Windkracht 14 - Meteorology

Far offshore wind conditions for wind energy purposes

Maarten Holtslag

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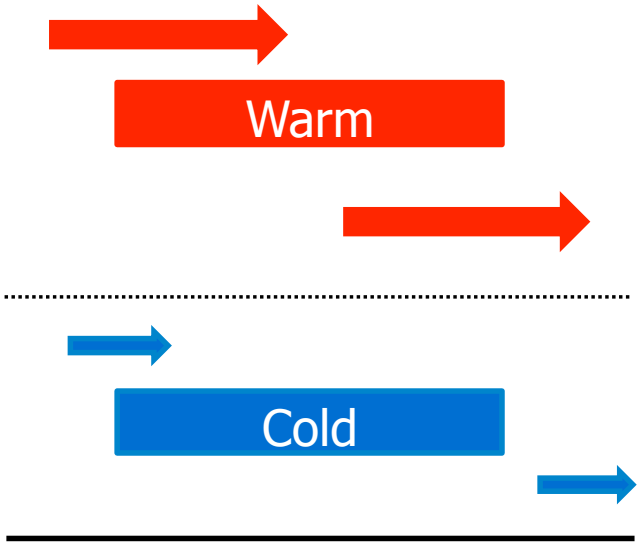
DUWIND
DELFT UNIVERSITY WIND ENERGY RESEARCH INSTITUTE

FLOW

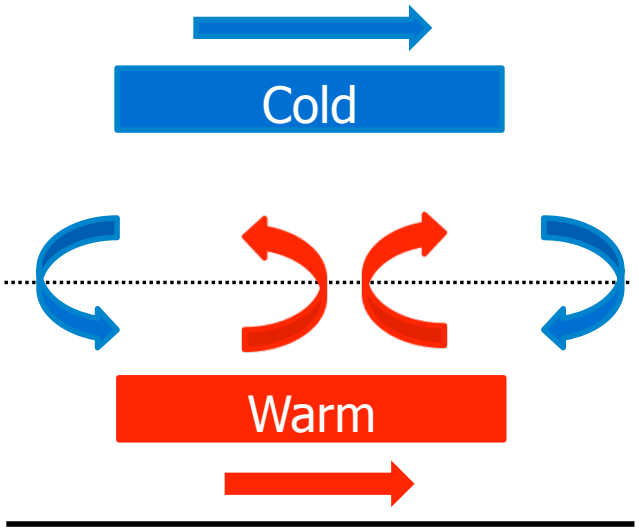
Far offshore atmosphere

- Why atmospheric research for wind energy?
  - Planning / resource assessment
  - Design (farm and turbines)
  - Wind farm performance
- Typically simple description of atmosphere
  - Statistical origin, conservative
  - Lack of physics, potential for improvement
- Can we apply a framework offshore that has been validated onshore?
  - Stability is the driving force close to the surface
  - Wind is a result, not a cause (offshore however…)

Atmospheric stability



Stable



Unstable

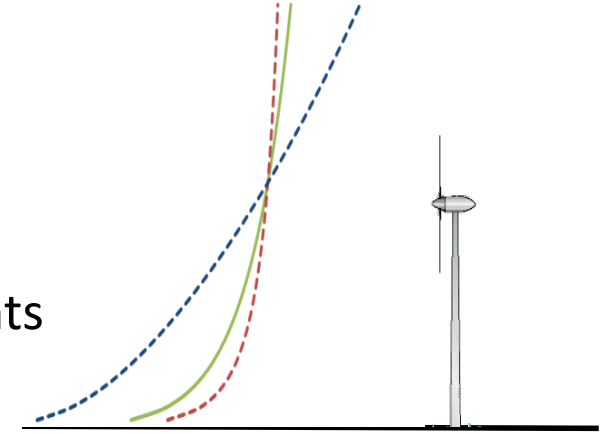
Strong wind shear
Little turbulence

Little wind shear
Strong turbulence

Observation data

- Data taken from metmast IJmuiden
  - 85 km offshore
  - Mast (U, P, T, RH, 27:92m height)
  - Buoy
  - LIDAR (58:315m height) → not used here

