Further characteristics of the atmospheric turbulent wind: Periods of constant wind speed and waiting times between gusts

Daniela Moreno, Jan Friedrich, Matthias Wächter and Joachim Peinke

ForWind, University of Oldenburg. Oldenburg, Germany

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Karlsruhe Institute of Technology (KIT), Germany

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2. Definition of *further* characteristics
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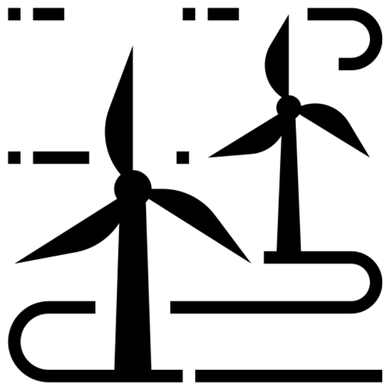
Motivation

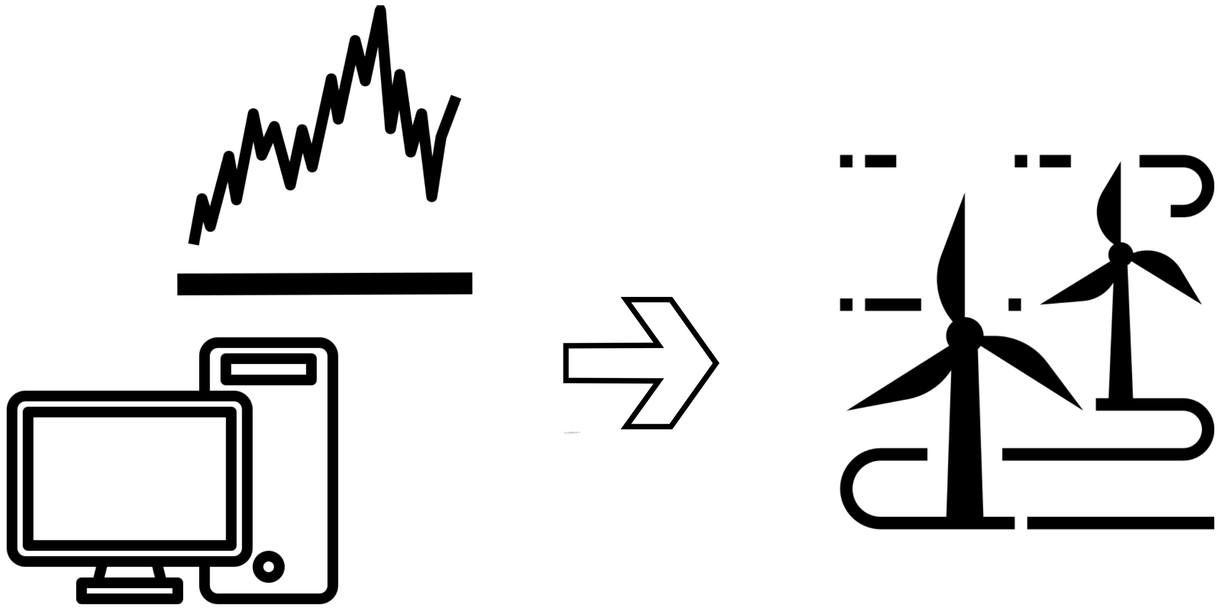
Why do we characterize the atmospheric wind?



Operating wind turbines

Motivation

Why do we characterize the atmospheric wind?



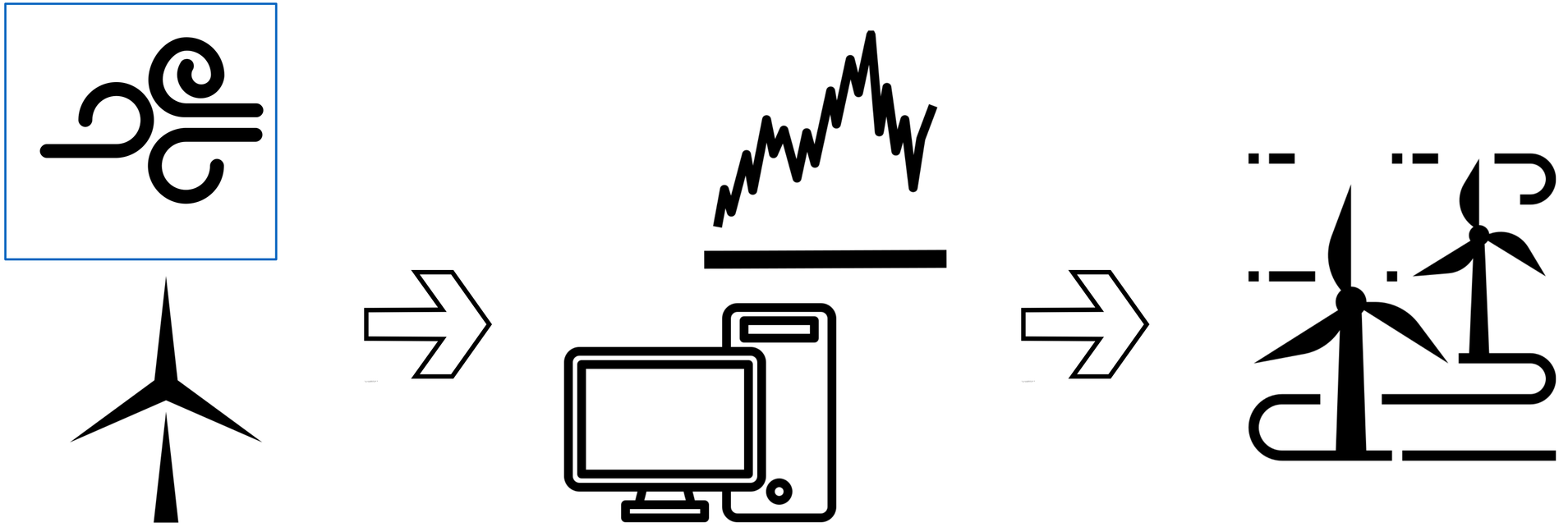
Numerical simulations

Operating wind turbines

Motivation

Why do we characterize the atmospheric wind?

Wind model:
To reproduce atmospheric wind



Turbine Model

Numerical simulations

Operating wind turbines

Motivation

Why do we characterize the atmospheric wind?

