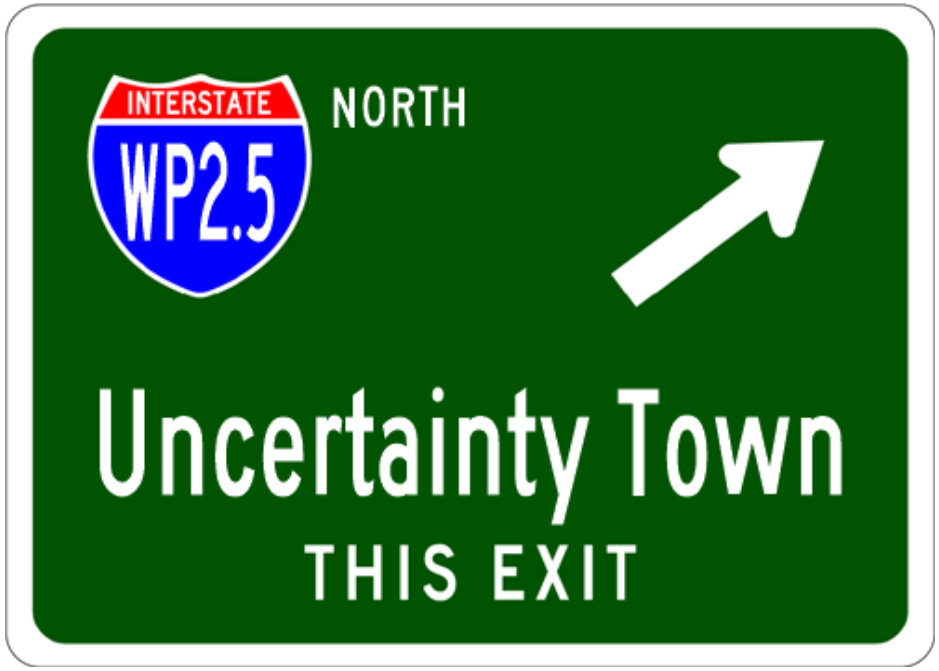
WP 2.5: Uncertainty Propagation

Laurent van den Bos



CWI

NWO Applied and Engineering Sciences

TU Delft

This research is part of the Dutch EUROS program, which is supported by NWO domain Applied and Engineering Sciences and partly funded by the Ministry of Economic Affairs.

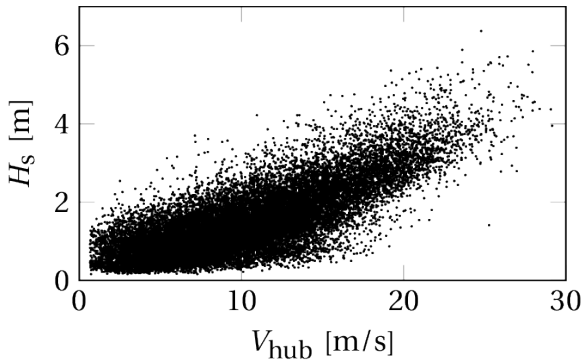
You are all cordially invited to attend the defense on my thesis titled

Quadrature Methods for Wind Turbine Load Calculations

on February 4, 2020 at 12:00 pm in the Senaatszaal of the Aula of TU Delft.

Main **goal** of my work:

$$\mathbb{E}[u] = \int_{\Omega} u(x)\, \rho(x)\, dx.$$



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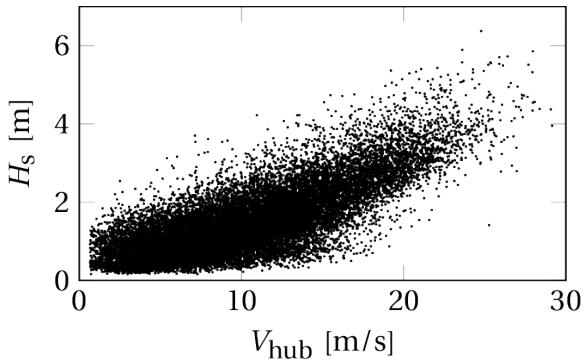
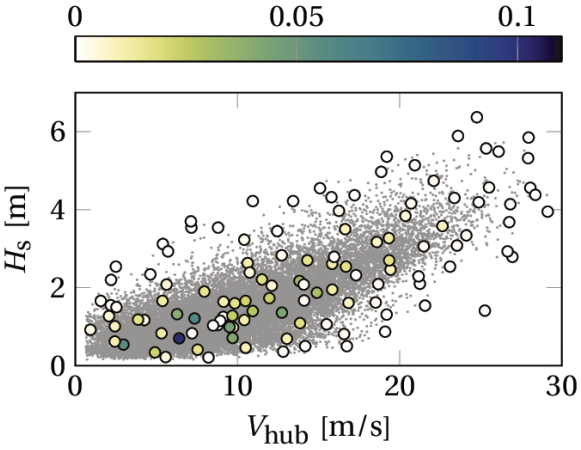


