Technical University of Denmark

State of the Art in Wind Power Forecasting

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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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DTU

State-of-the-Art for Wind Power

RISØ

ANEMOS.plus	SafeWind
"Advanced Tools for the Management of Electricity Grids with Large-Scale Wind Generation". EU FP6 Contract N°: 038692	"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
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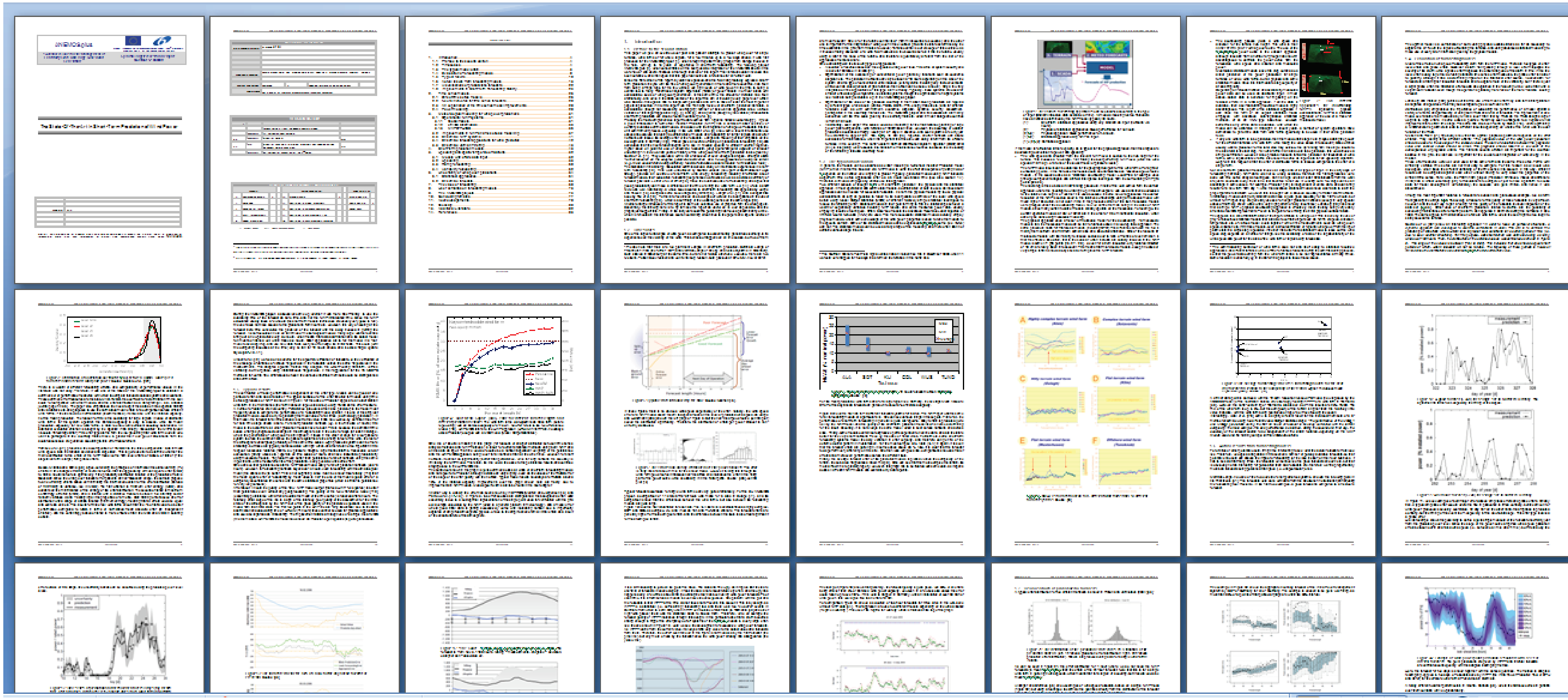
State-of-the-Art in Short-term Prediction



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

111 pages

>380 references

>230 citations

On Safewind.eu

Weather Intelligence for Renewable Energies WIRE

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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.**

WIRE SOTA

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

TOC:

1 Management summary

2 Political, economical and technical framework

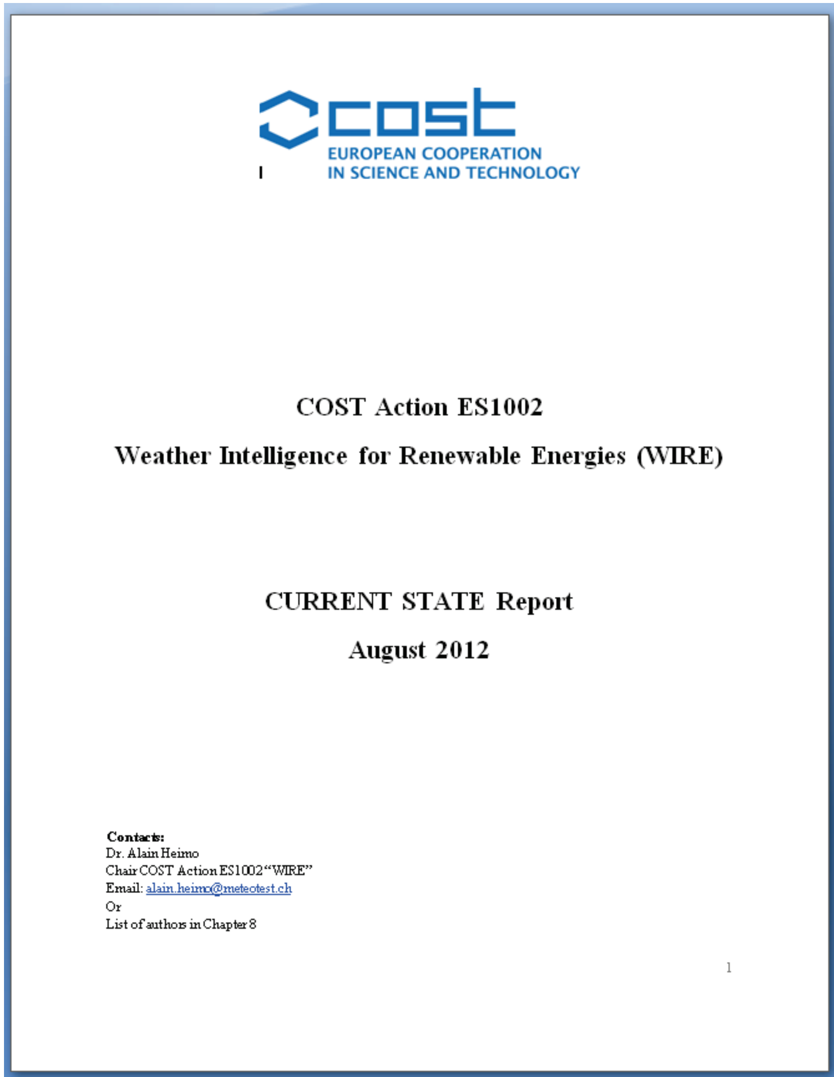
3 Research and Development: the European approaches

- 3.1Wind Energy
- 3.2Solar Energy
- 3.3Grid management
- 3.4Wave 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



cost
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

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

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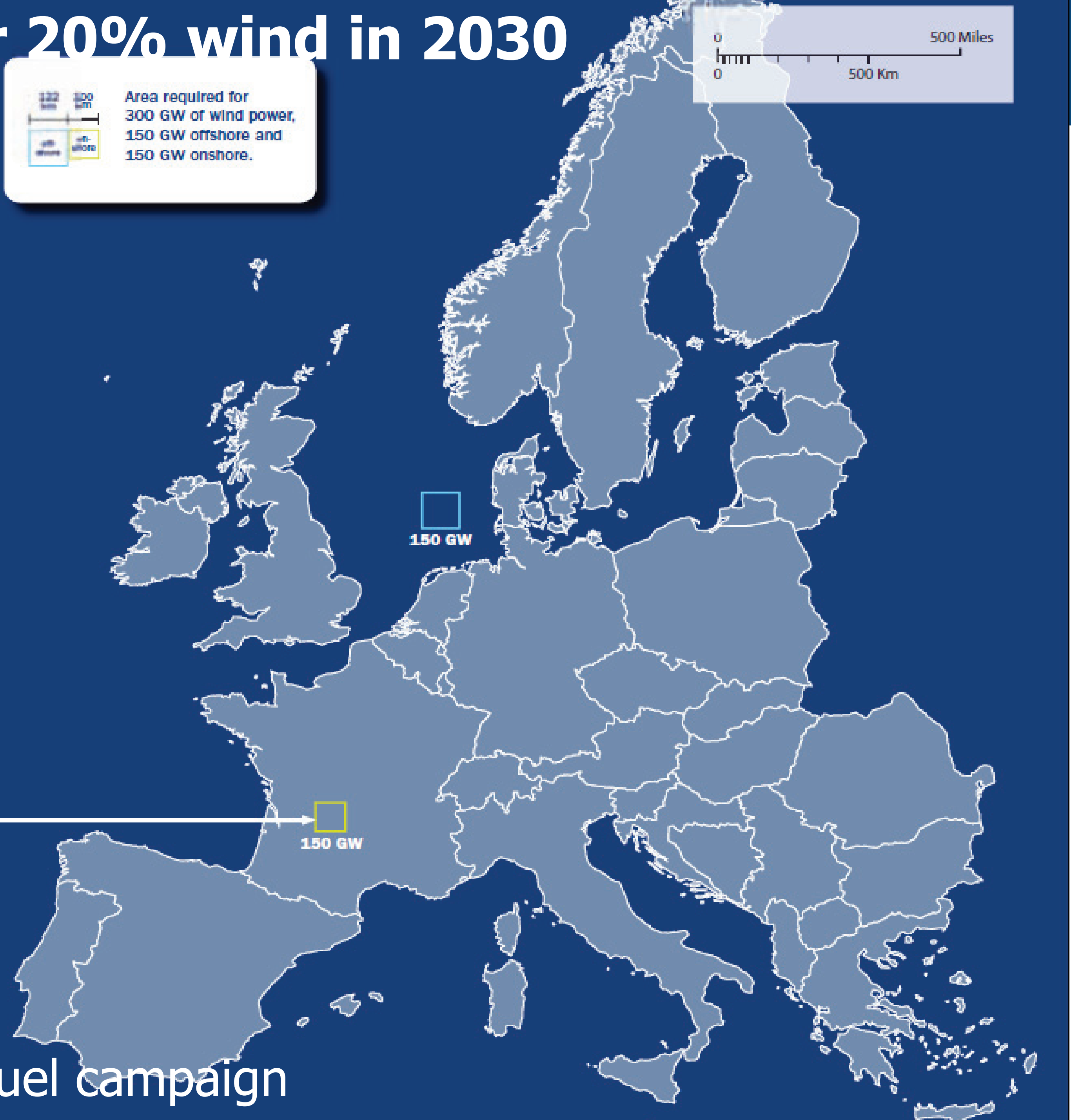
156 pages.

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

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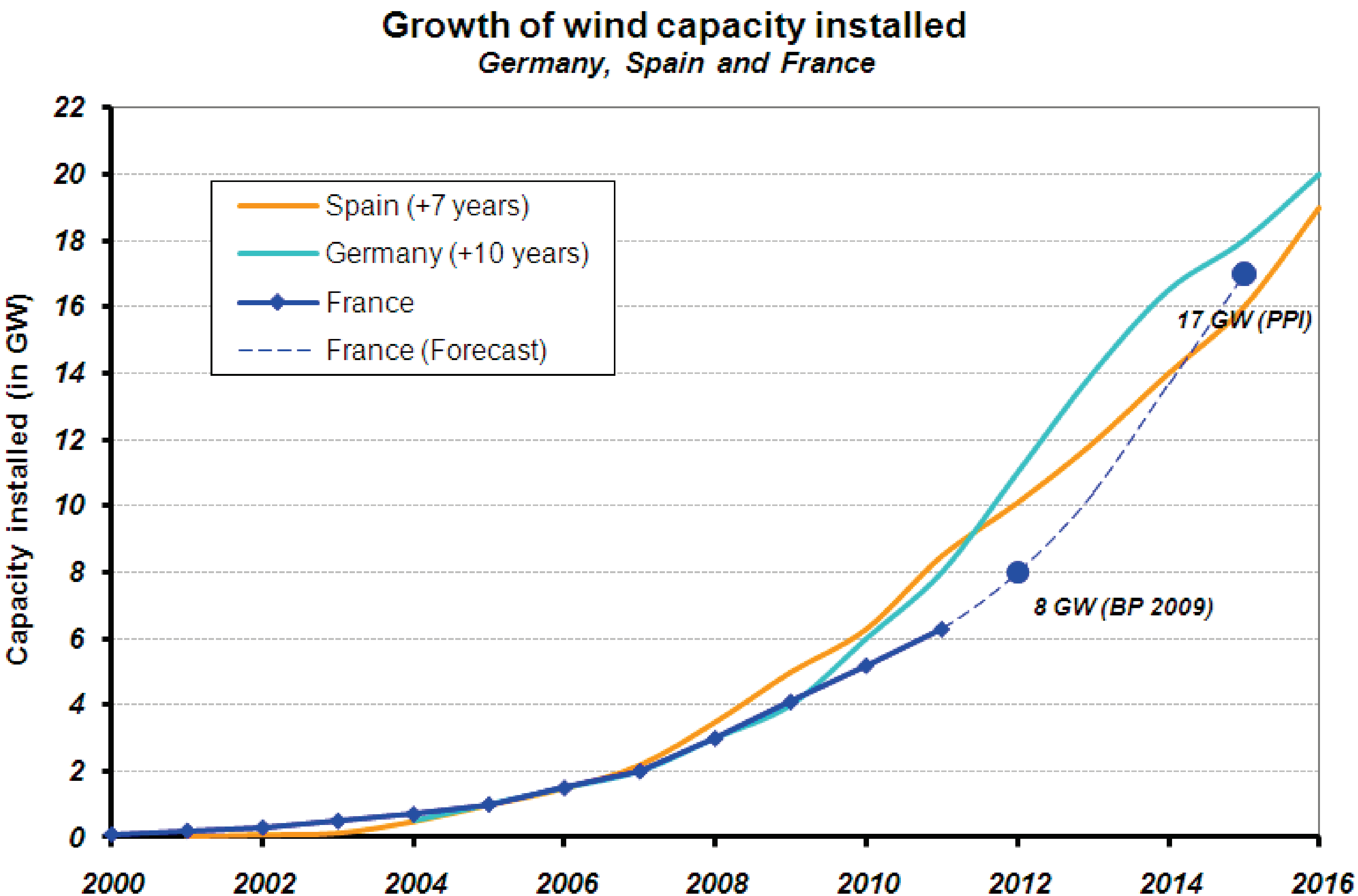