To have an analytical description of atmospheric phenomena → To be included in wind models

→ Accurate load calculations

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Standard characterization:

- Comparability/Replicability

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Standard characterization:

- Comparability/Replicability

- Some features not considered or simplified
- Valid for 30 years
- Turbines TODAY are different (Larger, more flexible)

Motivation

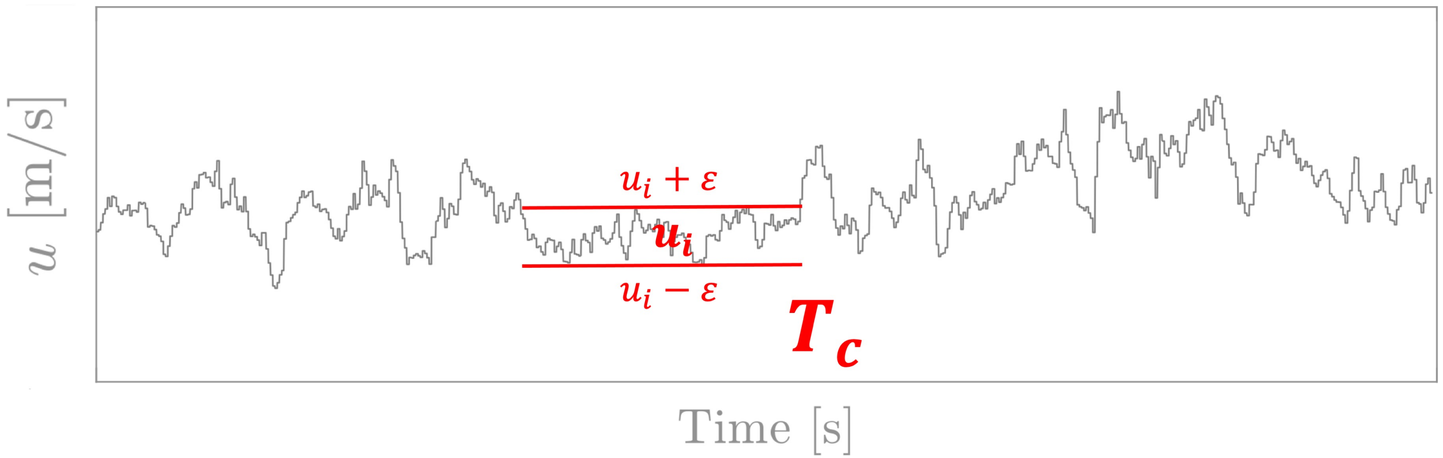
Why do we investigate further* characteristics the atmospheric wind?

To characterize **additional features** of the atmospheric wind that might be **relevant for current designs and operational conditions** of wind turbines

- Periods of constant wind speed
- Waiting times between gusts

*Further than the standard guidelines [1]

Definition of further characteristics:
periods of constant wind speed and waiting times between gusts

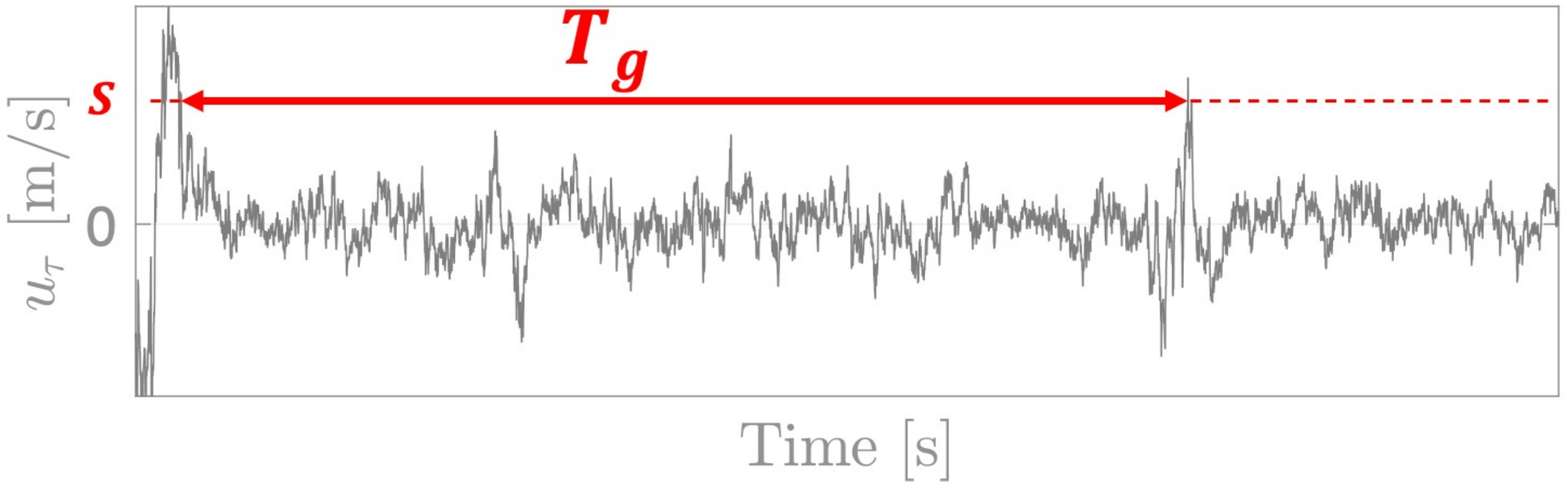


T_c - Length of the period of constant wind speed

Definition of further characteristics:

periods of constant wind speed and **waiting times between gusts**

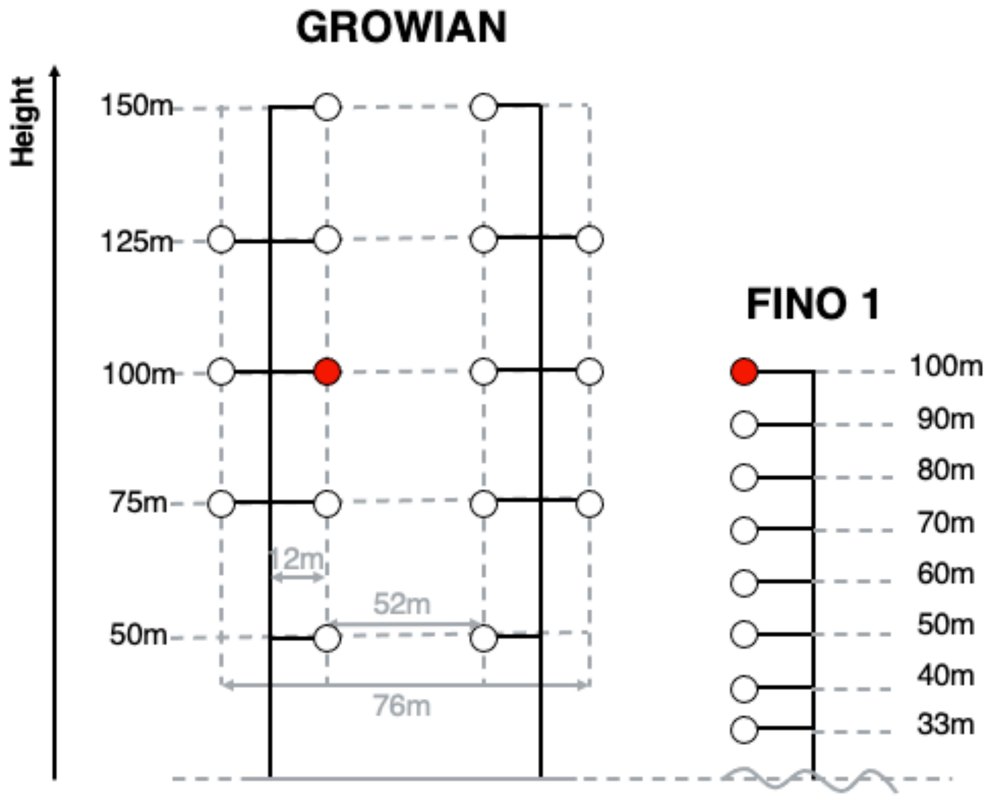
Velocity Increment: $u_\tau = u(t+\tau) - u(t)$



