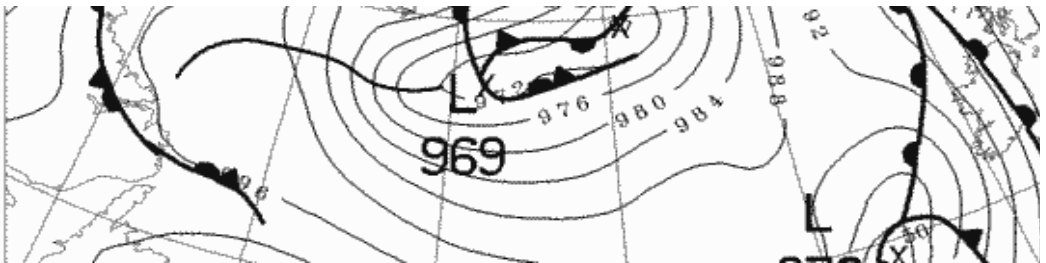
Best practice in wind power forecasting

Matthias Lange, Ulrich Focken, Anne Lenz

Southwest Power Pool
Stakeholder Meeting



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Overview

- Introduction to wind power prediction
- Reasons for forecasting errors
- Forecasting examples
- Data requirements for good forecasting
- Current developments

Company profile

- Integration of renewables into grids and markets
- Service provider for energy meteorology since 2004
- Areas of business
  - Wind and solar power predictions worldwide
  - Virtual power plant, software for :
    - decentralized energy management
    - Trading of wind power on wholesale markets
    - Demand side management
- Development
  - Industry projects
  - European research projects

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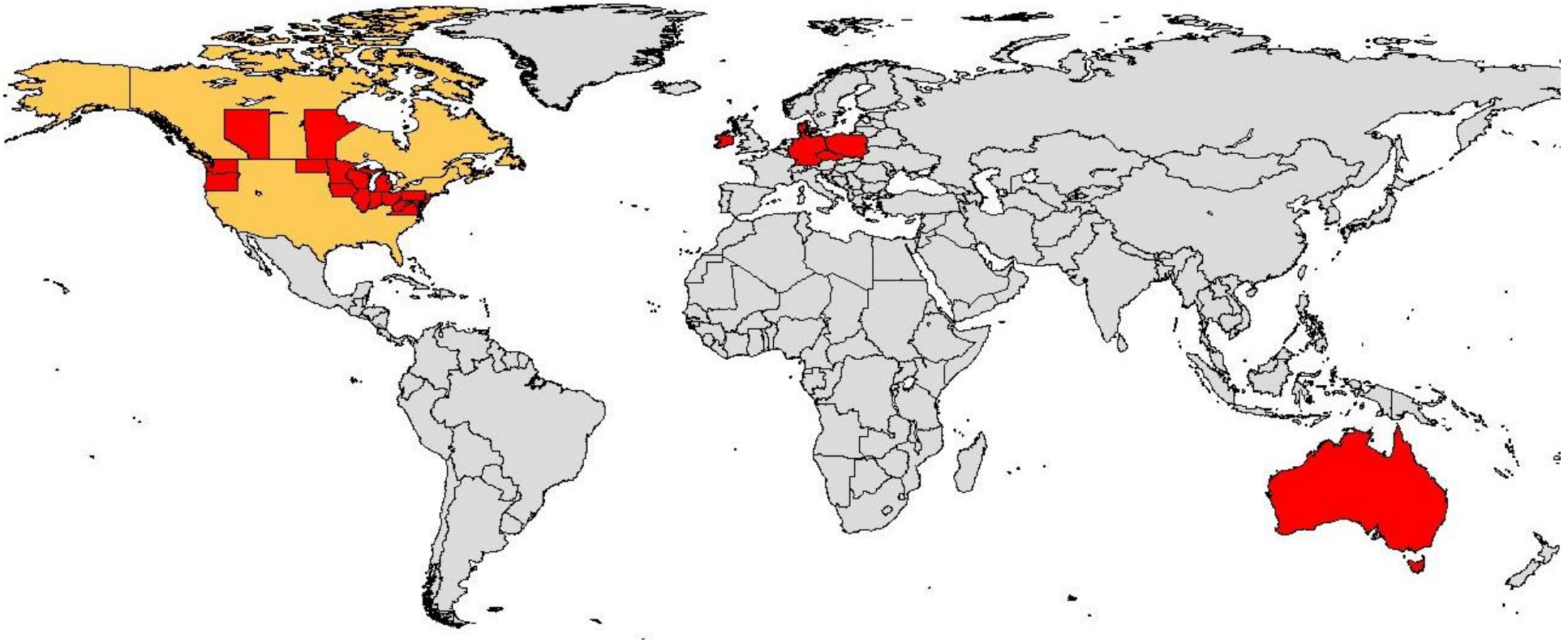
Areas with operational forecasting experience

- 80 GW of installed wind power currently predicted



Previento wind power forecasting for grid operators

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Choice of international customers

TenneT Taking power further

EWE

Midwest ISO We manage power.

PJM Interconnection

50hertz

RWE

TVA Tennessee Valley Authority

SPP Southwest Power Pool

amprion

elia

BPA
Bonneville Power Administration

Statkraft

EnBW

e·on

DEUTSCHE WINDTECHNIK

GREENPEACE ENERGY

VATTENFALL

akuo ENERGY

naturstrom ENERGIE MIT ZUKUNFT

wpd think energy

GRUND GRÜN

AEMO AUSTRALIAN ENERGY MARKET OPERATOR

WE²

Several international banks

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- Dayahead Market
- Intra-Day Market
- Balancing Market (MRL, SRL)

- Customer TradingSystem

Relized bids

bids

Forecast Vedor

- Price
- Windpower-
- Solarpower
- Load
- Weather Forecast

Virtual Power Plant

- Data management
- Standing Data, measurements, forecast
- Evaluate and combine foreacsts
- Technical monitoring

- Calculate optimuized schedules
- Distrubute schedlues
- Deal internal with forecast errors

BKV / TSO

Scheduling announcement

scheduling

measurements

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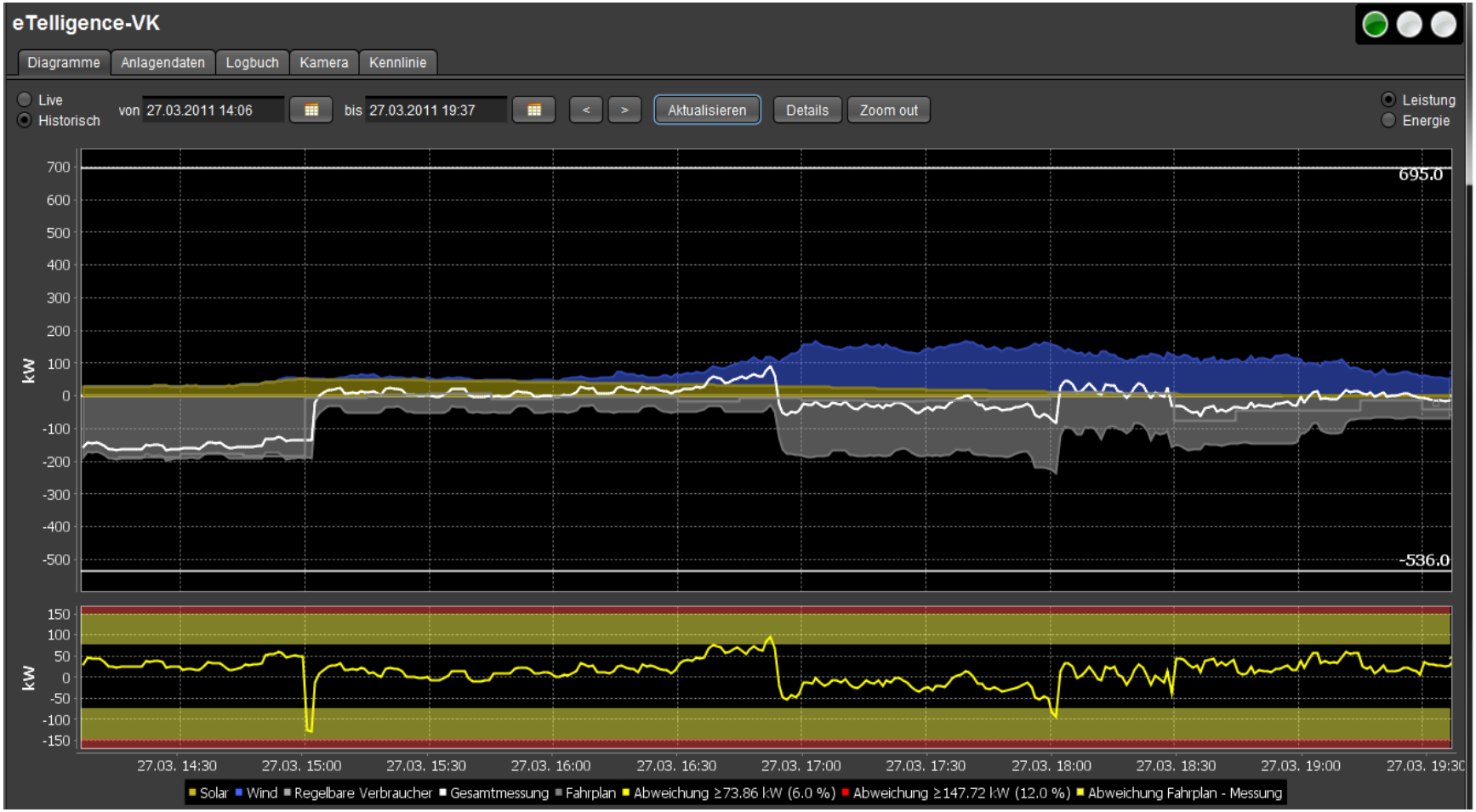
Software virtual power plant



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Introduction to wind power prediction

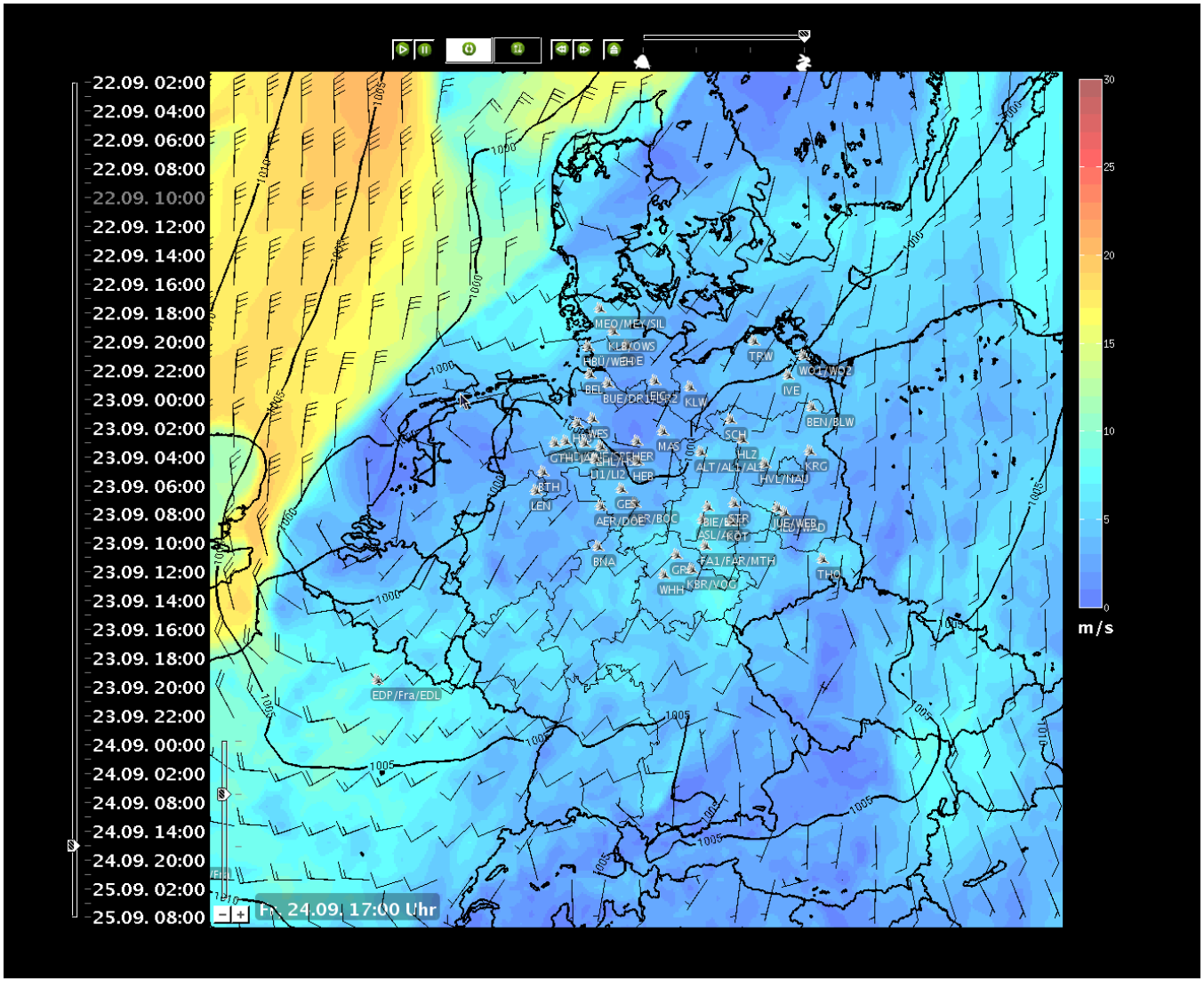
Best practice in wind power forecasting

How to produce accurate wind power forecasts

Lessons learned in Europe, North America, Canada and Australia

- Multiple weather model input
- Advanced and robust forecasting system
- Meteorological know-how to tune the models
- Extra module for very short-term forecasting (0 to 6 hours)
- Specific module for ramps
- Use of measurement data: historical as well as online

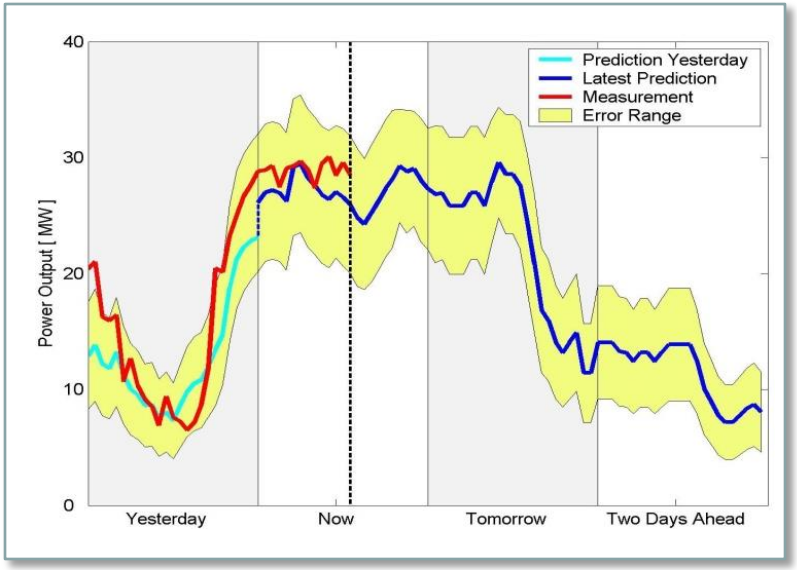
Numerical weather prediction is main input