Wind shear profile



- Consider shear as ratio of wind speed at two heights
- Typical power law profile:

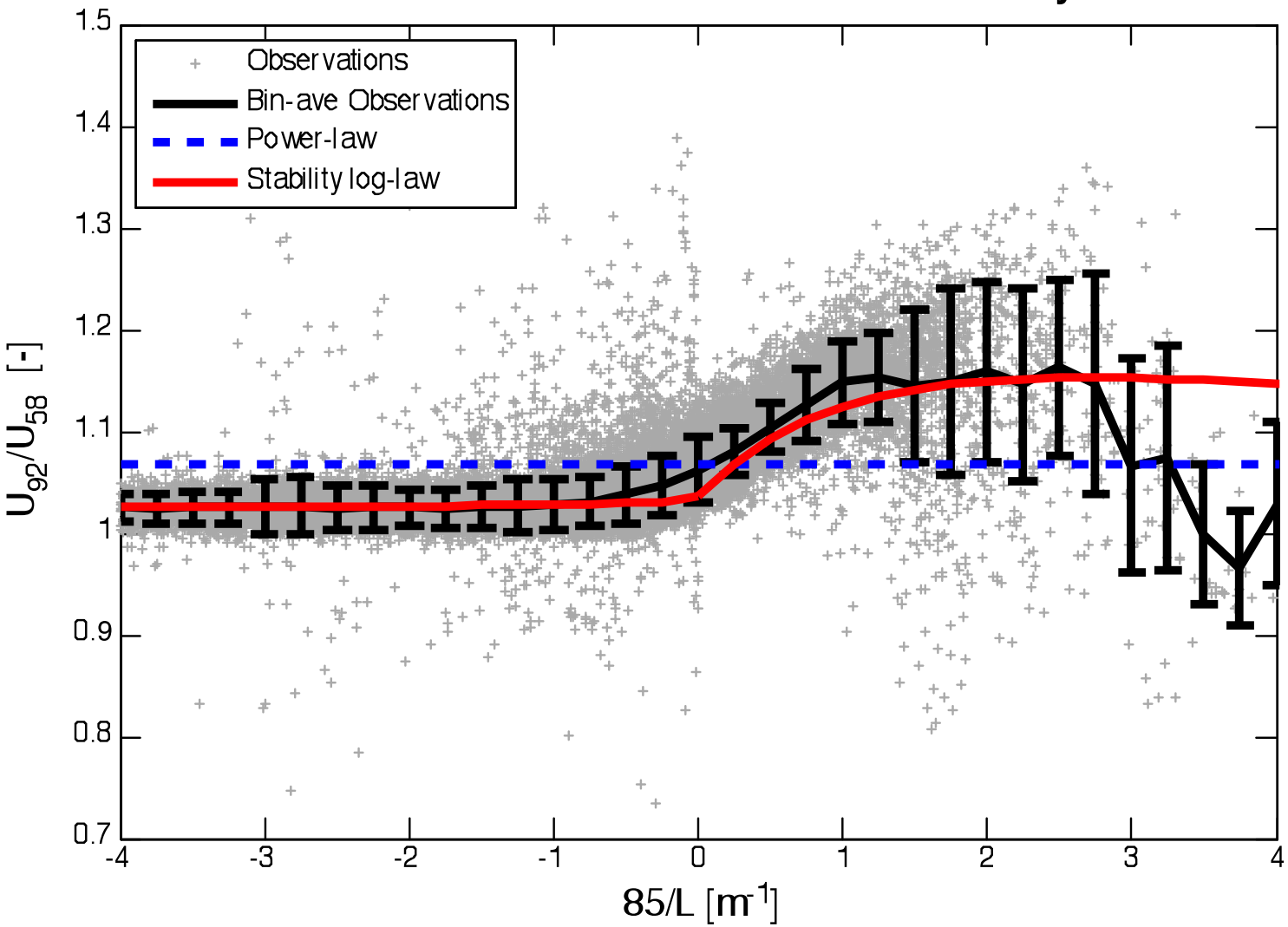
$$\frac{\overline{U}(z_2)}{\overline{U}(z_1)} = \left(\frac{z_2}{z_1}\right)^{\alpha} \qquad CST$$