Obtained in the following cases:

- Assessing the **effect** of an uncertain parameter
- Calculating the **equivalent loads** of a component
- Inferring **Bayesian predictions** of a quantity of interest

Approach to achieve main goal:

$$\int_\Omega u(x)\,\rho(x)\,dx \approx u(x_0)w_0 + \cdots + u(x_N)w_N.$$



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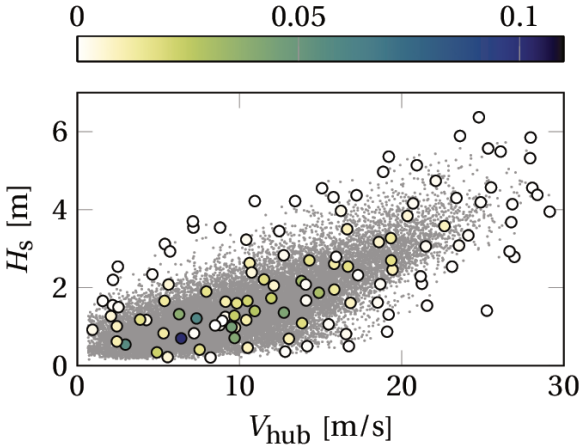


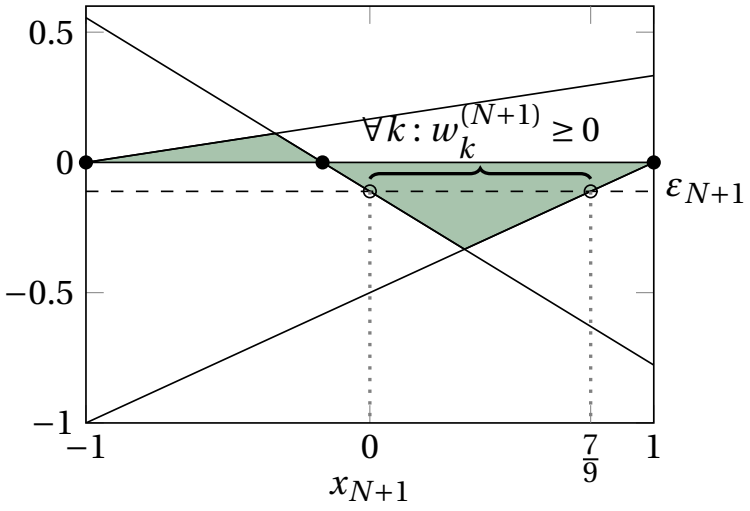
If ...

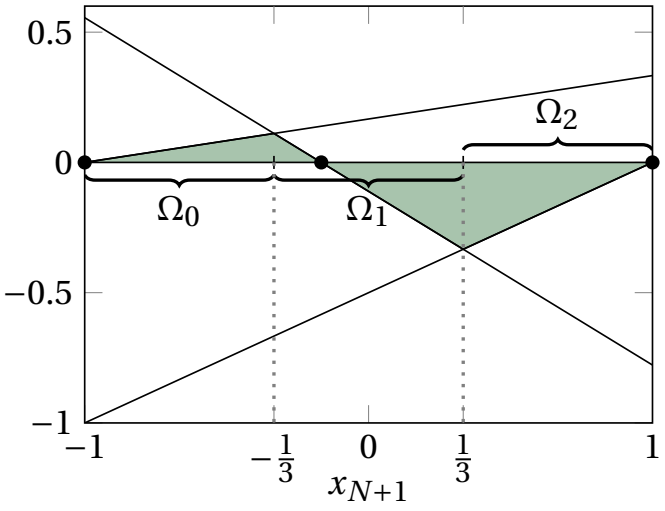
1. ... quadrature rule **accurate** for some polynomials
2. ... all **weights non-negative**

then

$$\left| \int_\Omega u(x)\,\rho(x)\,dx - (u(x_0)w_0 + \cdots u(x_N)w_N) \right| \leq 2E_N,$$

with E_N **only dependent on** u.





