The Wind Farm in its environment

Far offshore wind conditions in scope of wind energy

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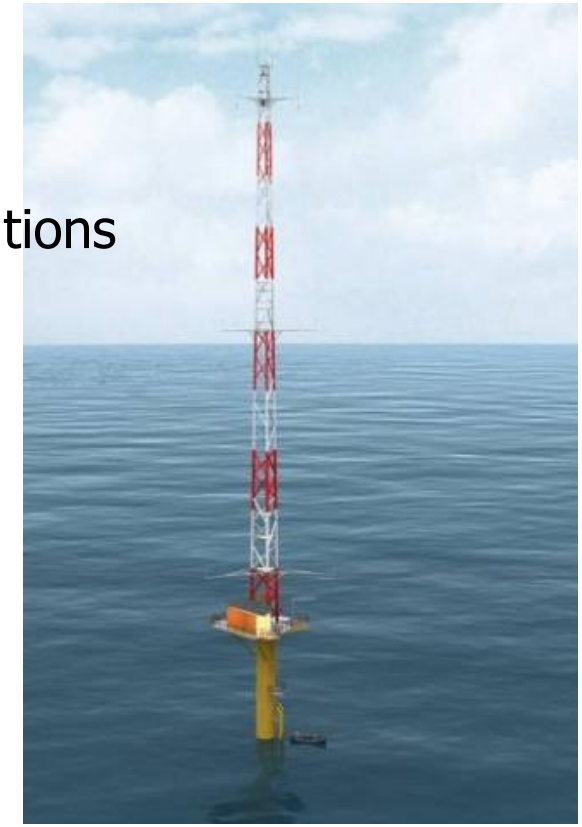
Far-offshore wind climate models

- Part of FLOW project: DUWIND's far offshore wind farm design PhD's

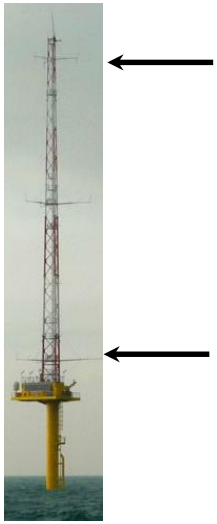
- Why atmospheric research for wind energy?
  - Planning / resource assessment
  - Design (farm and turbines)
  - Wind farm performance

