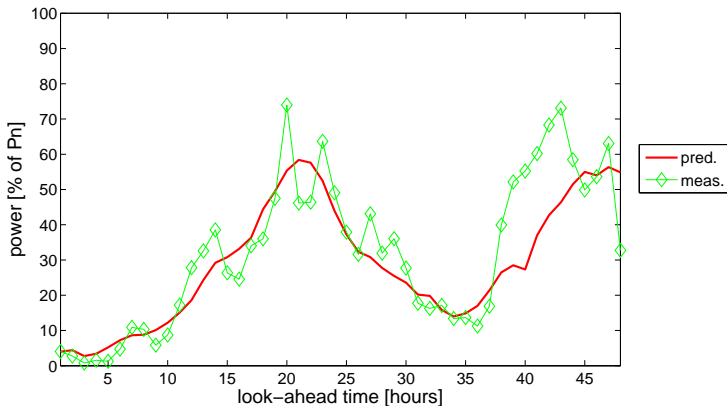
- Status: 75GW
- Targets for 2020:
 - 180GW total
 - incl. 40GW offshore



- Challenges: reliable large-scale integration, economic and secure management of power systems, competitiveness of wind energy in liberalized electricity markets
- **Forecasting is a cost-effective solution for easing large-scale wind power integration**

Background: single-valued forecasting

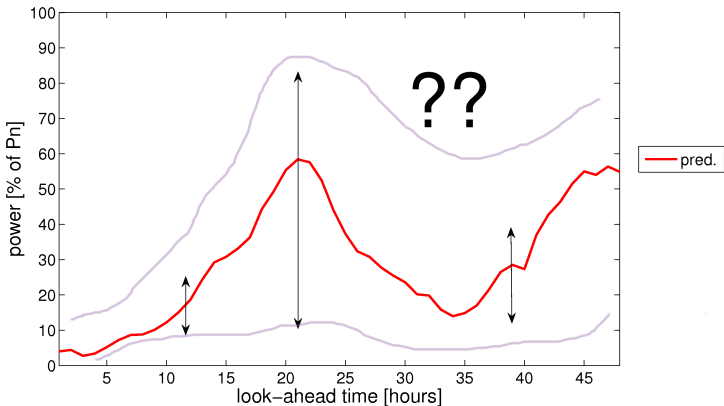
- Forecasts are commonly provided in the form of point forecasts (i.e. the conditional expectation for each look-ahead time)



- Several studies have permitted to establish their level of accuracy, depending on various factors (look-ahead time, terrain characteristics, climatology, etc.)

Background: uncertainty ?!?

- The level of accuracy is highly variable from one prediction to the other. This makes that wind power predictions may be somehow hard to handle...



- One cannot make optimal decisions from such forecasts, an information on their (non-Gaussian) uncertainty is necessary !!