Previento – the physical prediction system

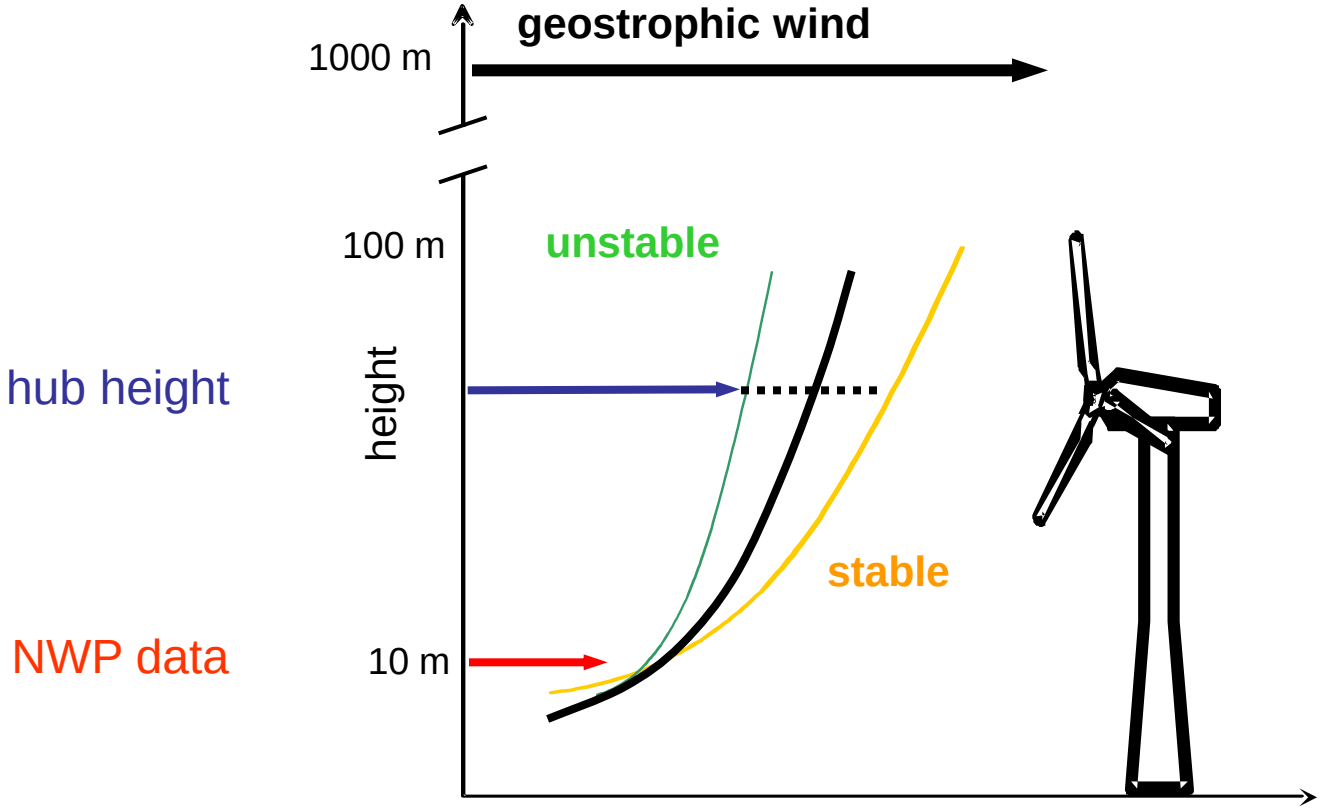
Previento – the physical model

- Optimal combination of weather models
- Spatial refinement to local conditions
- Site-specific power curve
- Extra ramp tuned and ramp parameter forecast
- Aggregation of wind farms to regions
- Forecast uncertainties provided



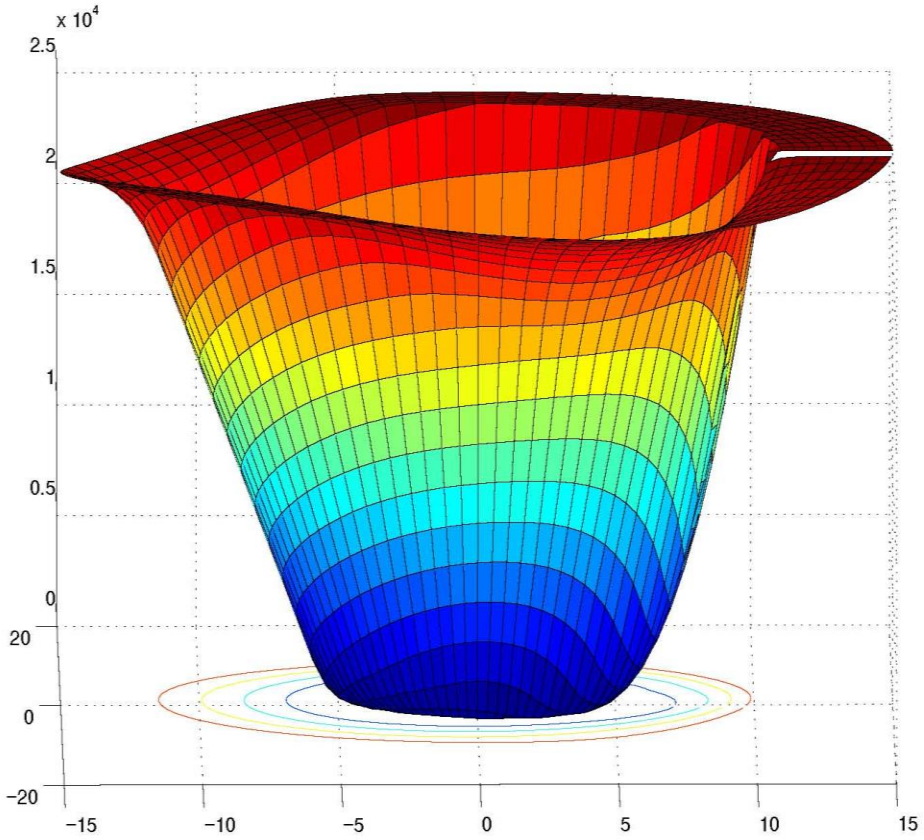
Set up of physical parametrisation

Correct wind profile in each situation



Three dimensional power curve

- Models the relationship of wind speed and power for each wind farm
- Accounts for direction dependent variations



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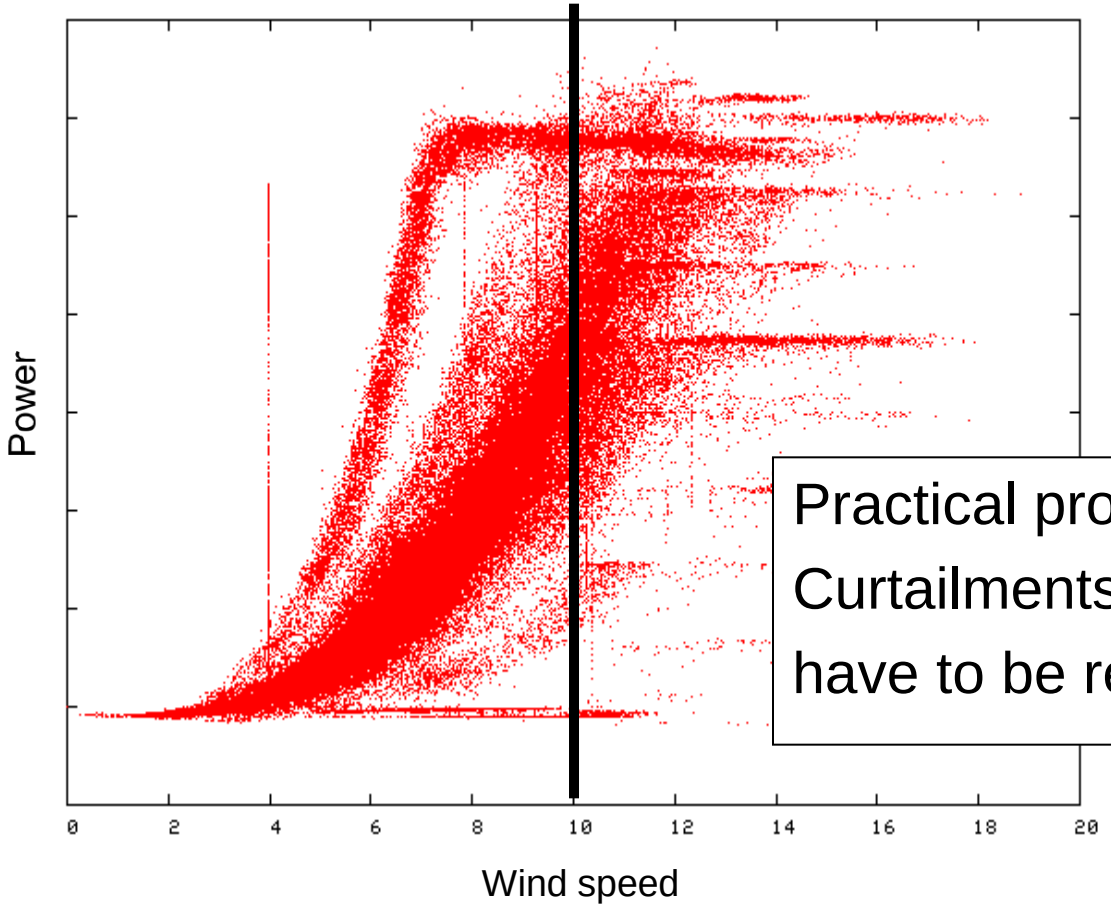
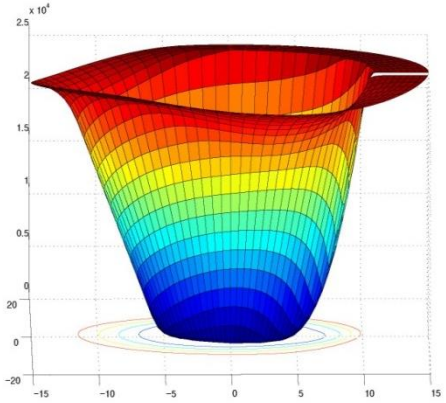
Historical power measurement data

2- dimensional power curve



3- dimensional is even more difficult



Practical problem:
Curtailments and outages have to be removed

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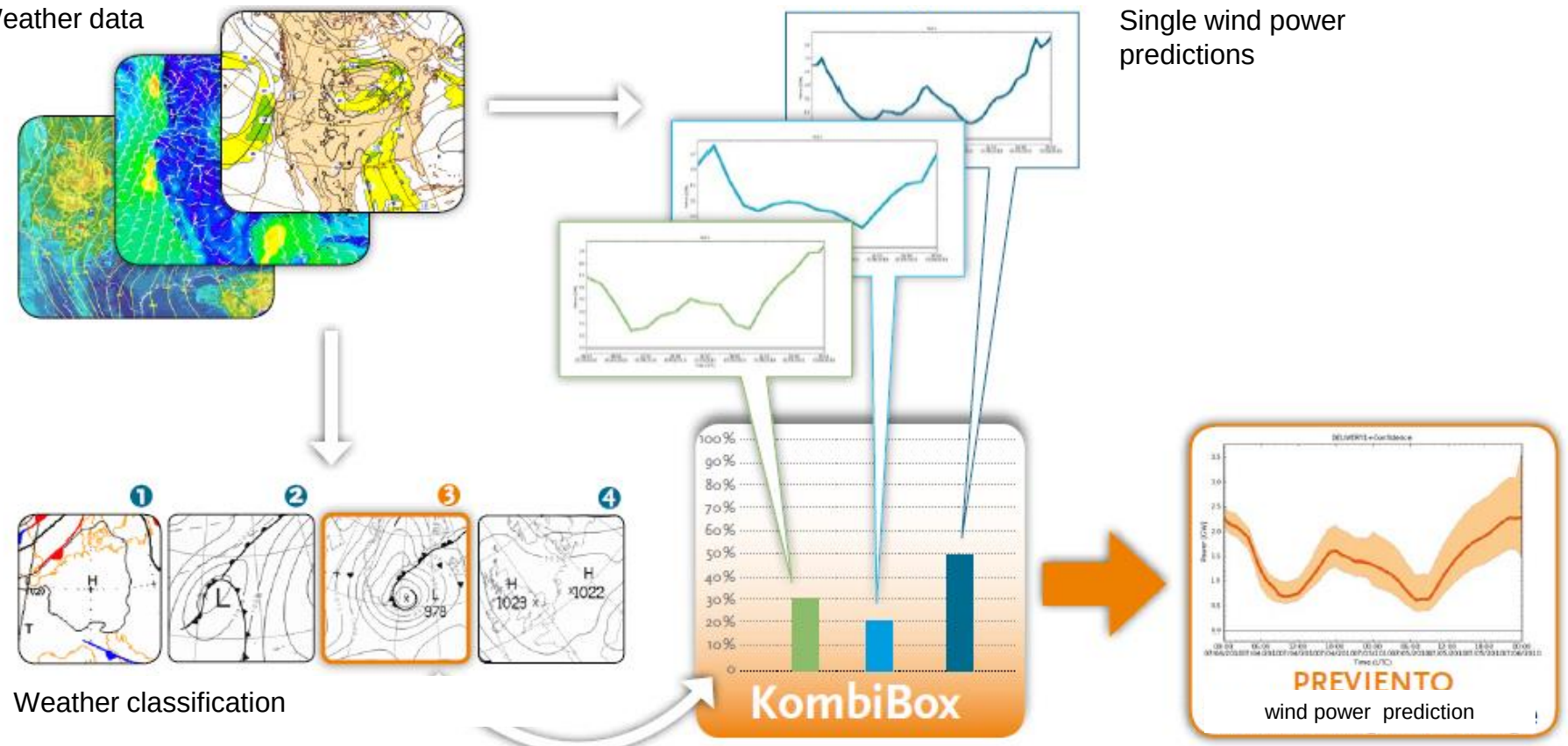
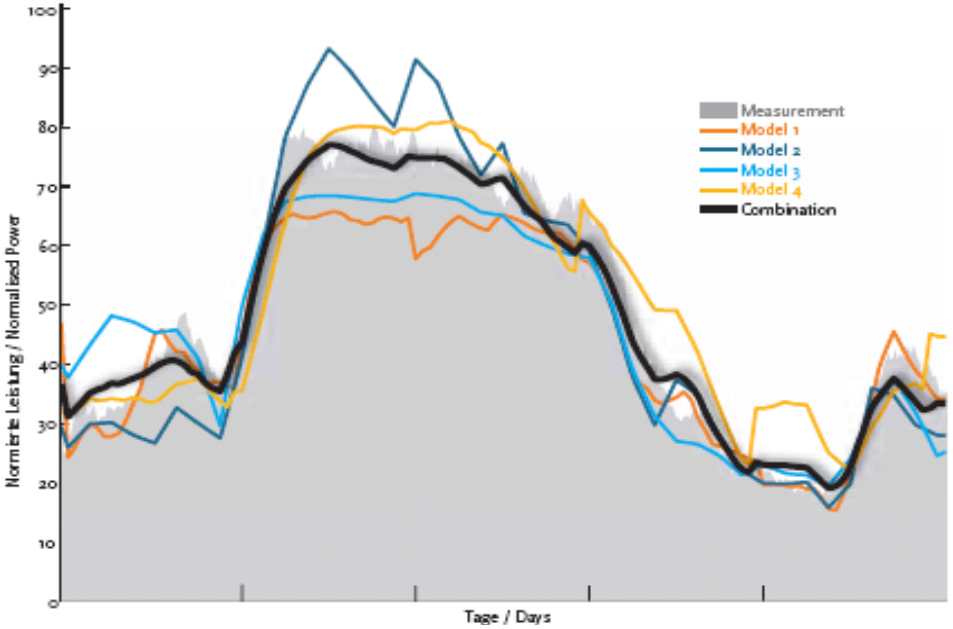
Combination of weather models

