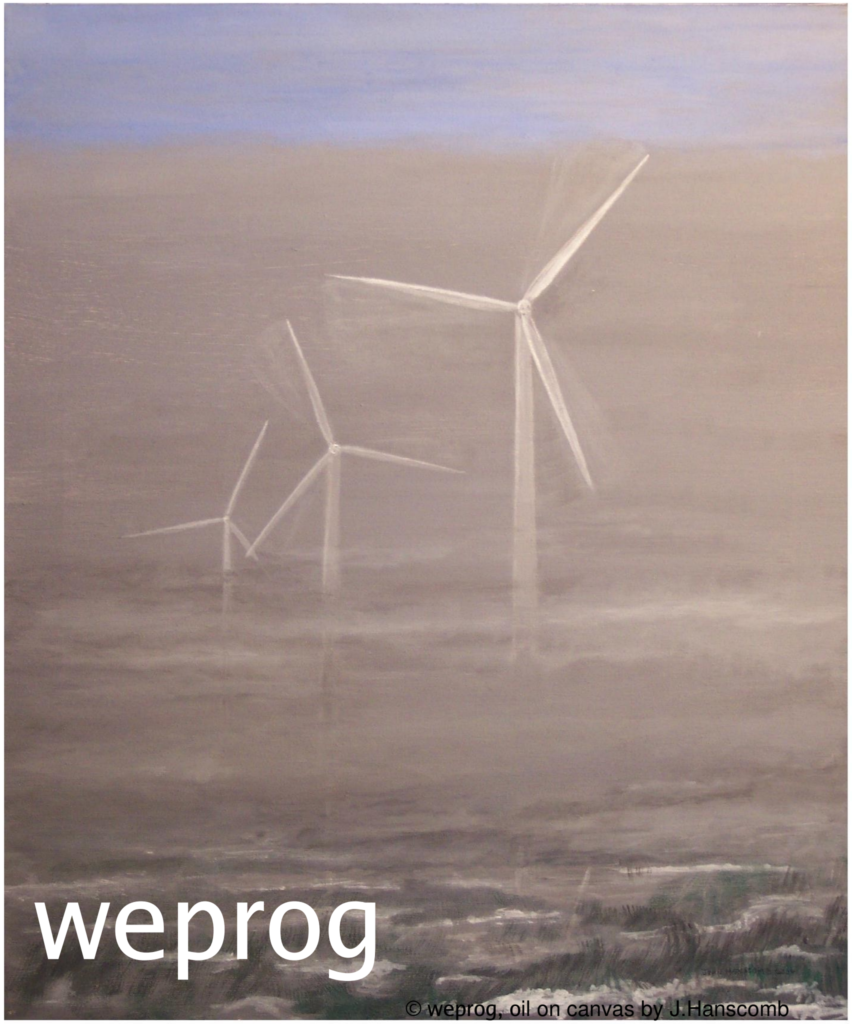
CanWEA / AWEA Joint Seminar

WIND ENERGY INTEGRATION AND FORECASTING

April 25 – 26, 2007 Calgary, Alberta, Canada



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Brief overview of the Danish Wind Energy history

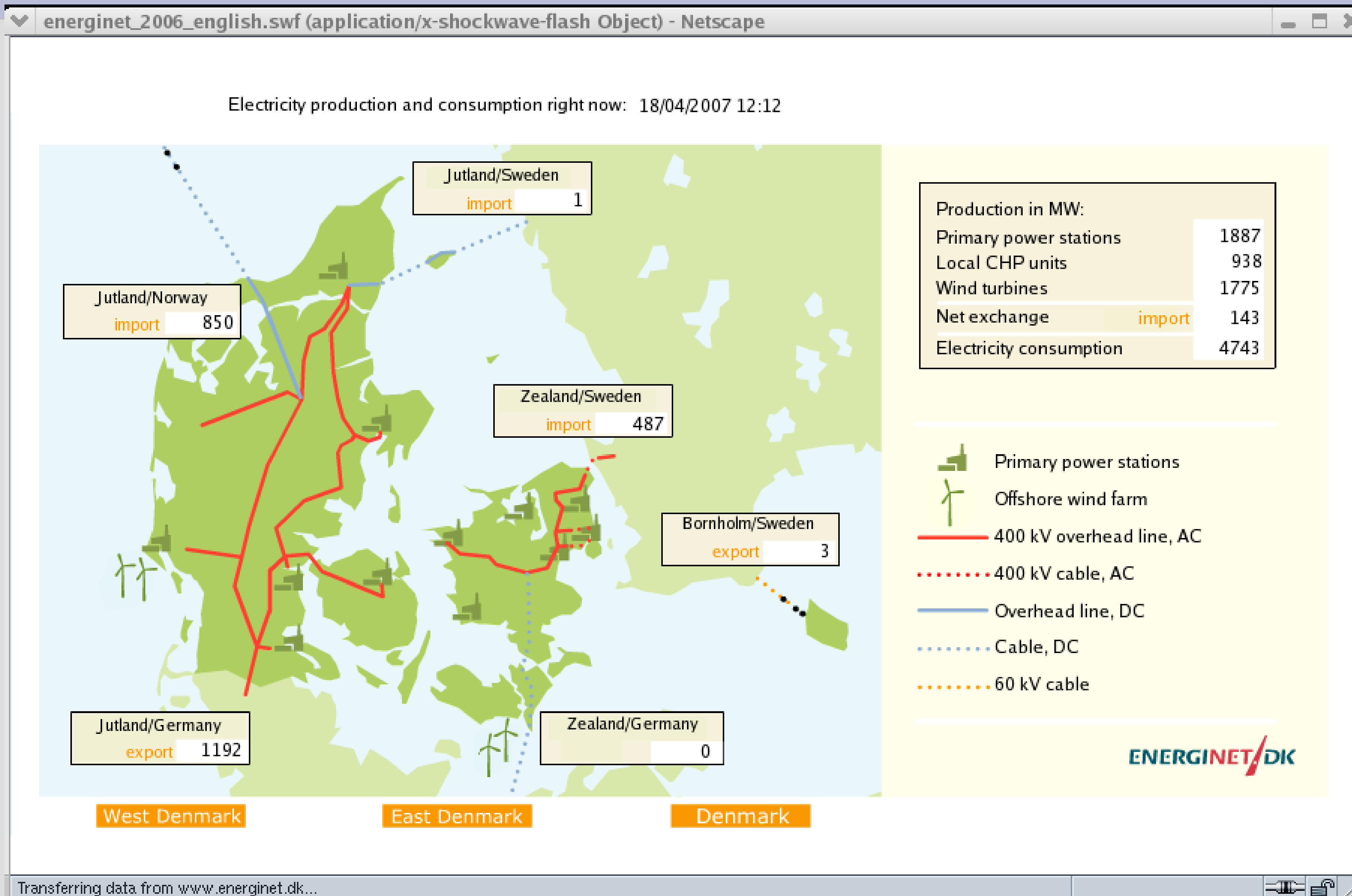
20 years with kW turbines & no recognition on TSO level

6 years of heavy development

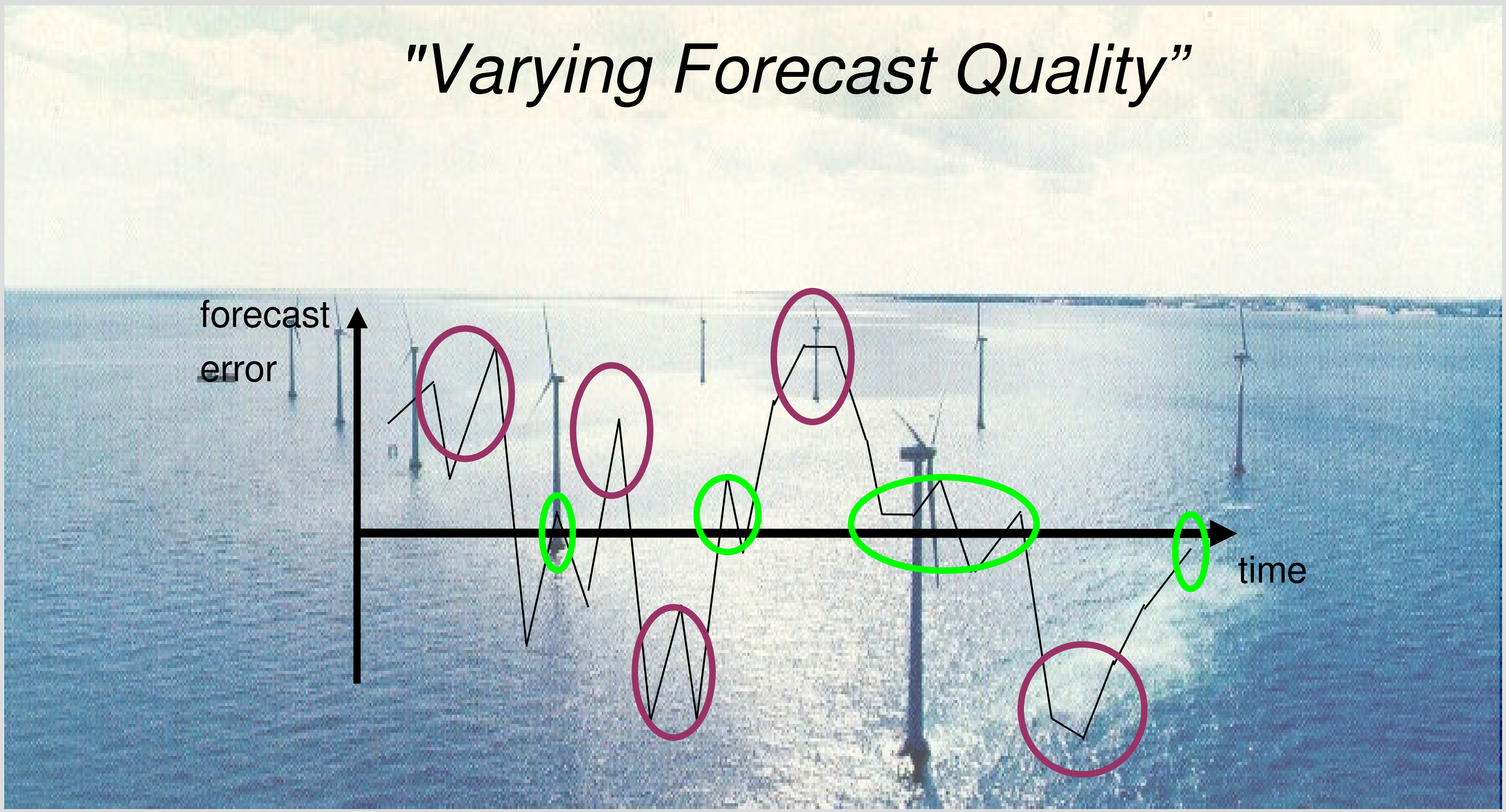
5 years experience with large integration of wind – min consumption 1.1GW – max production 2.5GW

