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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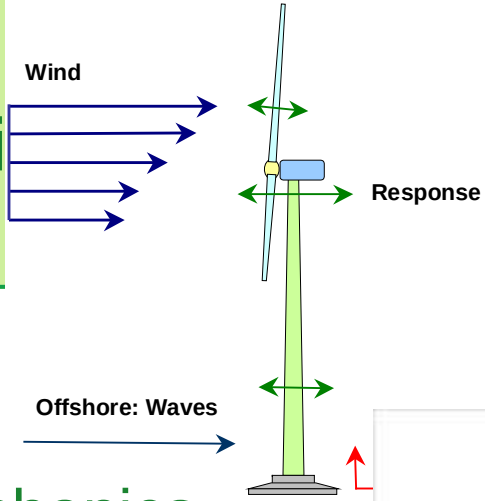
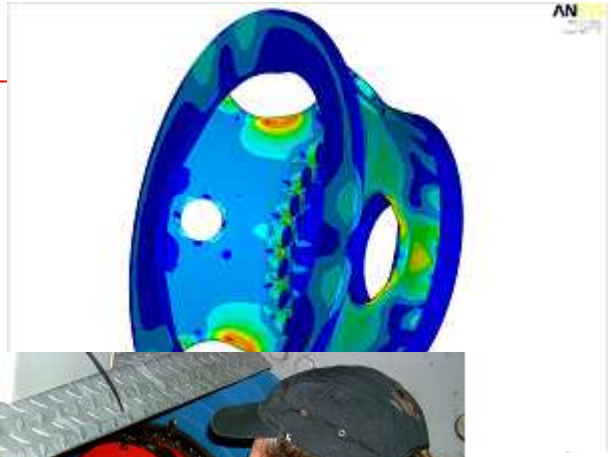


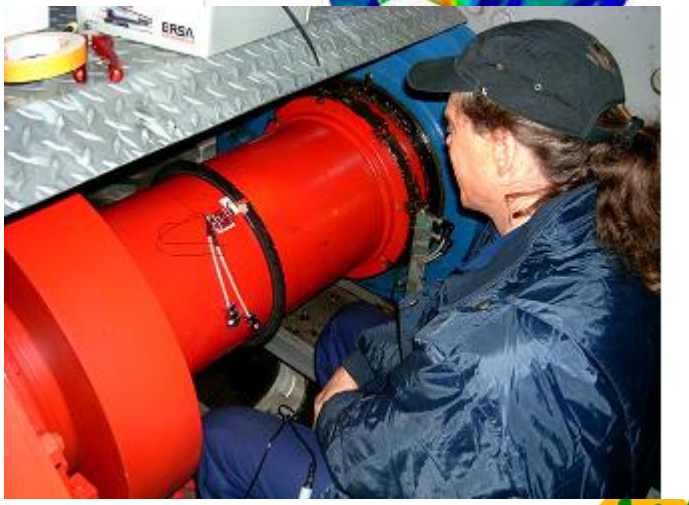
Simulation

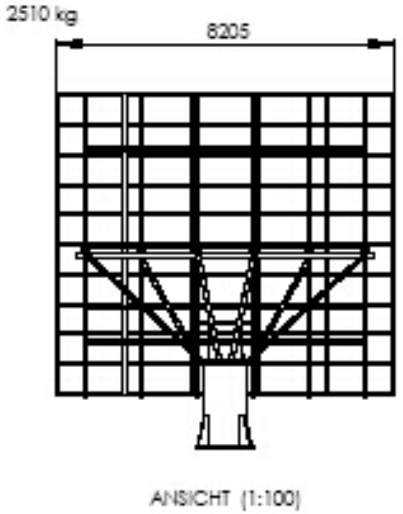
Structural mechanics

Measurement

Special machines







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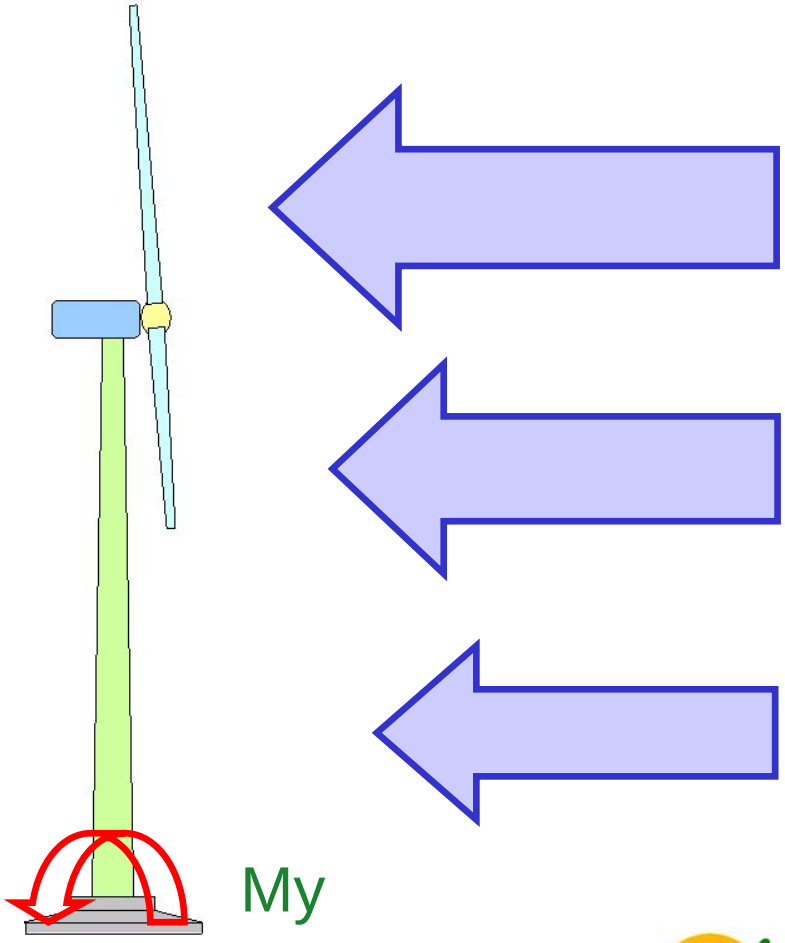
Why Extreme Value Theory



