



PARETO DISTRIBUTION FOR EXTREME LOADS ON WIND TURBINES

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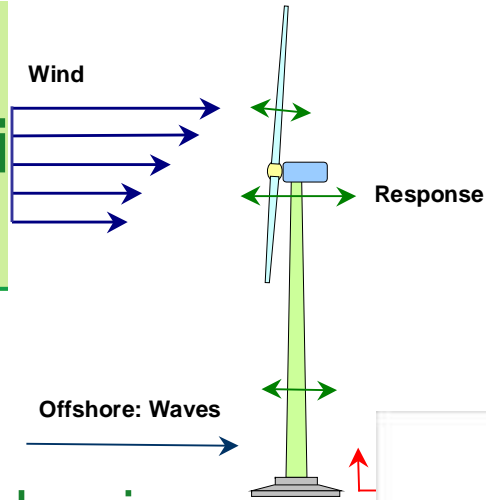


Overview



- Windrad Engineering GmbH
- Why Extreme Value Theory ?
- Theoretical background
- Application in load calculations
- Example: 50-years tower loads
- Summary and perspectives

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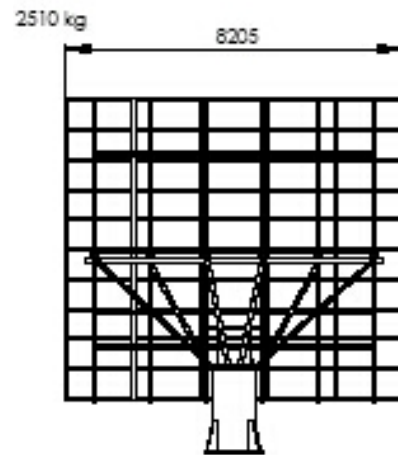
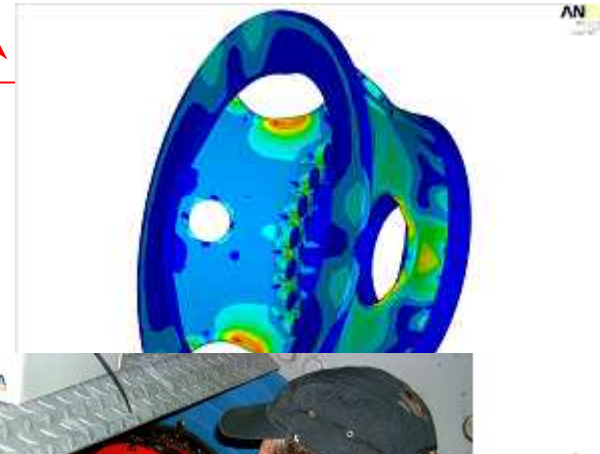


