



SafeWind

Wind Power Forecasting with Focus
on Extremes

Workshop, Palais Brongniart, 31.08.12, Paris

State of the Art in Wind Power Forecasting

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www.safewind.eu

State-of-the-Art for Wind Power



ANEMOS.plus

"Advanced Tools
for the Management of Electricity Grids with Large-
Scale Wind Generation".
EU FP6 Contract N°: 038692

SafeWind



"Multi-scale data assimilation, advanced wind modelling &
forecasting with emphasis to extreme weather situations
for a safe large-scale wind power integration"
EU FP7 Grant Agreement N°: 213740

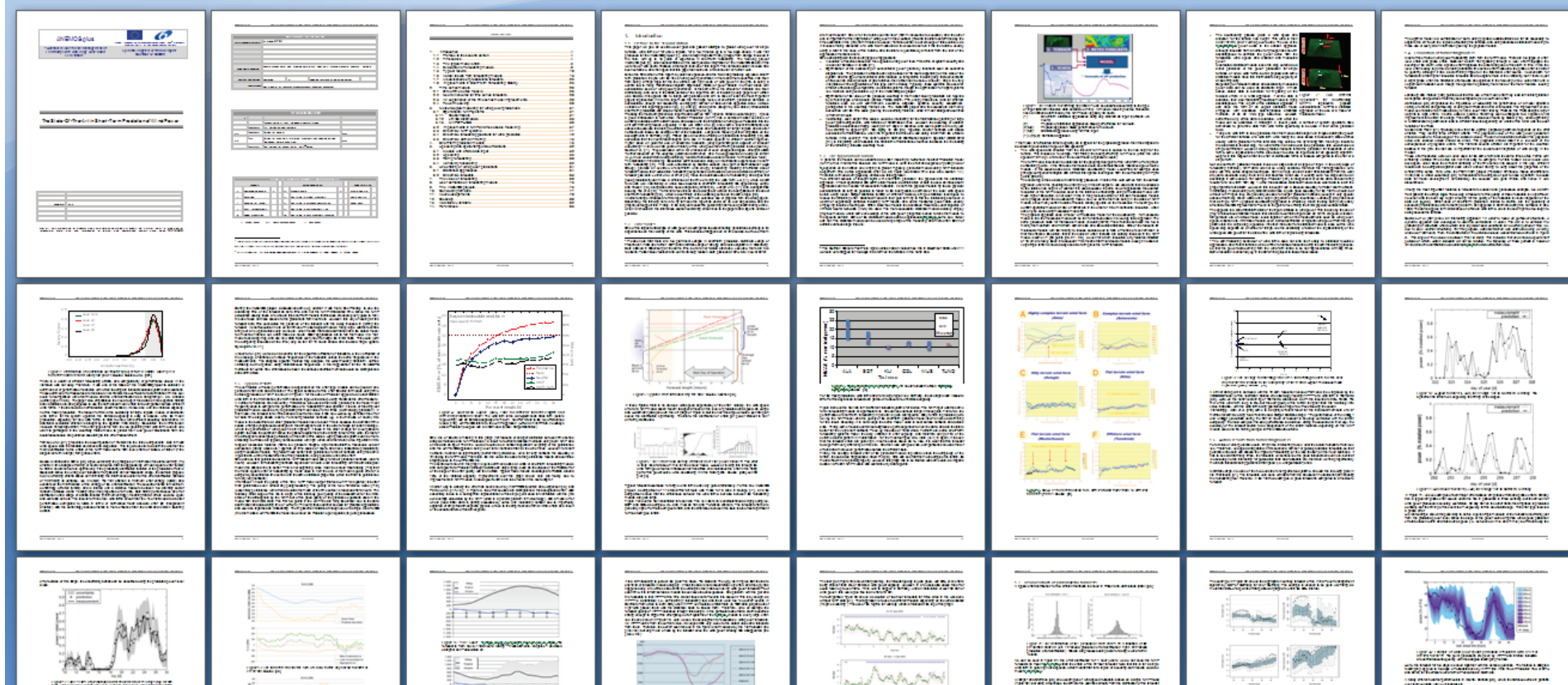


DELIVERABLE REPORT

The State of the Art in Short-Term Prediction of Wind Power
A Literature Overview, 2nd Edition

DOCUMENT TYPE	Deliverable
DOCUMENT NAME:	aplus deliverable_D1.2_STP-SOTA_v1.1.docx

State-of-the-Art in Short-term Prediction



State-of-the-Art in Short-term Prediction

111 pages

> 380 references

> 230 citations

On Safewind.eu

Weather Intelligence for Renewable Energies WIRE



Wind Power

Challenging to predict
Design of spinning reserves



Solar Power

Problems with voltage regulation



Transmission & distribution

Grid management
Thermal rating - Outages



Load Forecasting

Users' demands

Renewable energy supply and outage Issues are heavily influenced by weather:
intelligent weather integration is the key factor for efficient grid management.

Therefore: **COST Action WIRE** – see wire1002.ch.

Just about to be released on **wire1002.ch**:

TOC:

- 1 Management summary
- 2 Political, economical and technical framework
- 3 Research and Development:
the European approaches
 - 3.1 Wind Energy
 - 3.2 Solar Energy
 - 3.3 Grid management
 - 3.4 Wave Energy
- 4 National activities
AT, BE, BH, BG, HR, CZ, DK, FI, FR, DE, GR,
HU, IS, IL, IT, NL, NO, PL, RO, ES, CH, TU
- 5 Conclusions / Recommendations

156 pages.



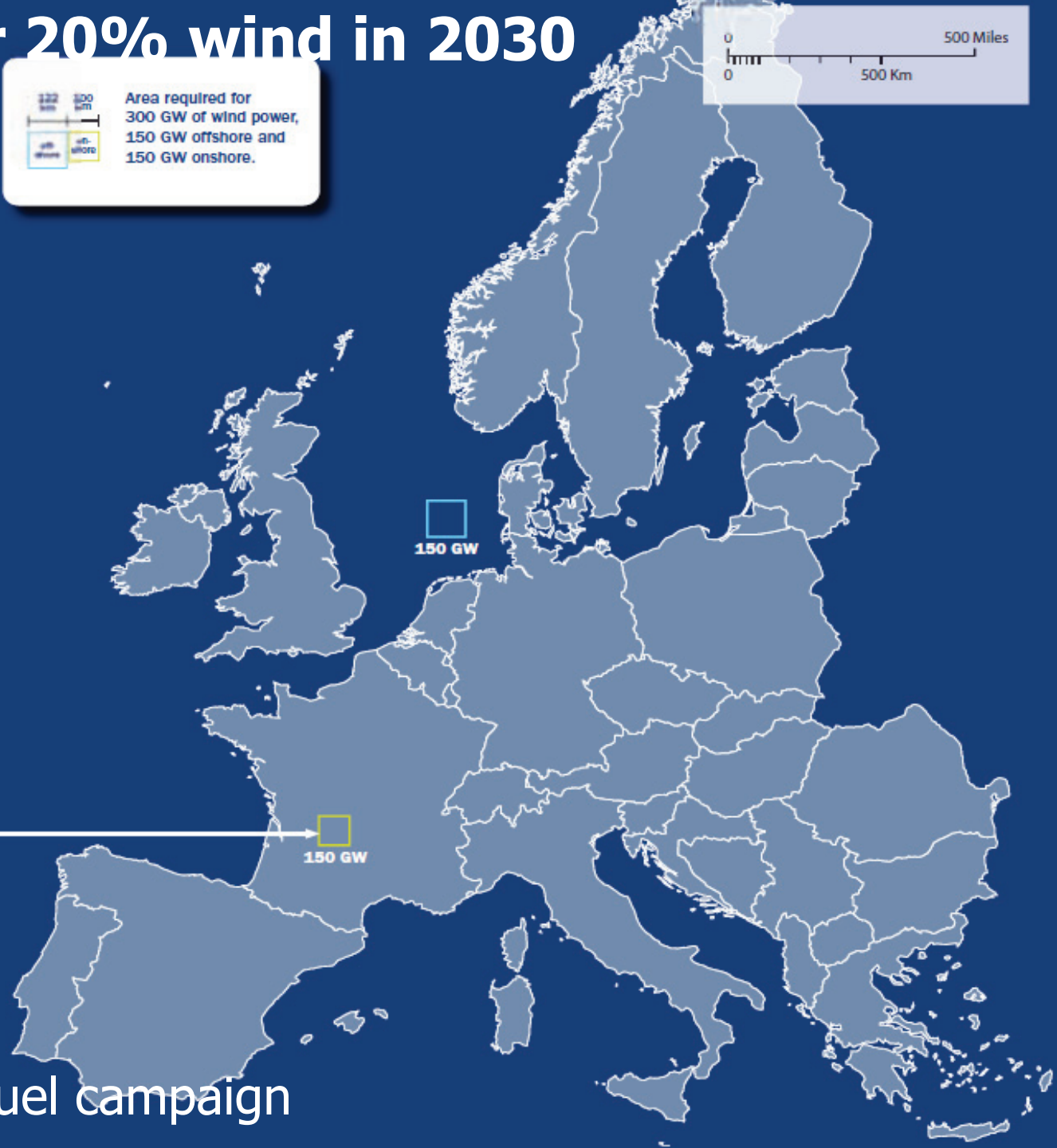
COST Action ES1002
Weather Intelligence for Renewable Energies (WIRE)

CURRENT STATE Report
August 2012

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Or
List of authors in Chapter 8

The Need

Area used for 20% wind in 2030



300GW = 965TWh

100x100km
onshore

+

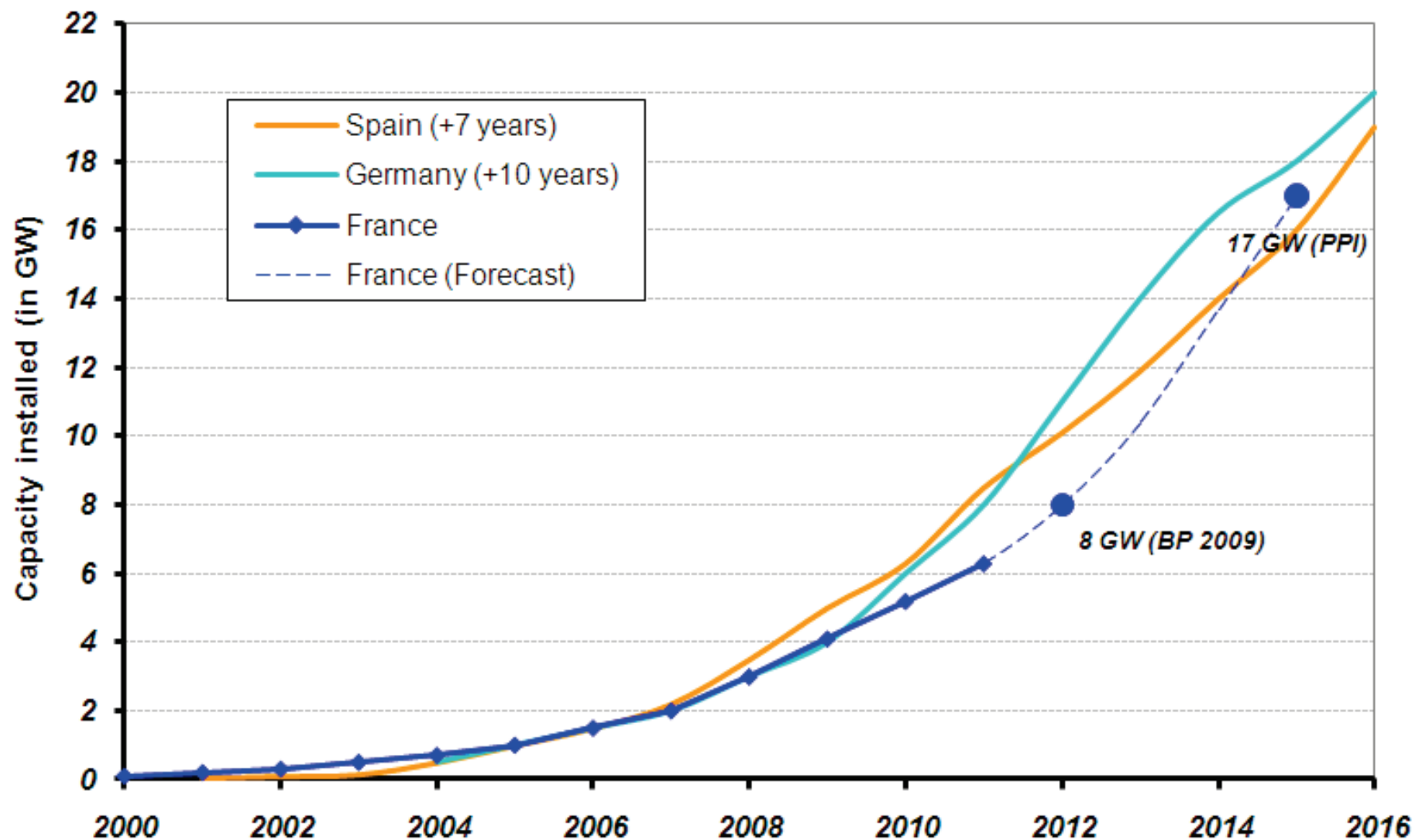
122x122km
offshore

In practice, wind farms occupy about 1% of the land surface area, so the actual land use needed for wind farms and roads, other services is in the region of a few hundred square kilometres.