Tilt moment My

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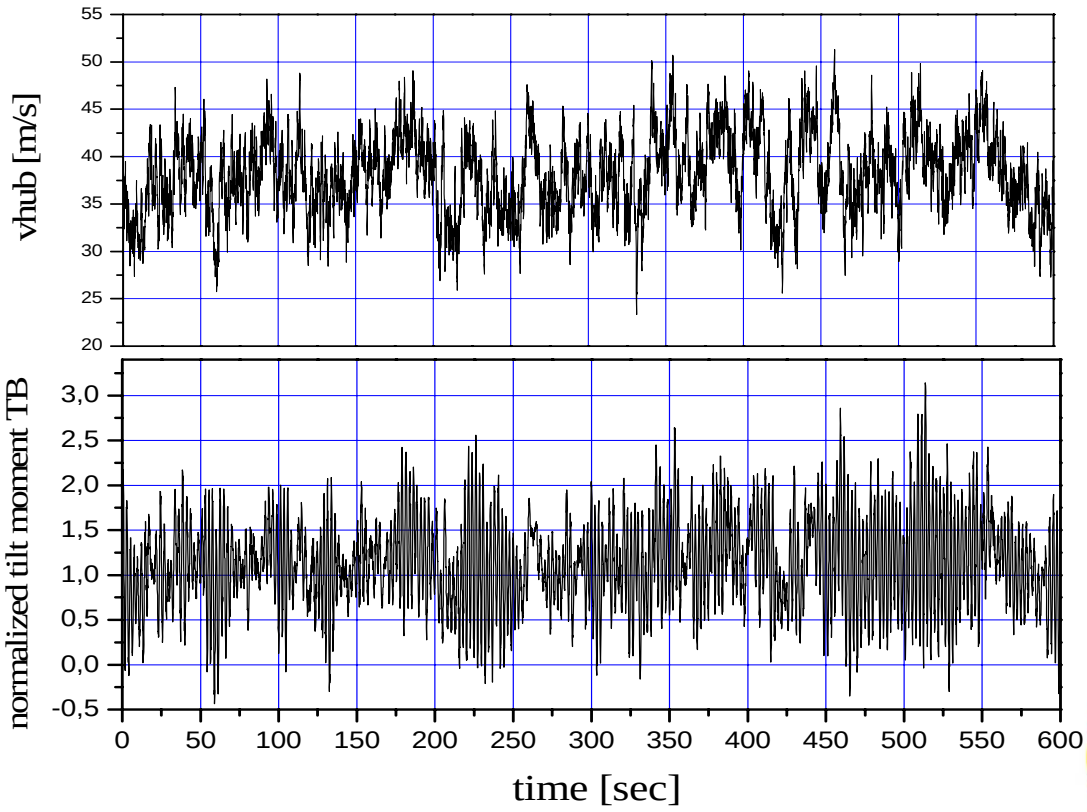
Why Extreme Value Theory

Simulated times series for tilt moment (normalized)