Simulation

Structural mechanics

Measurement

Special machines

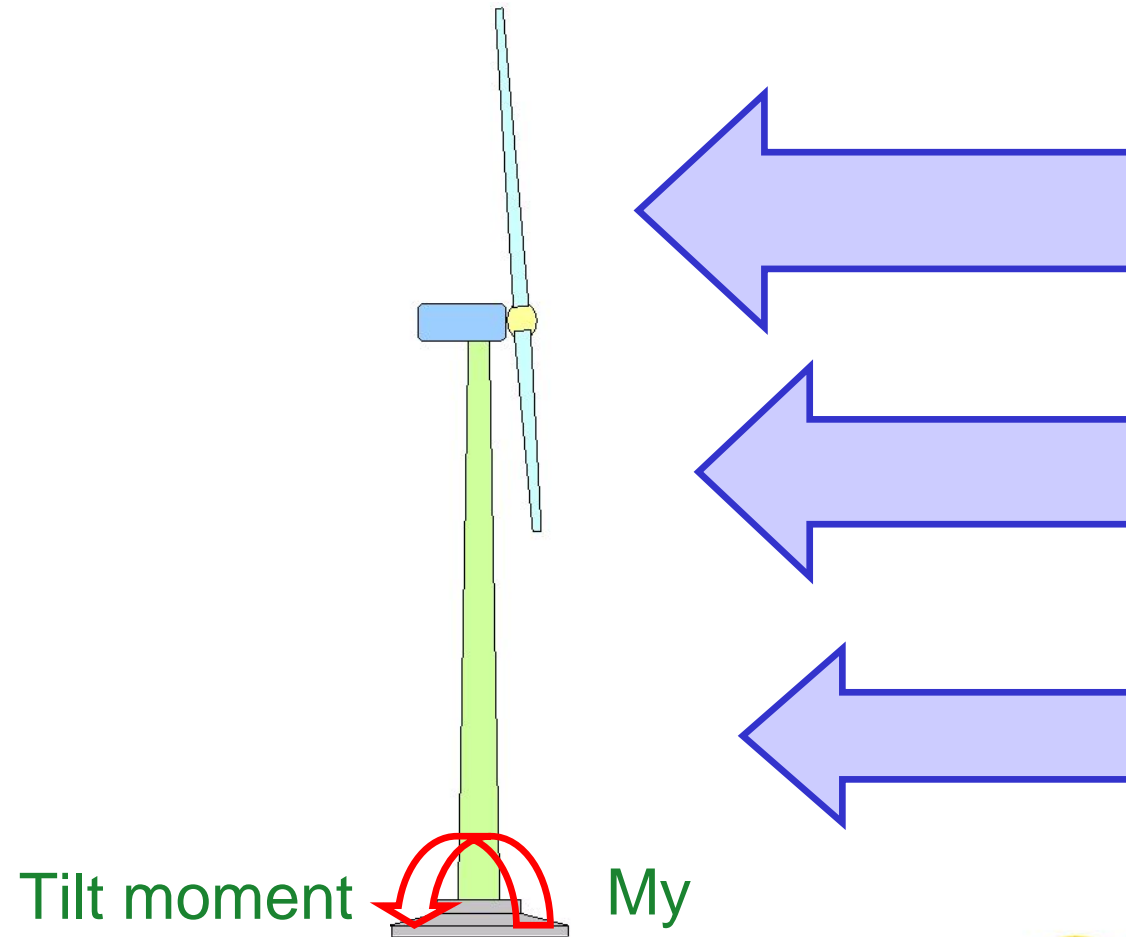


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Why Extreme Value Theory



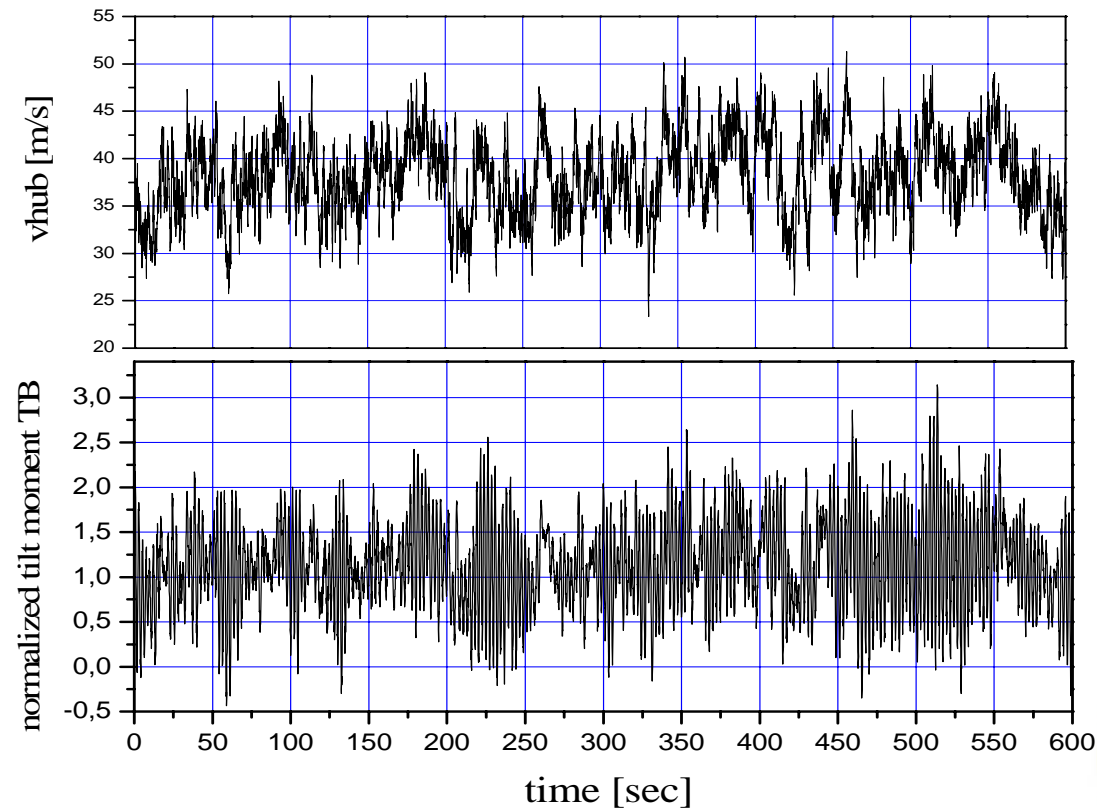
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Why Extreme Value Theory



