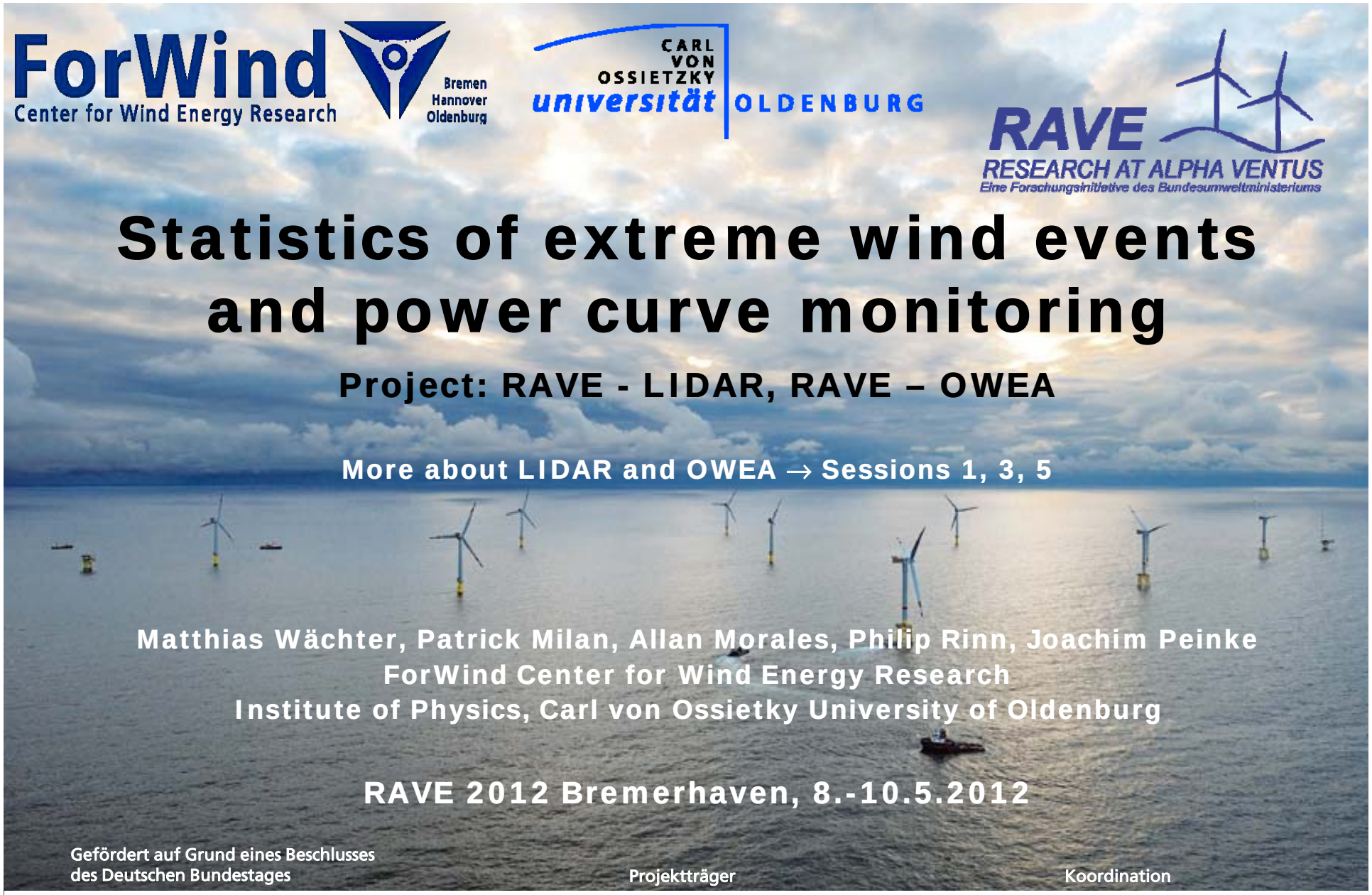

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RAVE RESEARCH AT ALPHA VENTUS
Eine Forschungsinitiative des Bundesumweltministeriums

Statistics of extreme wind events and power curve monitoring

Project: RAVE - LIDAR, RAVE – OWEA

More about LIDAR and OWEA → Sessions 1, 3, 5

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Projektträger

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ptj Projektträger Jülich Forschungszentrum Jülich