A mathematical description of ...

1. ... **removal** of nodes **from** a quadrature rule
2. ... **addition** of nodes **to** a quadrature rule
3. ... **replacement** of nodes **in** a quadrature rule

The **implicit quadrature rule** is based on **measurements**.

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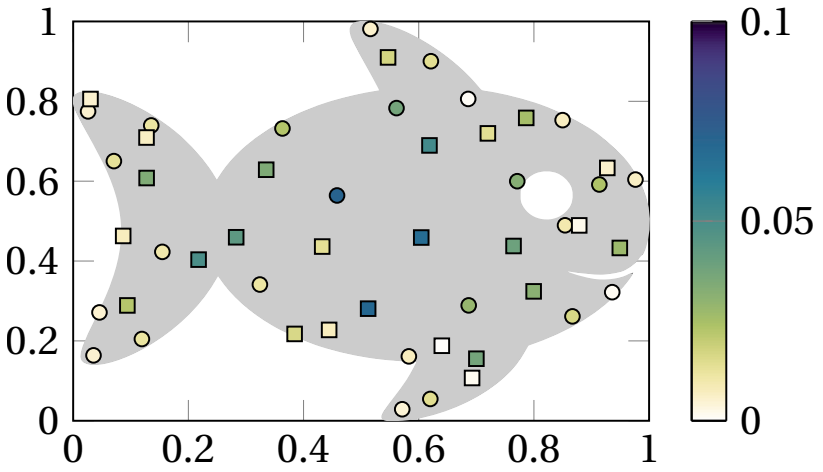
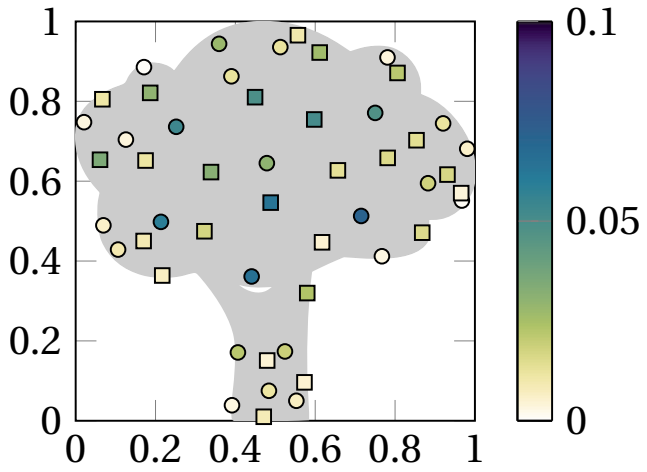
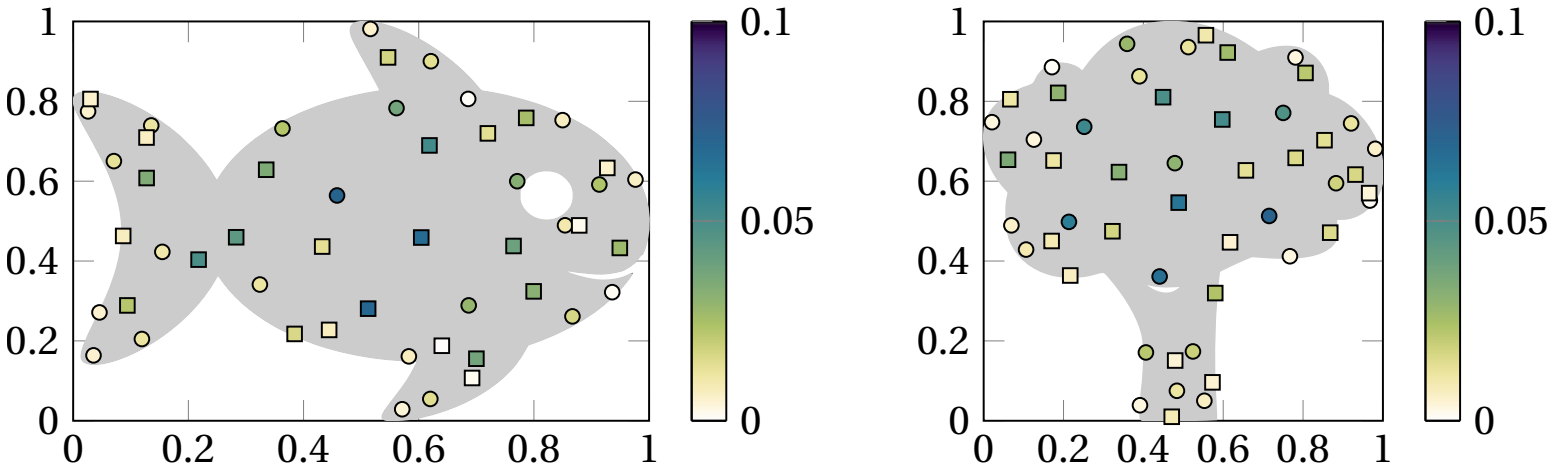