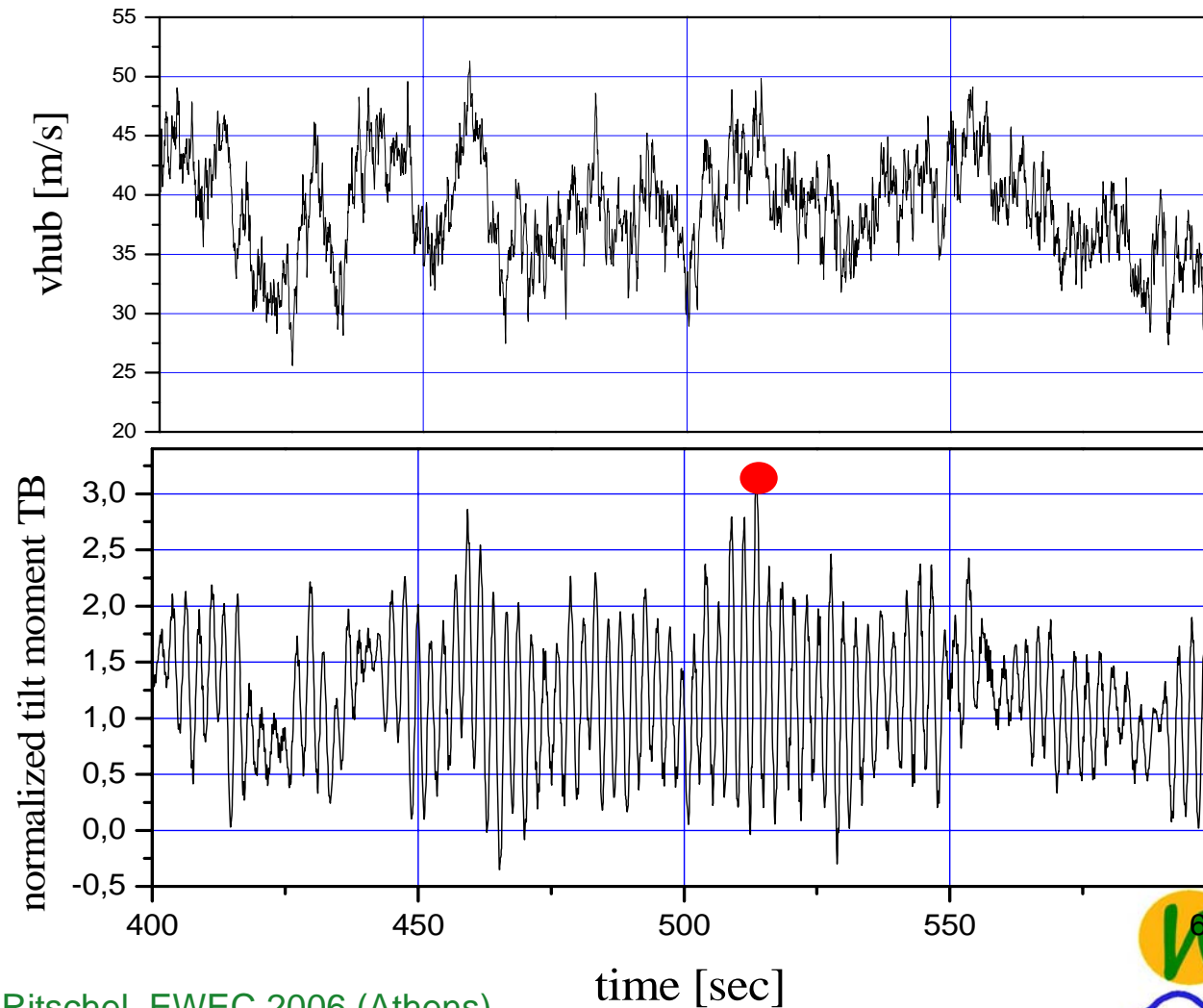
Simulated times series for tilt moment (normalized)

Wind turbine: 750 kW, 75 m hub height, 46 m rotor diameter



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Why Extreme Value Theory

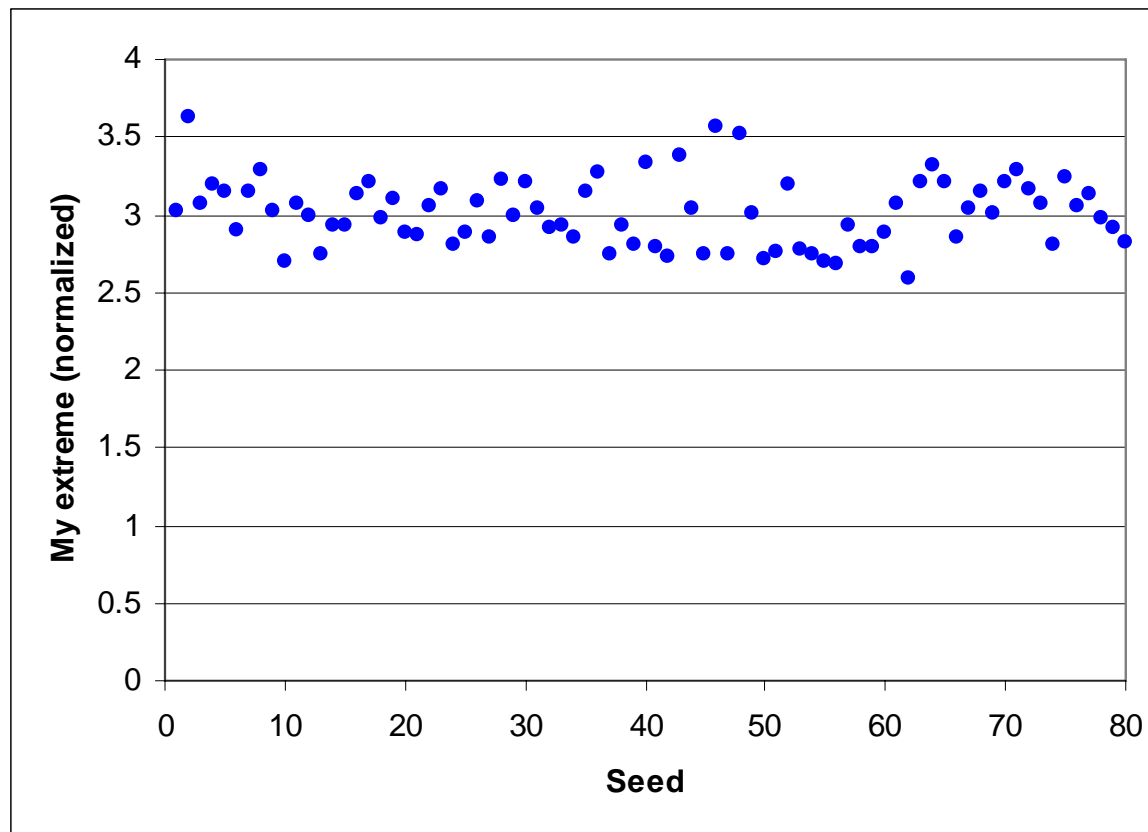


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Why Extreme Value Theory



Extreme values from 80 time series (10 minutes)