- We propose:

$$\frac{\overline{U}(z_2)}{\overline{U}(z_1)} = \frac{\left(\ln\left(\frac{z_2}{z_0}\right) - \Psi\left(\frac{z_2}{L}\right)\right)}{\left(\ln\left(\frac{z_1}{z_0}\right) - \Psi\left(\frac{z_1}{L}\right)\right)} \qquad f(L, z_0)$$

but impact z_0 << impact L

Wind shear as a function of stability

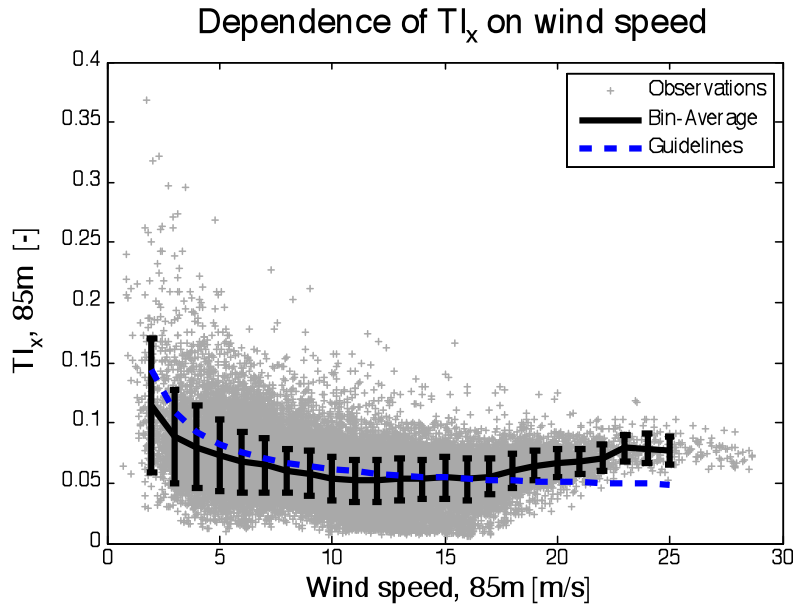


Unstable **Neutral** **Stable**

Turbulence Intensity

- TI according to guidelines

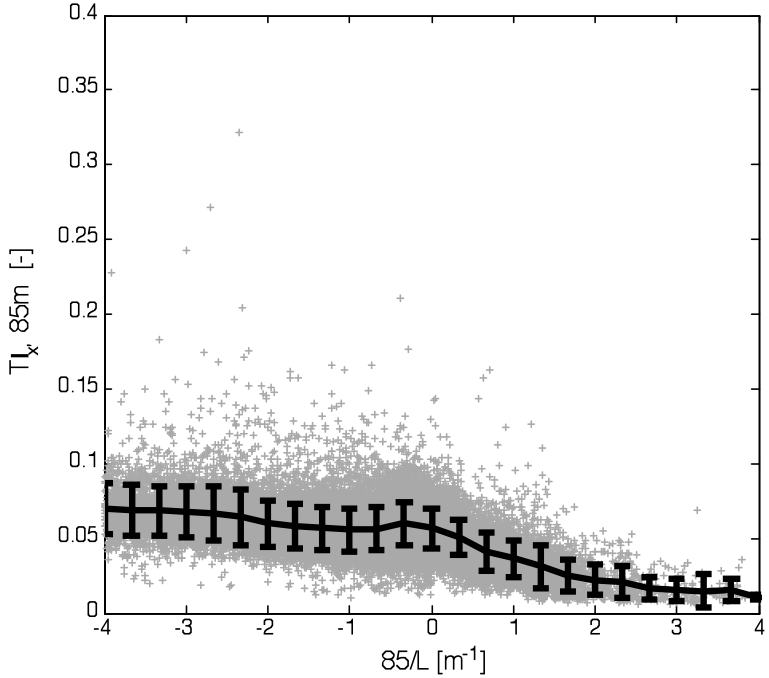
$$TI_x(z) = \frac{\sigma_x(z)}{U_x(z)} = \frac{1}{\ln\left(\frac{z}{z_0}\right)}$$



