Technical University of Denmark

Using forecast information for storm ride-through control

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Publication date:
2013

Using forecast information for storm ride-through control

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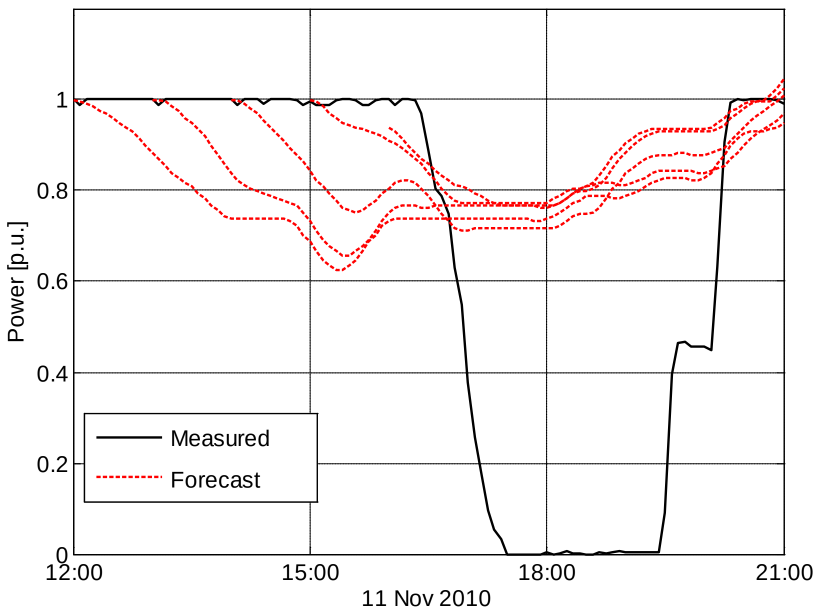
Outline

- Motivation
- The Radar@Sea experiment
- Control and forecast during storms
  - Probabilistic supervisor control
  - Statistical forecast
- Simulation results
  - Rule-based probabilistic supervisor
- Perspective and summary