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Why Extreme Value Theory



- Extreme values from individual time series are extremely unreliable +/- 20 %
- Solution 1: safety factor
- 1.35 actually too small
- Solution 2: calculate extreme value that comes with information about probability (return period)
- Tools provided by **extreme value theory**

Theoretical background



Basic equations from IEC 614001-1 ed. 3 (2004) Annex F

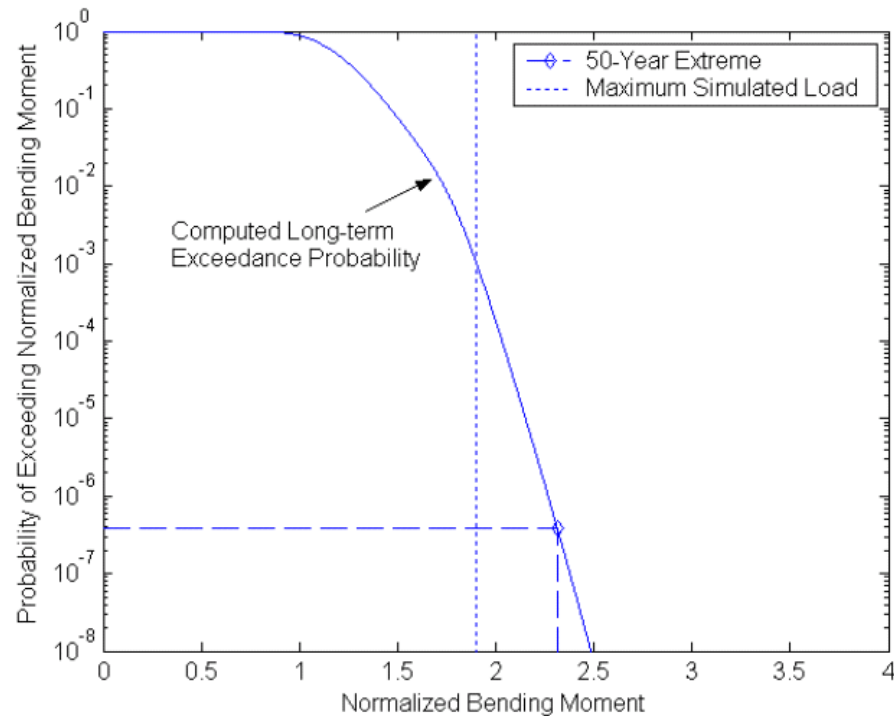
$$\text{Prob}(F_{\text{ext}} \geq F \mid T) \equiv P_e(F, T) = \int_{V_{\text{in}}}^{V_{\text{out}}} \text{Prob}(F_{\text{ext}} \geq F \mid V, T) p(V) dV$$

$$P_e(F_k, T) = \frac{T}{T_r}$$

$$P_e(F_k) = 3,8 \times 10^{-7}$$

for the 50 year recurrence period and the reference period of 10 min.

Theoretical background



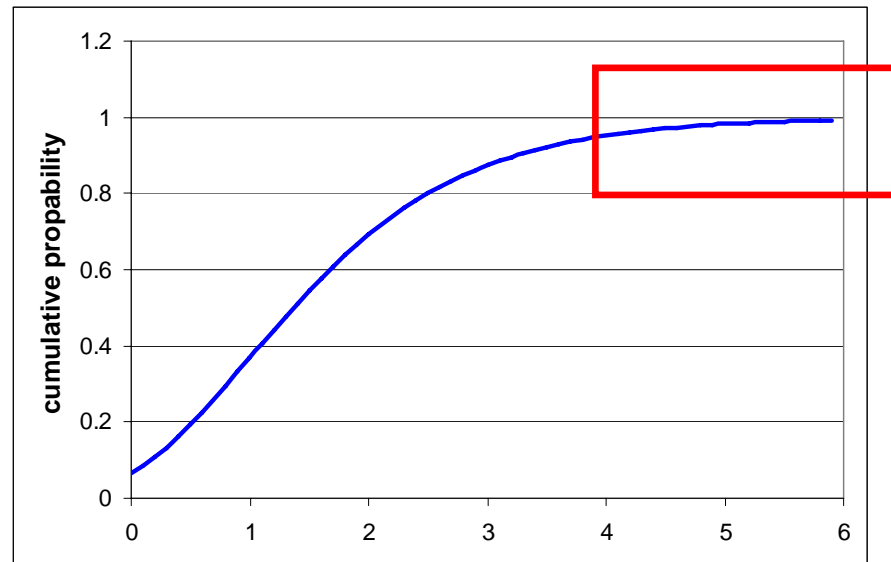
See also: P.J.Moriarty et al. , AIAA-2002-0050

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Theoretical background



Probability function for events of stochastic process



Essential result of extreme value theory (Gumbel, ...):