T_g - Length of the time between two successive gusts

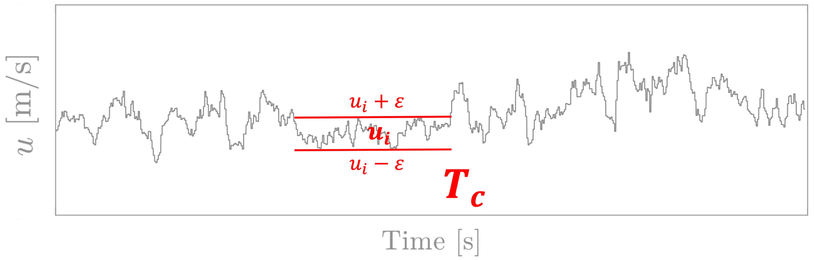
Results on the statistics

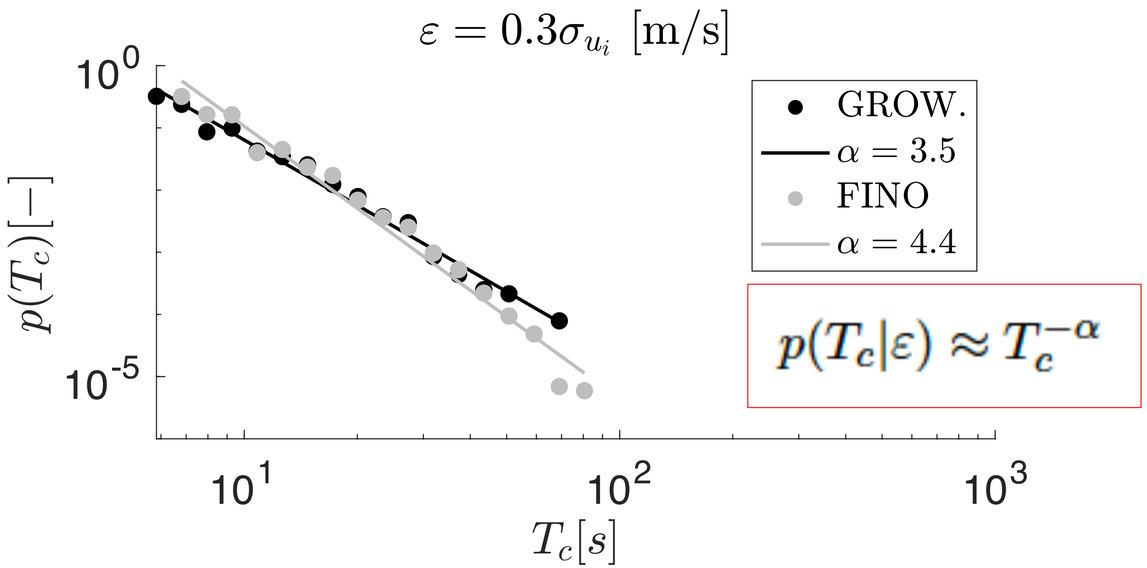
Data: Atmospheric measurements



[2, 3]

Results on the statistics
periods of constant wind speed and waiting times between gusts





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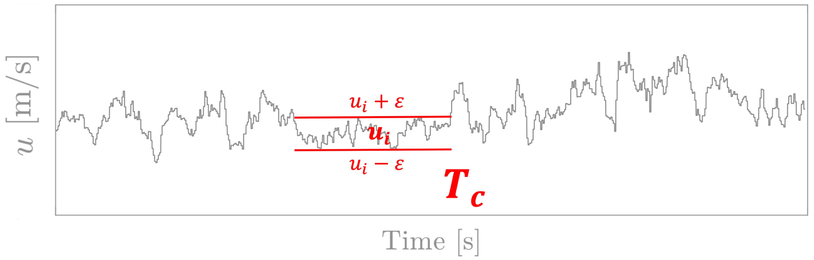
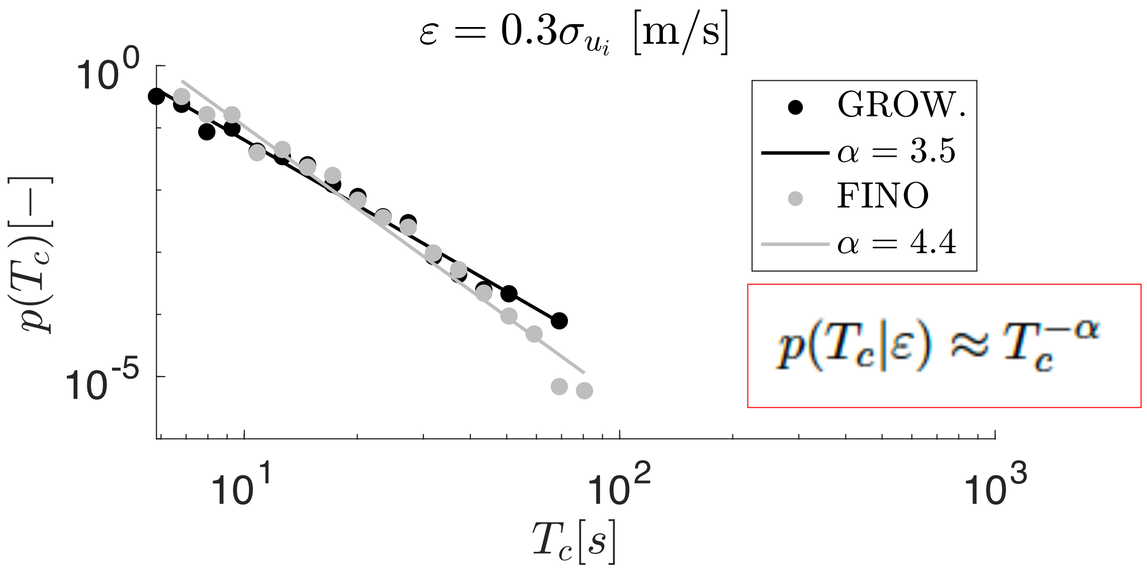
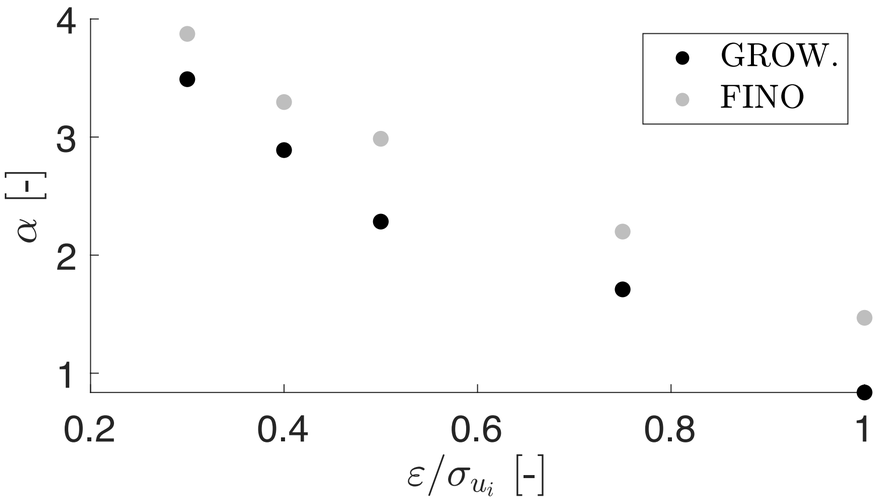
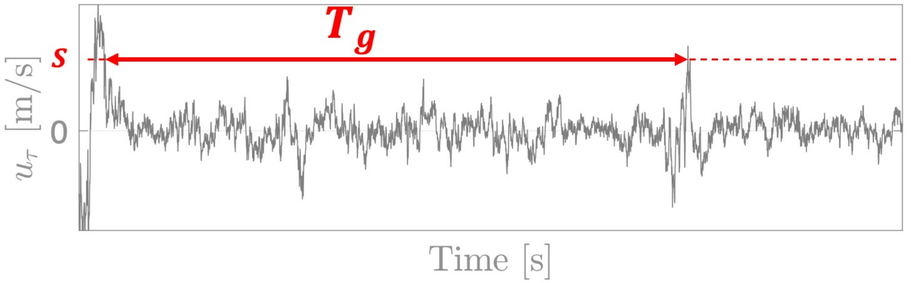