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



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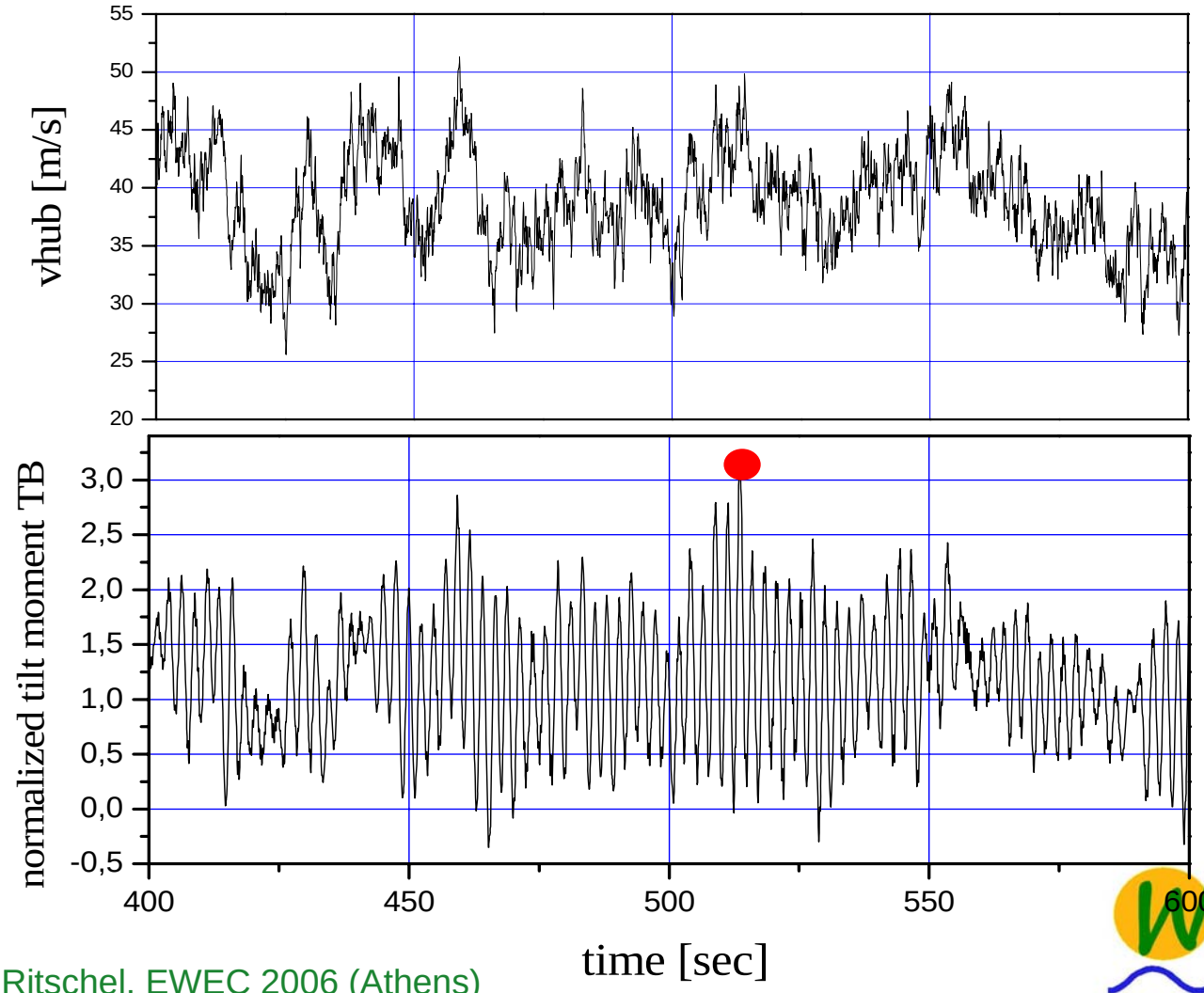
Why Extreme Value Theory



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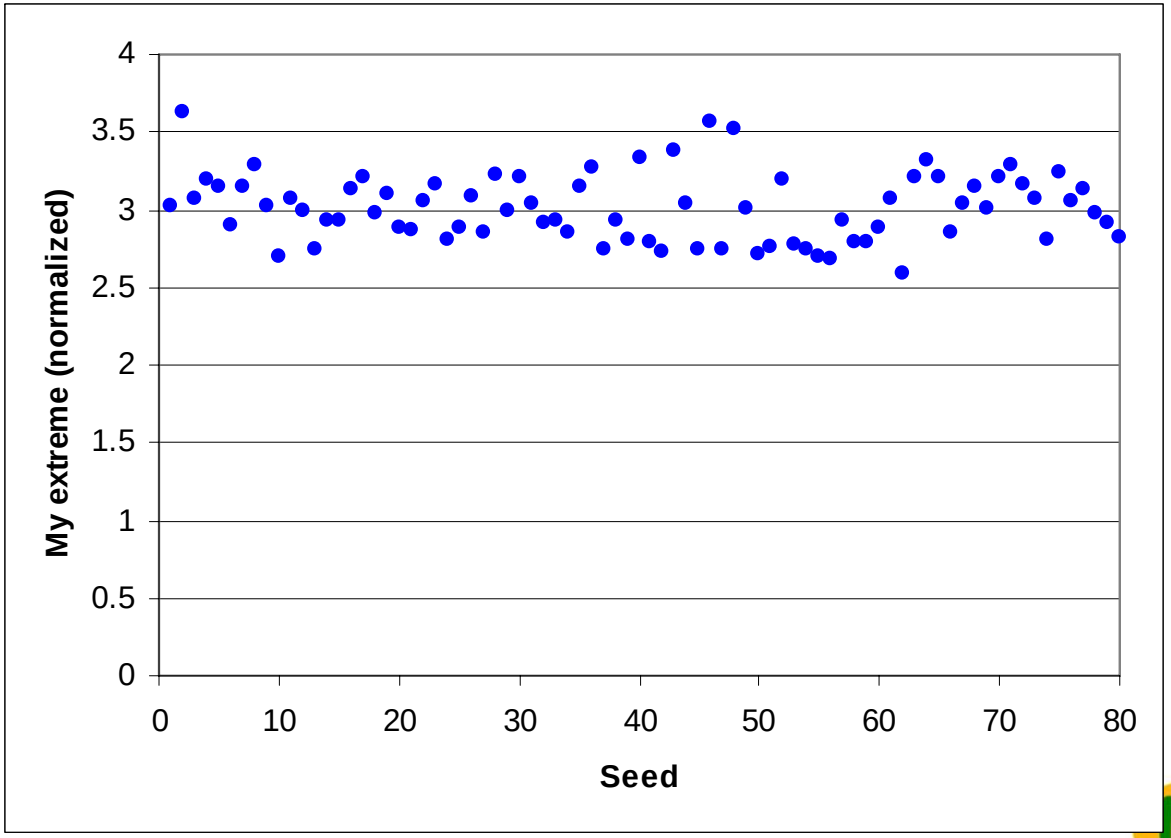
Why Extreme Value Theory