Source: EWEA no fuel campaign

Installation rates of wind power

Growth of wind capacity installed *Germany, Spain and France*



Who needs forecasts:

- **Transmission companies** in areas with high wind penetration (*eg Energinet.dk, Tennet, 50Hertz, Red Electrica de España, CaISO, AEMO, ...*)
- **Electrical utilities** (*eg DONG Energy, Vattenfall, Acciona, Iberdrola, E.On, NUON, RWE, EnBW...*)
- Everyone trading on markets with sizeable shares of wind power

General Behavior of System Operators (TSOs)

- Low wind (few percent) penetration -> wind is ignored
- Medium penetration -> afraid of system impact, assumption: system operation not changed (DENA Study = 2x wind penetration possible = 35 GW or 64 % considering IC)
- Medium to high -> Considering new solutions, very active research (attending conferences etc. - UK)
- High penetration: very motivated to find new innovative solutions (Denmark)

Thinking:

We know best what our system can do because we are engineers

Thinking:

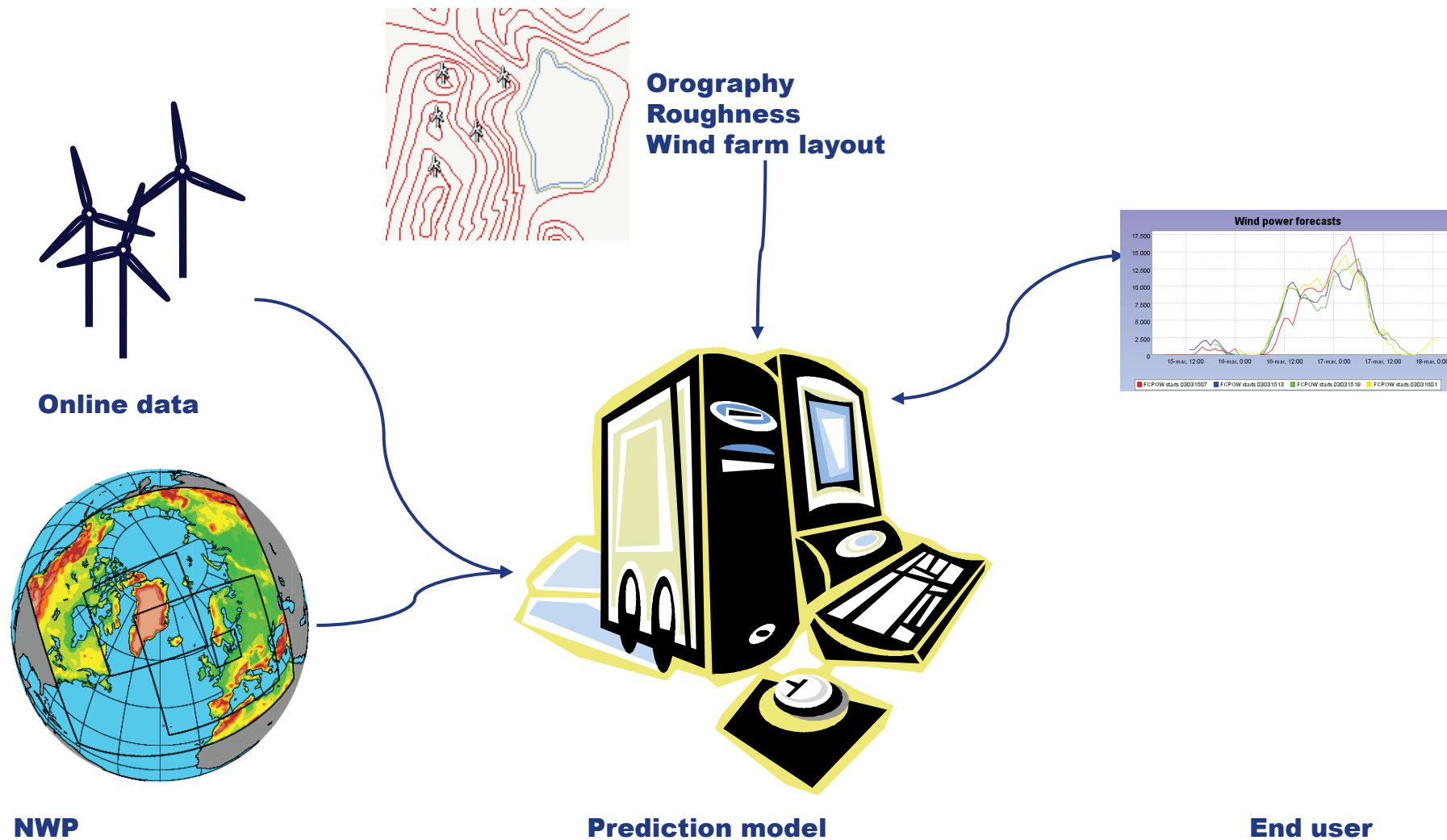
Because we are engineers we have to develop solutions for what society wants.

Predictions HowTo

Four timescales

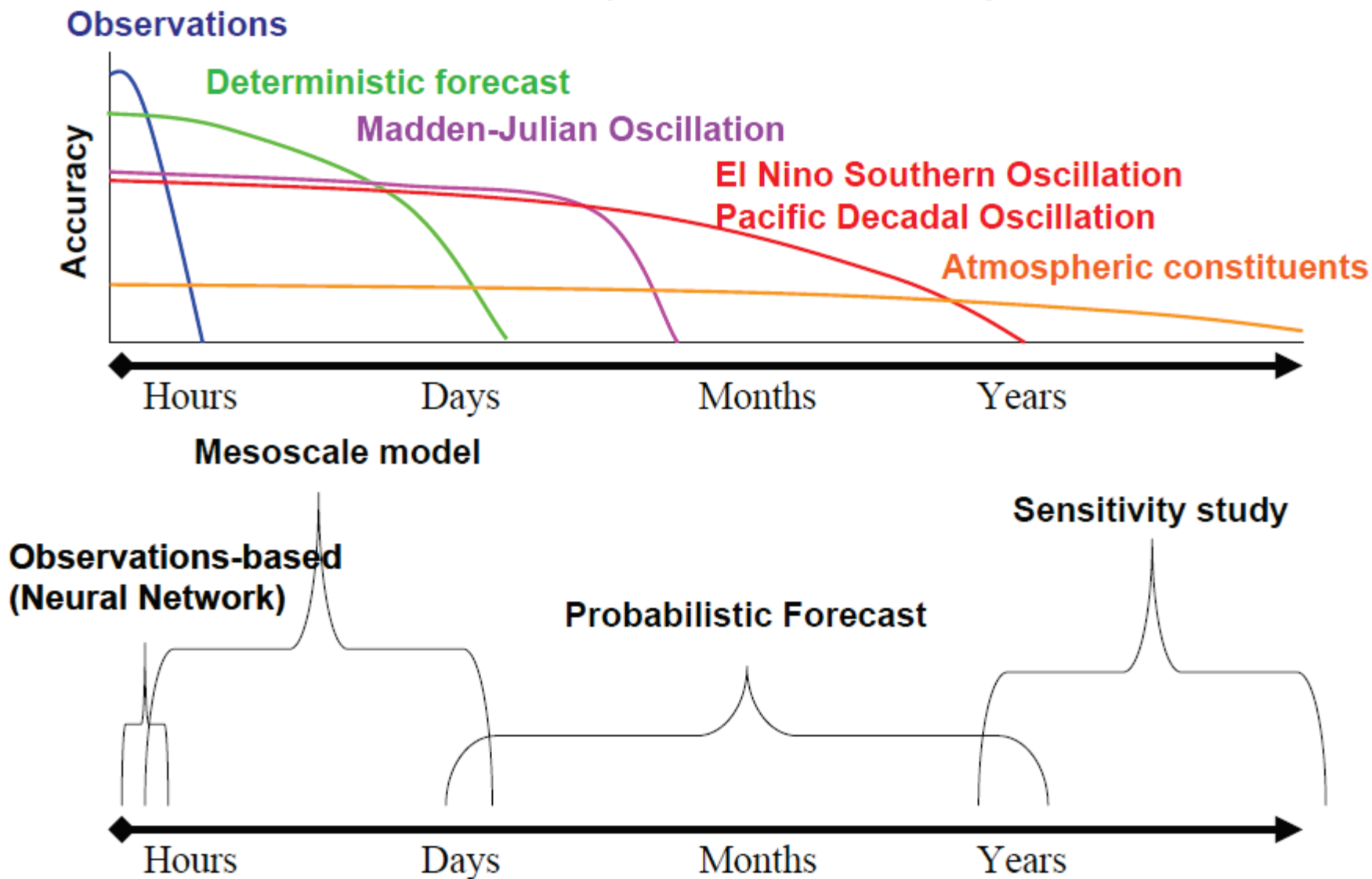
- Turbine Control: very short.
Seconds range (eg pitch angle)
- Power Plant Scheduling: short-term
Hours range (ramp up coal fired power plant = 6-8 hours)
- Electricity Markets: short-term
Many hours. NordPool: trading before 1200 for next day
- Maintenance Planning: medium-term
Eg crane movements – lead time of **days**
Ideally 2 weeks, or at least 5 days from Monday morning
In DK used also for fuel consumption predictions