The **implicit quadrature rule** is based on **measurements**.

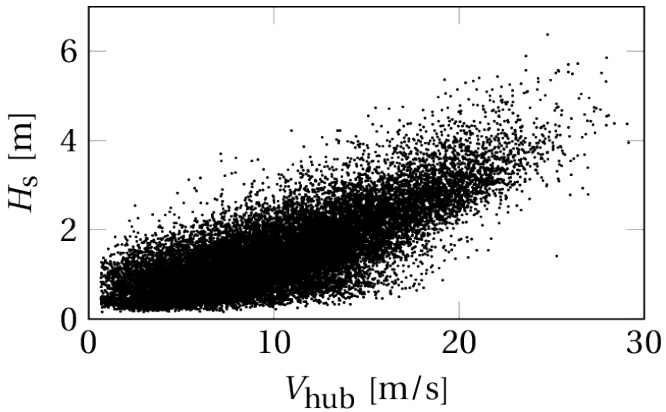


This work...

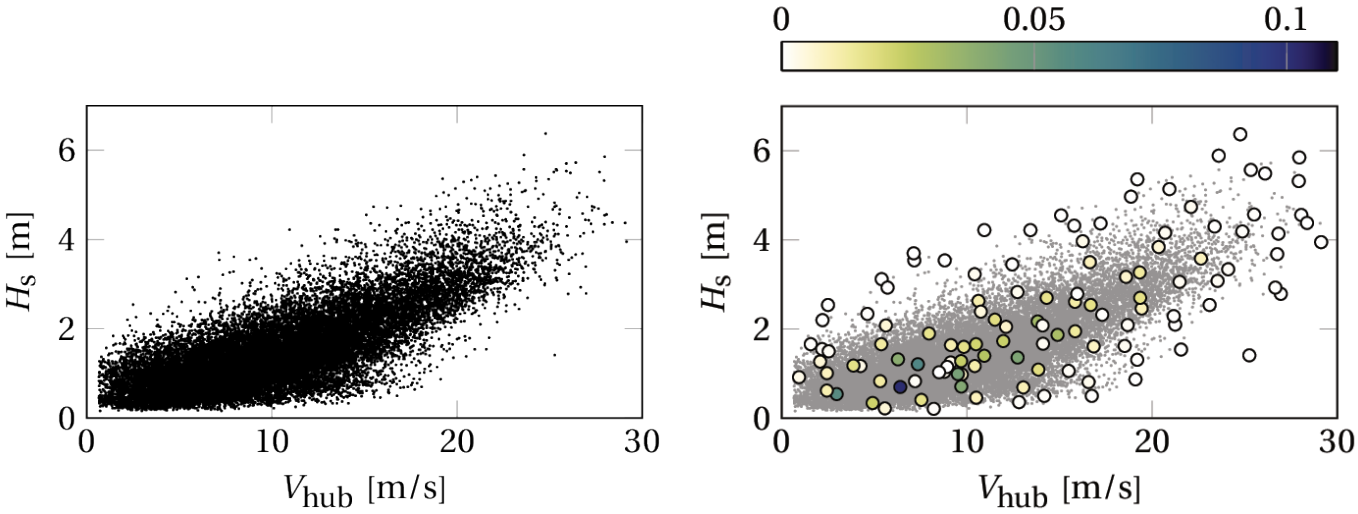
1. ... is on my **poster**
2. ... recently got **accepted** by SIAM
3. ... is available as free implementation on **Zenodo**:

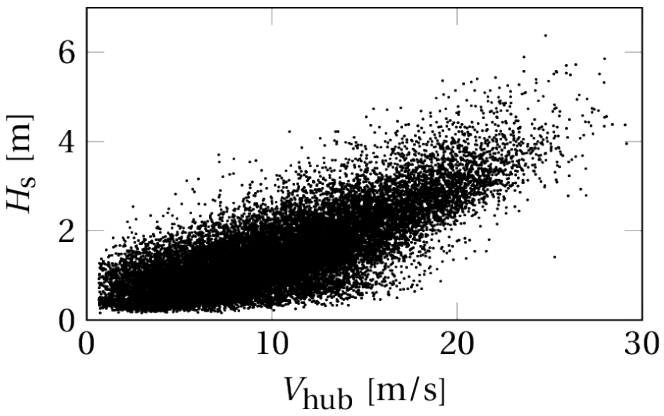
`10.5281/zenodo.3234434`

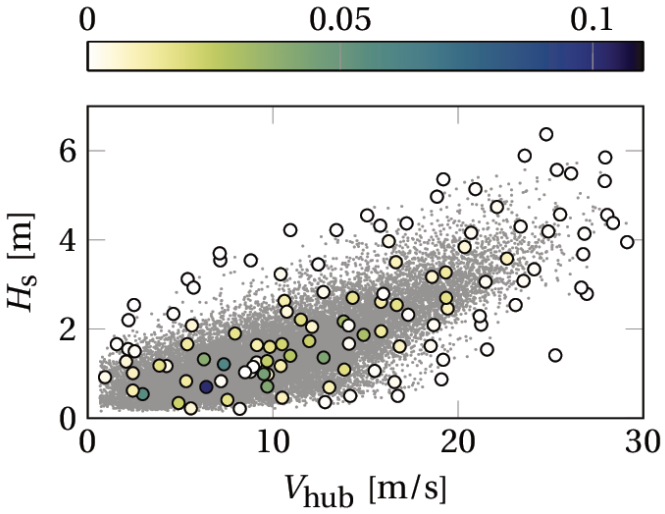
5. Design load case 1.2

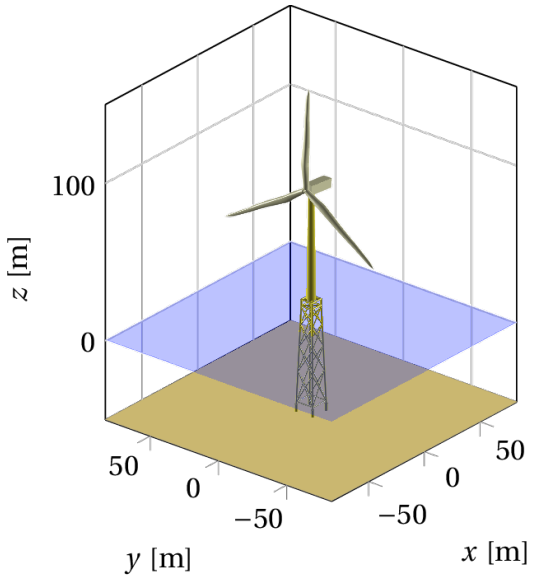


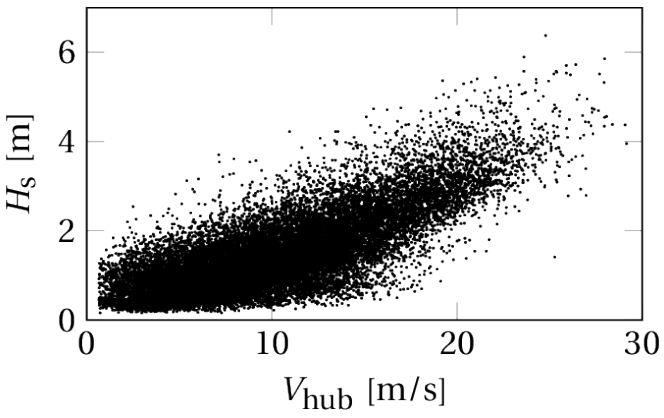
