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Wind profile characterization from scatterometry products and sea state parameters

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Motivation

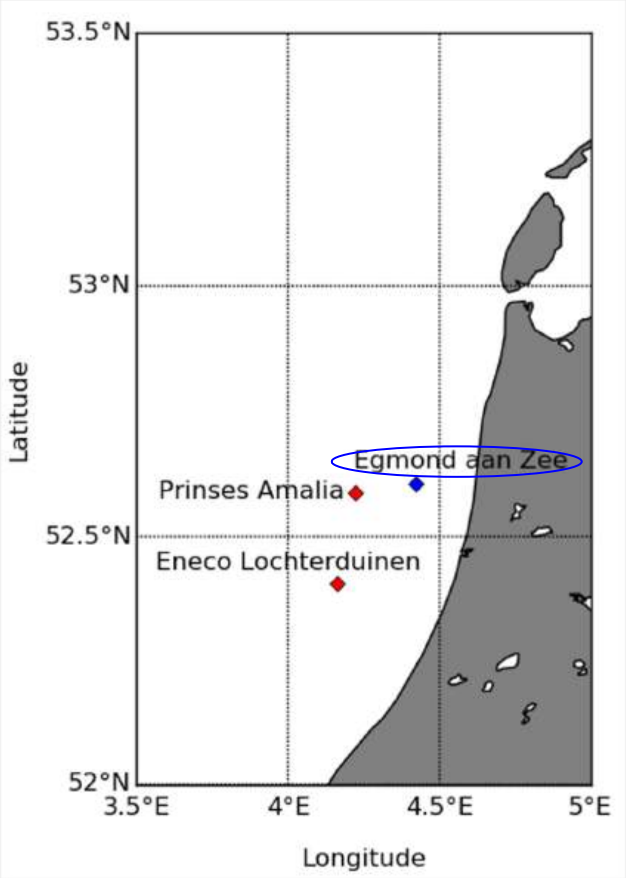
Study the wind-wave interaction, especially the effect of different wave conditions on the wind profile above the wave field.

Test the capability of the logarithmical law to determine the wind profile in offshore locations.

Find a non-empirical parameterization of the sea surface roughness length.

Produce an added-value product with 3D winds from scatterometers, radiometers, adn SAR for the wind industry

