Technical University of Denmark

Atmospheric stability and its influence on wind turbine loads

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Influence of atmospheric stability on wind turbine loads

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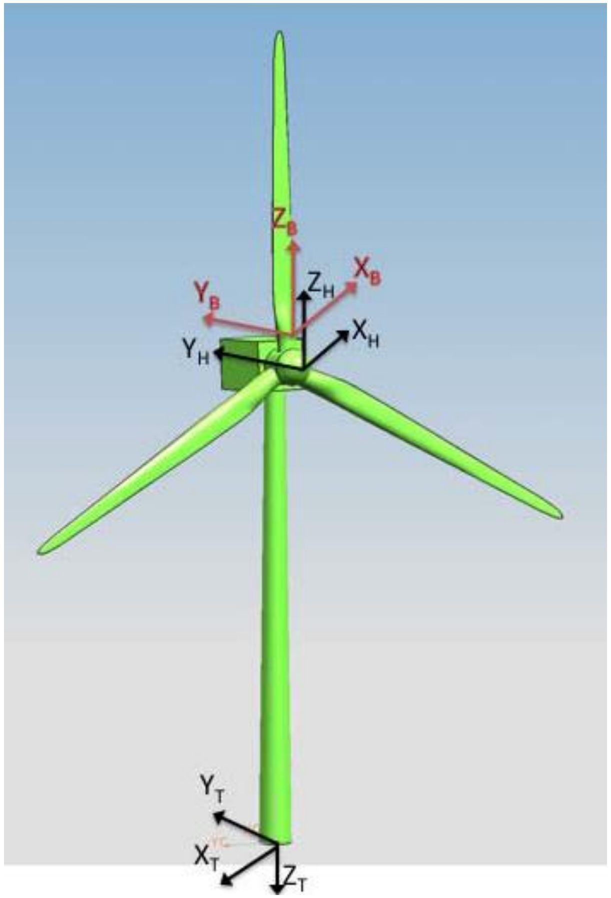
Wim Bierbooms, Gerard van Bussel

What loads are being investigated?

- Blade root flapwise and edgewise loads
- Tower foreaft loads
- Rotor Mx, My and Mz loads



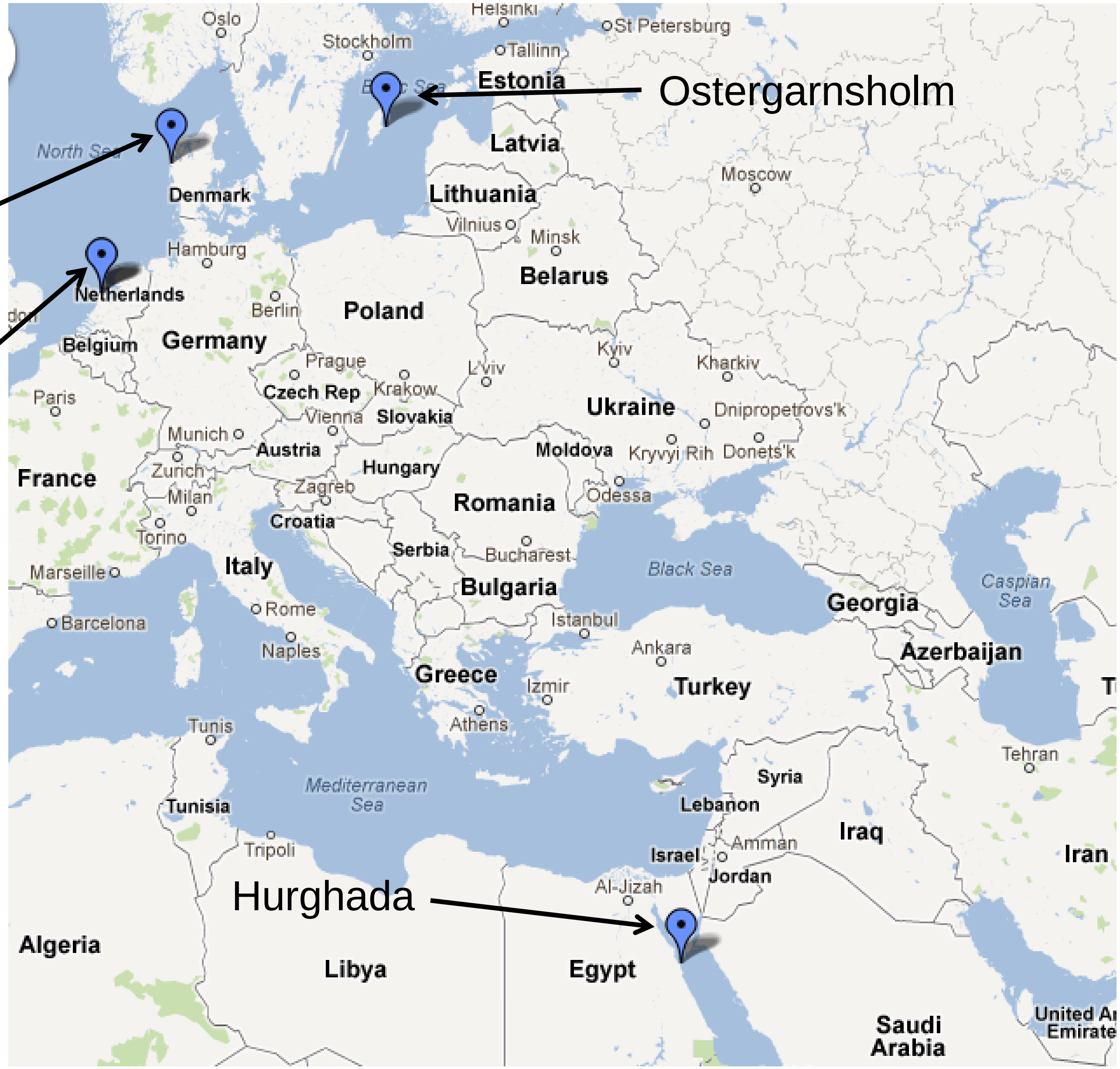
What inputs depend on atmospheric stability?