Short-Term Prediction Overview



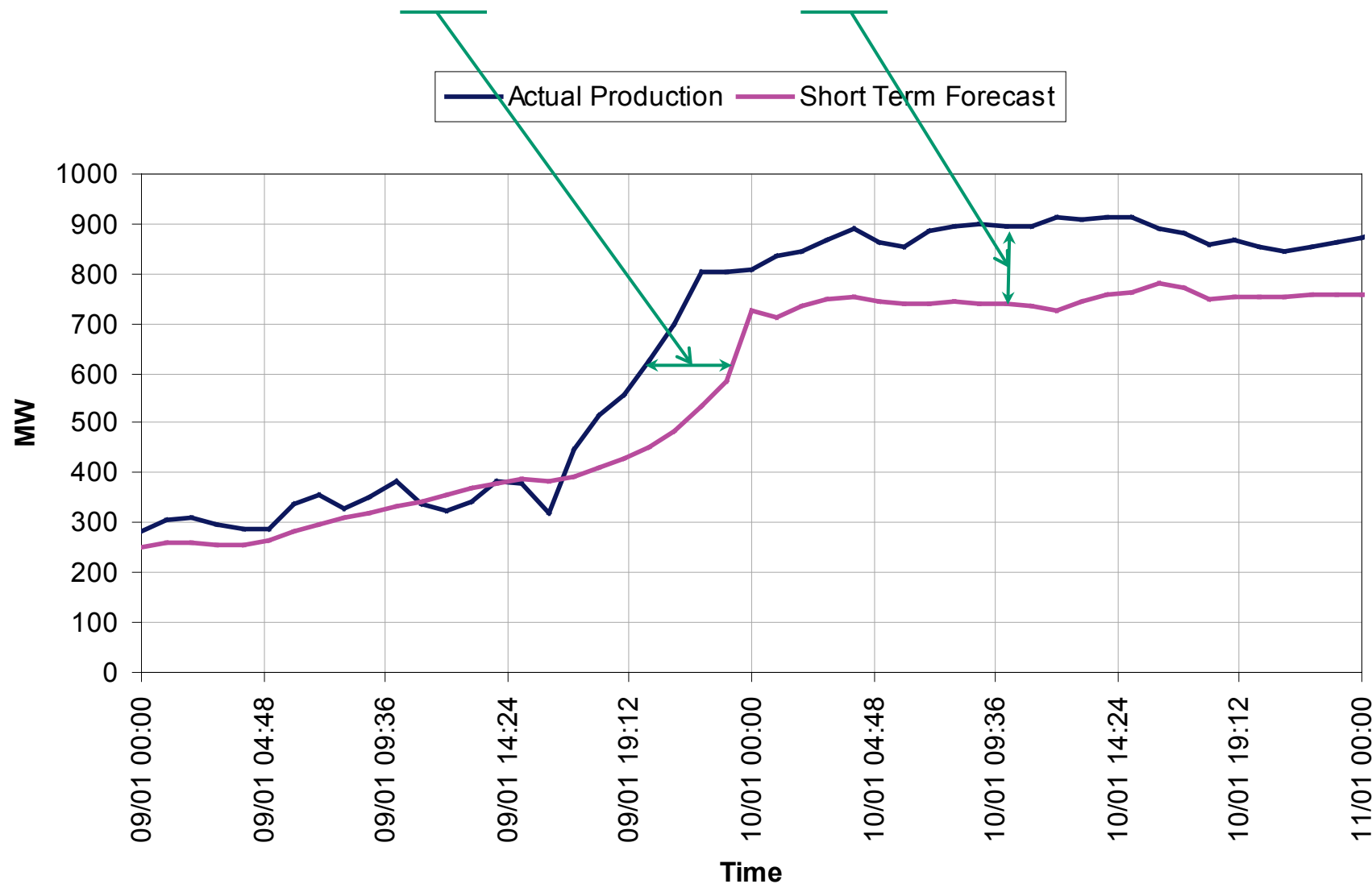
Performance

Atmospheric Predictability



Phase and Level errors

- Errors can be phase (timing) or level errors



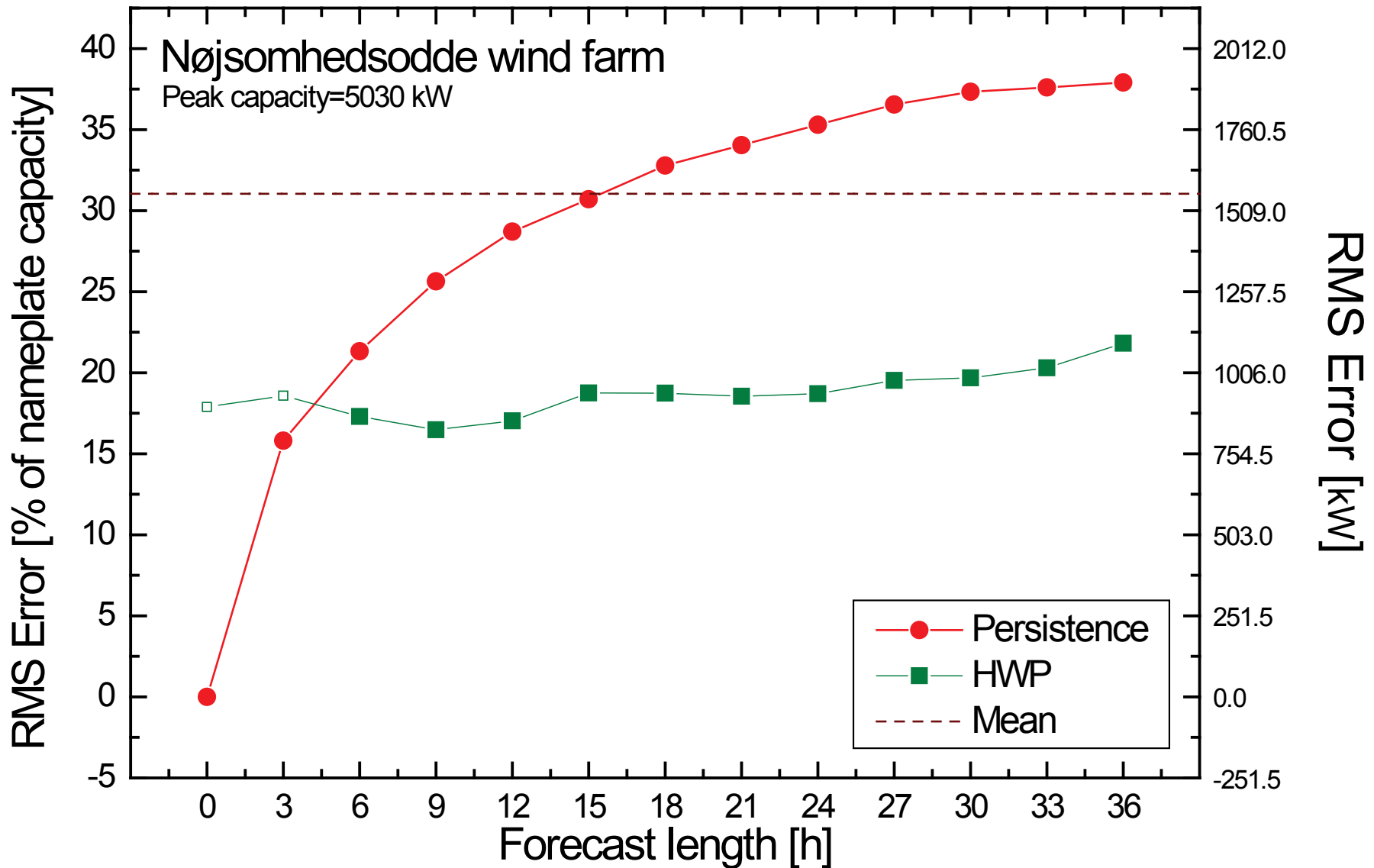
Since none were available, the ANEMOS project codified common criteria for performance measurements of short-term forecasting systems:

- Mean Error
- Mean Absolute Error
- Root Mean Square Error
- R^2 (coefficient of determination)
- Histogram of errors

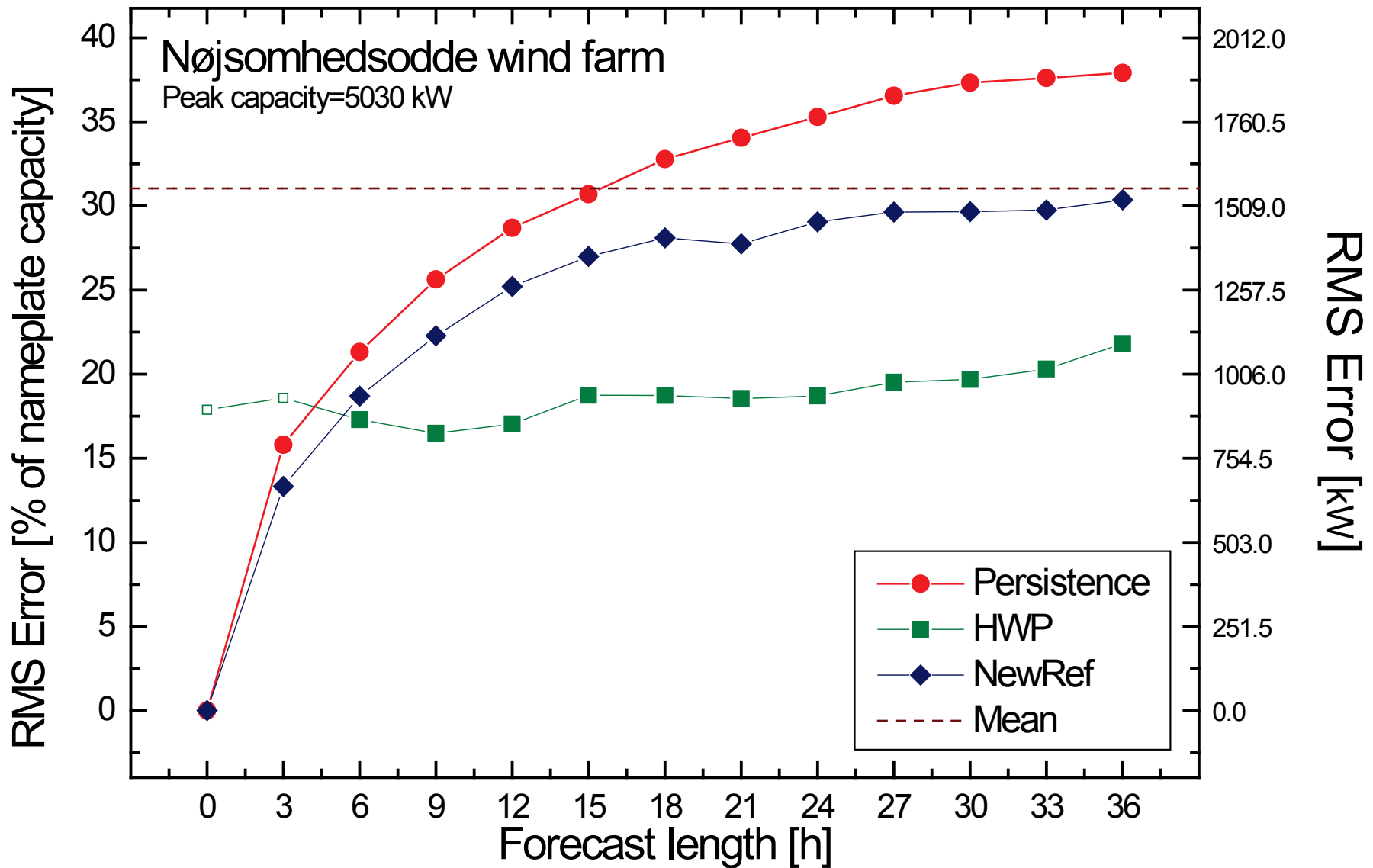
- Also, use separate training and validation datasets
- Present the errors normalised with the installed capacity

- Madsen, H., P. Pinson, G. Kariniotakis, H.Aa. Nielsen, T.S. Nielsen: *Standardizing the Performance Evaluation of Short-term Wind Power Prediction Models*. Wind Engineering **29**(6), pp. 475-489, 2005

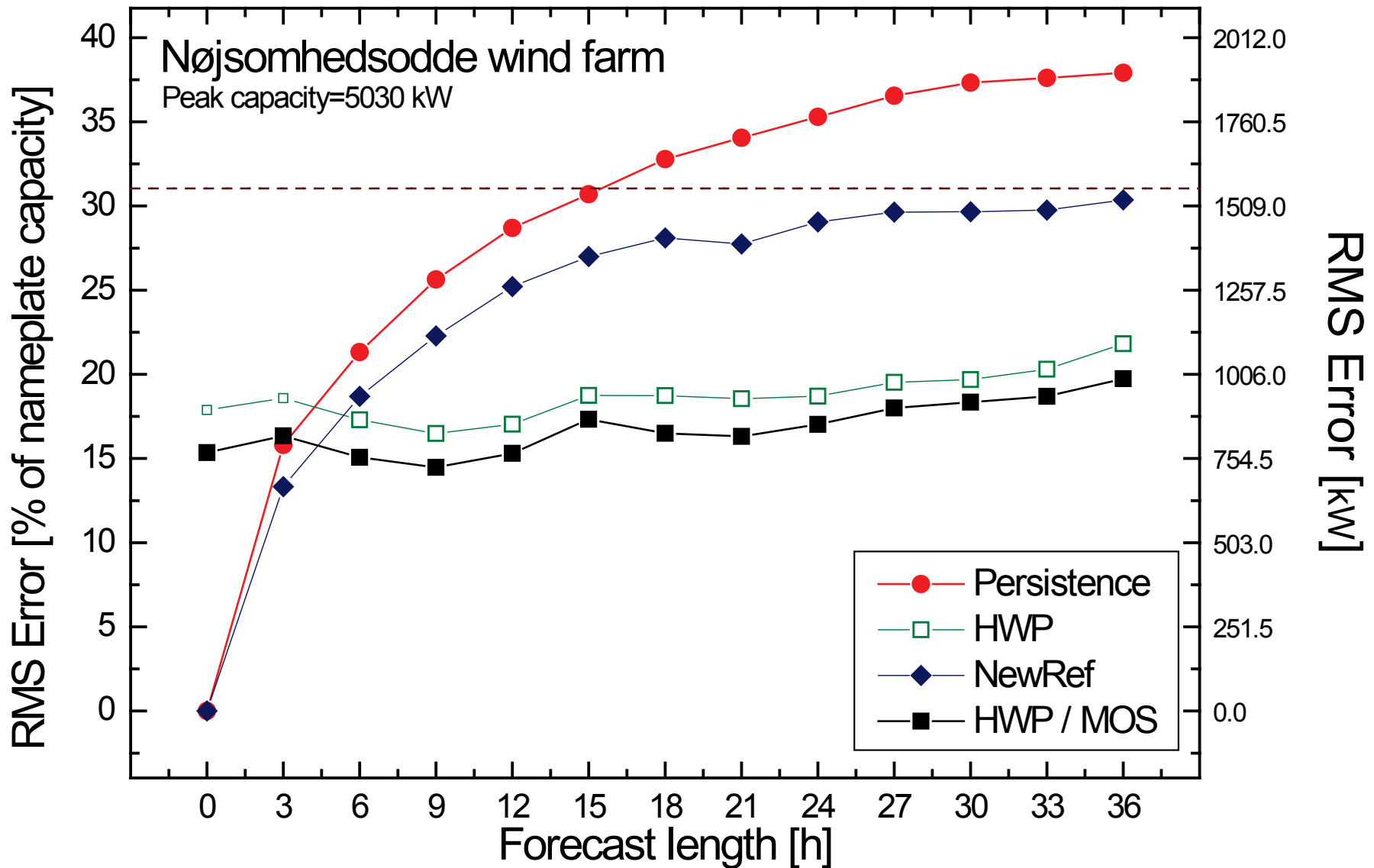
Typical results (1996 – now more like 10%)



Typical results (1996 – now more like 10%)

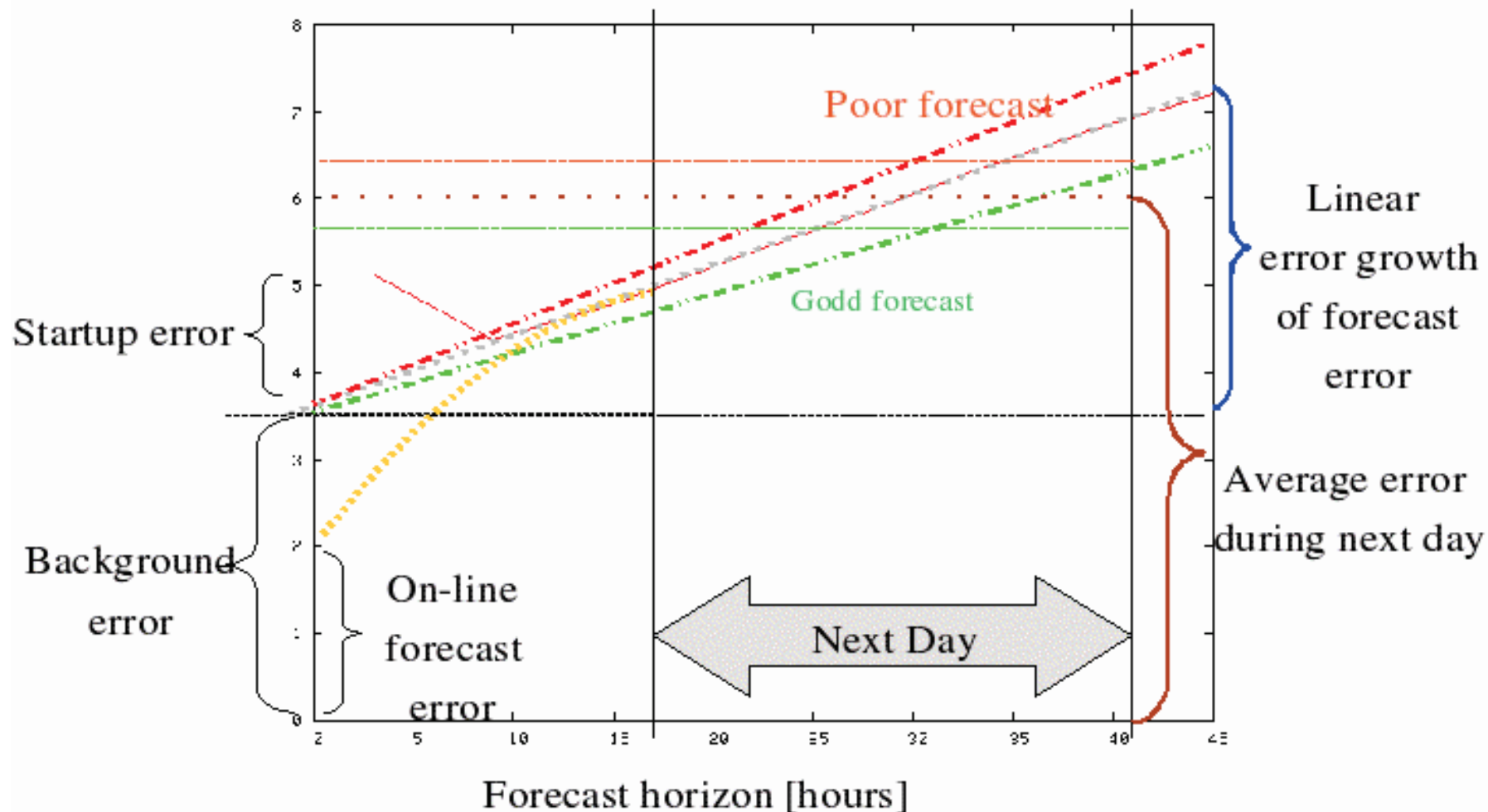


Typical results (1996 – now more like 10%)