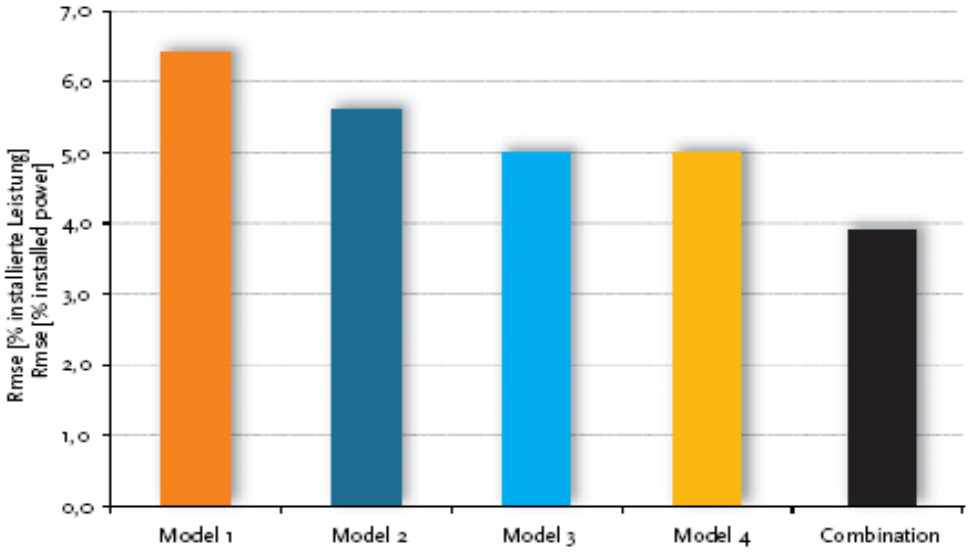


Weather-dependent combination of forecasts

Extremely large errors avoided



Improved overall accuracy



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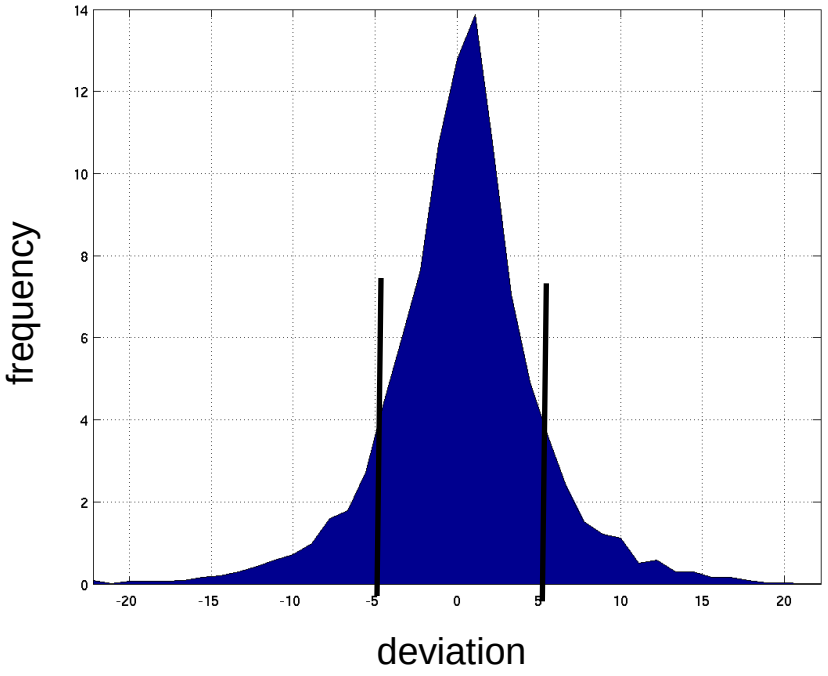
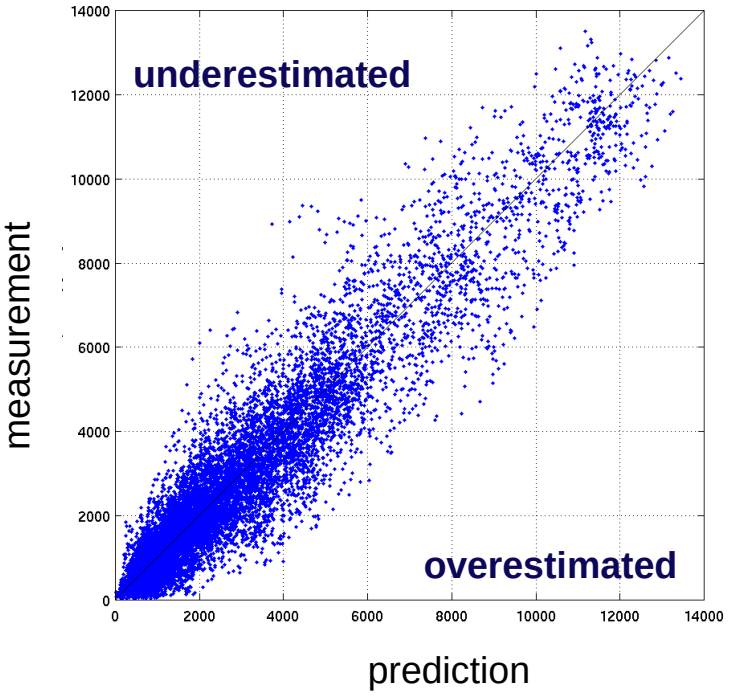
Distribution of forecast errors

Frequency distribution of errors

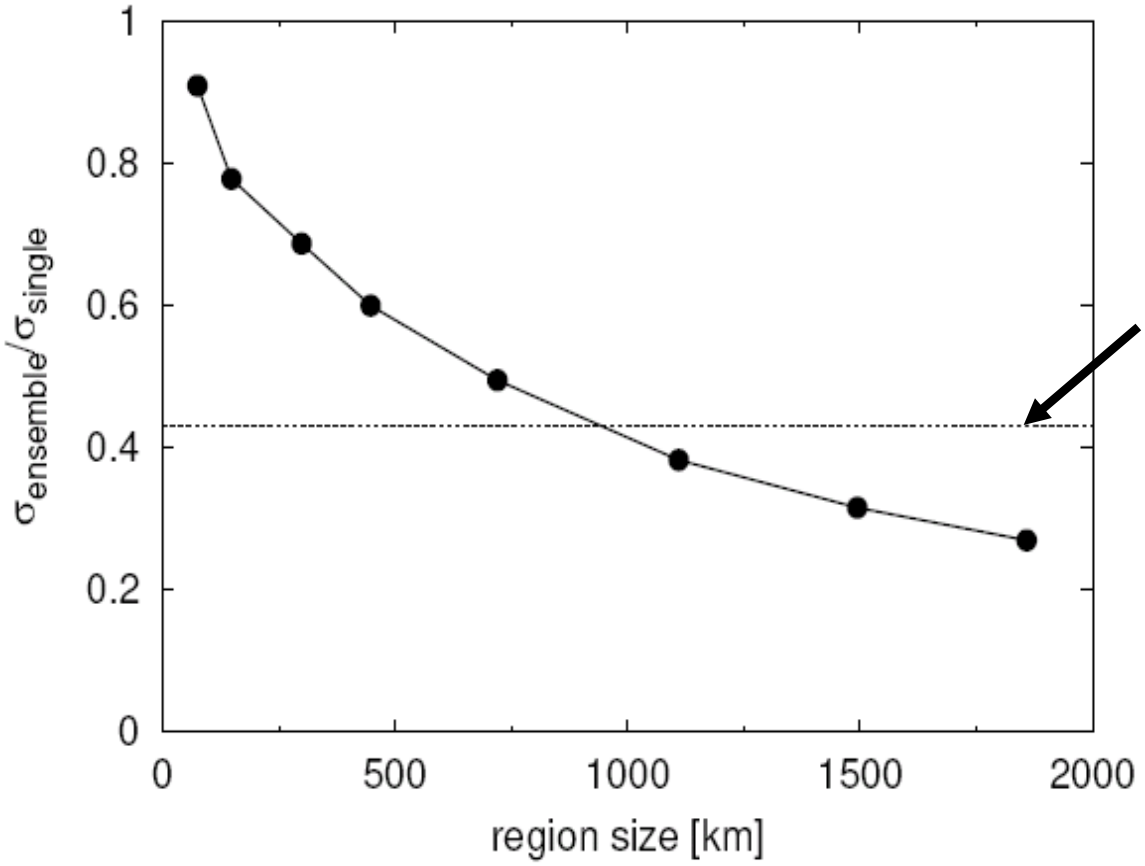


Scatter plot



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

More wind farms reduce prediction error



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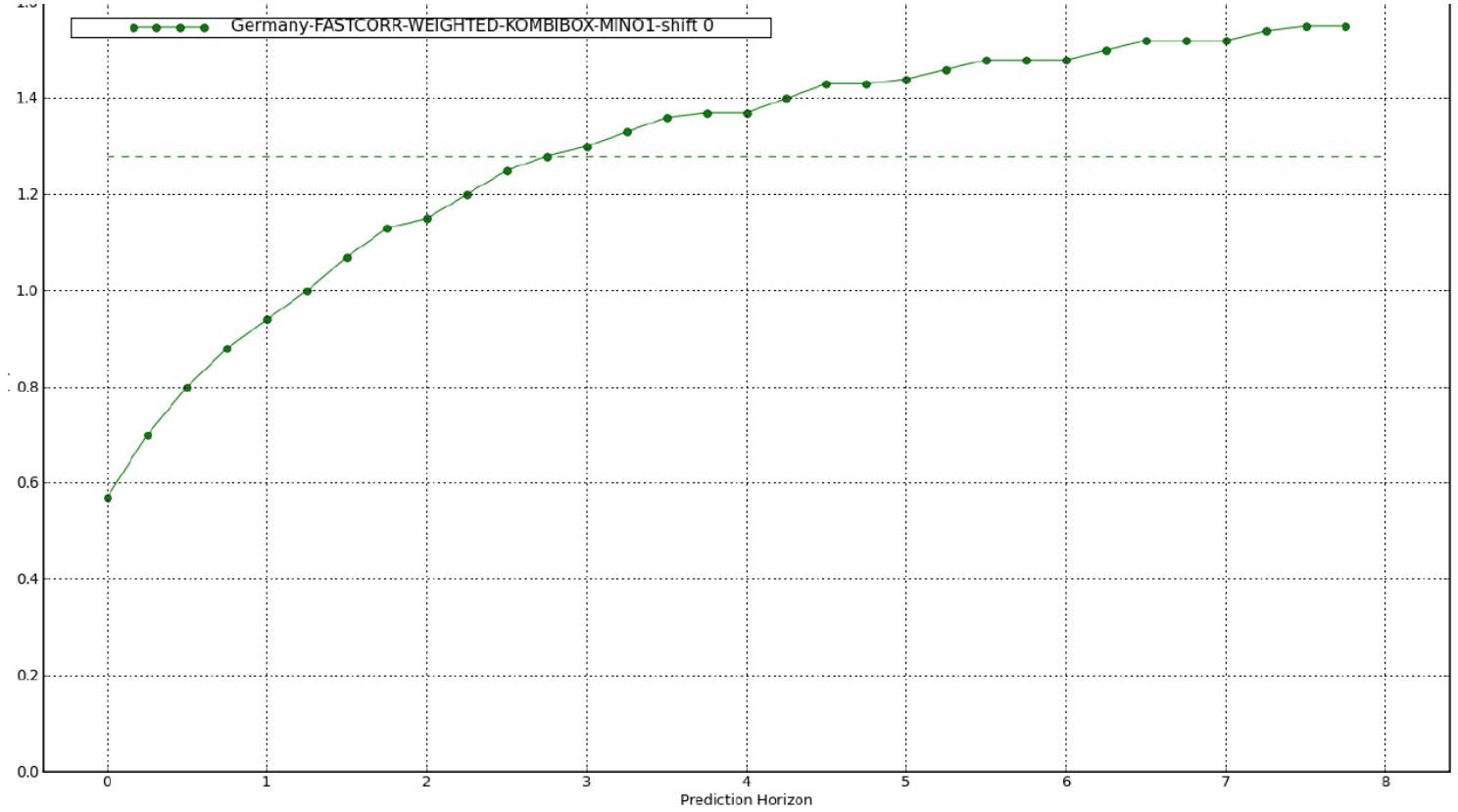
Very short term forecasting (few hours ahead): Instant Combi

- Input
  - several basic forecast on basis on different NWP (incl. last runs)
  - Power output of Wind farm
  - Down regulation information
  - Meterological data
  - Temperature information for icing

- Methodology
  - Which weather model performed best during the last hours ?
  - Which weather model generally performs best for this weather situation ?
  - What does the measurement look right now and within the last minutes / hours?
  - Is icing a problem ?

Online power measurements improves very short term forecast

Accuracy with increasing prediction horizon
Example Germany MAE



Online power measurements reduce error by 50 % within the first hours.