- Wind Profiles
- Atmospheric turbulence (free stream conditions)

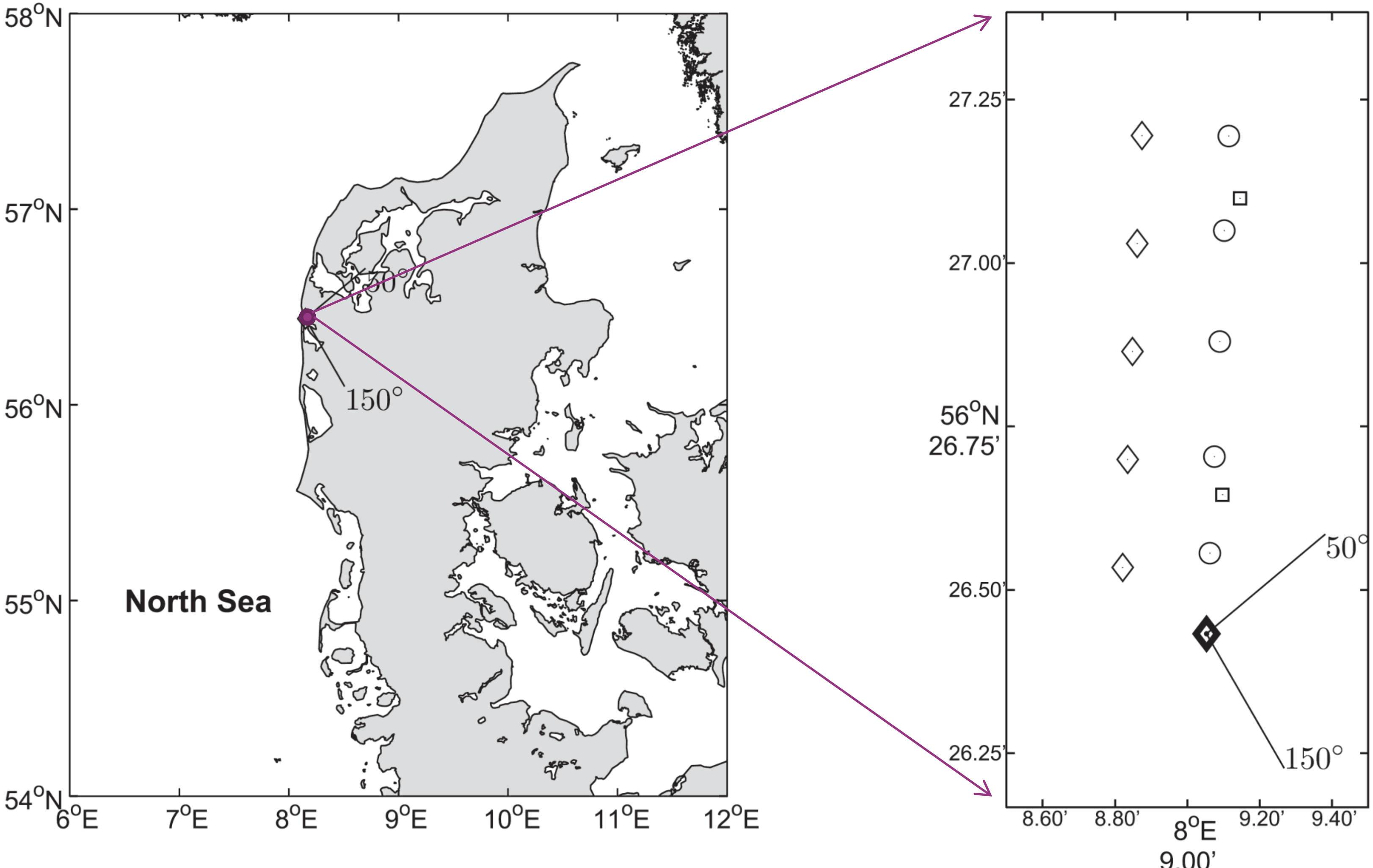
Outline

- Sites
- Wind speed and stability histograms
- Wind profiles
- Turbulence
- Simulation environment
- Load Cases
- Results of load calculations
- Conclusions

Sites


Høvsøre
Egmond aan Zee
Ostergarnsholm
Hurghada
Oslo
Stockholm
Helsinki
St Petersburg
Tallinn
Estonia
Latvia
Lithuania
Moscow
Vilnius
Minsk
Belarus
North Sea
Denmark
Hamburg
Netherlands
Berlin
Poland
Belgium
Germany
Paris
Prague
Krakow
Czech Rep
L'viv
Kyiv
Kharkiv
Ukraine
Dnipropetrovs'k
Vienna
Slovakia
Munich
Austria
Hungary
Moldova
Kryvyi Rih
Donets'k
Zurich
France
Milan
Zagreb
Romania
Odessa
Torino
Croatia
Serbia
Bucharest
Italy
Marseille
Black Sea
Bulgaria
Georgia
Caspian Sea
Rome
Barcelona
Istanbul
Naples
Ankara
Azerbaijan
Greece
Izmir
Turkey
Athens
Tunis
Tehran
Mediterranean Sea
Syria
Tunisia
Lebanon
Iraq
Tripoli
Amman
Israel
Iran
Jordan
Al-Jizah
Algeria
Libya
Egypt
Saudi Arabia

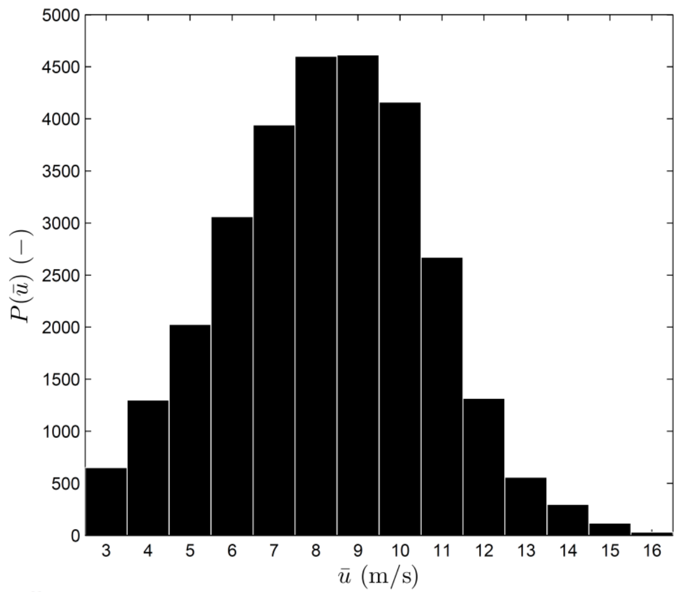
Høvsøre



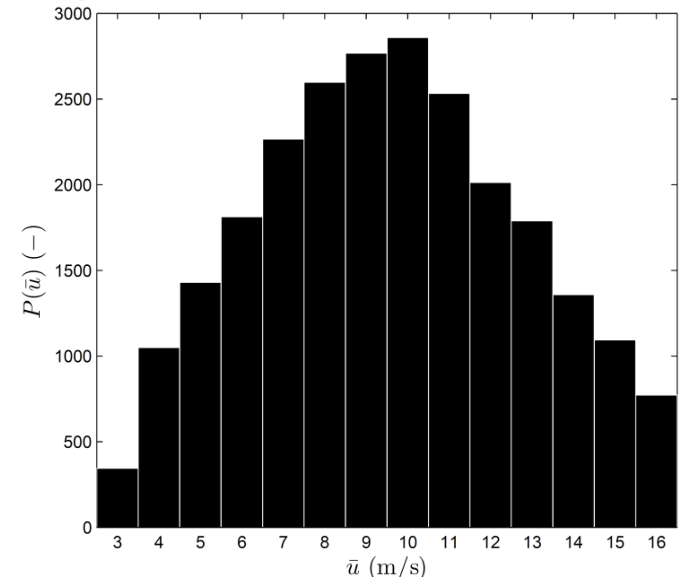
58°N
57°N
56°N
55°N
54°N
6°E
7°E
8°E
9°E
10°E
11°E
12°E
150°
North Sea
27.25'
27.00'
56°N
26.75'
26.50'
26.25'
8.60'
8.80'
8°E
9.00'
9.20'
9.40'
50°
150°