Locations and datasets

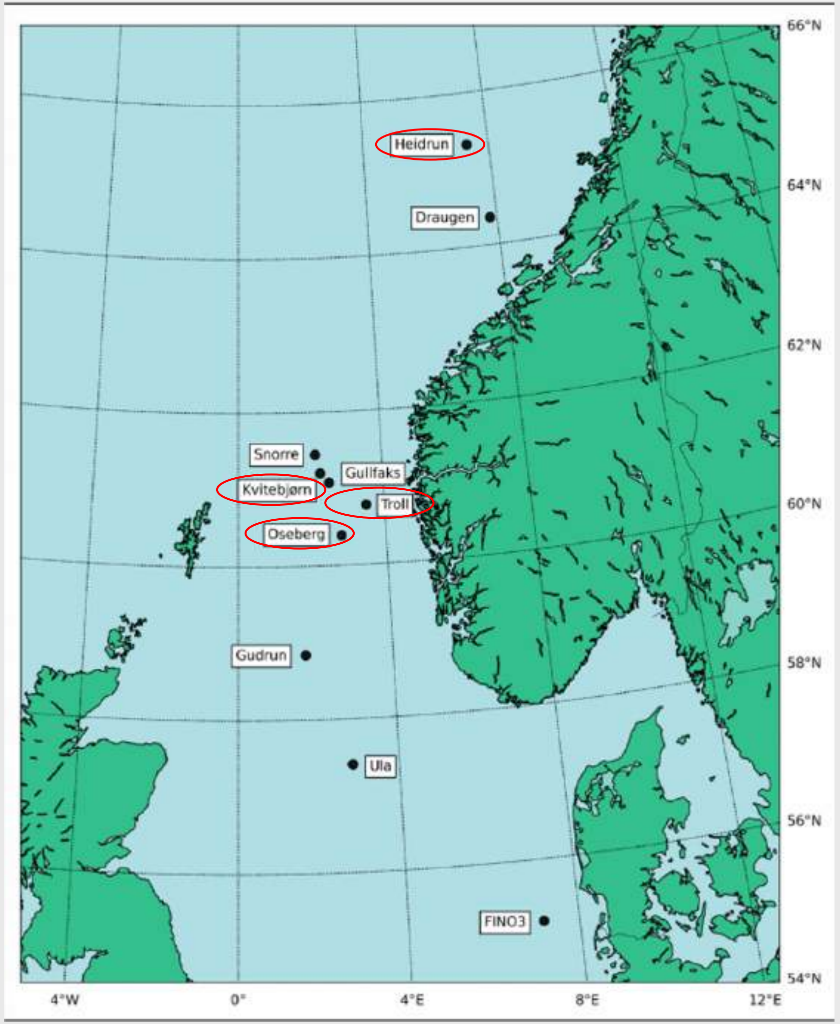


Met mast

Sea and atmospheric sensors at different heights/depths

Oil platforms

Only wind vectors, complemented with ERA5



Locations and datasets

		Egmond aan Zee (EZ)	Oil platforms
Data sources	**Wind vectors**	Cup & sonic anemometers	Cup anemometers
	Atmospheric parameters	In situ	ERA5
	Sea state parameters	In situ	ERA5
Considerations	**Stability**	Only neutral	All
	Time resolution	1h	1h
	Period	2005 - 2008	2022 onwards

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Theory recap

***C_d** : Drag coefficient*

h : effective obstacle height*

***s** : silhouette or cross-section area*

***n** : number of obstacles*

***A** : area of the domain*

***θ** : angle between wind and wave direction*

***L_p**: Wavelength*

***H_s**: Significant wave height*

Lettau's equation

$$z_0 = C_d h^* s(n/A)$$ Onshore

$$z_0 = \frac{u_*^2}{U_{10}^2}\frac{H_s^2}{L_p}|\cos\theta|$$ Offshore

Assuming deep seas in absence of white capping and breaking waves

New formulation still agrees with the direct proportionality between z_0 and u_* found by Charnock in 1952

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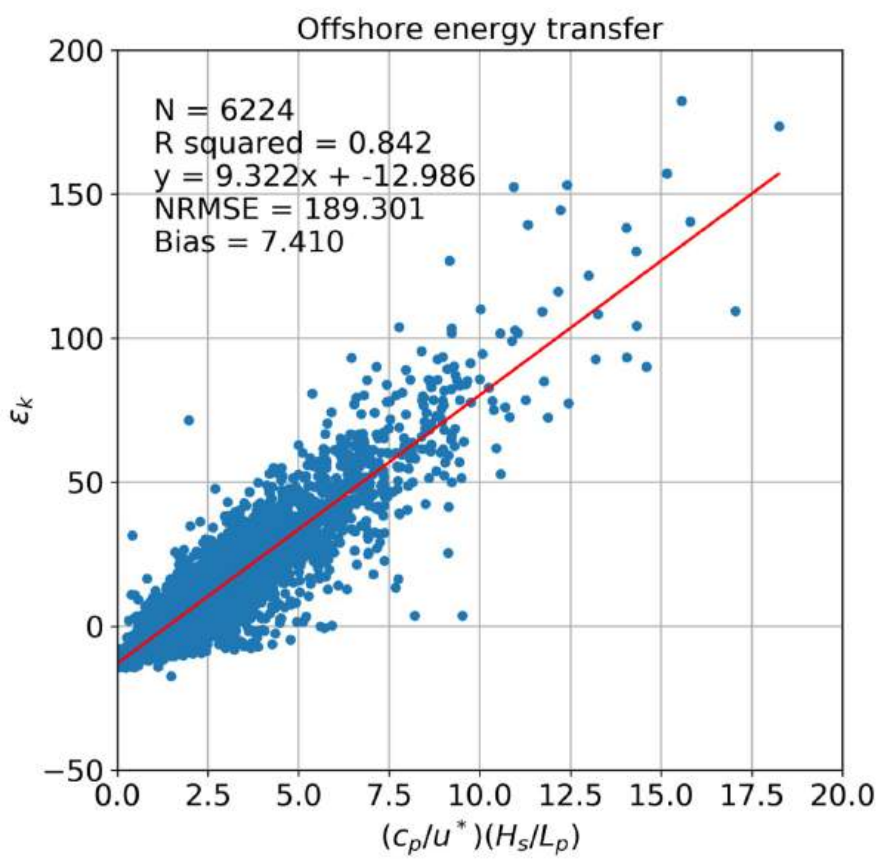
Theory recap