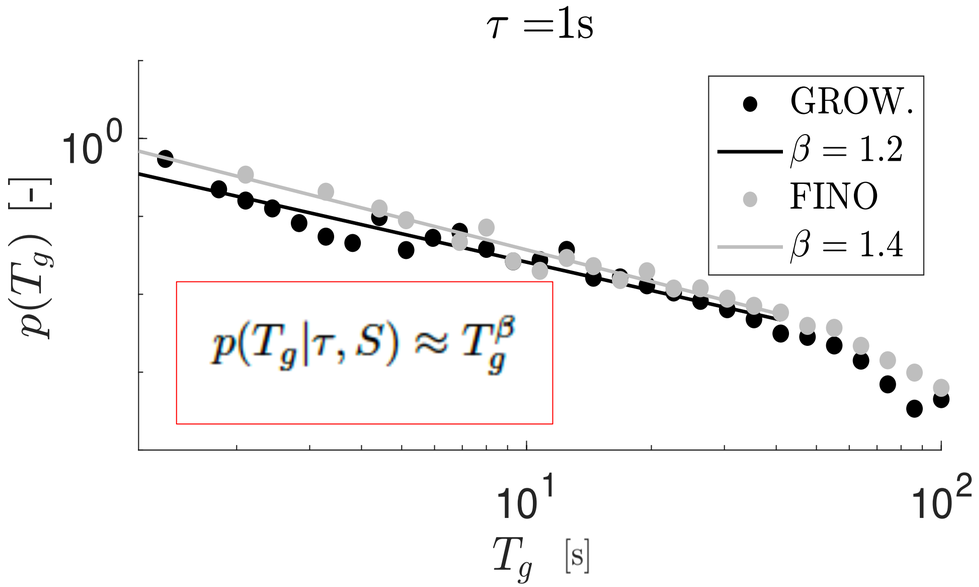




Results on the statistics

periods of constant wind speed and **waiting times between gusts**





Results on the statistics

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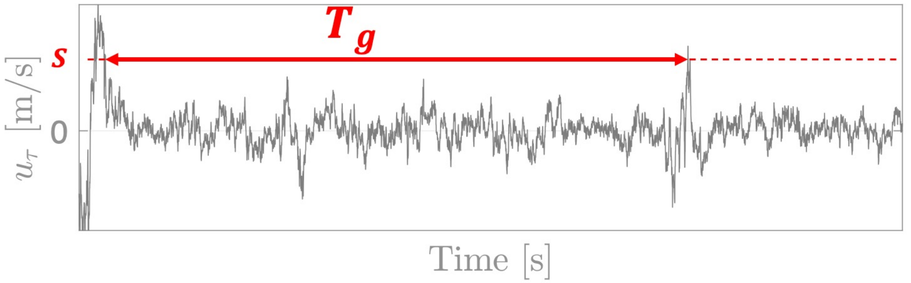
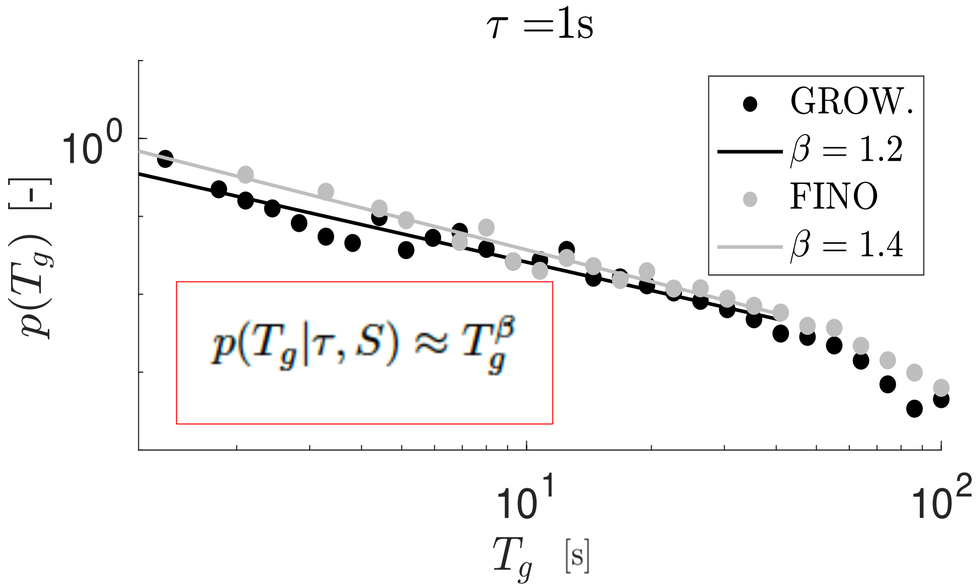
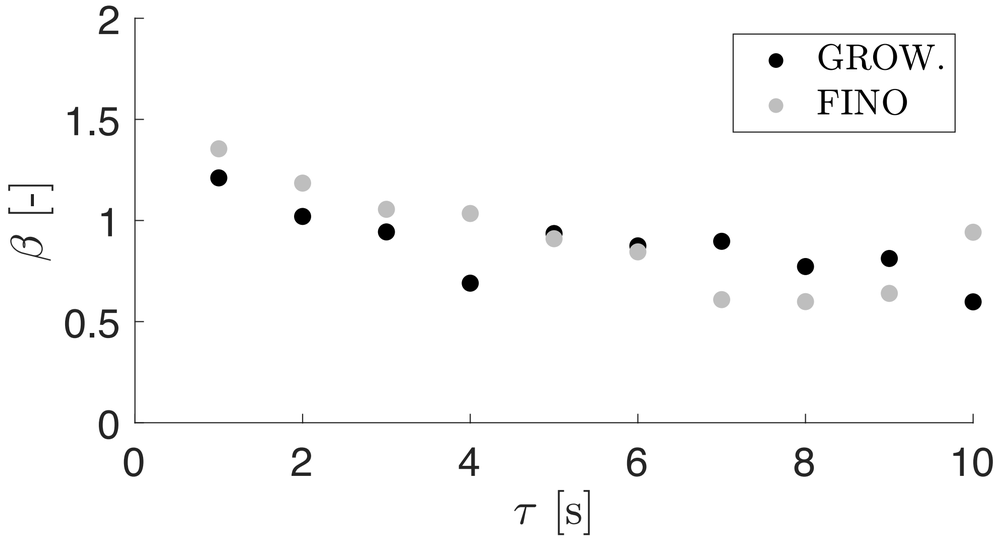
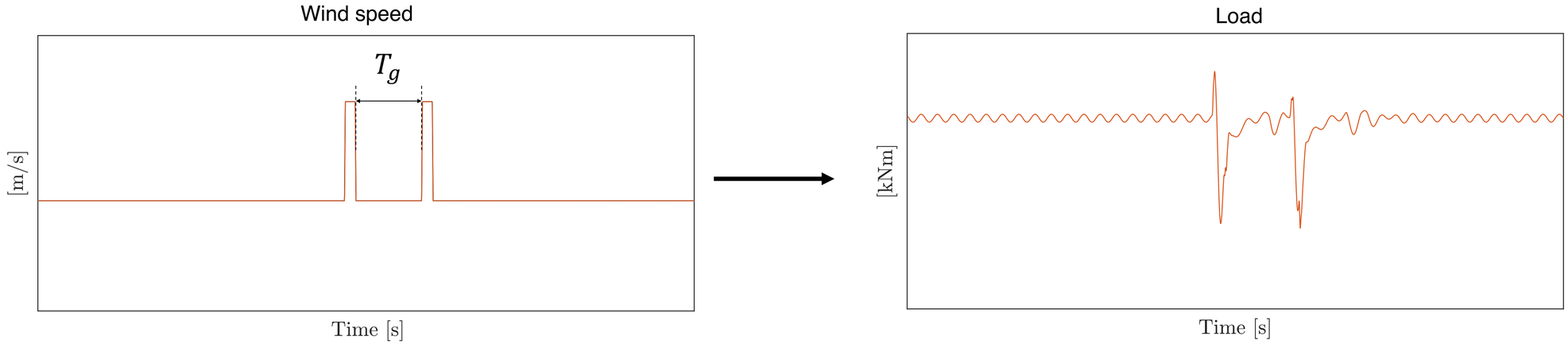






