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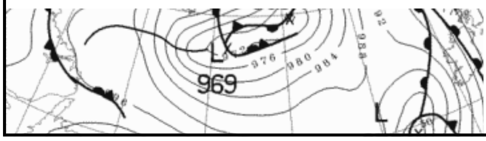
Wind Energy Forecasting

Dr. Ulrich Focken

Terna Workshop
Berlin, 15 September 2008



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Overview

- Motivation
- Basic approaches
- Uncertainty of forecast
- Combination of wind power forecast
- New developments
- Evaluation

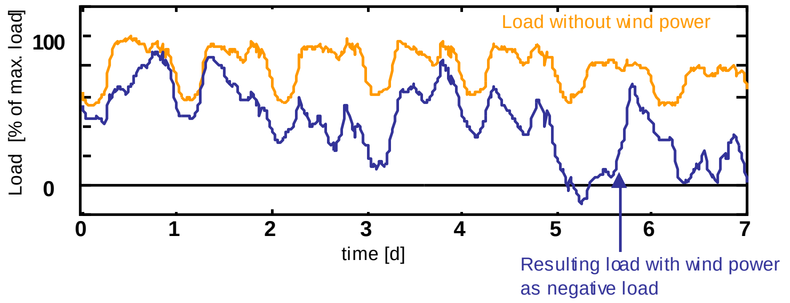
Company profile

- Integration of renewables into grids and markets
- Service provider for energy meteorology
- Areas of business
  - Operator and provider of wind and solar power predictions (forecast more then 30 GW wind power world wide)
  - Platform for trading of wind power on wholesale markets
  - Decentralized energy management / demand side management
  - Applied development
    - Industry projects
    - Research and develpment projects

EnBW RWE MidwestISO SONI aeso NEMMCO EirGrid EWE VATTENFALL energy & meteo systems

Motivation

Wind power production depends on weather conditions



Wind power production must be known it advance on different time scales

➡ Wind power forecasts are indispensable

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Where wind power predictions are used

- Grid operators
  - Balancing of wind power fluctuations
  - Grid operation and planning (e.g. congestion forecasts)
- Traders
  - Energy purchase
  - Impact of wind power on market price
  - Selling wind power on wholesale markets
- Wind farm owners
  - Selling wind power
  - Maintenance scheduling

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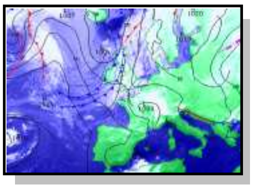
Approaches to wind power prediction



- In common:
  Numerical weather prediction (NWP) as input
- Statistical approach: „Training“:
  Statistical relation between NWP and power output of wind farms
- Physical approach: „Laws of physics“:
  Physical description of lower atmosphere

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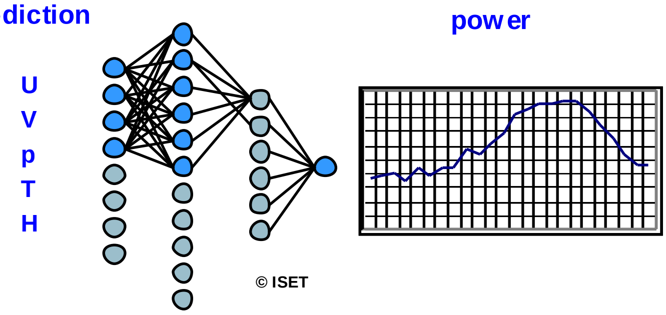
Statistical systems

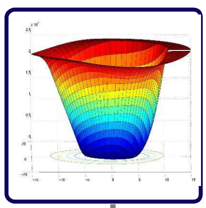
Example: ISET system based on artificial neural networks

numerical weather prediction

measured power



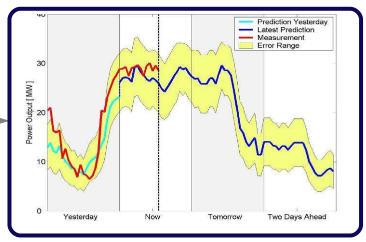
Physical system – Previento



Previento

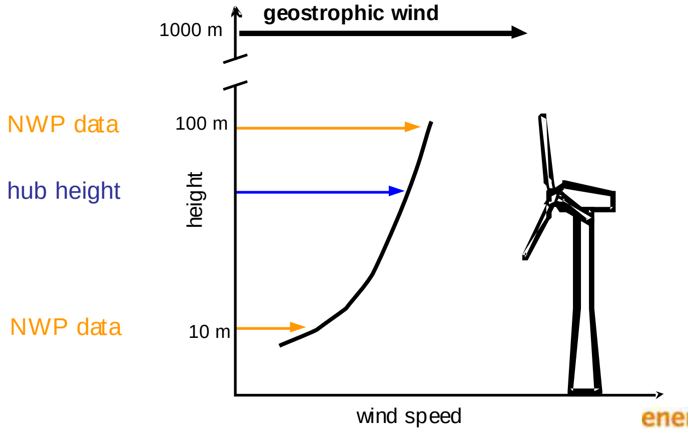
Physical Model:

- Spatial refinement
- Thermal stratification
- Site-specific power curve
- Forecast uncertainty



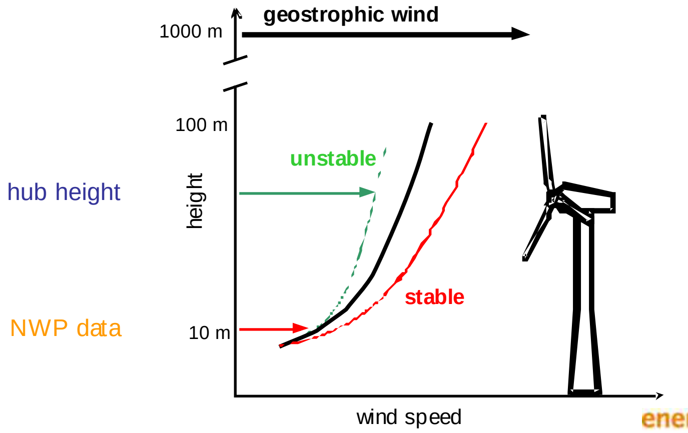
Physical modelling – example wind profile

Modelling the lower boundary layer

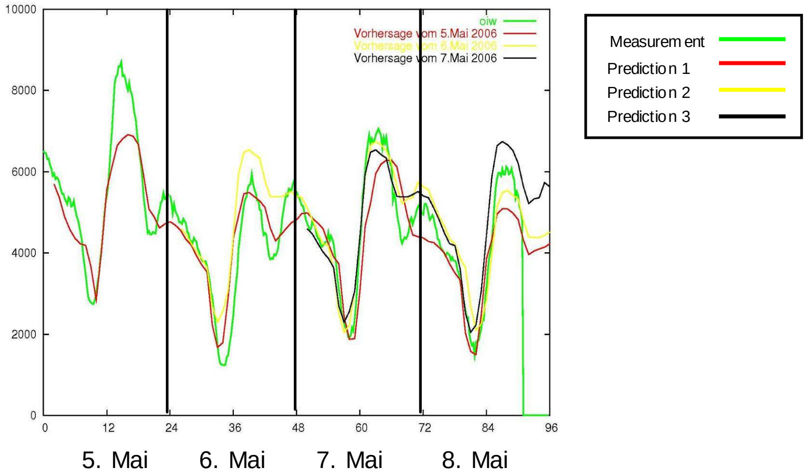


Physical modelling – example wind profile

Vertical wind profile strongly depends on weather conditions

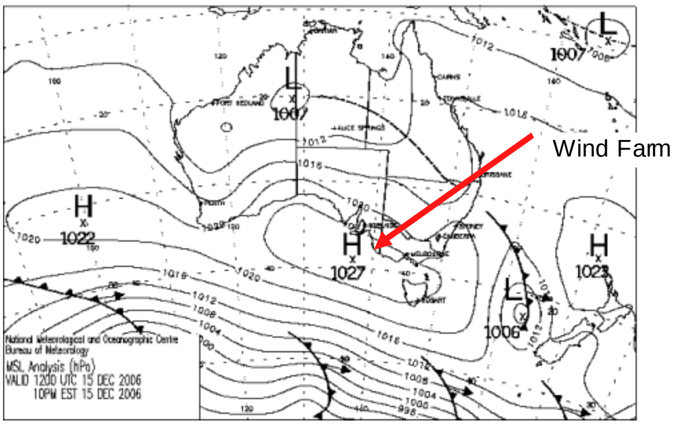


Example thermal stratification Germany



Example land-sea-breeze - Australia

December 14th to 21st 2006



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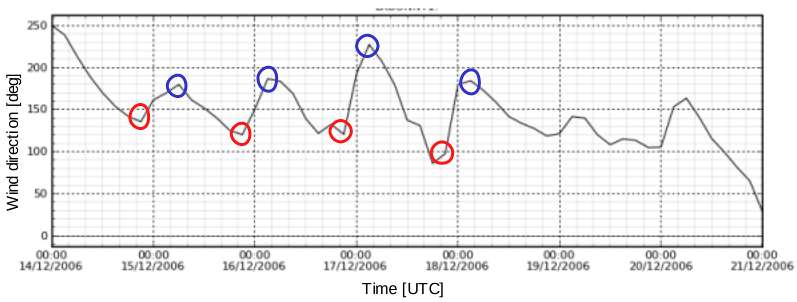