Year	Installations turbines/year	Installations MW/Year	installed by	Comment
1976	<10	0.025	private	First modern turbines installed
	100	1	private	First year with more than 100 turbines raised
1976-1979	300	20	private	First year with more than 350 turbines raised
	400	50	private	Changes in regulations on where to build
1980-1984				EU-funded forecasting projects started (JOULE)
1985-1986				Utilities split and 2 TSO formed
1990-1995	300	50	mixed	Utilties forced by government (1990-1995) to build 25 farms
1996				First operational wind power forecasting system (WPPT)
1996				Old turbines classified as depriorited
1997-2001				16 wind farms online only - used to with 120MW used for upscaling
1996-1999	450	300	private	All on fixed price
1996-2001				Doubling of capacity every year
2000	700	600	private	Economy good but many gearbox problems
2001	100	100	private	Public debate about too many turbines
2001				Balance costs considerable - energy price determined by the level of wind
2001				First events where all energy was supplied by wind
2002	400	500	private	Last year before price changes
2002				Payment reduced - no additional turbines raised since
2002				Forecast upgrade - now 40 sites online
2003-2004	160	330	Utilities	2 offshore projects in operation
2003				Liberalized balance responsability of depriorities wind
2003-2005				170 sites online - WPPT forecasting in 17 areas – Meltra in 25
2004				Intraday trading opened for East Denmark
2005-2006				GAS+Electricity system operators merged
2006				Political discission in interconnecting East and West
2007				Reserve market nation wide
2007				Intraday trading opened nation wide

Interconnectivity of the Danish Electricity system with the neighbouring countries



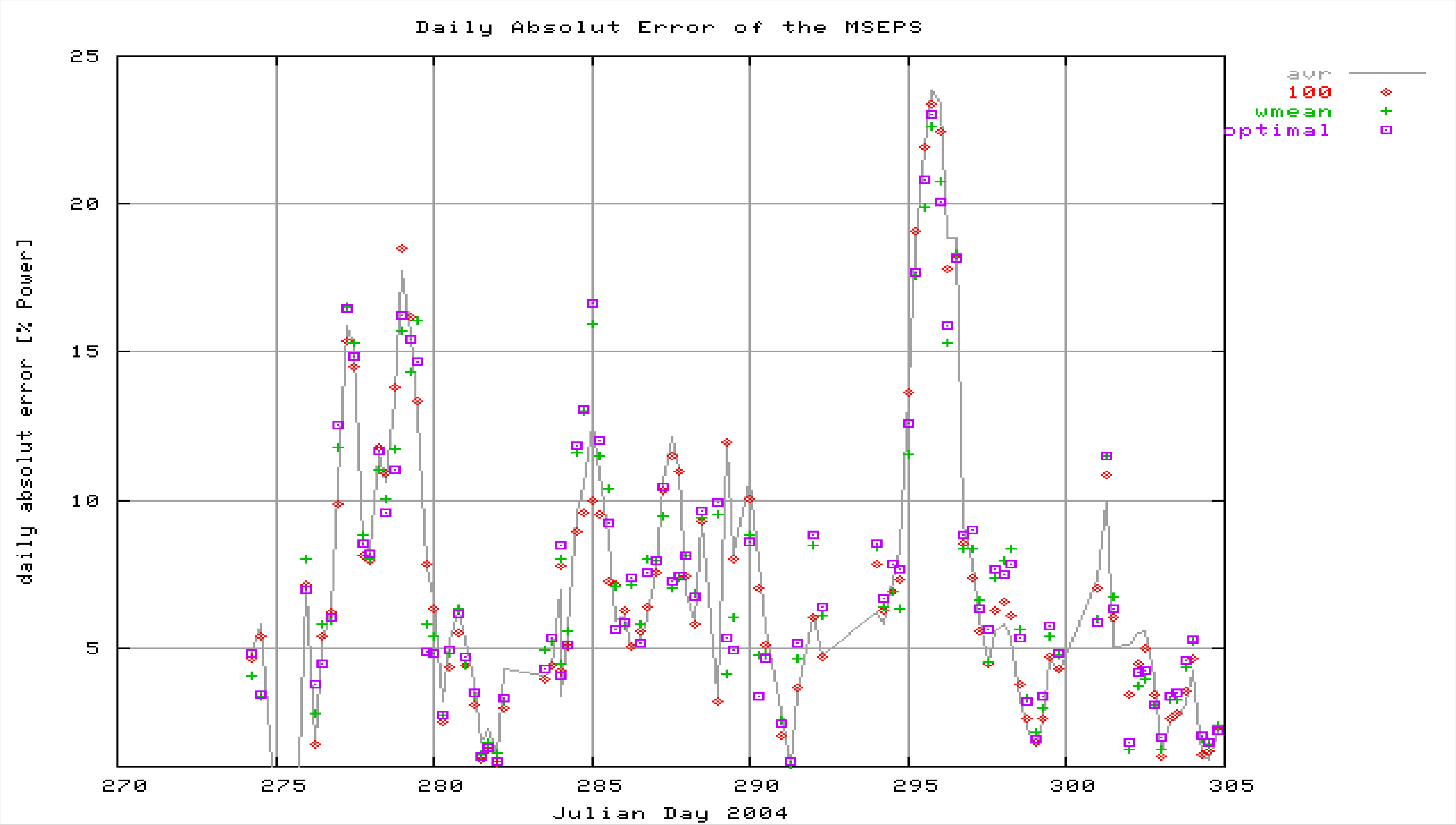
The Confidence Problem



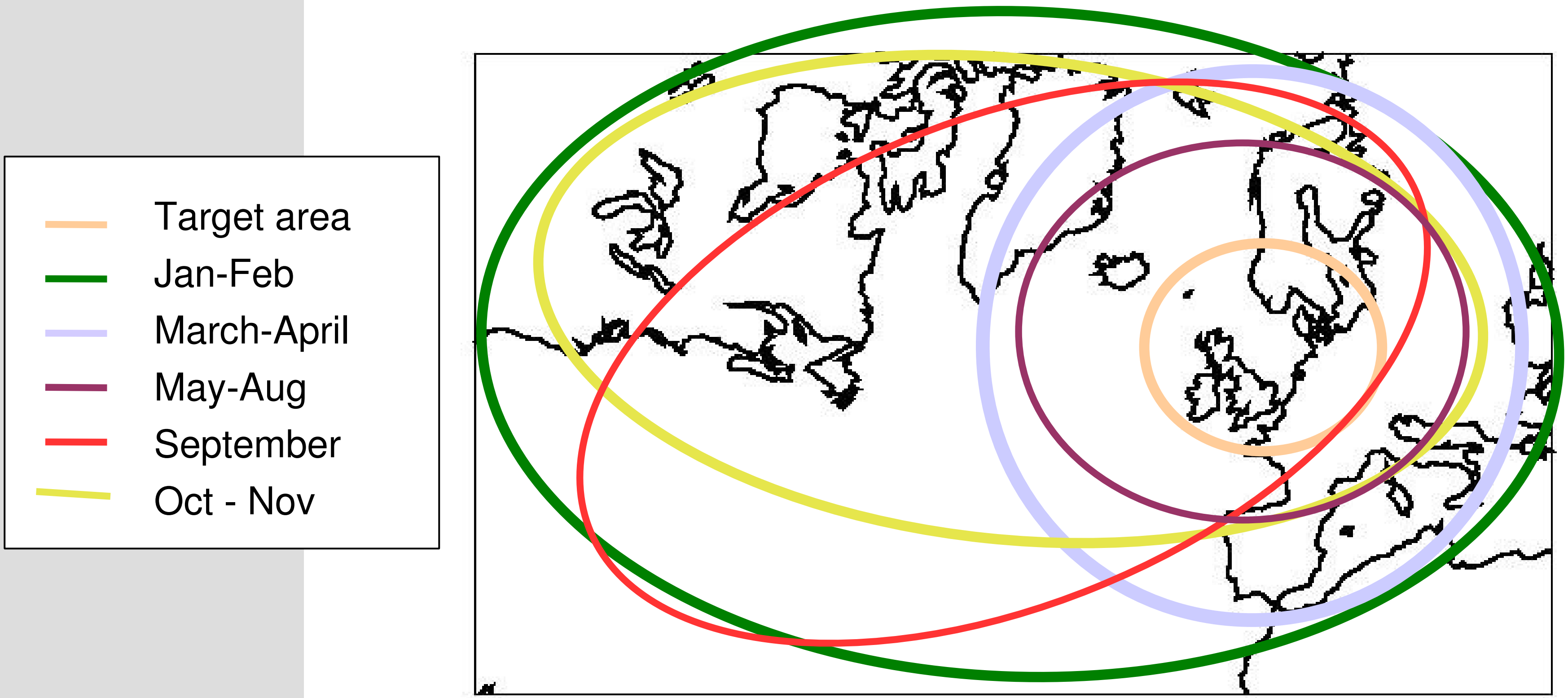
The background

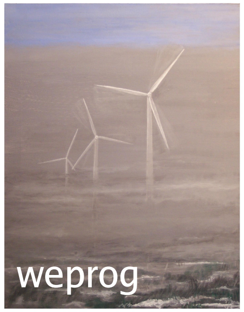
- the weather changes fast between **predictable** and **non-predictable**
- subjective methods are not sufficient to estimate predictability
- the commercial world suffers from various prediction mistakes