TI and stability

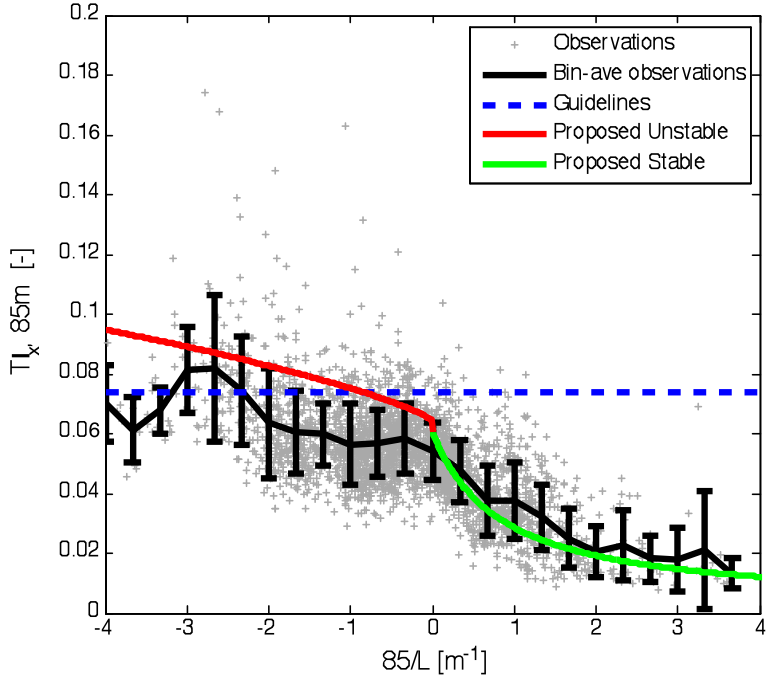
- Thus $TI(z) = f(z_0)$ → stability?
  - Assess dependence for given U, so z_0 ~ constant

Dependence of TI_x on stability (all)