High pressure system brings diurnal cycle in wind direction

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Example land-sea-breeze - Australia

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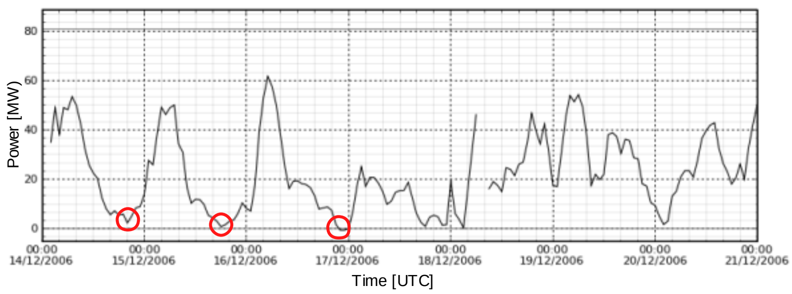

High pressure system brings diurnal cycle of irruption in wind power

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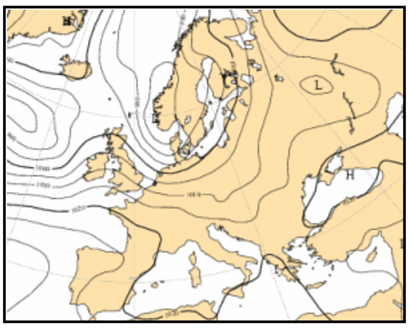
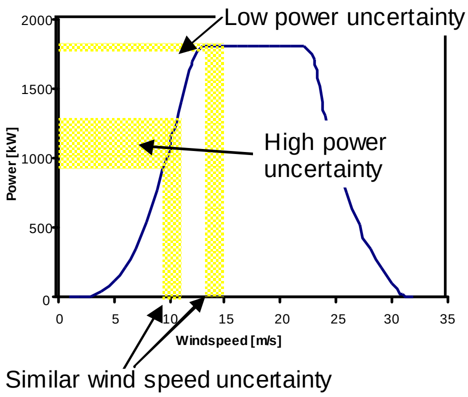
Weather dependent uncertainty

Weather situation



Each weather situation has its specific uncertainty

Power curve



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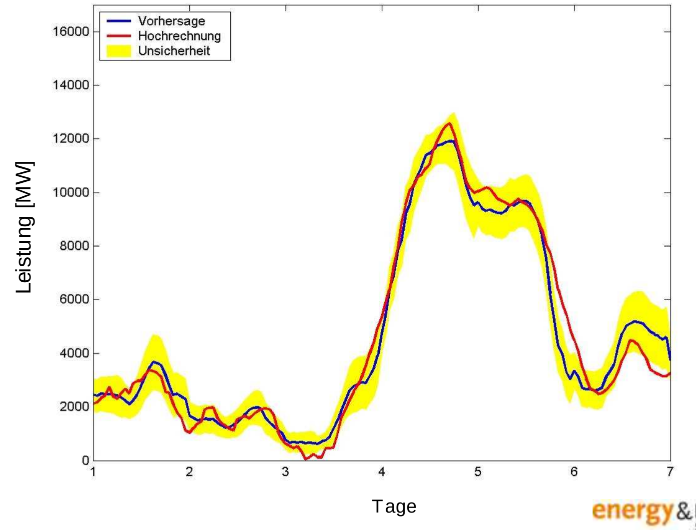
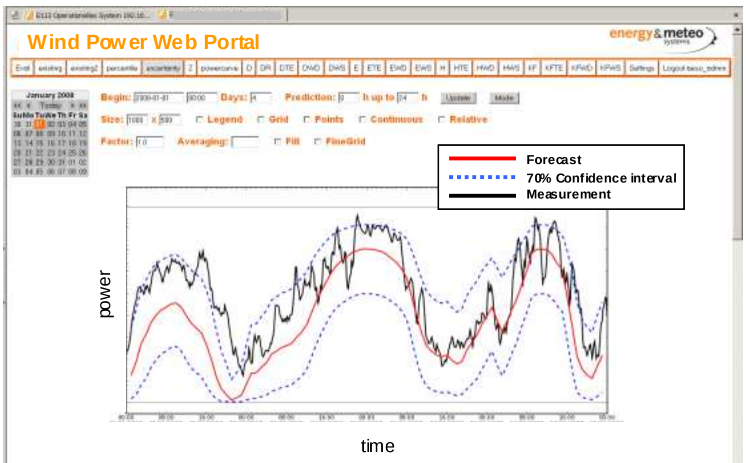
Example of prediction uncertainty - Germany