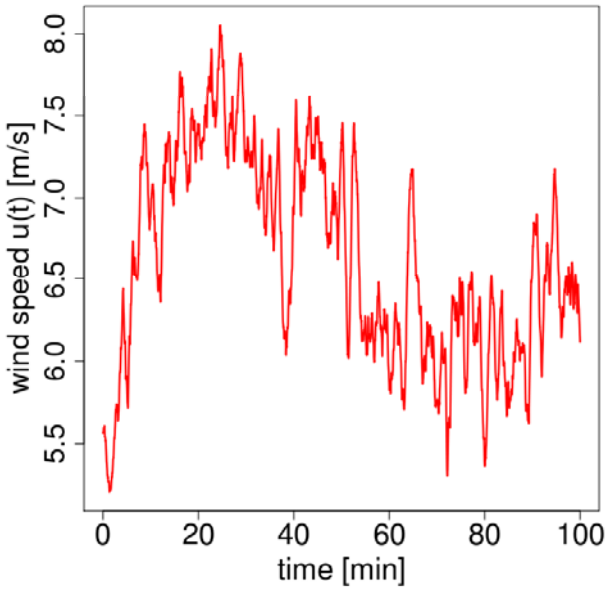
Koordination

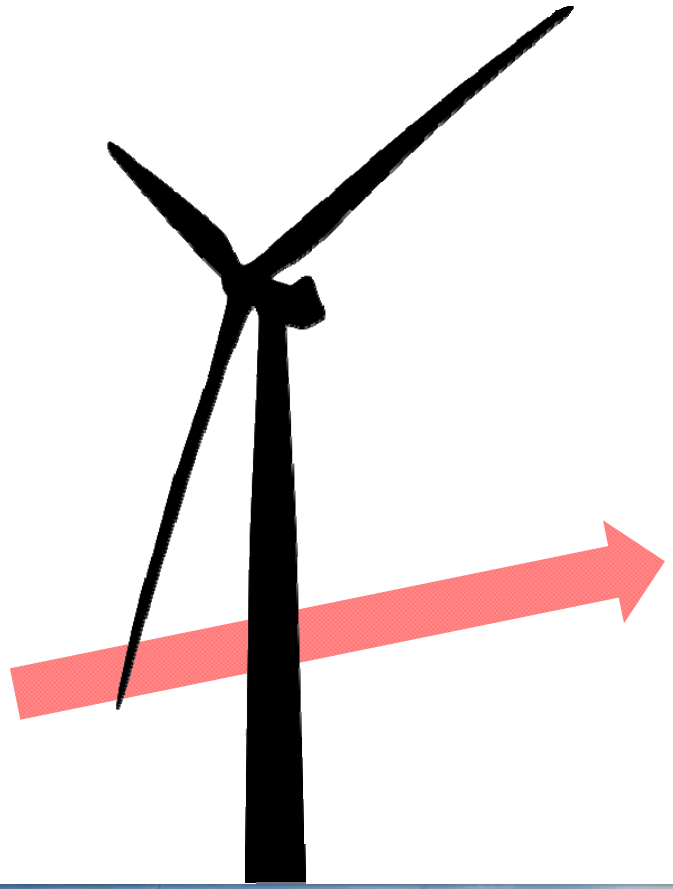
Fraunhofer IWES

Challenge of wind power conversion

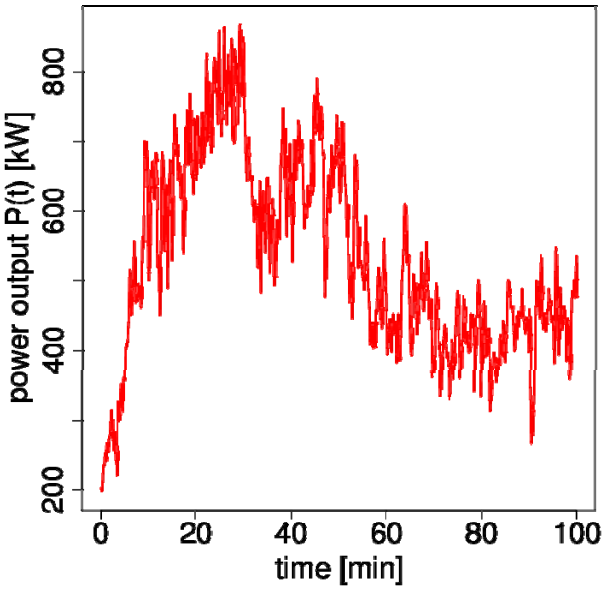
Conversion
Complex, nonlinear interaction