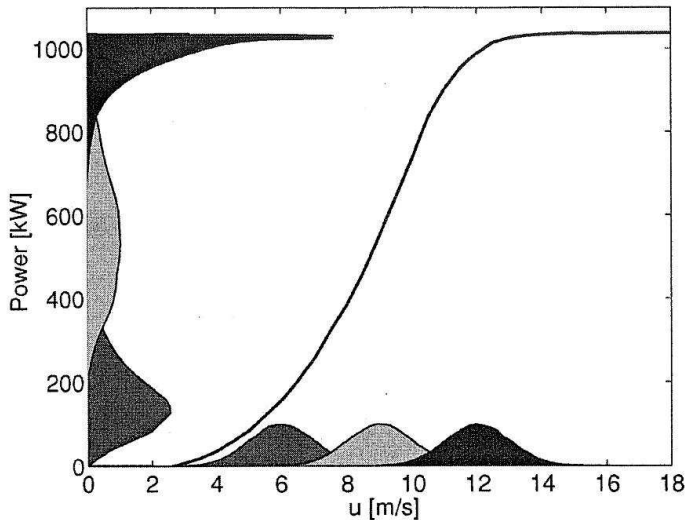
Various scales - Similar issues

- Different temporal (and potentially spatial) scales:
 - **seconds**: turbine control
 - **minutes**: wind farm control
 - **hours**: power plant scheduling
 - **hours to days**: trading
 - **days to weeks**: maintenance planning
 - **months to years**: resource, planning, investment (not relevant here)
- Similar issues:
 - wind power generation is a **nonlinear** process
 - it is also **nonstationary** for all those time scales considered
 - for most of the decision-making problems involved, one encounters **asymmetric, complex and nonstationary, cost functions**

- **Nonlinearity and nonstationarity**
 - influence of the power curve
 - predictability of meteorological variables
 - illustration of nonstationarity
- **Different loss functions**
 - in mathematical terms
 - in 'psychological' terms
- **Probabilistic scenario (/ensembles) forecasts**
 - statistical and ensemble-based approaches
 - predictive densities and scenarios
 - simple risk indices
- **Making decisions from forecasts**

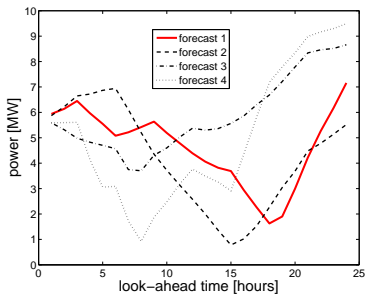
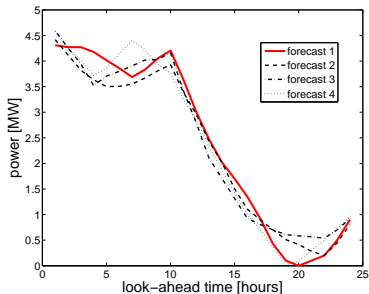
Influence of the power curve

courtesy of Matthias Lange



Predictability of meteorological variables

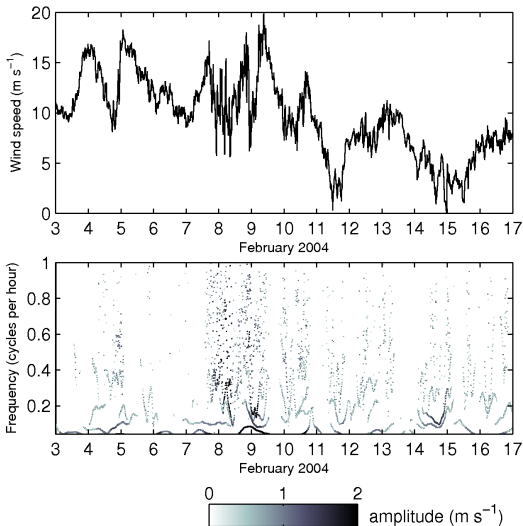
- A large part of the prediction error directly comes from prediction of weather variables
- This uncertainty in the meteorological forecast is then amplified or dampened by the power curve (model)



typical representation of what could be more and less easily predictable situations...

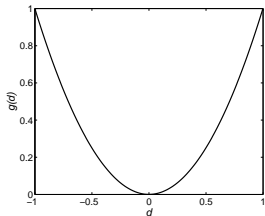
Illustration of nonstationarity

- Episode with one 2 weeks of 10-minute wind speed measurements
- Spectral analysis of the time-series with the Hilbert-Huang transform
- Evidence of successive periods with significantly different spectral behaviour of wind speed time-series

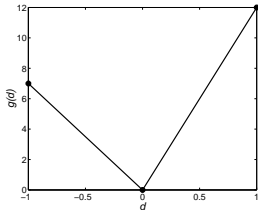


Different loss functions

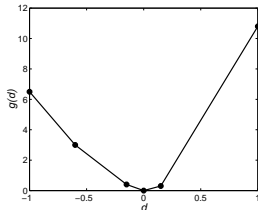
- Forecasters and forecast users have different loss functions
- Actually, each forecast user has its own cost function (that he does not necessarily know...!!)