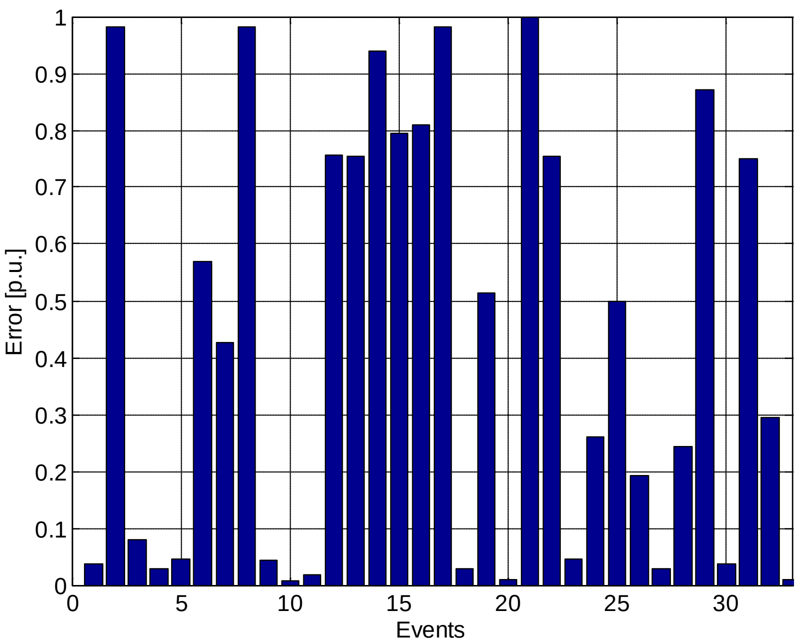
Motivation

Periods of extreme winds are difficult to accurately forecast

Measured and forecasted wind power



Maximum absolute wind power error in predicted events of Extreme Wind Periods

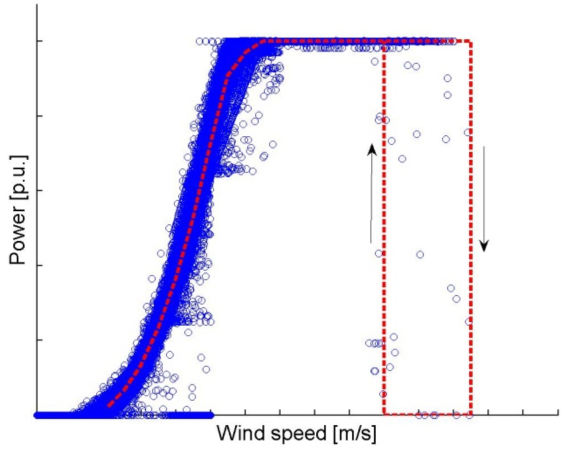


N. A. Cutululis, N. K. Detlefsen, and P. E. Sørensen, "Offshore Wind Power Prediction in Critical Weather Conditions," in *10th International Workshop on Large-Scale Integration of Wind Power into Power Systems as well as on Transmission Networks for Offshore Wind Farms*, 2011.

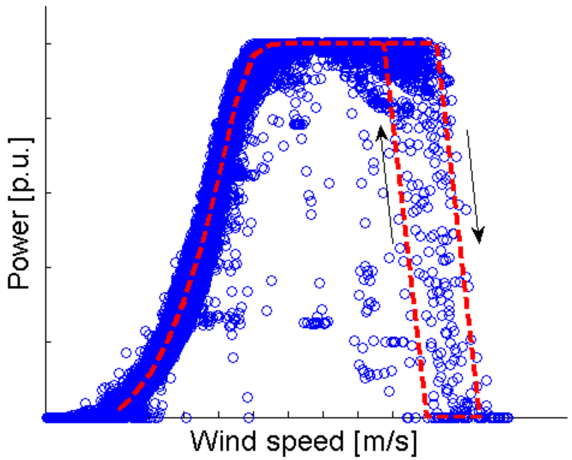
Motivation

Wind turbine and wind farm response during storms

Typical wind turbine power curve



Horns Rev 1 wind farm power curve



- Wind turbine will shut-down to avoid extreme mechanical loads

- The shut-down is triggered by
  a. Strong wind gusts
  b. High mean wind speed
  c. High turbulence

- The aggregated response of the wind farm shows smoothning effects
  a. Smaller shut-down wind speed
  b. Slope of power, as not all wind turbines shut-down at the same time