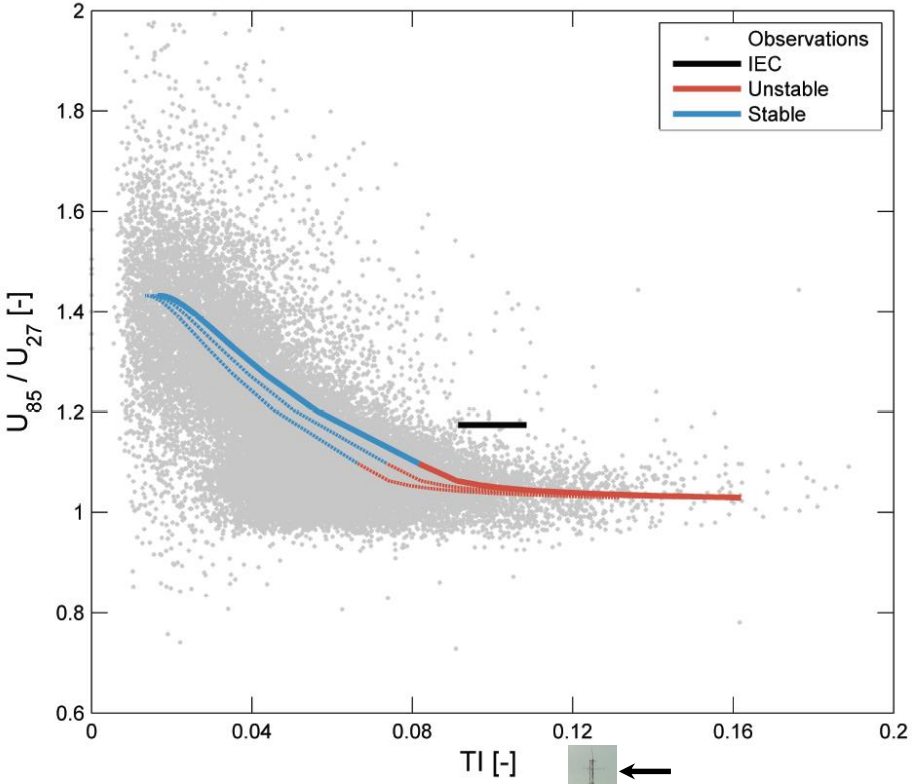
Met mast IJmuiden Far

- 85 km offshore (→ far offshore!)
- Fully equipped for atmosphere / sea observations
  - Cup / vane at 27 to 90m height
  - Sonic's at 85m height
  - LIDAR for 90 to 315m height
  - Temperature / humidity / pressure
  - Water temperature / waves / currents