Unst. **Stbl.**

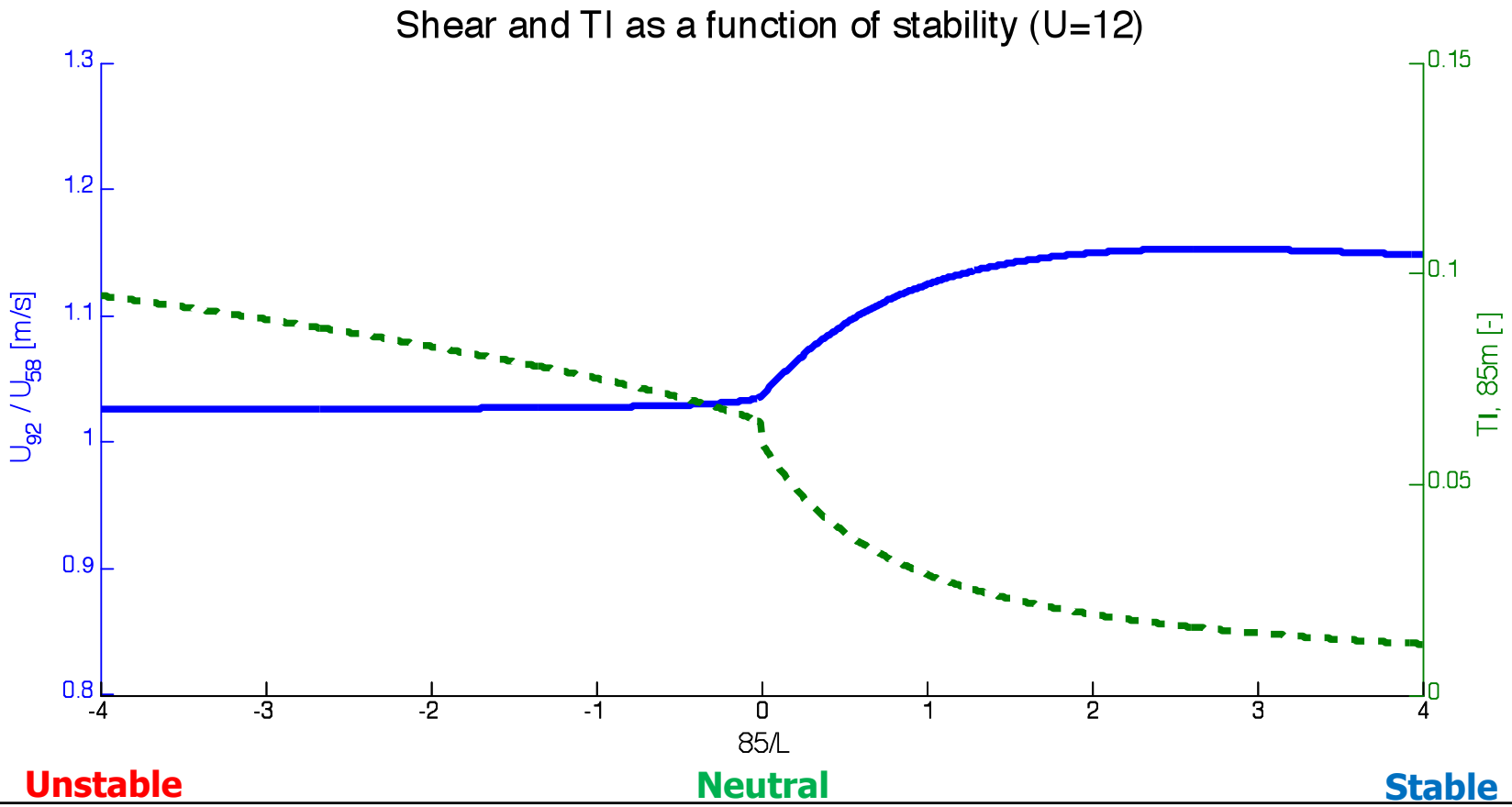
Dependence of TI_x on stability (U = 12 m/s)



Unst. **Stbl.**

Combined shear and TI

- Crucial: opposite dependence on stability



Conclusion

- Shear and TI (and spectra) are not independent but coupled
  - Dependence on Stability and height
  - Dependence on surface roughness (= wind speed)
- Relatively simple to implement
  - But stability has to be included in resource assessment
- TI and shear are oppositely dependant on stability!!
  - You will never have high shear and high turbulence levels
- Impact on wind turbine design?

Equations of TI and spectra

Turb. Intensity

$$TIU_x(nst\ .) = \frac{HAB_{xx}\left(\frac{\varphi_1 \propto}{\tau \div \phi \varepsilon}\right)^{1/3} \left(\frac{z}{L}\right)}{\ln\left(\frac{\varphi z z}{\tau \div \phi \varepsilon z_0 L}\right) - 2\Phi\left(\frac{\varphi \propto}{\tau \div \phi \varepsilon}\right)}$$

$$TIS_x(bl\ .) = \frac{HAC_{xx}\left(\frac{\varphi_1 \propto}{\tau \div \phi \varepsilon}\right)^{2/3} \left(\frac{z}{L}\right)}{\ln\left(\frac{\varphi z z}{\tau \div \phi \varepsilon z_0 L}\right) - 2\Phi\left(\frac{\varphi \propto}{\tau \div \phi \varepsilon}\right)}$$

Turb. Spectra

$$\frac{nS_x}{\sigma_x^2} = \frac{0.164\left(\frac{\varphi n z}{\tau \div \phi \varepsilon \bar{U} f_0}\right)}{1 + 0.164\left(\frac{\varphi n z}{\tau \div \phi \varepsilon \bar{U} f_0}\right)^{5/3}}$$

$$fU_{0xxx}(nstDE.) = 2\left(\frac{\varphi \propto}{\tau \div \phi \varepsilon}\right)^{2/3} \left(\frac{z}{L}\right)$$

$$fS_{0xxx}(blDF.) = + \left(\frac{z}{L}\right)$$