Forecaster



Trader (wind power only)



Portfolio manager

- So... What is the best forecast in such a case??

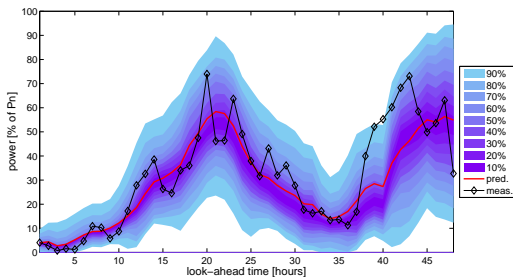
Different views of forecasting

- The caricature is that:
 - **Forecasters** are cold-hearted and like machines: they focus on being “the best” within evaluation frameworks they build themselves
 - **Forecast users** are human and emotional... Their appraisal of what makes a good forecast may not follow scientific reasoning
- Going in that direction, Murphy has introduced the following concepts:
 - **quality**: the accuracy of the forecasts from a forecaster’s ‘objective’ point of view
 - **value**: the benefits (for forecast users) from integrating forecasts in decision-making
- When the forecasting problem becomes complex, forecasters must also consider the **best way of communicating** their forecasts!!

Probabilistic forecasting

- The most common way of providing uncertainty estimates is to associate point predictions with (nonparametric) **probabilistic forecasts**, which can be:
 - **quantile** forecasts: there is a probability α that power production is below that value (e.g. the median, $\alpha = 50\%$)
 - **interval** forecasts: there is a probability $(1 - \alpha)$ that power production is covered by the interval – e.g. $(1 - \alpha) = 90\%$
 - **density** forecasts: give the full predictive distributions of wind power for each look-ahead time

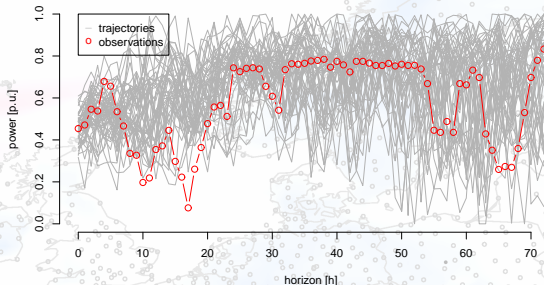
- Several statistical methods:
 - local quantile regression
 - time-adaptive quantile regression
 - adapted resampling
 - etc.



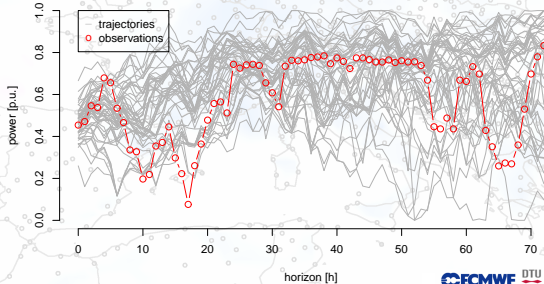
- They do not inform about the interdependence structure of forecast uncertainty!!

But is that important anyway?

- almost no temporal correlation

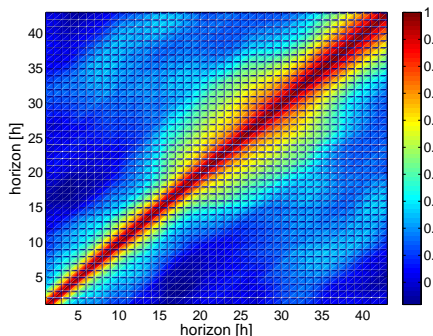


- appropriate temporal correlation



Statistical scenarios of wind generation

- If one knows
 - the **marginal distributions** of wind generation for each look-ahead time,
 - the **interdependence structure** of prediction errors,then one can generate a number of realistic scenarios of short-term wind power production.
- Such scenarios may be more appropriate for certain decision-making problems.
- The method involves:
 - transformation of marginal distributions to Normal,
 - tracking of the interdependence structure,
 - generation of 'Normal scenarios',
 - transformation back to marginals