Measured wind shear and turbulence intensity





You will never have a high shear and a high turbulence level at the same time

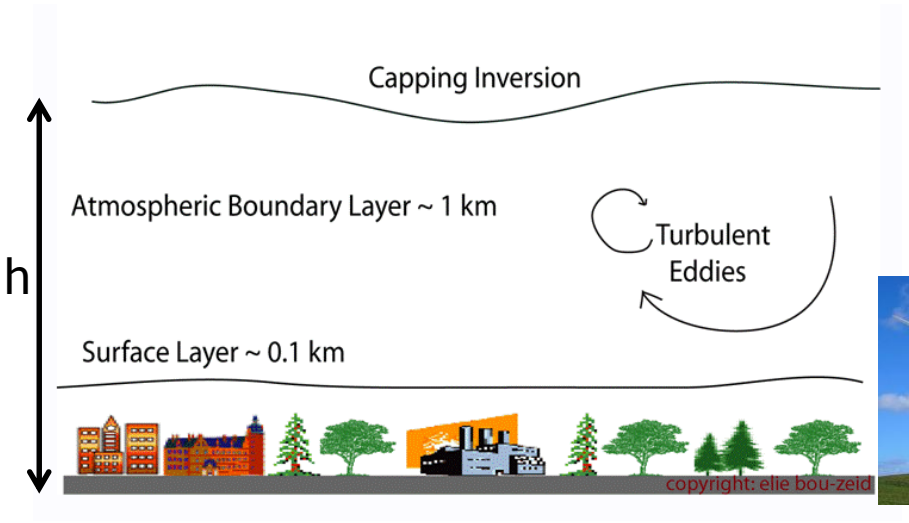
Wind shear profile – old formulation