Histograms of mean wind speeds

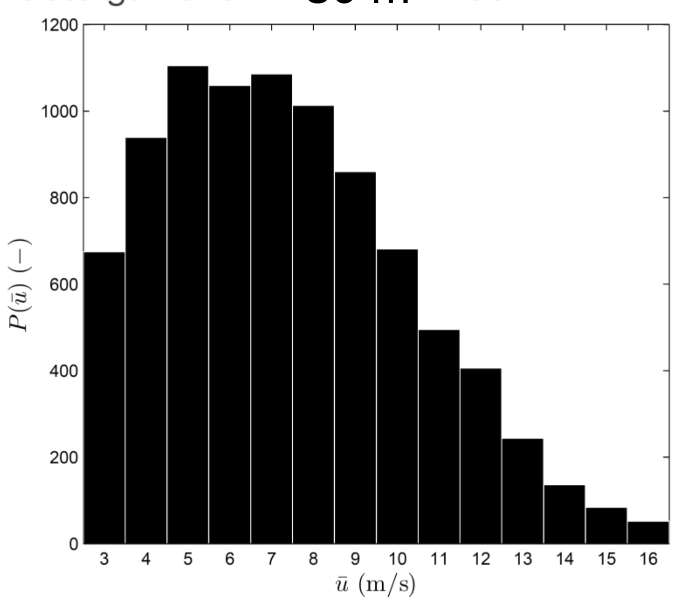
Høvsøre 90 m 9.13 3.82



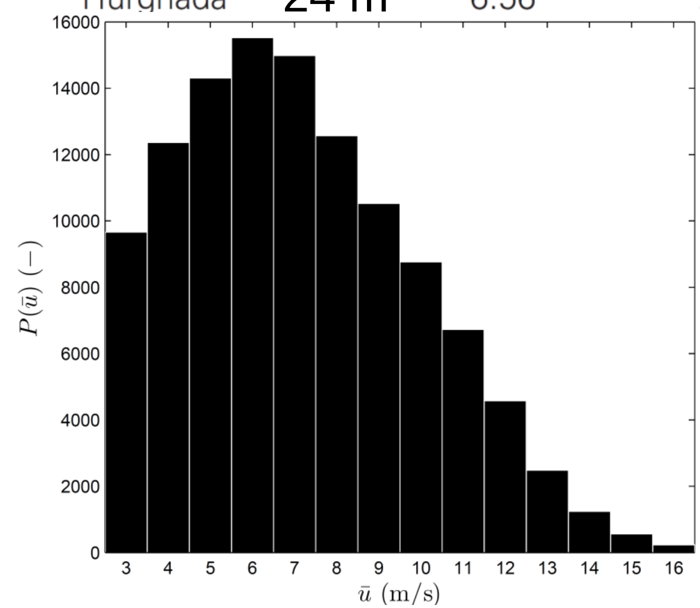
OWEZ 70 m 11.12 3.07



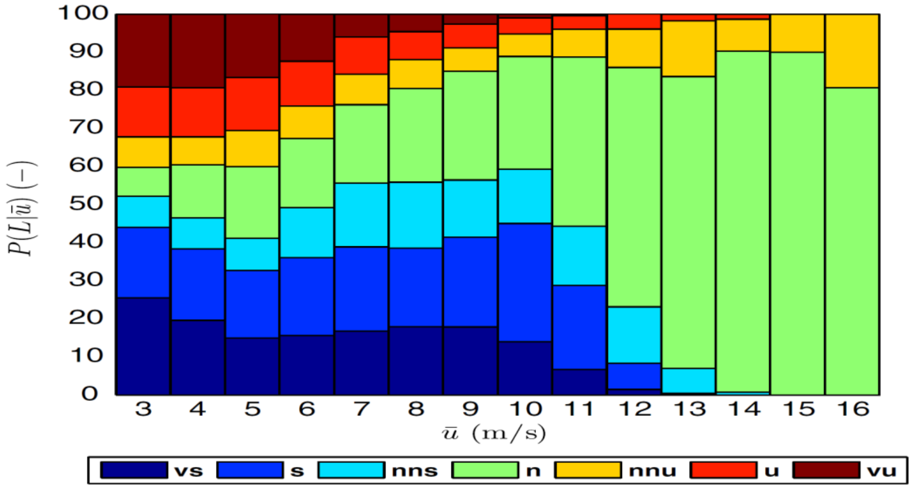
Östergarnsholm 30 m 7.86 2.18



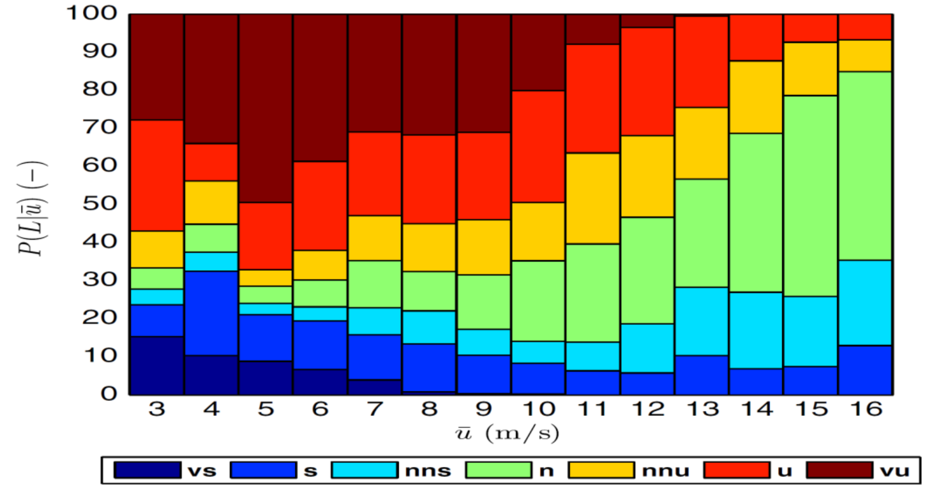