Radar@Sea experiment

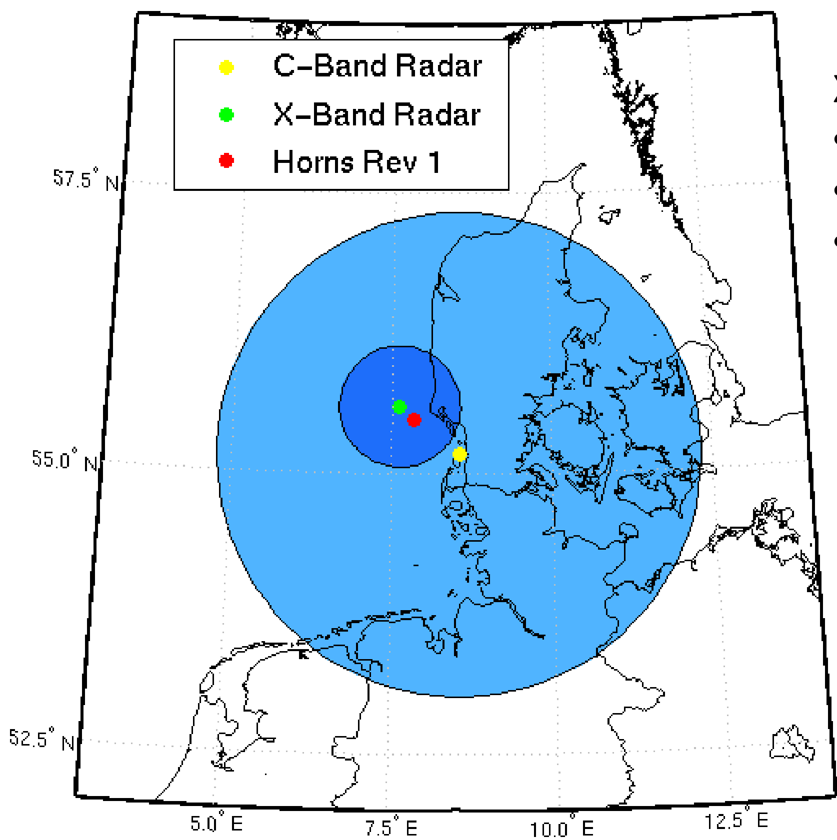
Overview

- Goals:
  1. Improve predictability of offshore wind power fluctuations and wind farm controllability

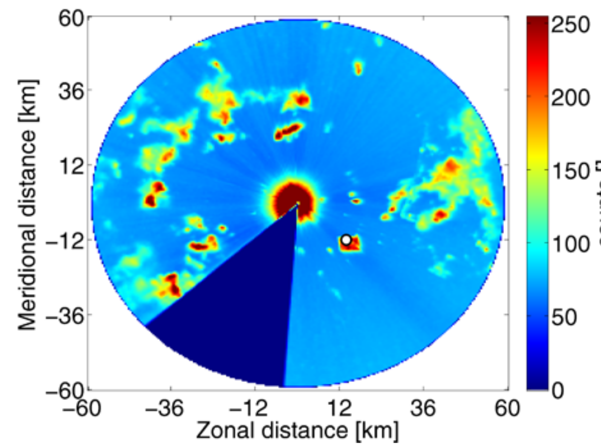
  2. Increased use of meteorological information → weather radars!