Input
Turbulent wind:
Intermittent,
extreme events



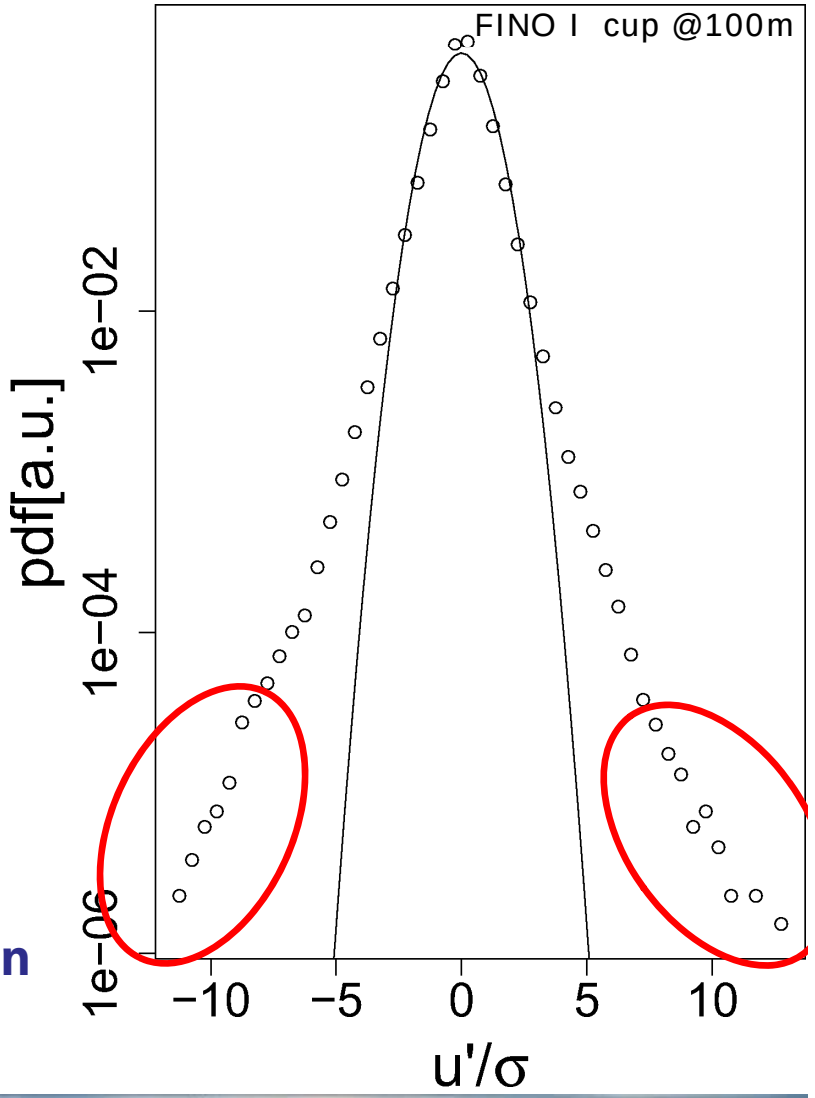


Output
»Turbulent« power



Statistics of extreme wind events

- Atmospheric turbulence: complex statistics
- PDFs of fluctuations $u' = u(t) - \bar{u}$ strongly intermittent
- Very high Probabilities of extreme events
- Relevant for
  - Load changes
  - Power fluctuations