A typical “real” daily forecast error



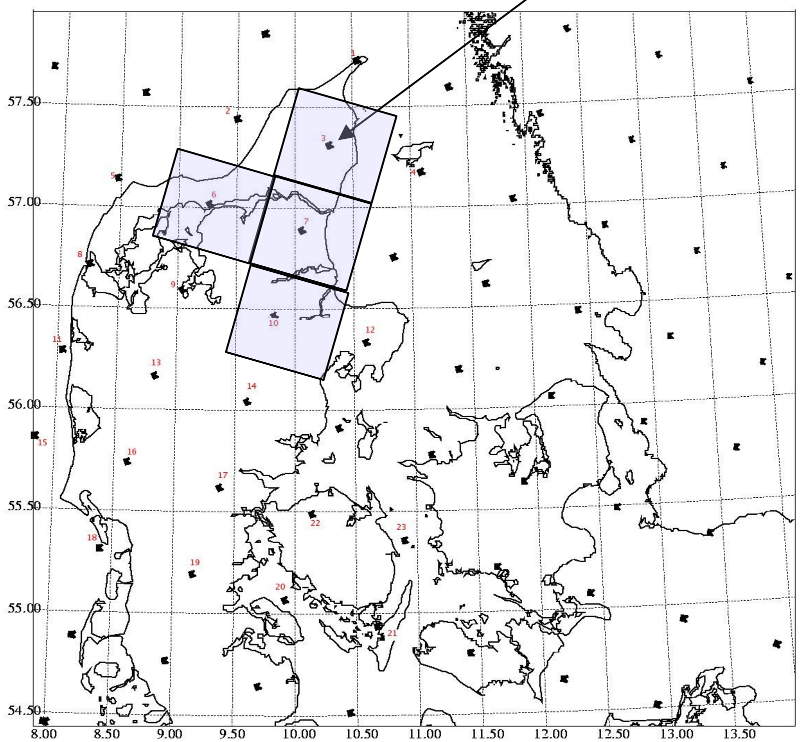
Area of influence at different times of the year



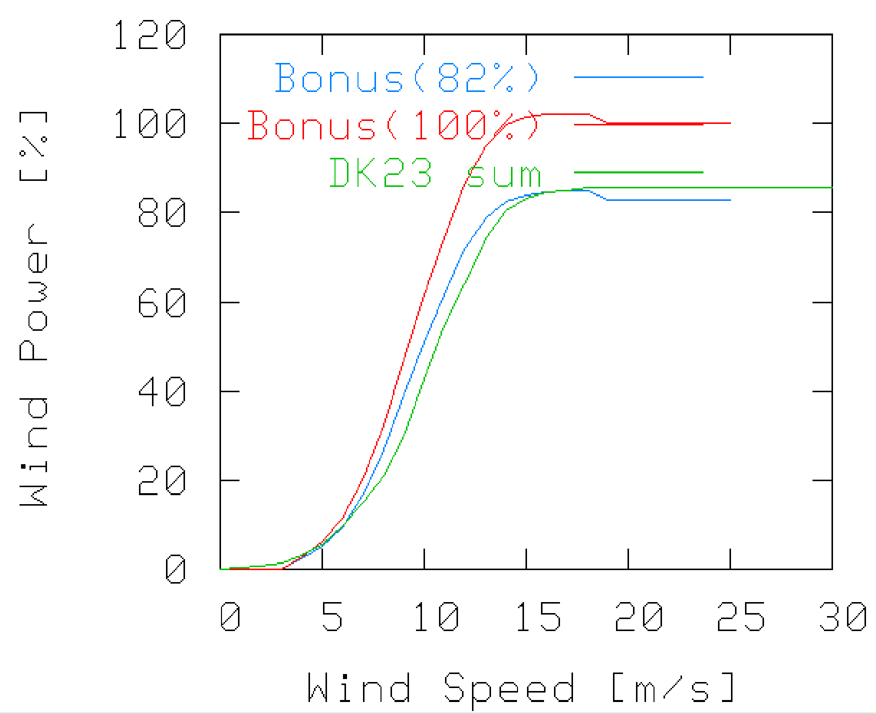


Power Prediction in a country with highly dispersed wind turbines and small wind farms

Power conversion in the NWP model gridpoints



Power Curves are generated from frequency distributions or least square methods of modelled wind speed and measured wind power as a gridbox-average



The solution to the confidence problems : Ensemble Predictions

Summary of the problems:

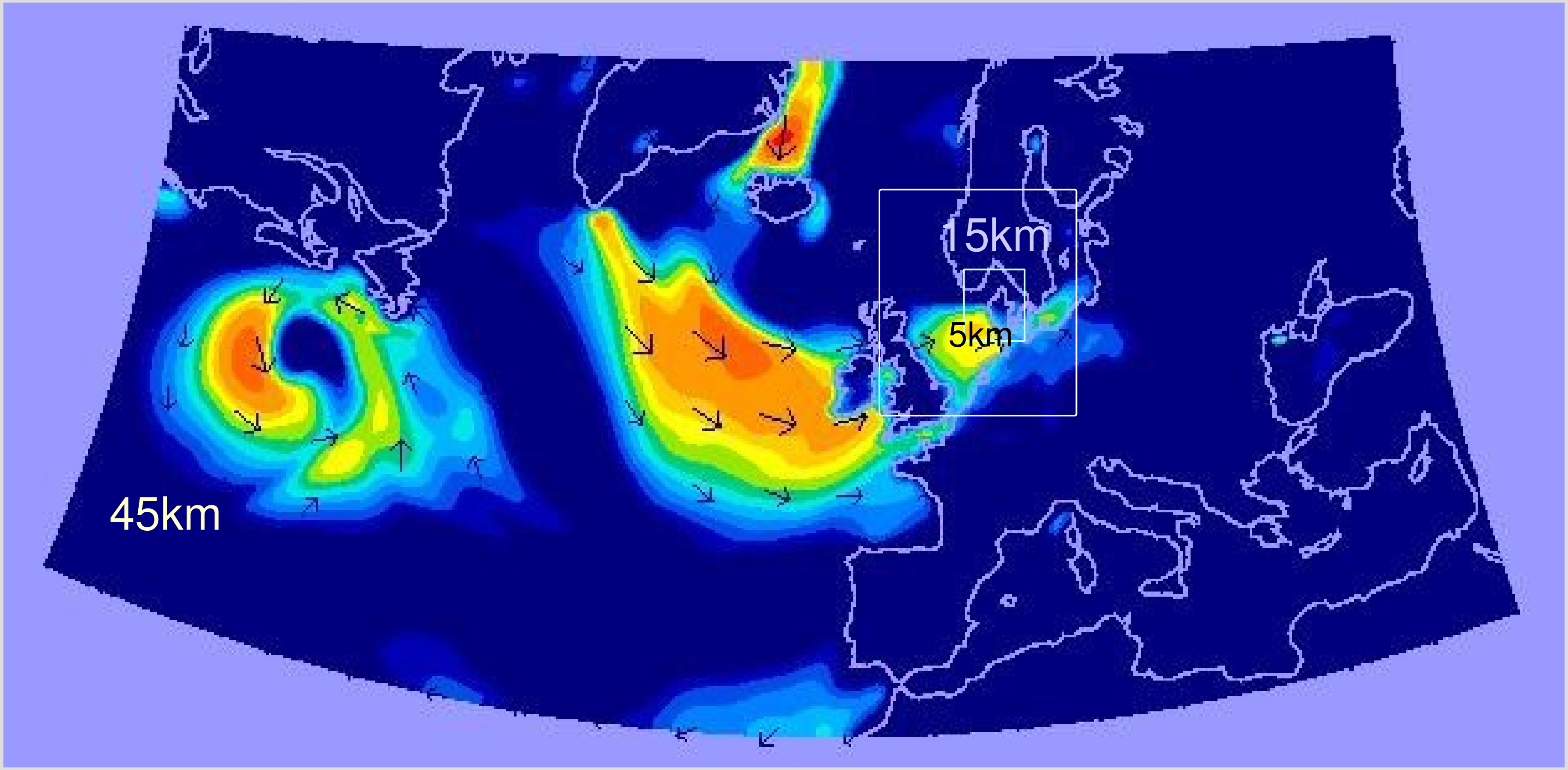
- Varying forecast quality
- anti-correlating forecasts – observations generate unwanted ramping
- confidence in forecasts are low – responsibility and requirement for security is high
- changing area of influence –> model area needs to be large -> unfeasible with high resolution

The solution:

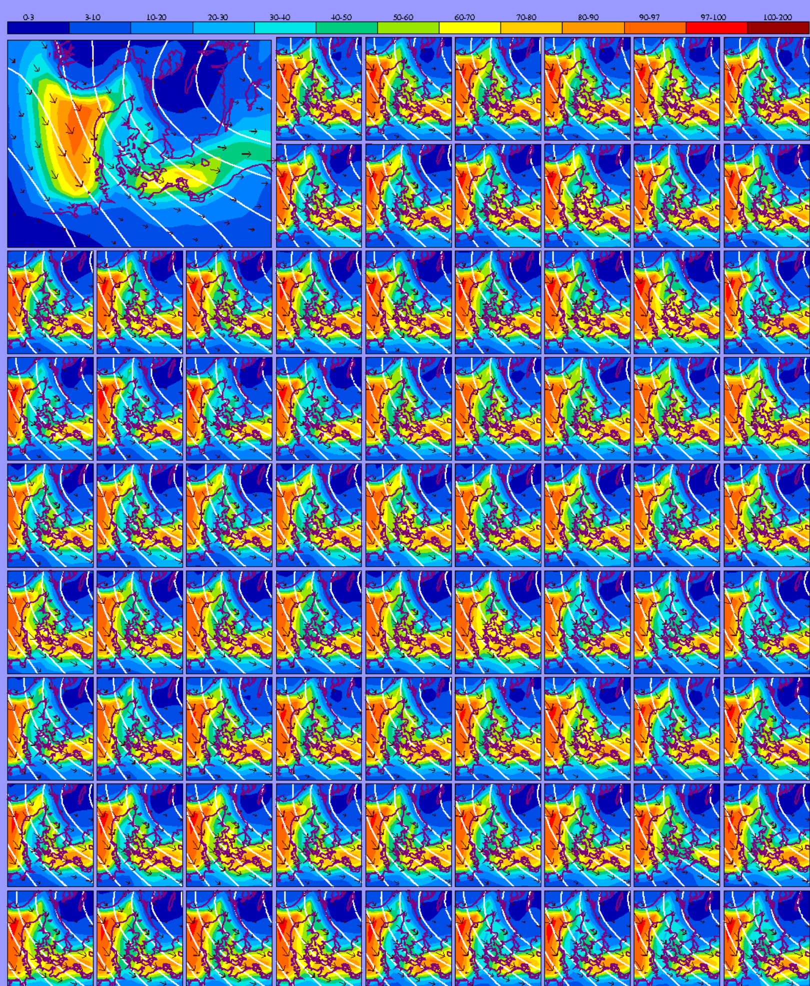
- run a large number of different independent model configurations
- evaluate the uncertainty directly on the final product