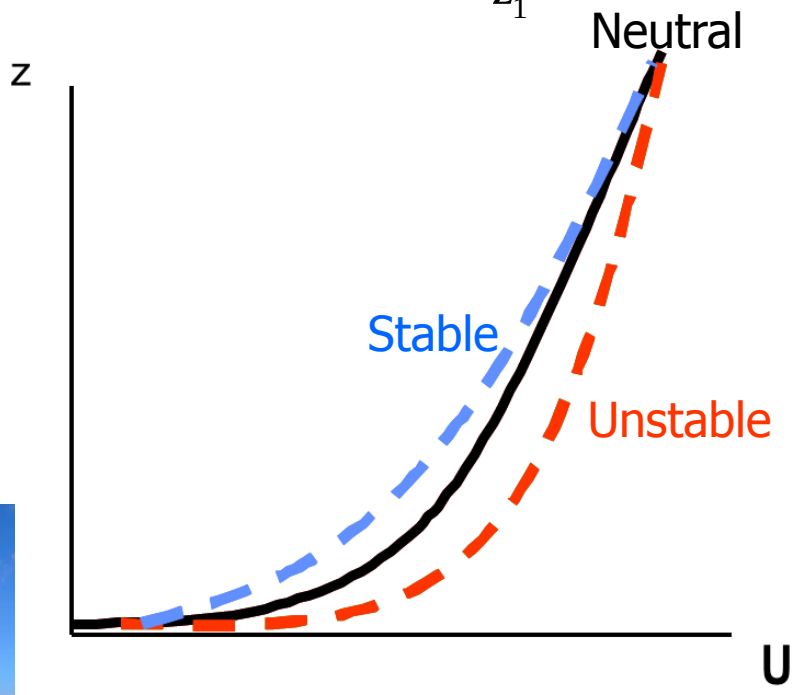
In standards

- log law / power "law"
- valid for surface layer only

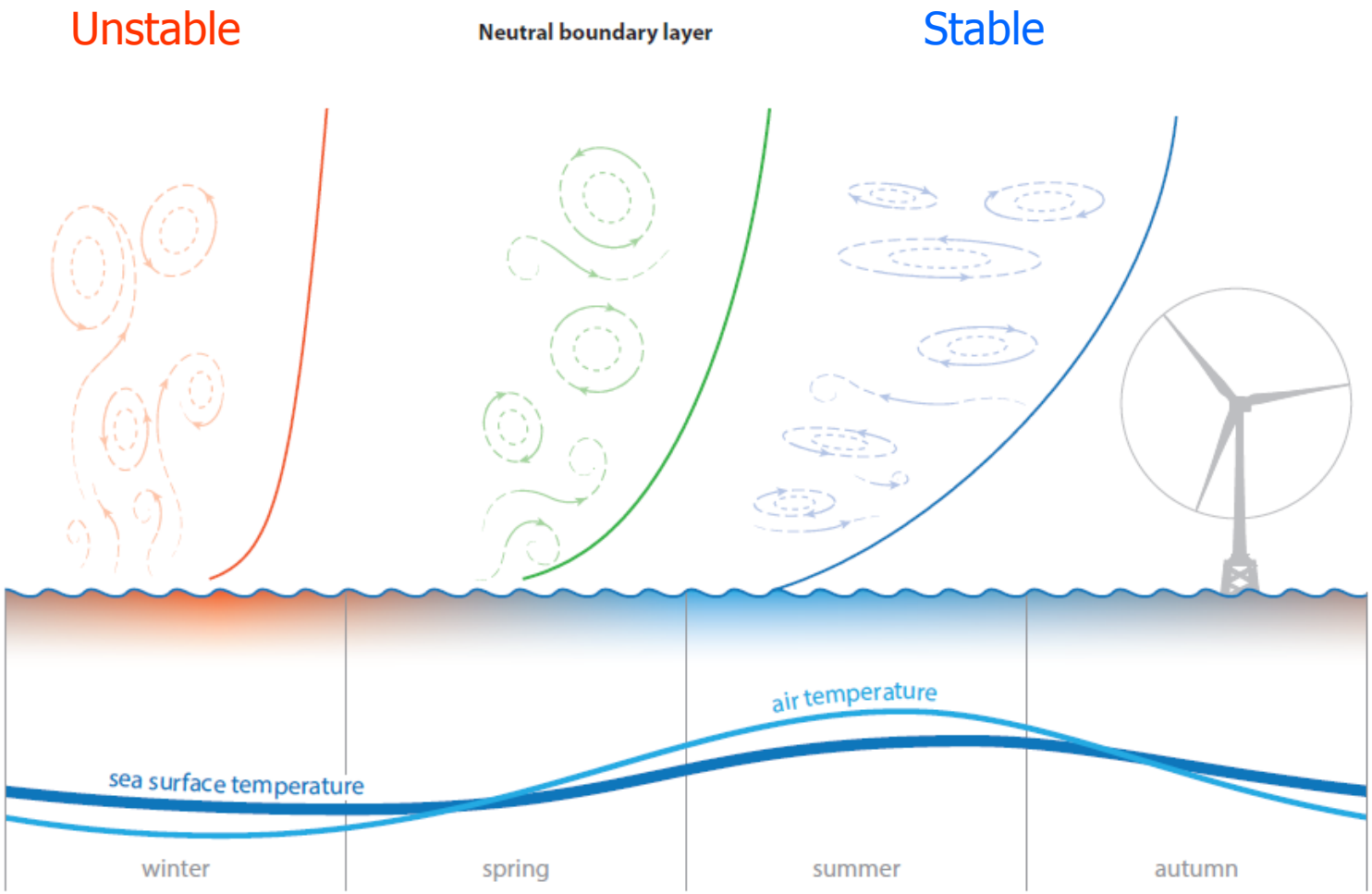
$$U(z_2) = U(z_1)\frac{\log(z_2 / z_0)}{\log(z_1 / z_0)}$$