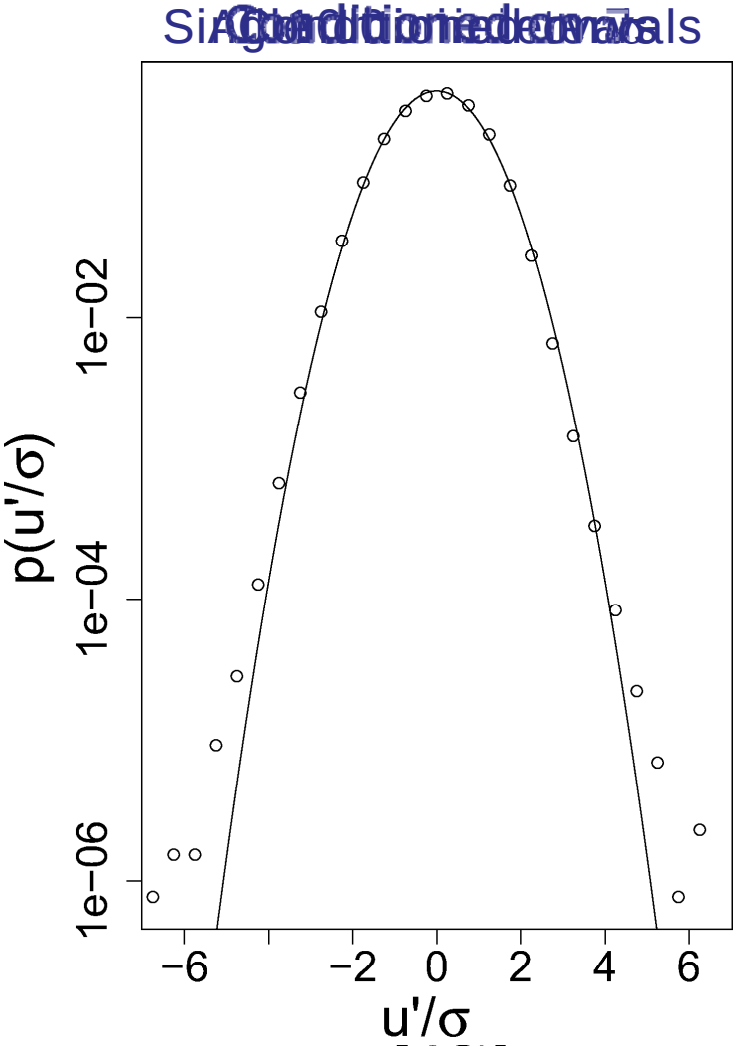


Understanding of intermittency is relevant for wind energy utilization

Origin of intermittency

- Single 10min intervals: approx. Gaussian
- All intervals: intermittent
- Conditioning on $\bar{u}$: little effect
- Conditioning on σ: close to Gauss

Intermittency in p(u′) is caused by varying $\sigma_{u'}$

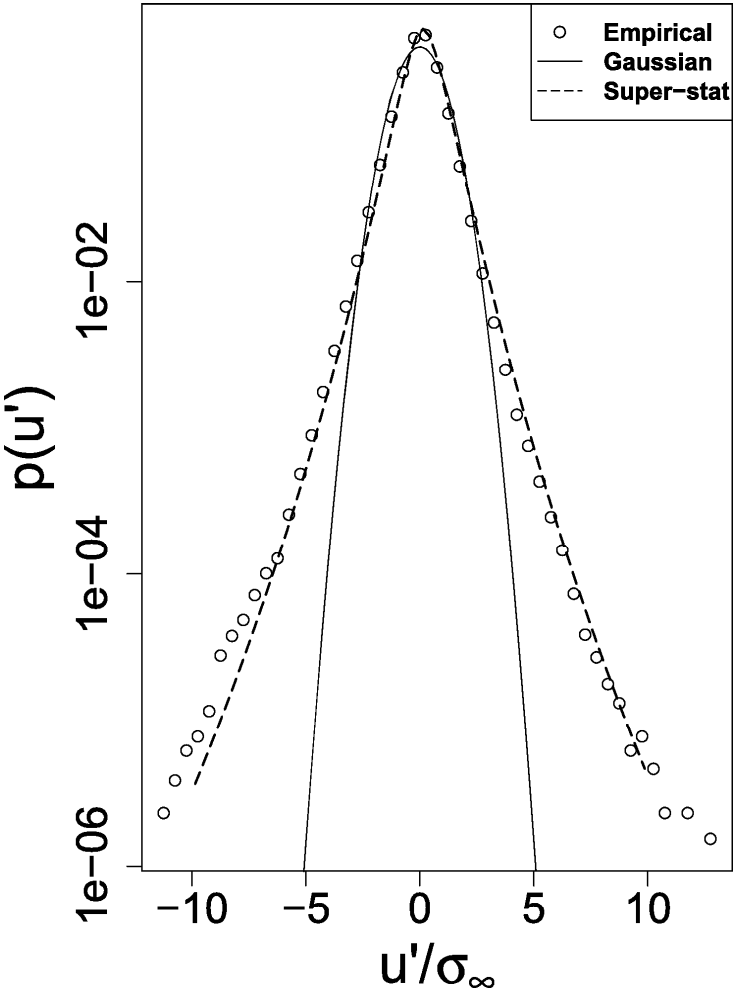


Model for fluctuation statistics

Compose p(u') in 3 steps:

1. Gaussian PDF for fixed σ
2. Log-normal PDF of σ
3. Integrate over σ

$$p(u') = \frac{1}{2\pi\alpha} \int \exp\left[-\frac{u'^2}{2\sigma^2}\right] \exp\left[-\frac{\log(\sigma/\sigma_0)^2}{2\alpha^2}\right] \frac{d\sigma}{\sigma^2}$$



[Morales, Wind Energy (2011)]

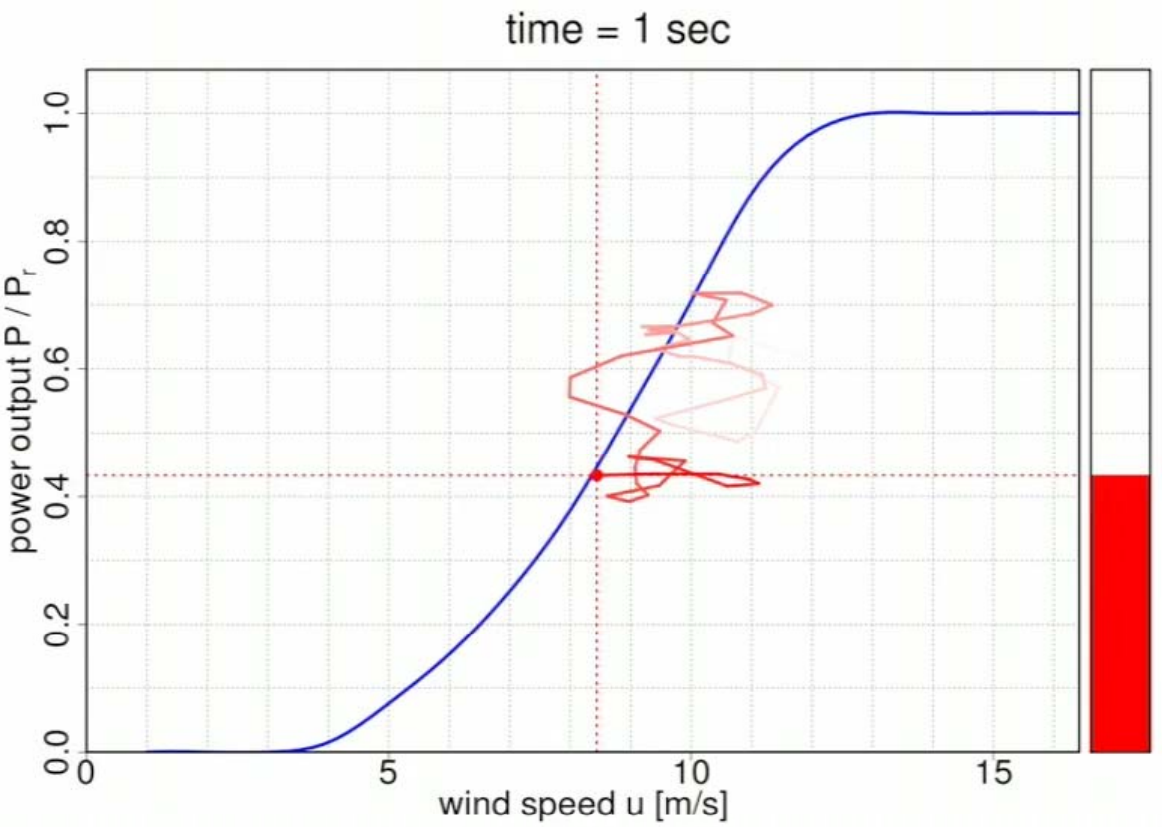
Remarks

- It's a model – not a fit
- Access to high-frequency u' statistics from 10min measurements
- Possible dependency on ū (straightforward)