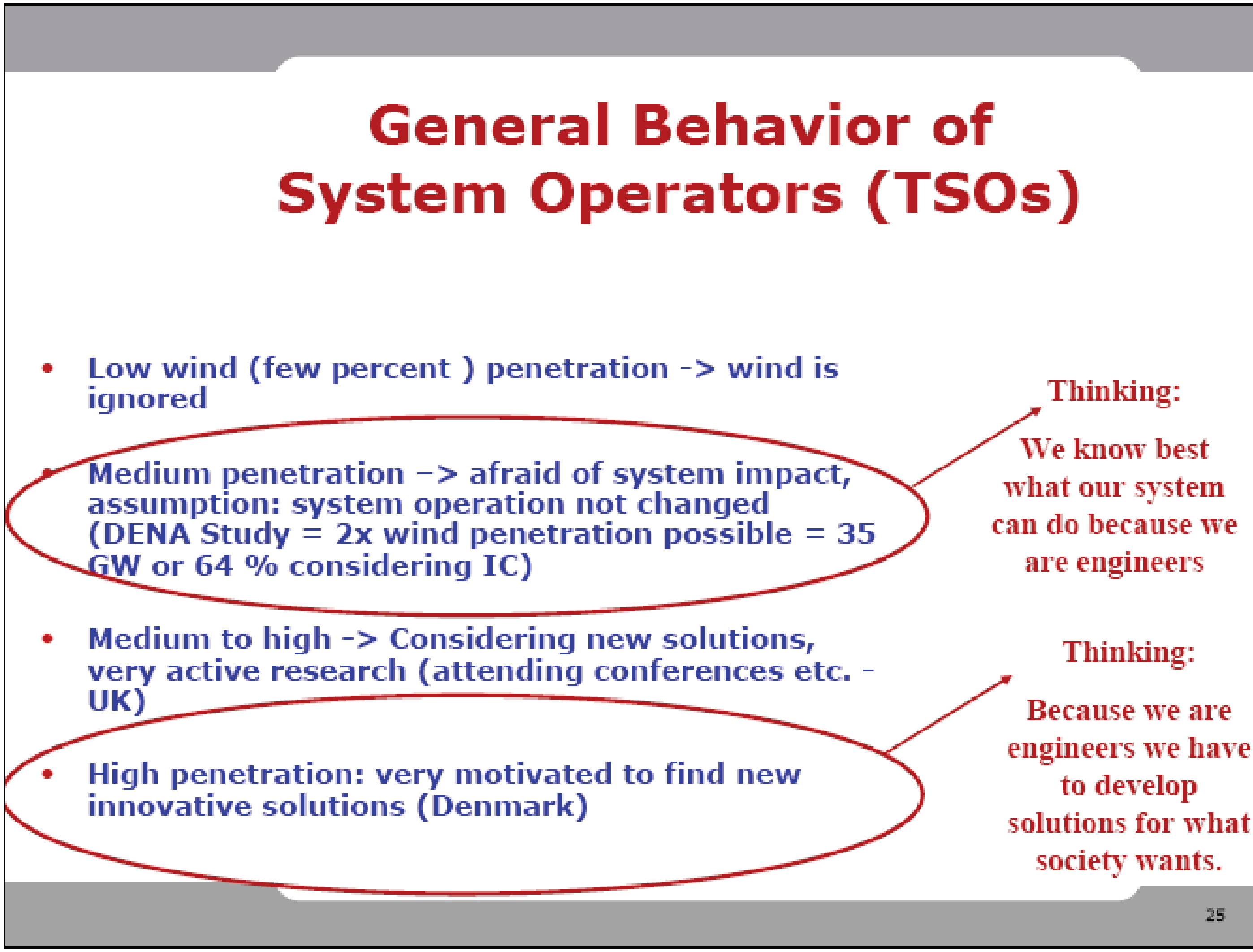
Source: Vincent Lefieux, RTE, on the SafeWind End User Workshop 2012 in Fredericia (see safewind.eu)

Users of forecasts

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

Thomas Ackermann about TSOs



Source: 1st Workshop on Short-term Forecasting, Uni NSW, Sydney (AUS), December 2005

Predictions HowTo

Four timescales

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- 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

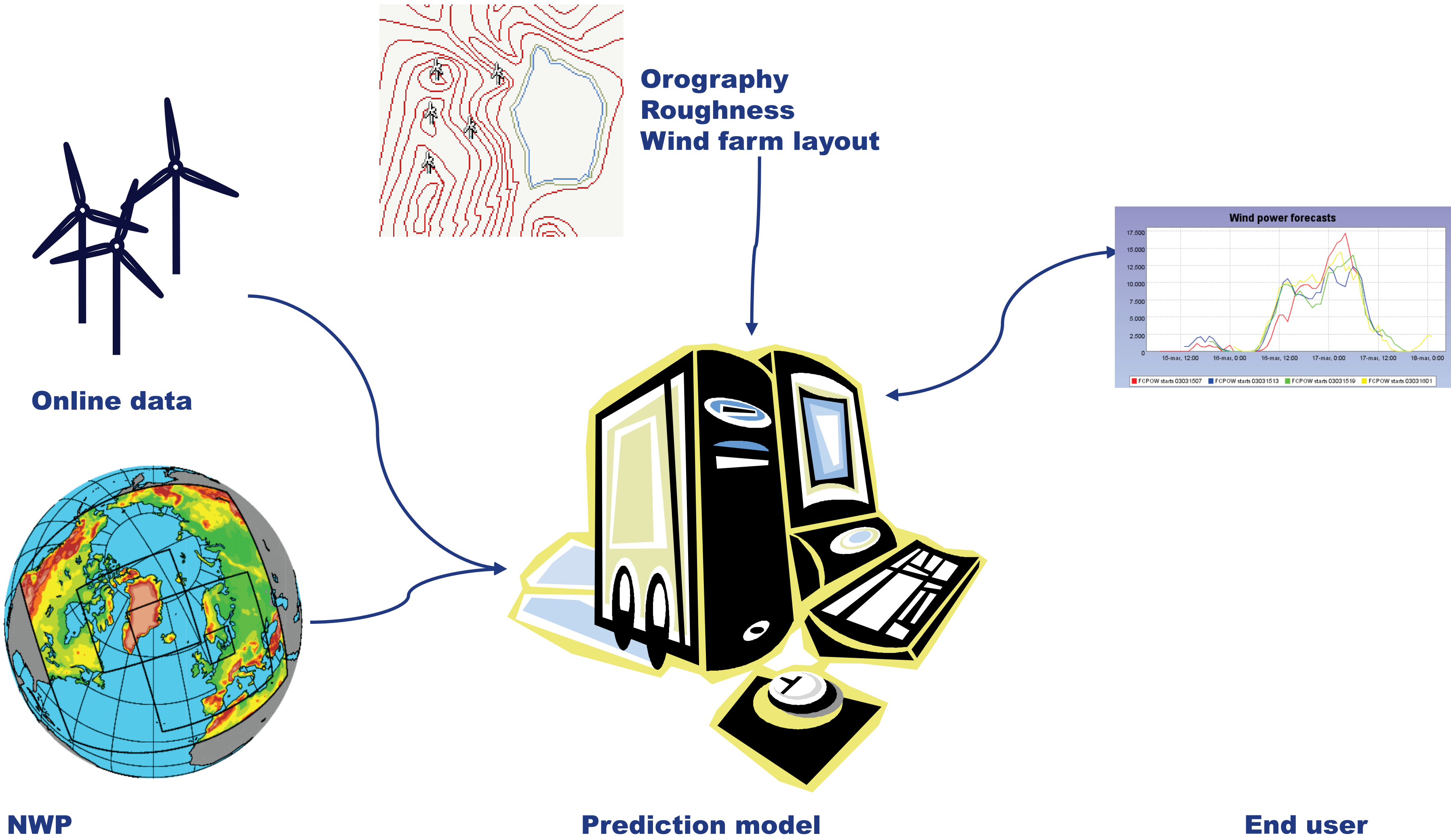
- Maintenance Planning: medium-term

  Eg crane movements – lead time of **days**

  Ideally 2 weeks, or at least 5 days from Monday morning

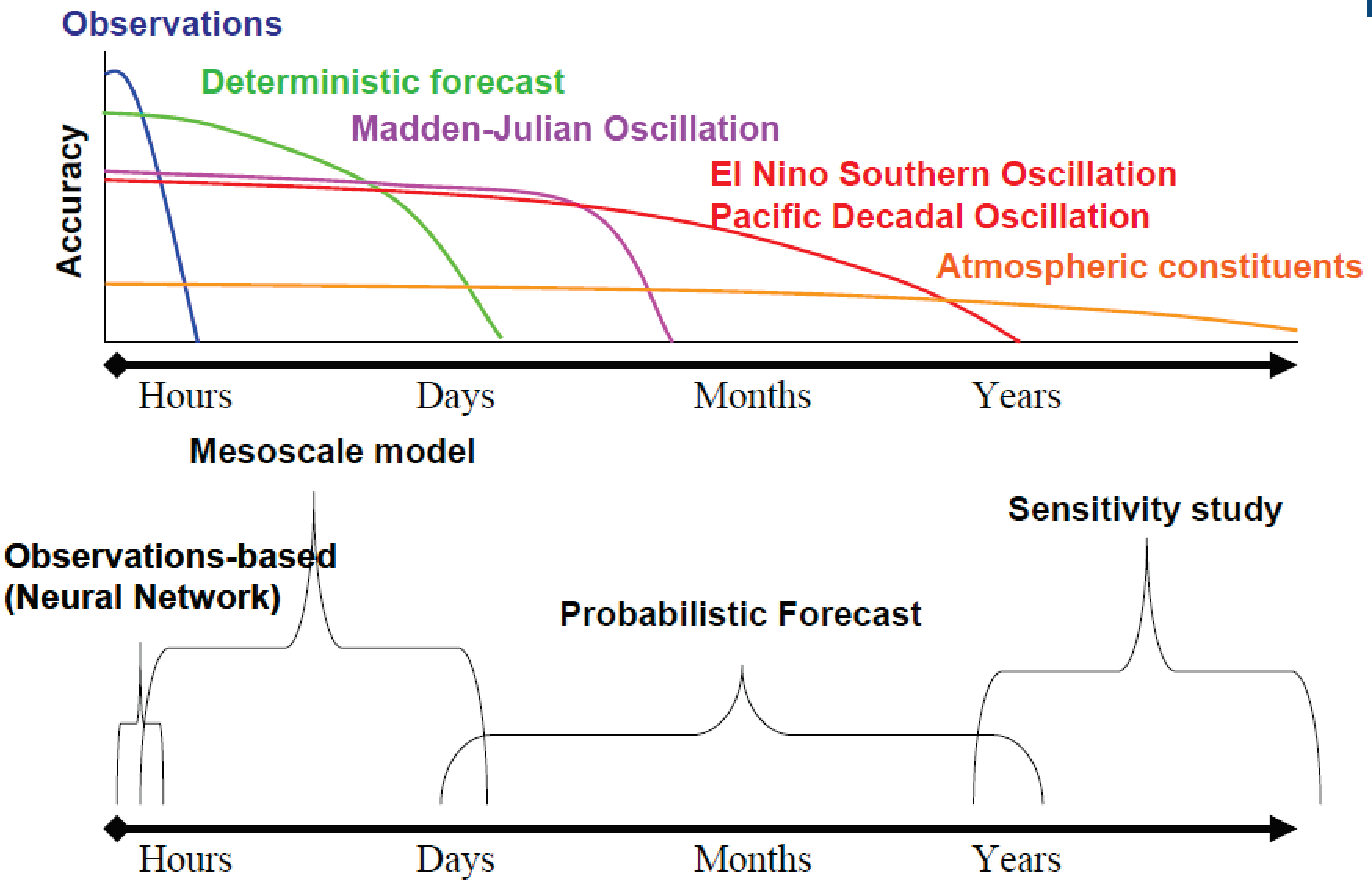
  In DK used also for fuel consumption predictions