Load analysis

Effect of **waiting times between gusts (T_g)** on the loads of the turbine



Resonance? Damping?
No effect?

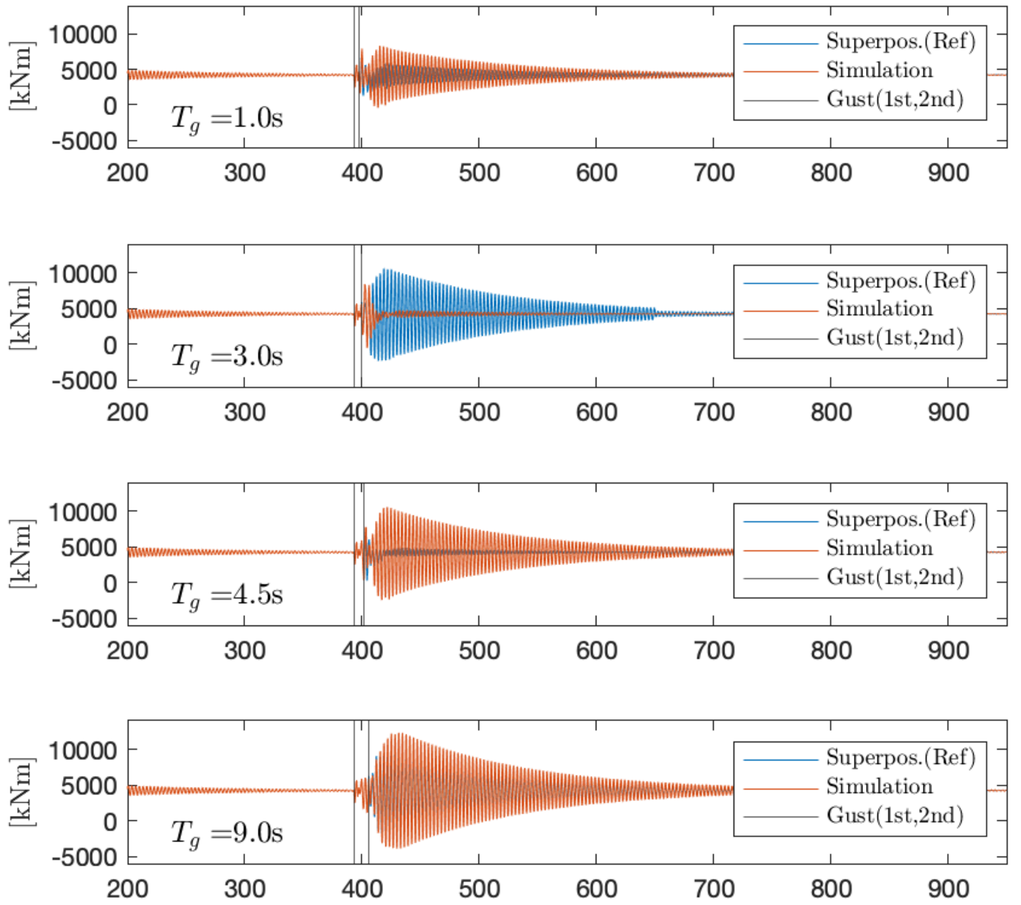
Load analysis

Effect of **waiting times between gusts (T_g)** on the dynamics of the turbine

Might certain T_g induce resonance or damping on the turbine?

Numerical Simulations

Load @ Tower



Conclusions

- Definition of two further (than standard) characteristics of the atmospheric turbulent wind: Periods of constant wind speed (T_c) and waiting times between successive gusts (T_g)

- Statistical parameterization of T_c and T_g from atmospheric wind measurements

- First results on load analysis: Different T_g introduce resonance/damping on the wind turbine

Future work

- Spatial correlations of T_c and T_g events

- Are the statistics of T_c and T_g included in the current wind models for turbine simulations?

  If not, how to include them?

- Considering more flexible rotor blades, how important is the effect of T_c and T_g on the loads?

Thank you for your attention!
Questions?