Wind energy conversion dynamics

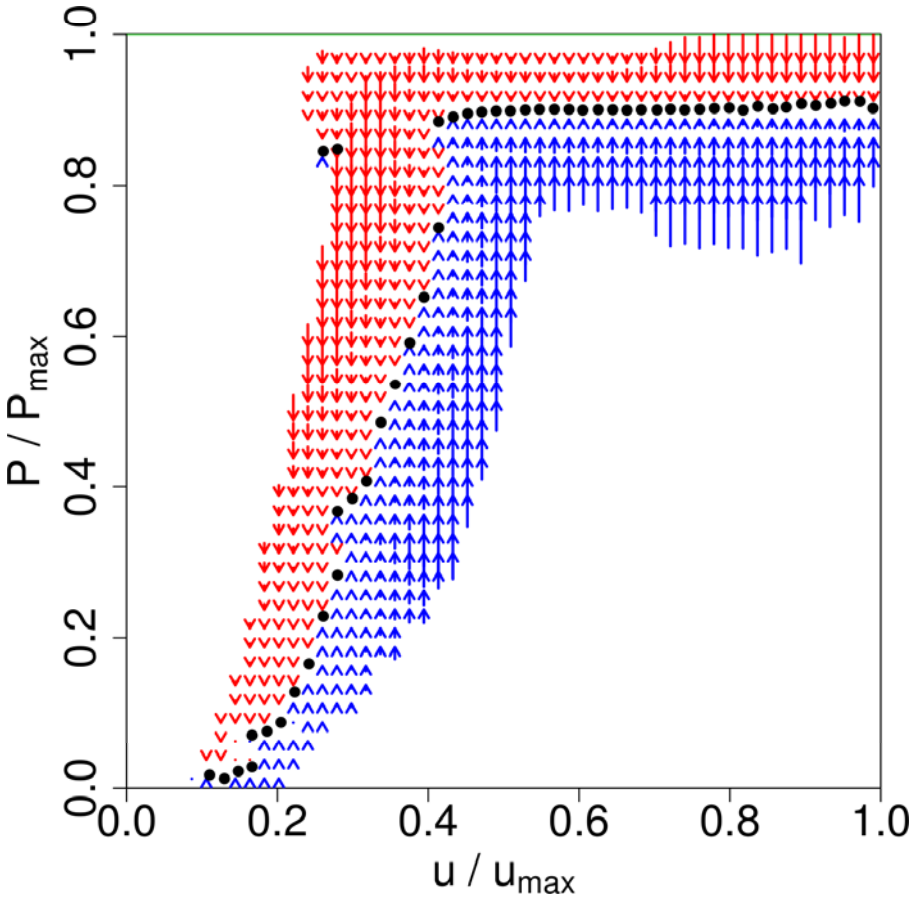
- Highly dynamical process on short time scales
- Driven by turbulent wind

- How to obtain the response dynamics of WEC?
- Possible from wind and power data ~1Hz



Langevin power curve

- Drift function reflects average slope of power signal
- Drift field shows deterministic dynamics of energy conversion
- Stable fixed points constitute Langevin Power Curve



