Uncertainties in offshore wind turbulence intensity

$$Turbulence\ Intensity = \mathrm{TI} = \frac{wind\ speed\ standard\ deviation}{wind\ speed\ mean} = \frac{\sigma_U}{U}$$

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Motivation

One of the input parameters for the development, design and operation of wind farms is the wind speed and turbulence intensity at hub height.

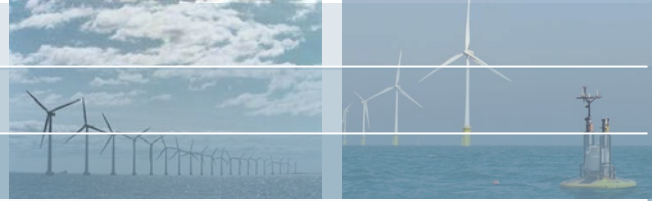
Given that measurements at hub height are rare, hub height wind speeds and turbulence intensities are often determined using simplified formulations.

$$U_z = U_{z_{ref}} \left(\frac{z}{z_{ref}}\right)^{\alpha} \qquad TI=\beta$$

These formulations are based on assuming a dependence only on wind speed at a reference level and neutral or fixed atmospheric stability.

Such assumptions involve large uncertainties given that the vertical wind profile – i.e. translation of wind speed and TI in height – depend both on the sea surface roughness and atmospheric stability.

Aim & Approach



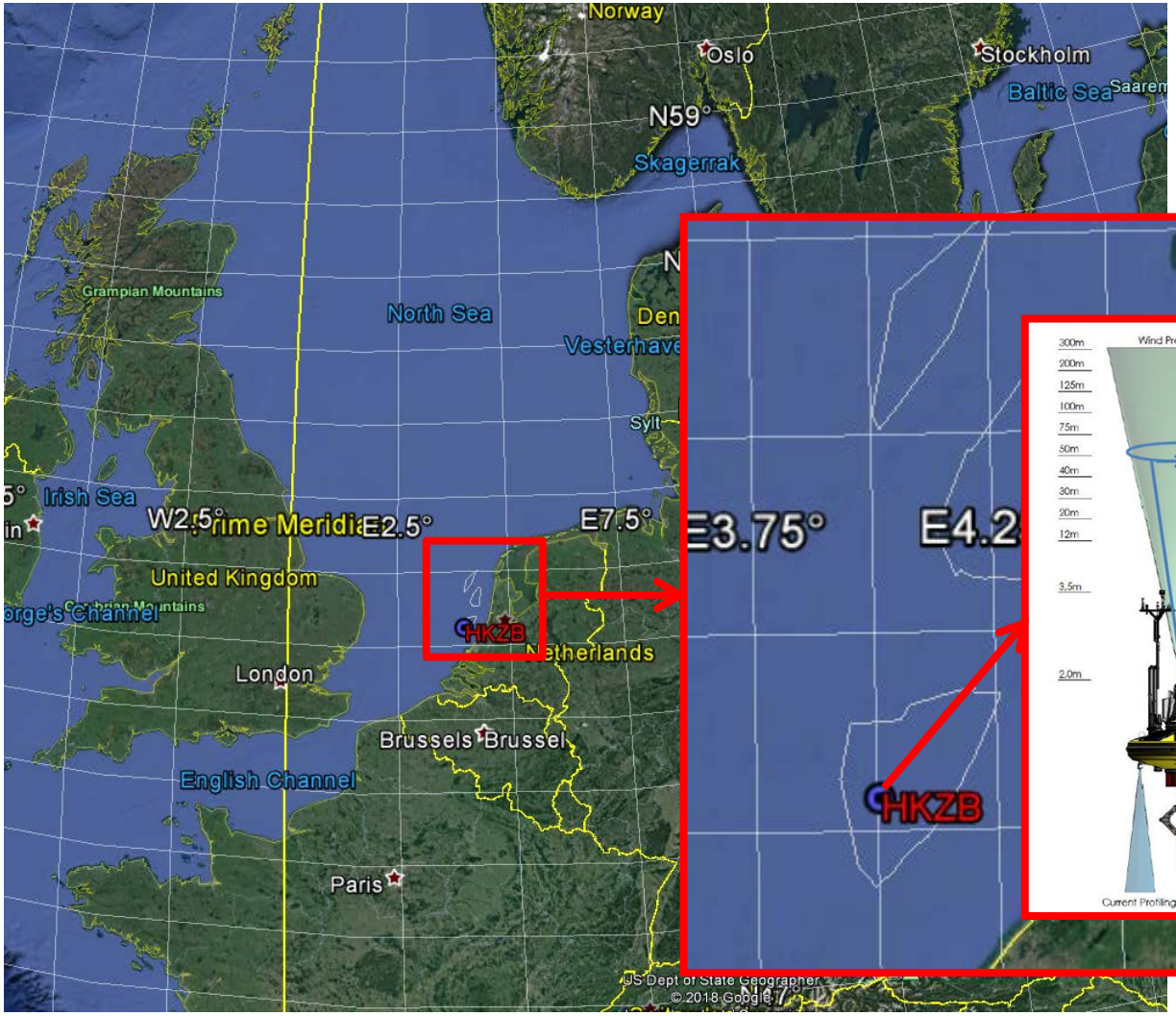
Aim:

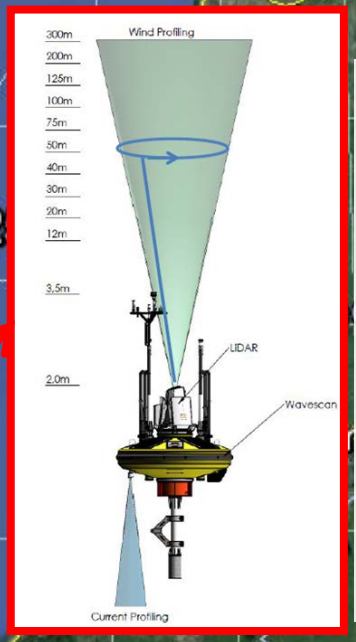
Study the dependence of turbulent intensity (and wind speed) on atmospheric stability and surface roughness.

Approach:

Use a comprehensive dataset of North Sea metocean observations to determine the variability of the turbulence intensity and wind speed with vertical temperature gradients, wind severity and surface roughness.

Data



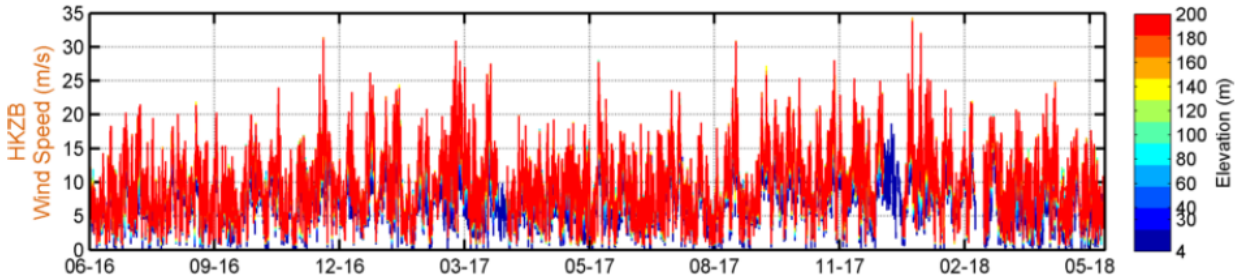


- -LiDAR (1Hz @ 30 to 200 m)
- -wind sensor (1Hz @ 4 m)
- -air temperature sensor
- -directional wave sensor
- -water temperature (@ -1 m)