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Federal Ministry
for Economic Affairs
and Climate Action

on the basis of a decision
by the German Bundestag

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References

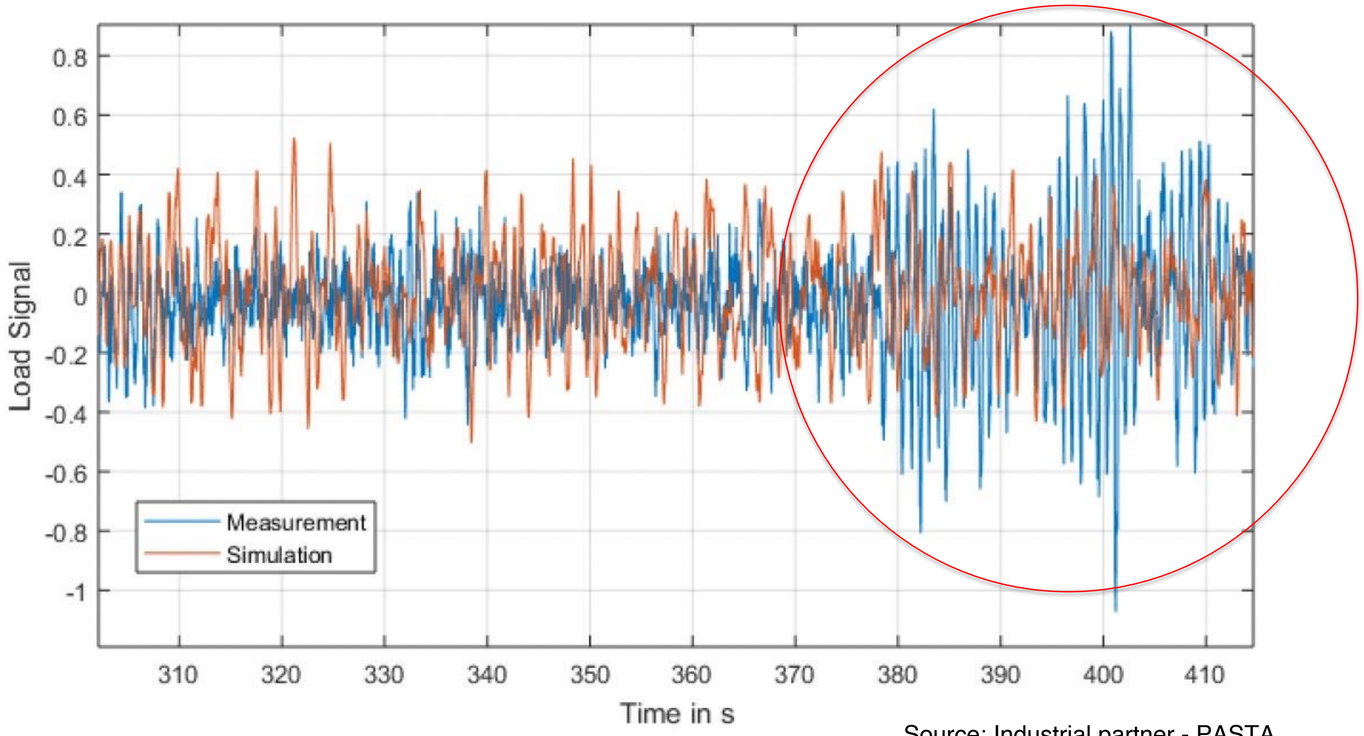
[1] IEC 61400-1 Wind energy generation systems. Standard, National Renewable Energy Laboratory, Feb 2019.

[2] F. Körber, G. Besel, and H Reinhold. Messprogramm an der 3 MW windkraftanlage GROWIAN: Förderkennzeichen: 03E-4512-A. Technical report, 1988.

[3] FINO1-Research Platform. https://www.fino1.de/en/

Motivation

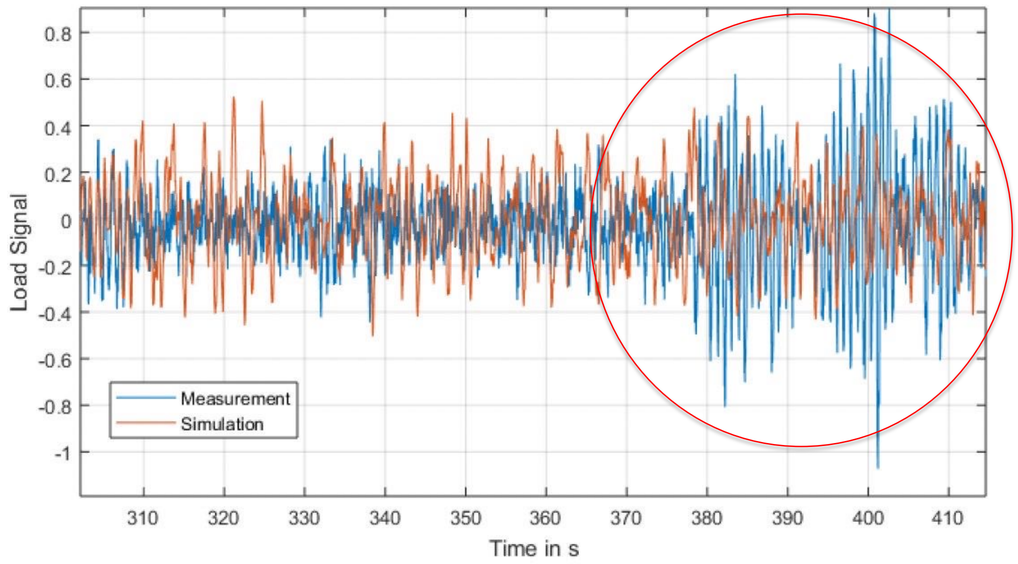
Why do we investigate further* characteristics the atmospheric wind?

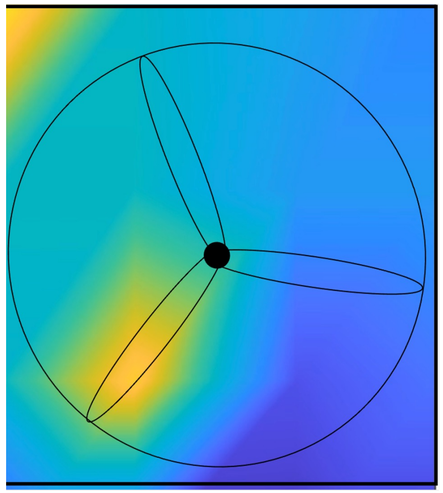


Source: Industrial partner - PASTA

*Further than the standard guidelines [1]