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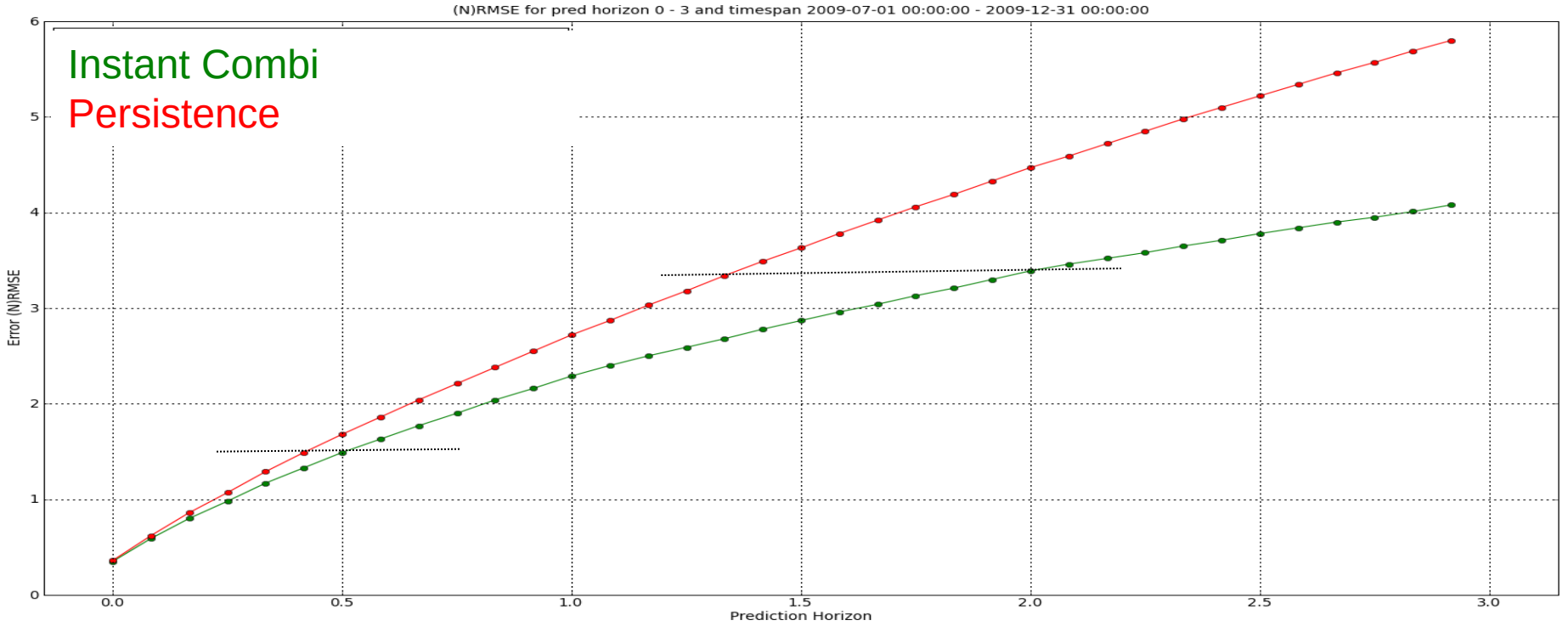
Fast methodology needed

evaluation for a 6 month period



For very short term forecast: methodology has to be extremly fast, so 1 min from measurement until delivery of forecast is optimum (incl. data transfer, data check, calculation time, forecast delivery)

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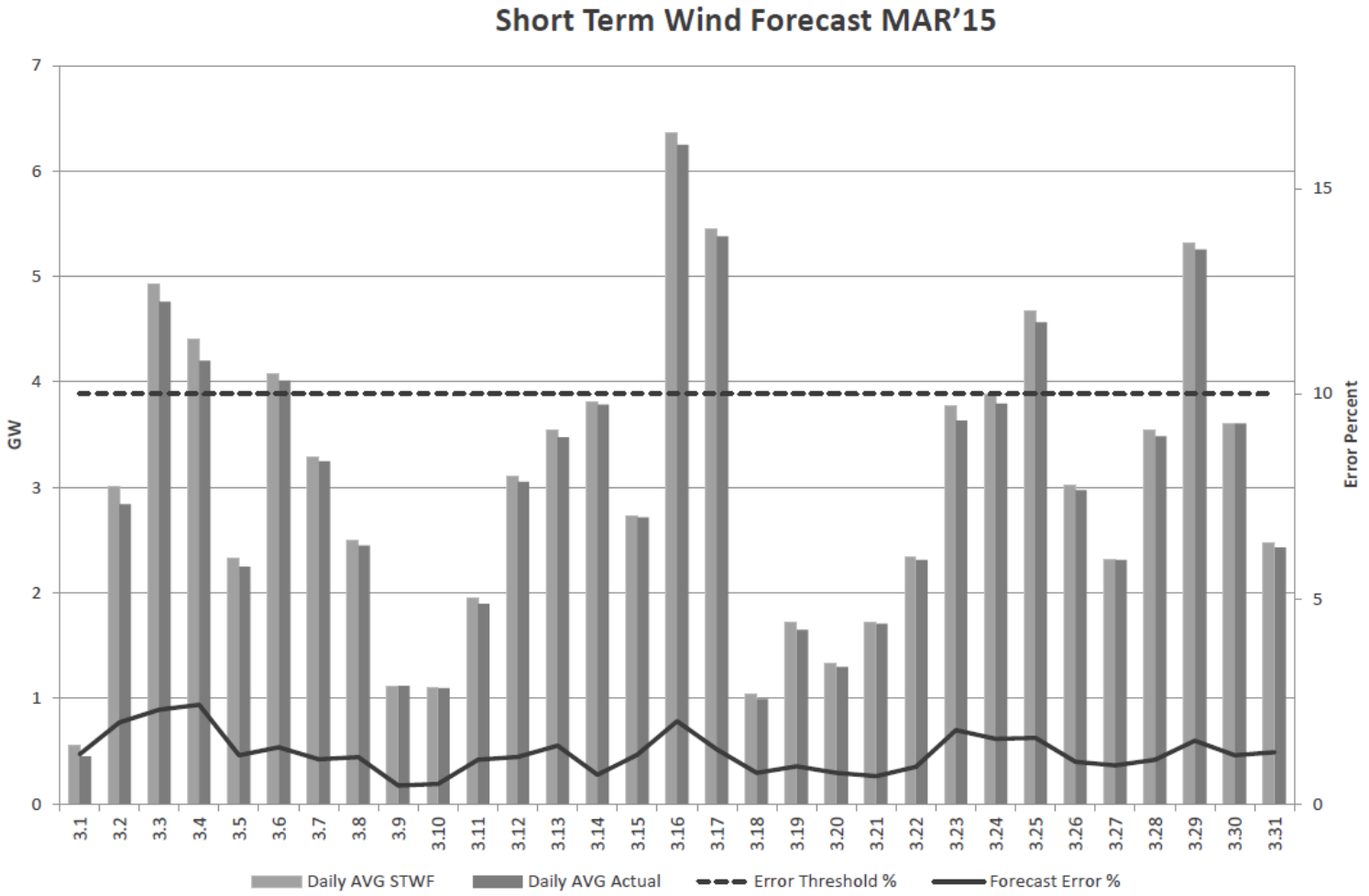
Forcasting accuracy for SPP fleet



Reasons for forecasting errors

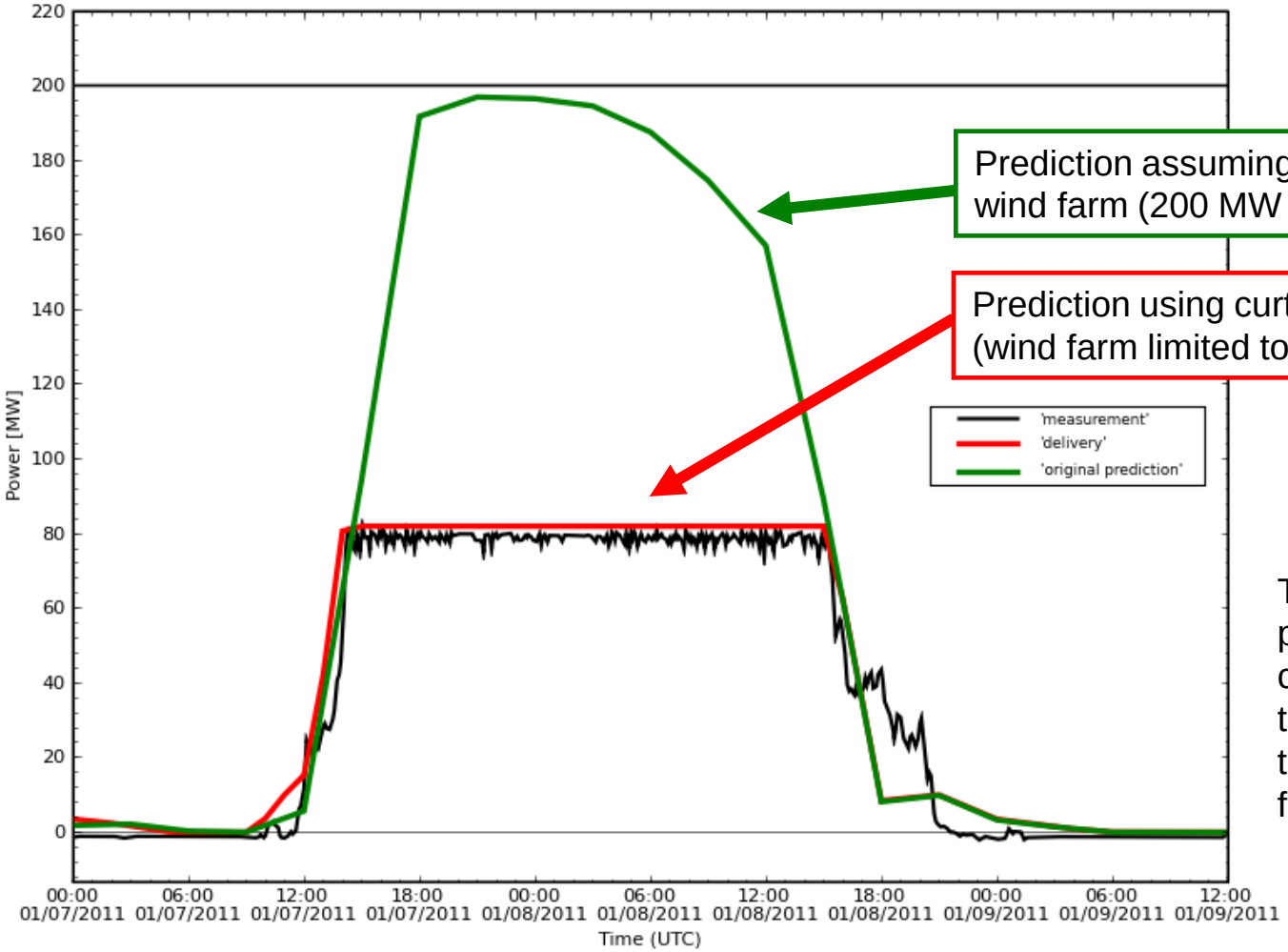
Reasons for deviations between forecast and measurement

- Avoidable forecasting errors due to lacking information from wind farms
  - Missing turbine availability information (due to maintenance e.g.)
  - Unannounced curtailments
  - Wrong pooling of wind farms

- Machine features that are difficult to predict, but where additional data from wind turbines could help:
  - turbine shut downs due to
    - high wind speeds
    - low temperatures

- Forecasting errors in NWP Data

To be considered: curtailment and scheduled outages



Prediction assuming full availability of wind farm (200 MW installed capacity)

Prediction using curtailment information (wind farm limited to 80 MW)

Time schedules for planned outages or curtailments can be transmtted to Previento to be considered in the forecasts.

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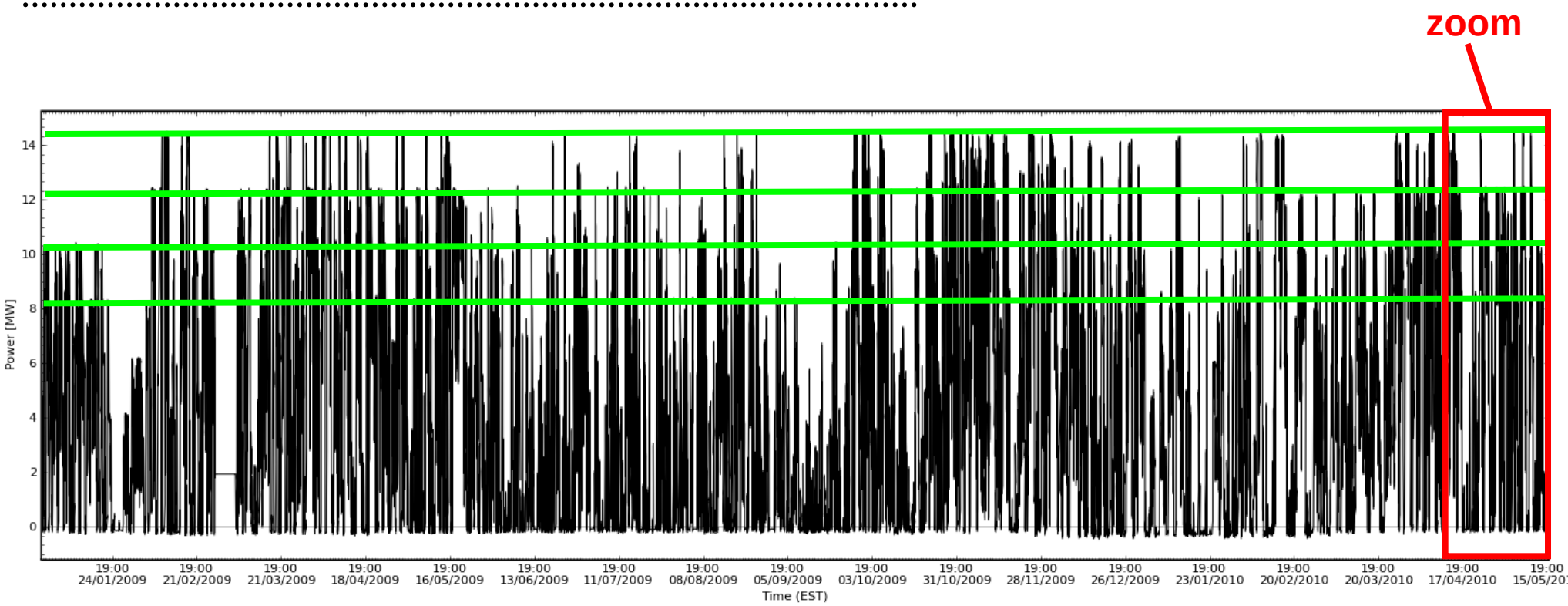
Availability



- several levels of maximum power output recognizable
- different levels because one or more turbines not running

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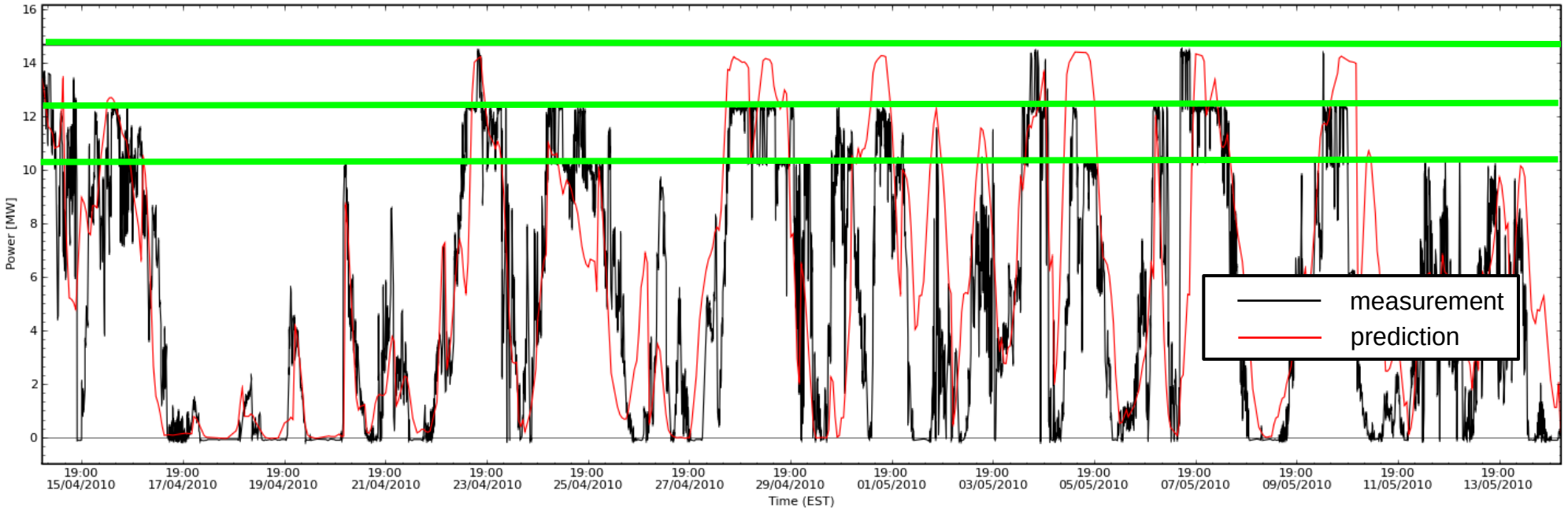
Availability