Example of prediction uncertainty - Canada



- Well-defined and weather dependent confidence levels

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To be kept in mind: non-linear dynamics of the atmosphere

Combination of different NWP models - Motivation

- Wind pow er prediction systems commonly use only one single numerical w eather prediction model (NWP).
- But everyday experience shows:
  NWP models have strengths and w eaknesses in different situations.
- Our approach:
  Optimal combination of w eather models adapted to different weather situations.

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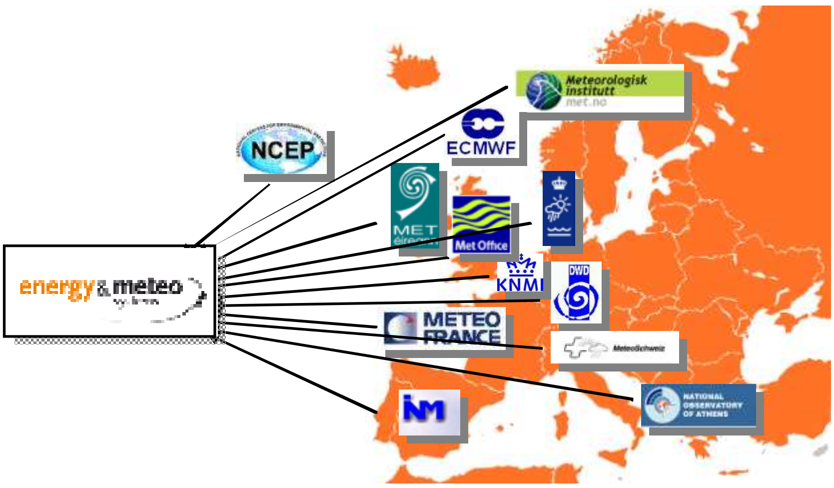
Combination of different NWP models



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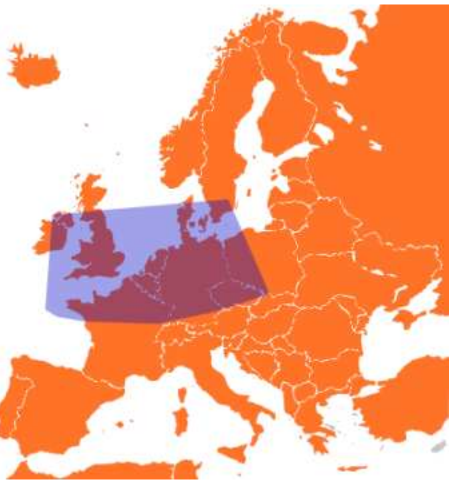
Overlapping NWP domains over Central Europe

12 weather services with different

- grids
- physical parametrizations
- vertical levels
- temporal resolutions and horizons



Aim:
Exploit capabilities of NWP models in different weather situations

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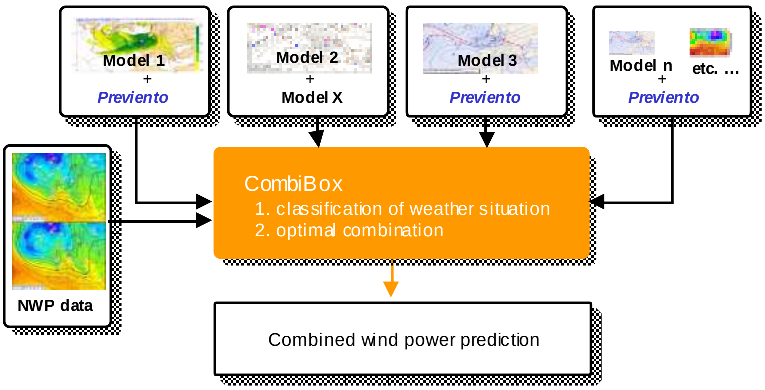
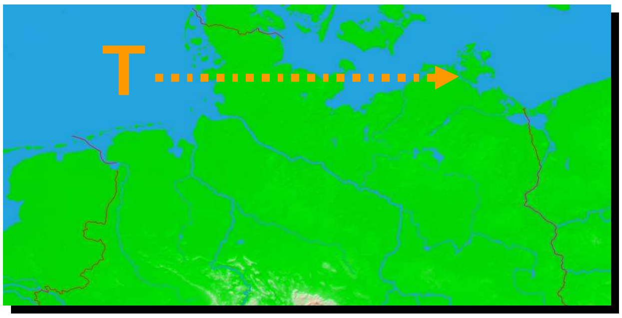
Combination of different weather models