$$U(z_2) = U(z_1)\left(\frac{z_2}{z_1}\right)^{\alpha}$$





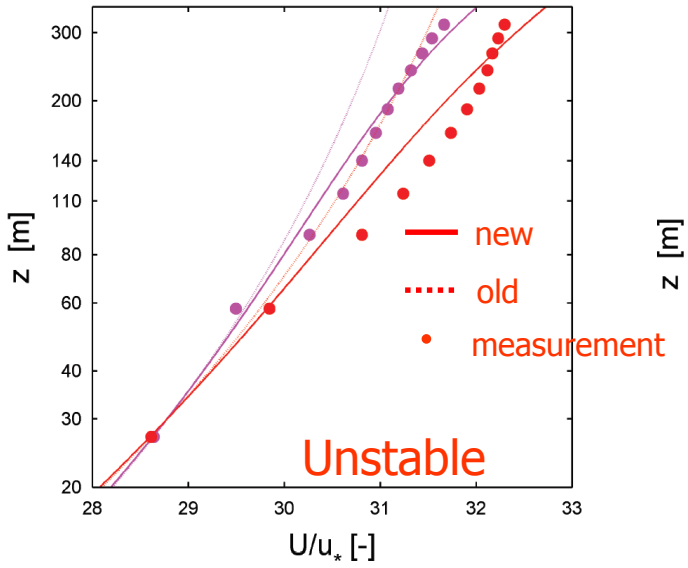
Atmospheric stability

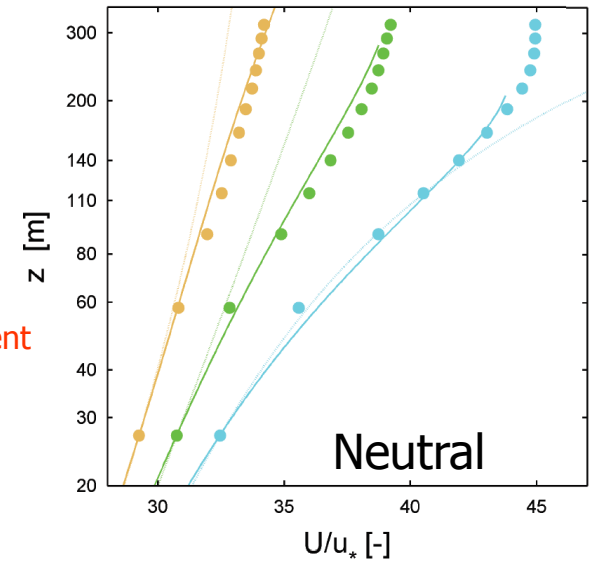


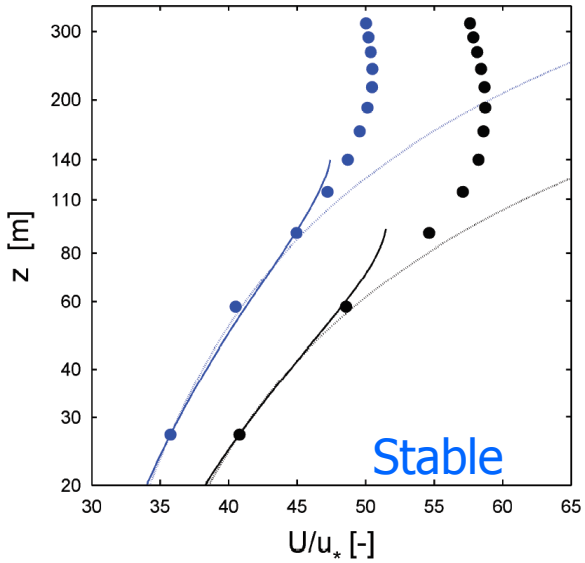
Wind shear profile – new formulation physics-based