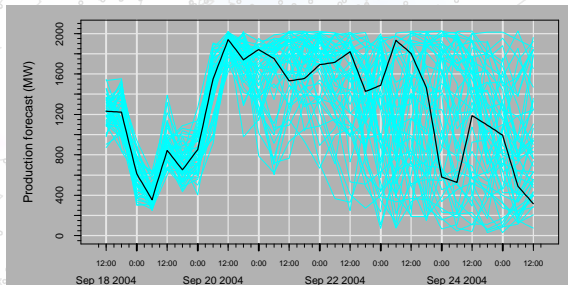


The good and the bad...

- Statistical methods can use different explanatory variables:
 - predicted power from a point prediction method (when used for post-processing them)
 - predicted wind speed and direction
 - other variables that are known to impact forecast uncertainty...
- They are **reliable** in the sense that their predictions are probabilistically correct:
50% prediction intervals indeed cover the measured wind power production 50% of the times !!
- ... but their **sharpness/resolution** is arguably not optimal, since they have a hard time integrating the information on the predictability of weather situations.
- **This motivates the research works on ensemble forecasting of wind power**

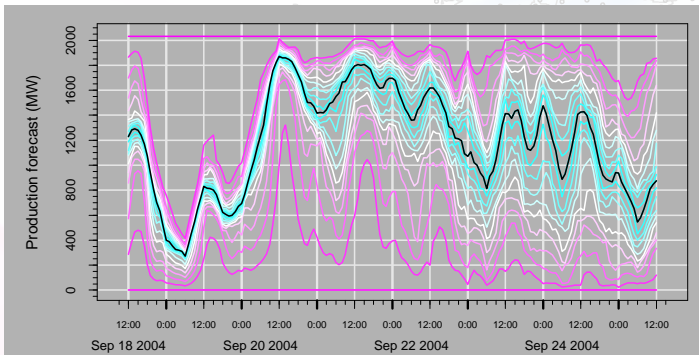
Ensemble forecasting

- **Ensemble forecasting** is the mainstream approach to uncertainty estimation developed by the meteorological forecasting community
- Ensemble predictions of **meteorological variables** consist in a set alternative scenarios for the following hours (and up to 2 weeks ahead):
 - ECMWF: singular vectors - 51 members
 - NCEP: breeding - 11 members
 - Weprog: multi-scheme - 75 members
 - etc.
- Ensemble predictions of **wind power** can be obtained:
 - from meteorological ensembles as input...
 - ... consequently converted to power with appropriate statistical methods



Probabilistic forecasts from ensembles

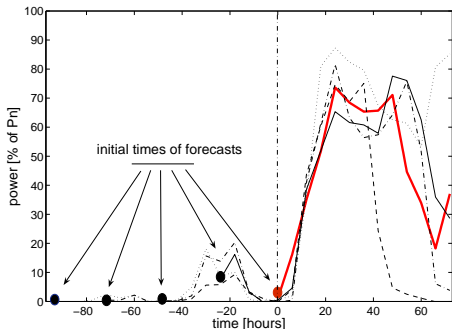
- It is known that ensemble forecasts of wind power are not correct in a probabilistic sense, i.e. they are **not reliable**
- They can be converted to reliable probabilistic forecasts with appropriate recalibration methods (e.g. conditional parametric models, smoothed bootstrap, bayesian model averaging)



Example from a real application: probabilistic forecast from ensembles for the area of Jutland (western Denmark)