5. Design load case 1.2

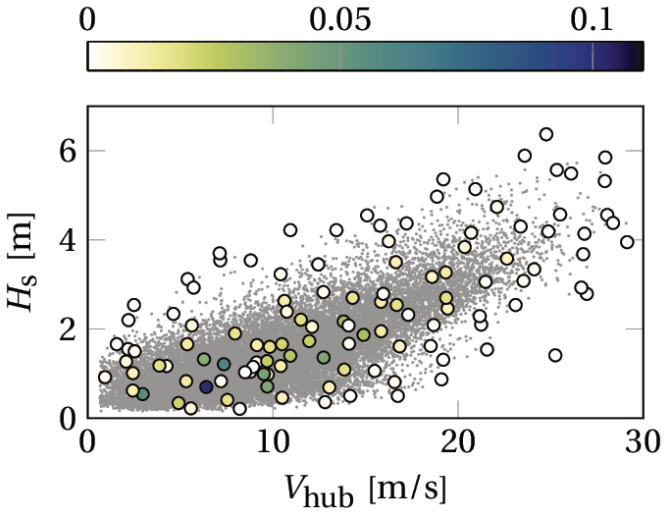



H_s [m]
0
2
4
6
0
10
20
30
V_{hub} [m/s]

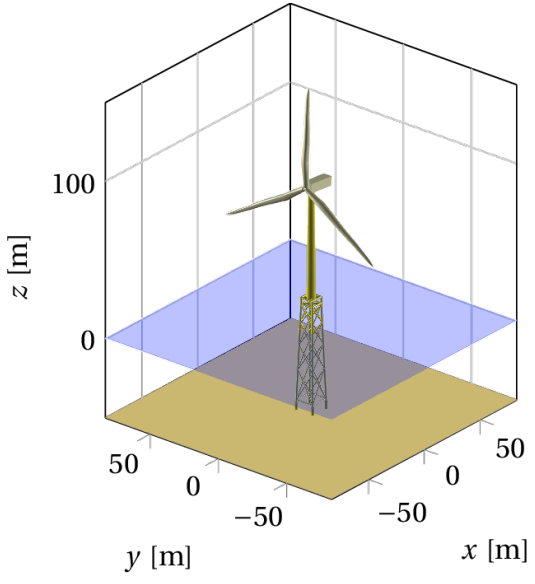

0
0.05
0.1
H_s [m]
0
2
4
6
0
10
20
30
V_{hub} [m/s]