Radar@Sea experiment

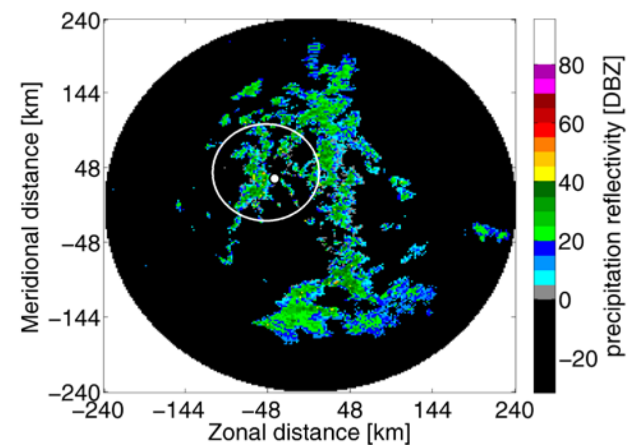
The 2 weather radars



X-Band:
- Range: 60km
- Pixel size: 500m
- Im. Freq: 1min



C-Band (Doppler):
- Range: 240km
- Pixel size: 2km
- Im. Freq: 10min

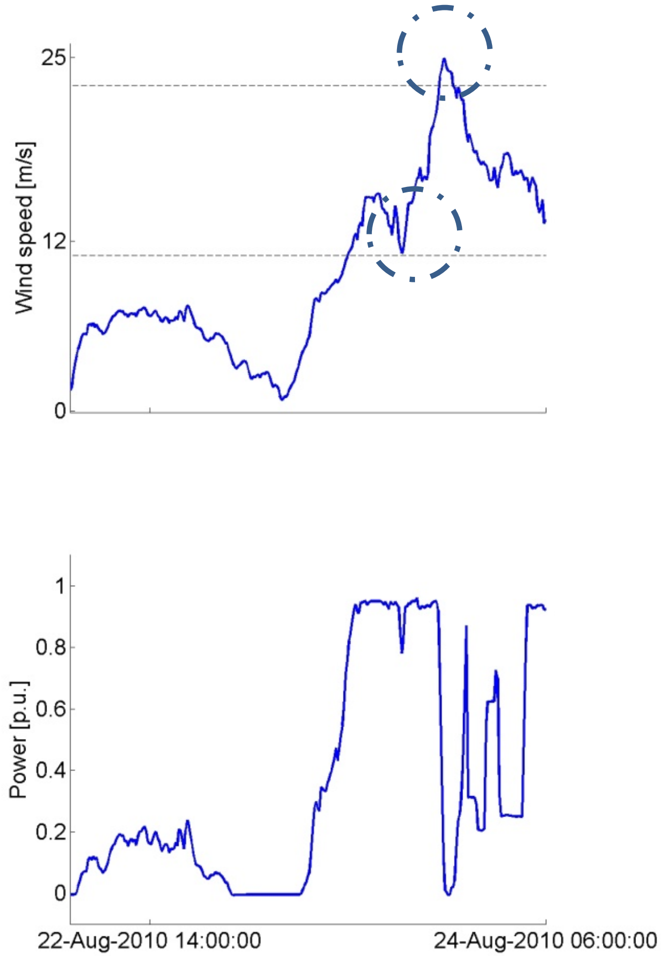


Weather radars measure reflectivity of rain drops and therefore they indicate precipitation

* Thanks to DMI and DHI for the Radar *

Control and forecast during storms

The use of forecast information can improve wind power controllability



- **Focus** on critical offshore weather conditions where
  1. **Extreme winds** and/or
  2. **High variability**

  cause sudden and large power loss

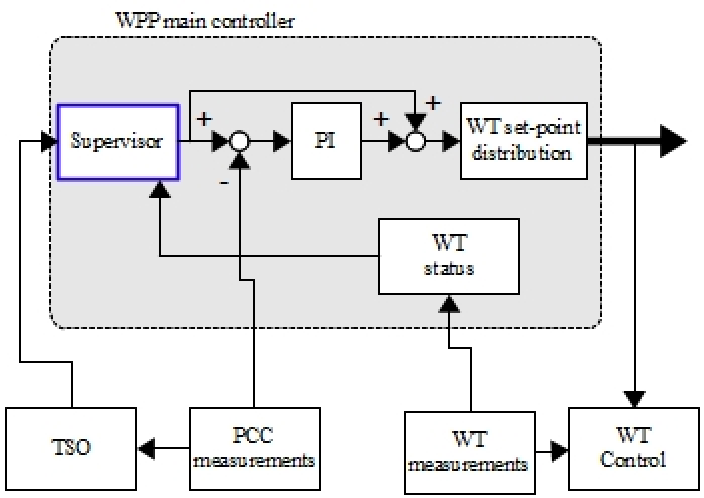
- Forecast target
  a. Resolution of 10-min
  b. Lead time up to 2-hrs

- **Control objective**
  a. To **ride-through** a storm with **softer ramp-down/up rates**
  b. Allow to a timely allocation of power reserves

Control

Supervisor control-modes using forecast information

Wind farm main controller



- Supervisor
  a. Dispatches set-points to wind turbines
  b. Specific control-modes for power regulation (delta, ramp limit, constant power)

