Windkracht 14 - Meteorology
Far offshore wind conditions for wind energy purposes
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22-01-2014
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...)

TU Delft
Atmospheric stability

Stable

Strong wind shear
Little turbulence

Unstable

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:

\[
\frac{\bar{U}_z(2)}{\bar{U}_z(1)} = \frac{\varphi^2}{\phi \varepsilon_1}^{\frac{\tau}{\varepsilon}} \quad CST
\]

• We propose:

\[
\frac{\bar{U}_z(2)}{\bar{U}_z(1)} = \frac{\chi^{\phi}_{\varepsilon} \varphi^{\frac{\tau}{\varepsilon}} \chi^2}{\psi^{\phi} \varepsilon} \quad 2 \Phi \frac{\varphi^{\frac{\tau}{\varepsilon}}}{\phi \varepsilon} \quad f(\varepsilon, \phi) \quad \text{but impact } z_0 << \text{ impact } L
\]
Wind shear as a function of stability

Unstable
Neutral
Stable
Turbulence Intensity

- TI according to guidelines

\[ TI(z) = \frac{\Omega(z)}{U_2(U)} \ \text{ref} \ \frac{\varphi}{\Phi^E} \ \frac{b}{1} \]
TI and stability

- Thus $\text{TI}(z) = f(z_0) \rightarrow \text{stability}$?
  - Assess dependence for given $U$, so $z_0 \sim \text{constant}$

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**Dependence of $T_{I_x}$ on stability (all)**

![Graph 1](image1)

**Dependence of $T_{I_x}$ on stability ($U = 12 \text{ m/s}$)**

![Graph 2](image2)

- Observations
- Bin-ave observations
- Guidelines
- Proposed Unstable
- Proposed Stable

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**Unst.**

**Stbl.**

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TU Delft
Combined shear and TI

- Crucial: opposite dependence on stability

Shear and TI as a function of stability (U=12)
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

\[ T_{IA}^{(st)} = \frac{H_A C_{IT}^3}{\phi \varepsilon} \left( \frac{z}{L} \right)^{1/3} \ln \left( \frac{\phi \varepsilon}{\tau_r} \right) \]

\[ T_{IA}^{(bl)} = \frac{H_A C_{IT} \varepsilon}{\phi \varepsilon} \left( \frac{z}{L} \right)^{21/2} \ln \left( \frac{\phi \varepsilon}{\tau_r} \right) \]

Turb. Spectra

\[ \frac{nS}{O_x^2} = \left( \frac{0.164}{10^{0.164}} \right) \left( \frac{\phi \varepsilon}{\tau_r U_f} \right)^{5/3} \]

\[ f_{U_{IA}^{(stDE)}} = 2 \left( \frac{\phi \varepsilon}{\tau_r U_f} \right) \left( \frac{z}{L} \right)^{21/2} \]

\[ f_{U_{IA}^{(lDE)}} = + \left( \frac{z}{L} \right) \]