Definition of further characteristics of the atmospheric turbulence



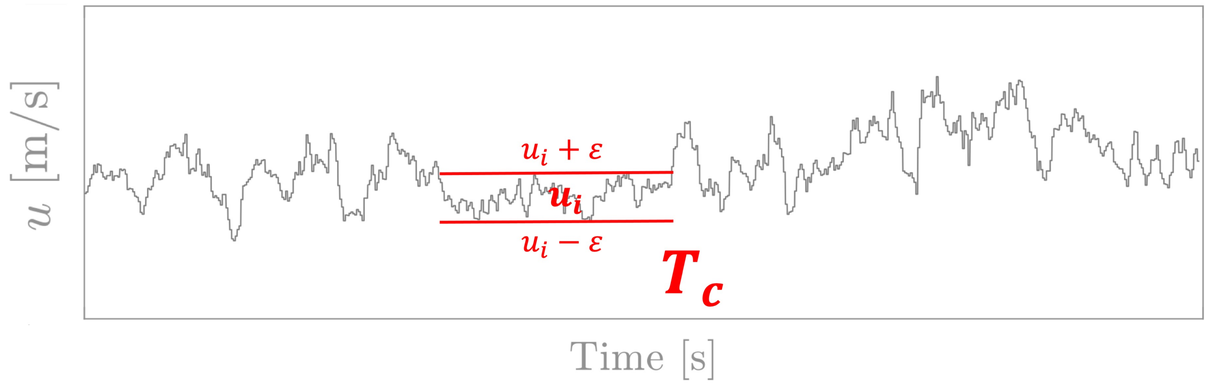


1. Periods of constant wind speed - T_c
2. Waiting times between successive gusts - T_g

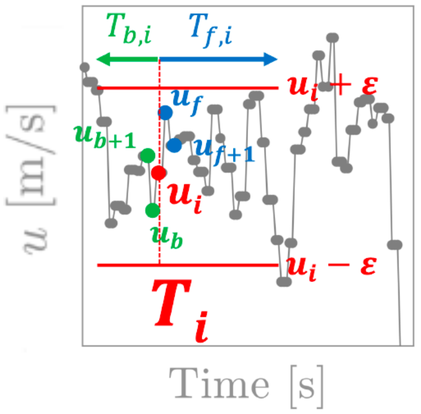
Definition of further characteristics of the atmospheric turbulence

1. Periods of constant wind speed - T_c

Hypothesis: Local jets/cigars on the rotor plane → 3P oscillations on the loads

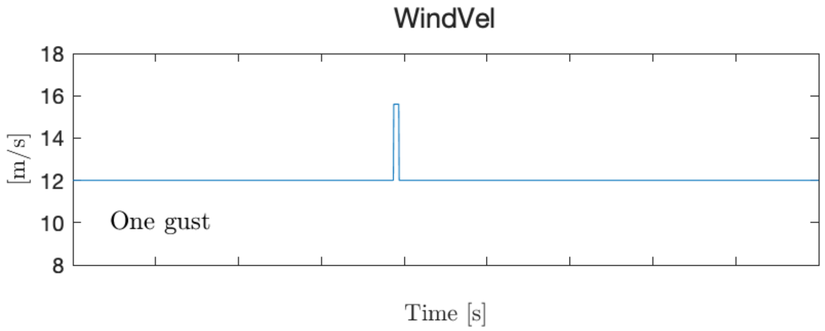


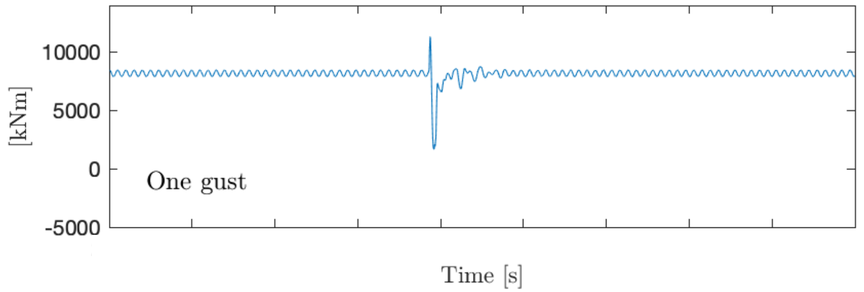
Development of MATLAB code for measuring T_c



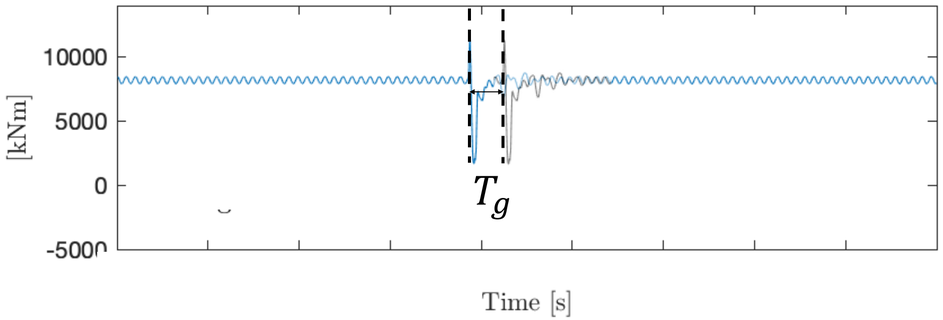
Analyzing the effect of time T_g between two gusts on the loads of the turbine

Reference Amplitude A_{ref}





Reference case: Superposition of two independent events (generated by one gust) separated in time by T_g



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Analyzing the effect of time T_g between two gusts on the loads of the turbine

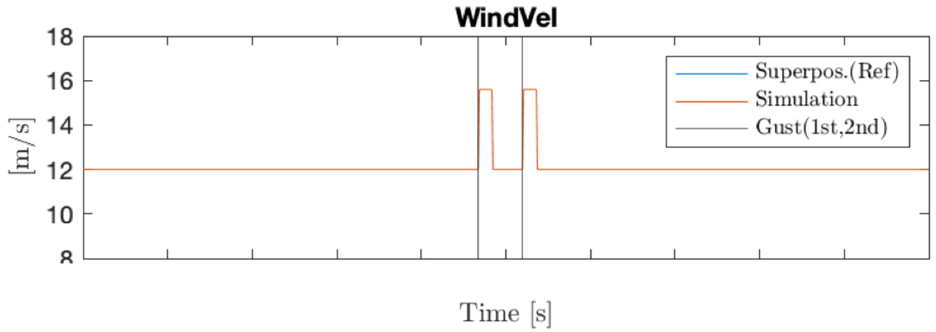
Clustering of wind gusts – Waiting time T_g

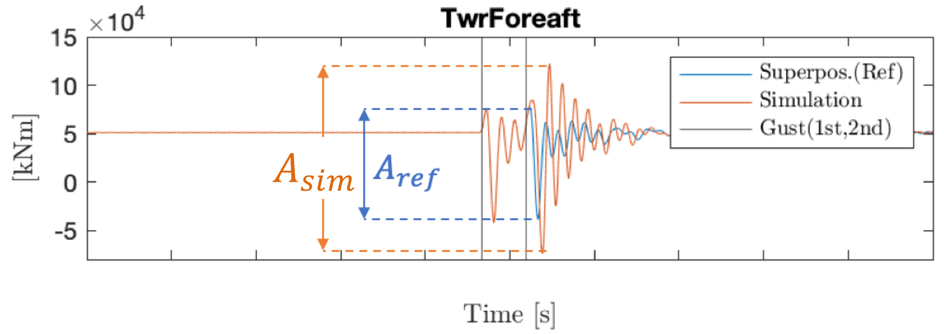
Additional investigation: BEM simulations

Reference Amplitude A_{ref}: From the superposition of two individual gusts separated by T_g.

Simulations Amplitude A_{sim}:
From BEM simulation with two gusts separated by T_g.