$$U(z) = \left(\frac{u_*}{\kappa}\right)\left[\ln\left(\frac{z}{z_0}\right) + \Psi_s\left(\frac{z}{L_s}\right) + \varepsilon_k\left(\frac{c_p}{u_*}, \frac{H_s}{L_p}\right)\right]$$

$$z_0 = \frac{u_*^2}{U_{10}^2}\frac{H_s^2}{L_p}|\cos\theta|$$

z_0 : aerodynamically consistent

$$U(z) = \left(\frac{u_*}{\kappa}\right)\left[\ln\left(\frac{z}{z_0}\right) + \Psi_s\left(\frac{z}{L_s}\right)\right]$$

$$z_0 = \frac{u_*^2}{U_{10}^2}\frac{H_s^2}{L_p}|\cos\theta| * \frac{1}{e^{\varepsilon_k}}$$

z_0 : wave age dependant

At 21m!!!!

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Theory recap

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$$z_0 = \frac{u_*^2}{U_{10}^2}\frac{H_s^2}{L_p}|\cos\theta| * \frac{1}{e^{\varepsilon k}}$$

z_0 : wave age dependant

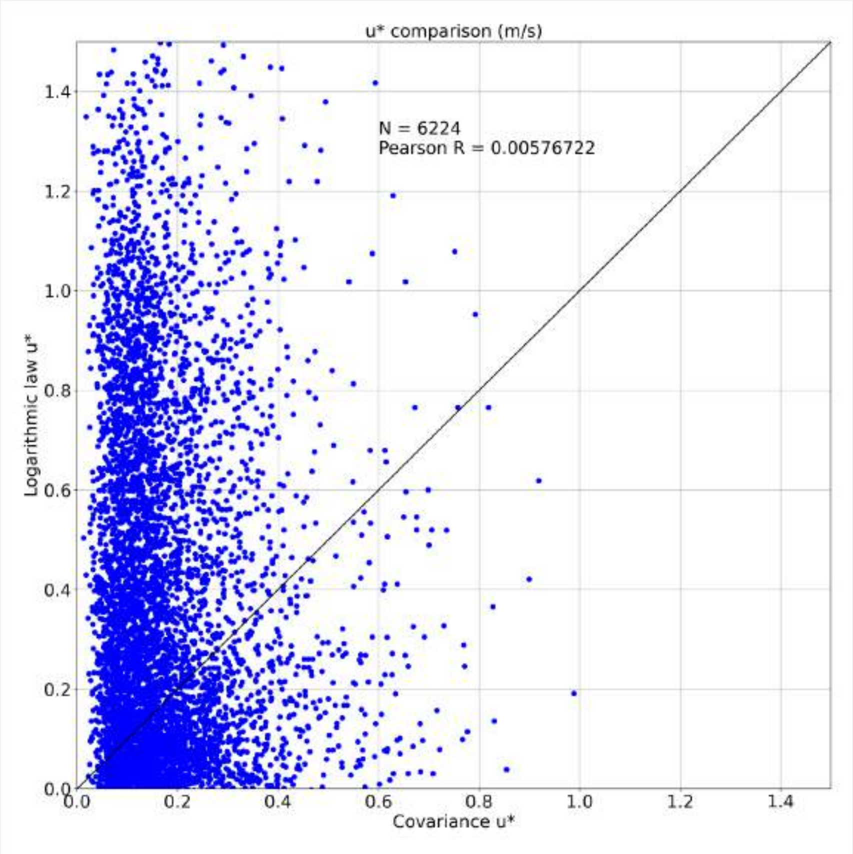
↓

If neutral stability

↓

$$u_* = \frac{\kappa(U_2 - U_1)}{\ln(z_2/z_1)}$$

$z_2 > z_1$



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Theory recap

$$U(z) = \left(\frac{u_*}{\kappa}\right)\left[\ln\left(\frac{z}{z_0}\right) + \Psi_s\left(\frac{z}{L_s}\right) + \varepsilon_k\left(\frac{c_p}{u_*}, \frac{H_s}{L_p}\right)\right]$$