Error classification

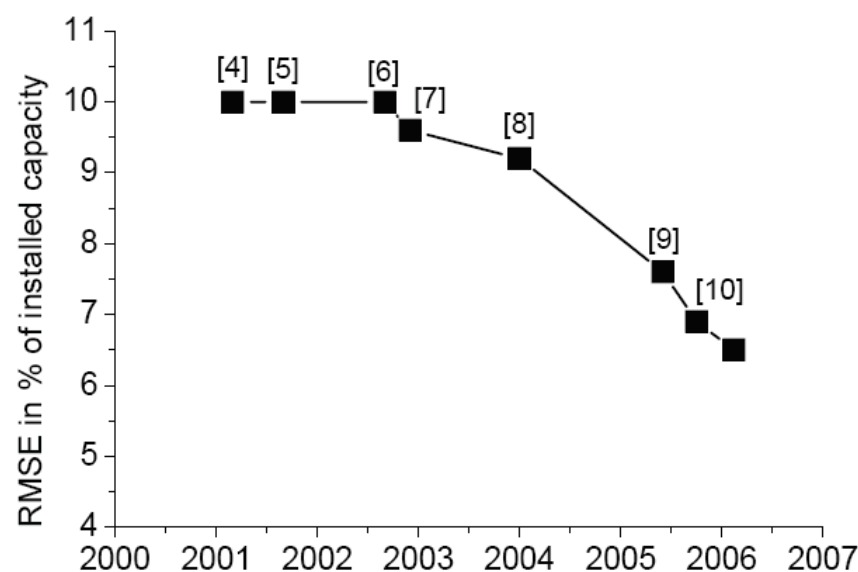
WEProg (Jørgensen and Möhrlen) have an interesting scheme:



Forecast accuracy, historical (eg ISET)

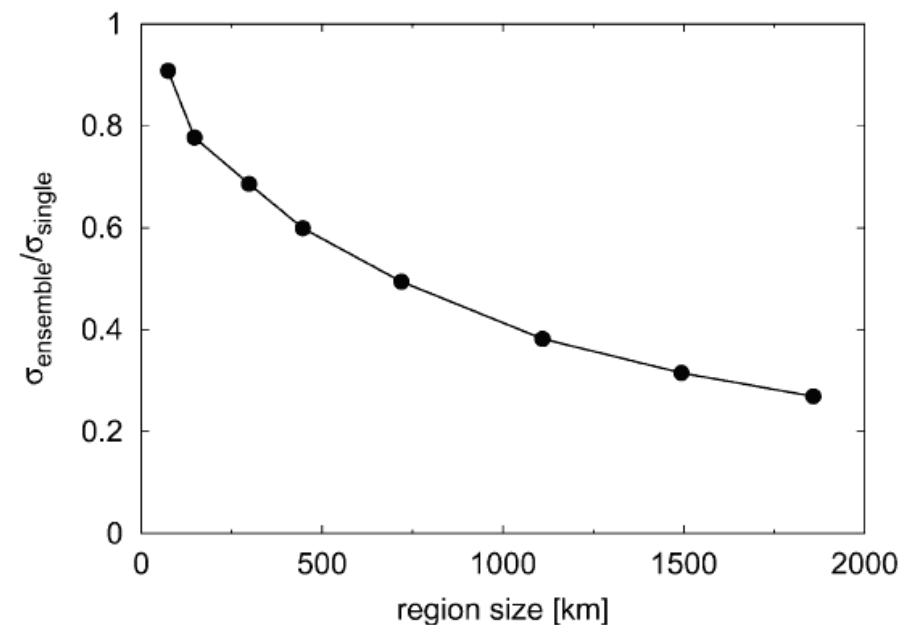
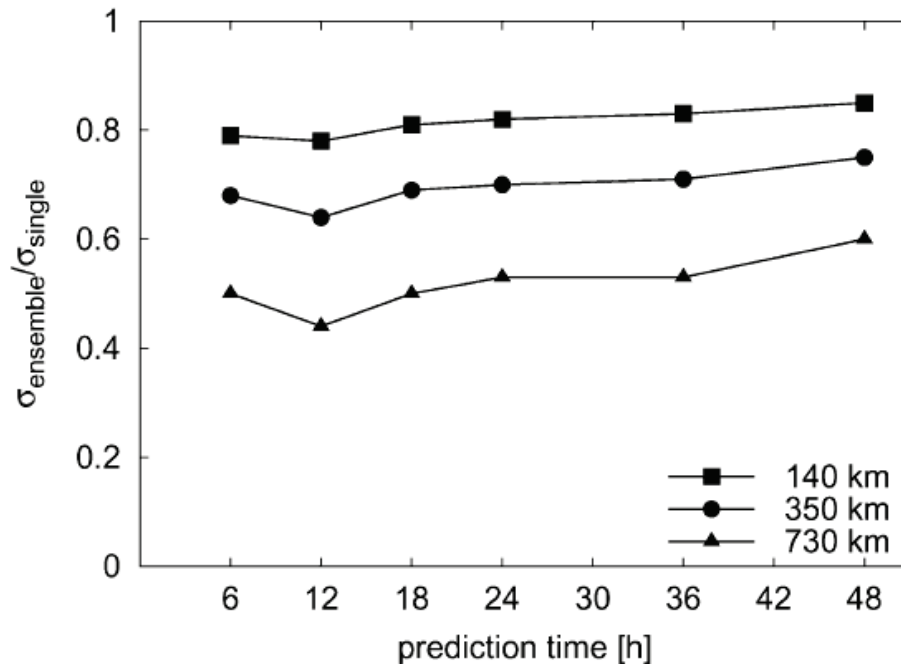
- Forecasting got better during the last years
- Some of it piggybacks on improvements in meteorology
- Some is due to better interface to meteorological models (e.g., using 100m wind speed)
- Some is using multi-model approach

Graph shows error in E.ON control zone over the years, with references from the paper



Smoothing of forecast errors

- Focken et al looked into the spatial smoothing of forecast errors – left is actual, right is derived model



- Therefore, predictions for a region always are better than predictions for a single wind farm
- Source: Lange, M., and U. Focken: [*Physical Approach to Short-Term Wind Power Prediction*](#). Berlin: Springer-Verlag, 2005

History

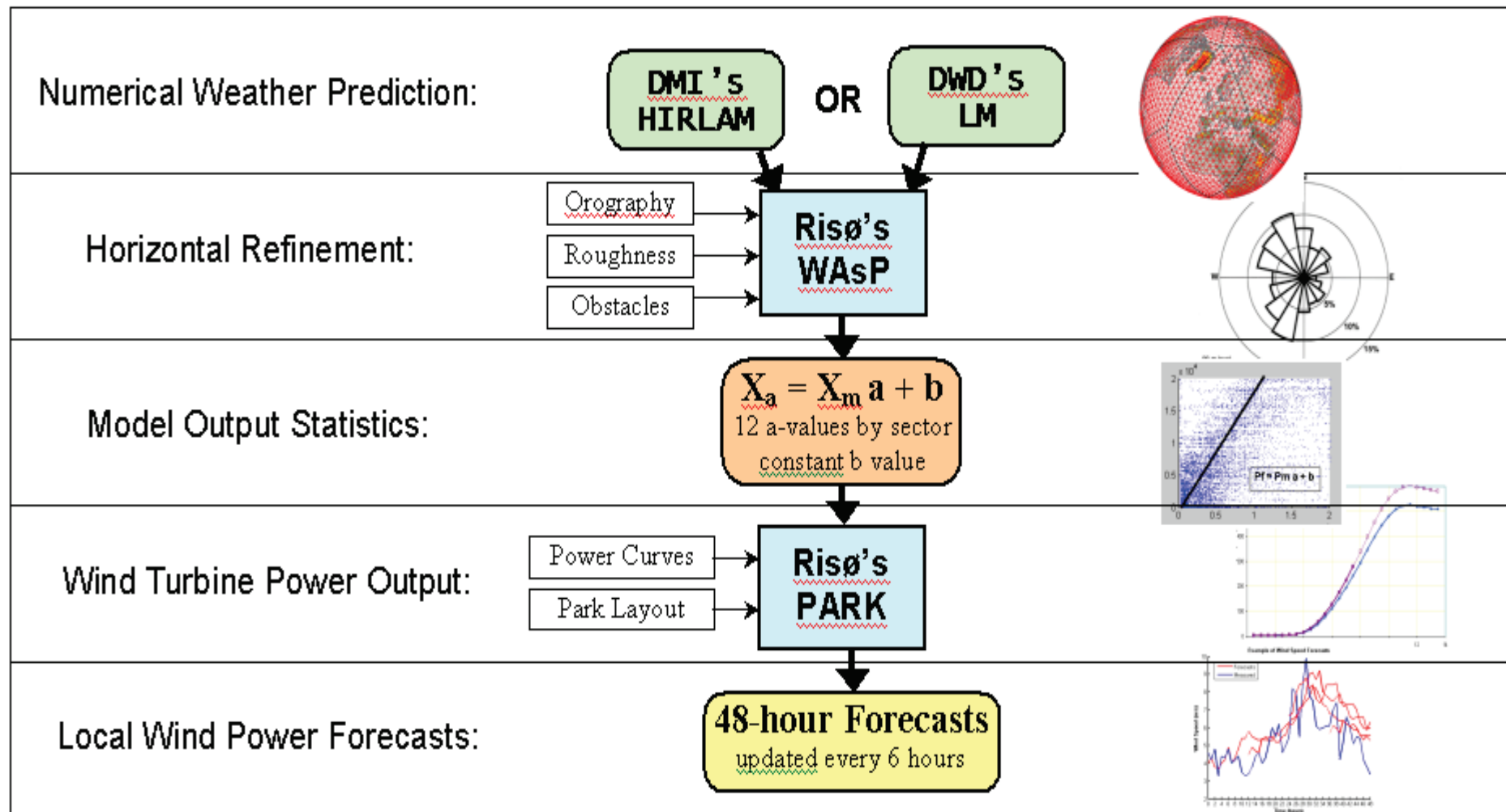
Ed McCarthy 1985-87

- Predicted for the large wind farms in California (Altamont, San Gorgonio etc)
- Was run in the summers of 1985-87
- On a HP 41CX programmable calculator



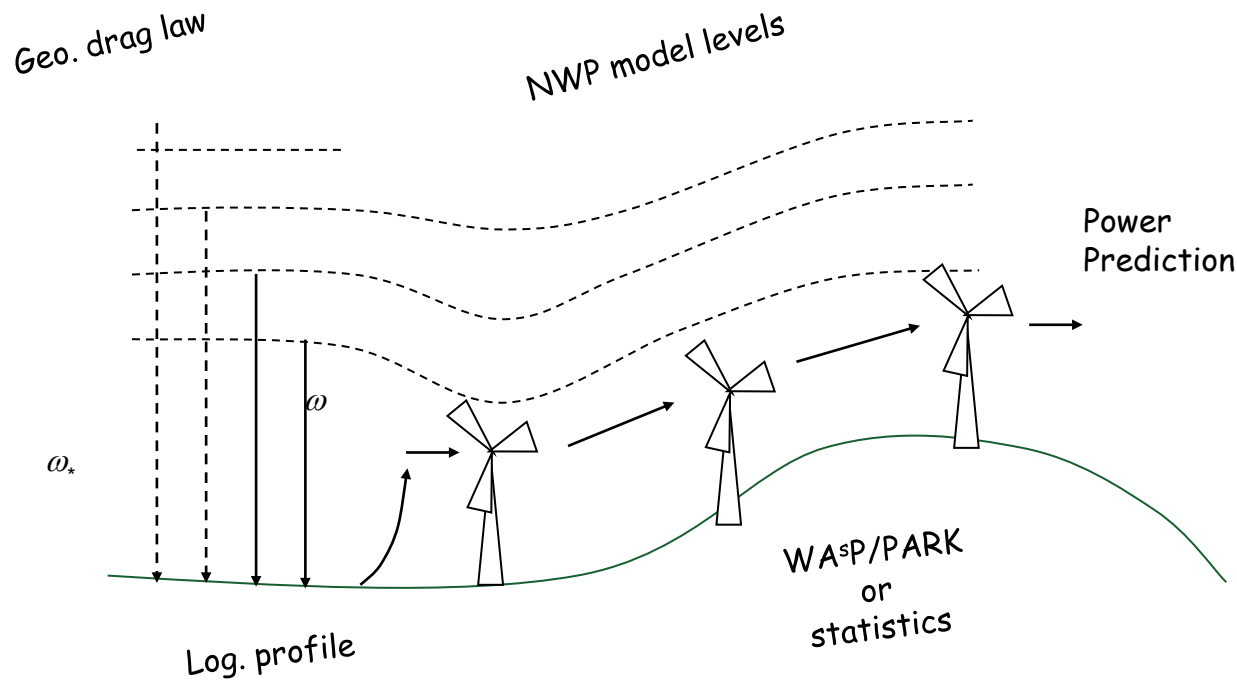
- Using meteorological observations and local upper air observations
- The program was built around a climatological study of the site and had a forecast horizon of 24 hours.
- It forecast daily average wind speeds with better skill than either persistence or climatology alone.