For entire boundary layer: $U(z)=f(u_*,z_0,L,h)$

- u_*: friction velocity (measure of turbulent stress)
- z_0: roughness length (measure of roughness sea surface)
- L: Obukhov length (measure of stability)
- h: boundary layer depth can be estimated based on u_* and L



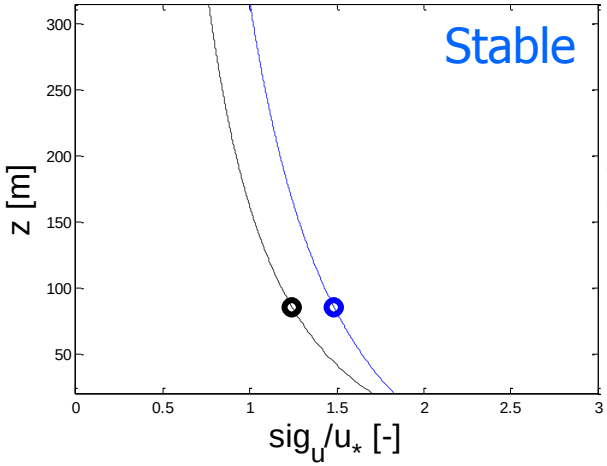


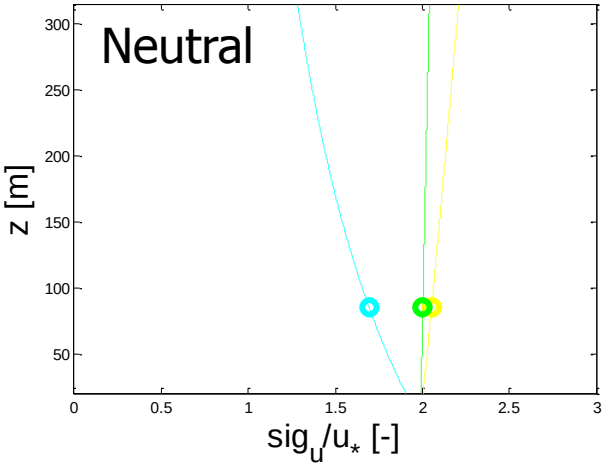


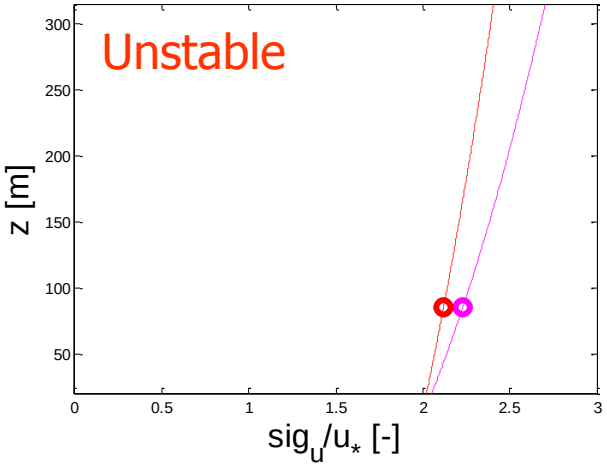
Turbulence

turbulence intensity: $TI = \frac{\sigma}{U}$

Also depending on mean wind speed and stability: turbulence increases for more unstable conditions