RWE DWD Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit energy & meteo systems

Example: low pressure system is passing



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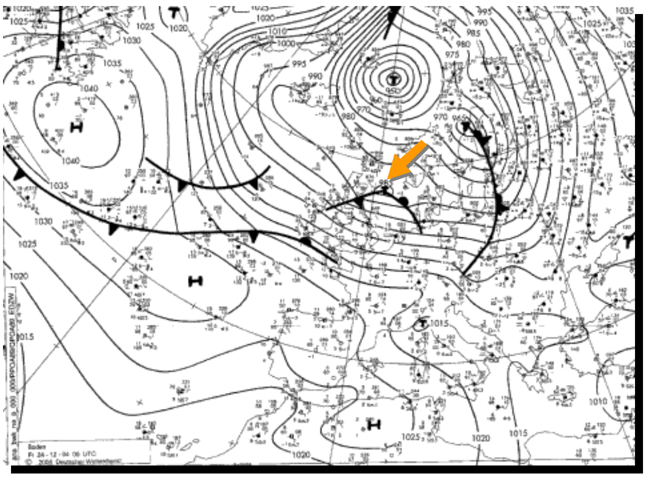
Example: low pressure system is passing



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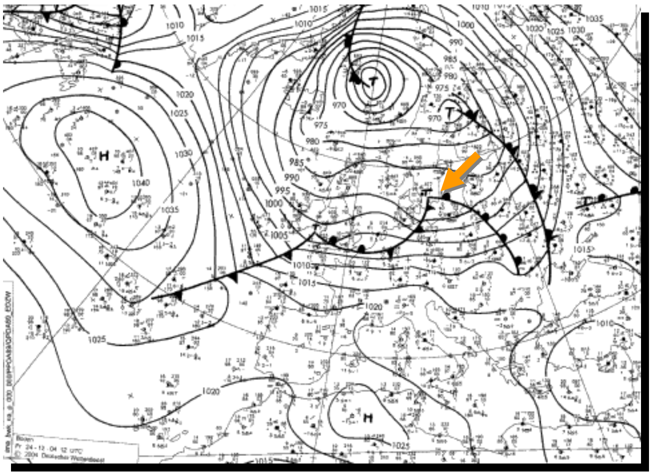
Example: low pressure system is passing



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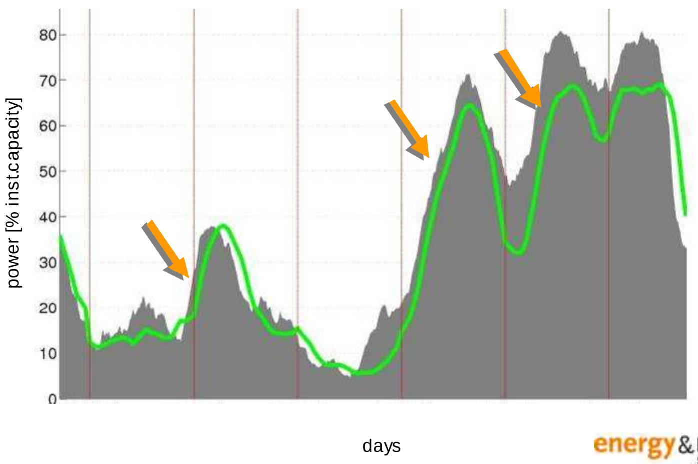
Example: low pressure system is passing