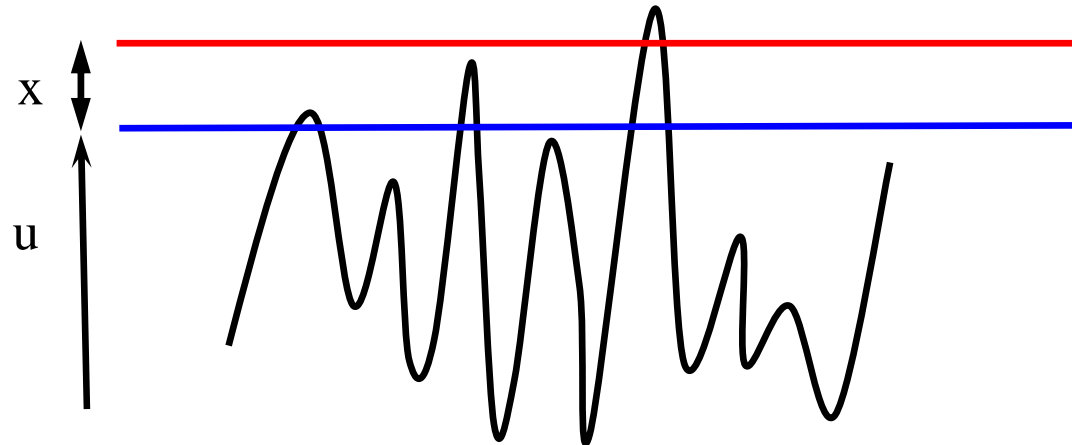
For most distributions extreme value tail takes a simple analytic form

Opens opportunity to fit data in the tail region and obtain results for probabilities of extreme events

Theoretical background



Peak over threshold method (POT)



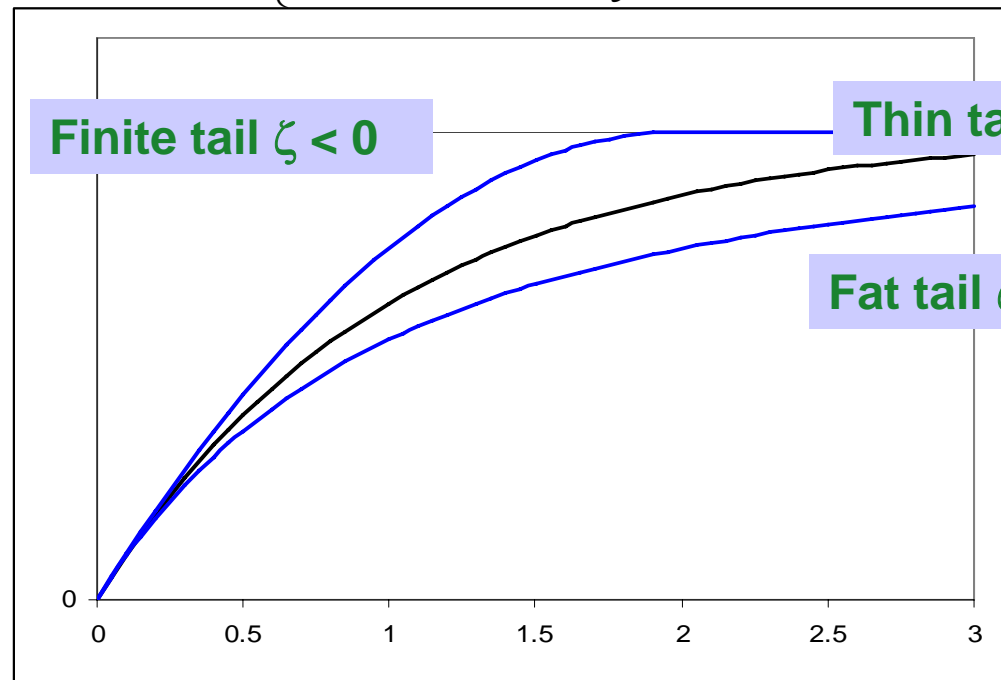
Conditional probability that event is below $u+x$ among all events that are above u . Can be determined by setting threshold u and counting extreme events between u and $u+x$

Theoretical background



Conditional probability tends to Pareto function

$$P_{\sigma, \xi}(x) = \begin{cases} 1 - \left(1 + \frac{\xi}{\sigma} x\right)^{-\frac{1}{\xi}} & \xi \neq 0, 1 + \frac{\xi}{\sigma} x > 0 \\ 1 - e^{-\frac{x}{\sigma}} & \xi = 0 \end{cases}$$