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**

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Theoretical background

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

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

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

$$P_e\left(F_k\right) = 3{,}8\times10^{-7}$$

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

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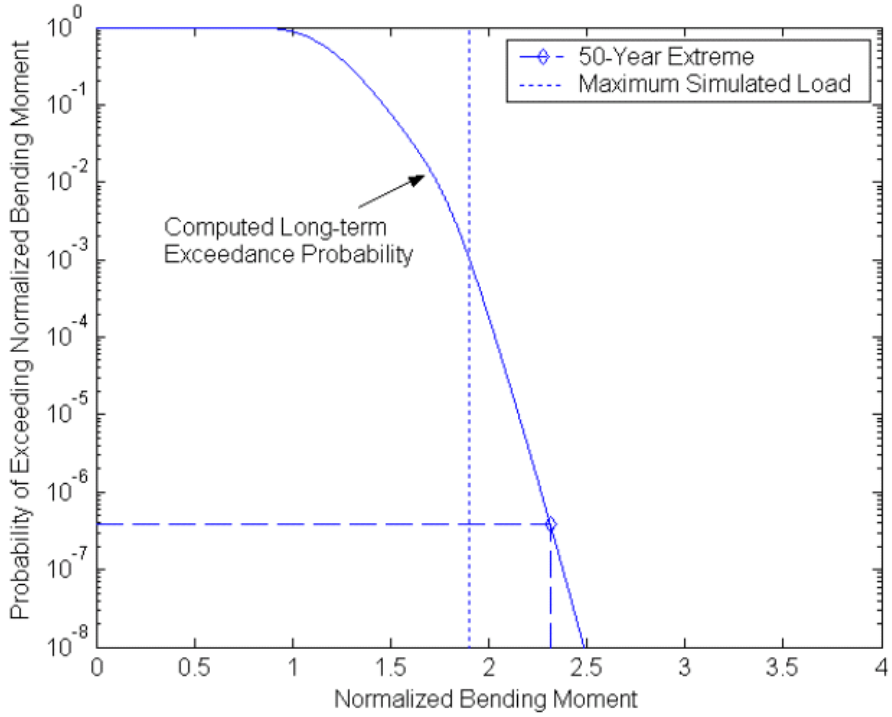
Theoretical background



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

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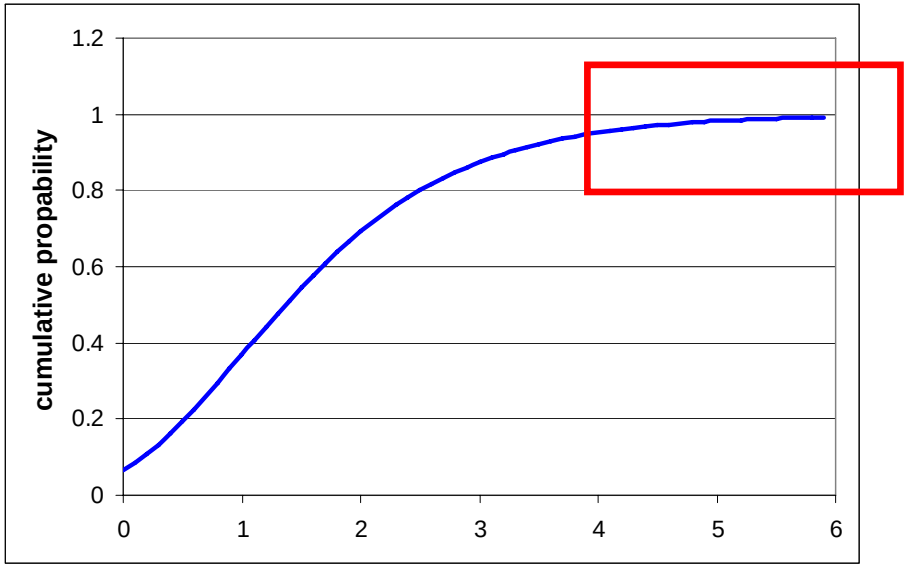
Theoretical background