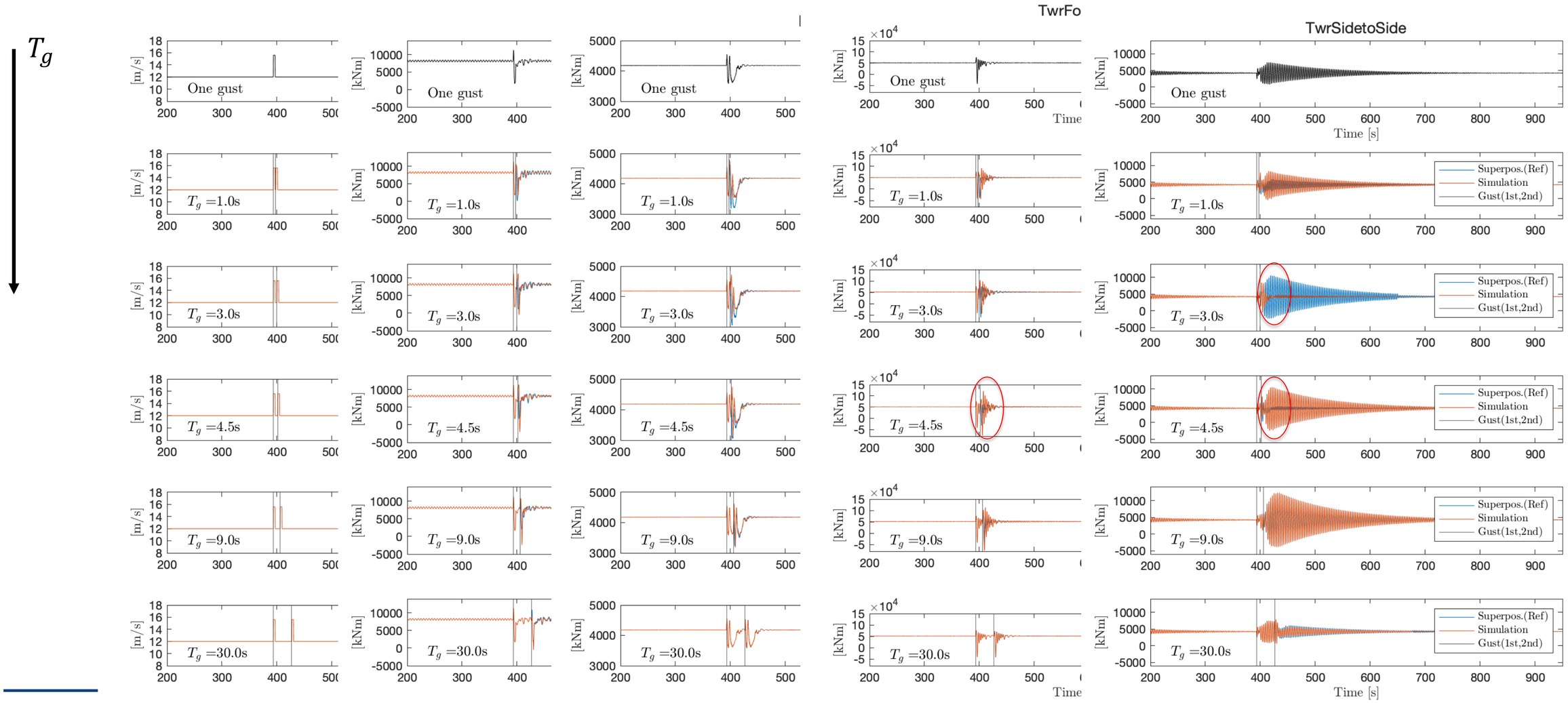
A_{ref} and A_{sim} correspond to the maximum amplitude after the second gust.





Analyzing the effect of time T_g between two gusts on the loads of the turbine

BEM Simulations: Analysis of four loads, time series



Analyzing the effect of time T_g between two gusts on the loads of the turbine

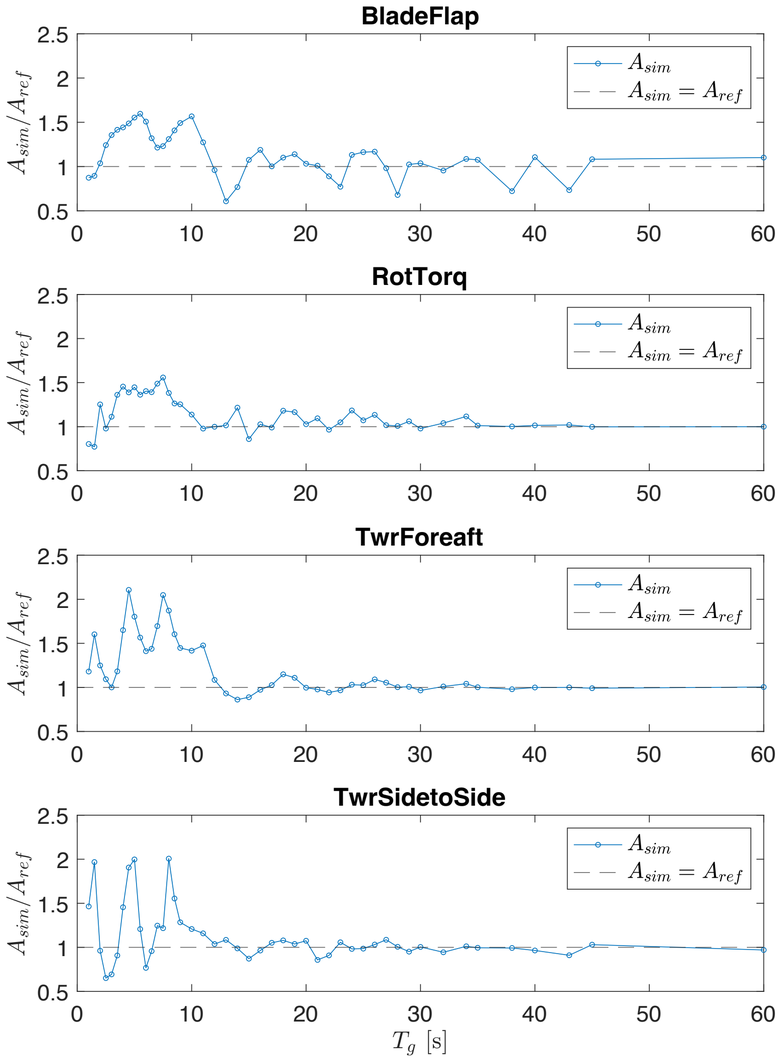
BEM Simulations: Difference between A_{ref} and A_{sim}

Reference Amplitude A_{ref}: From the superposition of two individual gusts separated by T_g.

Simulations Amplitude A_{sim}:
From BEM simulation with two gusts separated by T_g.

A_{ref} and A_{sim} correspond to the maximum amplitude after the second gust.

Normalized amplitude:
A_{sim}/A_{ref}



Analyzing the effect of time T_g between two gusts on the loads of the turbine

BEM Simulations: Analysis of four loads, three aeroelastic conditions, normalized amplitude