- Without availability information forecast assumes that all turbines are running
- Artificial forecast error that could be avoided with real-time and future availability data

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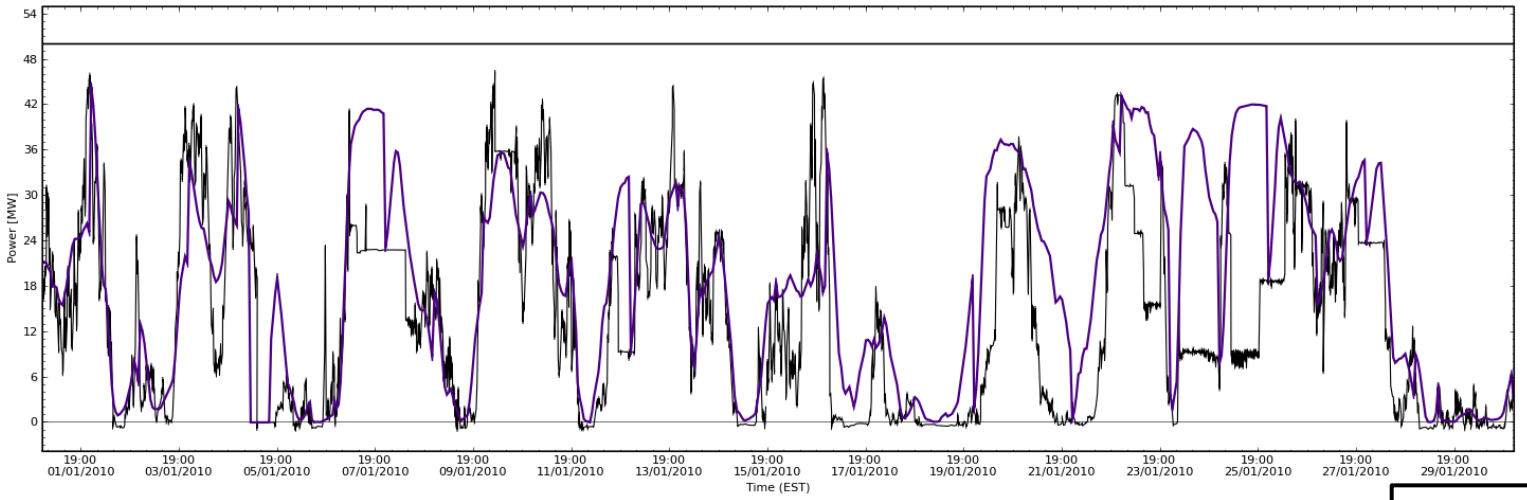
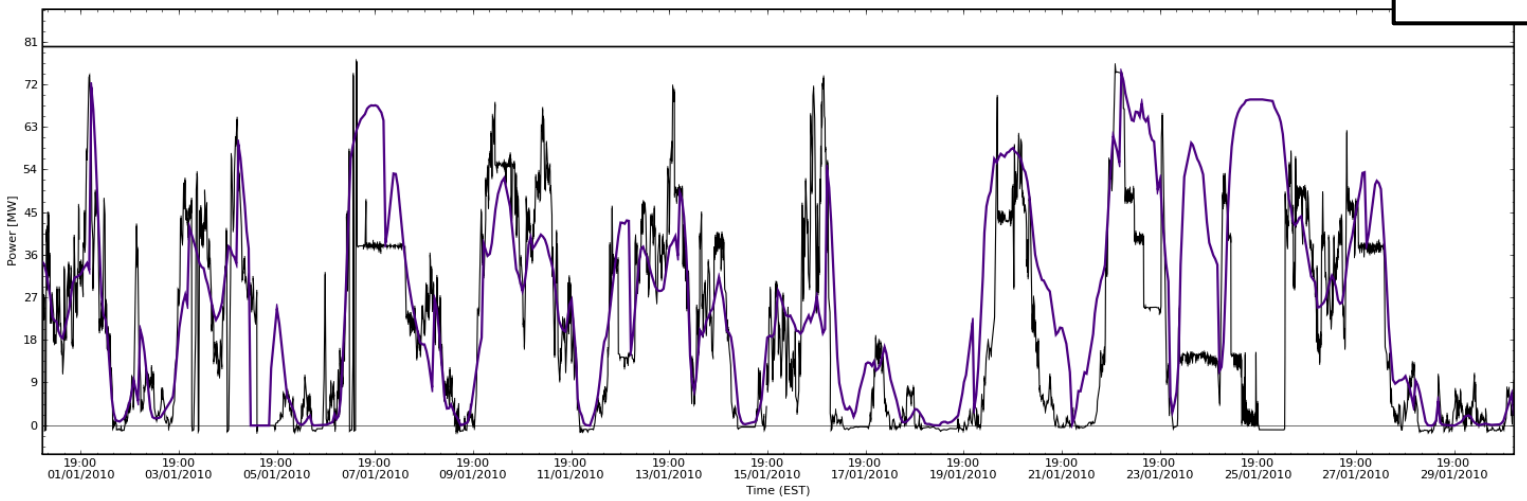
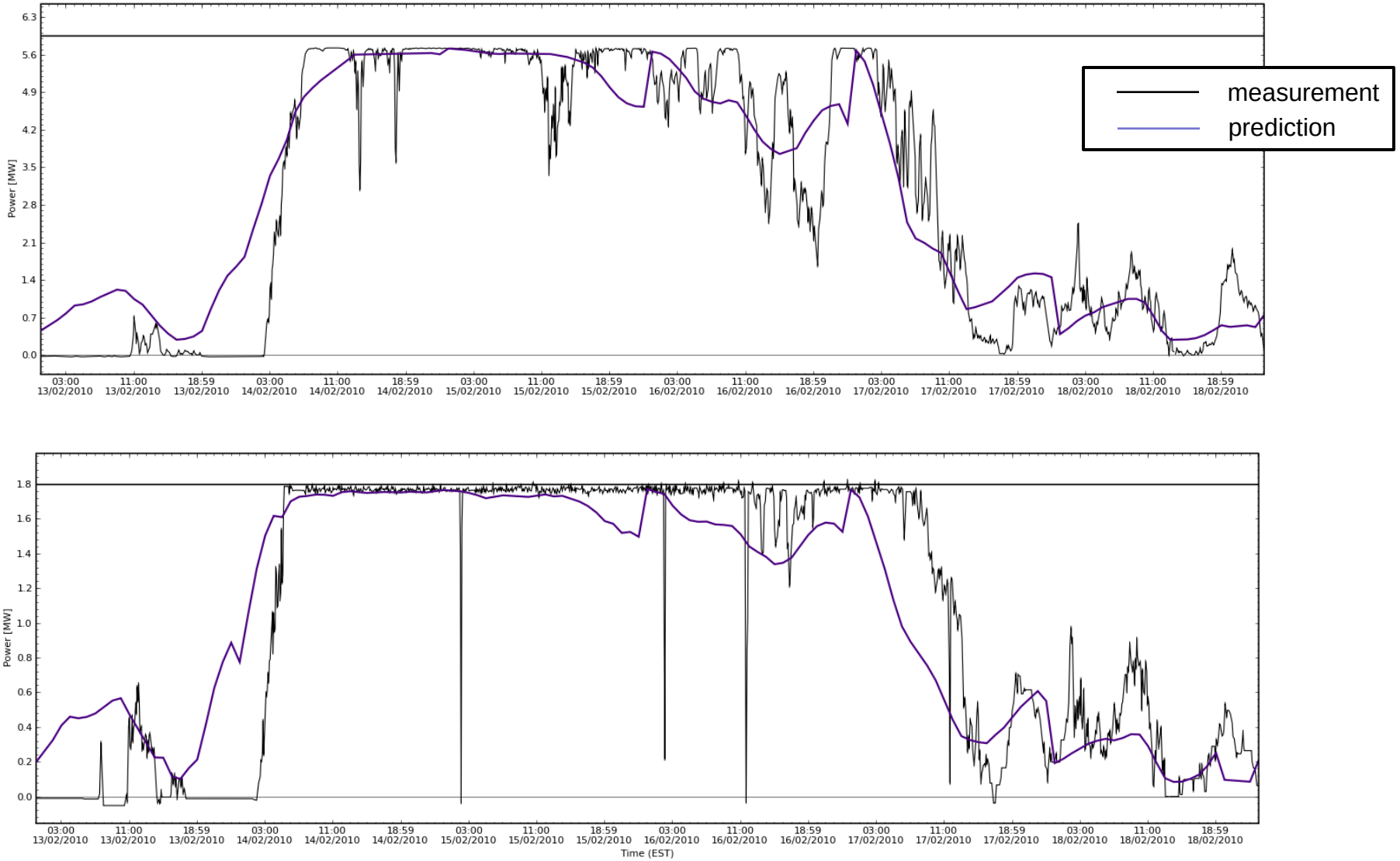
Curtailment