One model predicts fronts with delay



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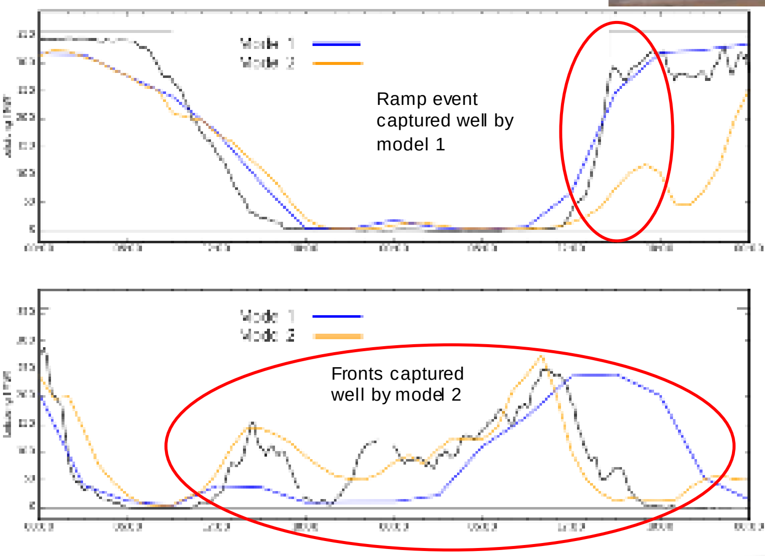
Apply forecast combination for Alberta

Alberta: NWP models have different capabilities



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International developments

- Multiple input data
  - Combination of different weather models
  - Ensemble predictions
- Improvement of conversion of wind into power
  - Offshore and complex terrain
  - High spatial resolution, e.g. grid nodes
  - Shortest term prediction (0 – 6 h)
  - Extreme event forecast (SafeWind)
- Intergration of predictions into decision making
  - Congestion forecasts, e.g. DACF by UCTE
  - Storage management (Anemos.plus)
  - Trading of wind power (Anemos.plus)

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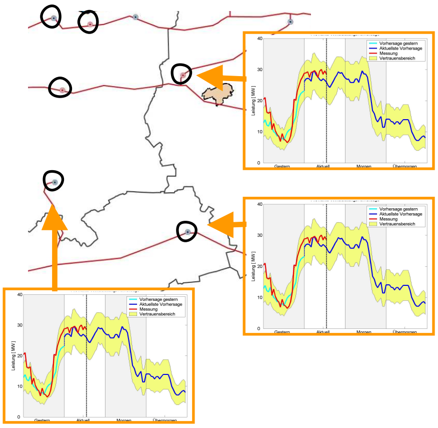
Grid congestion forecasting



- Forecasts with high spatial resolution for grid operators
- Integration of wind power prediction into load flow calculations
- Input for dayahead congestion management (DACF)
- Reduction of curtailment and grid enforcements

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R&D – Improvement of prediction systems

example: European project ANEMOS

- Benchmarking of approved prediction systems from DK, D, E, F, GB, GR, IRL
- improvement: uncertainty, upscaling, offshore, complex terrain
- implementation under common Shell
- practical evaluation with end-users

http://anemos.cma.fr

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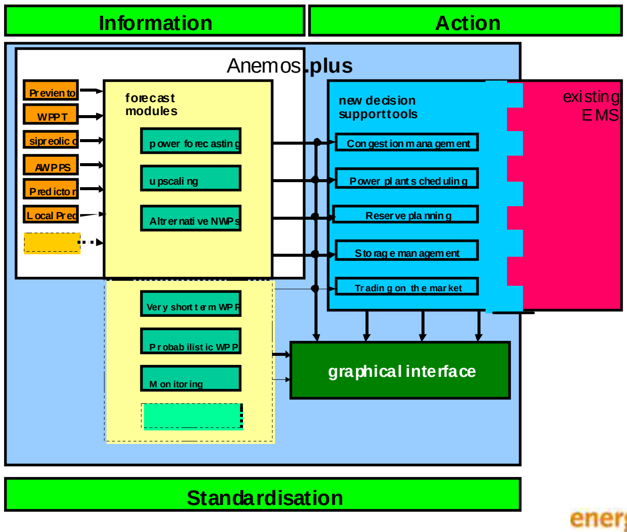
ANEMOS.plus – Integration of Wind Power Forecast



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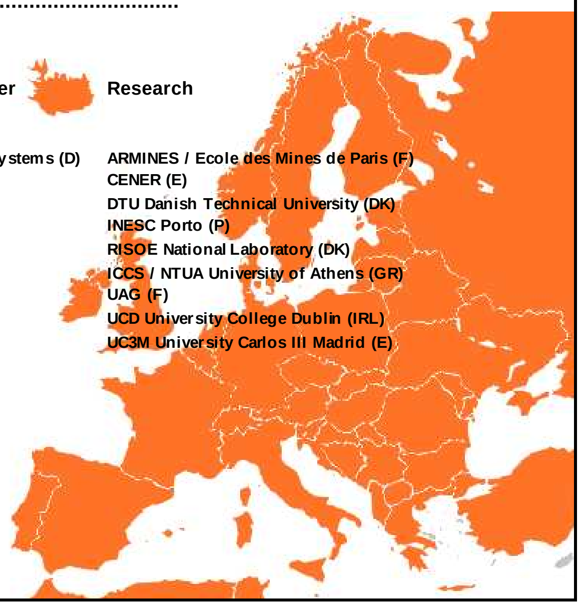
ANEMOS.plus – Consortium