Hurghada 24 m 6.56 2.70



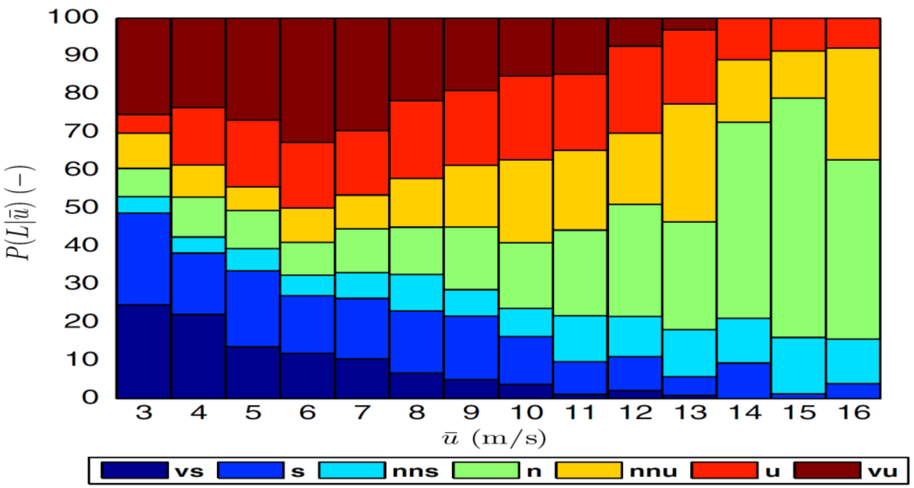
Stability Histograms



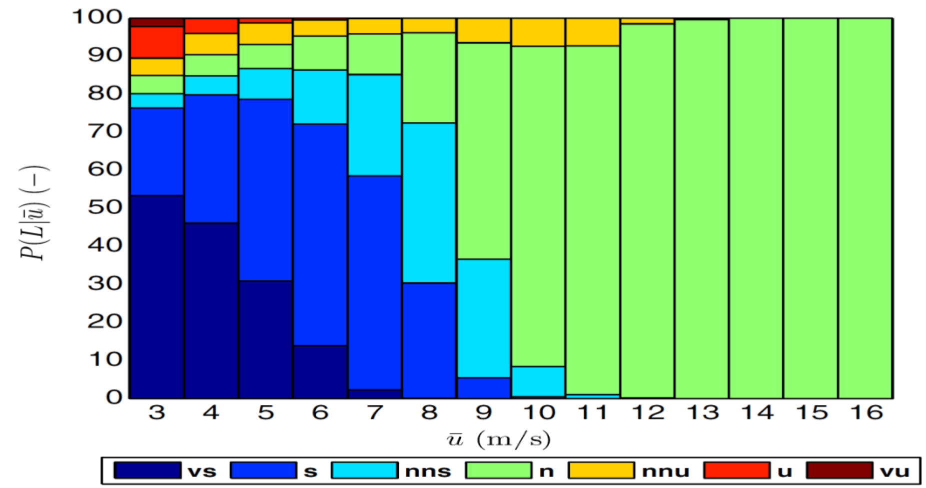
(a) Høvsøre



(b) OWEZ

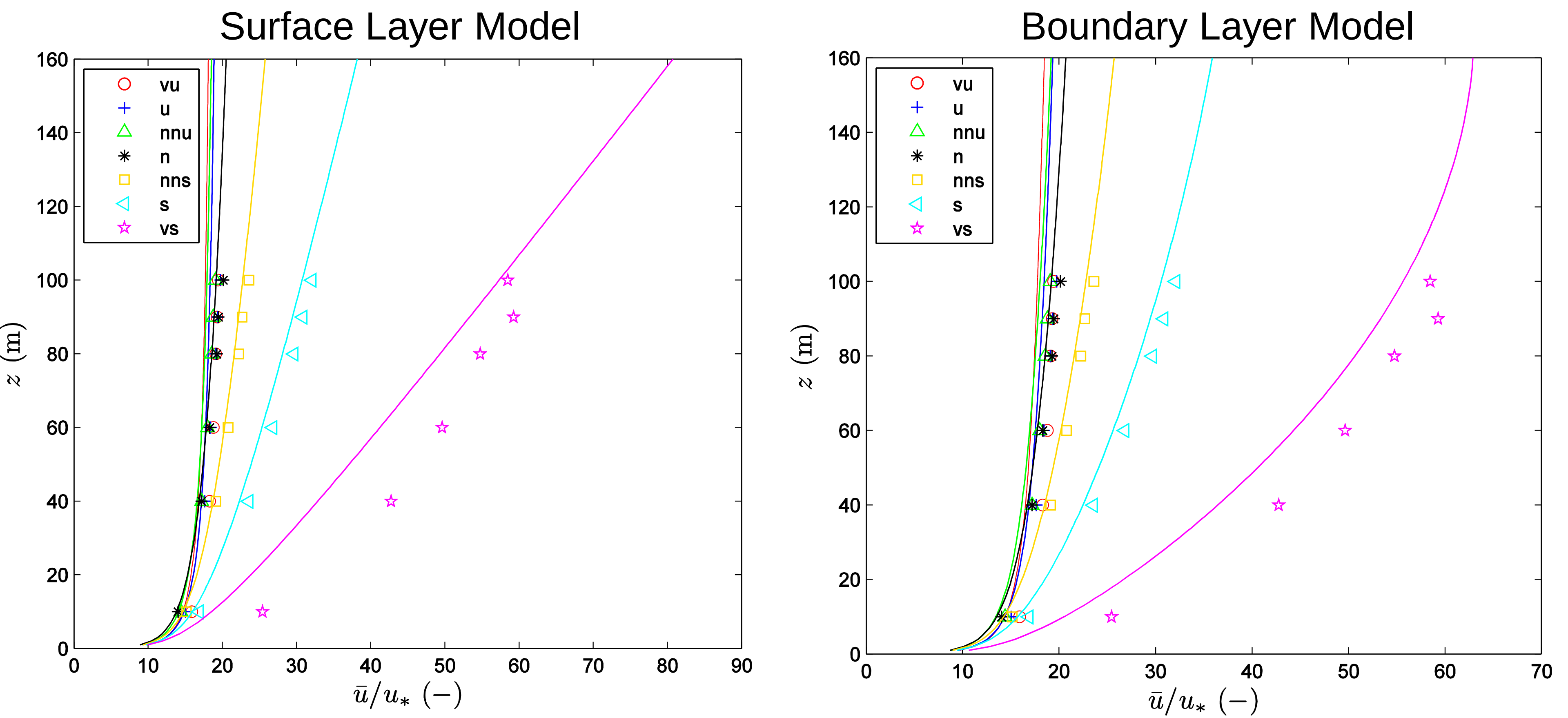


(c) Östergarnsholm



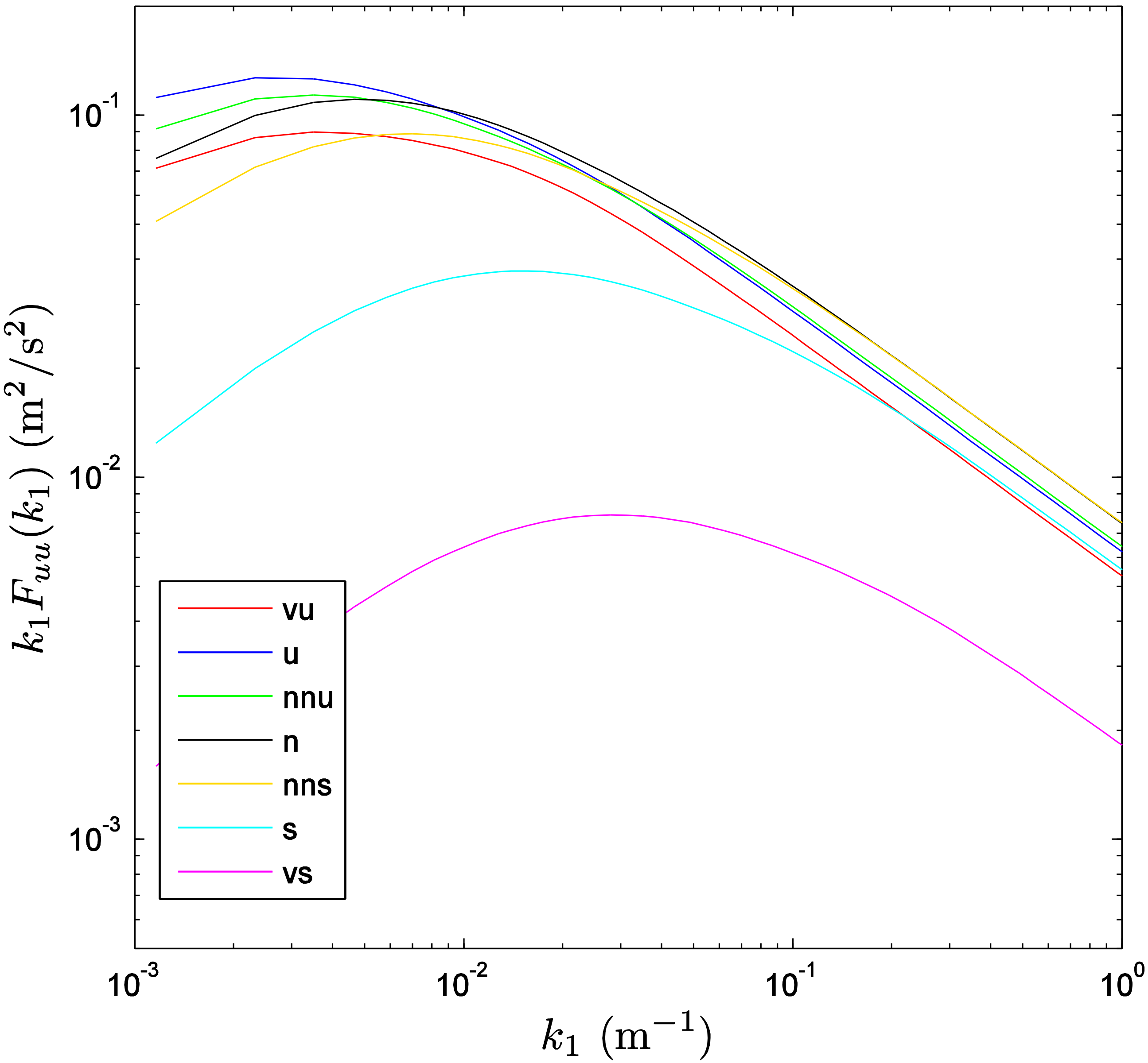
(d) Hurghada