Control-modes with probabilistic forecasts

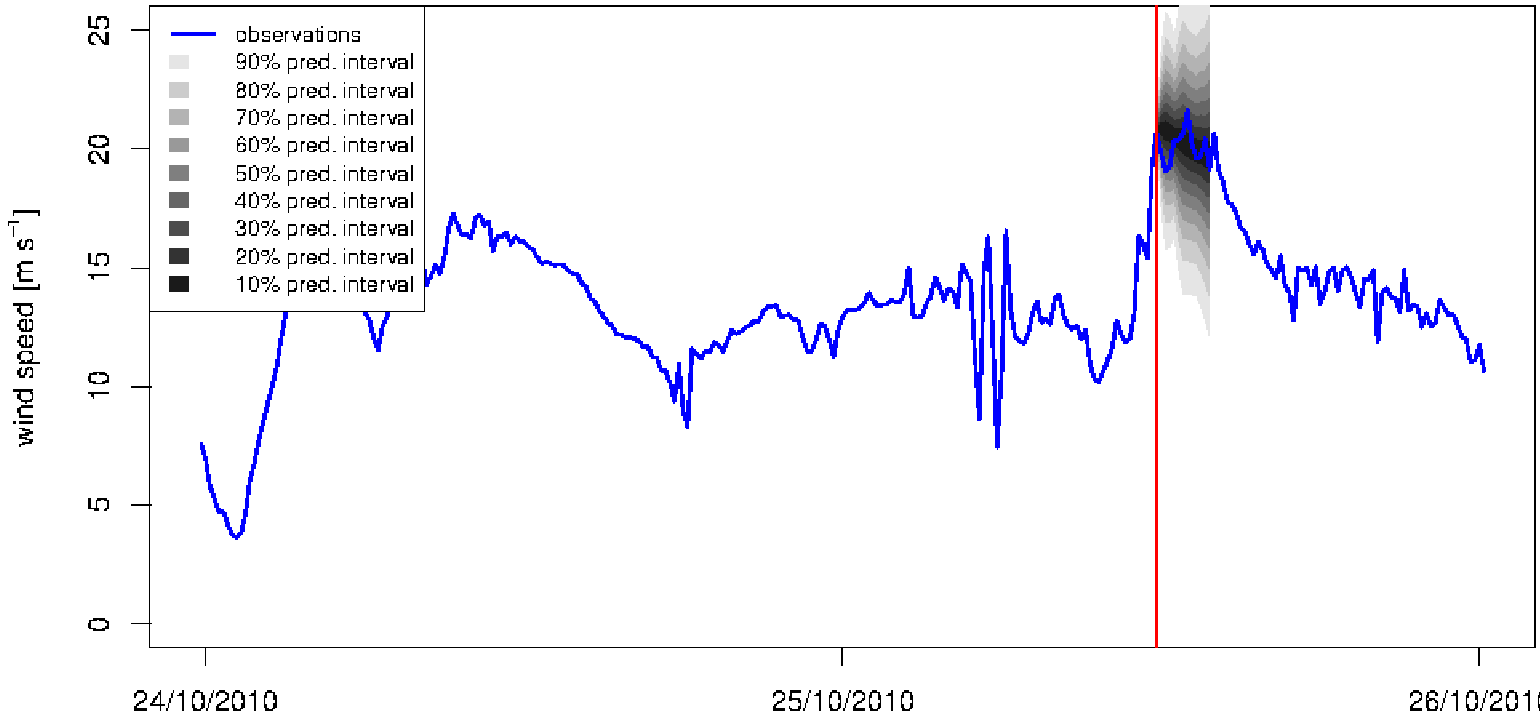
- Goal: to improve the controllability of wind power

- Types developed in this project:
  i. Rule-based
  - Aimed at **extreme wind conditions**
  - Uses **point forecast** and **predictive densities**
  - Lead time up to 2-hr

  ii. Regime-based
  - Aimed to reduce power fluctuations
  - Uses regime probabilities
  - Lead time 10-min only

Forecast

Statistical method applied to develop storm control



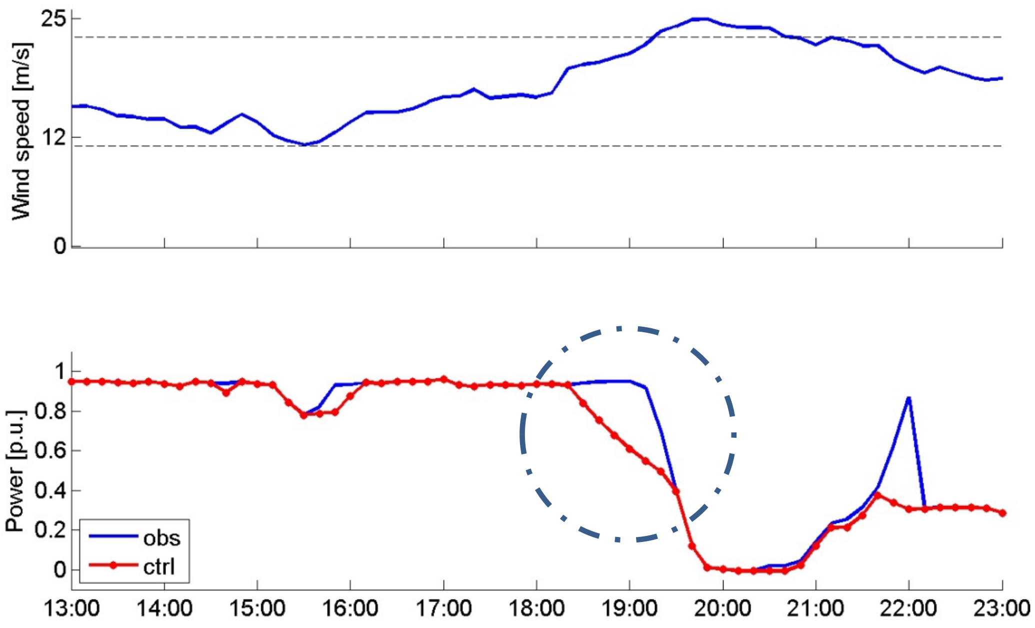
- Time series of wind speed (10-min resolution)