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

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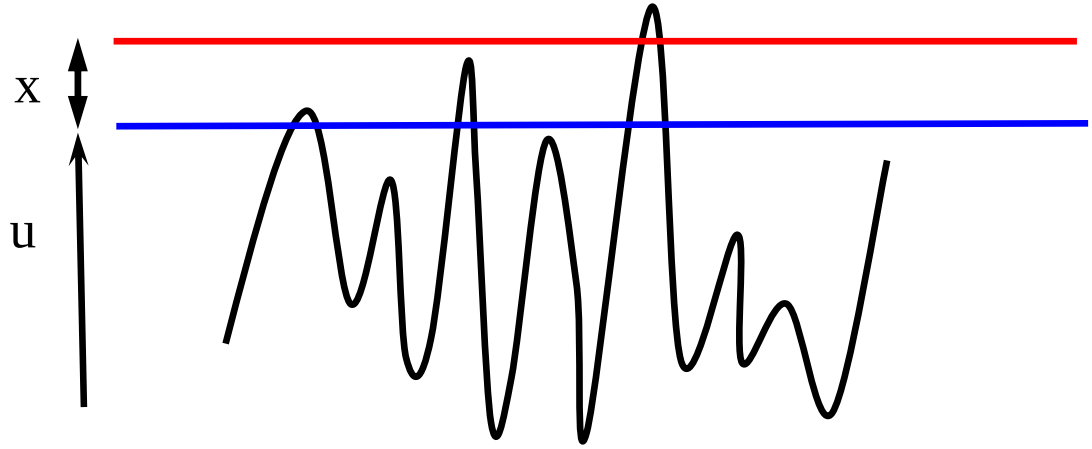
Theoretical background

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

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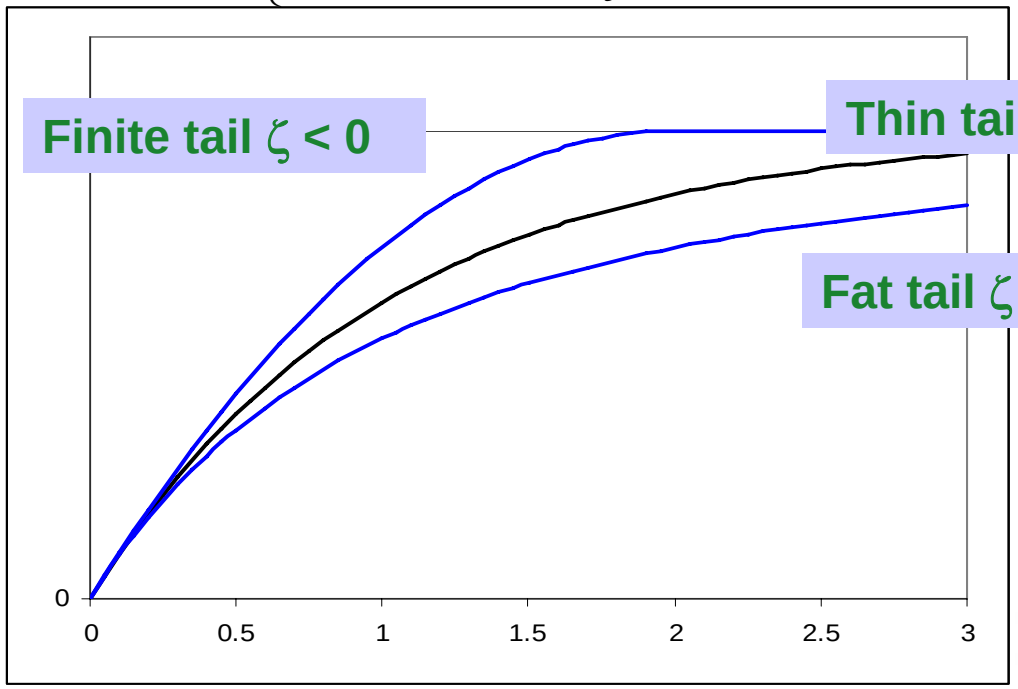
Theoretical background

Conditional probability tends to Pareto function

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



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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
- …