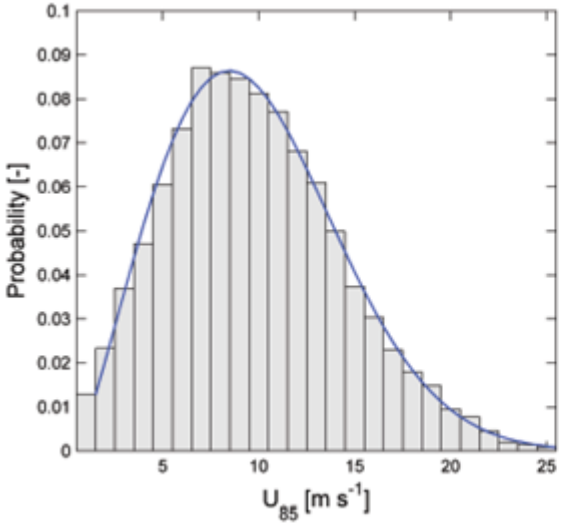




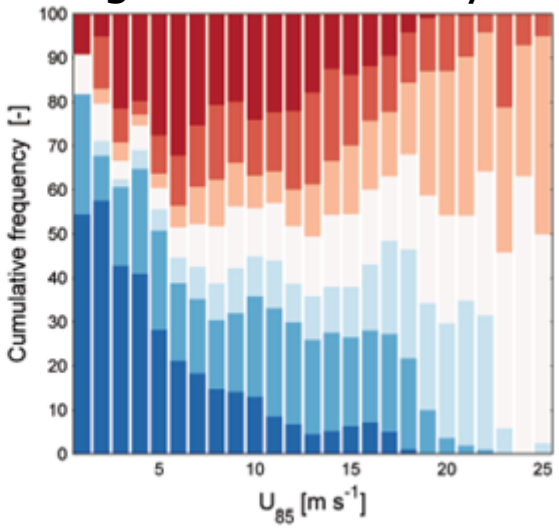


Stability

Weibull



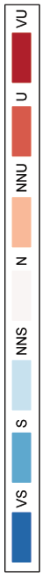
Histogram of 7 stability classes



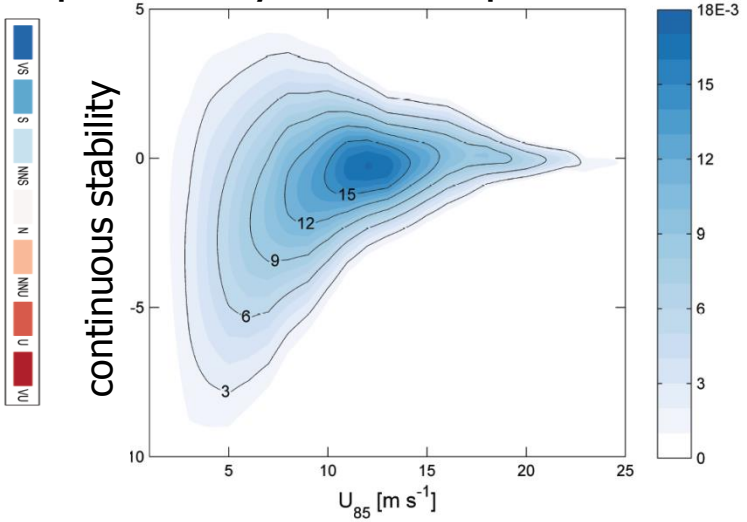
Unstable

Neutral

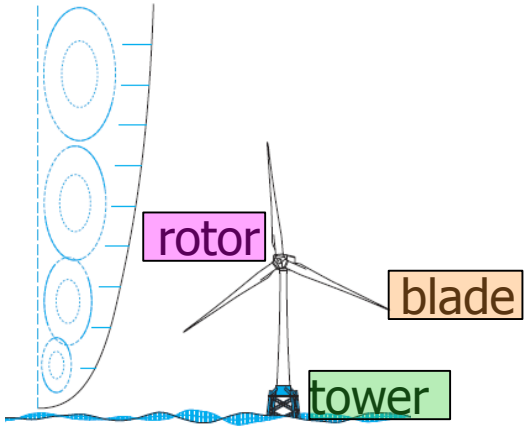
Stable



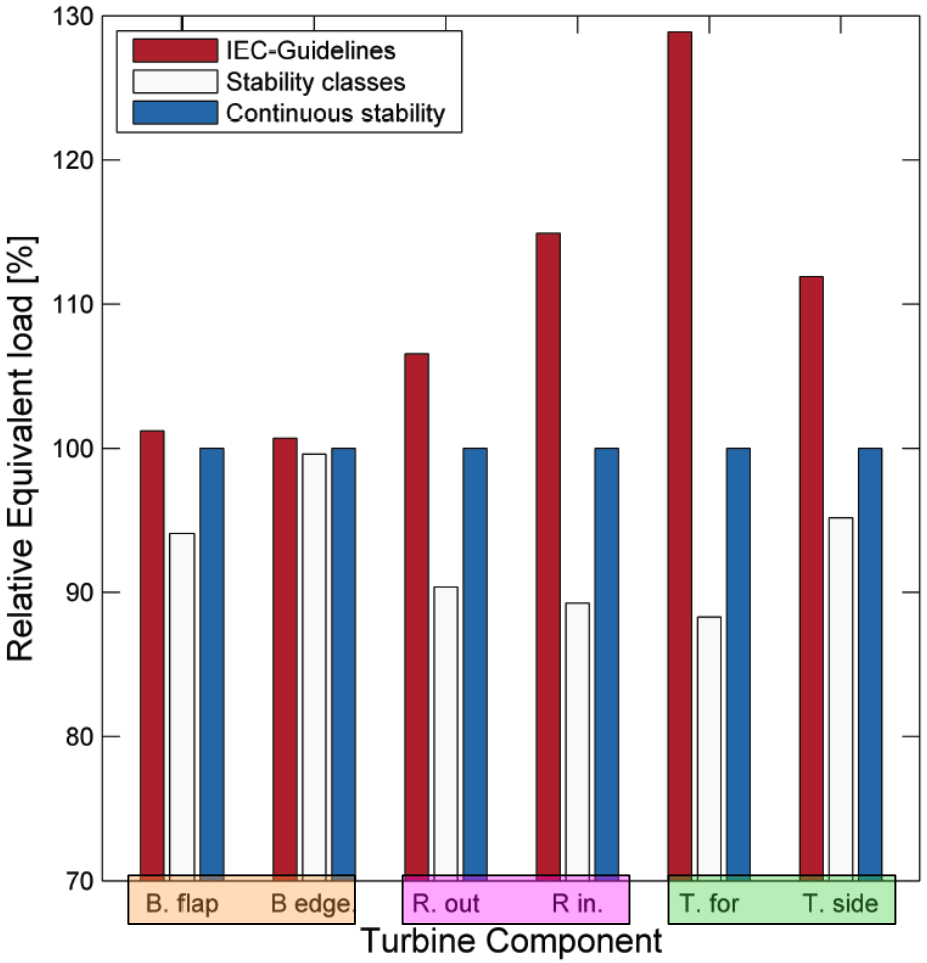
Joint probability of wind speed and stability