The Domain of Dependence for Denmark West for a 2-Day Forecast

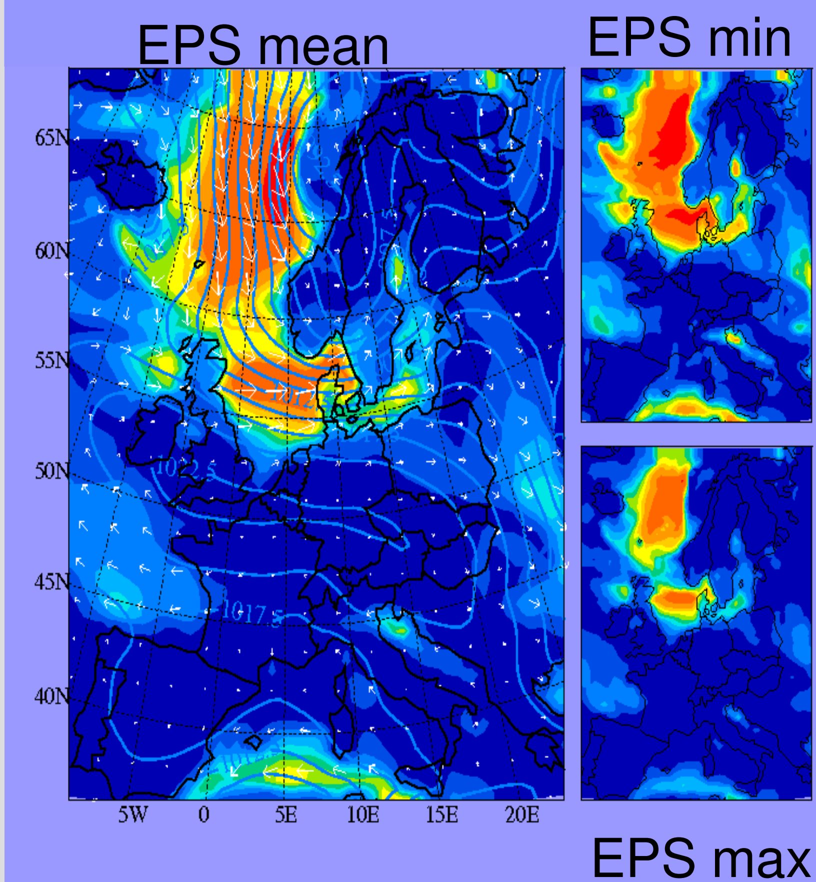
Triple nested grid with 3 different resolutions



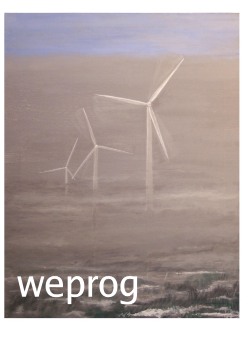
The solution to the confidence problem: Ensemble Predictions



75 Forecasts of Wind Power Potential over Denmark

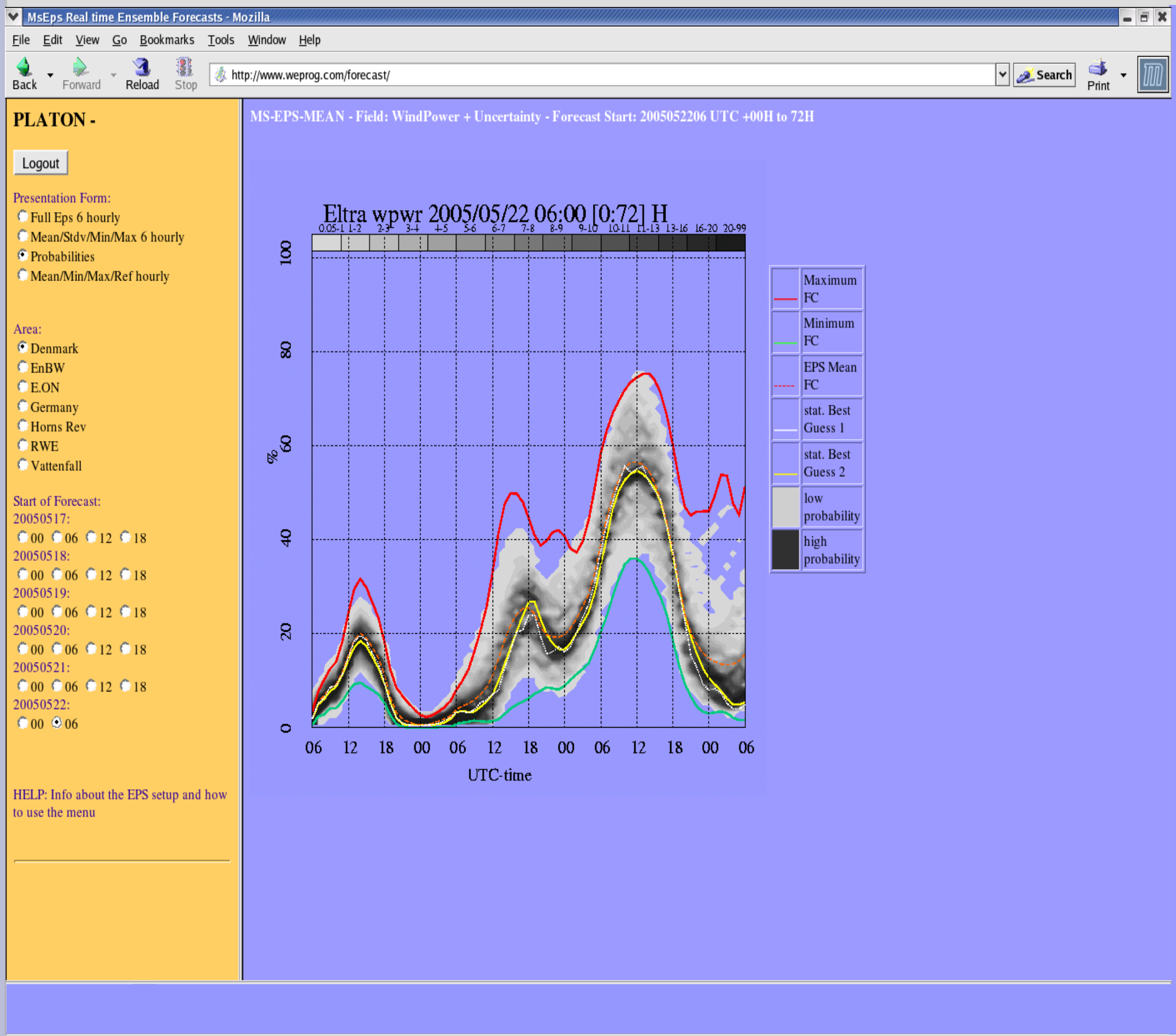


Potential Wind power over Europe

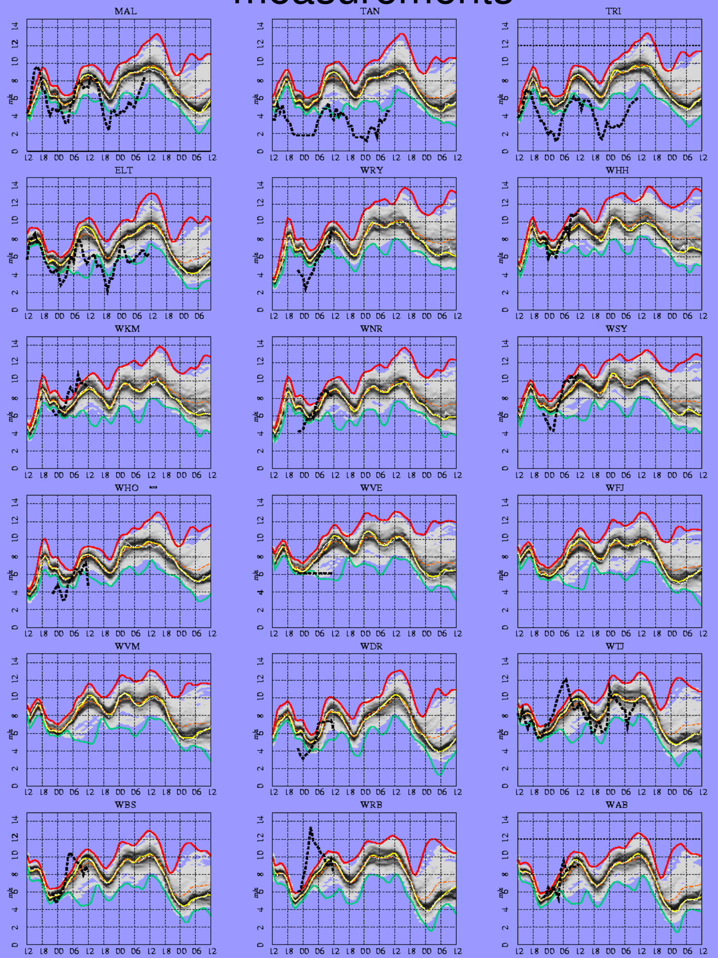


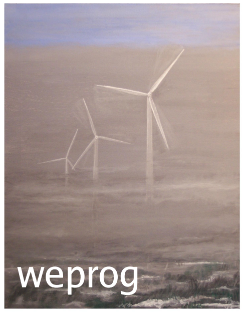
The solution to the confidence problem: Ensemble Predictions in the daily operation