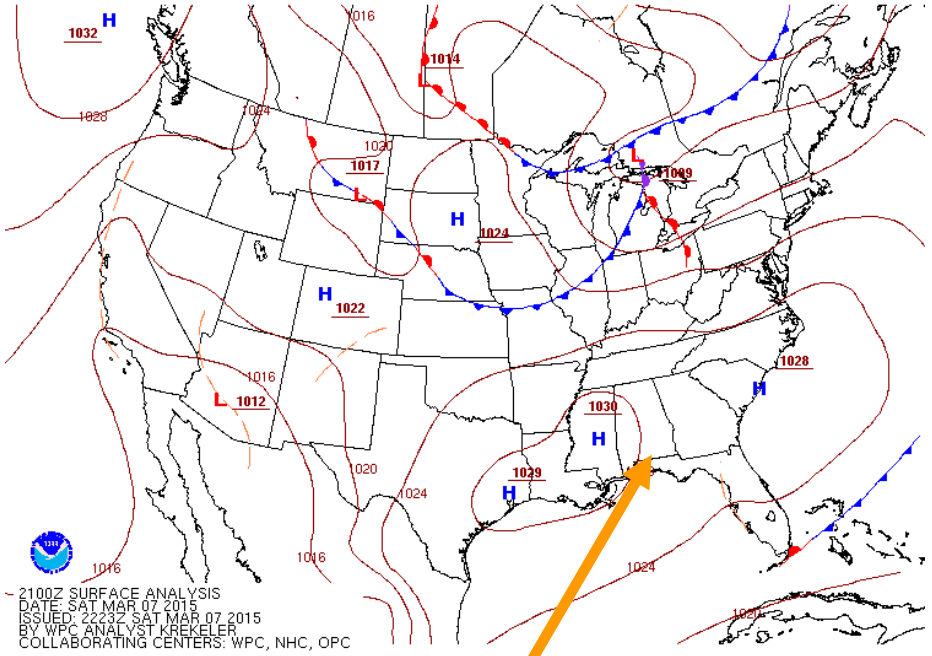
Cut-Offs due to High Wind Speeds



Forecasting examples from SPP area

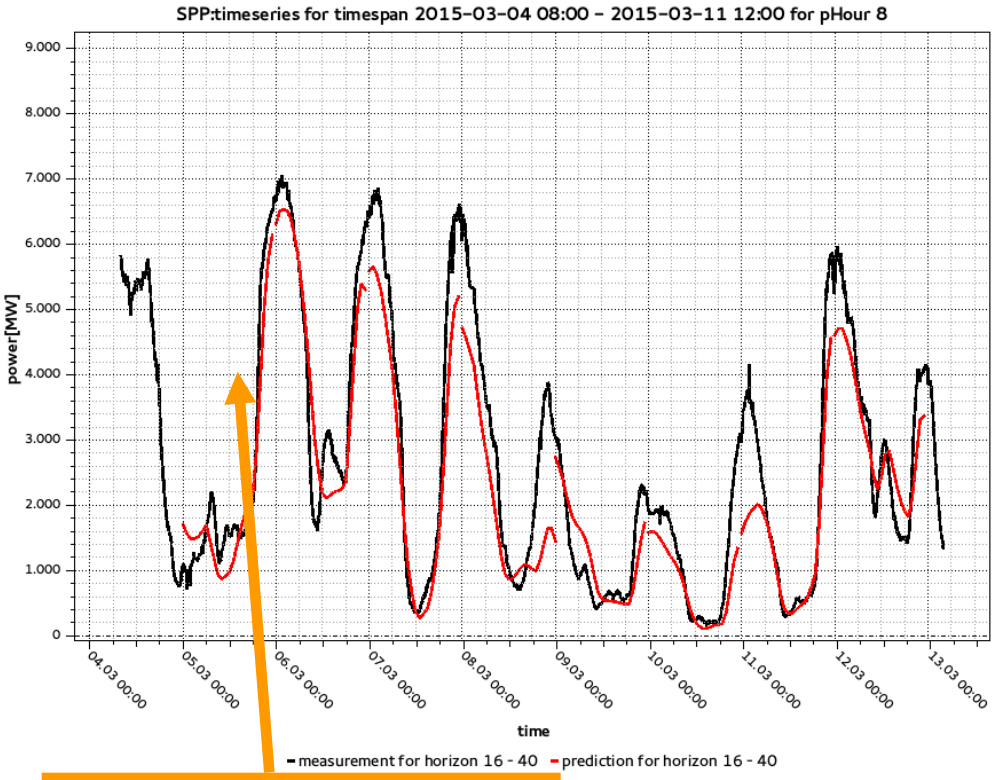
Daily Pattern: March 2015

Analysis



large high pressure system

Timeseries SPP



strong diurnal pattern

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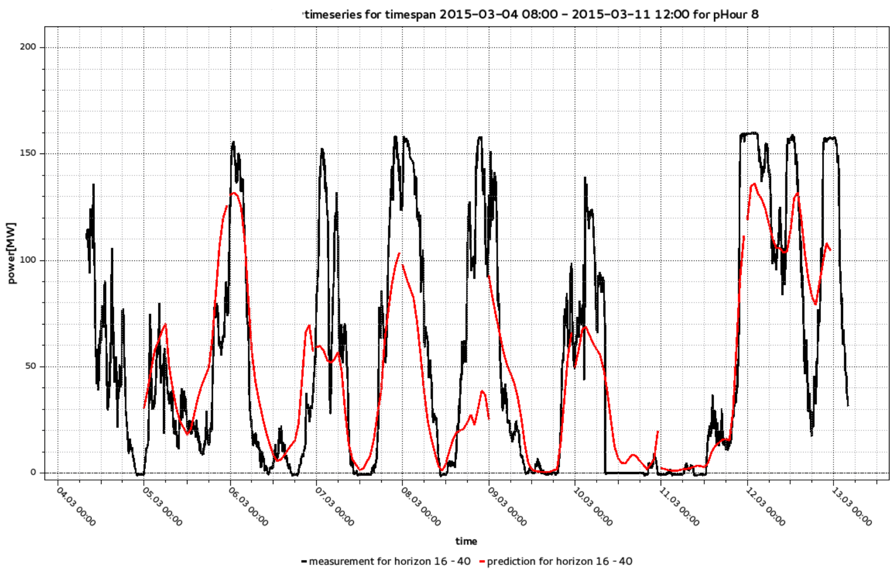
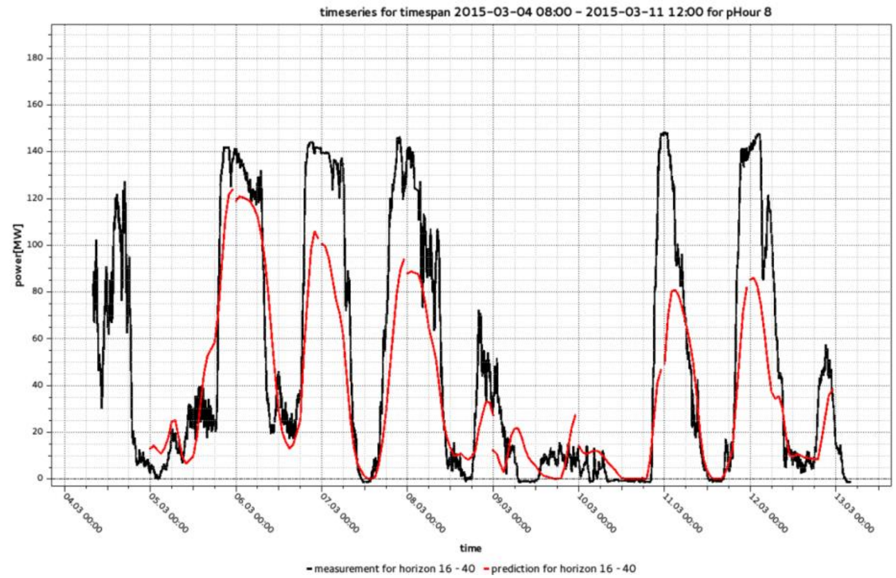
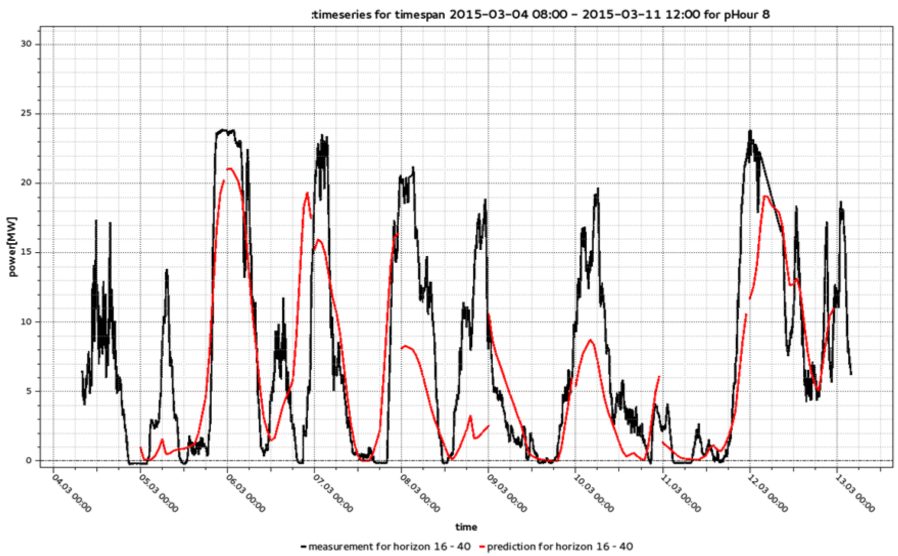
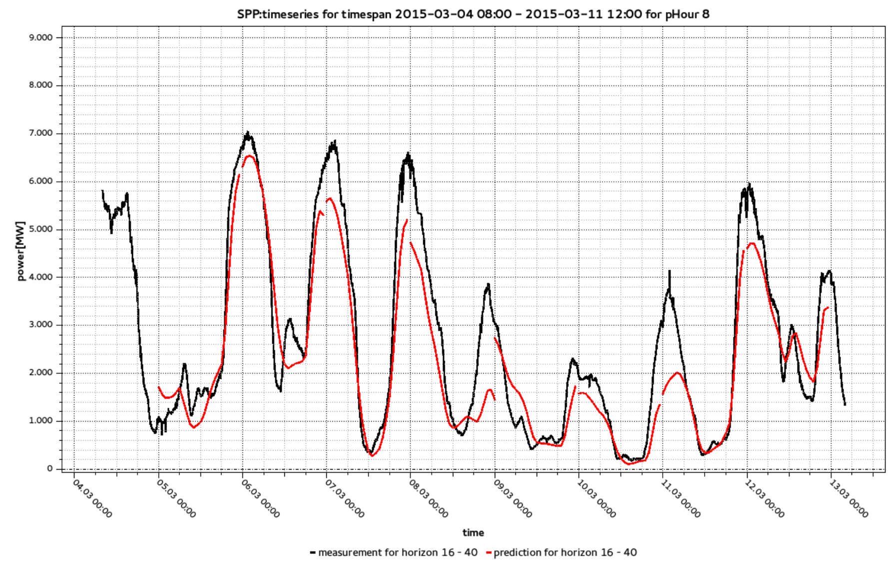
Daily Pattern: March 2015, wind farms

measurement
prediction

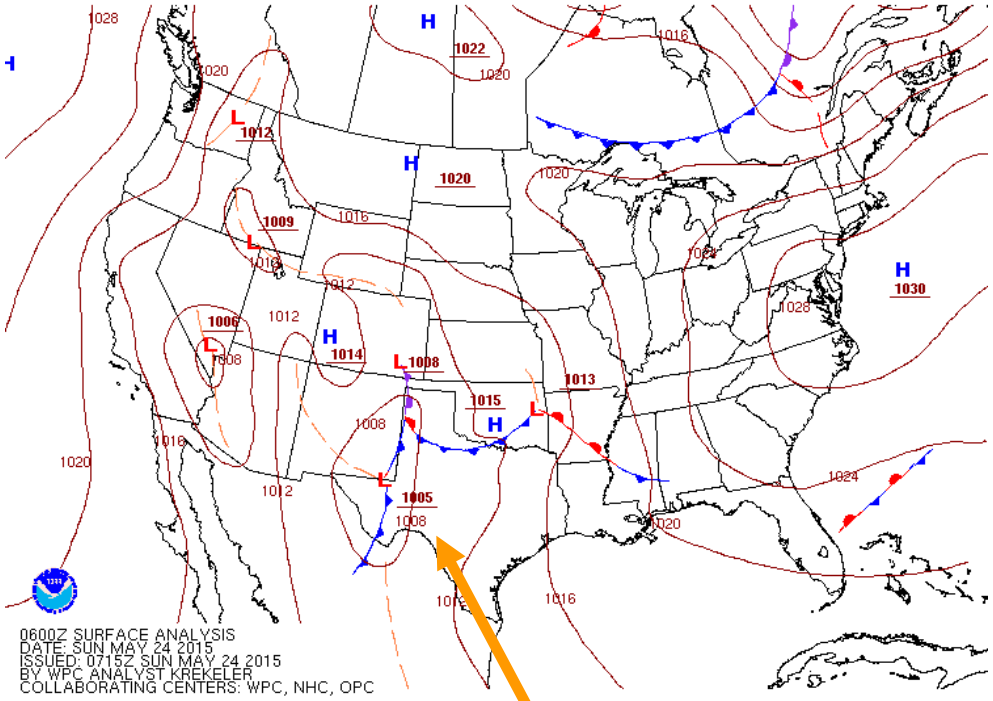








Forecasting Errors in NWP Data 5/23/2015



Low pressure system west of SPP region

- Low pressure system does not move
- Low pressure gradients lead to small wind speeds
- NWP very often overestimate the wind power production in these situations

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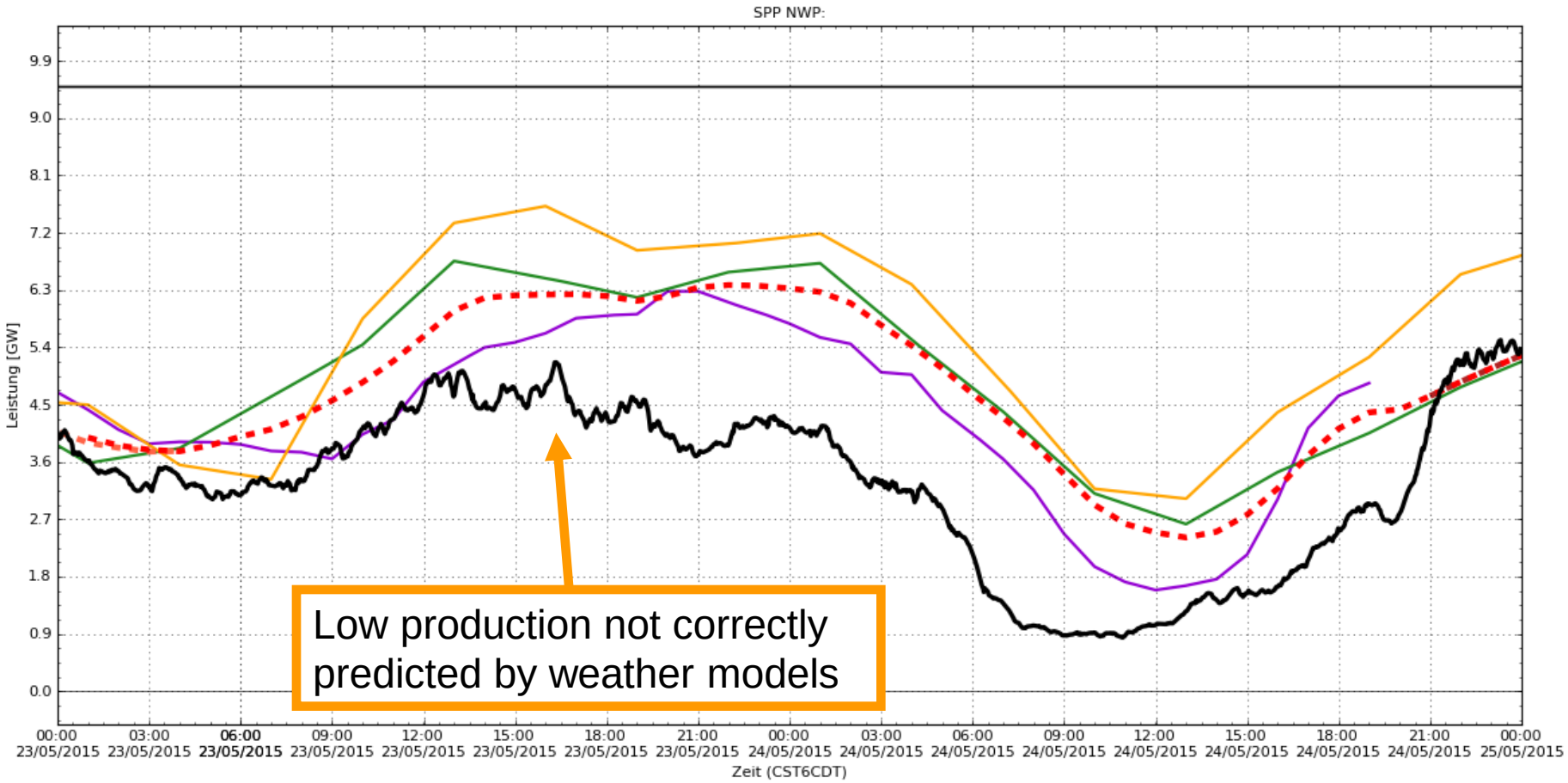
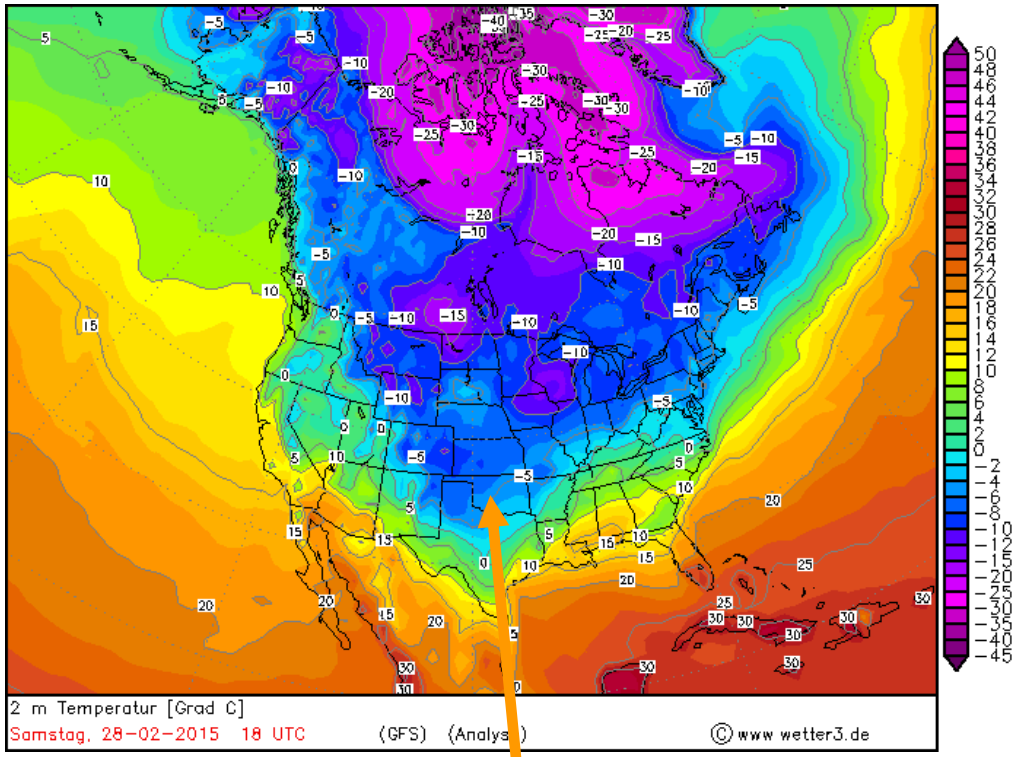
Forecasting Errors in NWP Data 5/23/2015

- Overestimation of production
- Meteorological situation: Stationary low pressure systems over Northern Texas