Short-Term Prediction Overview



Performance

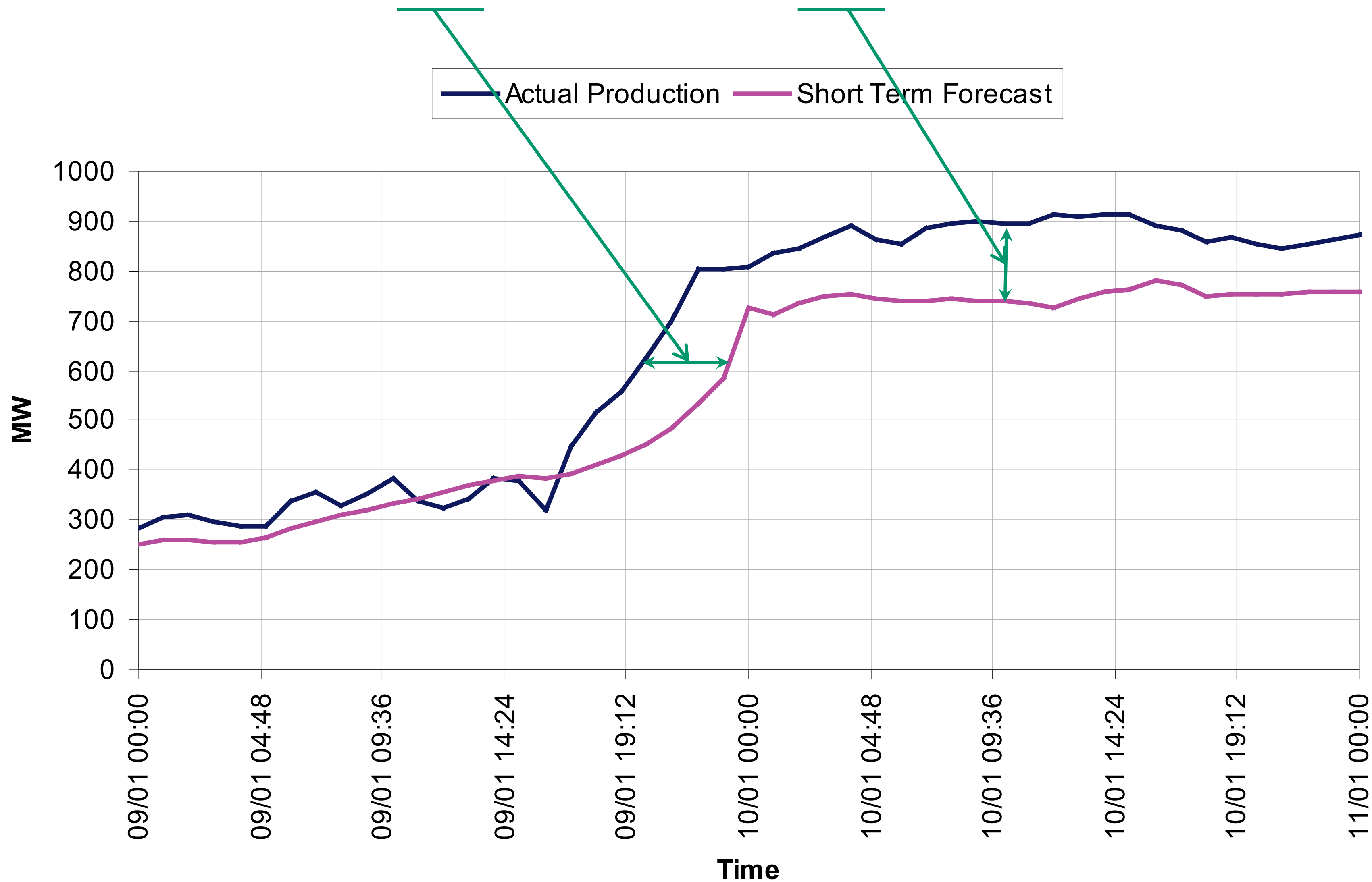
Atmospheric Predictability



Source: Advanced Short Range Wind Energy Forecasting Technologies-- Challenges, Solutions, and Validation
Kristin Larson and Tillman Gneiting, Global WINDPOWER 2004, March 31, 2004

Phase and Level errors

- Errors can be phase (timing) or level errors



Common evaluation criteria

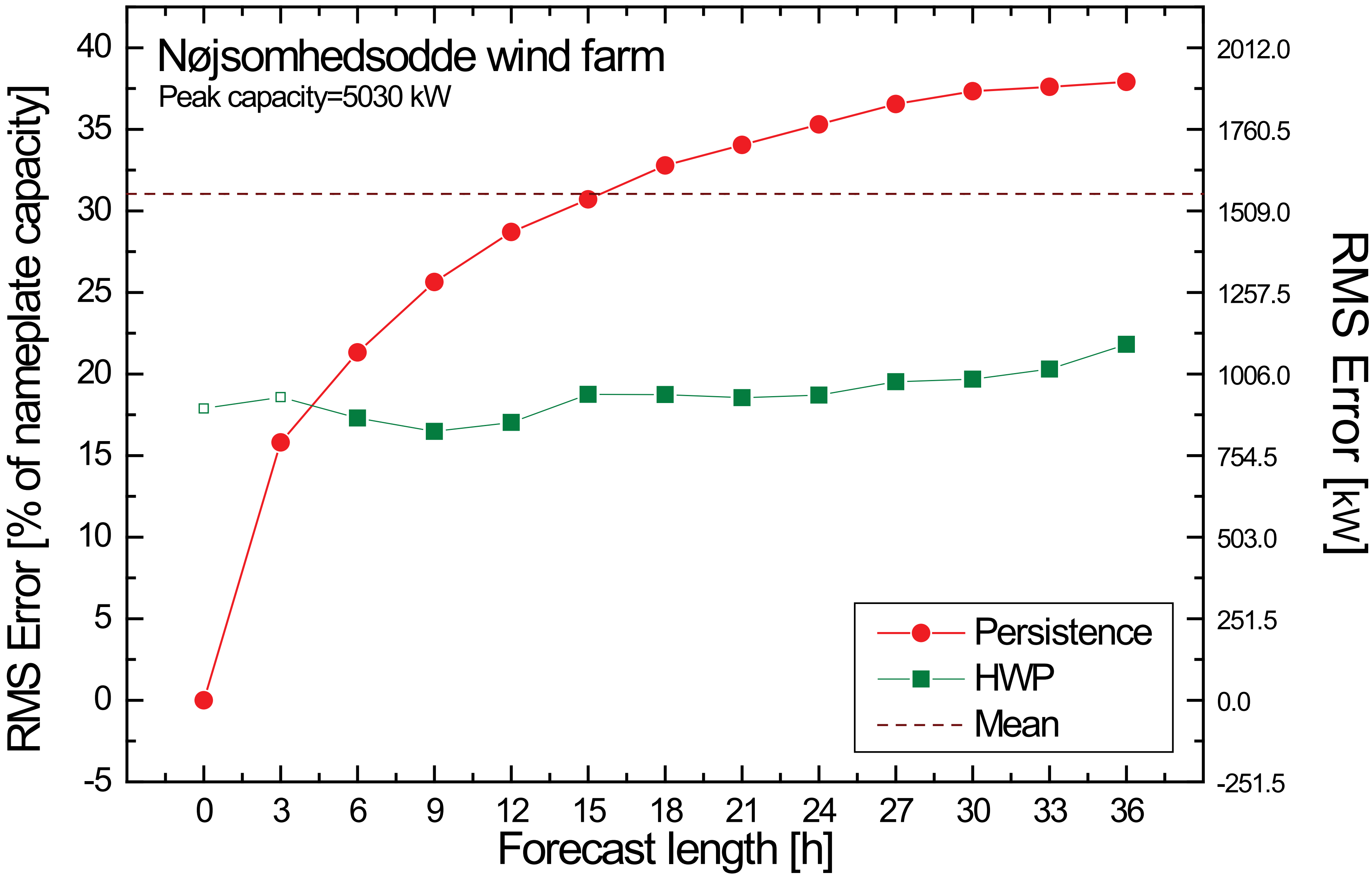
Since none were available, the ANEMOS project codified common criteria for performance measurements of short-term forecasting systems:

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

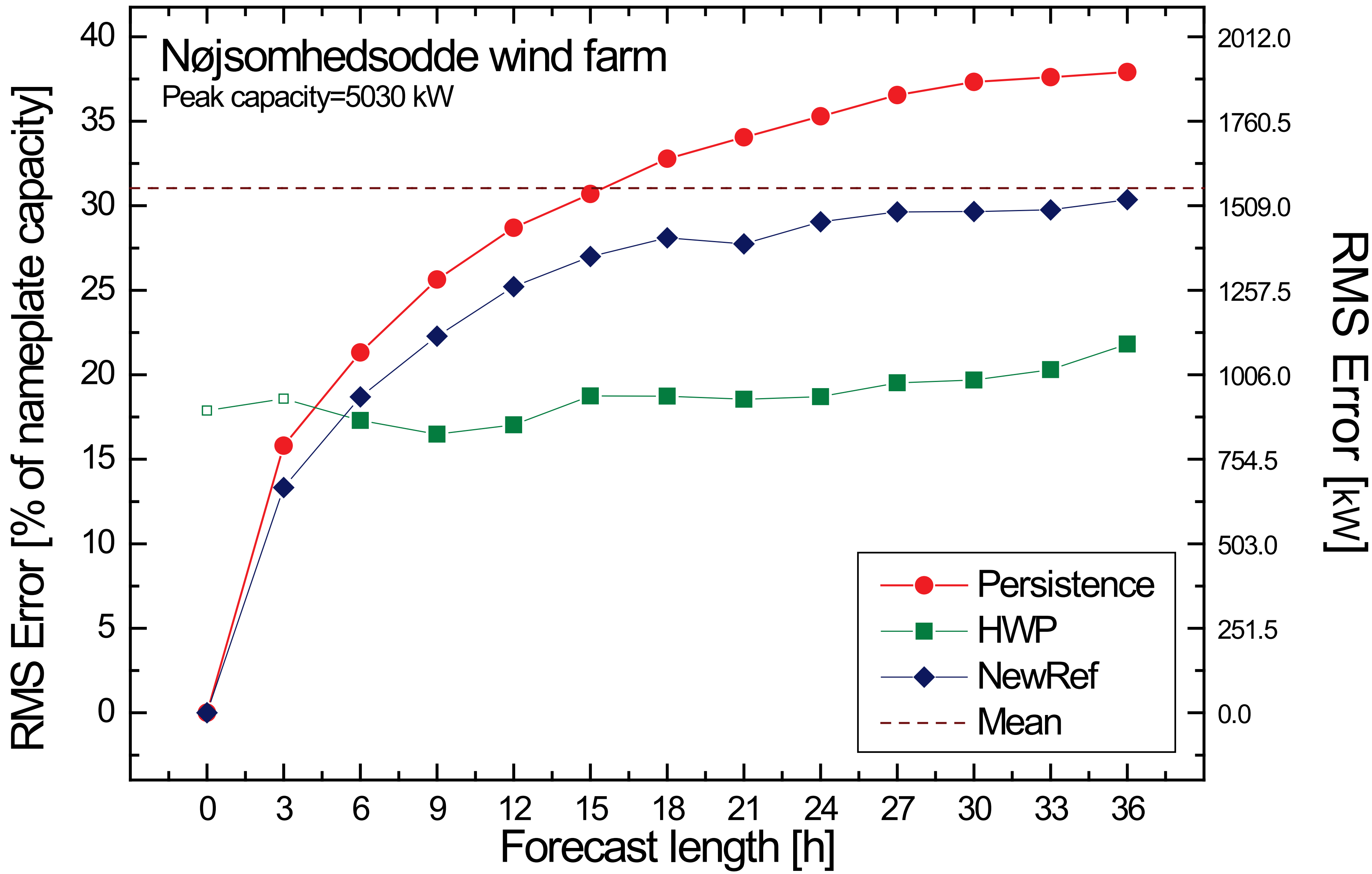
- Also, use separate training and validation datasets
- Present the errors normalised with the installed capacity