GUI for Wind Power Prediction with Probabilities

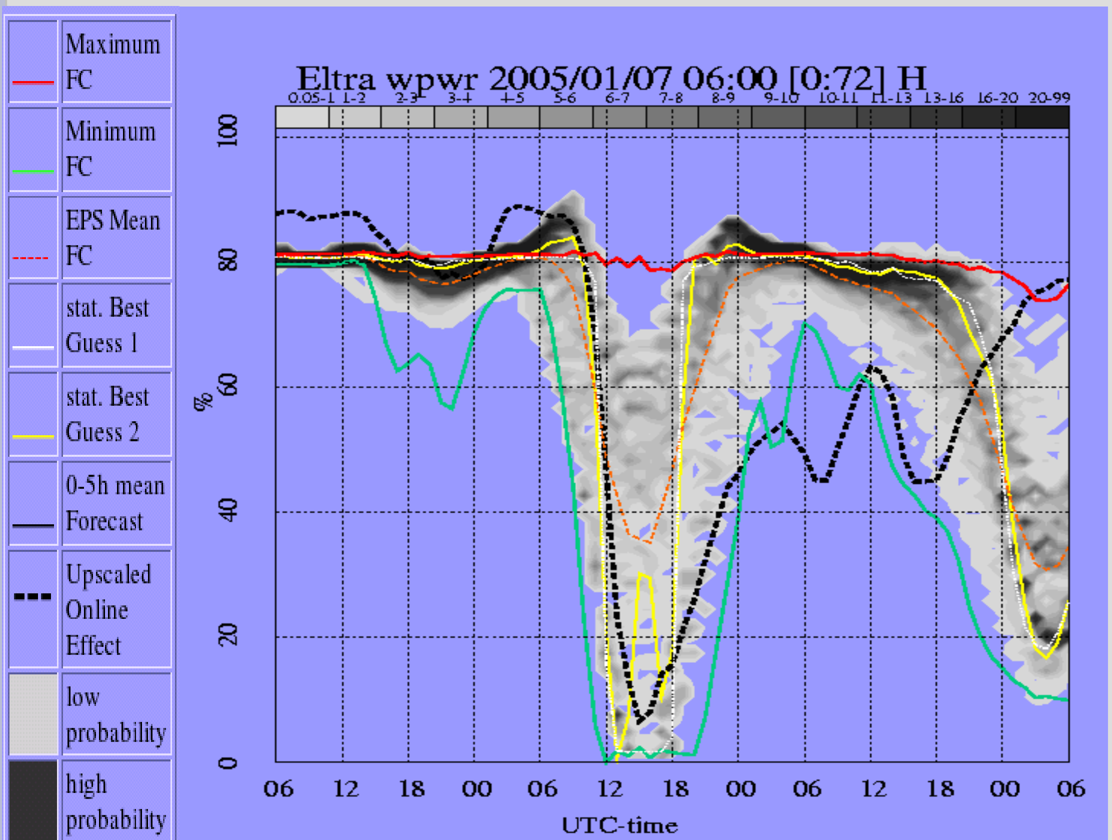


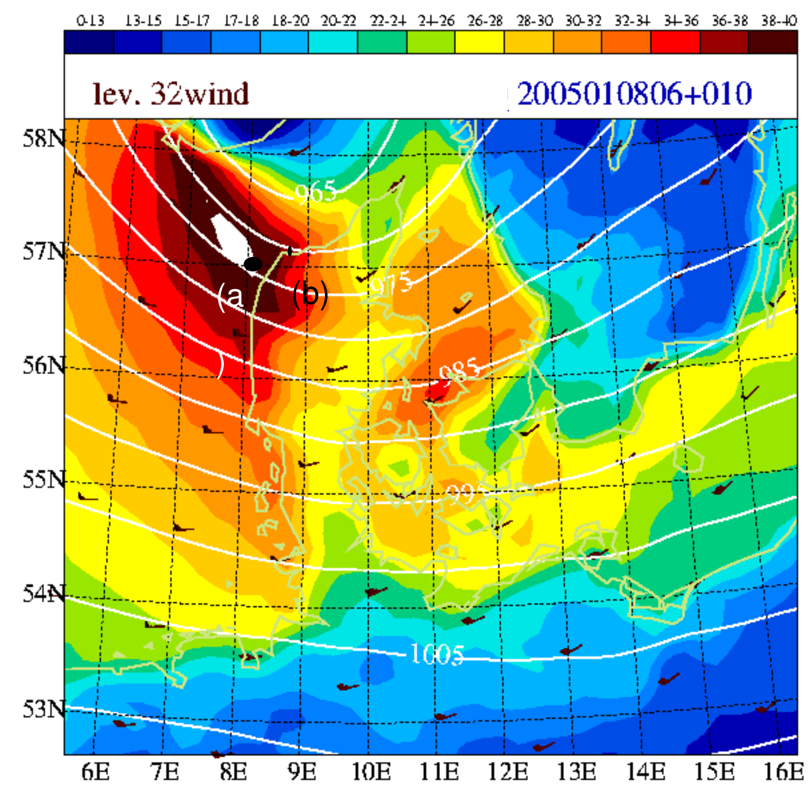
Probabilities for sites with wind measurements





Danish Storm 3rd of January 2005



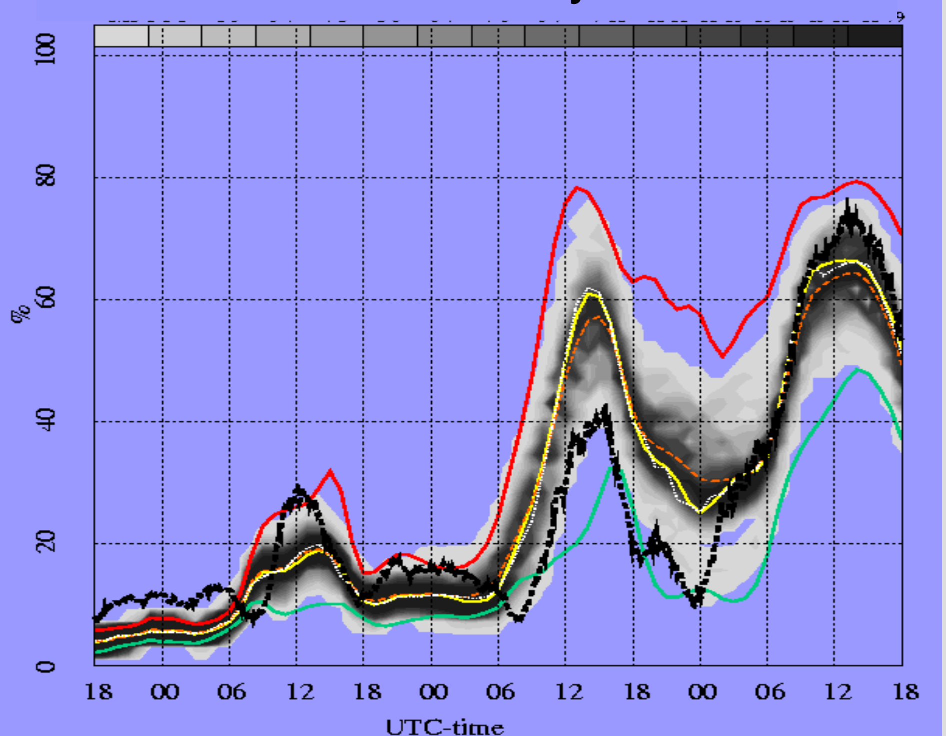


(a) Forecasted 41m/s at 16UTC

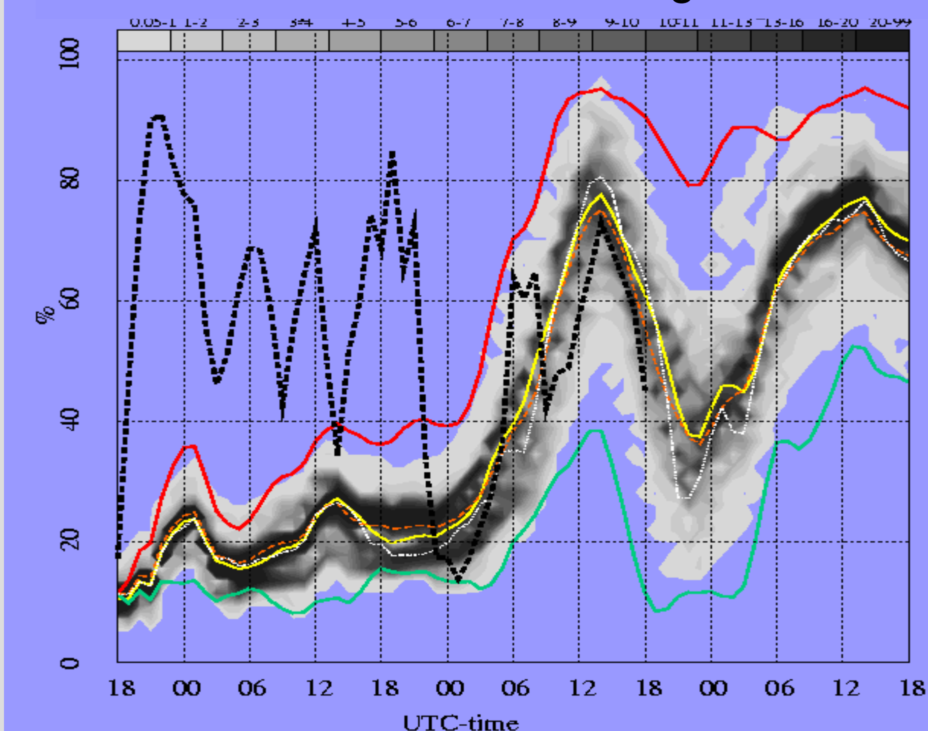
(b) Observed at Hanstholm 41.8 m/s at 16:20UTC

Onshore – Offshore Problem: *The same forecasts produces a perfect forecast onshore & a nightmare forecast offshore...*

140 Sites on land every 5min

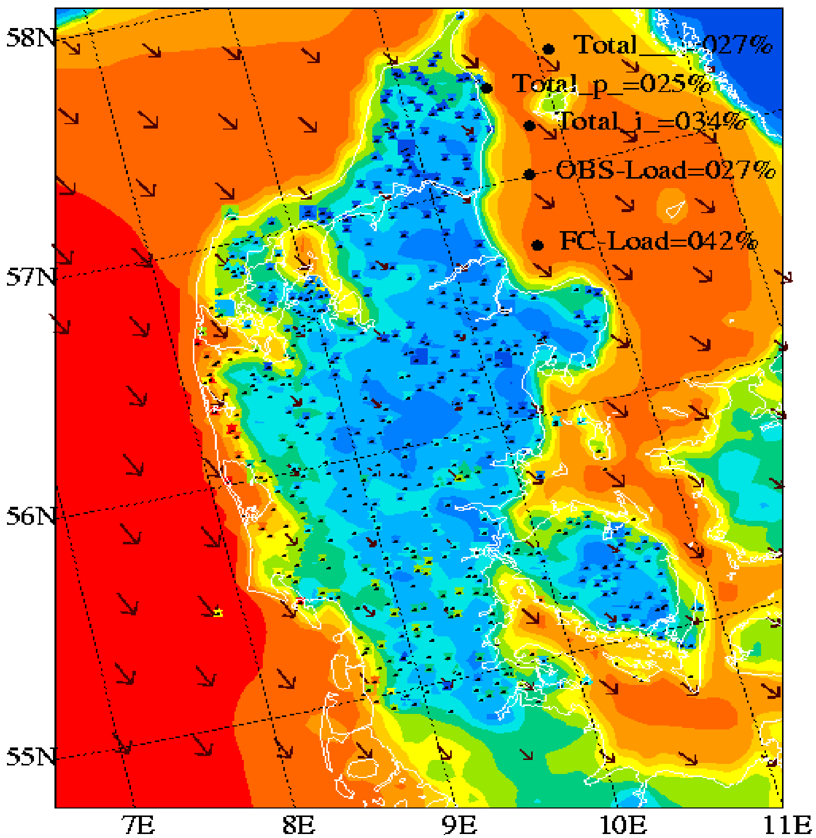


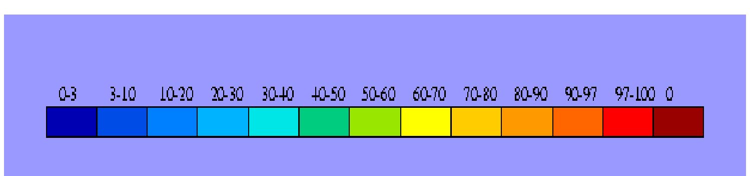
160MW offshore 1 hour average



The need for detailed measurements:

A typical Clear Night in November





This case demonstrates how much energy turbines along the coast produce during a clear night compared to turbines further inside the country

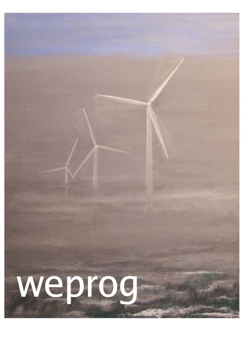
Graph shows:

The background colors indicate the predicted wind power production.