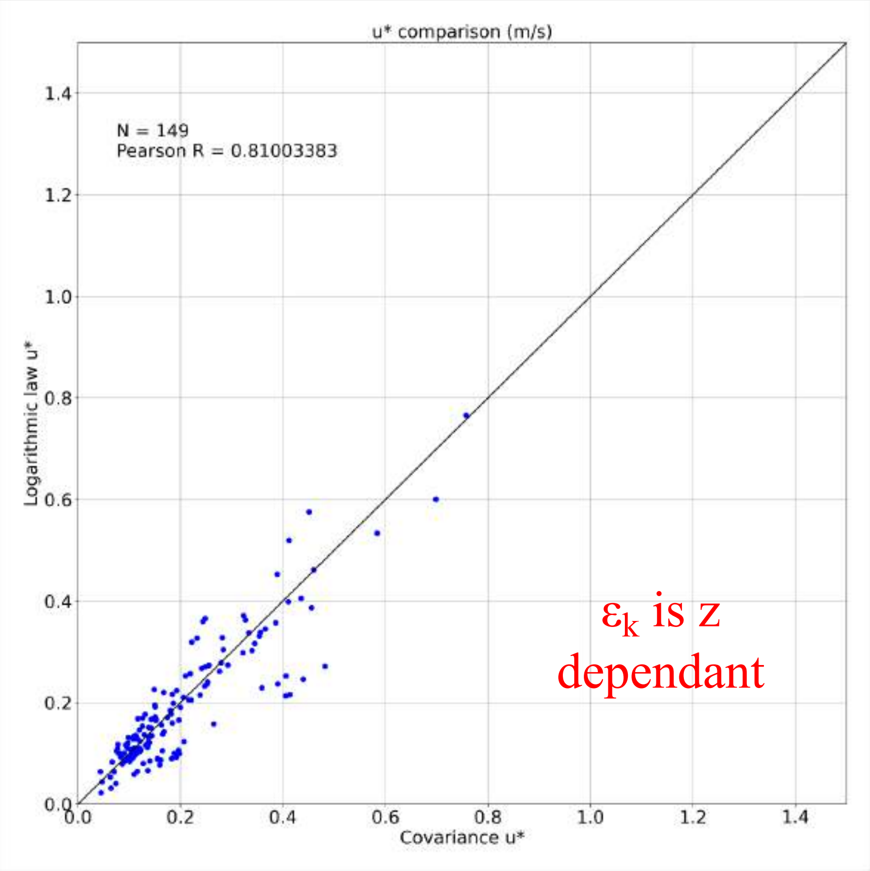
$$z_0 = \frac{u_*^2}{U_{10}^2}\frac{H_s^2}{L_p}|\cos\theta|$$