Grid Operator / Utilities	Service provider	Research
ACCIONA (E)	energy & meteo systems (D)	ARMINES / Ecole des Mines de Paris (F)
EDF (F)	ENFOR (DK)	CENER (E)
EIRGRID (IRL)	MeteoFrance (F)	DTU Danish Technical University (DK)
DONG (DK)	Overspeed (D)	INESC Porto (P)
EWE (D)		RISOE National Laboratory (DK)
PPC (GR)		ICCS / NTUA University of Athens (GR)
REE (E)		UAG (F)
REN (P)		UCD University College Dublin (IRL)
SONI (GB)		UC3M University Carlos III Madrid (E)

ANEMOS

www.anemos-plus.eu

Overview

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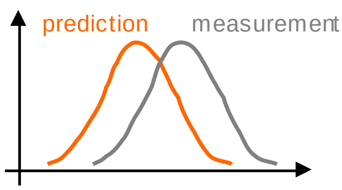
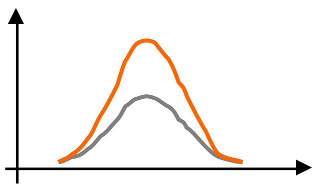
- **Evaluation**

Types of forecasting error

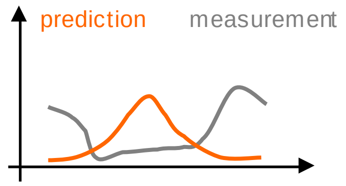


phase error:
fronts not in time
→ NWP



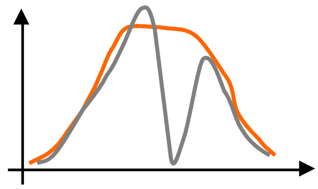
amplitude error:
wind speed at hub height wrongly predicted
→ NWP or wind profile

Types of forecasting error



shifted diurnal cycle:
thermal stratification wrongly predicted

→ wind profile



machine dependent errors:
cut-off, curtailment, availability

→ machine data

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Bad data example

- Curtailment info helpful to avoid this

power

wind speed [m/s]

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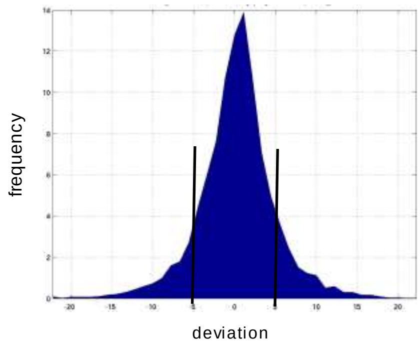
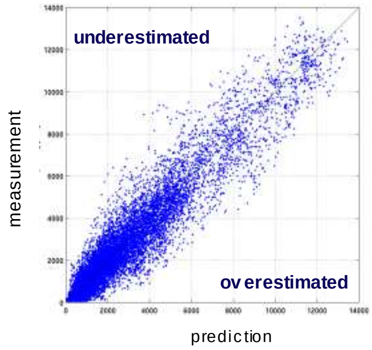
Distribution of forecast errors

Frequency distribution of errors



Scatter plot



Non-Gaussian distribution
approx. 72% of deviations in σ-interval

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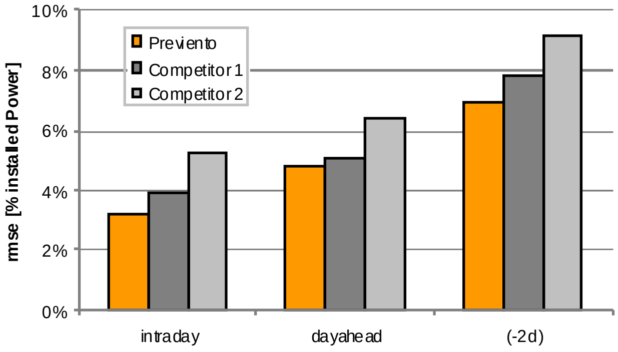
How accurate are wind power predictions ?