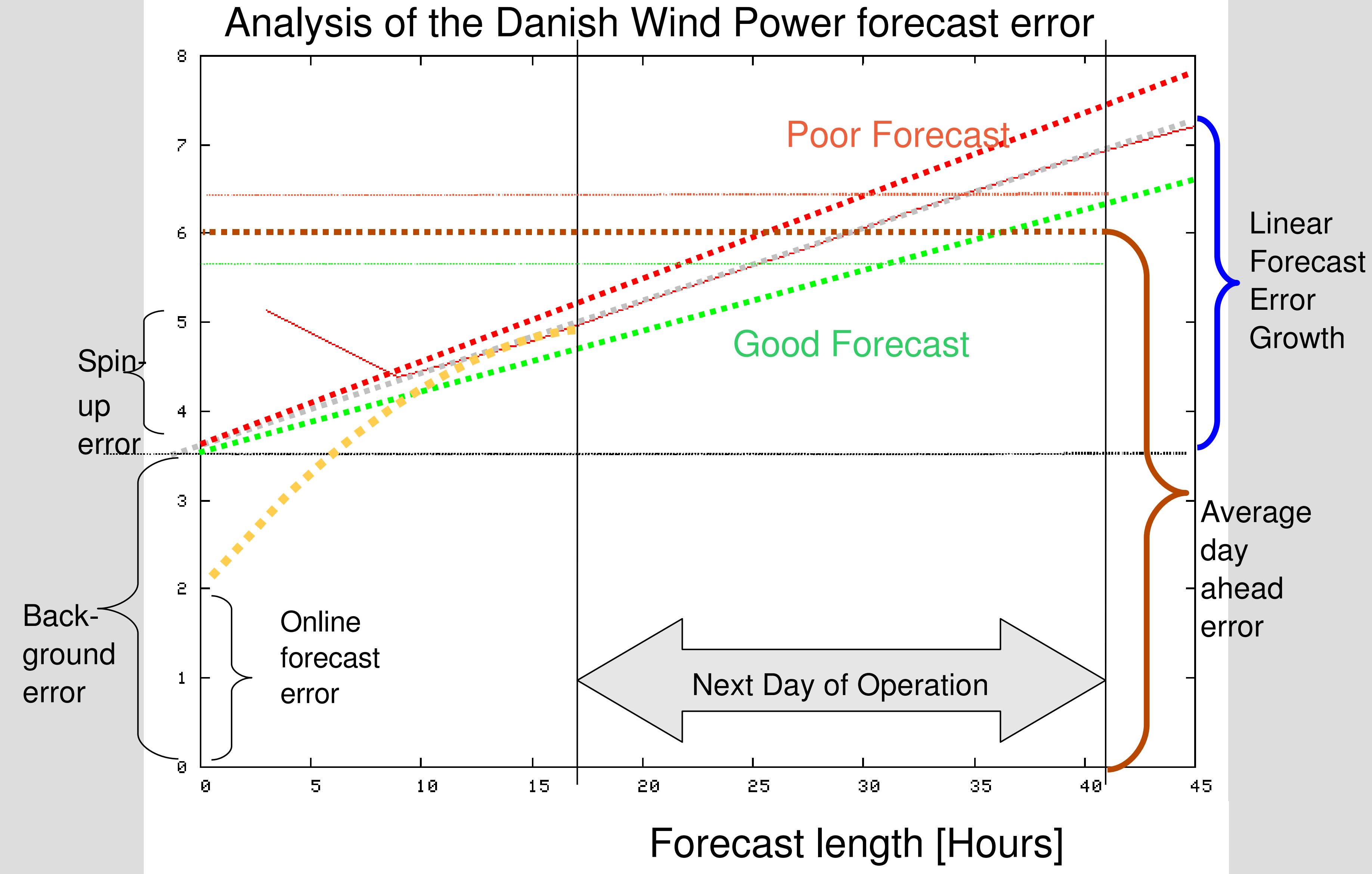
The color around each black dot indicate the measured production.

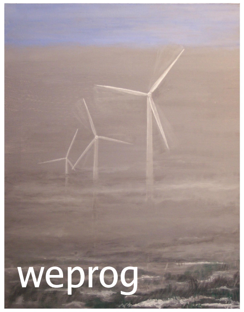
The boxes represent reference parks and the remainder are sums from 60kV stations representing the production in the area.

The values Total_? represent the total production computed via settlement data and OBS-Load the estimated production from online measurements



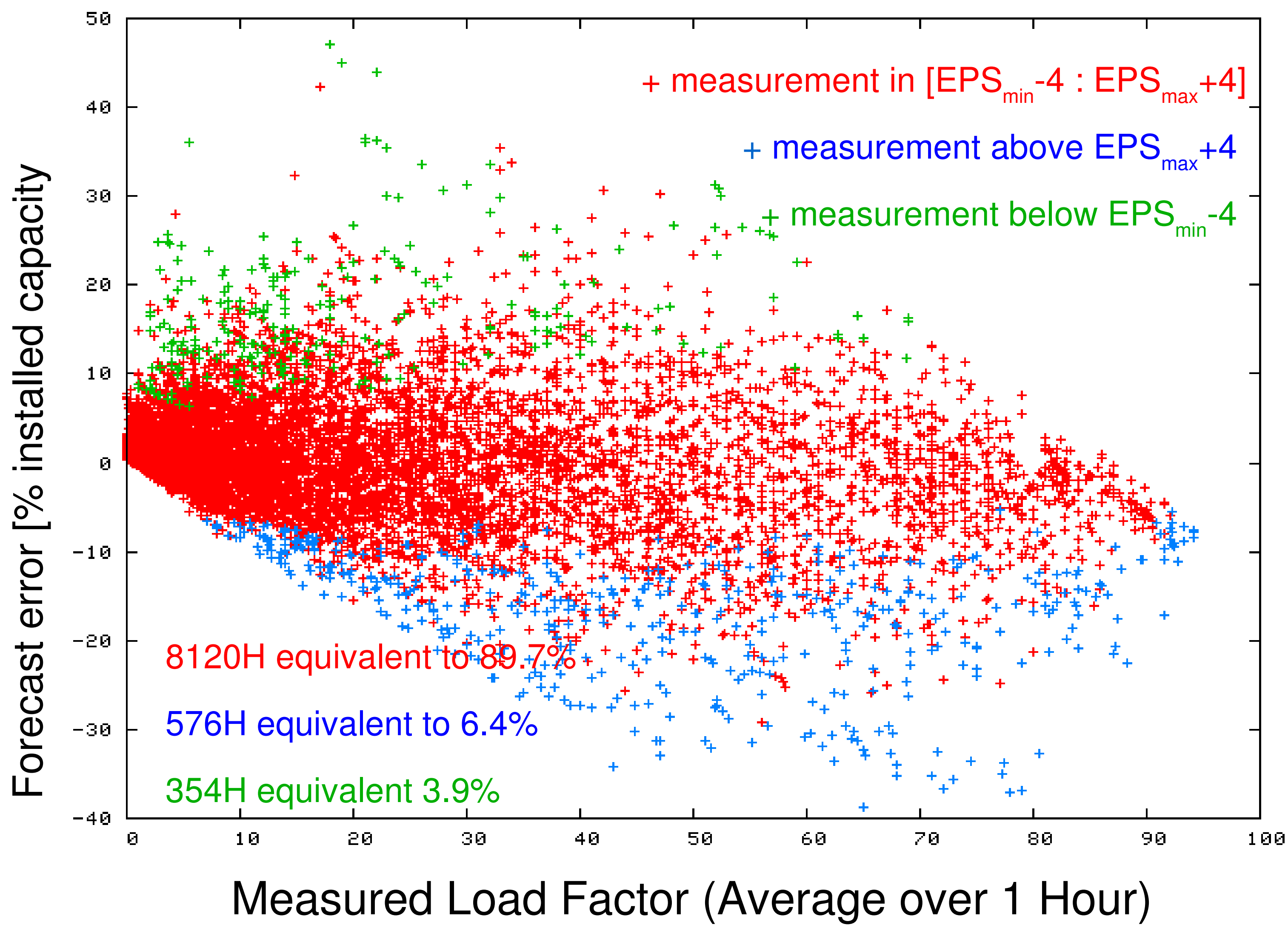
The next problem: Wind Power Forecast Error





Hourly Wind Power Forecast Error With the MS-EPS Ensemble Single Forecast

The Error is shown as Forecast - Measurement – Everything 06UTC forecast – Day ahead verified



Summary of the optimal use of uncertainty estimation for reserve allocation

Load factor [%]	Competition on regulation	Forecast choice	Regulation
0-20	Good on down regulation	EPS minimum	Downward
20-70	Good on up and down regulation	Best Forecast	Up & Downward
70-100	Good on up regulation	EPS maximum	Upward

Note, a cost model has to be included to take account for the skewness of the reserve cost and that the forecast with the lowest balance cost is not always the one with the lowest absolute error.