Wind Profile Analysis - Høvsøre



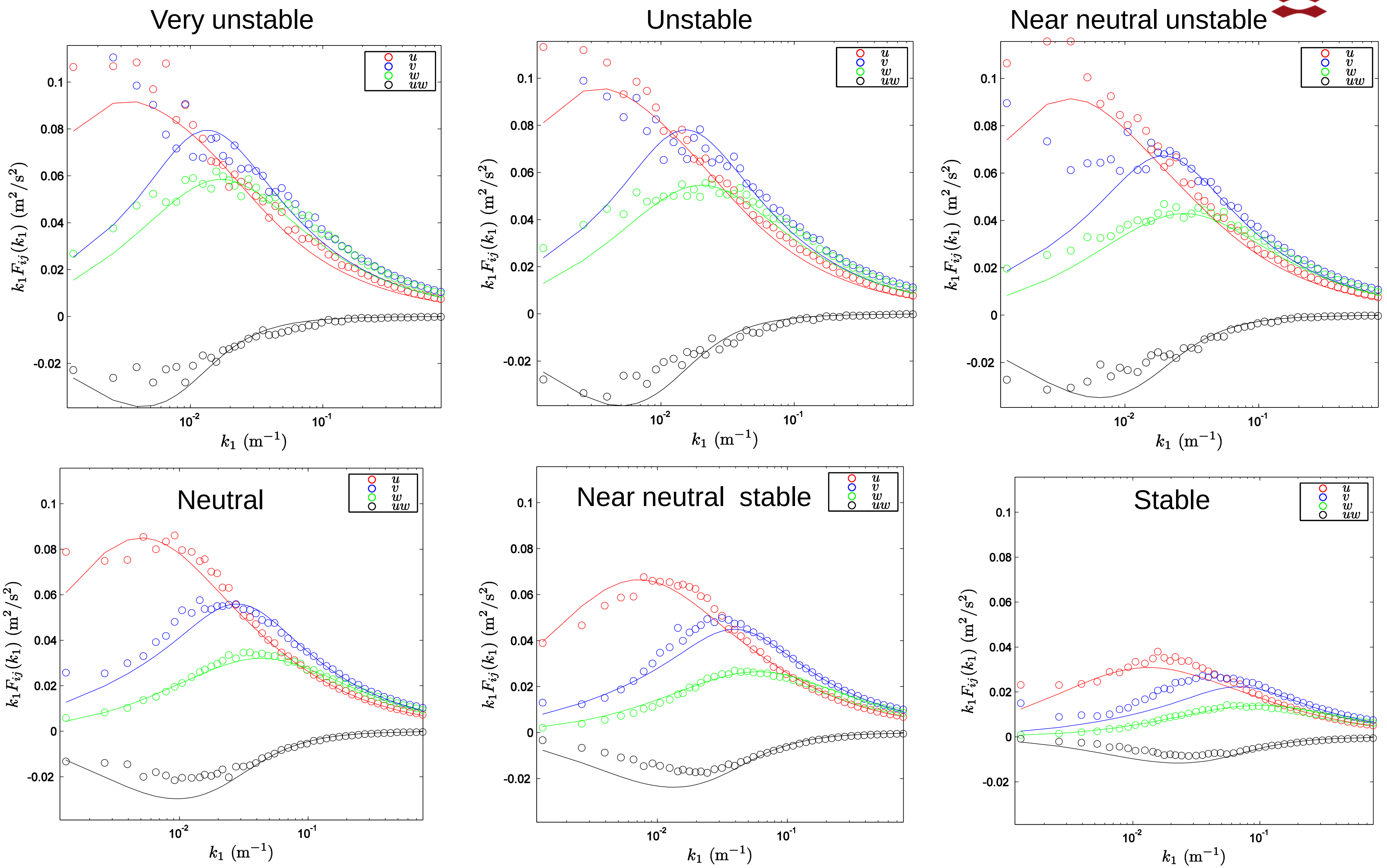
Sathe A, Gryning SE, Peña A. Comparison of the atmospheric stability and wind profiles at two wind farm sites over a long marine fetch in the North Sea. *Wind Energy* 2011; **14**(6): 767–780. DOI: 10.1002/we.456.