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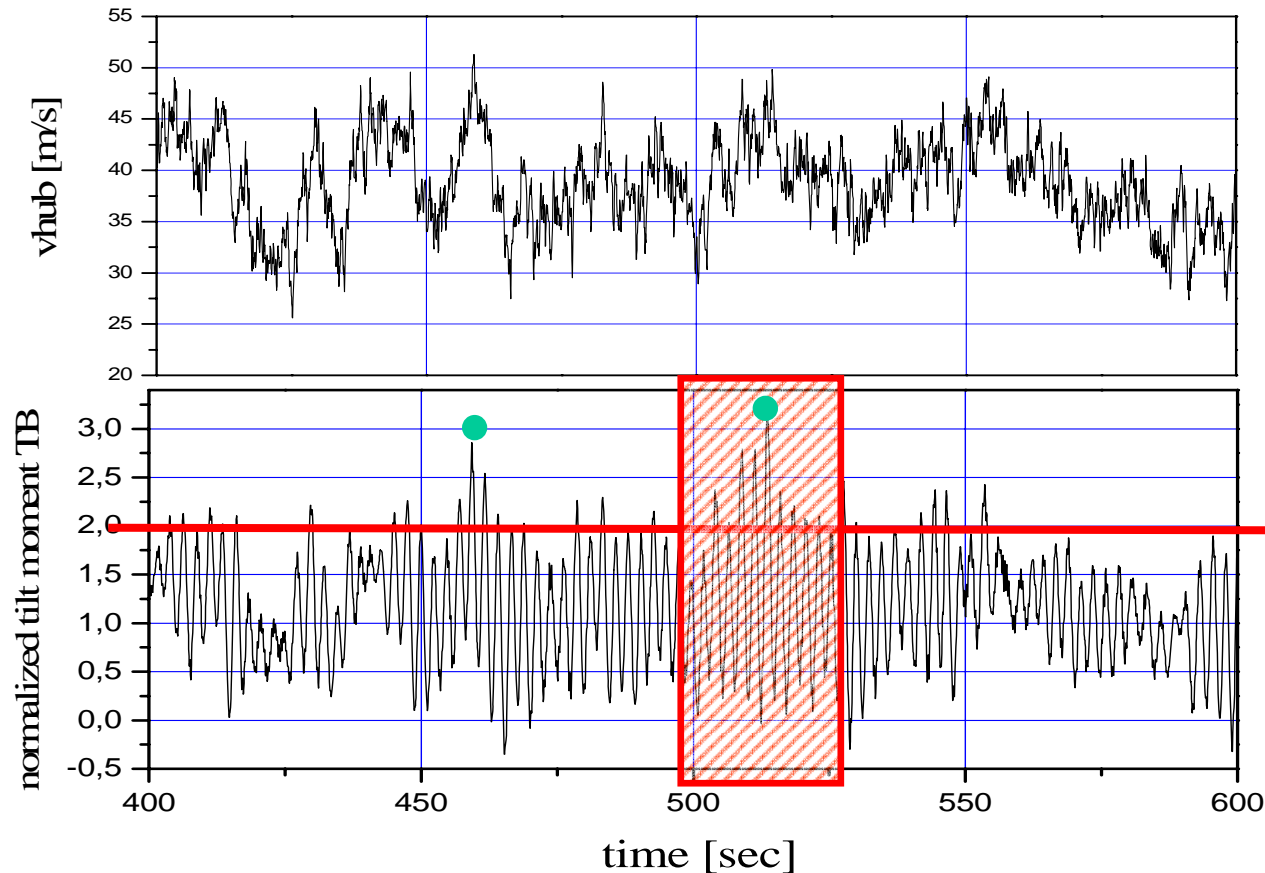
Application in load calculations



Applicable for determination of extreme values:

- From measured time series
- From simulated time series with turbulent wind
- Sectional moments and forces
- Tip-to-tower distance
- ...

Application in load calculations



Events have to be statistically independent !

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Application in load calculations



Procedure:

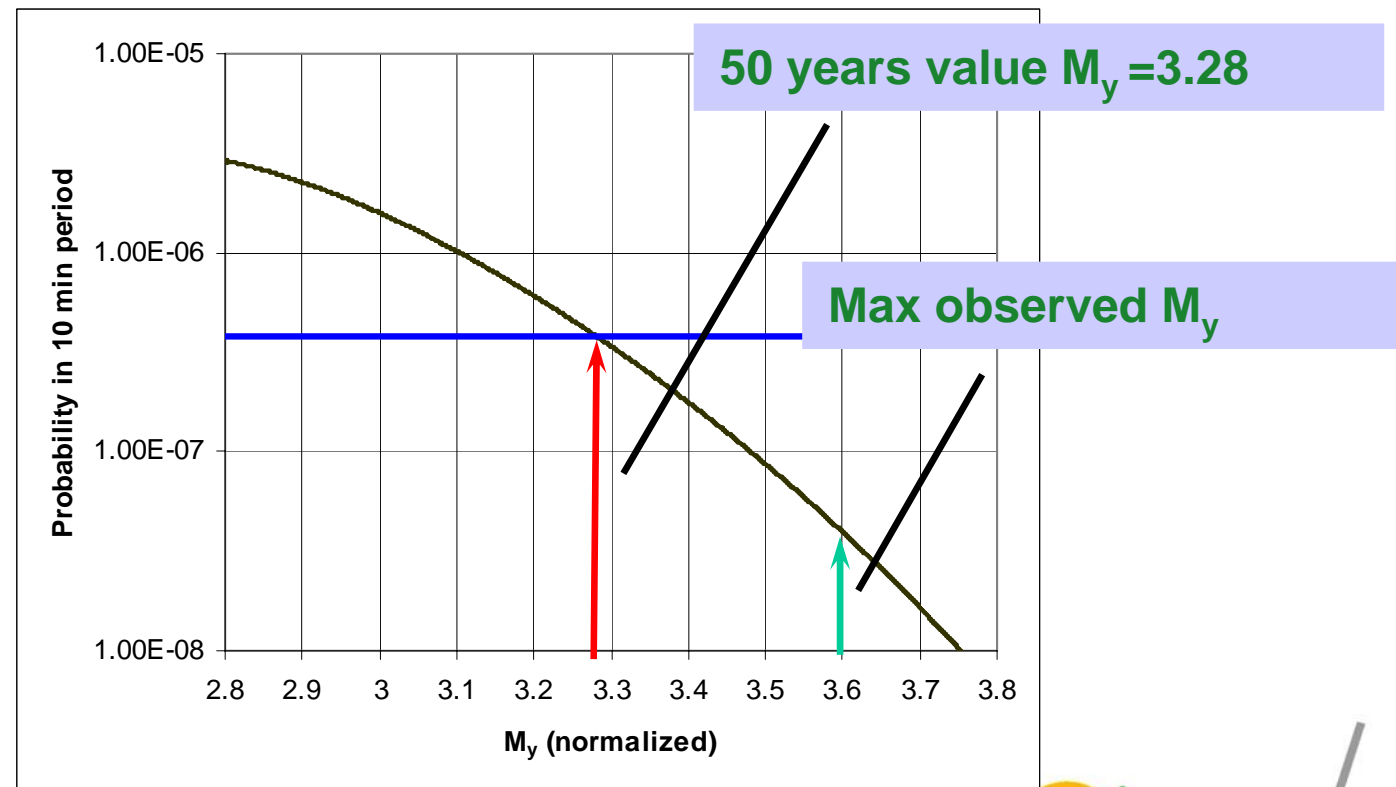
- Choose threshold and carry out POT count
- Fit Pareto function (maximum likelihood method)
- Quality checks: mean excess and χ^2 test
- From Pareto function obtain 50-years value of load from