AV 4: REpower 5M

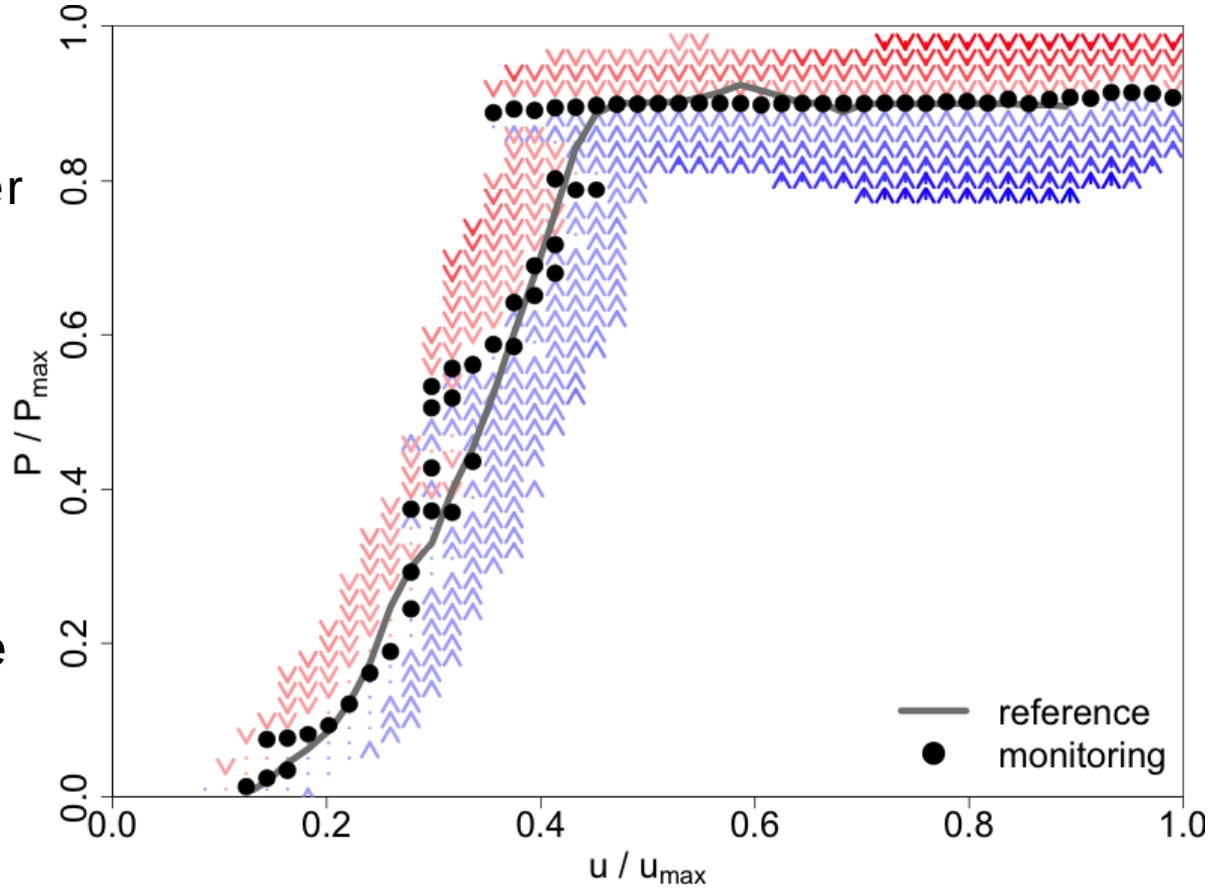
Important properties

- Shows short-time dynamics (~1s)
- Quick detection of changes
- Multiple fixed points possible
- State-based vs. global averaging (as of IEC 61400-12)

Langevin power curve monitoring

- Daily LPC over 10 days, February 2011
- Wind: nacelle anemometer
- Artifact caused by wind measurement