- Forecast method accounts for changes in variability of wind
  - Auto-Regressive with time-varying variance (AR-GARCH)
  - Point forecasts and predictive densities
  - Lead times: from 10-min up to 2-hr ahead

Simulation results

Probabilistic supervisor with input from probabilistic forecast

Episode of extreme wind during a summer day



- Wind farm shut-down due to extremely high wind

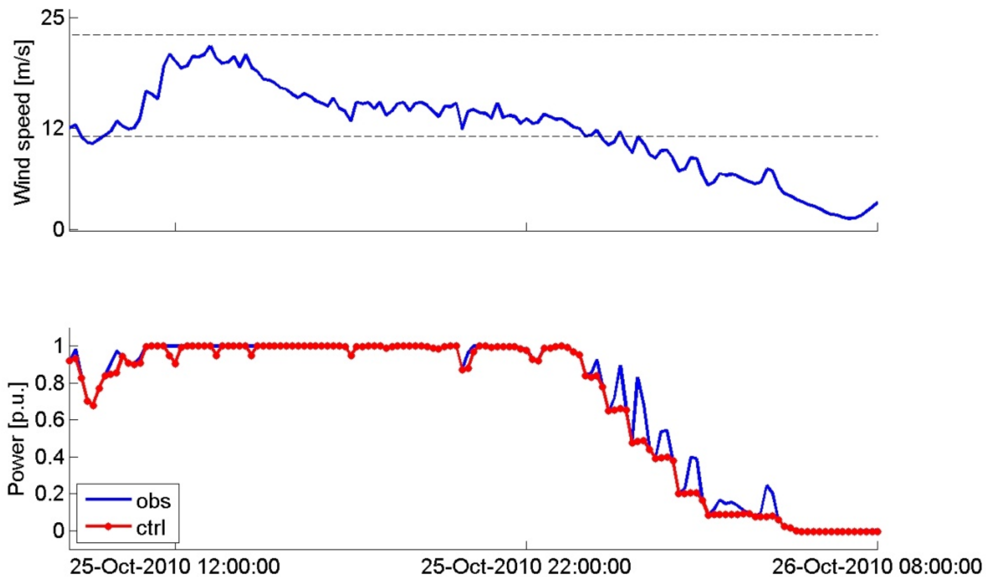
- Control settings:
  1. High wind: wind speed > 11 m/s
  2. Use forecast over 2-hr lead time to
     a. Ramp-down when
        - 95% Pred. Interval > 23 m/s
        - Point forecast < 12 m/s
     b. else Ramp-up

Control starts ramp-down about 50-min before achieving a softer cut-off

Simulation results

Probabilistic supervisor with input from probabilistic forecast

Episode of extreme wind variability and high winds during the autumn



- High wind variability around rated operation
- High wind speeds but not shut-down
- Control settings:
  1. High wind: wind speed > 11 m/s
  2. Use forecast 10-min lead time to
     a. Ramp-down when
        - 95% Pred. Interval > 23 m/s
        - Point forecast < 12 m/s