- 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

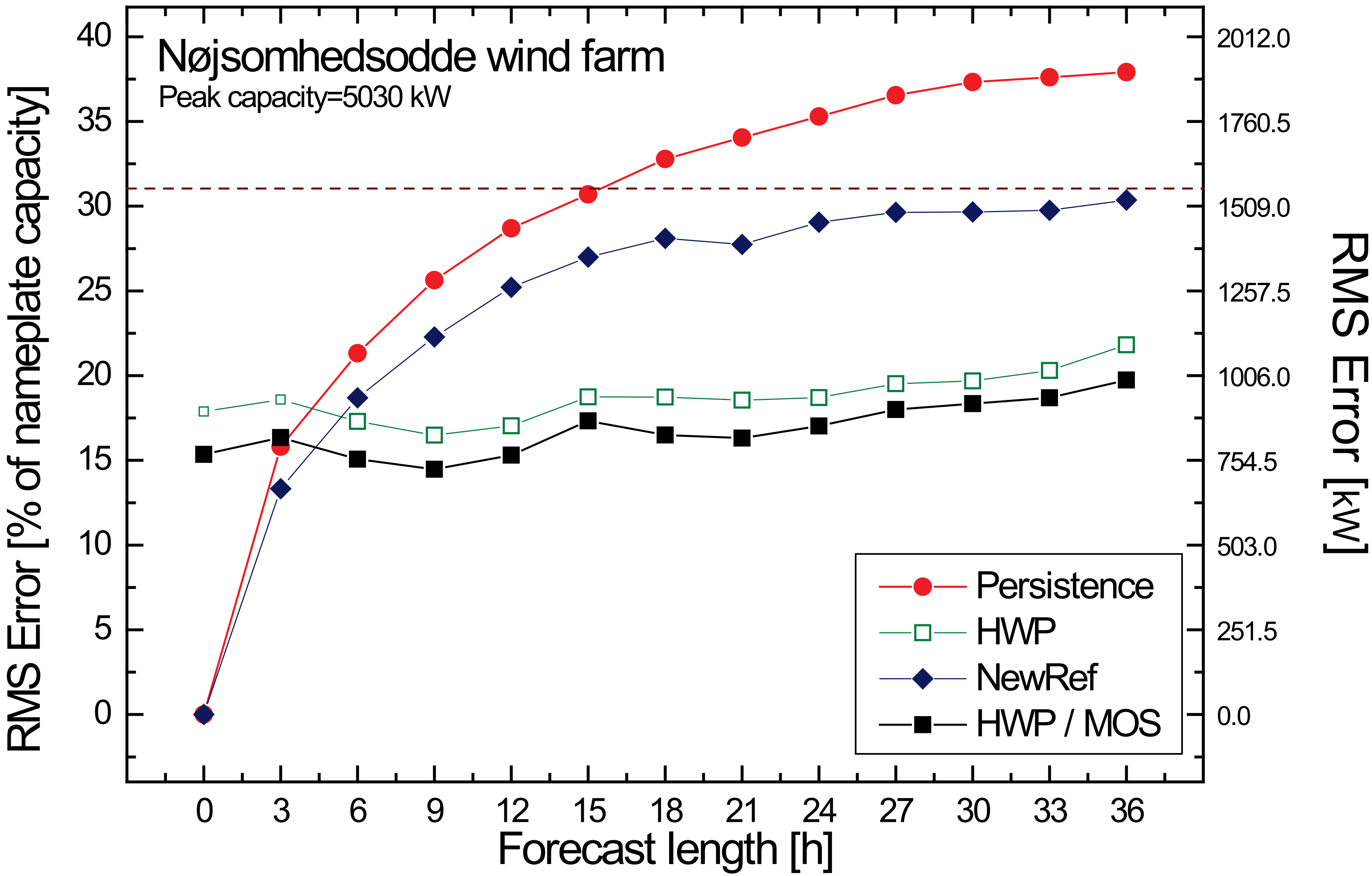
Typical results (1996 – now more like 10%)



Typical results (1996 – now more like 10%)

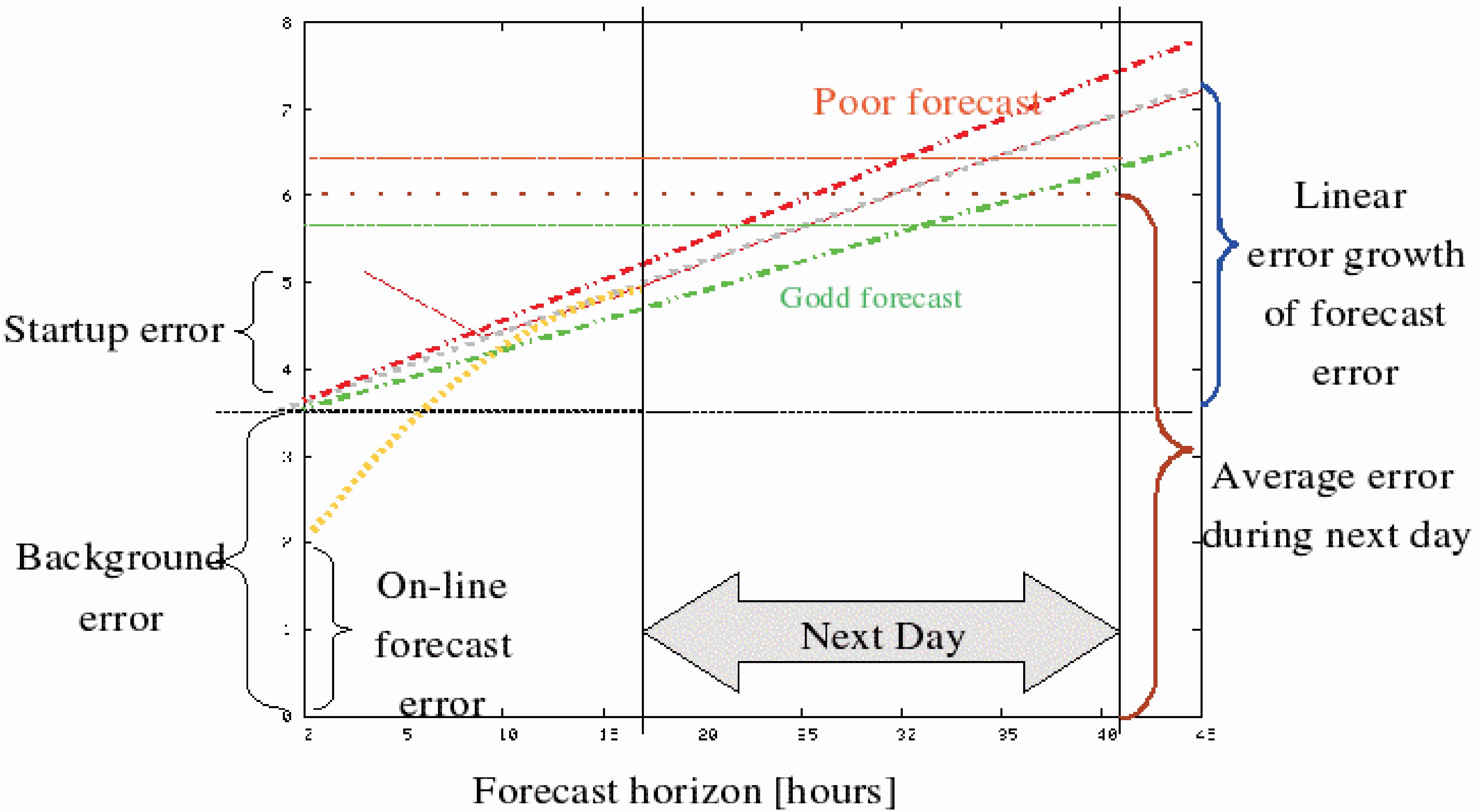


Typical results (1996 – now more like 10%)



Error classification

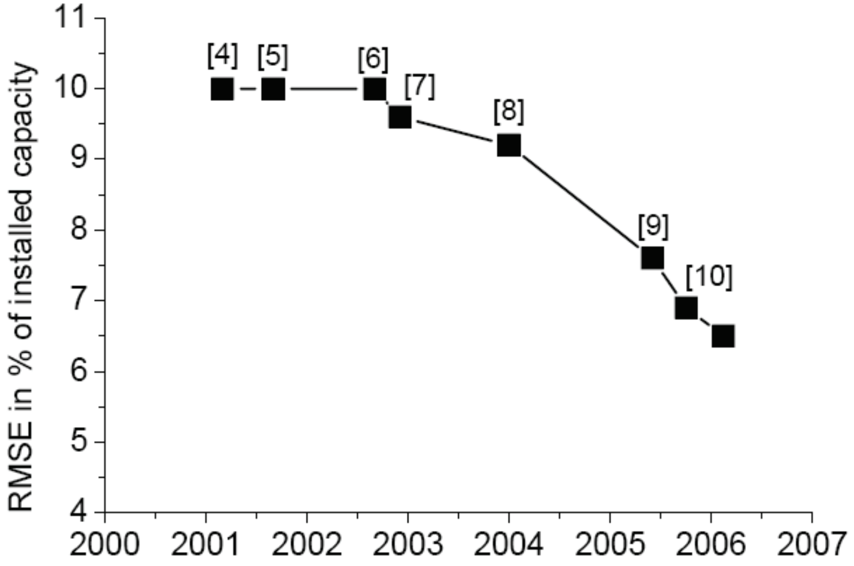
WEProg (Jørgensen and Möhrlen) have an interesting scheme:



Source: PDF on WEProg.com, 2007

Forecast accuracy, historical (eg ISET)

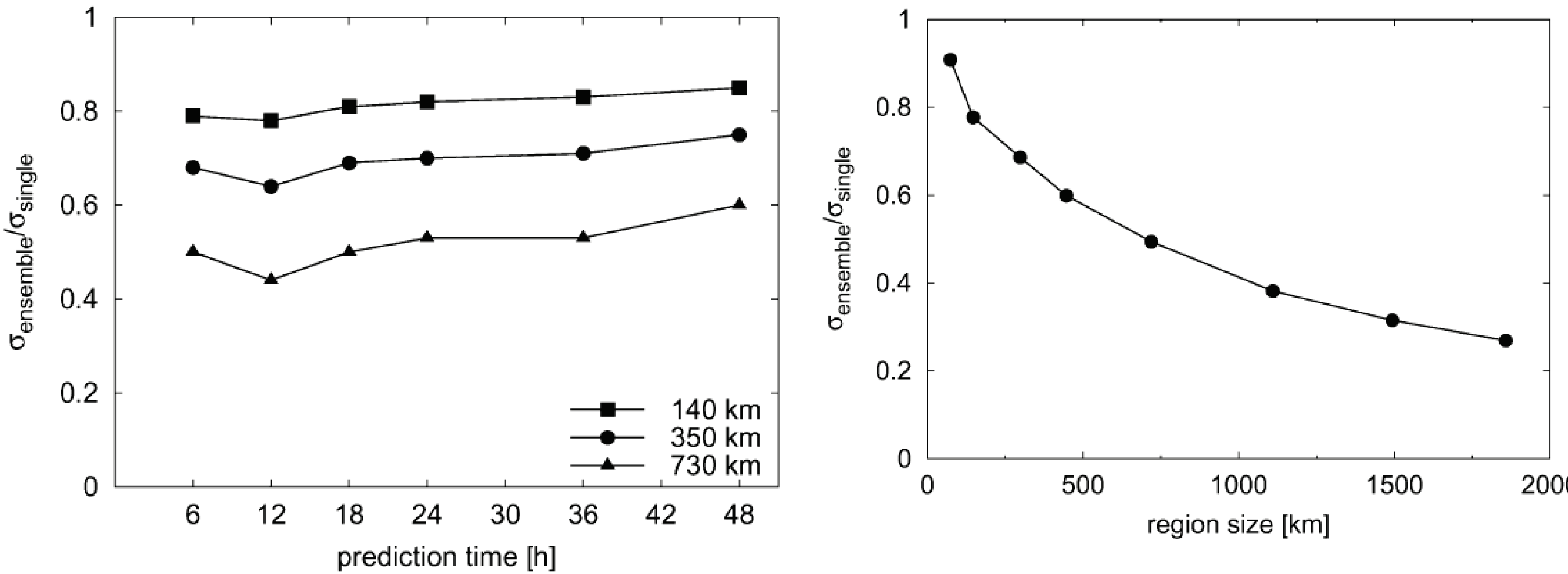
- Forecasting got better during the last years
- Some of it piggybacks on improvements in meteorology
- Some is due to better interface to meteorological models (e.g., using 100m wind speed)
- Some is using multi-model approach