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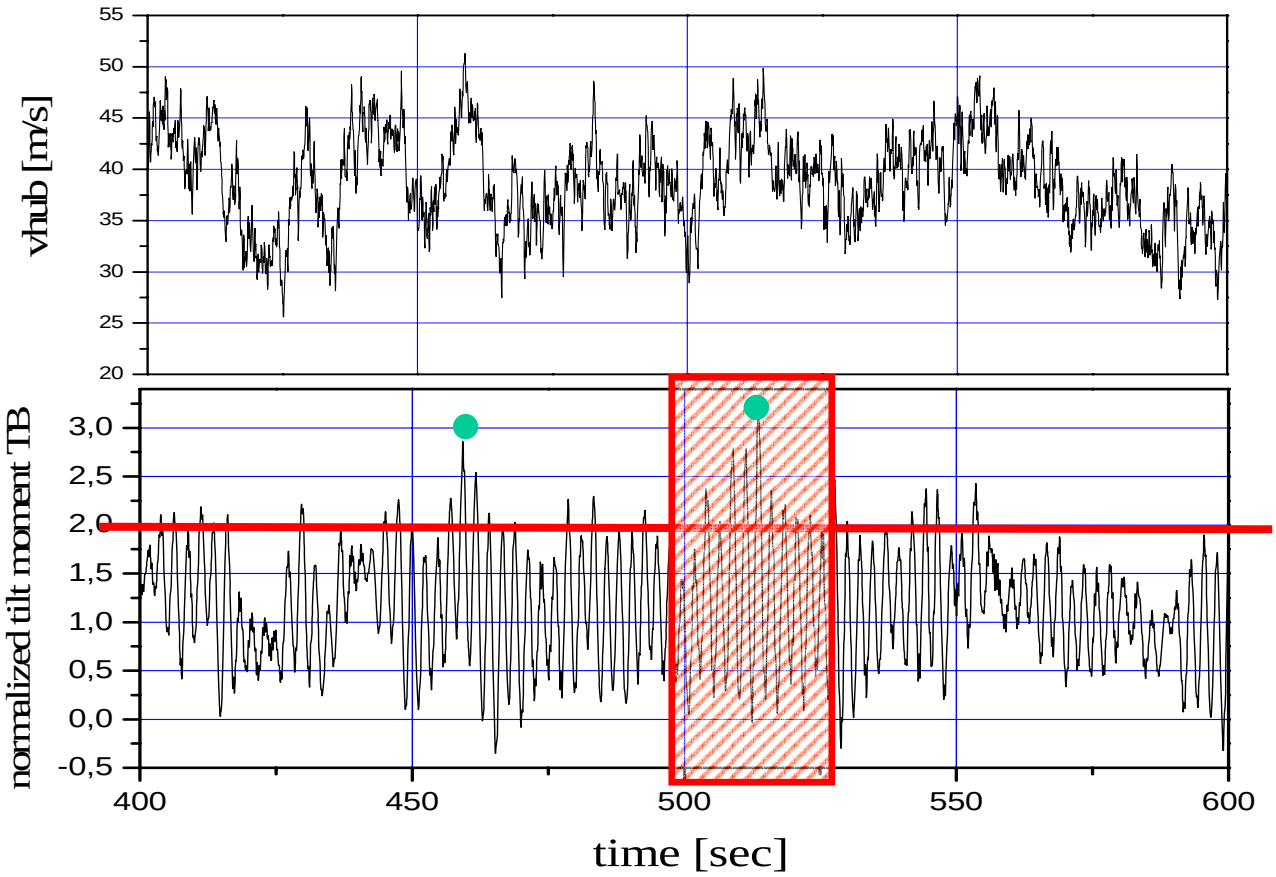
Application in load calculations



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

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

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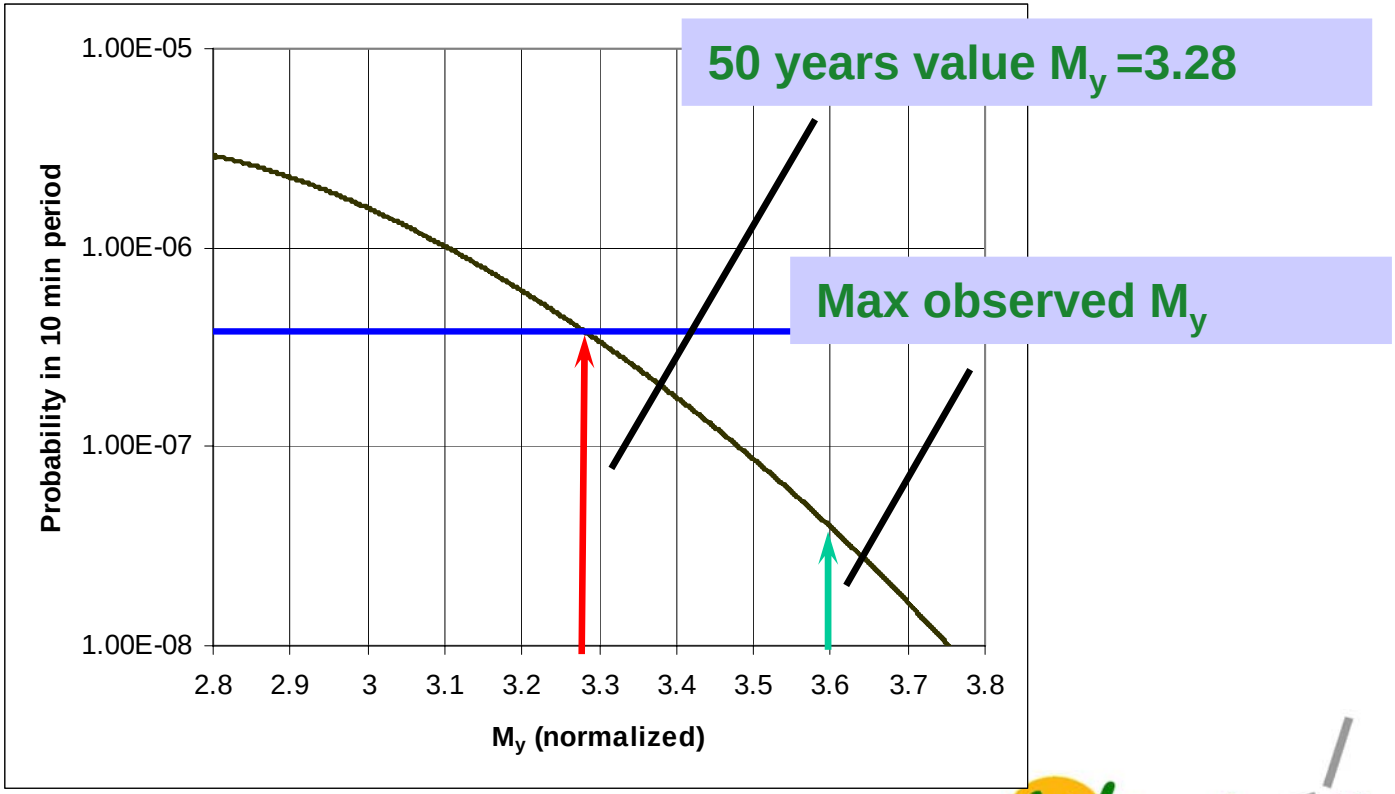
Example: 50-years tower loads