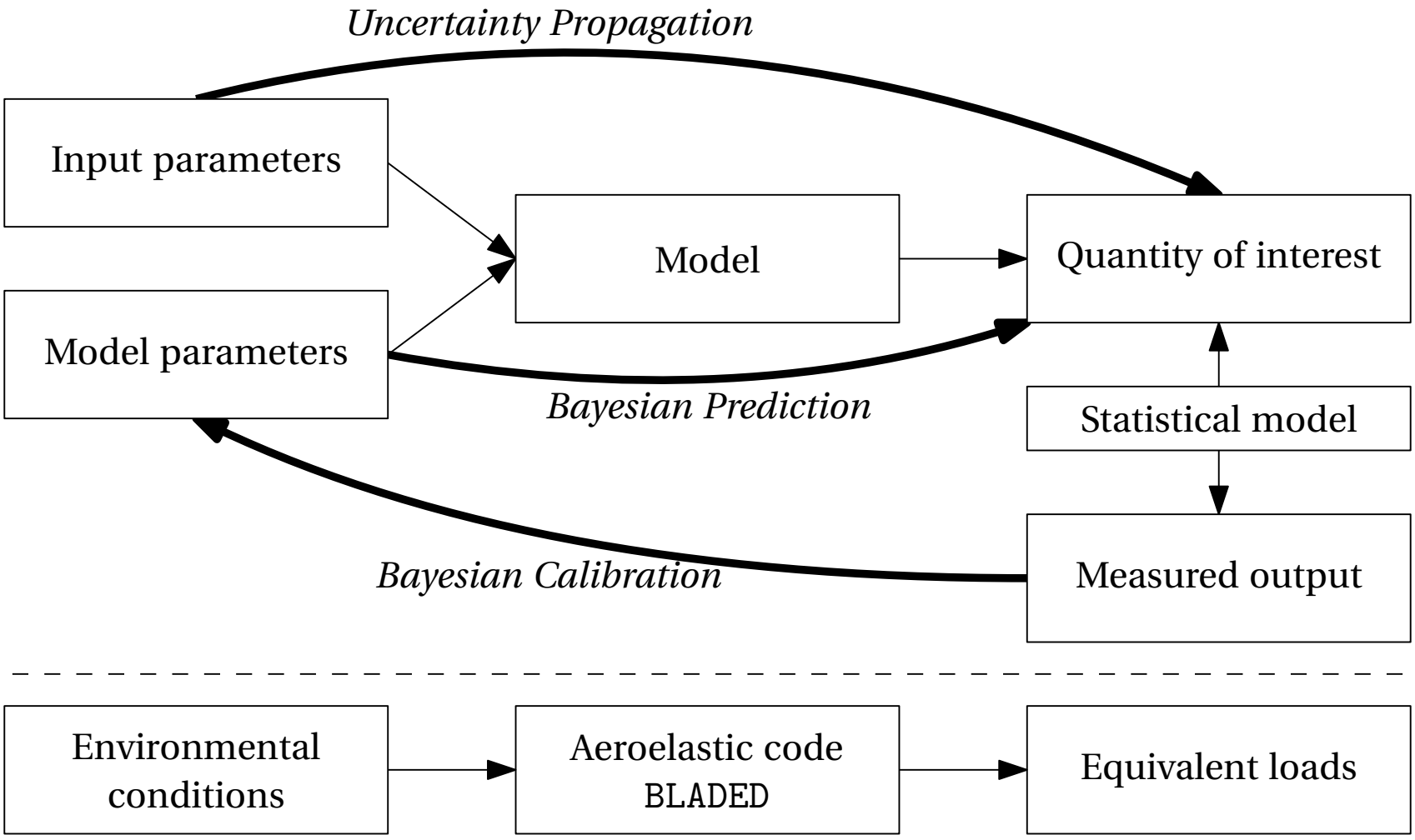

z [m]
100
0
50
0
−50
y [m]
50
0
−50
x [m]



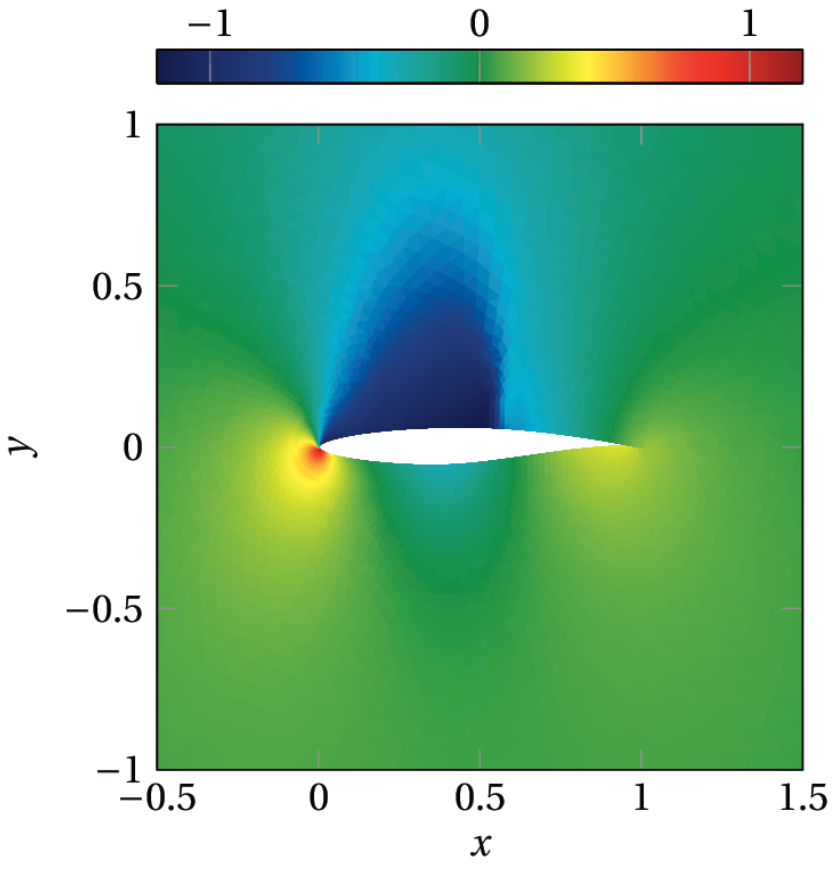


Equivalent loads following IEC standard!