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

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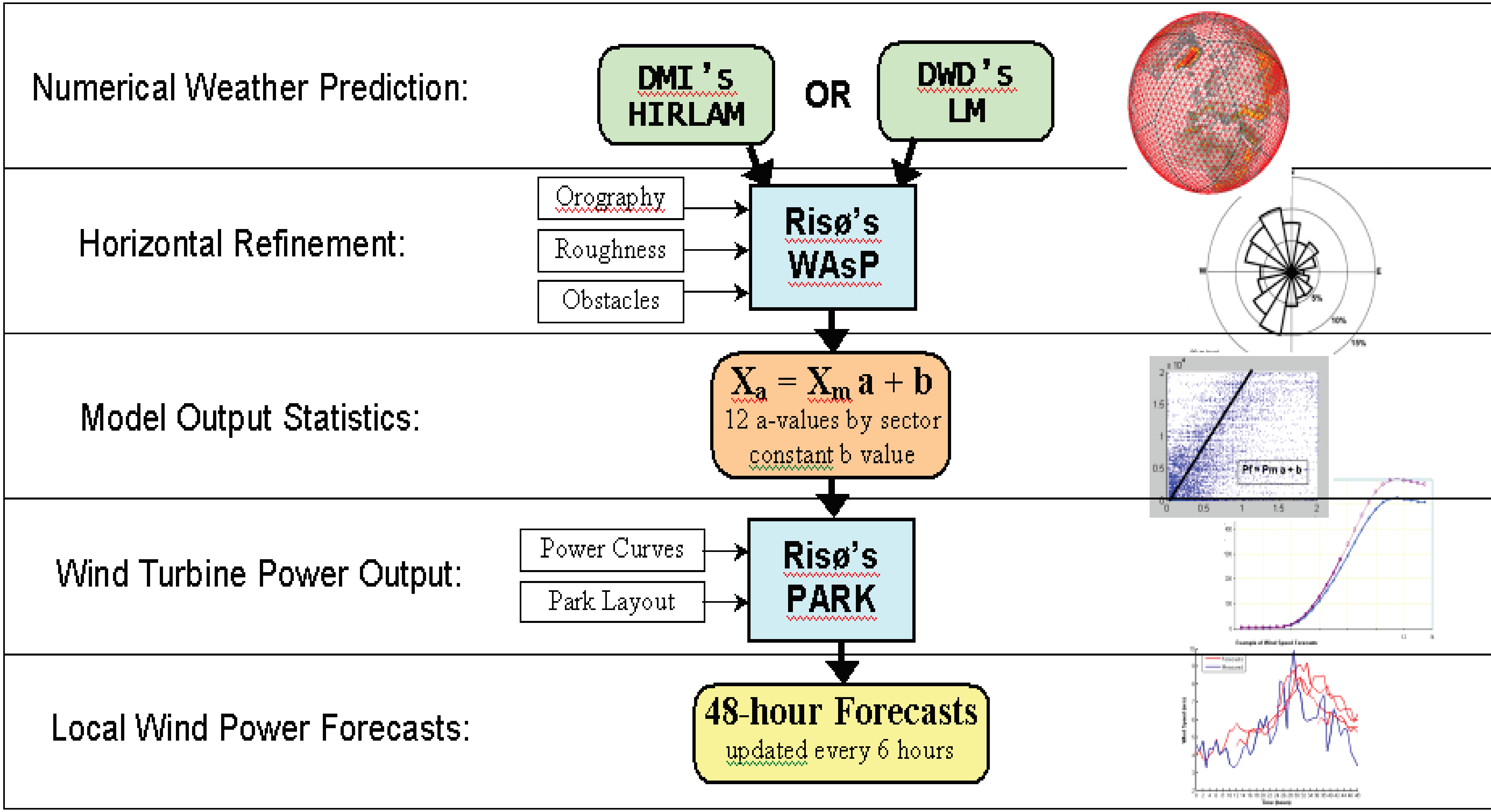
- Predicted for the large wind farms in California (Altamont, San Gorgognio etc)
- Was run in the summers of 1985-87
- On a HP 41CX programmable calculator

- 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.

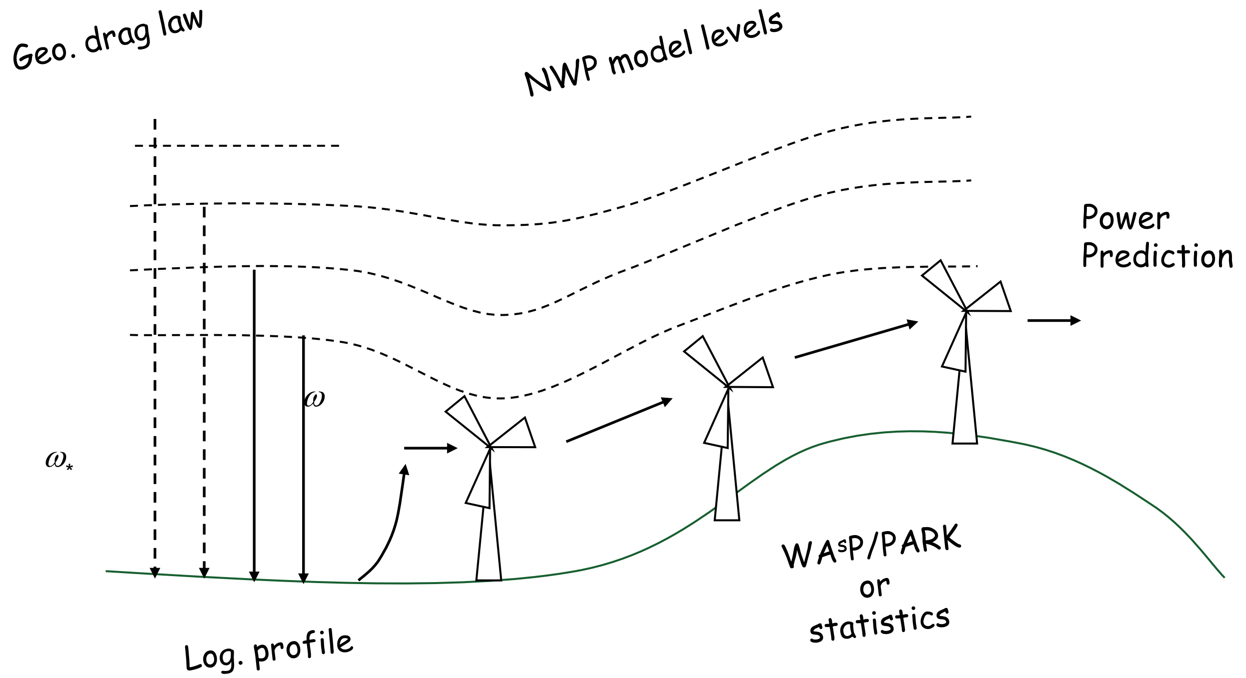
Prediktor



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

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

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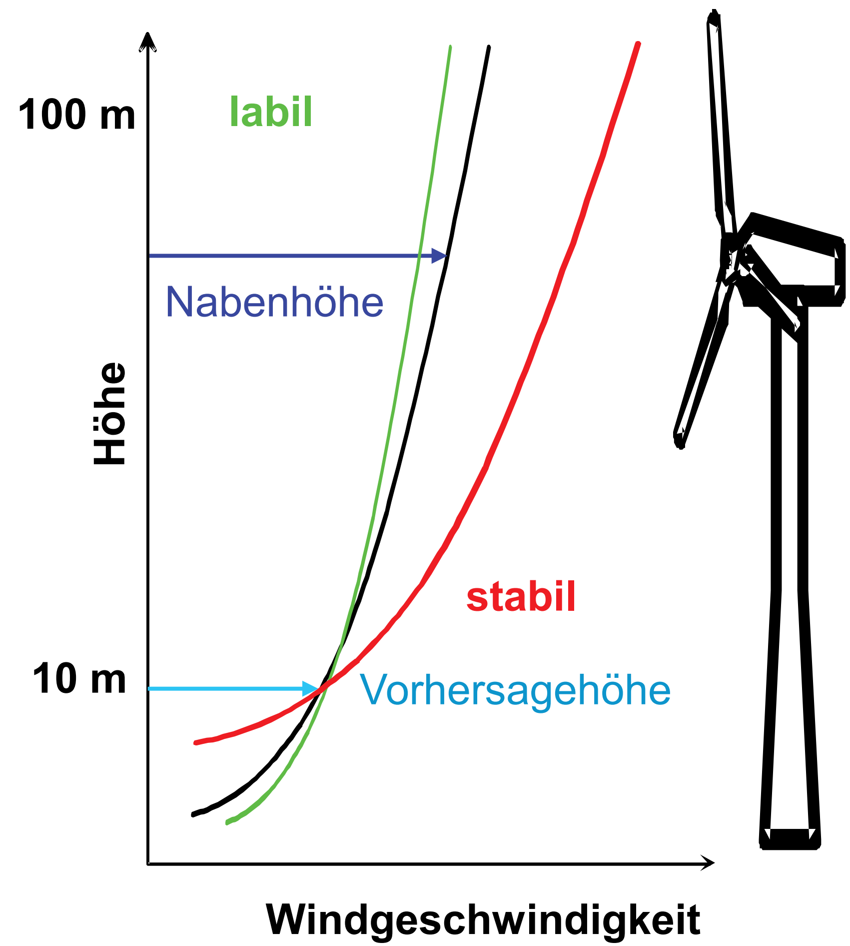
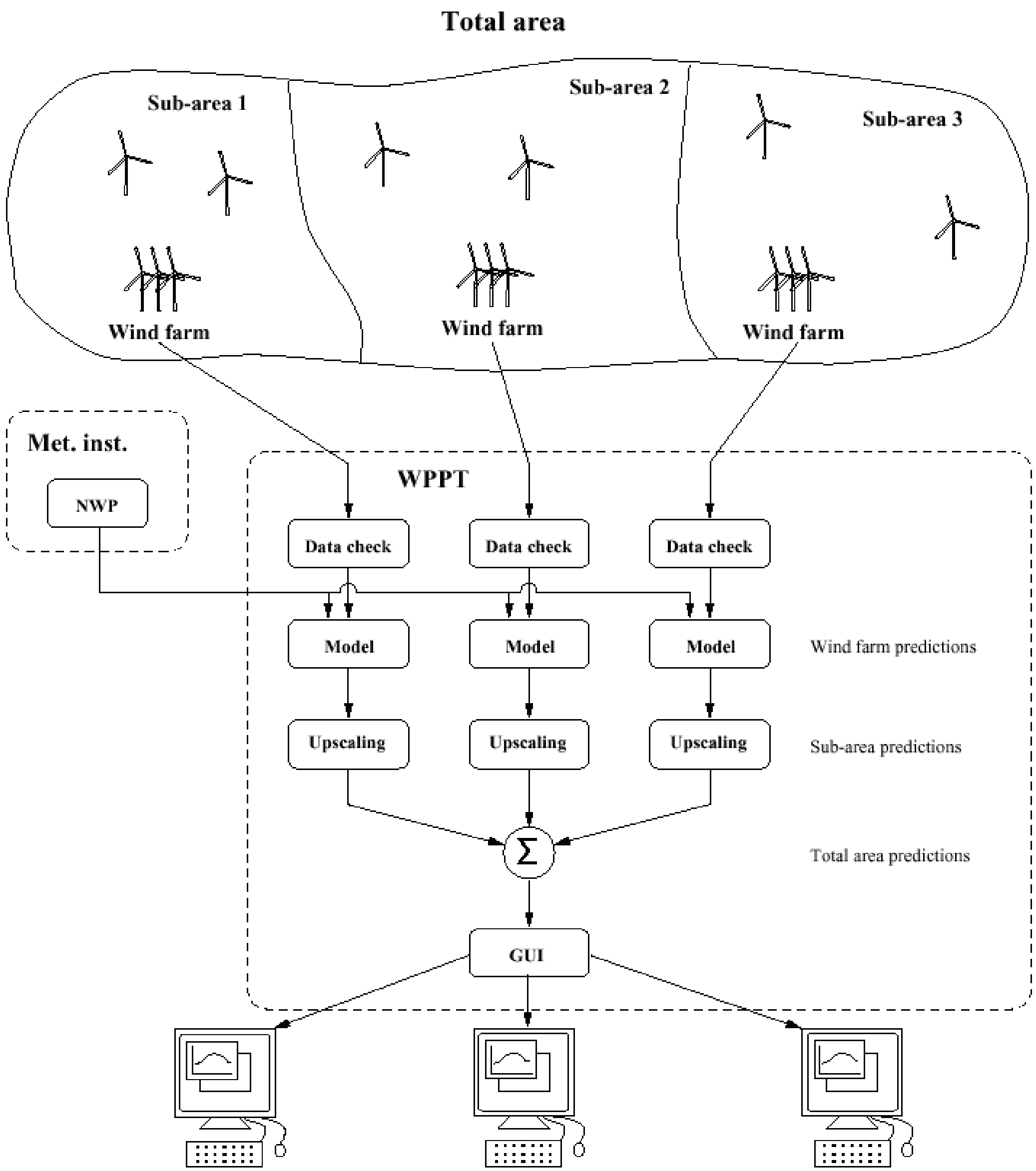
- Numerical weather prediction
- **Spatial refinement**
- Wind park modelling
- Upscaling
- Regional wind power forecast