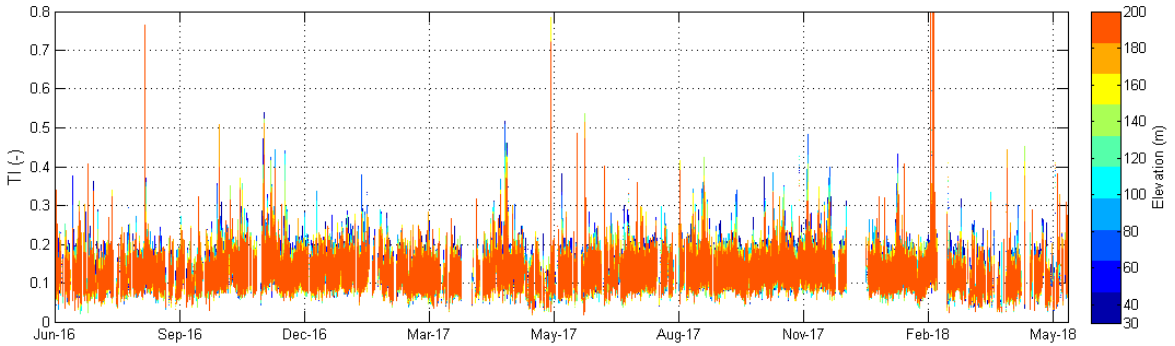
SEAWATCH Wind LiDAR buoy observations from June 2016 until June 2018