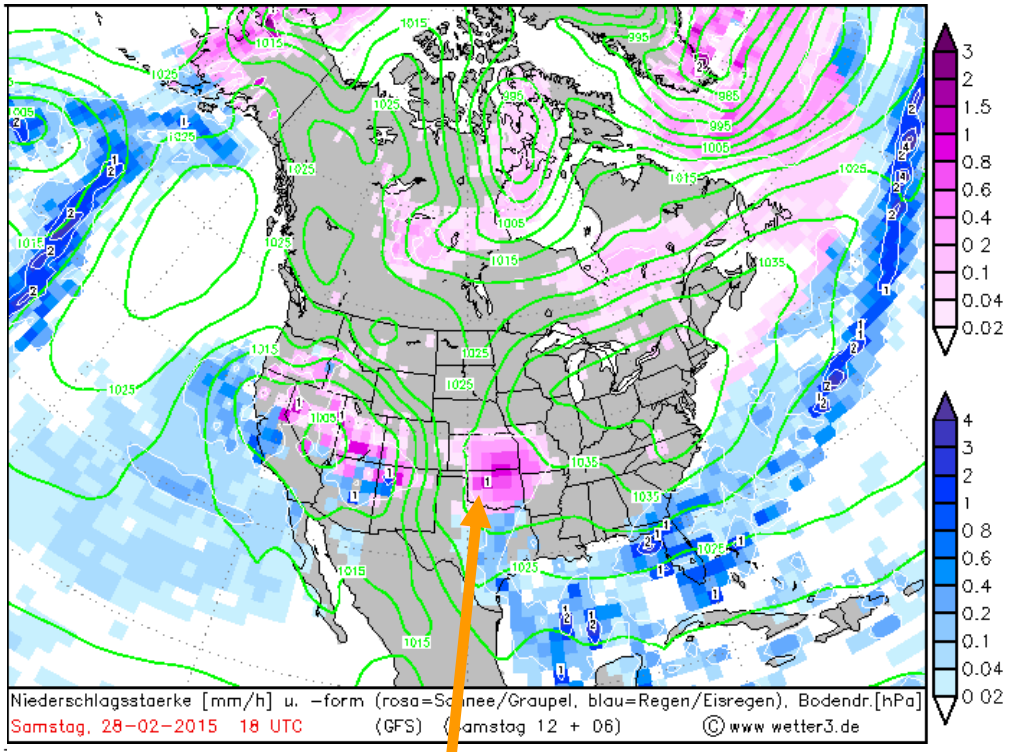
Icing: 2/28/2015

Surface temperature



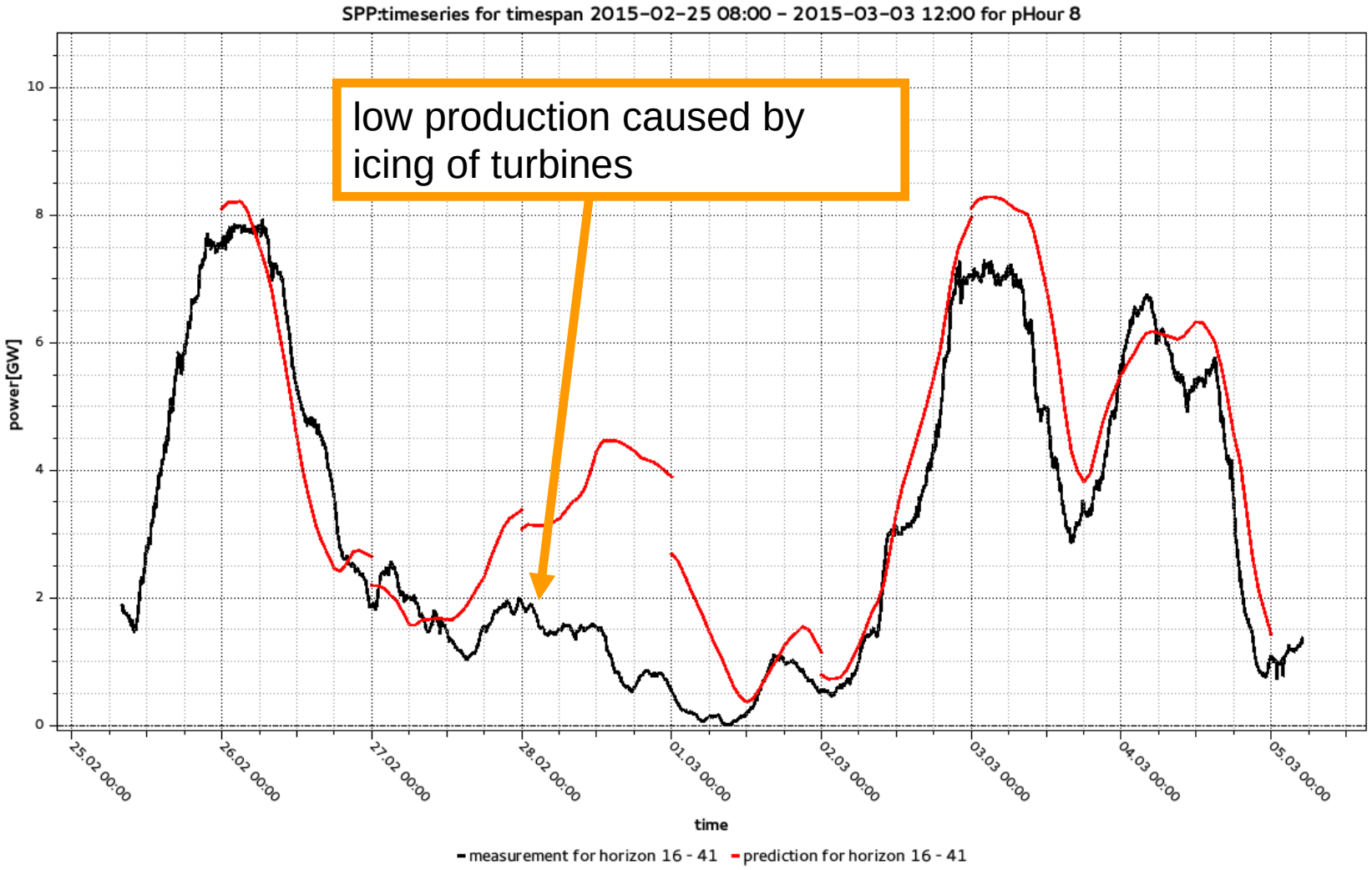
Freezing temperature

Type of precipitation



Snowfall

Icing: 2/28/2015



Data requirements for good forecasting

Value of real-time data from wind farms

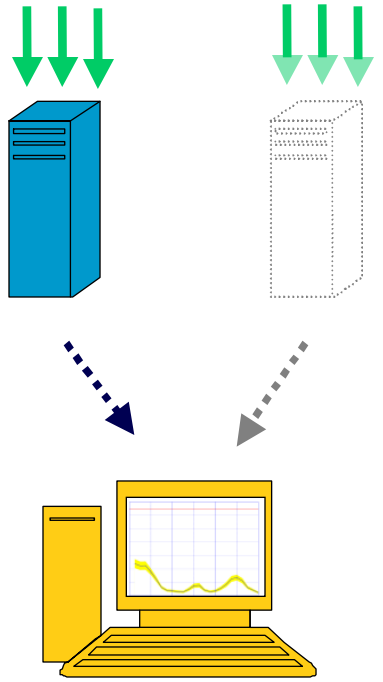
- Wind power measurements (very high influence on accuracy)
  - Very short term forecast (0 – 10 h)
  - Essential for ramp forecasting
- Wind turbine availability (very high influence on accuracy)
  - Adjust prediction for all prediction horizons
  - Include availability into forecasting process
- Meteorological measurements (high influence on accuracy)
  - Very short term forecast
  - Detect deviations and correct forecast

Standardization and accuracy of data is important

- Availability of wind farm:
  - Number of turbines up and running or
  - Maximum available power output?
- Scheduled Maintenance
  - Update of time periods through maintenance crew
- Curtailment
  - Information flow between grid operator and wind farm operator

Redundancy

- Input: several NWP forecast
- Calculation: Two redundant server
- Delivery: Several ways



NWP Data

2 independent Previento servers

first come first serve

(web interface, ftp, e-mail)

Customer

Alert initialisation

24 / 7 support

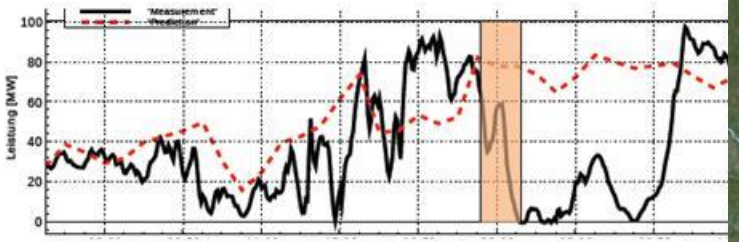
- IT persons trained on the SPP forecast system
- Response to SPP within one hour
- start working on the problem directly after the notification to SPP
- SPP will receive also a notice when the disruption is solved
- This service is already in place for several other customer

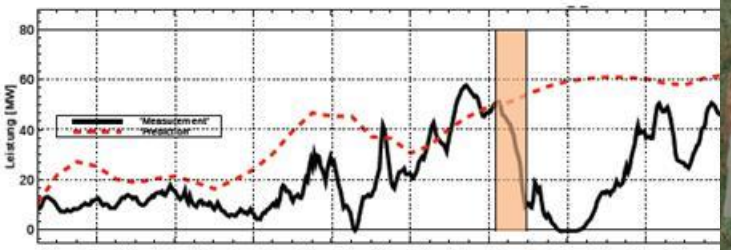
Current developments

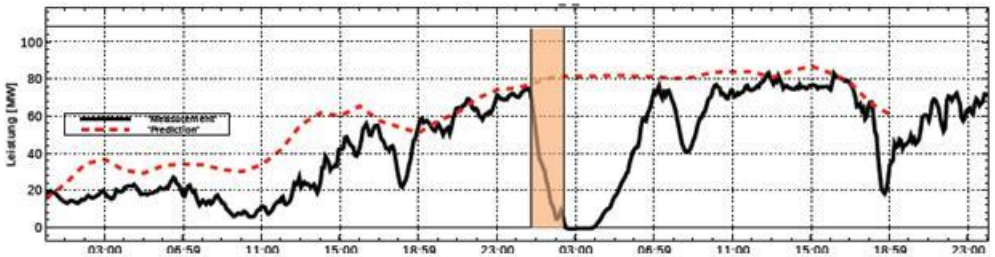
Current developments in wind power forecasting

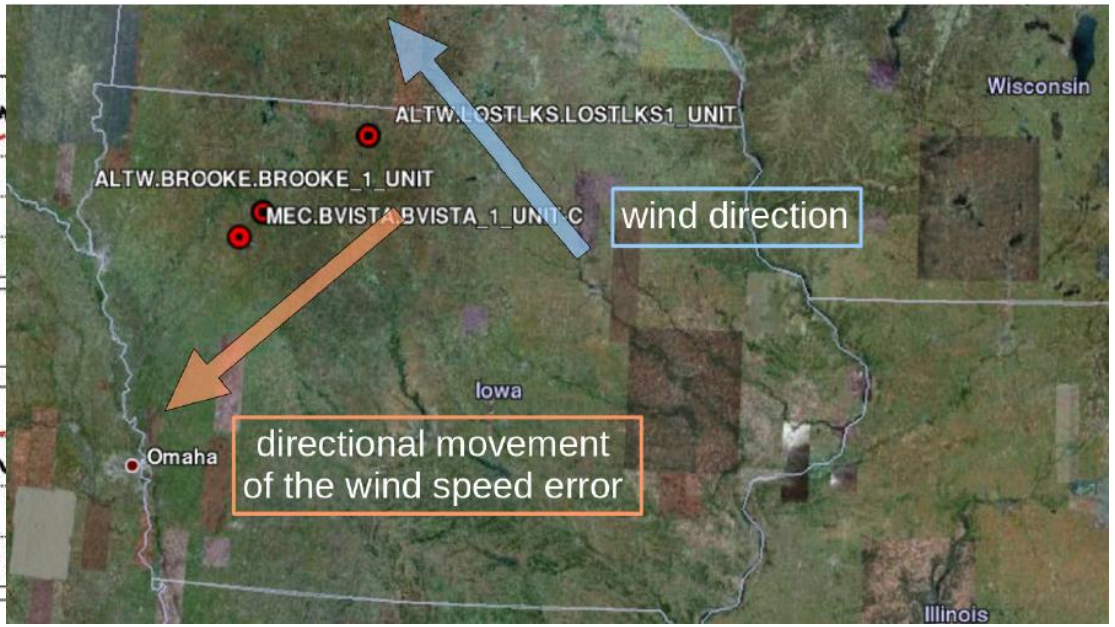
- Make better use of input data
  - Combination of different weather models
  - Ensemble predictions
  - Involvement of weather services
- Cover smaller spatial and temporal scales
  - High spatial resolution, e.g. grid nodes
  - Shortest term prediction (0 – 6 h)
  - Ramp Forecasting
- Integration of predictions into decision making
  - Living with uncertainty
  - Congestion forecasts
  - Maintenance of the grid
  - Storage management
  - Trading of wind power

How does the forecasting error move?









The propagation direction of the wind speed error is different to the wind direction.

It is necessary to observe the overall “energy weather” situation and not just focussing on the upstream direction.

Thanks for your attention !