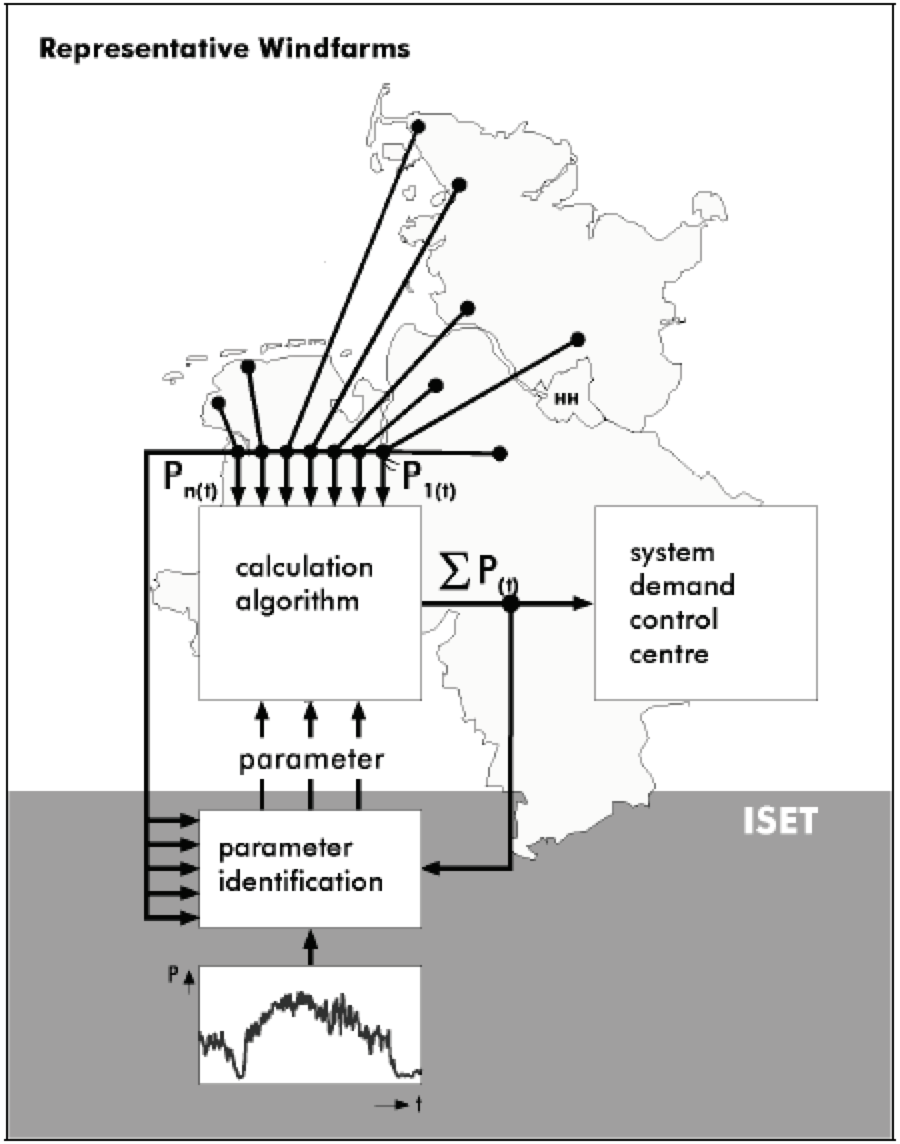


Wind Power Prediction Tool



- 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*

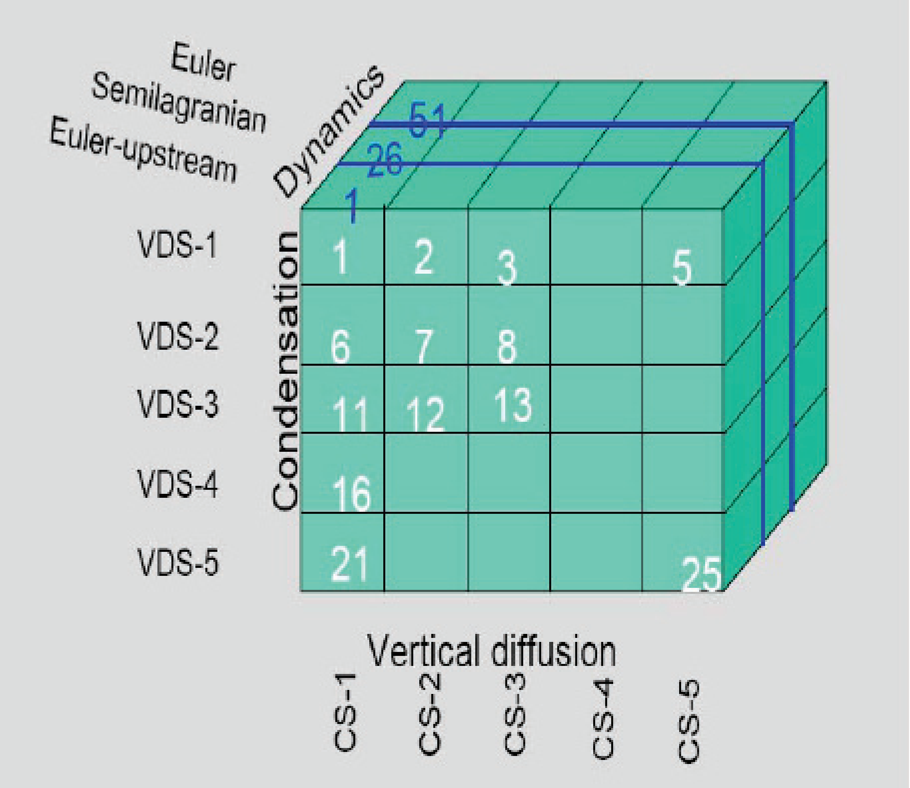
Fraunhofer IWES (ISET) WPMS



- 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



Other current models

- **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 Vindtekknik, met.no, ...

Uncertainty

- 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

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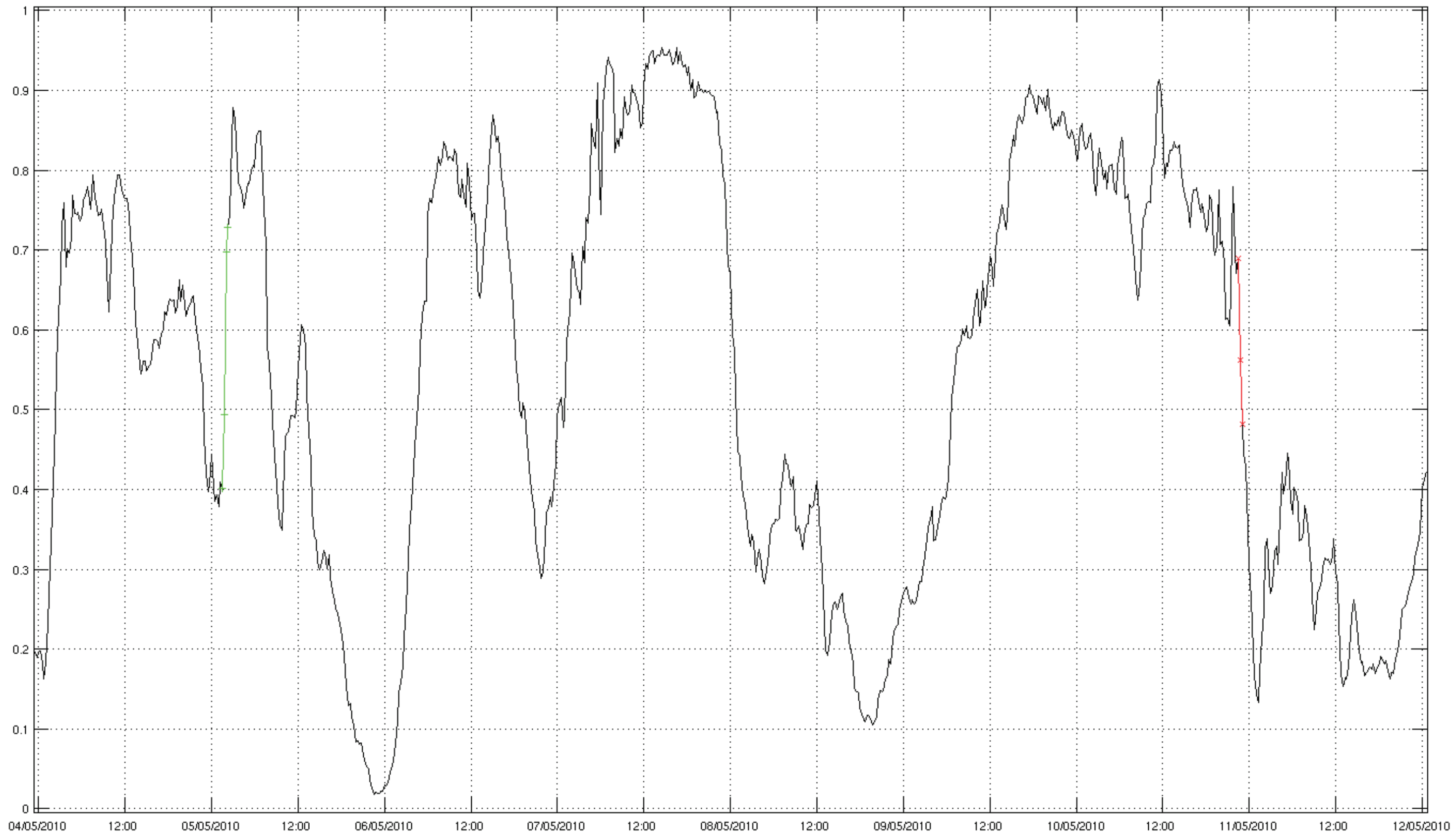
- Relatively new topic, on the agenda only since “chunk sizes” of wind power installations get quite large (>100 MW)
- Work by Garrad Hassan, CSIRO, Risø DTU, energy&meteo systems, Enfor and many others

What is a ramp ?

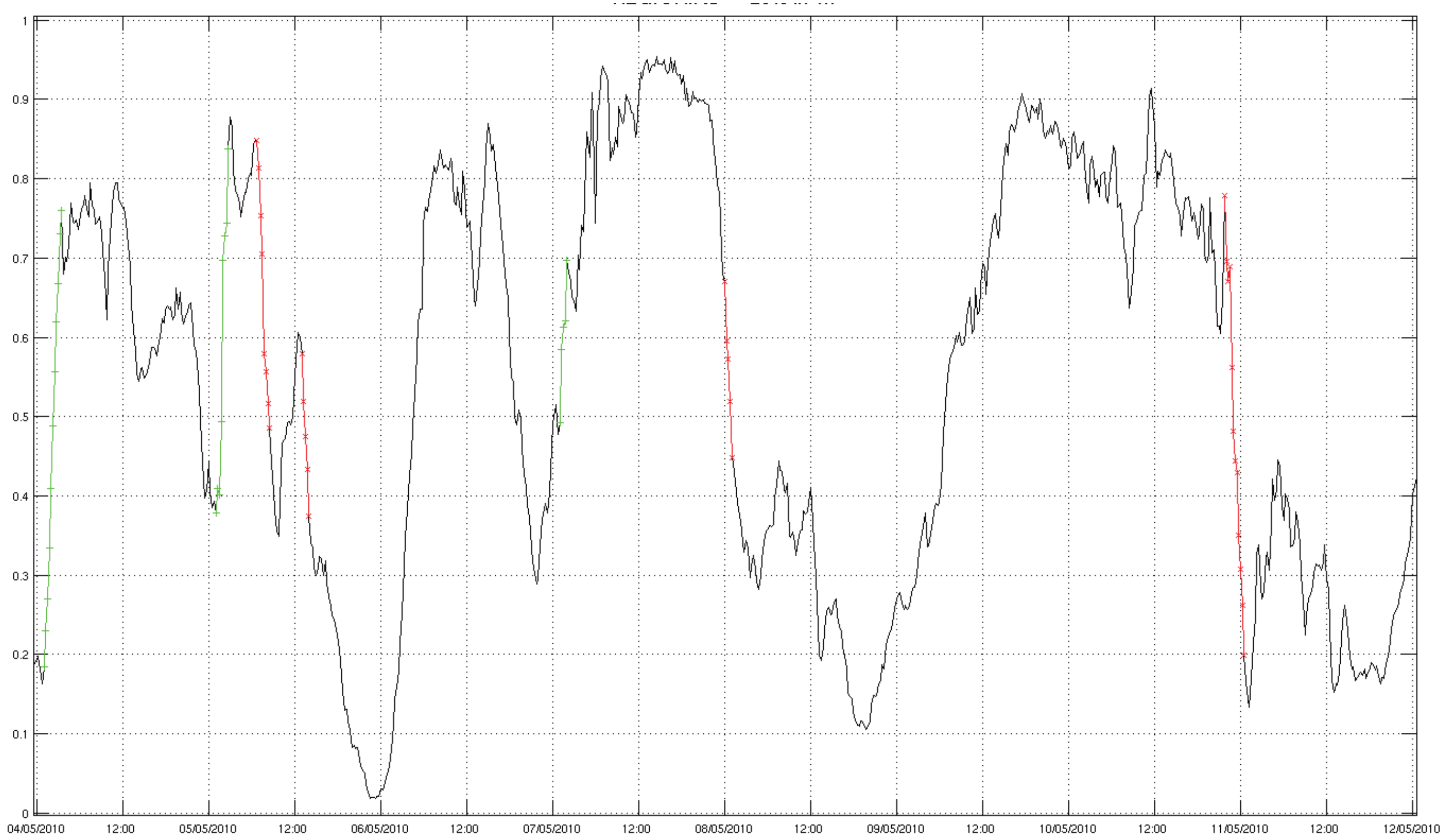


20 % in 30 min ?

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 ?