An example of such a reserve prediction model based on WEPROG's MSEPS has been introduced at DEWEK 2006 in Bremen, Germany (http://www.weprog.com/pub/documents/mseps-dewek-2006.pdf and http://www.weprog.com/pub/documents/weprog_reserve_A4poster.pdf

Lessons learnt in Denmark...

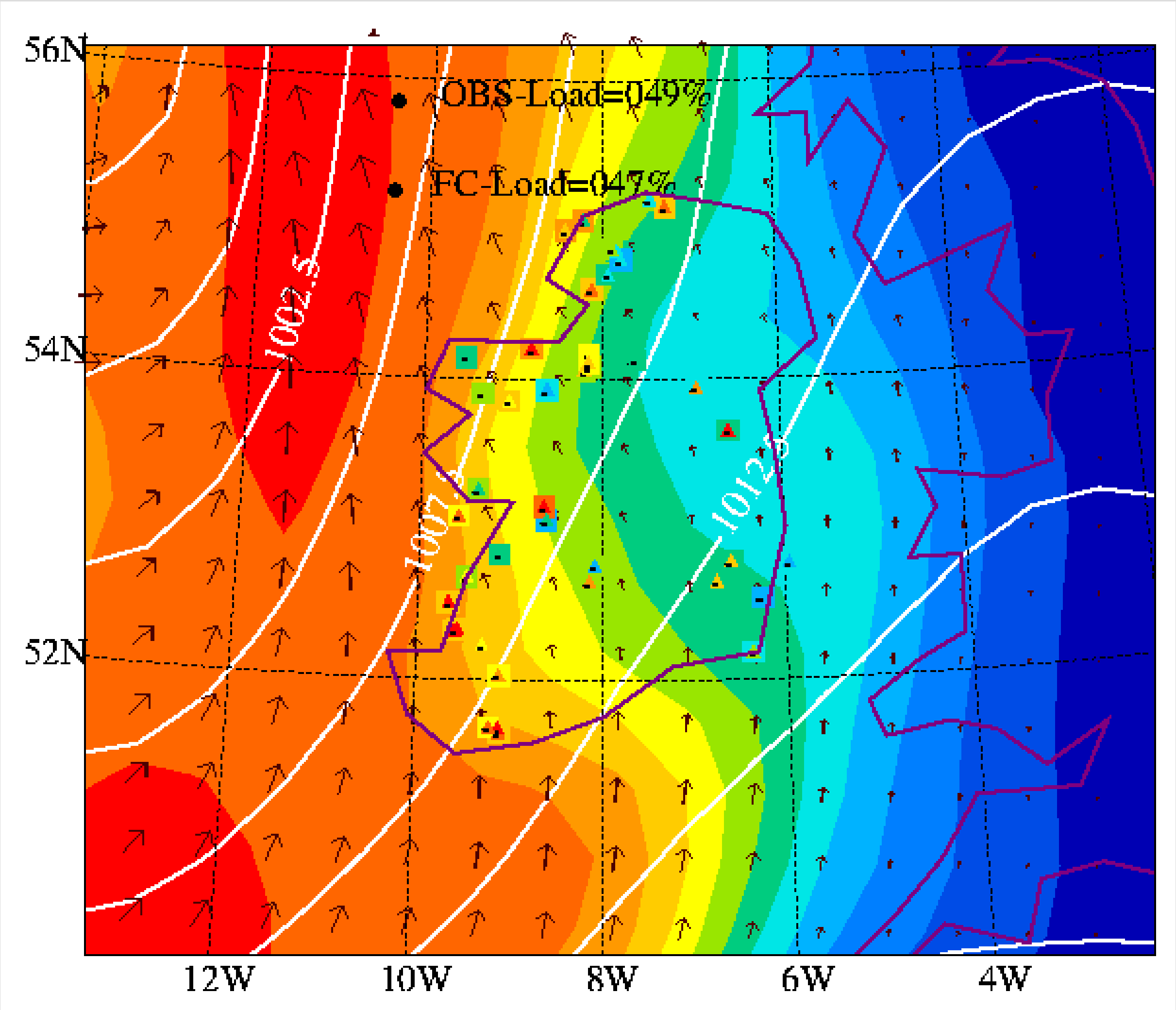
- A certain amount of the forecasting error will stay
- The reserve requirements for wind are different than for other sources of energy – therefore it requires separate reserve prediction for wind energy
- The market price is dominated by wind generation until there are large enough storage solutions available
- The forecasting and measurements are sensitive information
- Wind energy export will be an important tradable in the future: at times where the wind in one place there is no wind at other places
- The integration of large amounts of wind energy has proven to be feasible and managable – but it has not been possible to make wind energy competitive on market prices

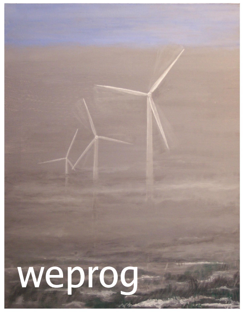
Ireland & the Island Problem

Denmark is the pioneer in wind energy – Ireland has the highest wind resource in Europe

…but also highly variable weather coming from the Atlantic

…and Ireland is almost an island grid – only a 200MW connection to Northern Ireland





A historic Overview of the Irish Wind Integration from 1998 - 2007

Plans and deliveries of the Renewables integration Programmes

Programme Time	AER I -III 1995-1999	AER IV-VI 2000-2004	REFIT 2005	REFIT 2006	REFIT 2010
planned	120MW	480MW	-	-	1100MW
delivered	67.3MW	279MW	495MW	645MW	-
average price [EUR/MWh]	52**	~53	53.6+sub*	66.1+sub*	-

PROBLEMS FACED:

- **Competitive process for the procurement** of electricity generated **lead to prizes where many projects could not be delivered**

- In AER I-III no planning permission was required: projects had AER contracts & no planning permission

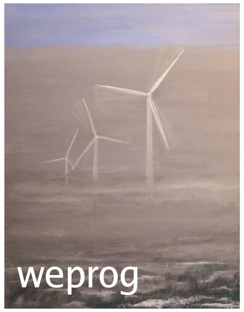
- In 2004 **150MW** out of 279MW were **built in free competition from renewable energy suppliers**

- In AER V-VI still challenges in short term, because no grid connection contract is required

- Missing development plans for local authorities

- Delay in identifying technical issues regarding wind integration lead to a **Moratorium** from TSO/Energy Regulator in December 2003-July 2004: cap of installed capacity to **500MW** for security reasons

AER = Alternative Energy Requirement -- REFIT = Renewable Energy Feed-in-tariff *subsidy =>1. 2EUR/MWh for windfarms > 5MW 2. 15% of 57EUR/MWh 3. plus (57-av.price) if av. price<57 ** Comparisons to other countries: GER = 126, DK=115, ES=99, UK=64



How the Problems are solved today...

- Moving from AER schemes (V-VI and VII) to REFIT: from competitive process to feed-in tariff

- upfront payment option to address investor concerns
- indexation to the change in the consumer price index,
- new category offshore wind
- resubmission allowance for projects selected in AER V

- New grid code for Wind to increase system security and to end Moratorium

<u>New grid code (1. July 2004):</u>

Signals List #1 - Status of the electrical equipment

Signals List #2 - Meteorological Data;

Signals List #3 - Availability Data;

Signals List #4 - MW Curtailment Data;

Signals List #5 - Frequency Response System Settings.

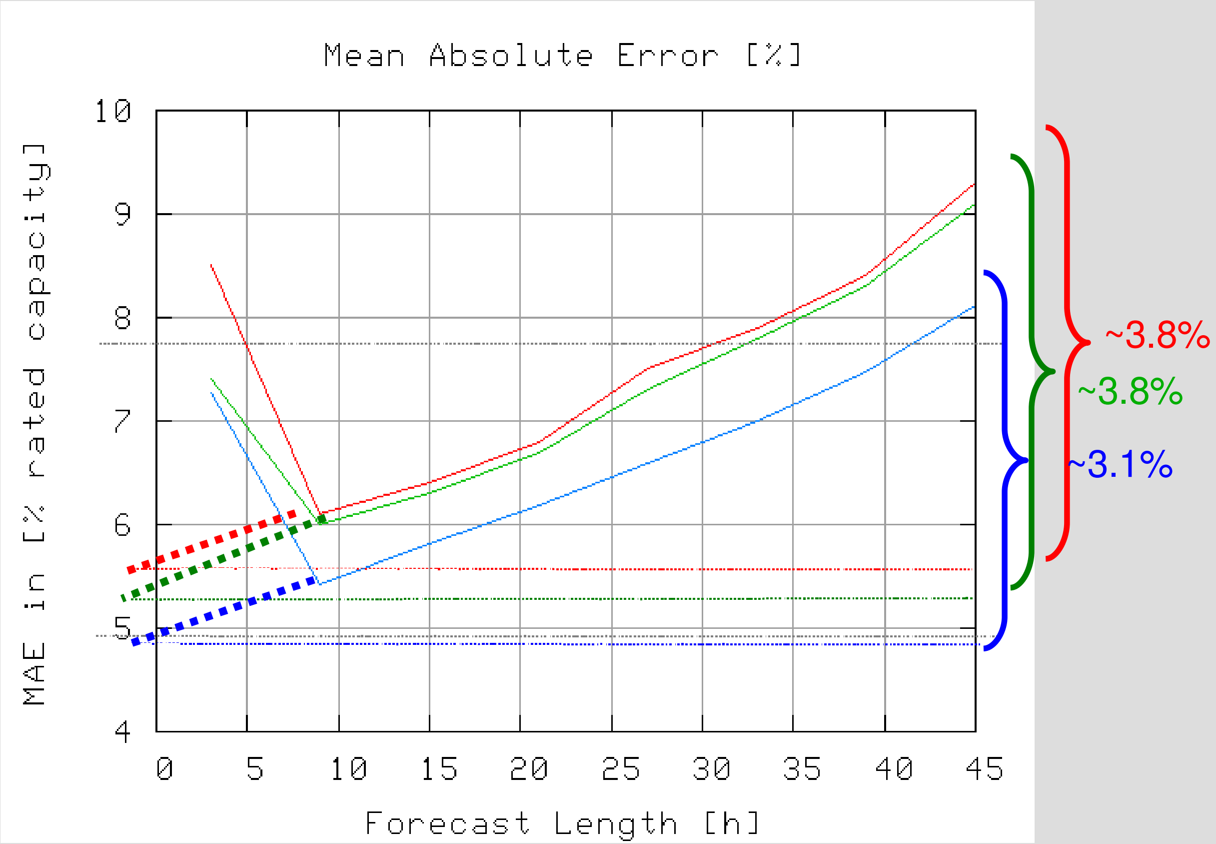
Signal #1 => ALL WIND FARMS
Signa #2 - #5 => WIND FARMS > 10MW