HKZB Field Measurement Campaign Data

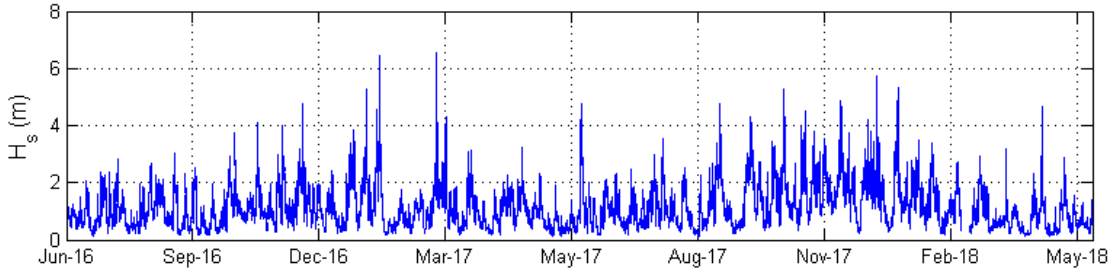
10-min data



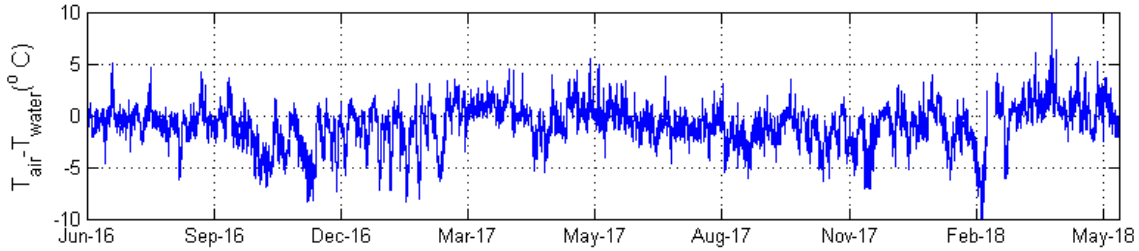
Wind Speed



Turbulence Intensity
U>5 m/s



Significant Wave Height

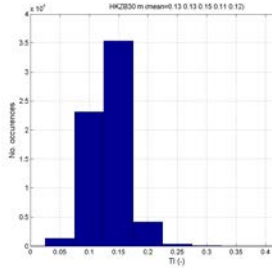


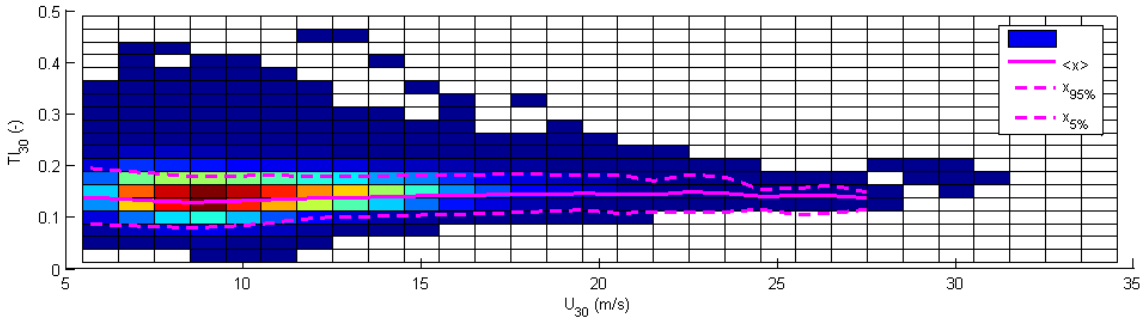
temperature gradient

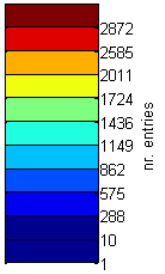
FUGRO

Deltares

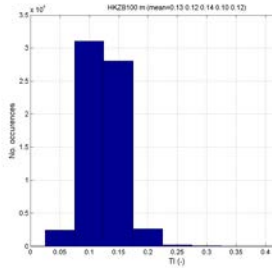
Variation of turbulence intensity with wind speed