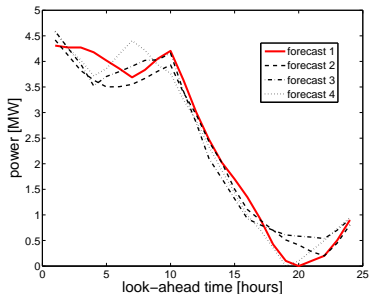
Skill forecasts from ensembles

- **Skill forecasts** are an alternative/complementary way of providing an information on expected uncertainty
 - Instead of predictive distributions, a **risk index** (i.e. a single numerical value) tells on the confidence to have in the provided point predictions...
 - ... for a single look-ahead time or from a look-ahead period (e.g. day 1, day 2, etc.)
-
- Risk indices can be given from the spread of
 - 'real' ensembles (ECMWF, etc.)
 - multi-model (poor man's) ensembles
 - temporal ensembles

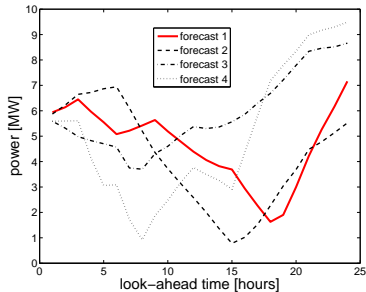


They may allow one to make a choice among a set of more or less risk averse decisions...

Back to original illustration



- low risk index value -



- high risk index value -

- One can define categories of risk index values (e.g. [1,2,3,4,5] or [green,orange,red]) and communicate forecast uncertainty in a simple manner...

Using probabilistic forecasts

- Several decision-making problems start to be considered in the literature:
 - definition of **reserve** requirements
 - operation of **combined wind-hydro**
 - operation of wind associated with **storage**
 - design of optimal **trading** strategies
- Inputs for these methods are:
 - power production **scenarios**: ensemble members, monte-carlo simulation, time-series models
 - **predictive distributions**: from ensemble predictions or purely statistical methods
 - **risk indices** from ensemble predictions (or some other kind of classification methods of weather situations)

The *value* of wind power

- The *value* of wind power corresponds to the effective revenue per generated MWh in operational conditions
- In a liberalized market environment, this revenue is composed by the benefits from contract on the spot market, minus the 'unavoidable' costs for regulation
- We consider here the simplest situation of having:
 - a day-ahead spot market (with gate closure 12-16 hours before actual delivery), combined with a regulation market,
 - wind as a unique portfolio
- For each Program Time Unit (PTU) k on the market, this writes

$$R_k = p_k E_k^* - \pi_k d_k$$

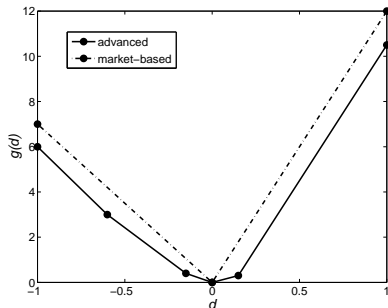
where:

- p_k : spot price on the market for PTU k ,
- E_k^* : amount of energy *actually* generated for that PTU,
- π_k : regulation unit cost (either π_k^+ or π_k^- depending on the sign of needed regulation),
- d_k : deviation from contract, i.e. $E_k^c - E_k^*$

Implications of the market structure

- The first part of the revenue is fatal, since it corresponds to actual wind generation...
- ... but the second part (regulation costs) is a stochastic variable, whose behaviour is directly influence by the wind power producer's bid

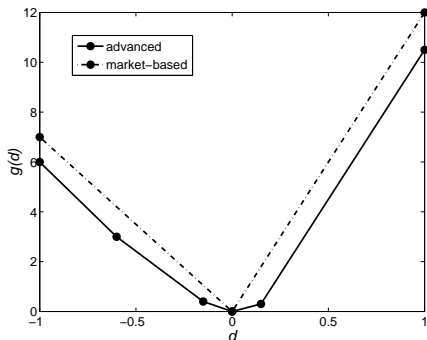
- The regulation costs are influenced by:
 - the error in wind power predictions, as they are used as a basis for making bids,
 - the regulation unit costs on the regulation market, that may be highly variable and difficult to predict.
 - the asymmetry of these regulation costs encourage wind power producers to be more strategic in their way of bidding !!!