Wind turbine loads

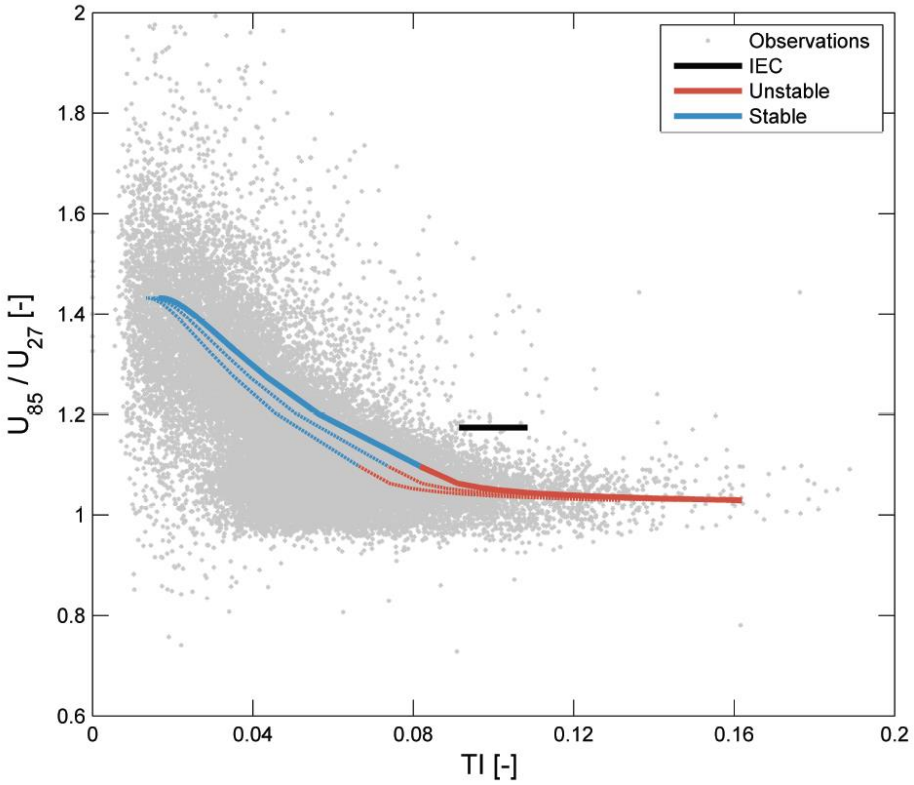


- NREL 5 MW
- For each mean wind speed:
  - wind shear / turbulence
  - stability
    - 1 (IEC-Guidelines)
    - 7 (Stability classes)
    - 34 (Continuous stability)



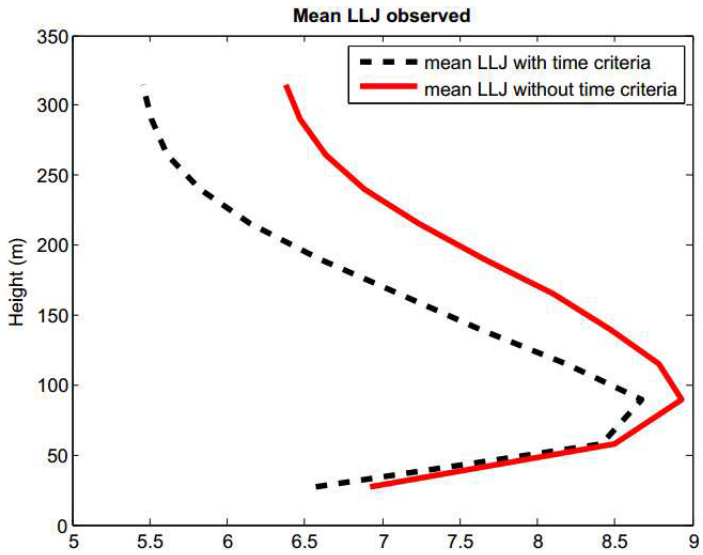
Equivalent turbulence intensity

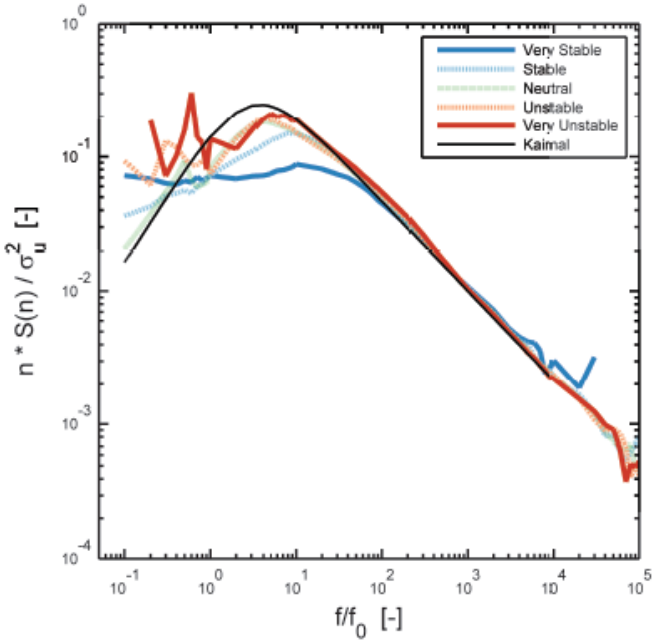
- will lead to the same fatigue damage
- 1 value only (for each mean wind speed)
- it depends on the turbine component
- about the same as the mean value



Also considered

- Low Level Jet (LLJ)
- Turbulence spectra
- Energy yield





Conclusions and outlook

- Atmospheric stability should be included in wind turbine load assessment as well as energy yield calculations

- Include measurement of turbulent fluxes (offshore met-masts) in order to determine stability directly
- Improve model for (very) stable conditions

- PhD defence Maarten Holtslag: Friday 17 June, 12:30
- http://www.library.tudelft.nl/en/collections/tu-delft-repository
- Currently employed at start-up company: Whiffle (weather finecasting)