Forecast evaluation Germany

Customer evaluation of aggregated forecast of German wind farms (approx. 10000 wind farms)



Source:
EnBW Trading
2006

Different metrics to assess accuracy: here root mean square error normalized to installed power

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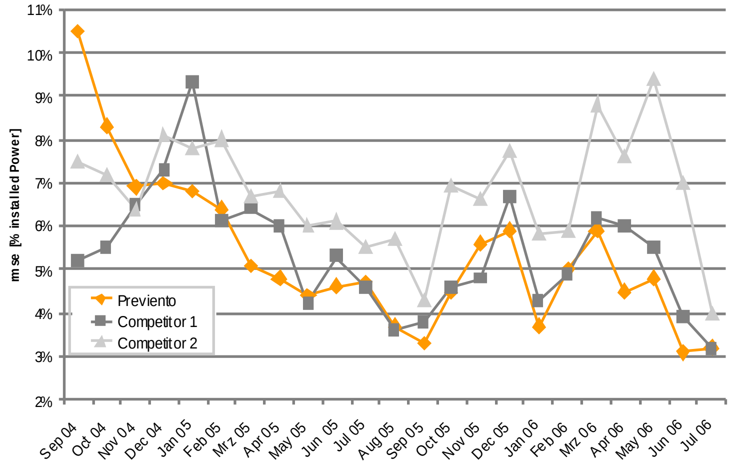
Seasonal variations in forecast accuracy

Forecast evaluation Germany



Source: EnBW Trading

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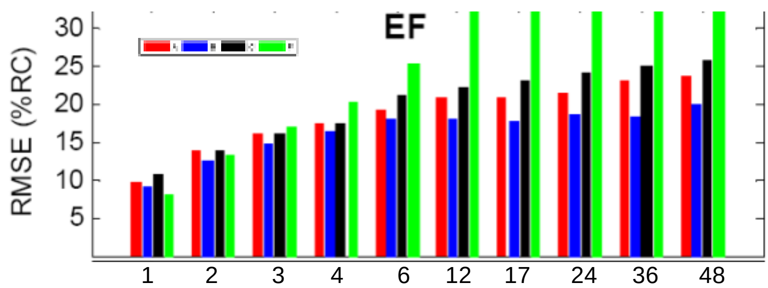
Forecast evaluation AESO, Canada

- Normalized RMSE of regional
- existing facilities: 7 wind farms

Close to Rocky Mountains



Source: Alberta Electric System Operator (AESO), Canada

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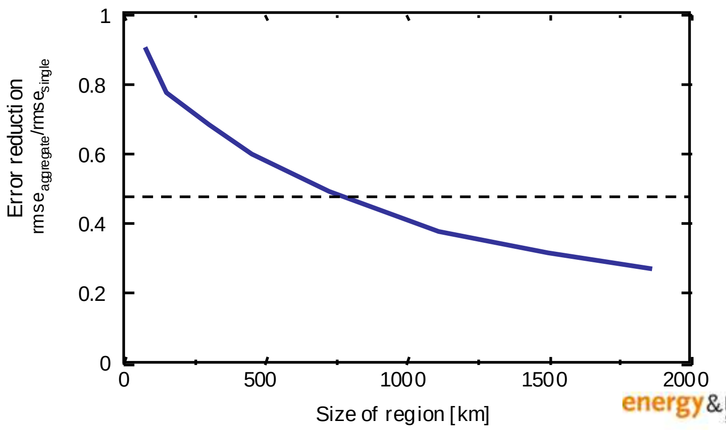
Aggregation of spatially dispersed wind farms

- Significant error reduction due to spatial smoothing effects
- The larger the spatial dispersion of the wind farms the better the forecast accuracy



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Conclusion

- Wind power predictions established in grid operation and energy markets
- Improving accuracy due to on-going development
- Further development of forecasting tools on very advanced level
- Important approaches:
  - Combination of different NWP models and Ensemble predictions
  - Integration into decision support tools and downstream processes
  - Spatially high resolution forecasts
- Decision processes:
  - Congestion forecasts (DACF)
  - Trading wind power
- Large potential for further applications in the future

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Outlook

- Forecast improvements through
  - Advanced multi-model approaches
  - Ensemble predictions
  - Optimization of NWP towards wind energy
- Integrate wind power forecasts into downstream processes (ANEMOS.plus)
  - Use for load flow calculations / congestion forecasts
  - User-friendly way to use uncertainty
- Online monitoring of the current weather situation (SafeWind)
  - detect wrong predictions with large errors
  - issue warnings to users in extreme events
  - produce „quick and dirty“ forecast updates
- Wind power in virtual power plants (eTelligence)
  - Renewables together with conventional generation, storage and demand side management
  - Management of distributed generation
  - Standardization of communication

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Thanks for your attention!

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