$$P(M_{y,ext}, T) = \sum_v [1 - (P_{\sigma, \zeta}(M_{y,ext}))^n] \cdot p(v) = 3.8 \cdot 10^{-7}$$

Example: 50-years tower loads



Result for M_y

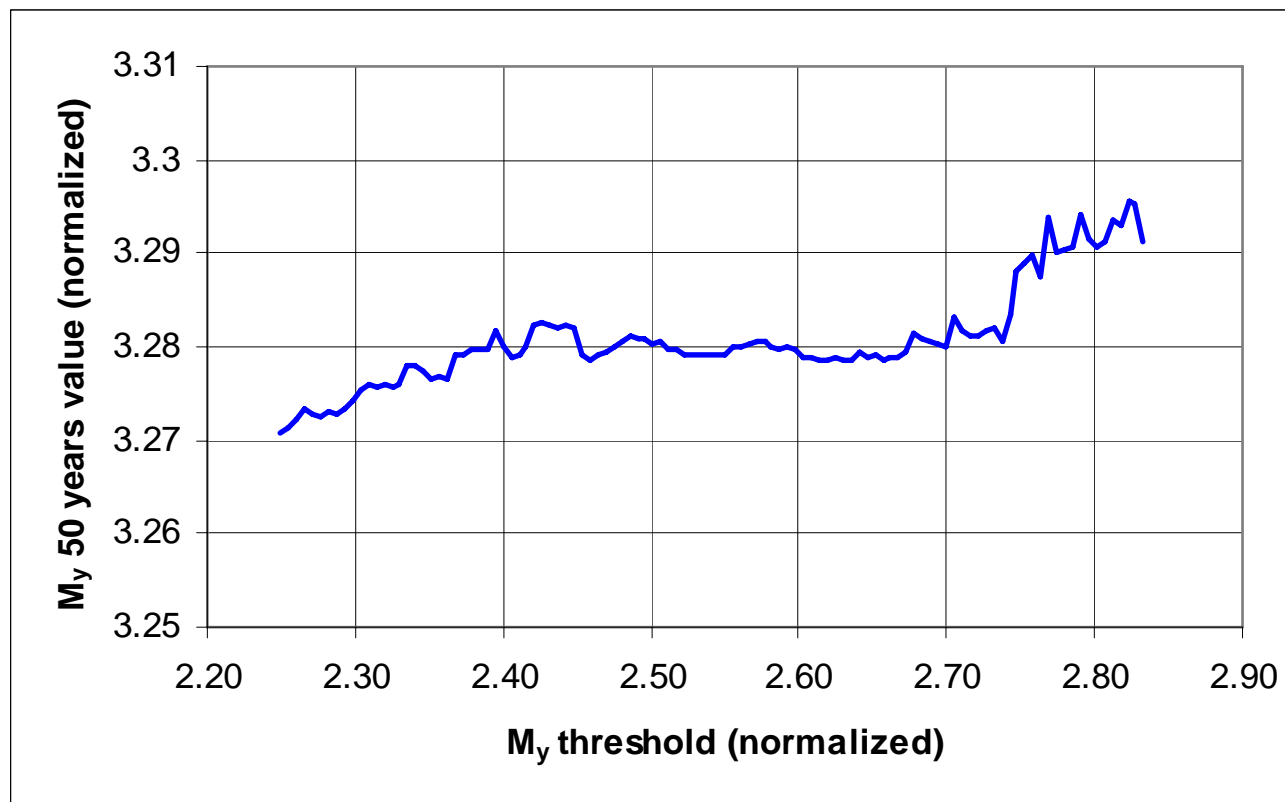


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Example: 50-years tower loads