- »Unfortunately« no turbine anomalies here

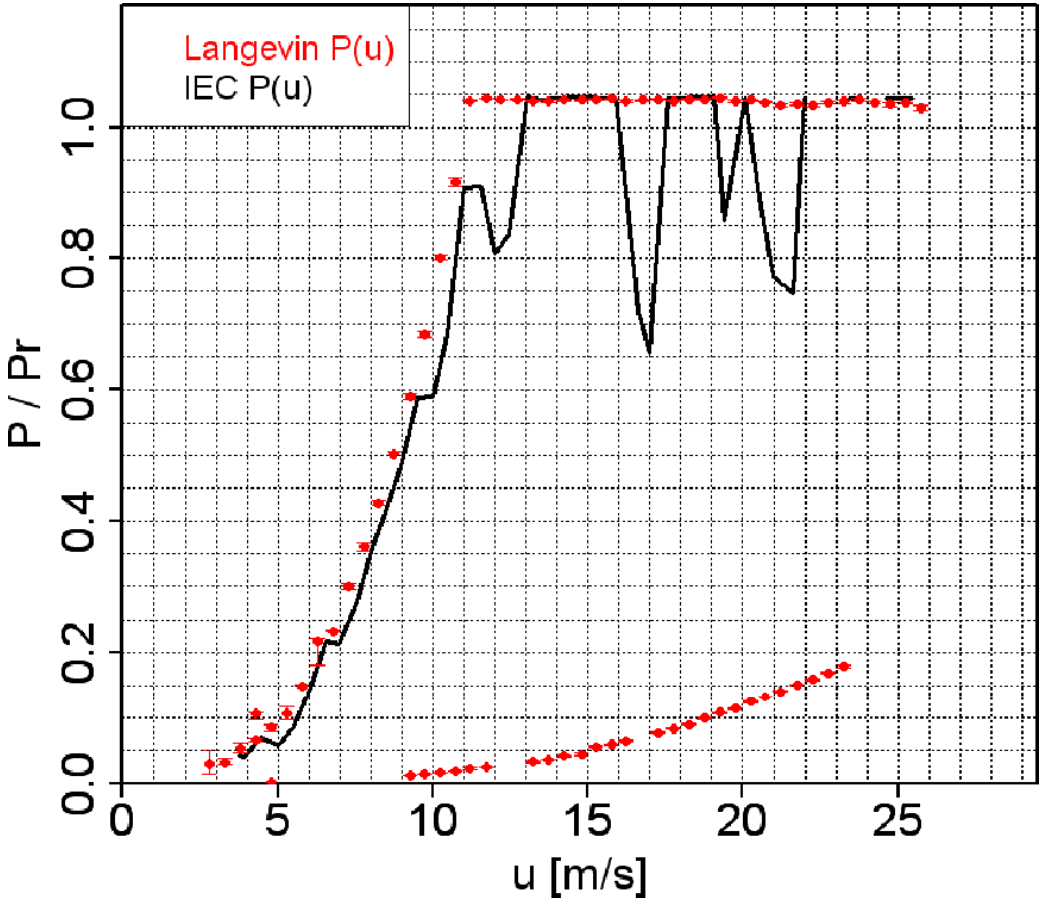


AV 4: REpower 5M

Changes in dynamical behavior are detected

Langevin power curve monitoring

- Example showing anomaly
- FAST simulation of WindPact 1.5 turbine
- Artificial pitch failure: one blade fixed to 45°
- LPC after 1000min of failure

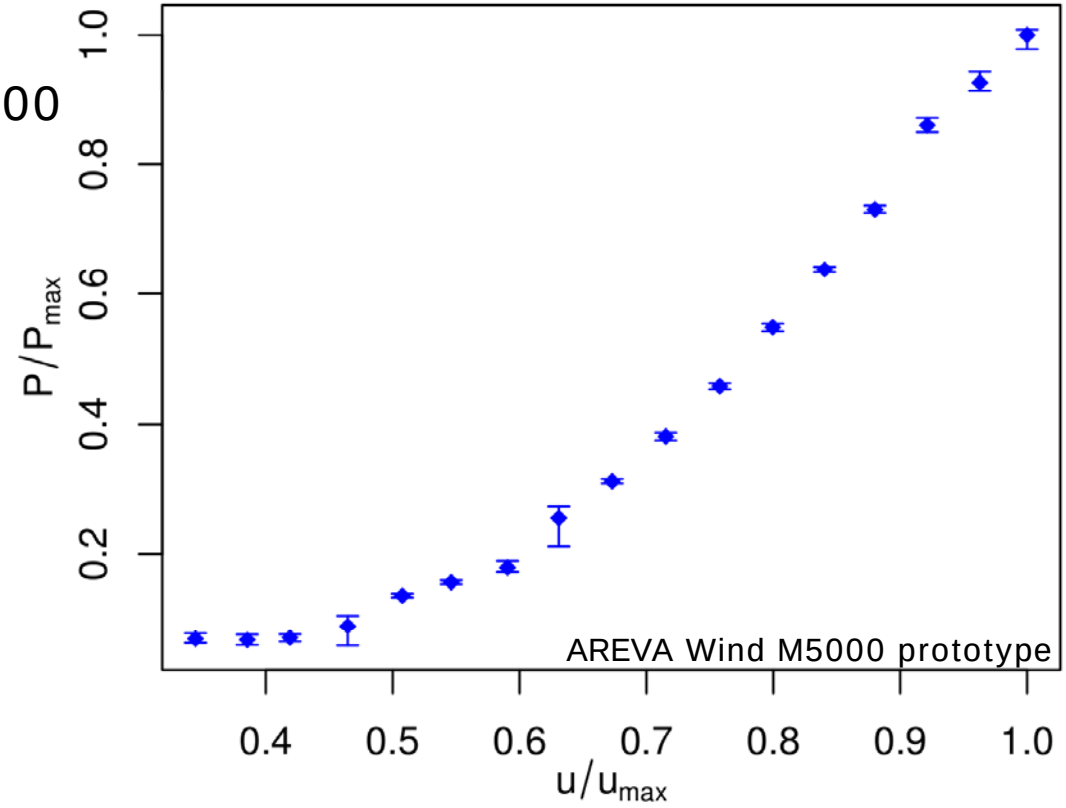


(Significant) Pitch failure clearly detected

[Muecke, PhD Thesis, to be published]

Nacelle lidar-based Langevin power curve

- Lidar scanner developed by SWE, U Stuttgart
- Deployed at AREVA Wind M5000 prototype, BHV
- 1 day measurement



Large potential of nacelle lidar-based power curve measurements

Conclusions

- Model for atmospheric fluctuation PDFs p(u')
  - High-frequency statistics from 10min data
  - Especially statistics of extreme events are well reproduced

- Langevin power curve suitable for monitoring of power performance
  - Quick and clear detection of anomalies
  - Large potential for nacelle-based lidar wind measurements

Thank you for your attention!

Thanks to: SWE U Stuttgart, AREVA Wind GmbH, REpower Systems SE, and the RAVE initiative