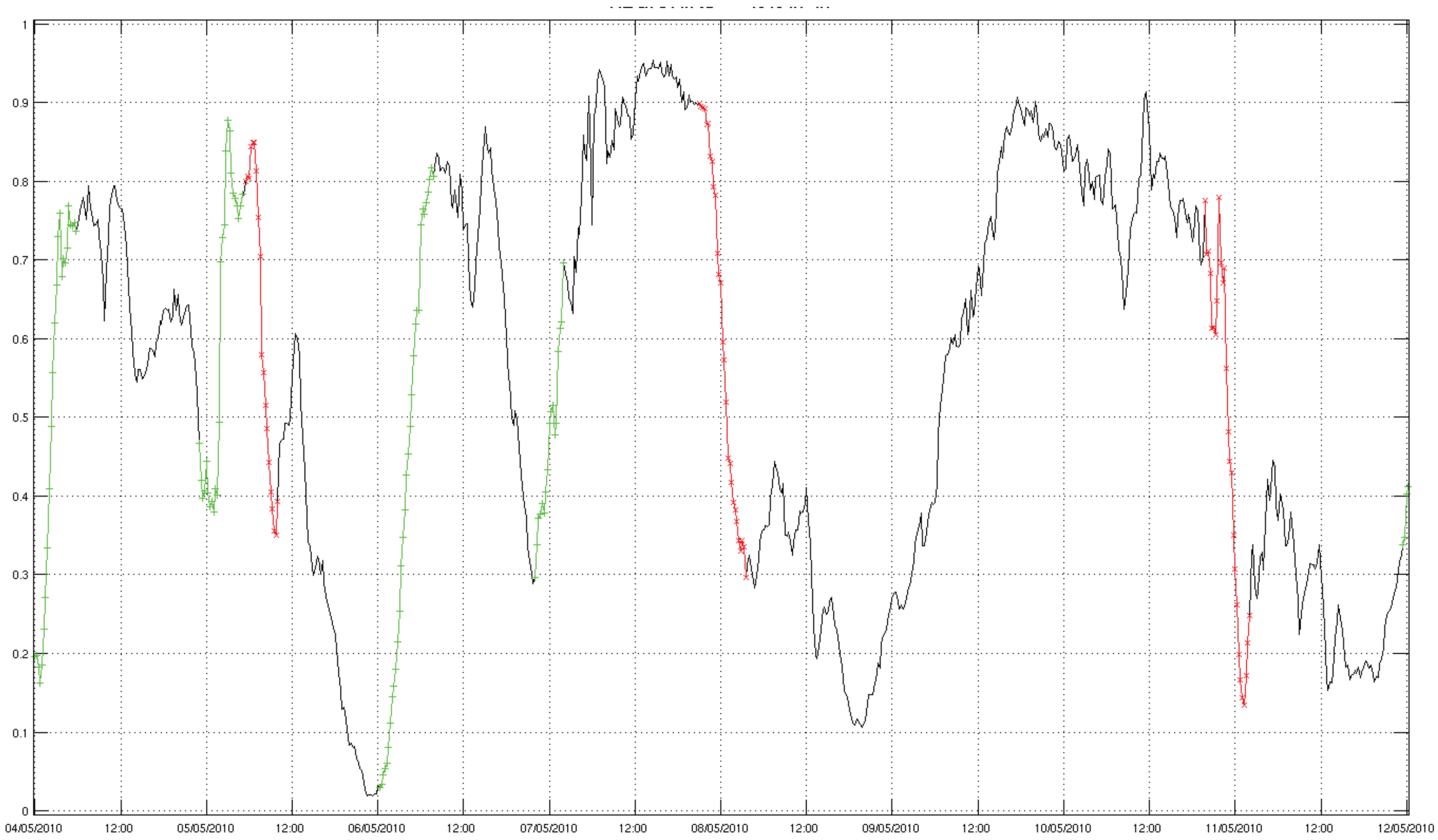
RISØ



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

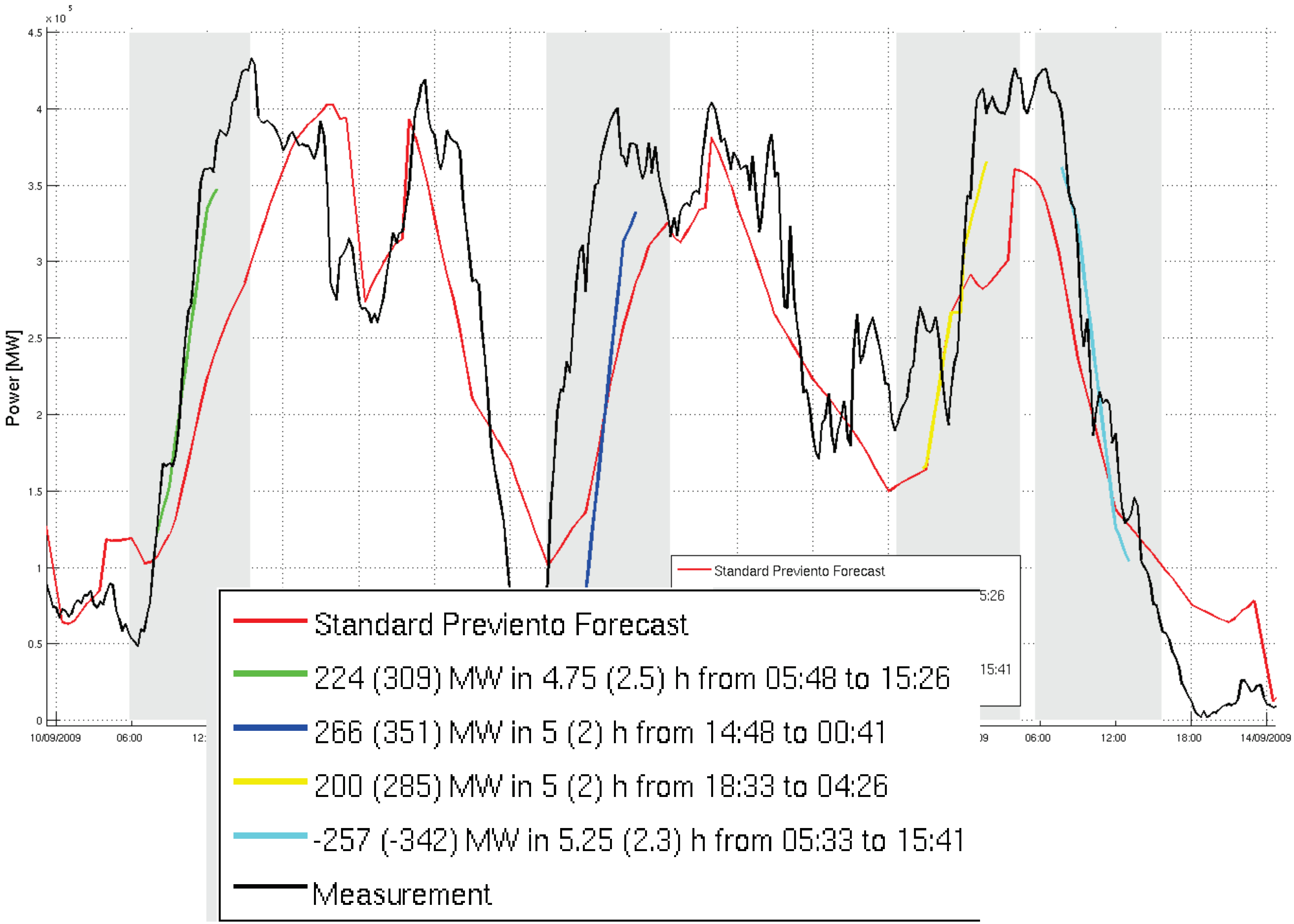
What is a ramp ?



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



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

GL Garrad Hassan Ramp Forecasting Results - individual wind farm

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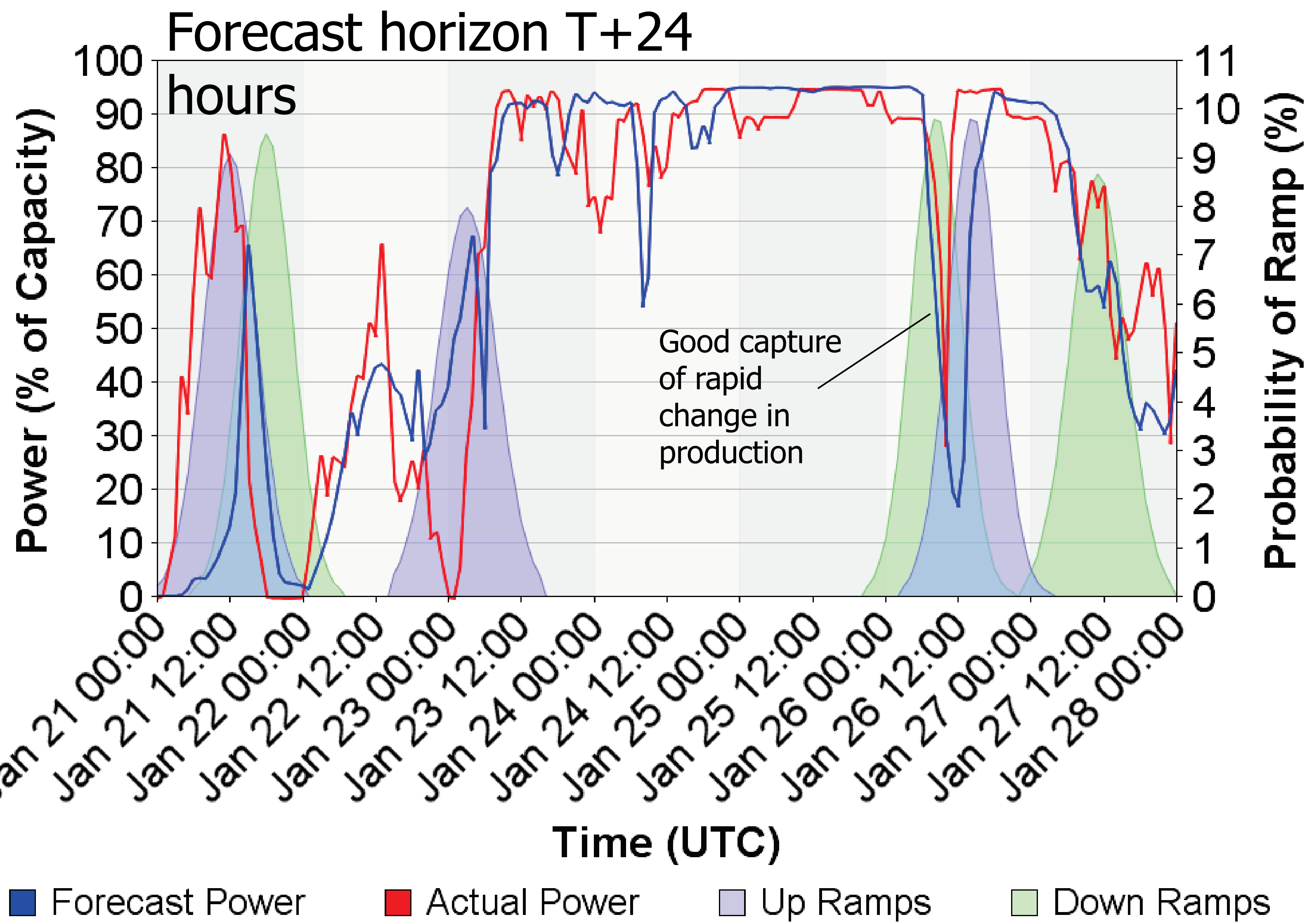
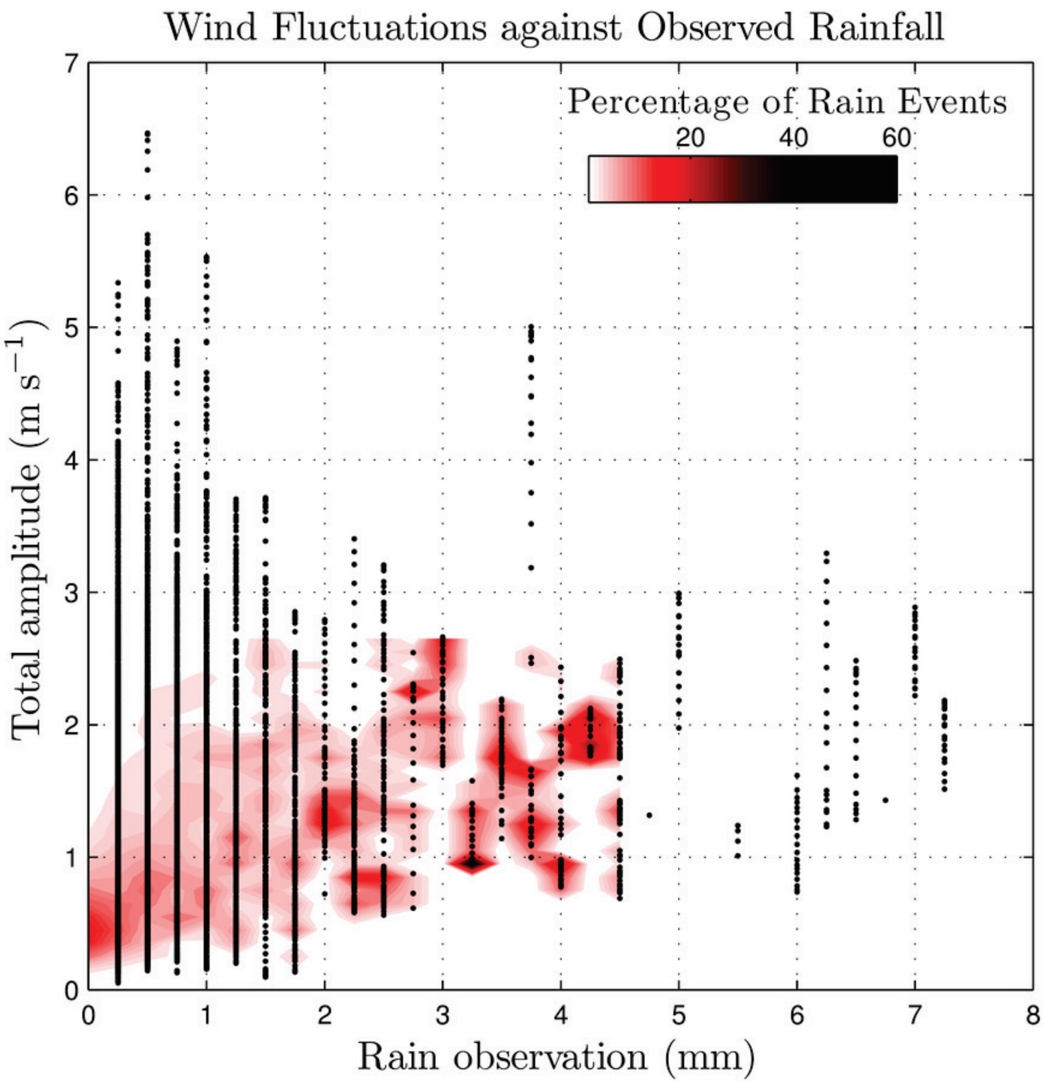