Turbulence Spectra



Mann J. The spatial structure of neutral atmospheric surface-layer turbulence. *Journal of Fluid Mechanics* 1994; **273**: 141–168. DOI: 10.1017/S0022112094001886.

Turbulence Spectra



Simulation Environment

NREL 5 MW wind turbine
HAWC 2 code
Wind speed bins: 3 – 16 m/s

Maximum power	5 MW
Number of blades	3
Rotor diameter	126 m
Hub height	90 m
Cut-in wind speed	3 m s^{-1}
Rated wind speed	11.4 m s^{-1}
Cut-out wind speed	25 m s^{-1}
Control	Variable speed, collective pitch

Load Cases

$$D = \sum D_i^m N_i = D_{\mathrm{EQ}}^m N_{\mathrm{EQ}}$$

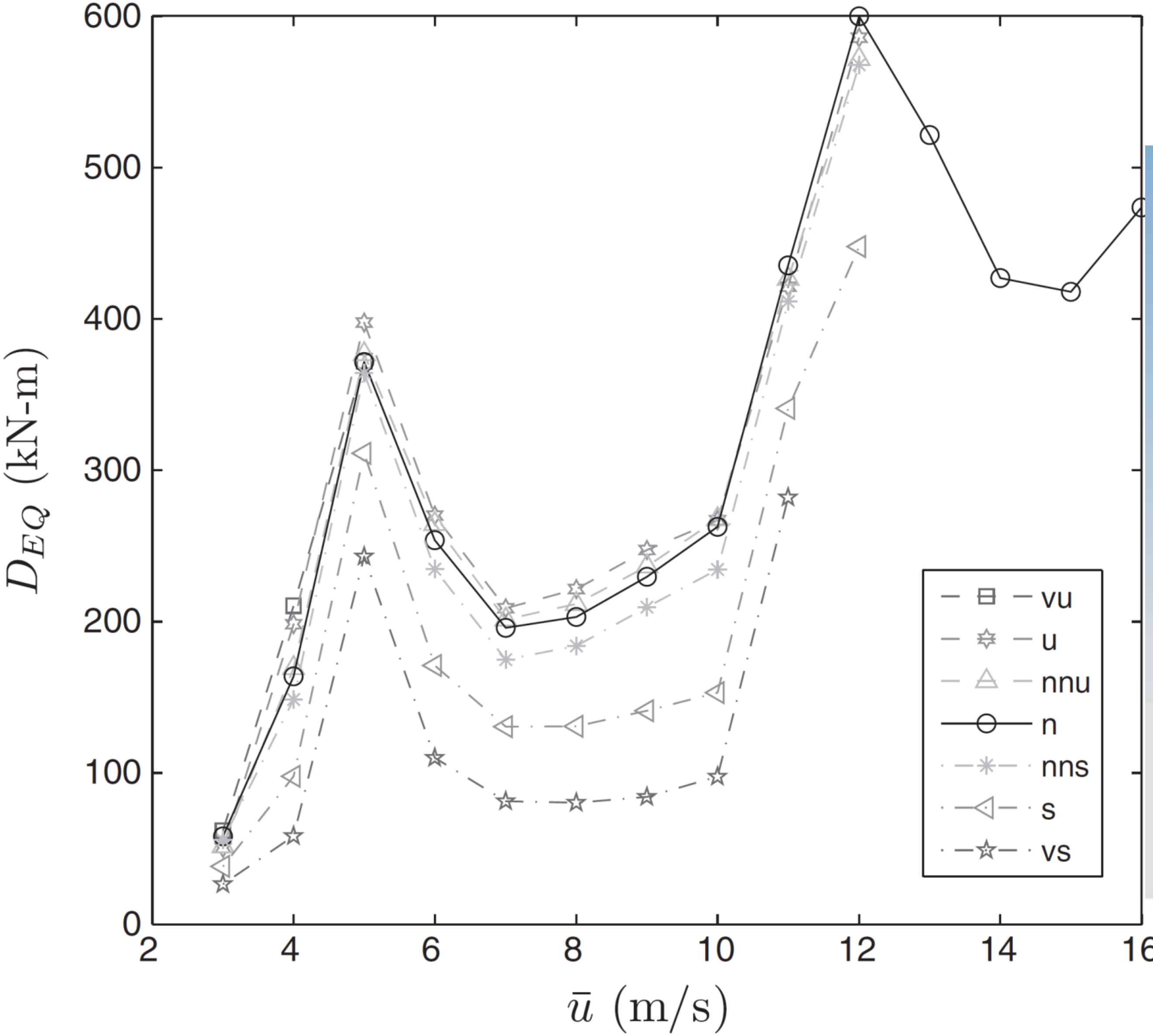
$$D_{\mathrm{EQ}} = \left(\frac{\sum D_i^m N_i}{N_{\mathrm{EQ}}} \right)^{1/m}$$

$$D_{\mathrm{EQ}_C} = \sum_{\bar{u}=3}^{16} \left(\sum_{L=\mathrm{vu}}^{\mathrm{vs}} D_{\mathrm{EQ}} \times P(L|\bar{u}) \right) \times P(\bar{u})$$

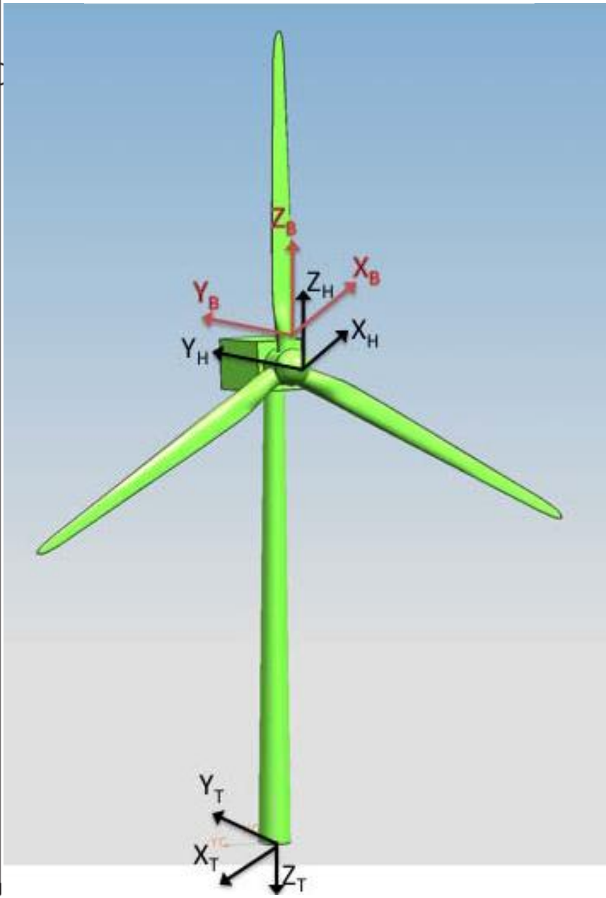
Table IV. Load cases.