Result for M_y



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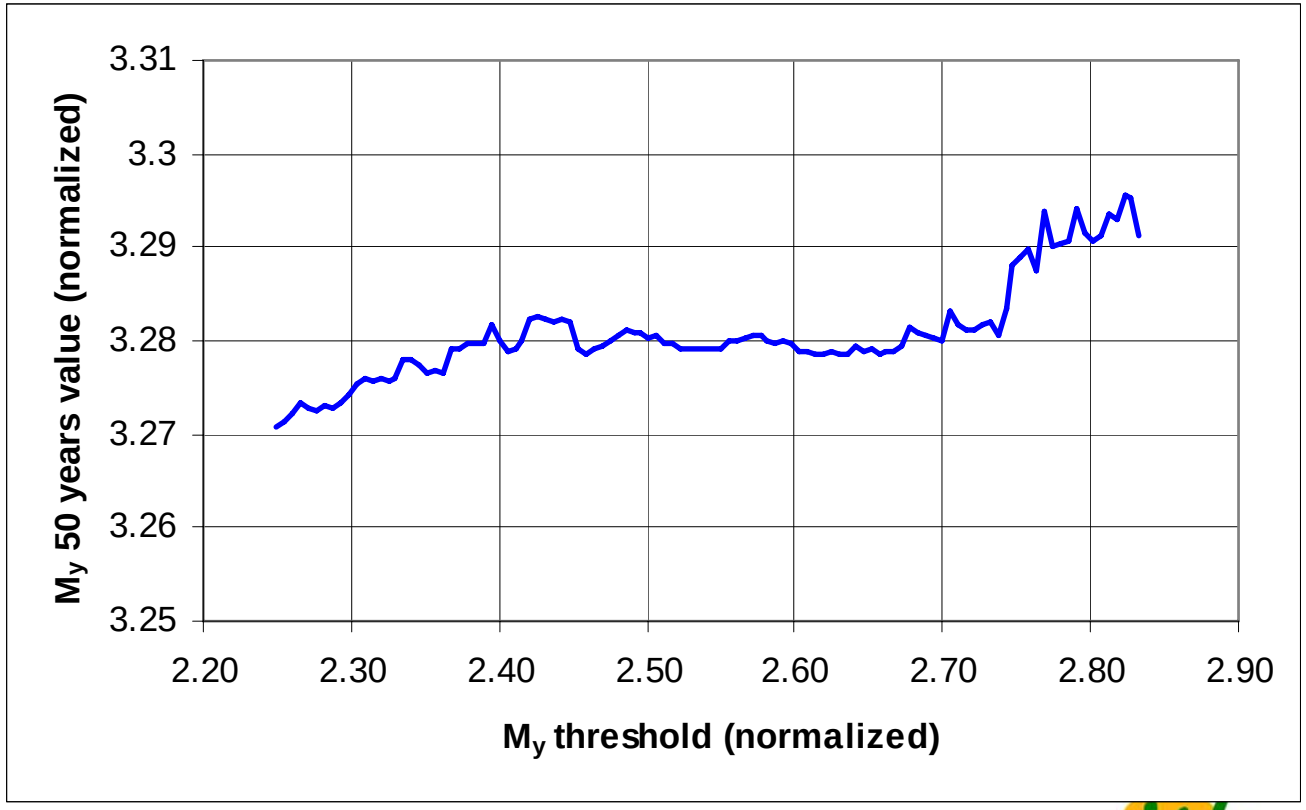
Example: 50-years tower loads