Source: Jeremy Parkes on 3rd Workshop Best Practice in Use of STP, Bremen 2009

Precipitation

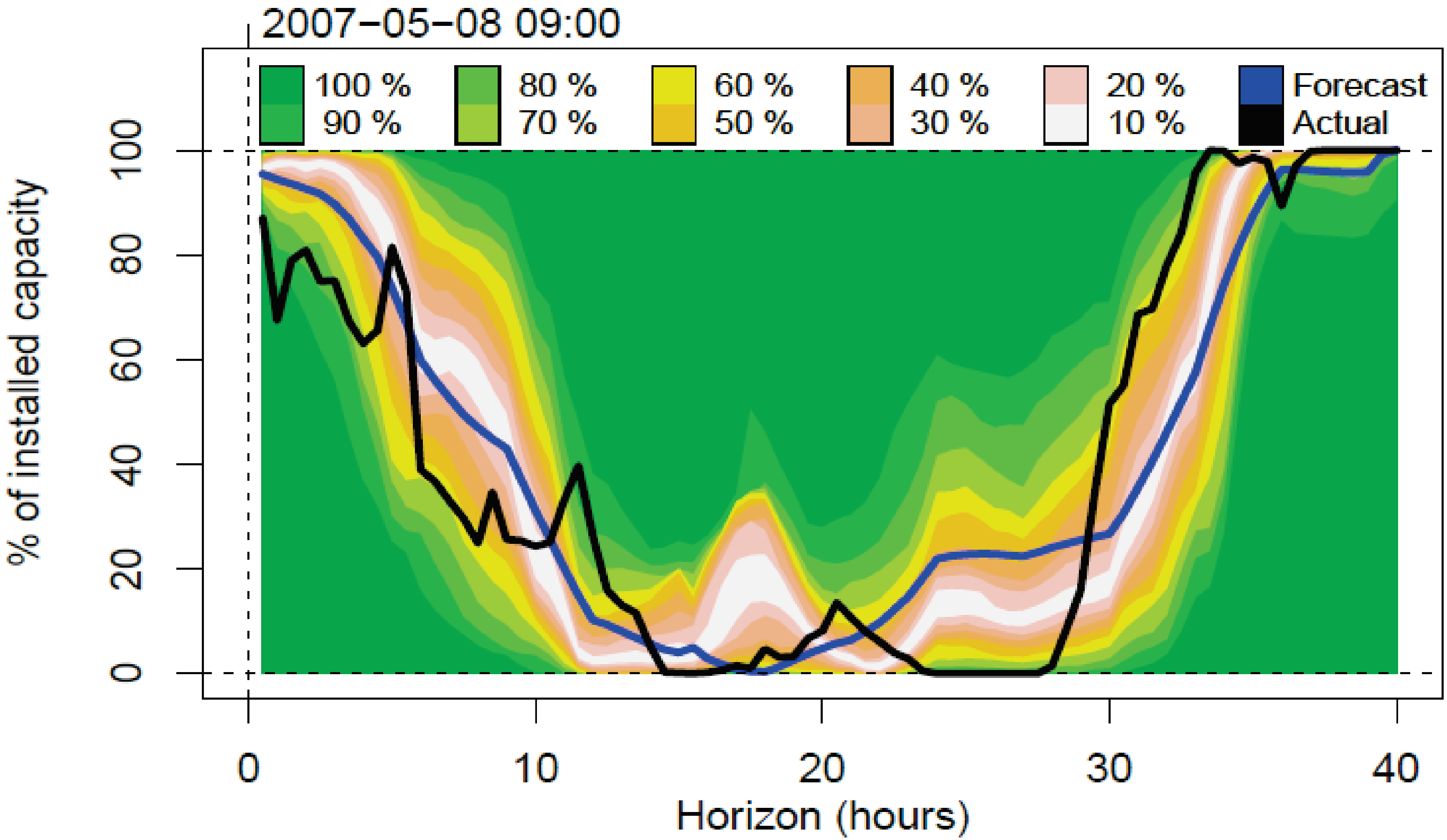


$$R_{max}(n) = max(R(n-9), R(n-8) \ldots R(n) \ldots R(n+8), R(n+9))$$

Slide source: Claire Vincent, Risø DTU

Scenarios

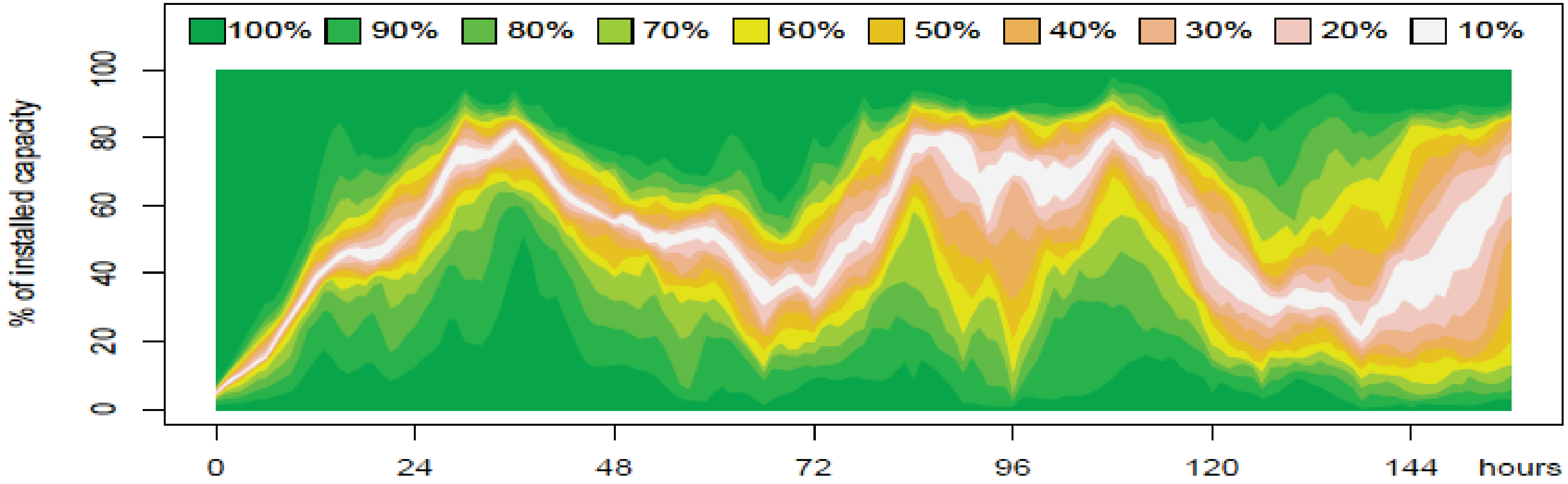
Example of WPPT point and quantile forecasts



Source: Henrik Aalborg Nielsen, Enfor

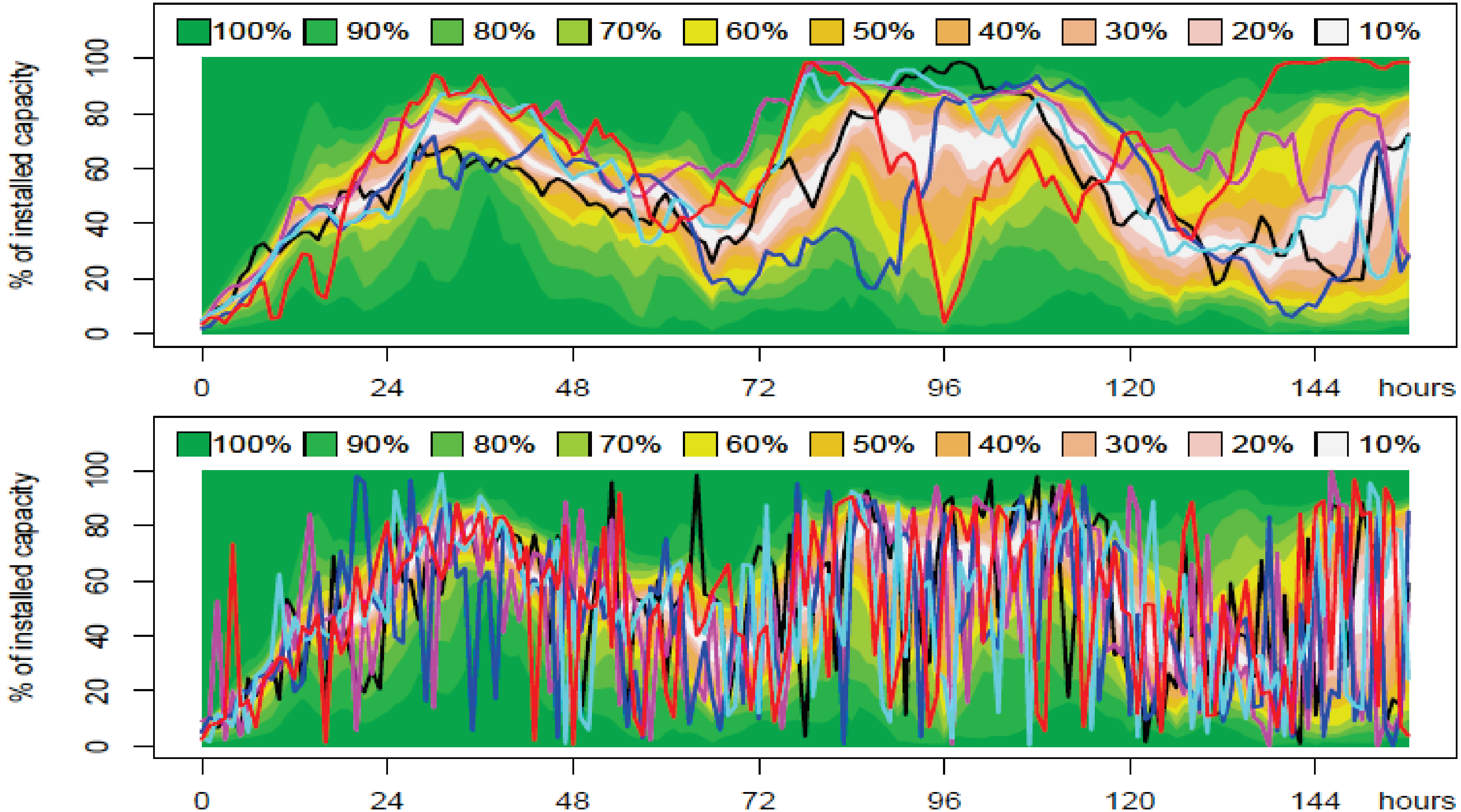
Scenarios

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



Source: Henrik Aalborg Nielsen, Enfor

Correct (top) and naive (bottom) scenarios



Source: Henrik Aalborg Nielsen, Enfor

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.

Source: Henrik Aalborg Nielsen, Enfor

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

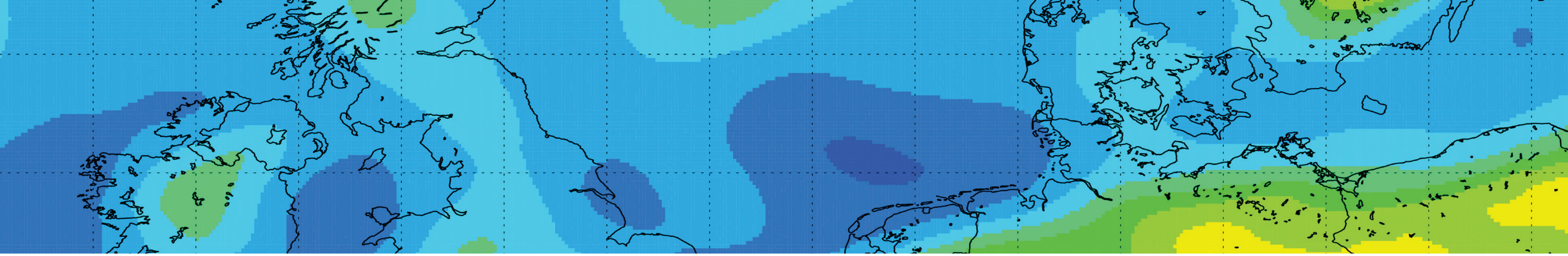
Best Practice

- 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 .



SafeWind

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Workshop - 31.08.2012

L'Auditorium, Palais Brongniart, Paris