Cases	
I	Diabatic boundary-layer wind profile and turbulence
II	Neutral boundary-layer wind profile and turbulence
III	Diabatic surface-layer wind profile and turbulence
IV	IEC load case, power law exponent = 0.2

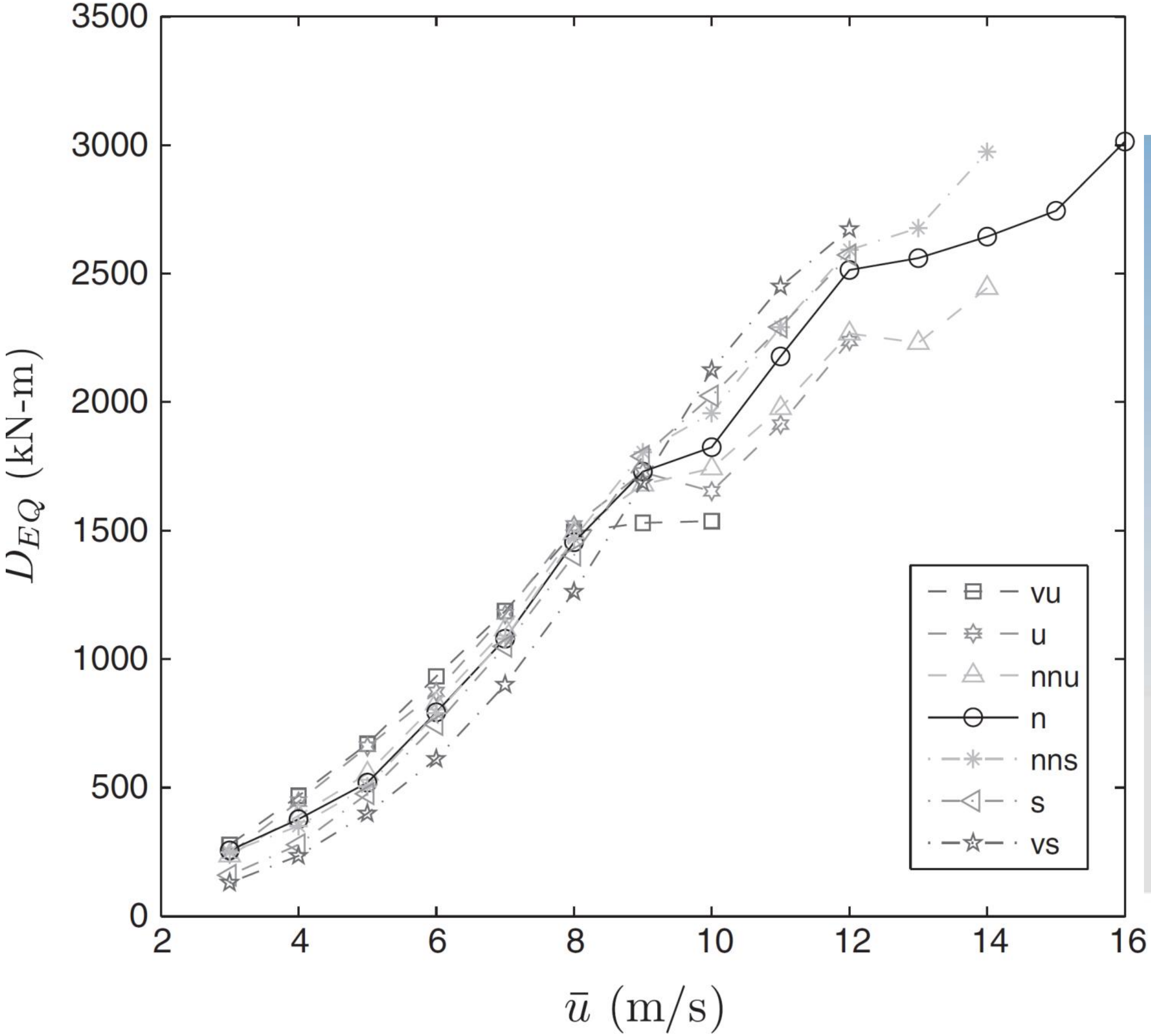
Tower base fore-aft bending moment



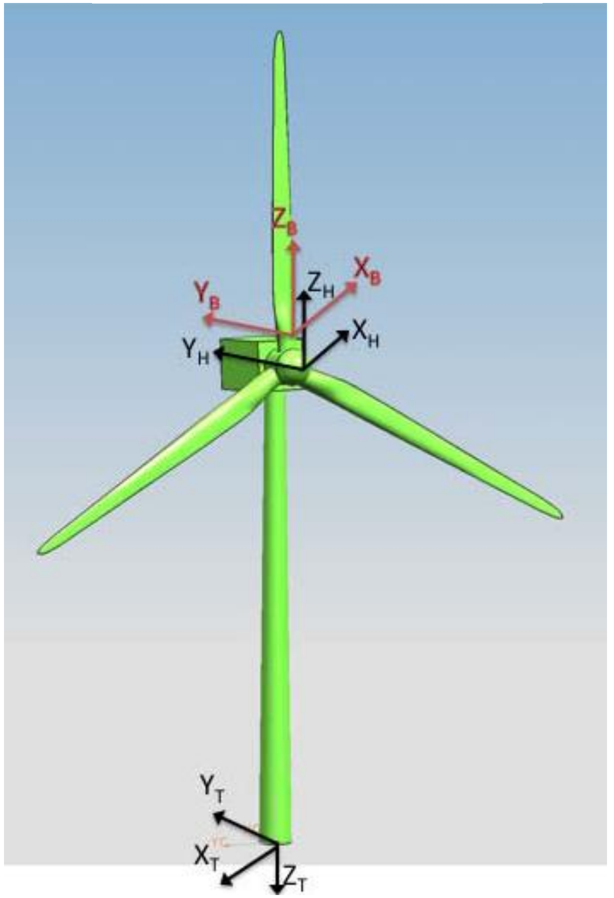
$$D_{\mathrm{EQ}} = \left(\frac{\sum D_i^m N_i}{N_{\mathrm{EQ}}} \right)^{1/m}$$