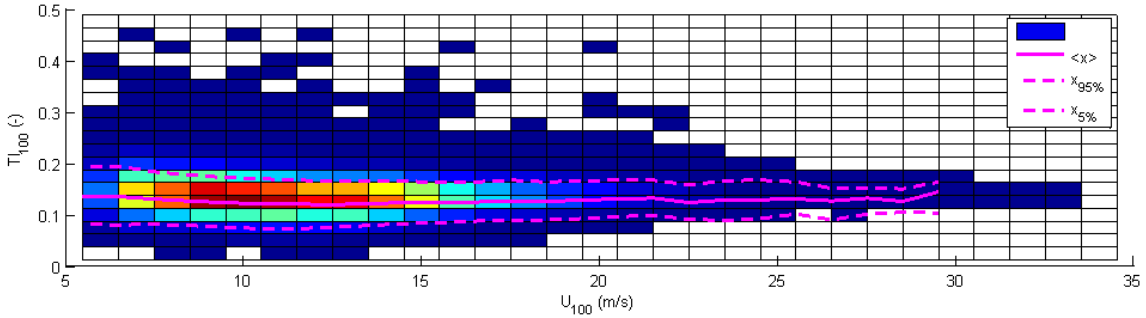


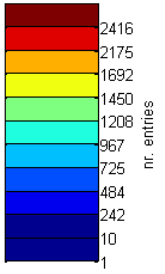




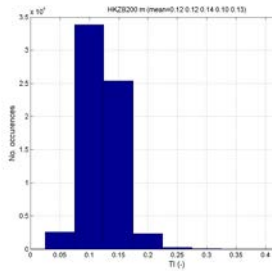
@30m

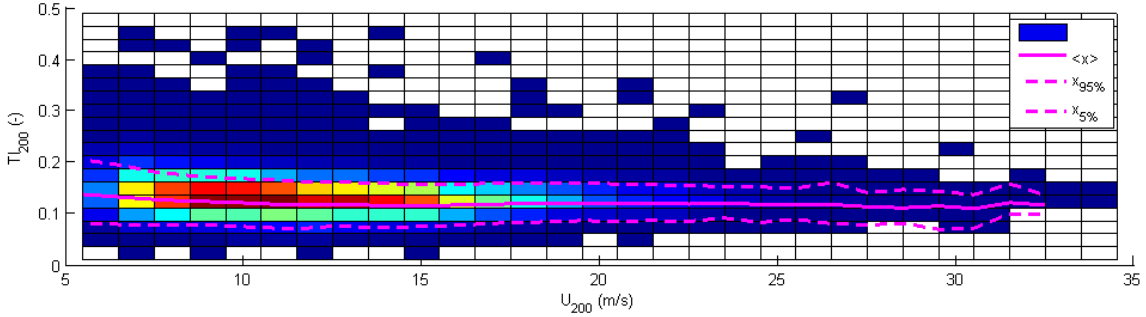


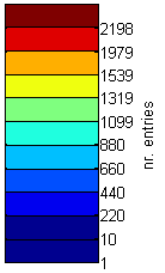




@100m

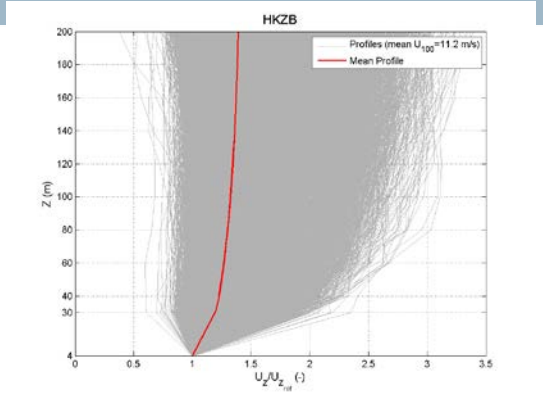