Prediktor

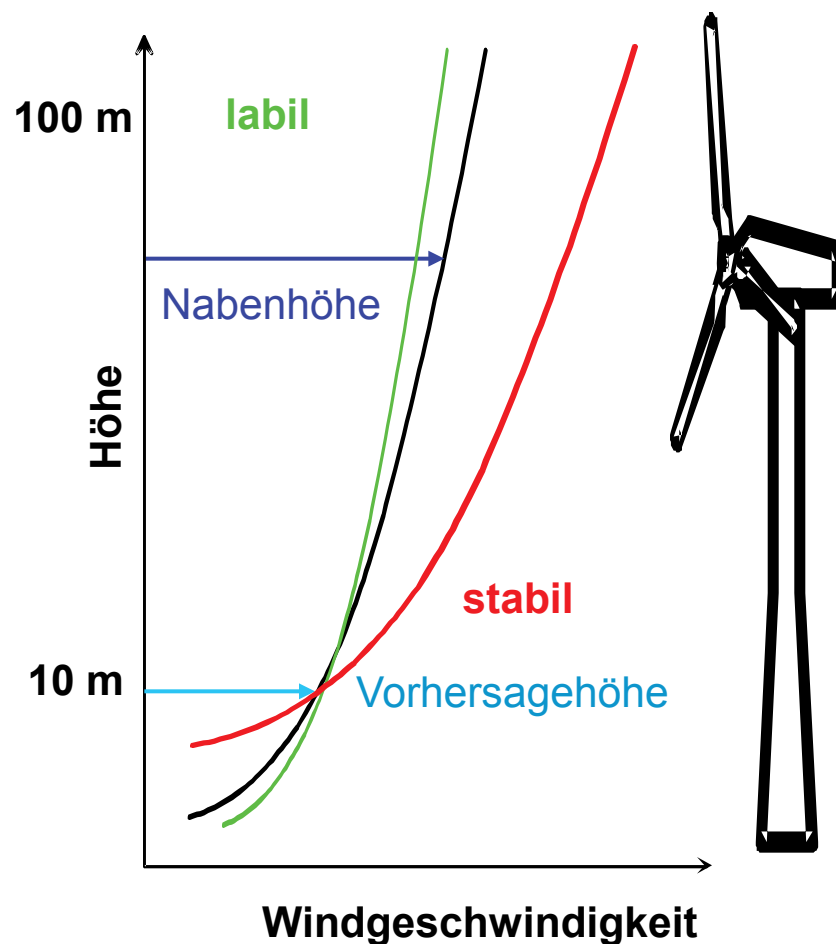
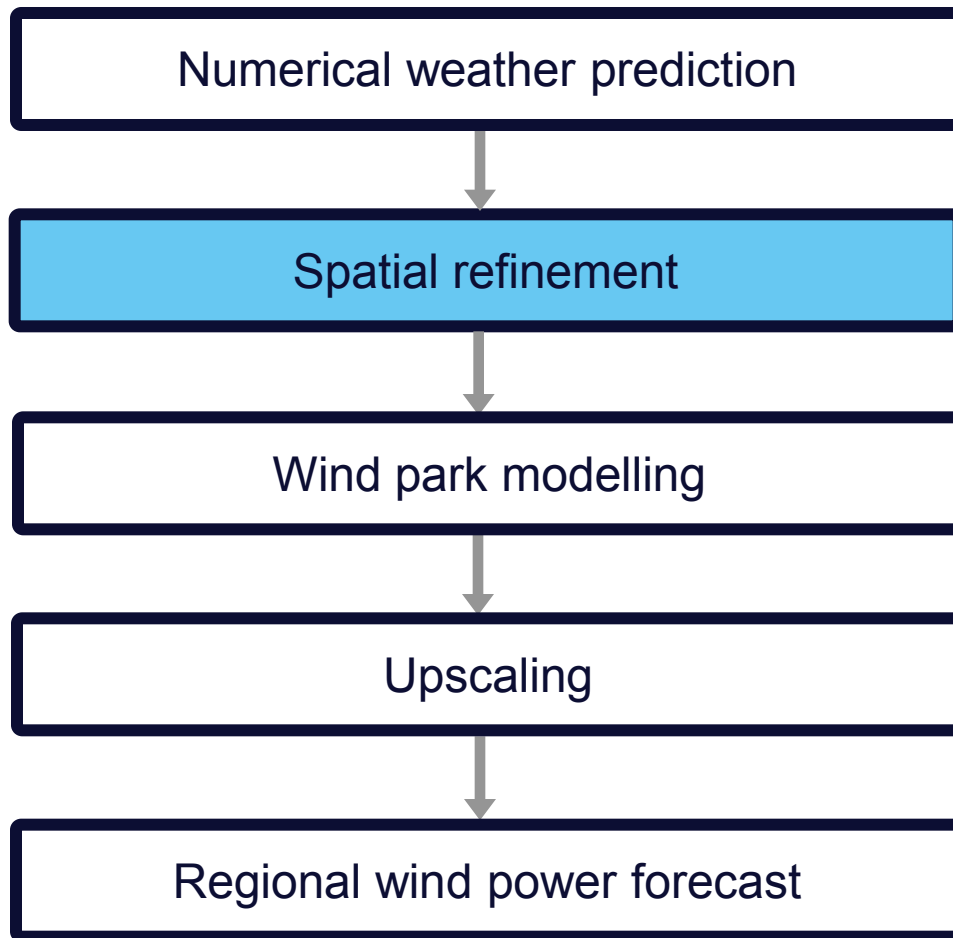


- Applied in Eastern Denmark between 1993 and 1999
- *Similar: Previento*

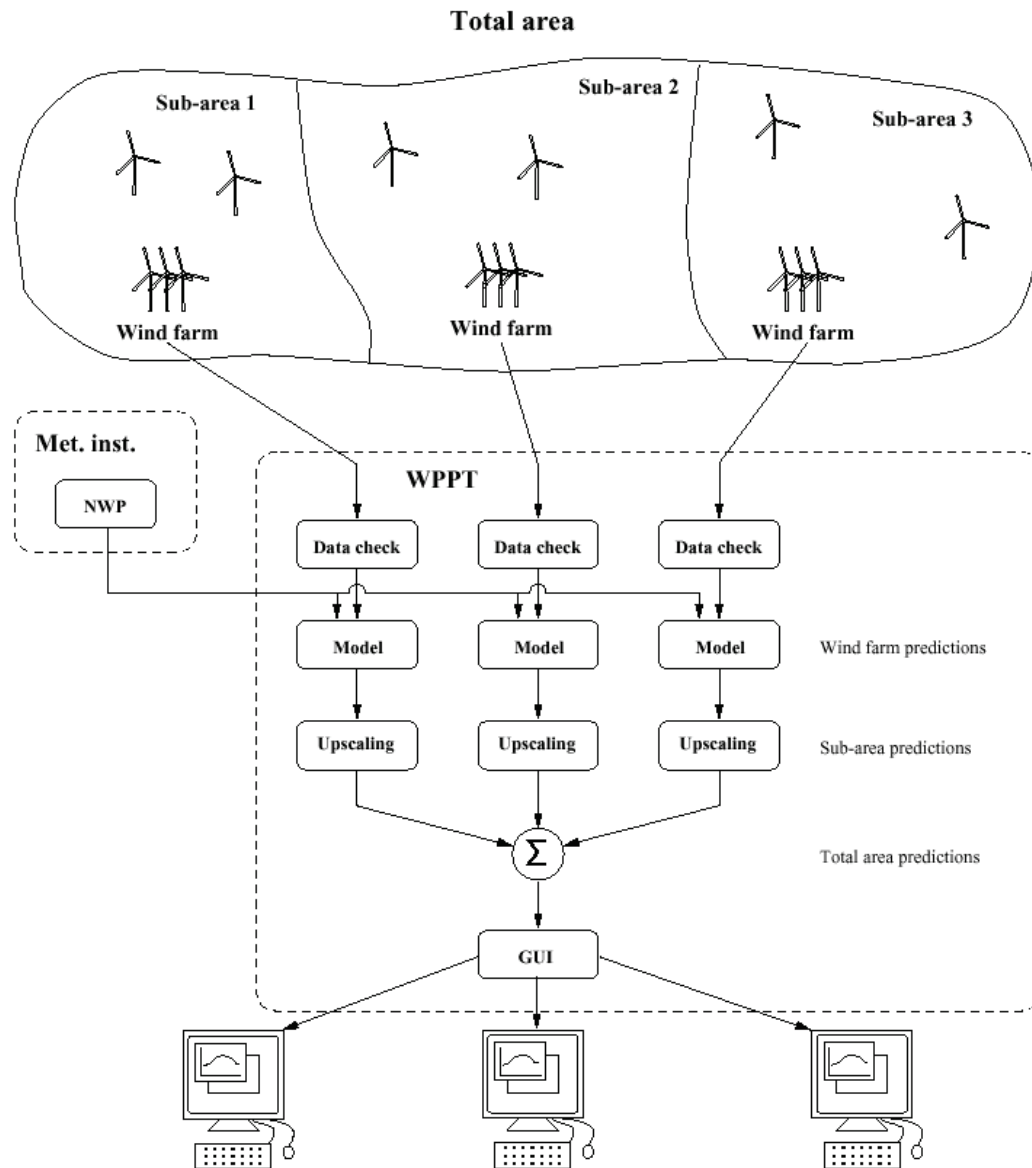
Similar to Prediktor, but uses more stringent physical downscaling (incl stability) and specialised upscaling
Operational at EWE, E.On, RWE, Vattenfall, EnBW
University of Oldenburg / energy & meteo systems GmbH