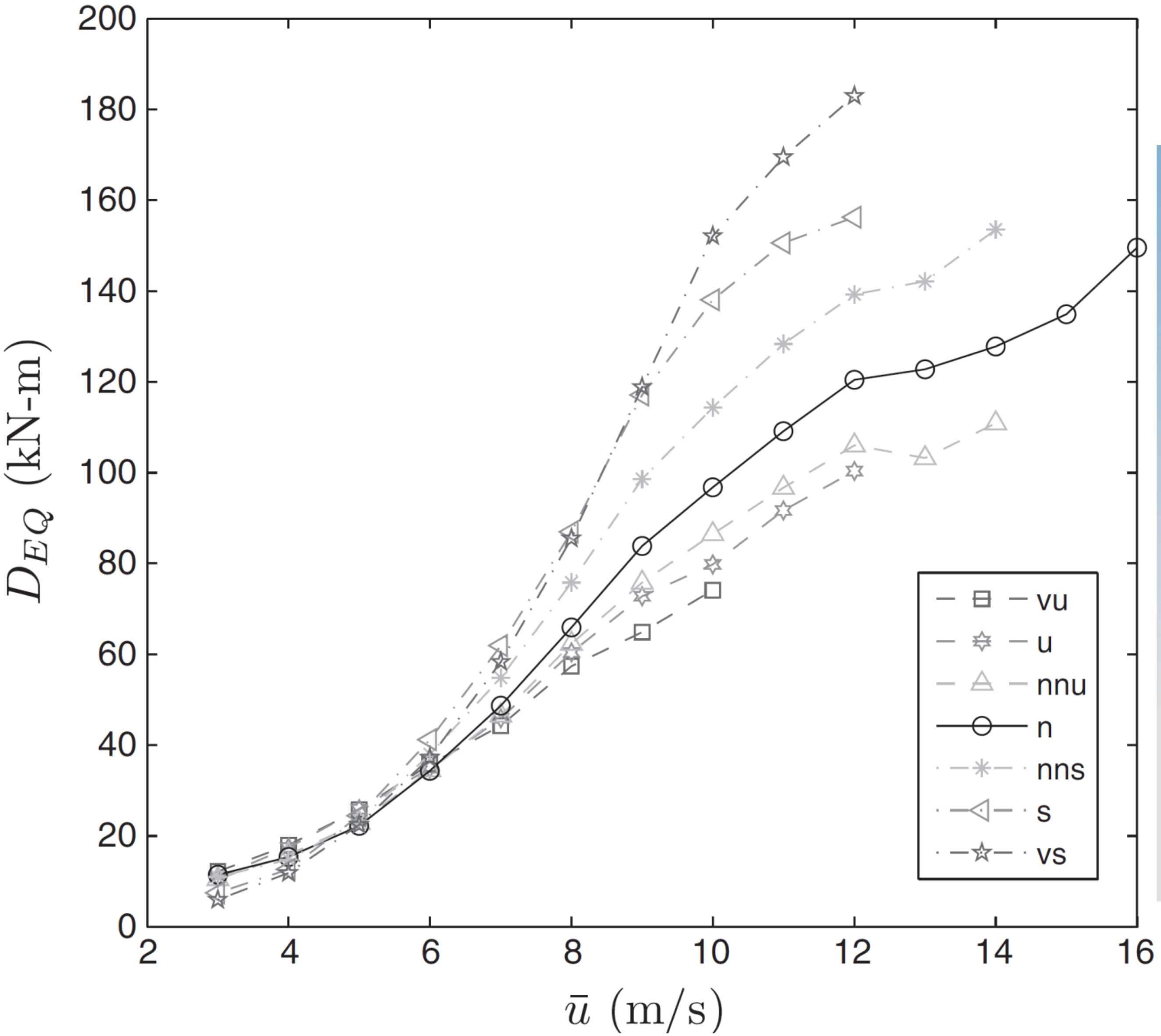
Blade root falpwise bending moment



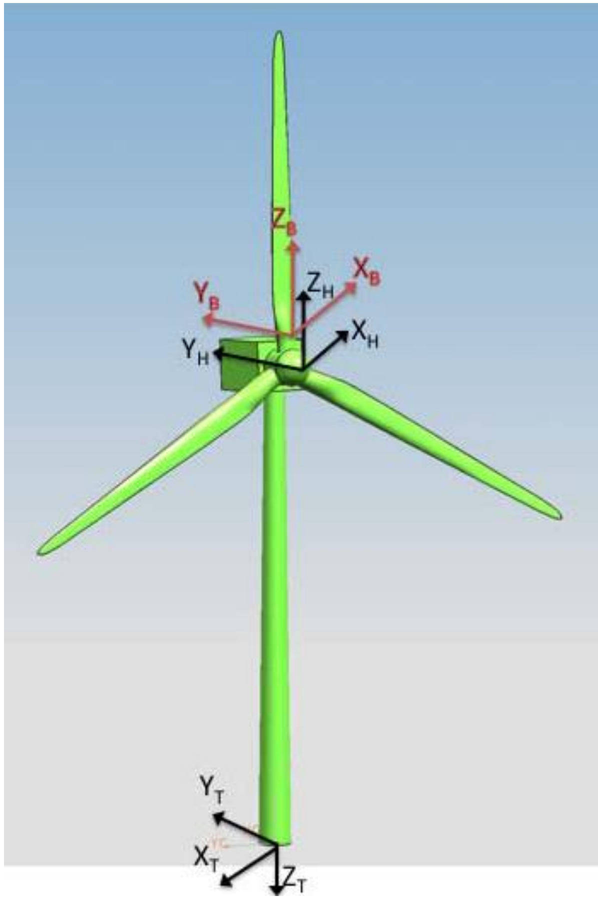
$$D_{\mathrm{EQ}} = \left(\frac{\sum D_i^m N_i}{N_{\mathrm{EQ}}} \right)^{1/m}$$



Rotor Mx bending moment



$$D_{\mathrm{EQ}} = \left(\frac{\sum D_i^m N_i}{N_{\mathrm{EQ}}} \right)^{1/m}$$



Cumulative Damage Equivalent Load

$$D_{EQ_C} = \sum_{\bar{u}=3}^{16} \left(\sum_{L=\mathrm{vu}}^{\mathrm{vs}} D_{EQ} \times P(L|\bar{u}) \right) \times P(\bar{u})$$

Table IV. Load cases.

Cases	
I	Diabatic boundary-layer wind profile and turbulence
II	Neutral boundary-layer wind profile and turbulence
III	Diabatic surface-layer wind profile and turbulence
IV	IEC load case, power law exponent = 0.2

Table V. Normalized D_{EQ_C} of bending moments at different sites.

Cases	Blade root	Tower base	Rotor loads
Høvsøre			
I			
II			
III			
IV			

Conclusions

- The influence of atmospheric stability on loads can be considered significant (up to 17 %) depending on the component of interest
- The influence of using different wind profile models is up to a limited extent (up to 7 %), and depends on the component of interest.

Open questions

- Should atmospheric stability be included in load calculations?
- Are the differences in the calculated loads larger than the uncertainties in the load calculations?

Thank you!

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