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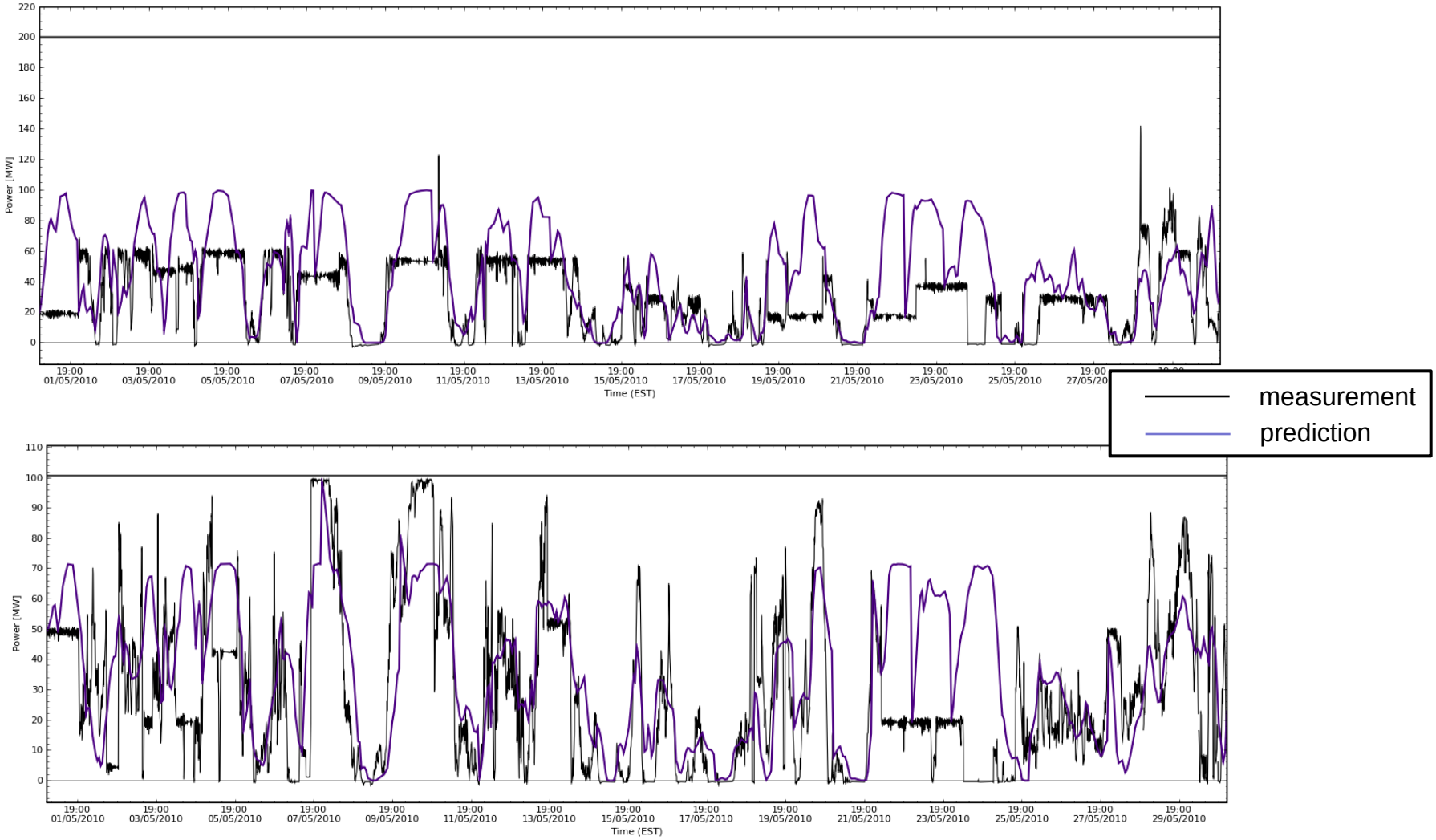
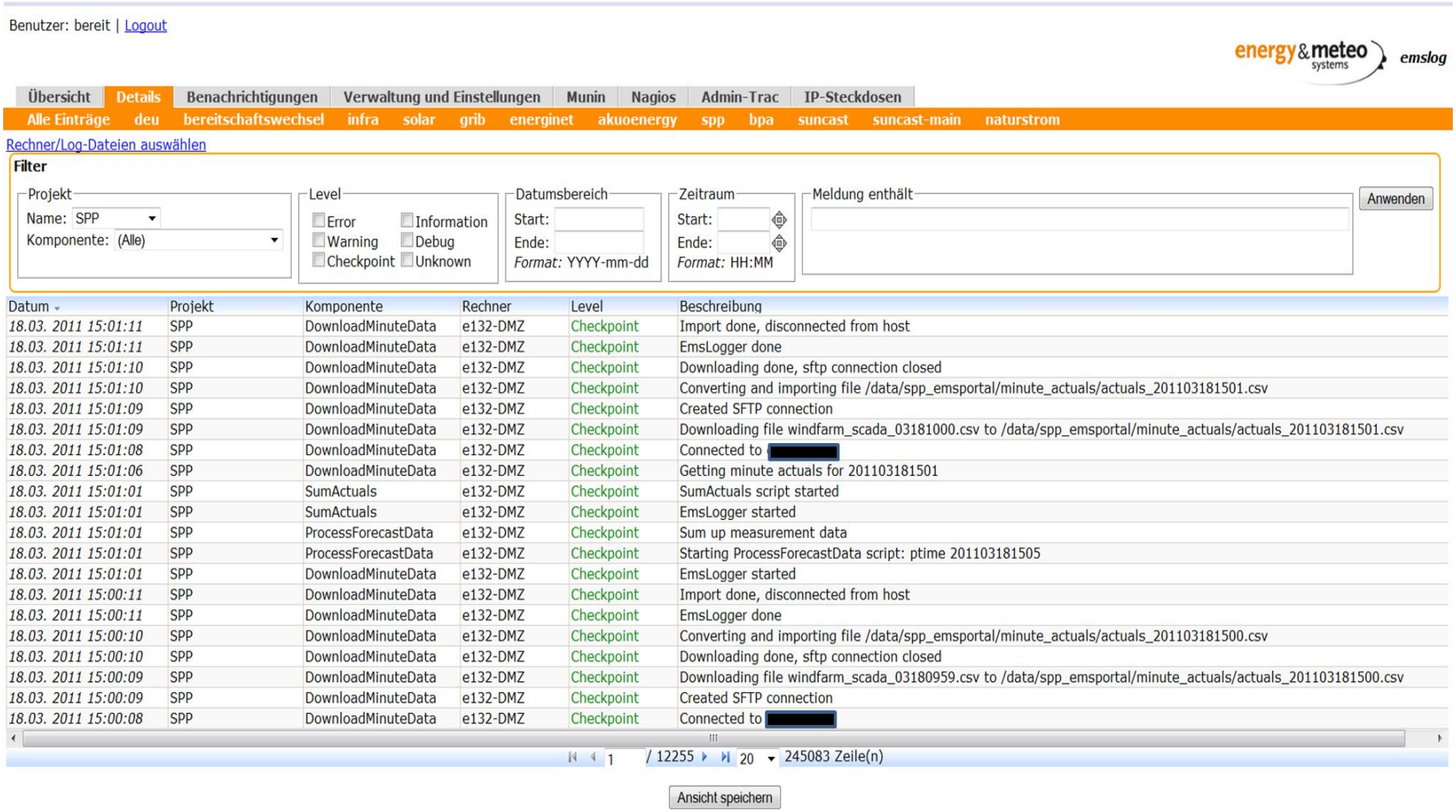
Contact

Dr. Ulrich Focken
energy & meteo systems GmbH
Marie-Curie Straße 1
26129 Oldenburg
Germany
ulrich.focken@energymeteo.com
www.energymeteo.com

Curtailment



Internal logging and alarming



Benutzer: bereit | Logout

energy&meteo systems emslog

Übersicht | Details | Benachrichtigungen | Verwaltung und Einstellungen | Munin | Nagios | Admin-Trac | IP-Steckdosen

Alle Einträge | deu | bereitschaftswechsel | infra | solar | grib | energinet | akuoenergy | spp | bpa | suncast | suncast-main | naturstrom

Rechner/Log-Dateien auswählen

Filter

Projekt: Name: SPP; Komponente: (Alle)

Level: Error, Information, Warning, Debug, Checkpoint, Unknown

Datumsbereich: Start: Ende: *Format:* YYYY-mm-dd

Zeitraum: Start: Ende: *Format:* HH:MM

Meldung enthält

Anwenden

Datum	Projekt	Komponente	Rechner	Level	Beschreibung
18.03. 2011 15:01:11	SPP	DownloadMinuteData	e132-DMZ	Checkpoint	Import done, disconnected from host
18.03. 2011 15:01:11	SPP	DownloadMinuteData	e132-DMZ	Checkpoint	EmsLogger done
18.03. 2011 15:01:10	SPP	DownloadMinuteData	e132-DMZ	Checkpoint	Downloading done, sftp connection closed
18.03. 2011 15:01:10	SPP	DownloadMinuteData	e132-DMZ	Checkpoint	Converting and importing file /data/spp_emsportal/minute_actuals/actuals_201103181501.csv
18.03. 2011 15:01:09	SPP	DownloadMinuteData	e132-DMZ	Checkpoint	Created SFTP connection
18.03. 2011 15:01:09	SPP	DownloadMinuteData	e132-DMZ	Checkpoint	Downloading file windfarm_scada_03181000.csv to /data/spp_emsportal/minute_actuals/actuals_201103181501.csv
18.03. 2011 15:01:08	SPP	DownloadMinuteData	e132-DMZ	Checkpoint	Connected to [redacted]
18.03. 2011 15:01:06	SPP	DownloadMinuteData	e132-DMZ	Checkpoint	Getting minute actuals for 201103181501
18.03. 2011 15:01:01	SPP	SumActuals	e132-DMZ	Checkpoint	SumActuals script started
18.03. 2011 15:01:01	SPP	SumActuals	e132-DMZ	Checkpoint	EmsLogger started
18.03. 2011 15:01:01	SPP	ProcessForecastData	e132-DMZ	Checkpoint	Sum up measurement data
18.03. 2011 15:01:01	SPP	ProcessForecastData	e132-DMZ	Checkpoint	Starting ProcessForecastData script: ptime 201103181505
18.03. 2011 15:01:01	SPP	DownloadMinuteData	e132-DMZ	Checkpoint	EmsLogger started
18.03. 2011 15:00:11	SPP	DownloadMinuteData	e132-DMZ	Checkpoint	Import done, disconnected from host
18.03. 2011 15:00:11	SPP	DownloadMinuteData	e132-DMZ	Checkpoint	EmsLogger done
18.03. 2011 15:00:10	SPP	DownloadMinuteData	e132-DMZ	Checkpoint	Converting and importing file /data/spp_emsportal/minute_actuals/actuals_201103181500.csv
18.03. 2011 15:00:10	SPP	DownloadMinuteData	e132-DMZ	Checkpoint	Downloading done, sftp connection closed
18.03. 2011 15:00:09	SPP	DownloadMinuteData	e132-DMZ	Checkpoint	Downloading file windfarm_scada_03180959.csv to /data/spp_emsportal/minute_actuals/actuals_201103181500.csv
18.03. 2011 15:00:09	SPP	DownloadMinuteData	e132-DMZ	Checkpoint	Created SFTP connection
18.03. 2011 15:00:08	SPP	DownloadMinuteData	e132-DMZ	Checkpoint	Connected to [redacted]

1 / 12255 20 245083 Zeile(n)

Ansicht speichern

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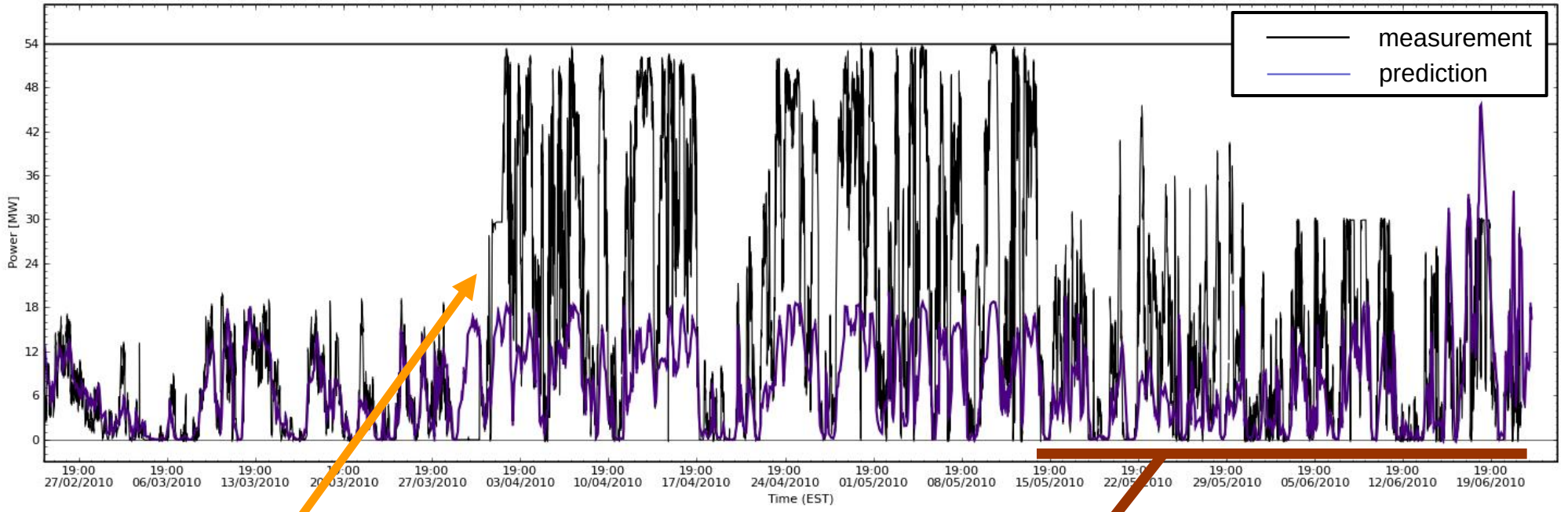
Pooling of Wind Farms



two wind farms were pooled

In this time span no information why power output is on such a low level

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How accurate are wind power predictions ?

- Different metrics
  - Mean absolute error (MAE)
  - Root mean square error (RMSE)
  - Correlation between
  - Skill scores
  - Contingency tables
  - CSI (ramps)
- Different normalizations
  - Installed power
  - Average output
  - Actual forecast value
- Visusal / subjective
  - Scatter plots
  - Time series plots (ramps)

There is not THE ONE metric.
Each metric can tell a different story about the forecasting error.

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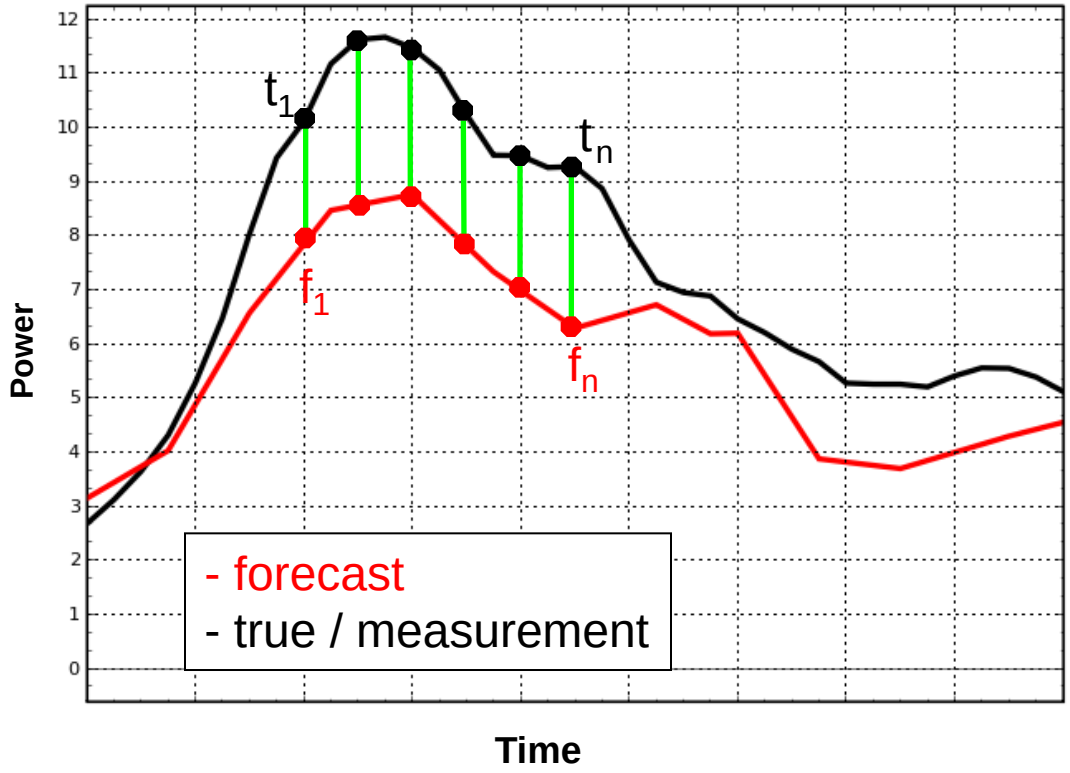
Error Measures

$$MAE = \frac{1}{n} \sum \left| forecast_i - true_i \right|$$

$$RMSE = \sqrt{\frac{1}{n} \sum forecast_i - true_i}$$

$$BIAS = \frac{1}{n} \sum forecast_i - true_i$$



Cut-Offs due to High Wind Speeds