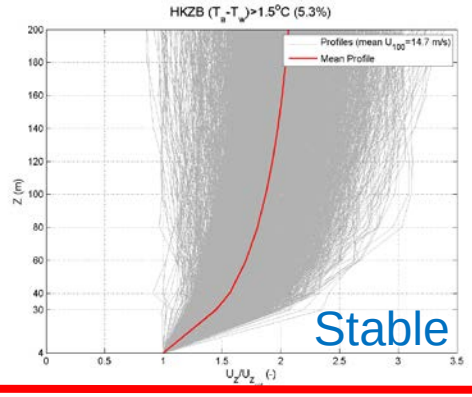
@200m

Variability in the vertical wind speed profile

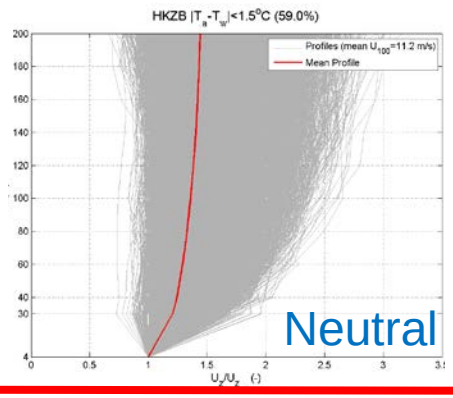


All

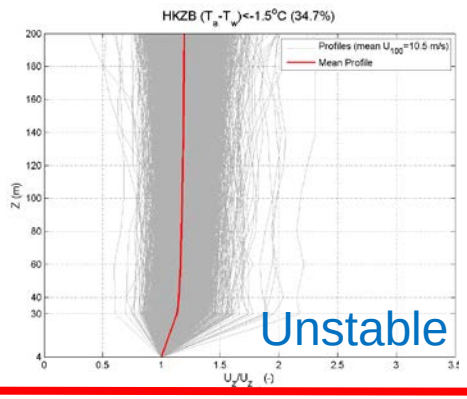
Atmospheric stability filtering



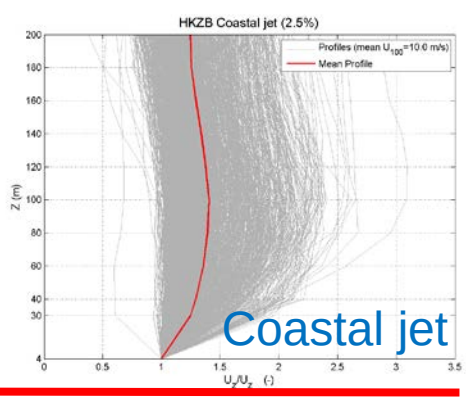
Stable



Neutral

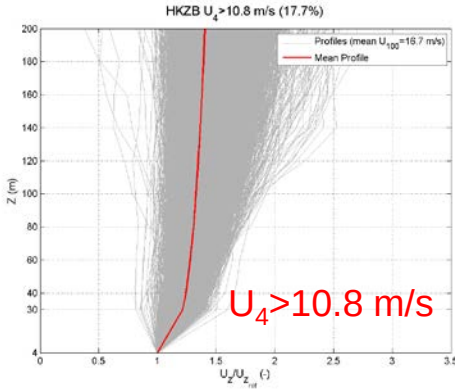