- Increased research & development in wind energy forecasting and dynamic modeling of wind generator

- Operational wind forecasting today:
  - MORE-CARE (since 2002)
  - ANEMOS (Previento, Predictor,AWPPS, since 2006)
  - WEPROG's MSEPS (since 2006)

Predictions are based on:
- Upscaling total wind power from 11 wind farms (2002-2005)
- Upscaling total wind power from 30 wind farms (since 2005)
- Additionally total wind power from all 52 wind farms (since 2006)

Error growth in Ireland with 52 wind farms



Verification results for 2005

Keyword	mean	mae
worst farm	43.60	16.0
best farm	35.04	10.5
Average	33.95	12.3
method 1	32.98	7.61
method 2	32.6	7.36
method 3	33.32	6.74

method	description
method 1	All farms individually - direction dep. and individual member weight
method 2	All farms individually - direction dep. and individual member weight in stability
method 3	300 member EPS - All farms handled individually with 4 ws, dir,stab, member dependency

Summary of Forecast Information provided to ESBNG

- Forecast frequency provision: 4 times per day (00,06,12,18 UTC)

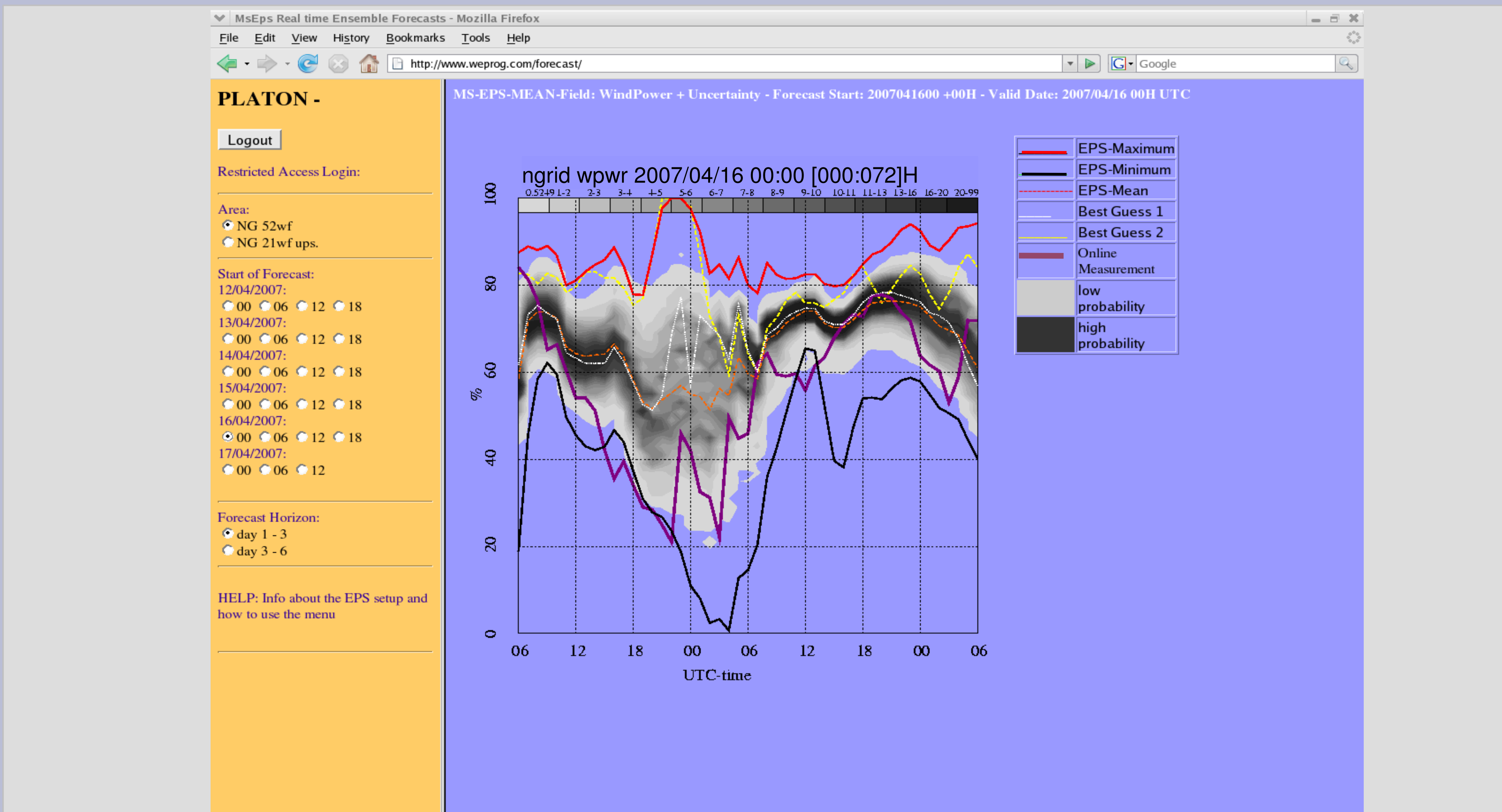
- Hourly forecasts out to a horizon of 144 hours

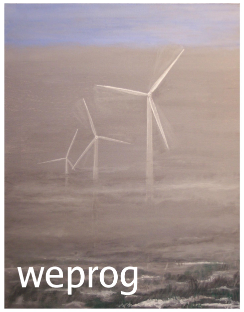
- GUI with wind power and probability information for total aggregate production
- Each forecast contains:

  - Total aggregate wind farm power output (645MW)
  Wind power is computed individually for all 54 wind farms from 300 forecasts
  and summed up to a total production for Ireland
  Additionally, the minimum and maximum is delivered

  - Forecasts for 21 wind farms for use of current ESBNG forecasting system of
  Weather forecasts for Eirgrid's other forecasting system (MORE CARE) are delivered

Interpretation tool for the Probabilistic Forecasts from WEPROG's MSEPS





Lessons leart in Ireland...

- For the integration of larger amounts of wind energy, long term security of investments are necessary:

  => competitions regulations prevent initial investments

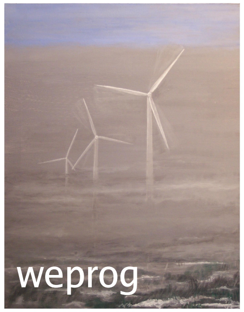
- Dispersion of wind farms is important, because the predictability of the wind farms differs significantly

  => ~16% versus ~10% MAE for the worst and the best wind farm

  => power prediction for all farms with direction dependency and stability included halves the error compared to a single wind farm.

  => it's not only the weather forecast, but also the conversion to power that needs to have a certain quality

- Accumulation over multiple wind farms reduce the error significantly and increases system security



Questions ?

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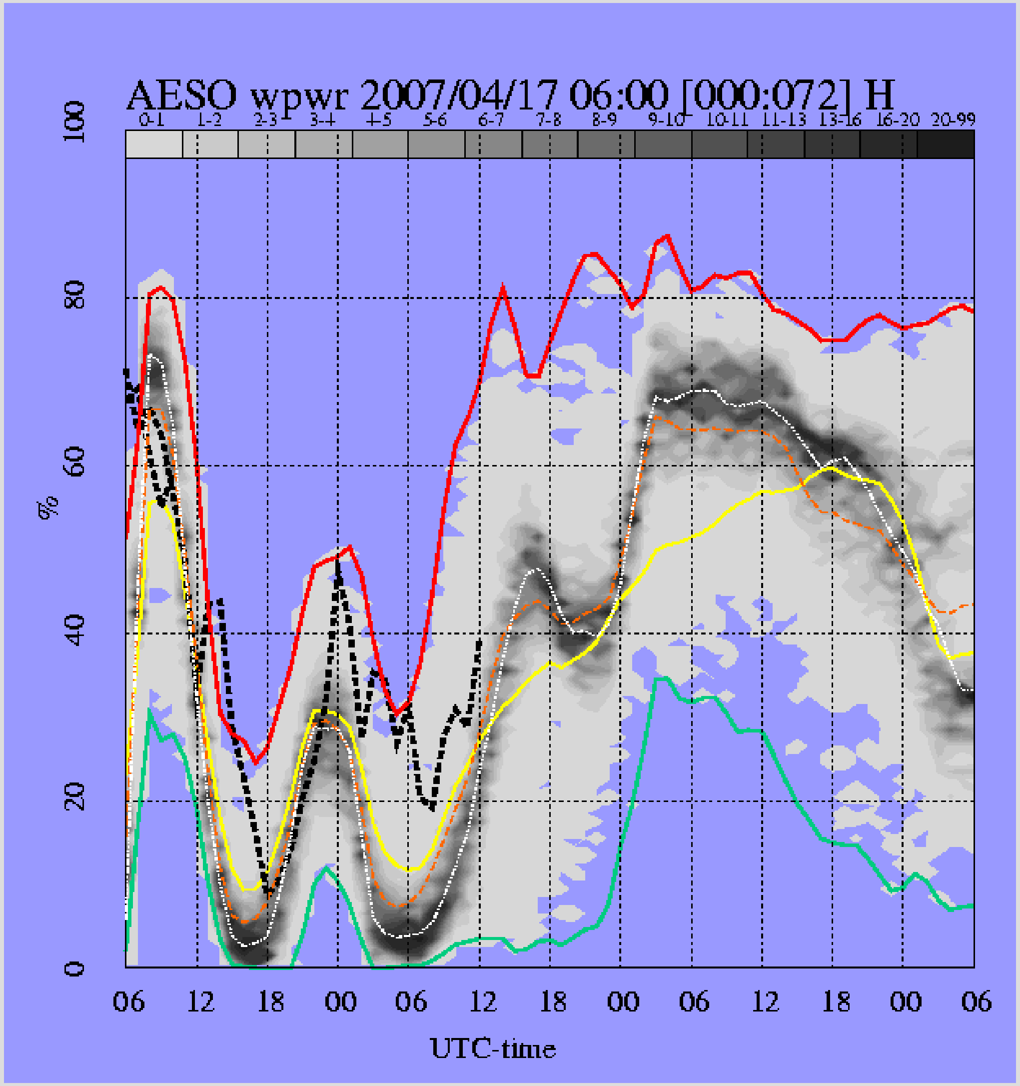

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