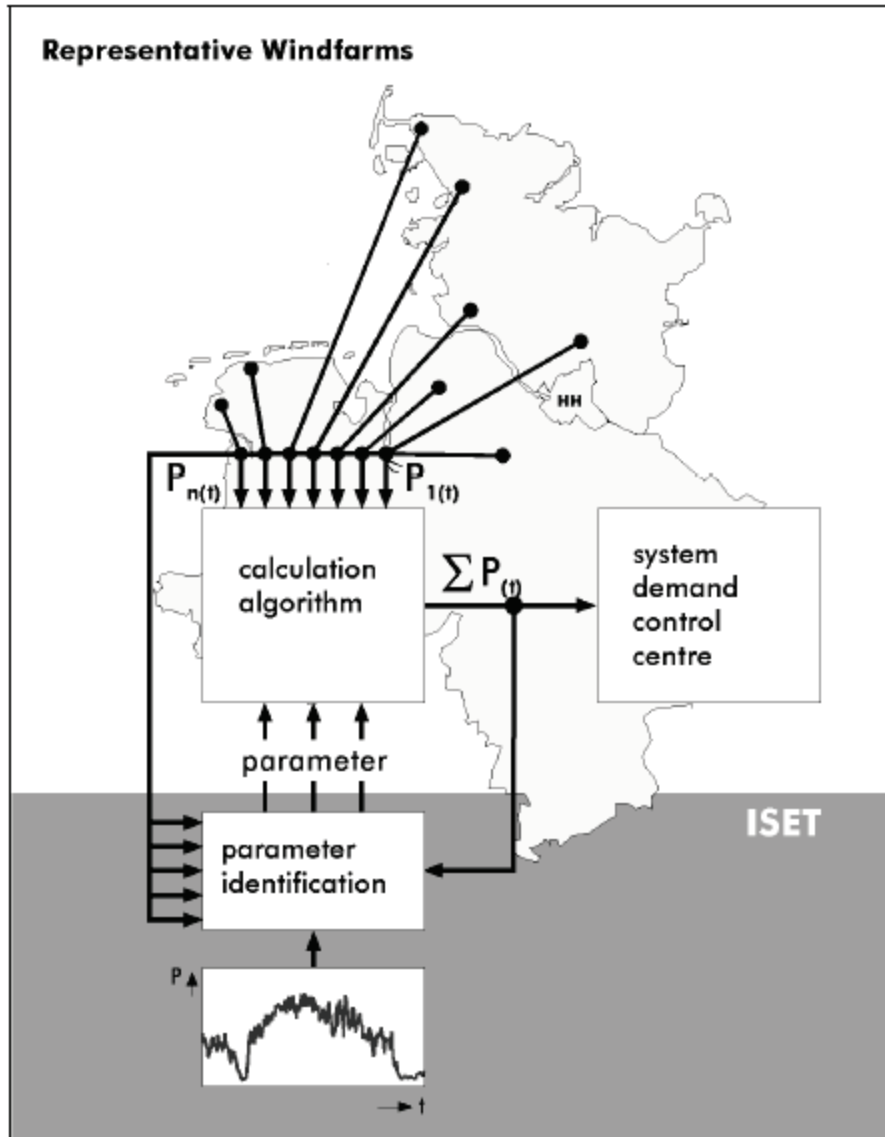
Overview Previento



Wind Power Prediction Tool



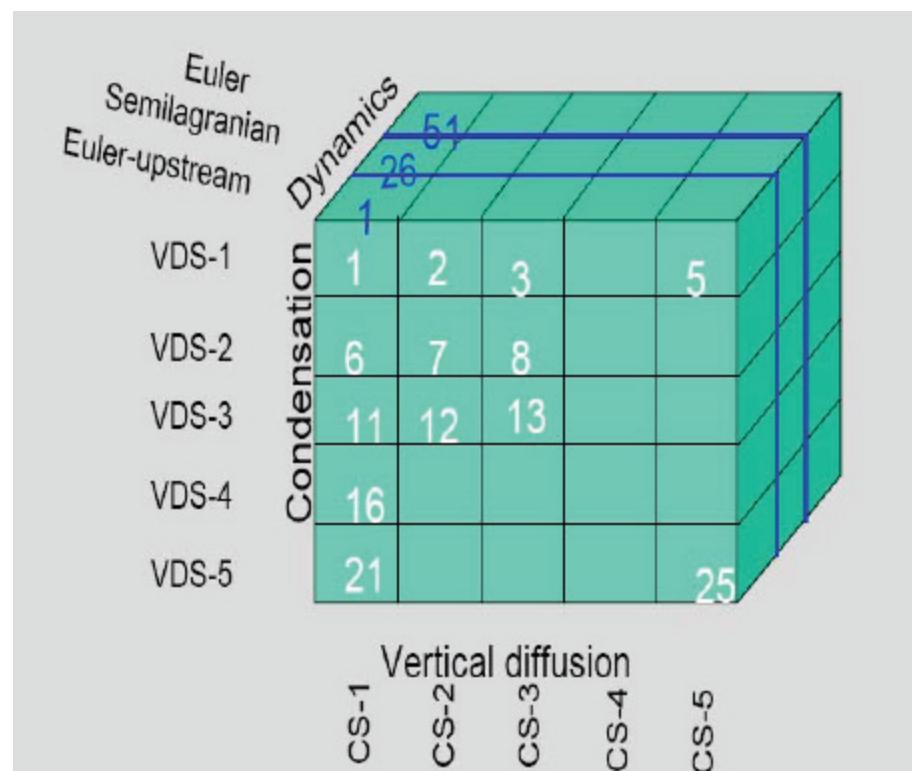
- Developed at IMM/DTU
- Operational in Western DK 1994
- Operational for all of DK 1999
- Statistical non-parametric adaptive models for prediction of representative farms
- Upscaling statistically to installed capacity
- Employs data cleaning
- *Similar: Sipreólico, WPMS, MORE-CARE*



- Wind Power Management System = Nowcasting + Forecasting
- In use at E.On Netz since 2001, RWE since 6/2003, Vattenfall Europe 2004
- E.On case: 50 representative wind farms (soon more) from WMEP -> ANN upscaling = Nowcast
- DWD Lokalmodell and others provide for forecast
- Accuracy: after 7 hours purely NWP dominated (5% RMS for E.On Netz total area)

MSEPS Power Prediction by WEPROG

- Power prediction built on the 75 member Multi-Scheme Ensemble Prediction System (MSEPS)
- Auto-adaptive approach
- Using dynamic weight of the individual ensemble members
- Applied on individual wind farms and area aggregated wind power
- The MSEPS is operated globally and forecasts for more than 90% of the world's installed capacity
- Forecasts are generated 4 times per day to 144 hours ahead



- **Sipreólico**

Developed by Uni Carlos III for Red Electrica España
Uses combined forecasting with advanced statistical models

- **LocalPred**

More research oriented model by Martí of CENER
Combines CFD and meso-scale modelling with Principal Component Analysis and sophisticated statistics

- **MORE-CARE**

Developed by ARMINES and RAL
Uses Fuzzy Neural Networks
Operational in Crete, Madeira, Azores, ...

Marketplace for models

During the last 8 years, many commercial companies have appeared

Market place contains some 20-40 models

Notably:

3Tier, TrueWind, Windlogics, Precisionwind, Eurowind, GL GarradHassan, UK MetOffice, Kjeller Vindteknik, met.no, ...

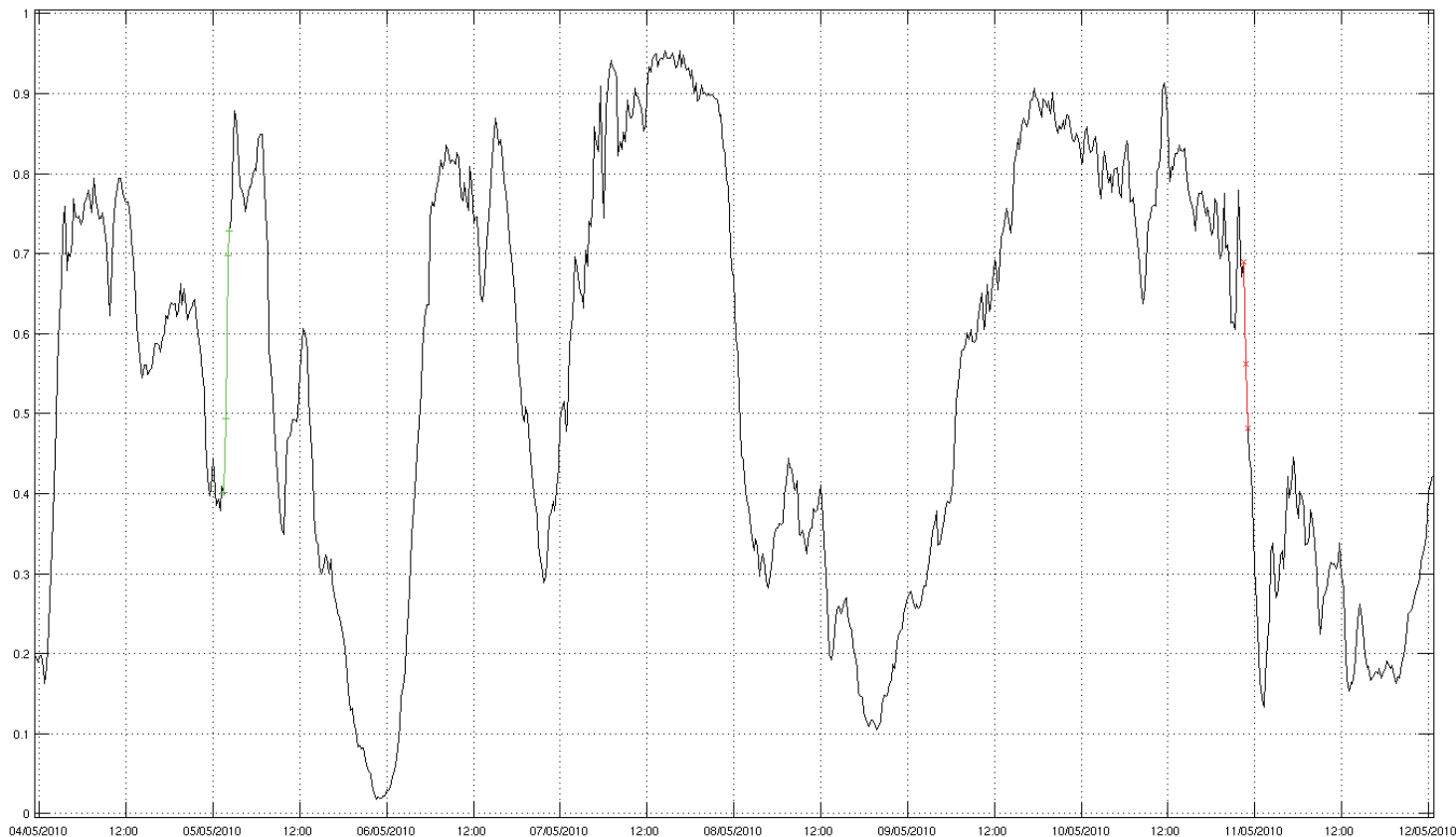
- Usually coming from the adaptive statistical tools
- Means, they are based on the (medium term) past performance
- New topic (200x): weather dependent uncertainties / quantiles
- Original work done by:
 - Armines (MRI, NPRI)
 - Uni Oldenburg (large-scale weather situation, uncertainty modelling)
 - Bremnes (Local Quantile Regression)
 - Risø/IMM/DMI (Ensembles)
 - ... and many more groups

Ramps and Variability

Ramps and Variability forecasts

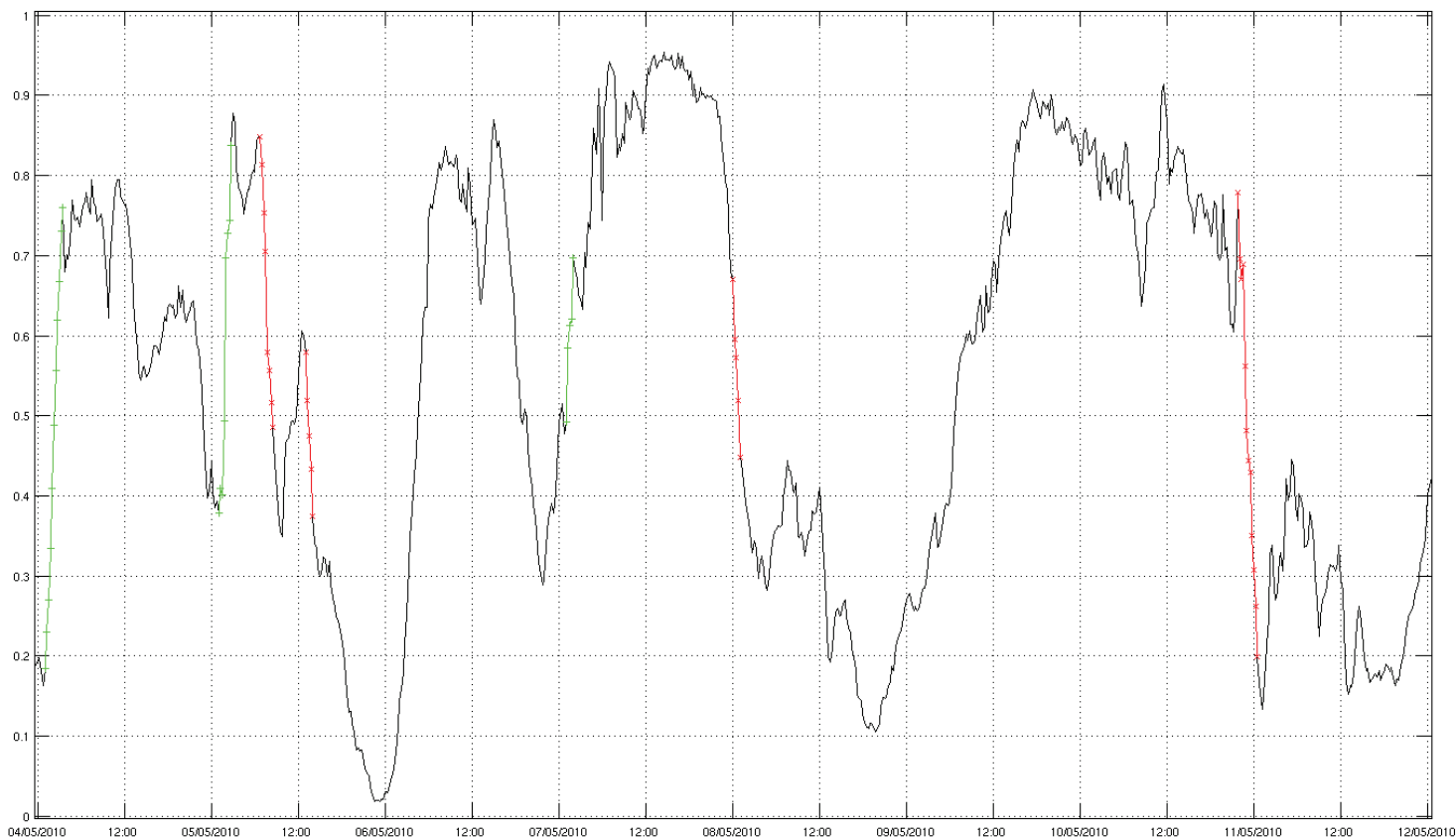
- Relatively new topic, on the agenda only since “chunk sizes” of wind power installations get quite large (>100 MW)
- Work by Garrad Hassan, CSIRO, Risø DTU, energy&meteo systems, Enfor and many others

What is a ramp ?



20 % in 30 min ?