Unstable

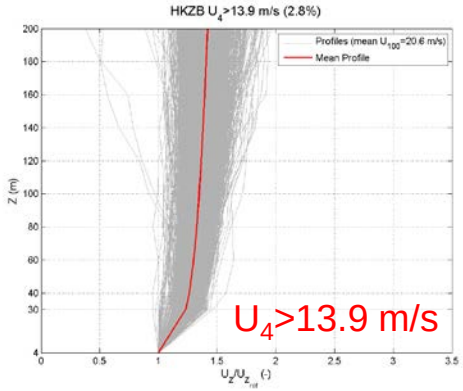


Coastal jet

Wind speed threshold filtering



U_4>10.8 m/s



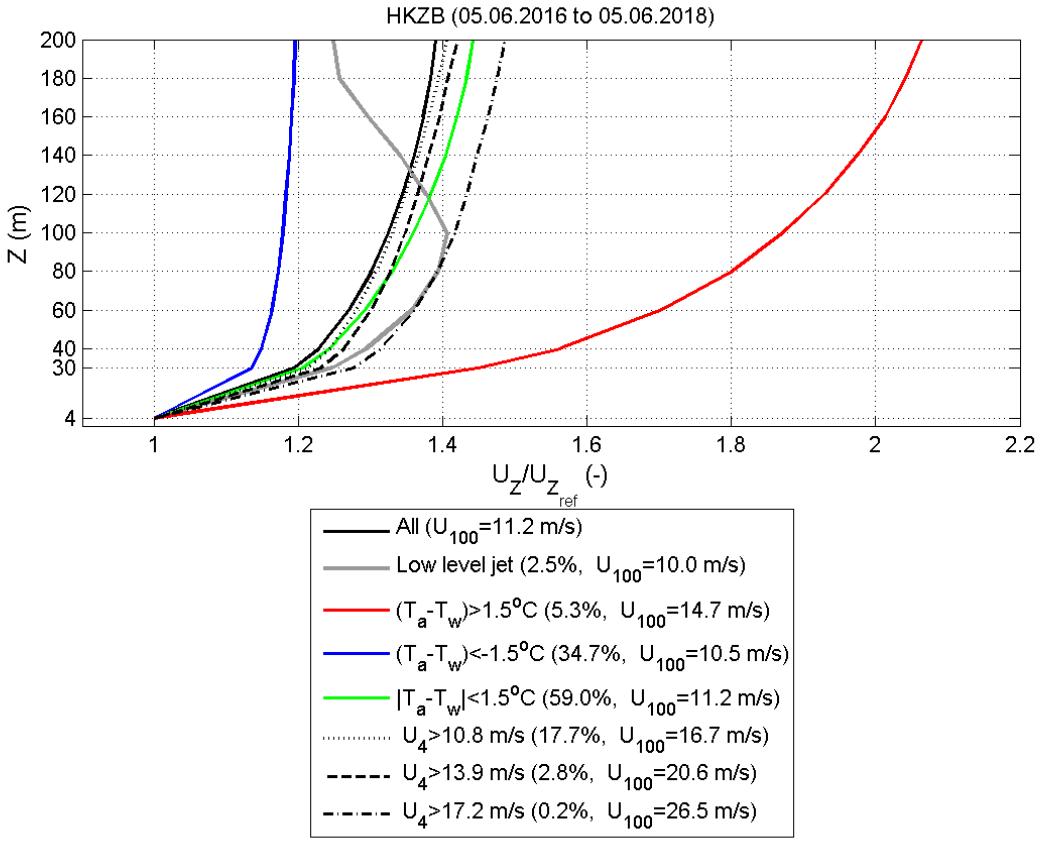
U_4>13.9 m/s

FUGRO

Deltares

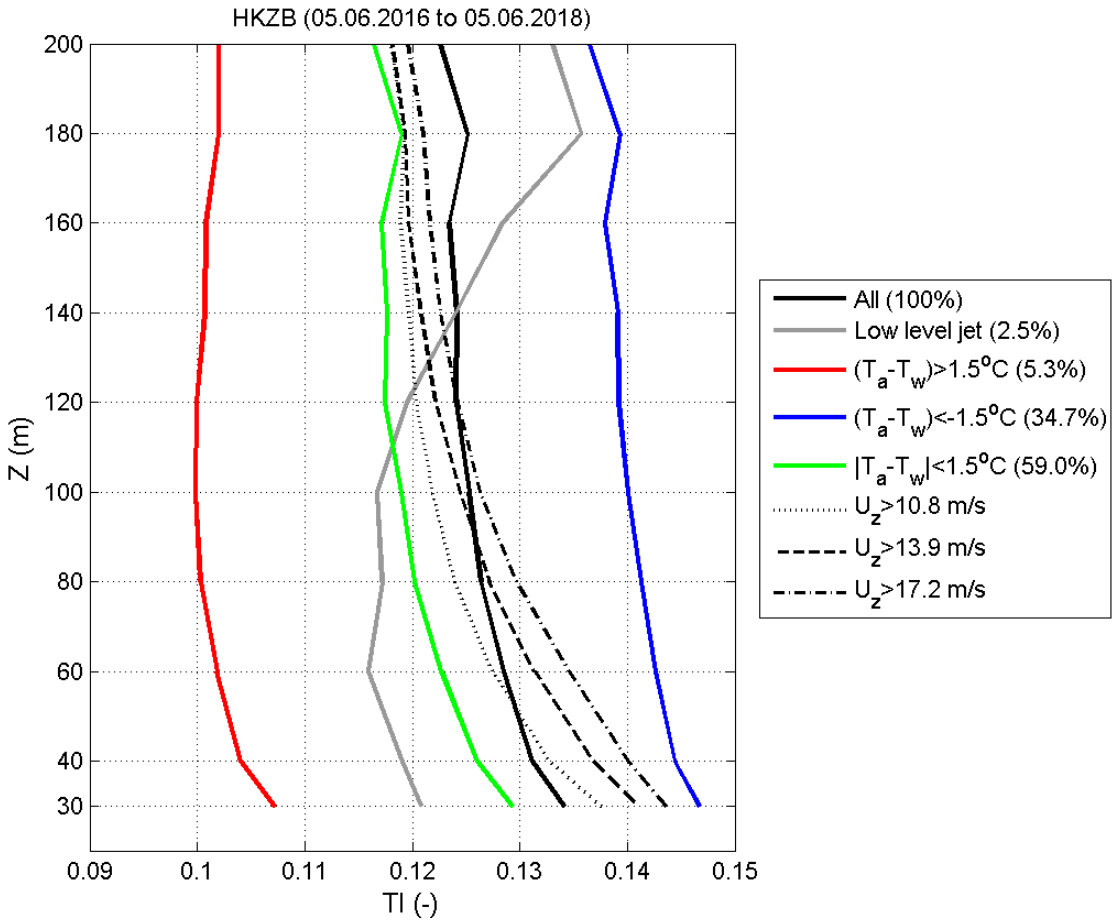
Variability in the vertical wind speed profile