Dependence on threshold

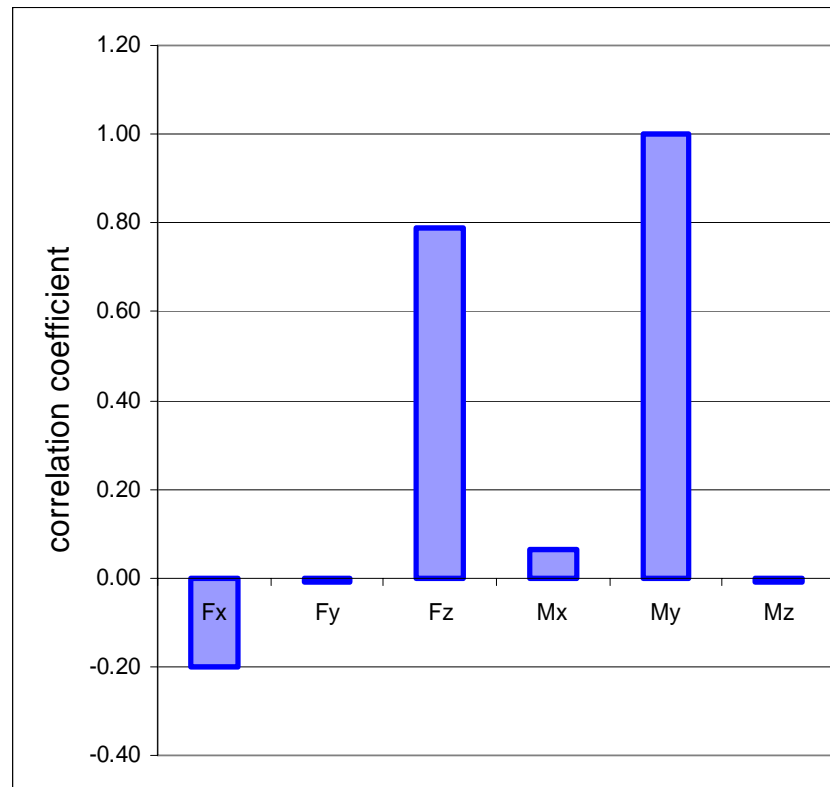


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Example: 50-years tower loads



Correlations of synchronous components

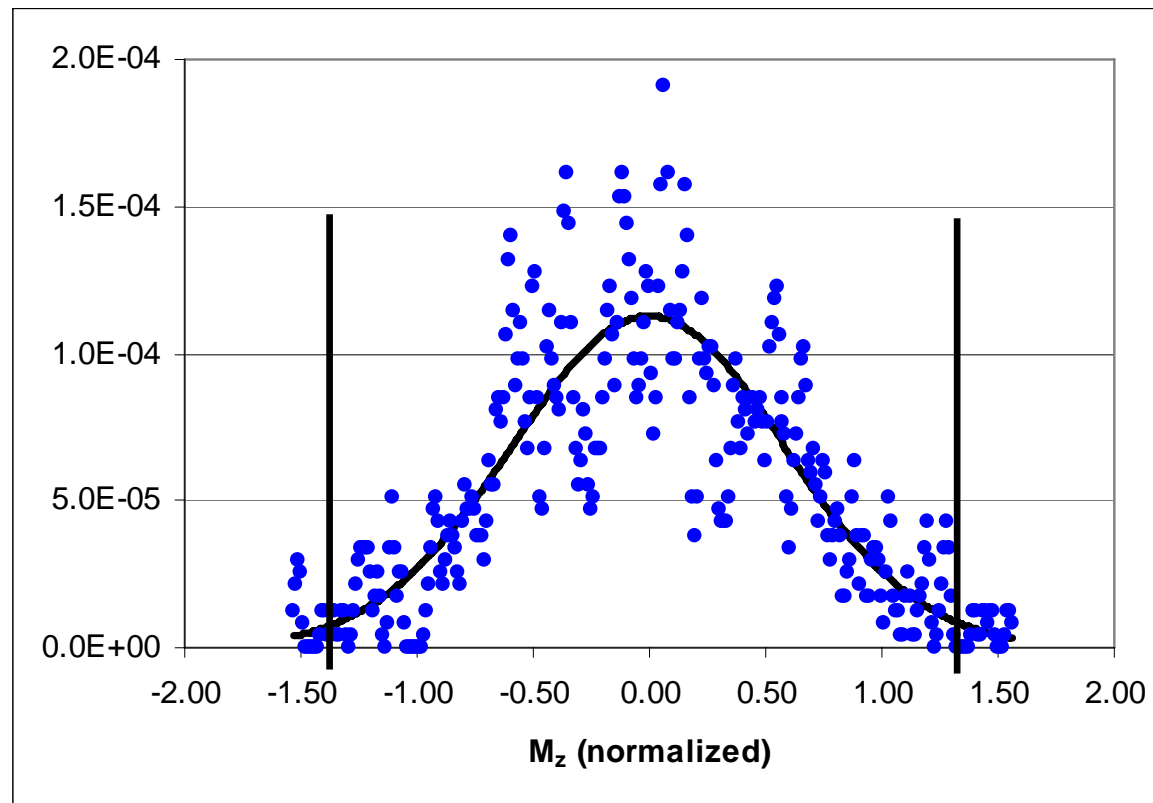


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Example: 50-years tower loads



Distribution for synchronous components: Normal distribution



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Summary and perspectives



Procedure to determine extreme loads from time series

- With extreme value theory
- Obtain extreme value with precise return probability
- Example: Extreme tower base moment
- Synchronous components normally distributed
- Post-processing tool comparable to rain-flow count for fatigue loads

Perspectives, open questions

- Tip-to-tower distance
- Analyses of measured loads
- Comparison simulation vs. measurements, tail properties



Thank you for your attention

Homepage: www.windrad-engineering.de

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