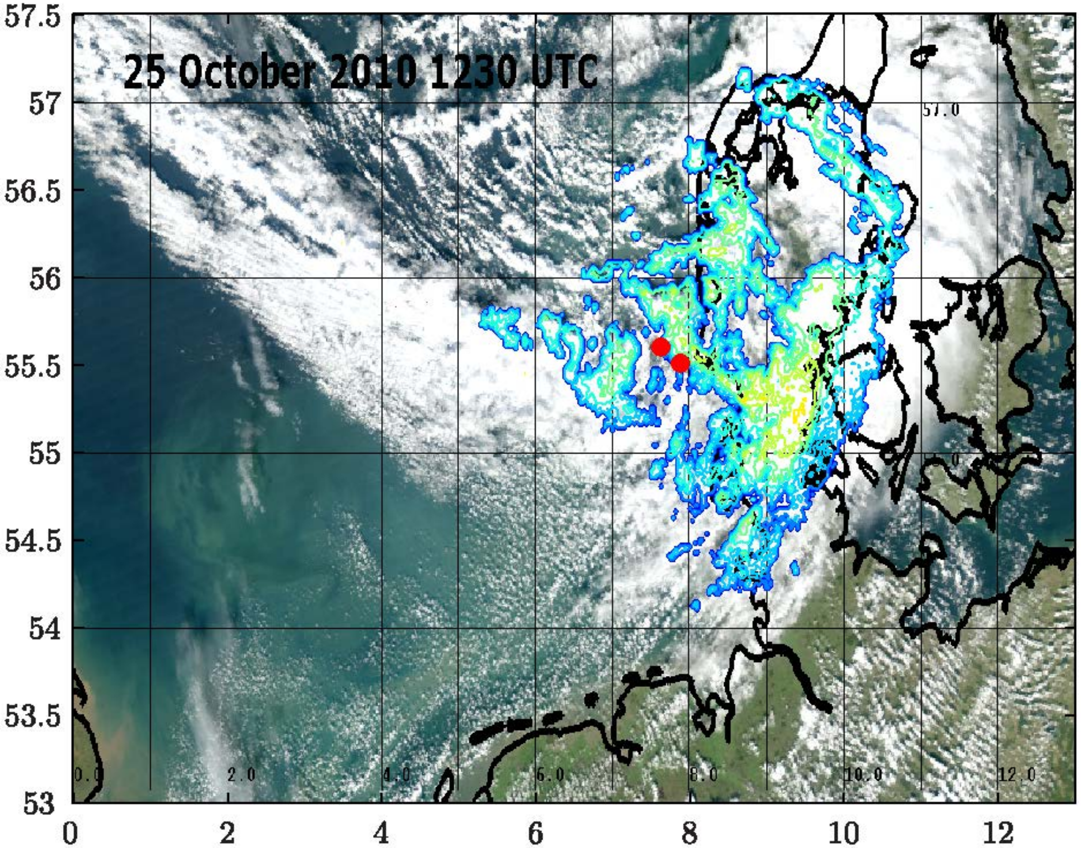
     b. else Ramp-up

Softer ramp-up during high variability episodes

Perspective

Storm passage as observed by radar and satellite

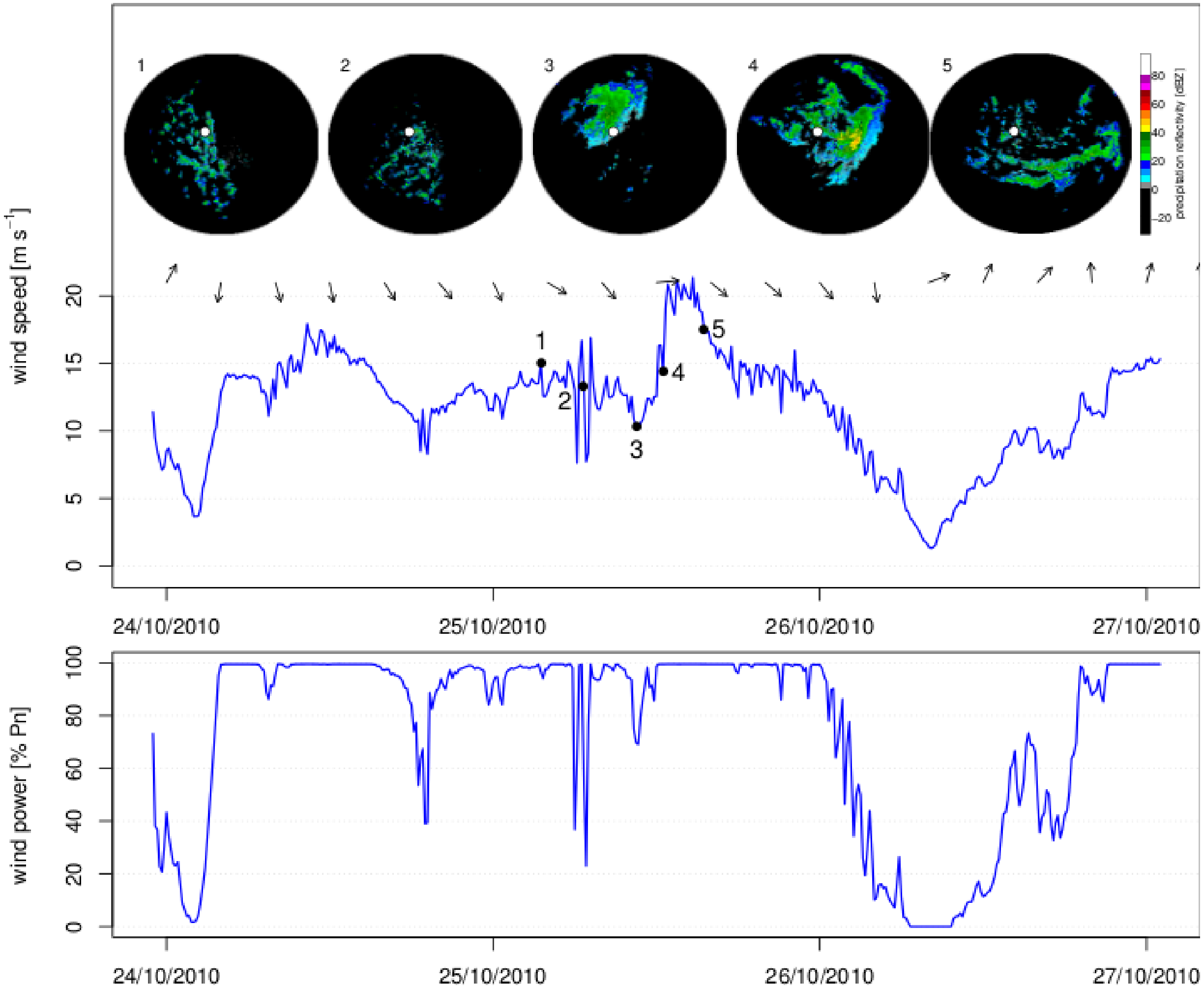
Episode of extreme wind variability and high winds during the autumn



- The approach of weather fronts can be observed in real-time
- Image from AQUA satellite shows
  a. low pressure
  b. open cellular convection
- Reflectivity contours from radar
  a. Satellite image is mirrored by precipitation observed by radar

Perspective

Storm passage as observed by a weather radar and onsite wind farm measurements



- Very different variability levels
- The radar observes
  a. Small and scattered precipitation cells (1-2)
  b. Embedded low-pressure front that produces precipitation (3-5)
- Wind speed peaks up with the arrival of the front
- Wind decreases after the passage hits the leading edge

Video link

P.-J. Trombe, P. Pinson, T. Bøvith, N. A. Cutululis, C. Draxl, G. Giebel, A. Hahmann, N. E. Jensen, B. P. Jensen, N. F. Le, H. Madsen, L. B. Pedersen, A. Sommer, and C. Vincent, "Weather radars - The new eyes for offshore wind farms?," *under review*, 2012.

Summary

- Control using forecast information
    1. There is potential in the use of probabilistic forecasts to improve wind power controllability
    2. Examples of a rule-based supervisor control-mode showed that
        a. Softer wind farm cut-off can be achieved during extreme winds with the use of probabilistic forecast with up to 2-hr lead time
        b. Probabilistic forecast with short lead time can be used to achieve softer ramp-up when wind variability is very high

- The Radar@Sea experiment
    1. Has provided data, experience and methods for the use of radars for wind power applications
    2. Controls at wind farm level that use forecast have been developed showing there is potential for their application