Summary of mean wind profiles under different conditions

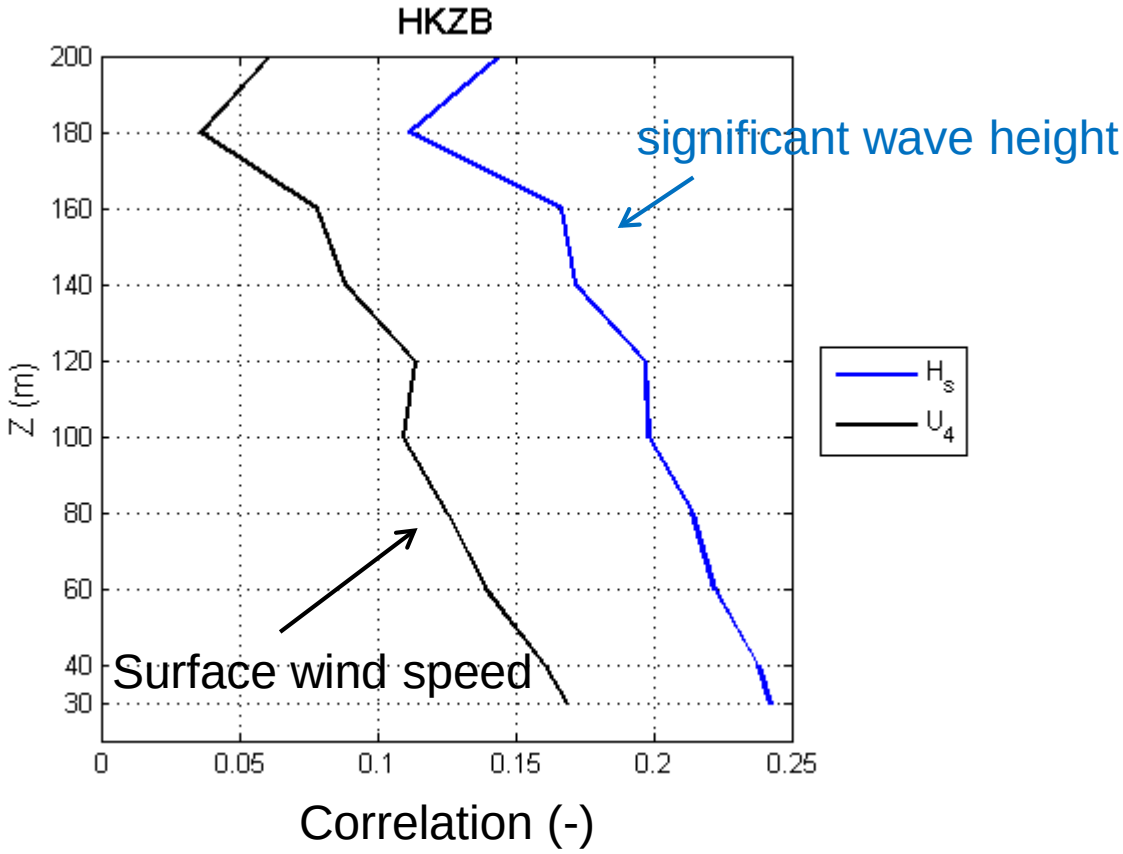


Variability in the Turbulence Intensity

Summary of mean turbulence intensity under different conditions



Correlation Turbulence Intensity & sea surface roughness



Correlation between the turbulence intensity (TI) and the surface roughness proxies surface wind speed and significant wave height.

Final remarks

- The turbulence intensity is shown to depend strongly on the atmospheric stability and less strongly on the sea surface roughness.
- The lower turbulence intensity values are observed under stable atmospheric conditions.
- The dependence of the turbulence intensity on the surface roughness is higher at the lower levels.
- The significant wave height is the proxy of the sea surface roughness with the stronger correlation with the turbulence intensity.

- **Atmospheric stability should be considered when determining turbulence intensities.**

- **If not possible due to lack of data, the uncertainties that result from not accounting for these should be considered when determining turbulence intensities using the standard formulations.**