Dependence on threshold



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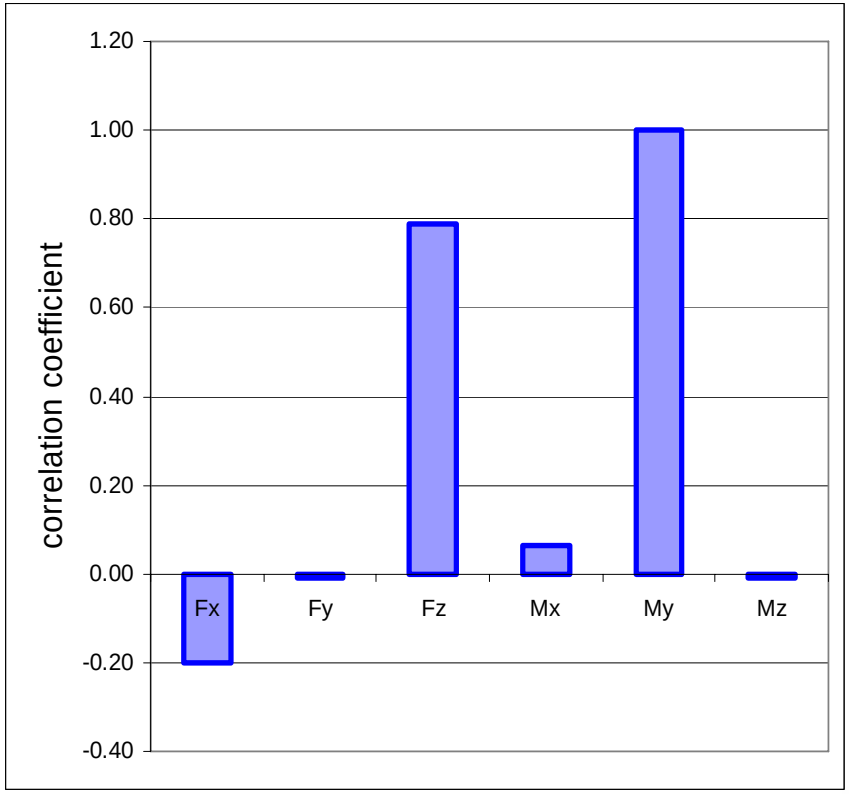
Example: 50-years tower loads

Correlations of synchronous components



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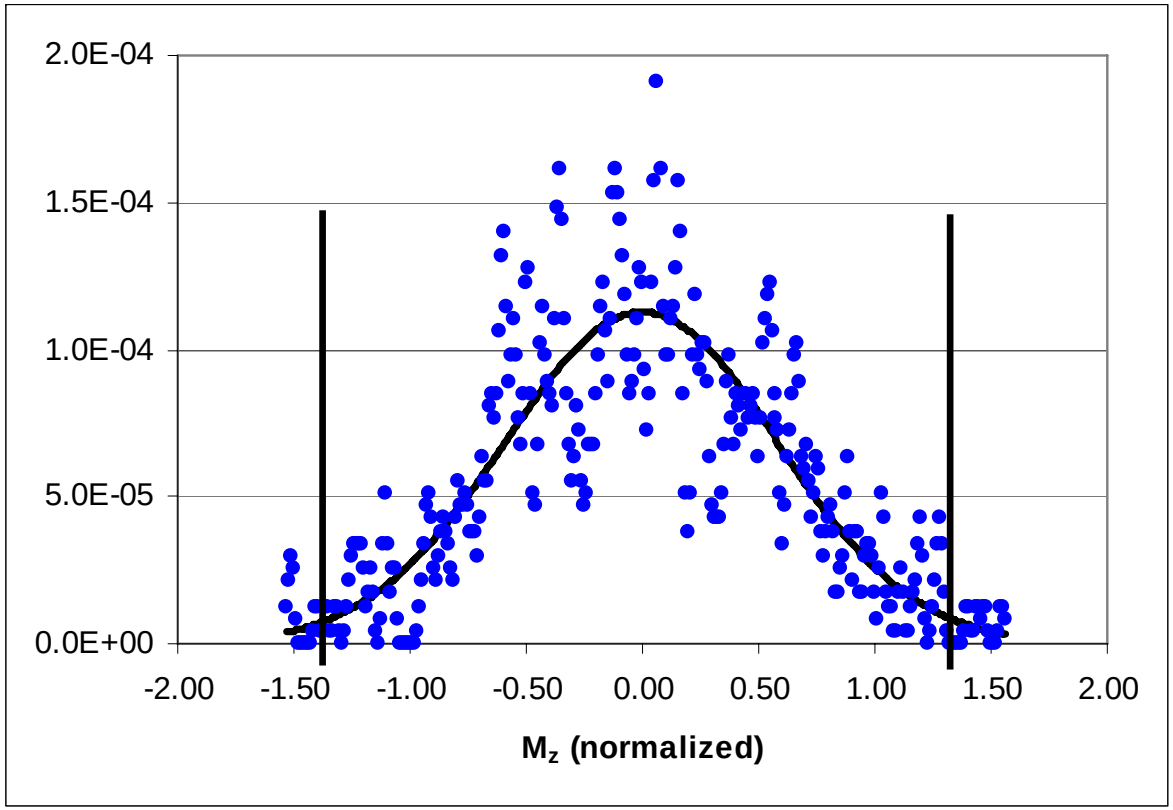
Example: 50-years tower loads

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

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Thank you for your attention

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