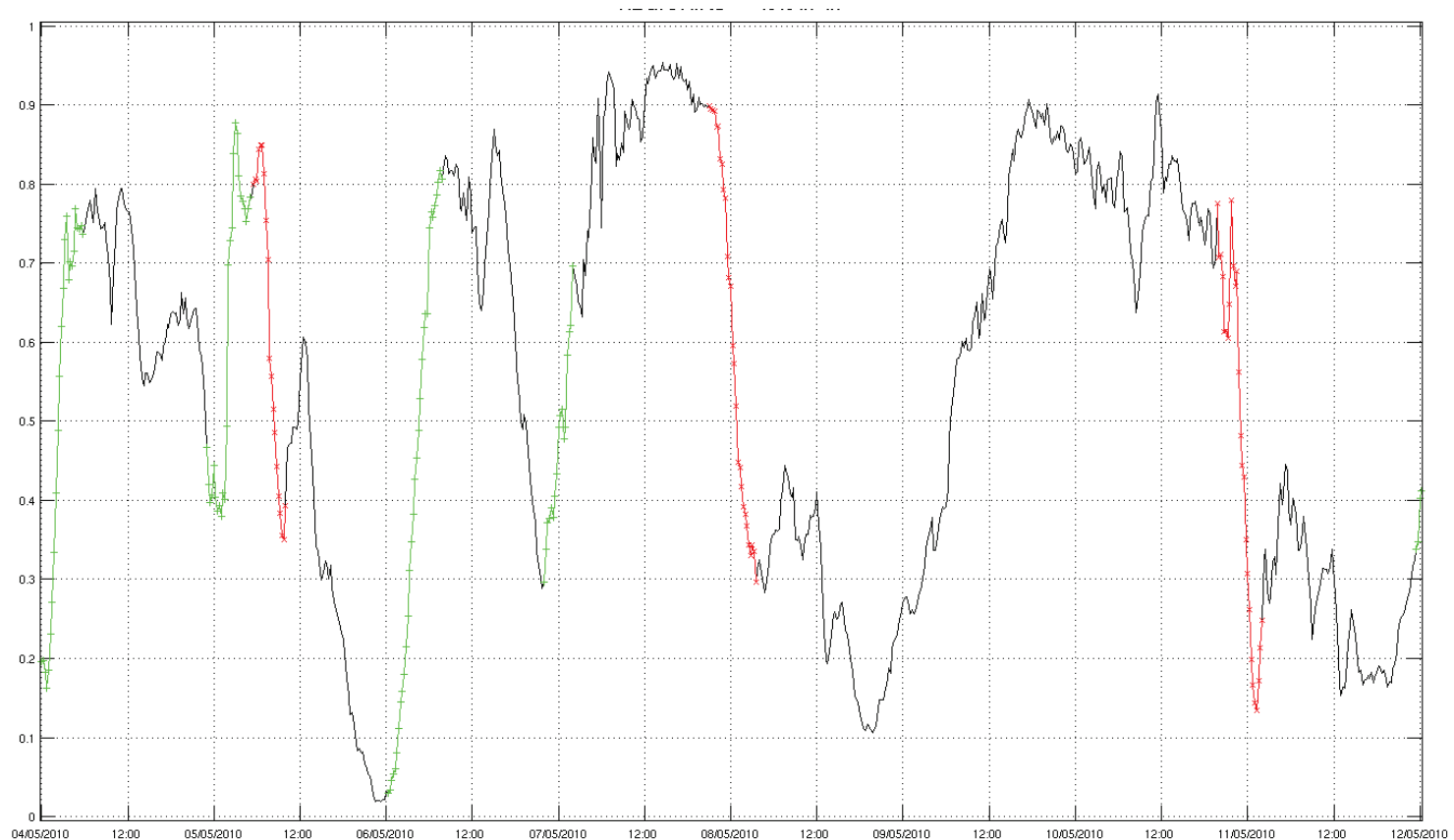
What is a ramp ?



20 % in 1 hours ?

Source: Ulrich Focken, energy&meteo systems, DE: [Experiences with Extreme Event Warning and Ramp Forecasting for US Wind Farms](#). Talk on the 4th Workshop on Best Practice in the Use of Short-term Forecasting, Quebec, 16 October 2010

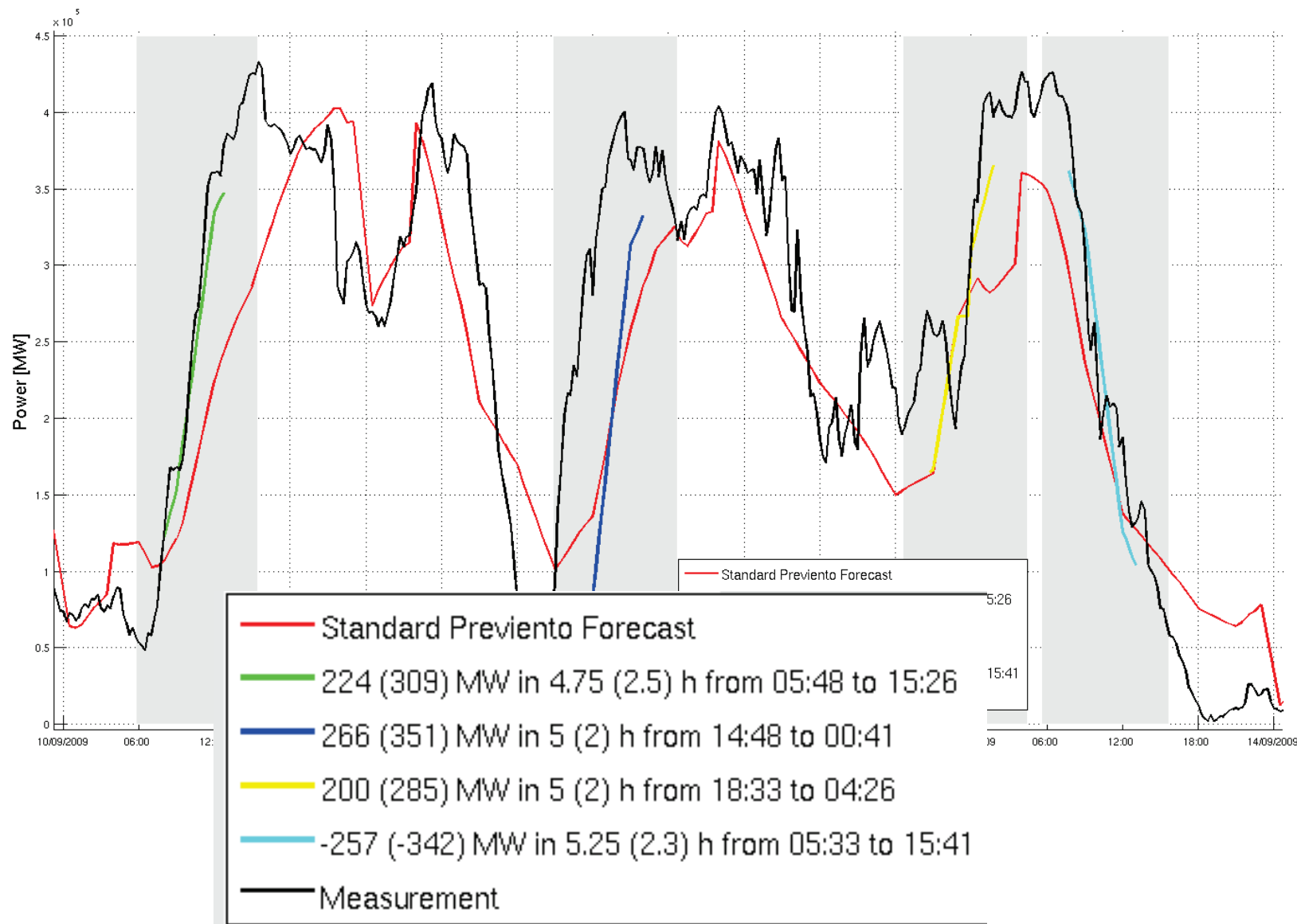
What is a ramp ?



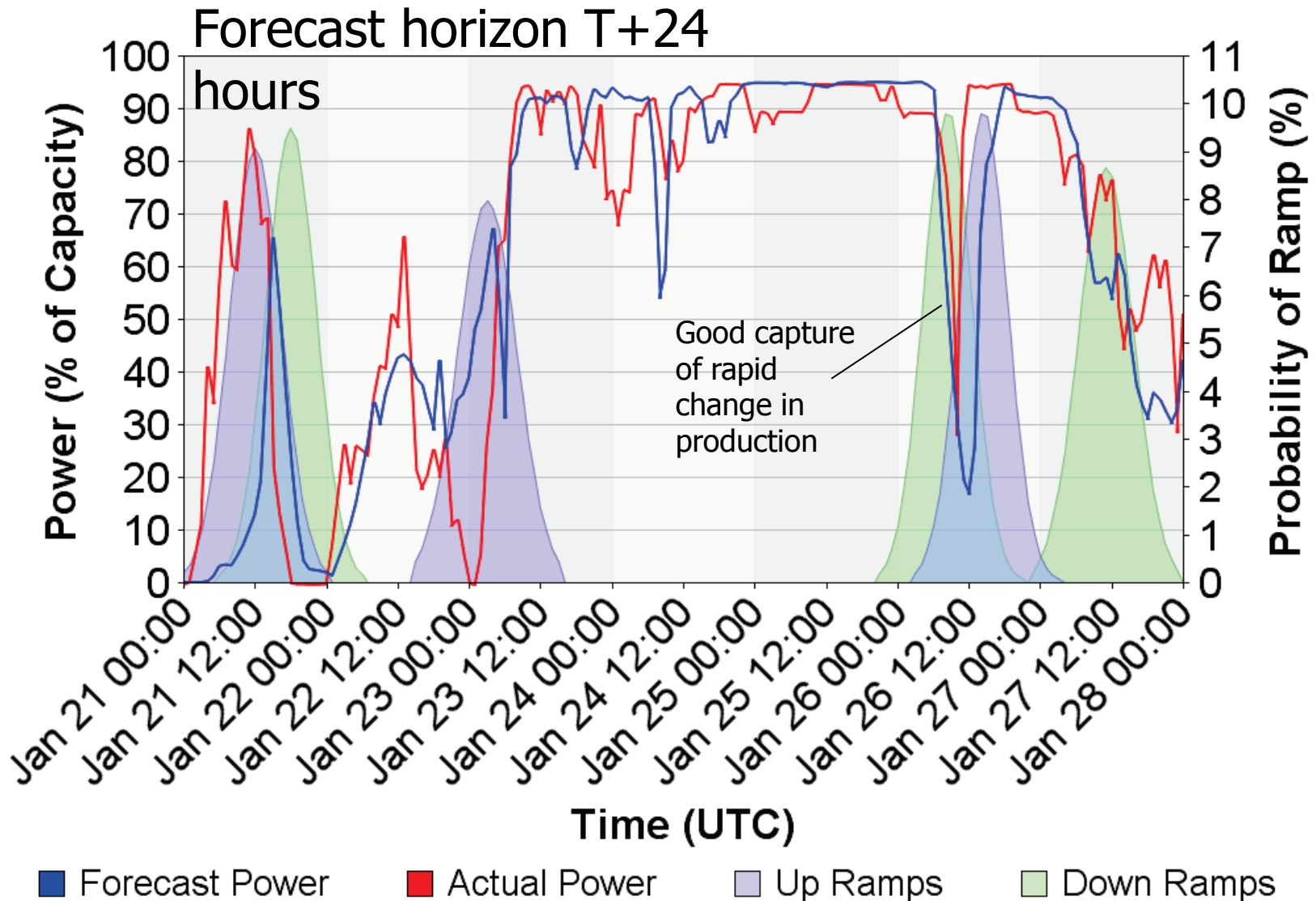
40 % in 2 hours ?

Source: Ulrich Focken, energy&meteo systems, DE: [Experiences with Extreme Event Warning and Ramp Forecasting for US Wind Farms](#). Talk on the 4th Workshop on Best Practice in the Use of Short-term Forecasting, Quebec, 16 October 2010