And so what can we do ??

- Develop *stochastic optimization* methods that accounts for the stochastic behaviour of wind and market prices, in order to
 - optimize **long-term revenues**, by minimizing the expectation of regulation costs,
 - minimize the **short-term losses**, by accounting for the risk-averse attitude of the wind power producer, and hence minimize the risk of large regulation costs

- This can be by using input such as
 - a model of the loss function of the wind power producer, i.e. a model of his sensitivity to the cost of deviations from contract,
 - predictions of wind generation, along with an information on their uncertainty...



Example application of trading strategies

- **Dutch electricity market** over the year 2002:
 - day-ahead market APX
 - regulation mechanism managed by TenneT, the TSO for the Netherlands
- Participation of a **15 MW wind farm**, without any storage device and without any control on the power production
- **Point** and **probabilistic** predictions (full predictive distributions) generated with state-of-the-art statistical methods
- **Revenue-maximization** strategies
 - based on point predictions only (persistence or advanced method)
 - derived from probabilistic predictions and a model of the participant's sensitivity to regulation costs
- Note that it can be shown that **point predictions are not the optimal bids** to be made on the spot market


Trading results

	Pers.	Adv. point pred.	Prob. pred.	Perfect pred.
Contracted energy (GWh)	44.37	45.49	62.37	46.41
Surplus (GWh)	18.12	9.87	4.89	0
Shortage (GWh)	16.08	8.95	20.85	0
Down-regulation costs (10^3 €)	195.72	119.99	42.61	0
Up-regulation costs (10^3 €)	79.59	52.01	61.46	0
Total revenue (10^3 €)	1041.38	1145.69	1212.61	1317.69
Av. down-reg. unit cost (€/MWh)	10.80	12.15	8.71	0
Av. up-reg. unit cost (€/MWh)	4.95	5.81	2.95	0
Av. reg. unit cost (€/MWh)	8.05	9.13	4.04	0
Av. energy price (€/MWh)	22.44	24.68	26.13	28.37
Part of imbalance (% prod. energy)	73.69	40.55	55.46	0
Performance ratio (%)	79.1	86.99	92.1	100

Concluding remarks

- Wind power forecasting is a “mature” research field, with advanced products available and proven in operational conditions
- The main characteristics of the prediction **uncertainty** are **well understood**, and different frameworks have been proposed for its further understanding
- **Ensemble forecasts** are recognized as a crucial input to wind probabilistic forecasting methodologies...
- ... and a large number of research teams are working on using them optimally.
- So far, **however**:
 - few prediction systems provide their end-users with appropriate and reliable probabilistic information
 - only few decision-making methods are based on probabilistic forecasts, even though decisions cannot be optimal if relying on a point prediction only (!!)
 - quality and value of forecasts (point or probabilistic) are often not considered in an integrated manner

- **Education and training** are to play a significant role in better use of forecasts and decision-making
- **Collaboration** between meteorologists, statisticians (or mathematicians in general), power systems engineers and all type forecast users is one of the key for future breakthroughs
- A **probabilistic** view of the forecasting problem is mandatory even though for operational/commercial applications one may provide forecast users with a single point value only
- For that, the various (complex) loss functions of the various forecast users have to identified and understood...

A map of Europe and its surrounding regions, including parts of North Africa and the British Isles. The map is overlaid with a grid of small, light-colored circles representing observation points. The background of the map is color-coded with a gradient from light blue to light red, likely representing a meteorological variable like temperature or pressure. The text "Thank you for your attention..." is centered on the map.

Thank you for your attention...