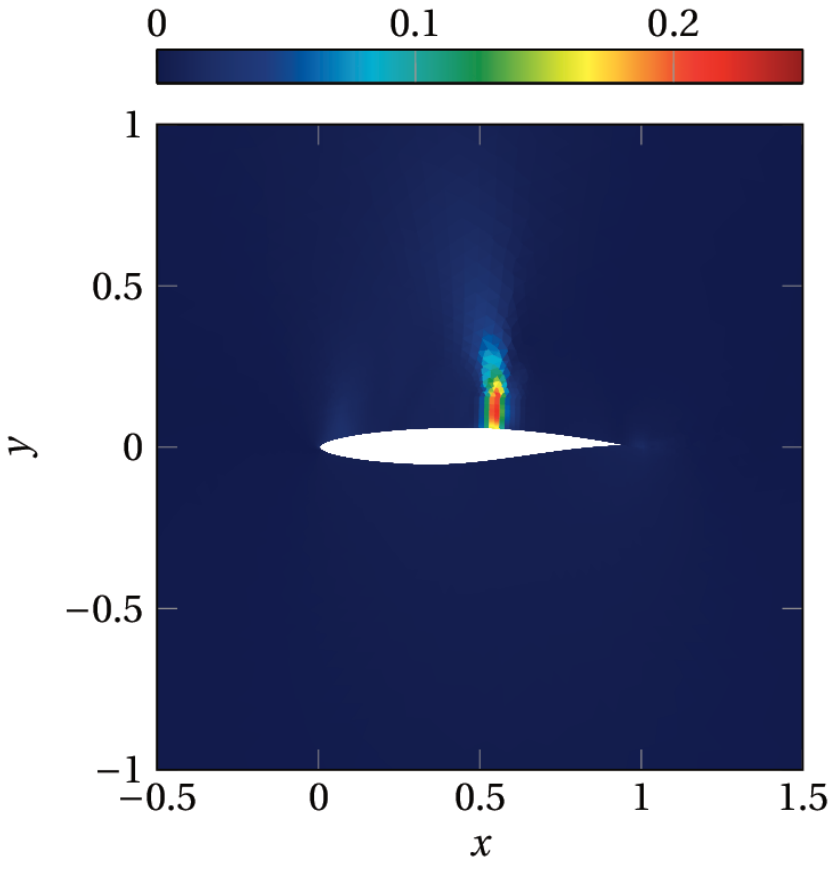



Uncertainty Propagation
Input parameters
Model
Quantity of interest
Model parameters
Bayesian Prediction
Statistical model
Bayesian Calibration
Measured output
Environmental conditions
Aeroelastic code BLADED
Equivalent loads

Combine measurement data and models obtaining:



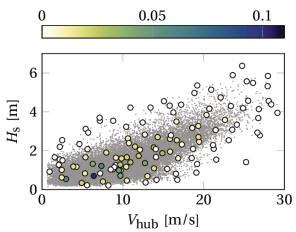
Mean

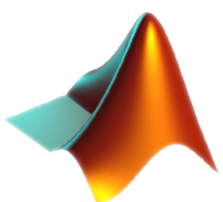


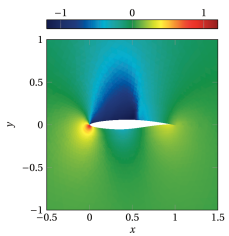
Standard deviation

Conclusion:

- It was **fun**!
- Derived a set of **quadrature rules** for UQ
- Methods are applicable to standardized wind turbine problems
- **WindTrue** project continues where I left off







Thank you all for being part of this journey!

In particular...

- **Lindert Blonk** and his colleagues from DNV GL
- **Johan Peeringa** from ECN part of TNO for WindTrue

Remember: February 4, 2020, 12:00 pm, Aula, TU Delft