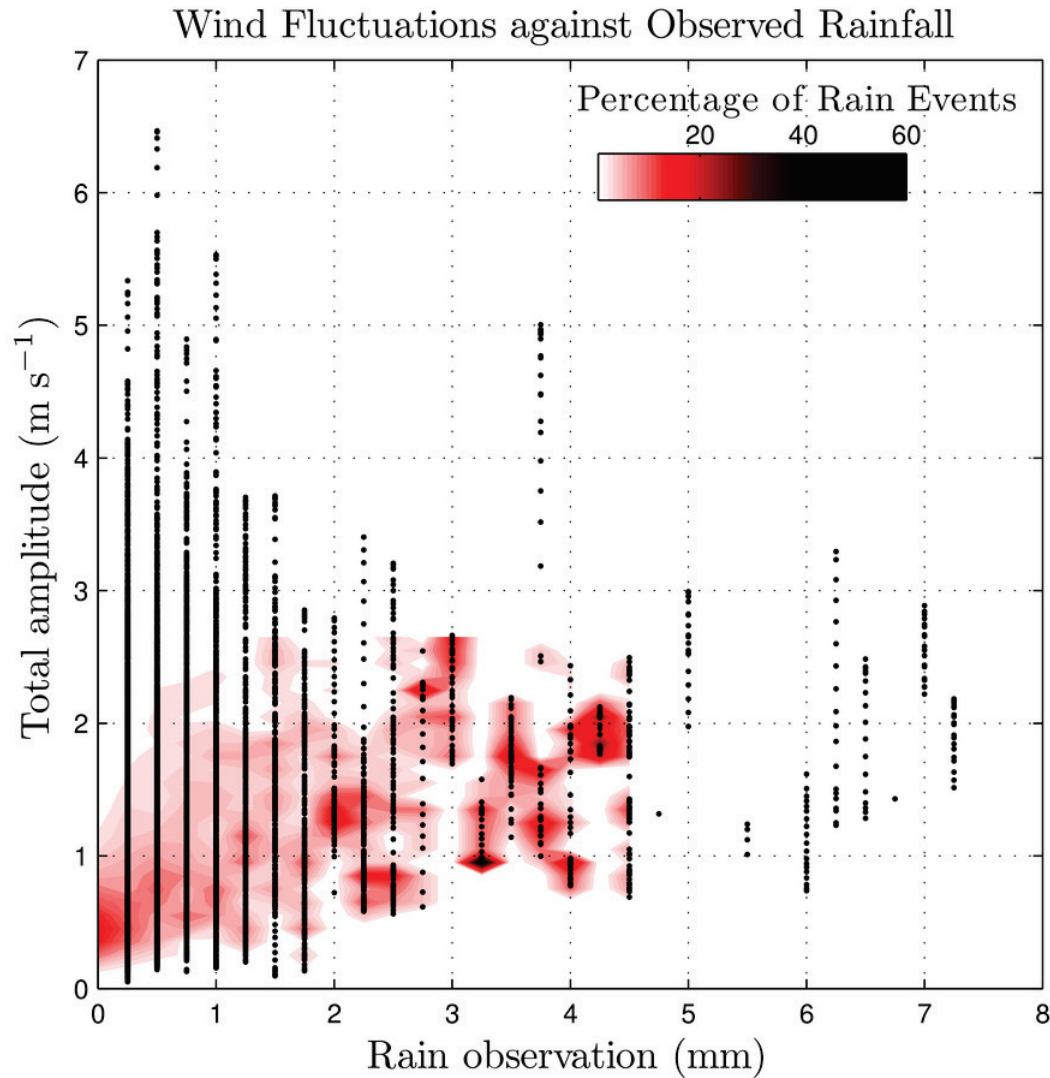
Possible approach, energy&meteo systems



GL Garrad Hassan Ramp Forecasting Results - individual wind farm



Precipitation

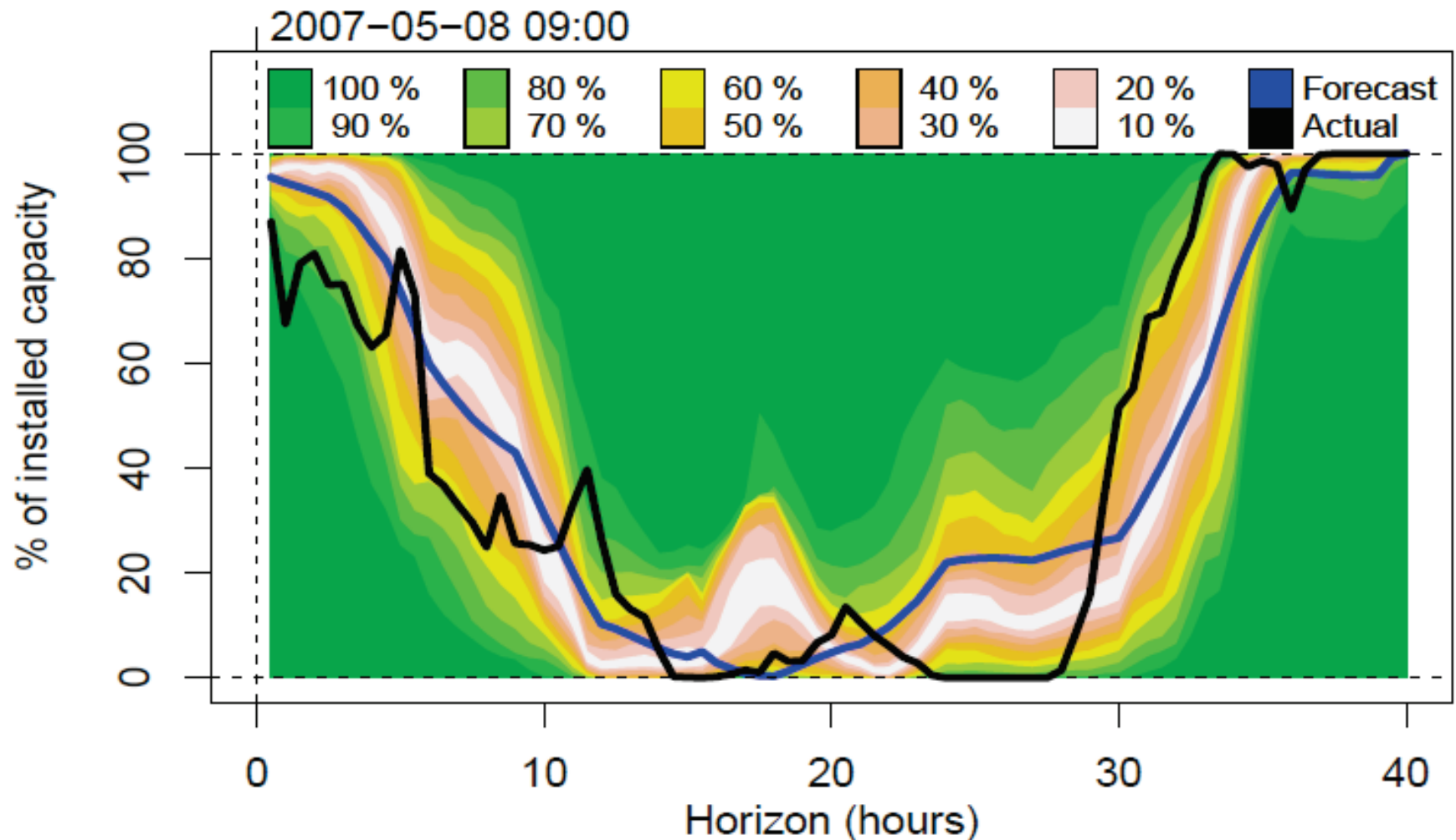


$$R_{max}(n) = \max(R(n-9), R(n-8) \dots R(n) \dots R(n+8), R(n+9))$$

Scenarios

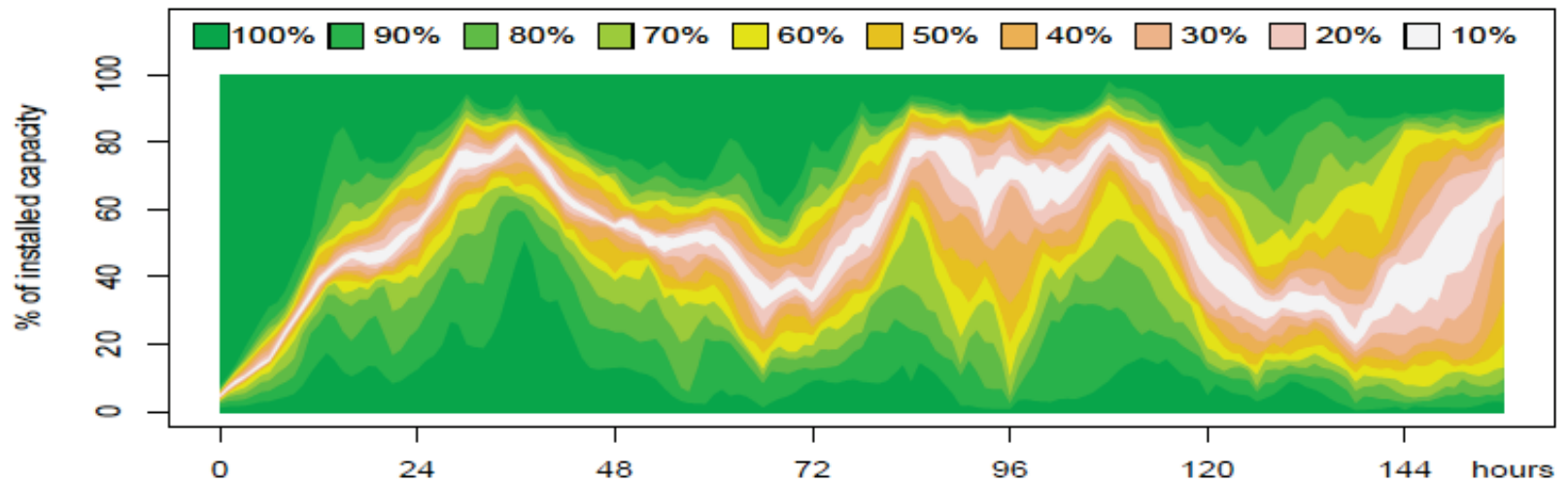


Example of WPPT point and quantile forecasts

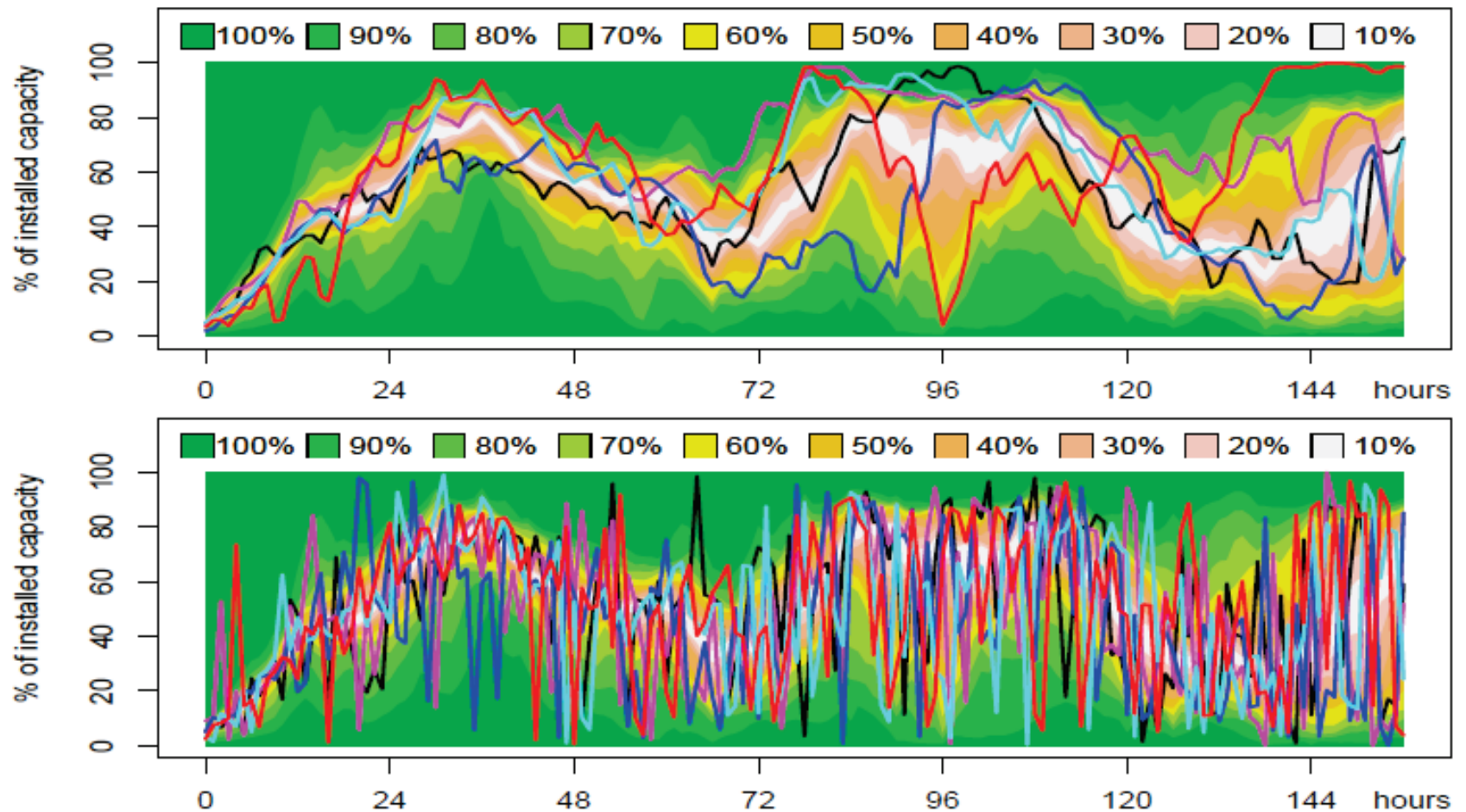


Scenarios

- Realistic development of the future – reflect the correctly calibrated quantiles and the observed auto correlation (on an appropriate scale).



Correct (top) and naive (bottom) scenarios



Types of forecasts required

Basic operation: Point forecasts

Operation which takes into account asymmetrical penalties on deviations from the bid: Quantile forecasts

Stochastic optimisation taking into account start/stop costs, heat storage, and/or 'implicit' storage by allowing the hydro power production to be changed with wind power production: Scenarios respecting correctly calibrated quantiles and auto correlation.

Best Practice

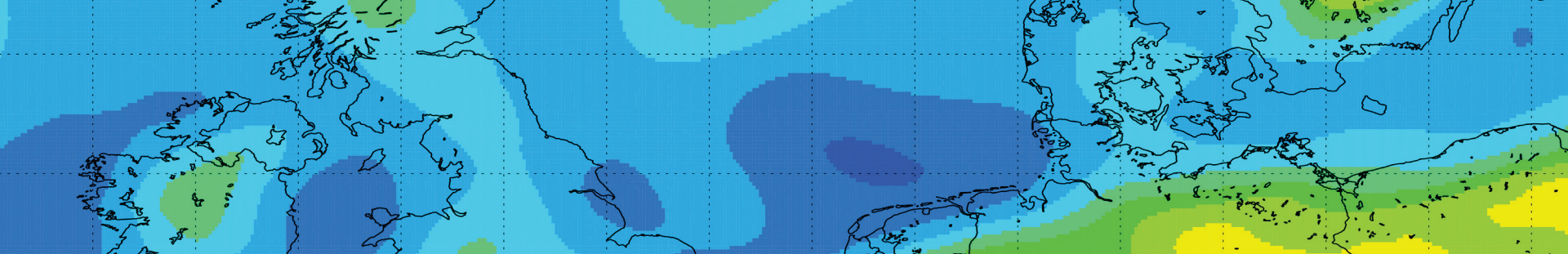
Best Practice in making the forecasts

- Use statistical approaches and NWP
- Get NWP input close to hub height
- Build a power curve from NWP wind speed and direction vs measured power
- Give uncertainties and/or quantiles
- Use several NWP models and/or ensembles
- Provision of forecasts as model installed at the client or as a service

- Get a model
- Get another model (NWP and / or short-term forecasting model)
- Work together with service provider / academia to continuously improve model accuracy
- Reduce error by predicting for a larger area (smoothing)
- Balance all errors together, not just wind
- Use the uncertainty / pdf
- Do forecasting on TSO level, not necessarily on wind farm / developer level
- Use intraday trading
- Use longer forecasts for maintenance planning
- Meteorological training for the operators
- Meteorological hotline for special cases
- Also in report on powwow.risoe.dk (Giebel and Kariniotakis: *[Best Practice in Short-term Forecasting. A User's Guide](#)*. Project report for the POW'WOW project, 6 pages, 2009)

Best Practice Workshop

- 5 Workshops held in Delft, Madrid, Bremen, Quebec and Aarhus
- On Best Practice in the **Use** of Short-term Forecasts
- Should evolve into something like a wind power forecast user group
- Based on the idea that research delivers far more than TSOs/utilities actually use – and that utilities have figured out how to use forecasts for themselves, so why not share this knowledge
- See details on powwow.risoe.dk/BestPracticeWorkshop.htm .



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