z_0 : aerodynamically consistent

If neutral stability and

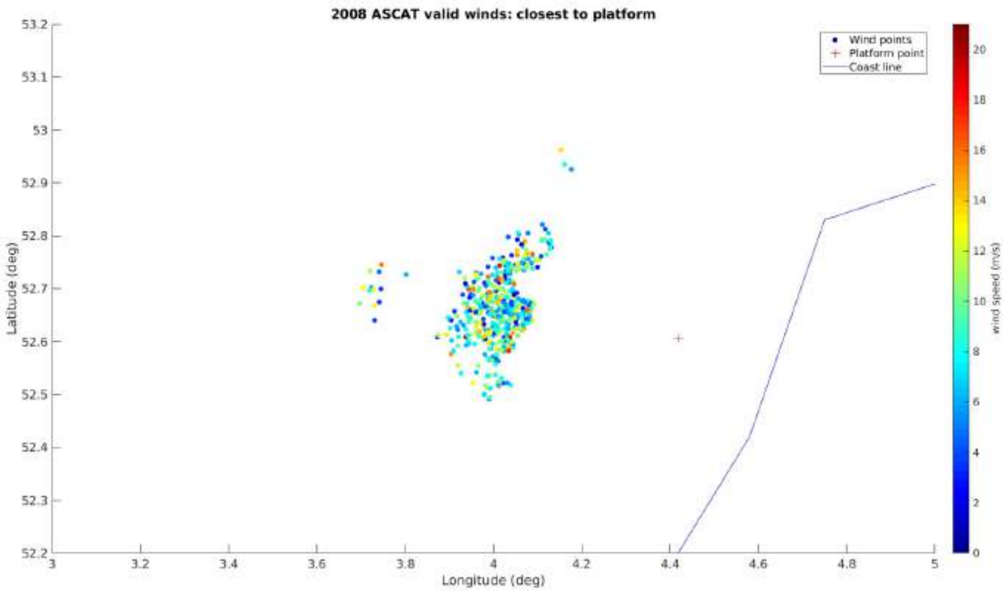
ε_k at z_1 = ε_k at z_2

$$u_* = \frac{\kappa(U_2 - U_1)}{\ln(z_2/z_1)} \qquad z_2 > z_1$$



ε_k is z dependant

Theory recap



Closest measurements to EZ by the dispersometer ASCAT in 2008.

Acknowledgements to Dr. Federica Polverari and Dr. Marcos Portabella for the reprocessed ASCAT data.

1. Following formulation in previous slide, C_{Dz} is solved by iteration:

$$C_{Dz} = \frac{u_*^2}{U_z^2}$$

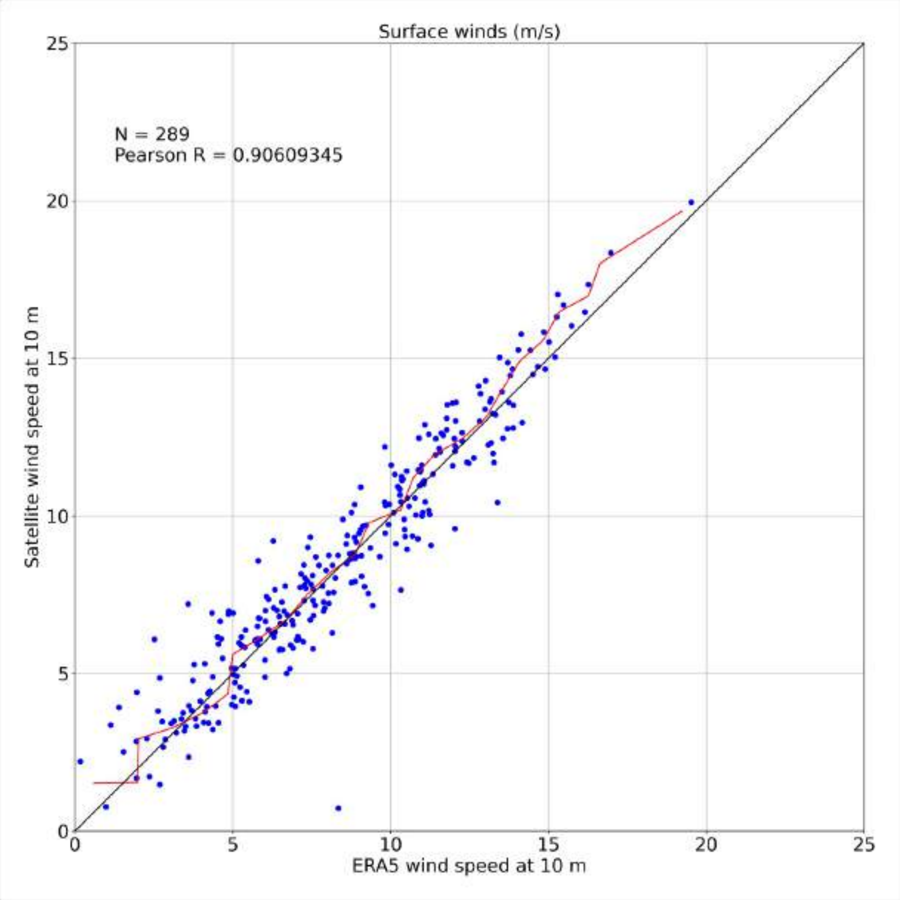
$$C_{Dz} = \left[\frac{\kappa}{\ln\left(\frac{z\, L_p}{C_{Dz}\, H_s^2\, |\cos\theta|}\right) + \varepsilon_k + \Psi_s} \right]^2$$

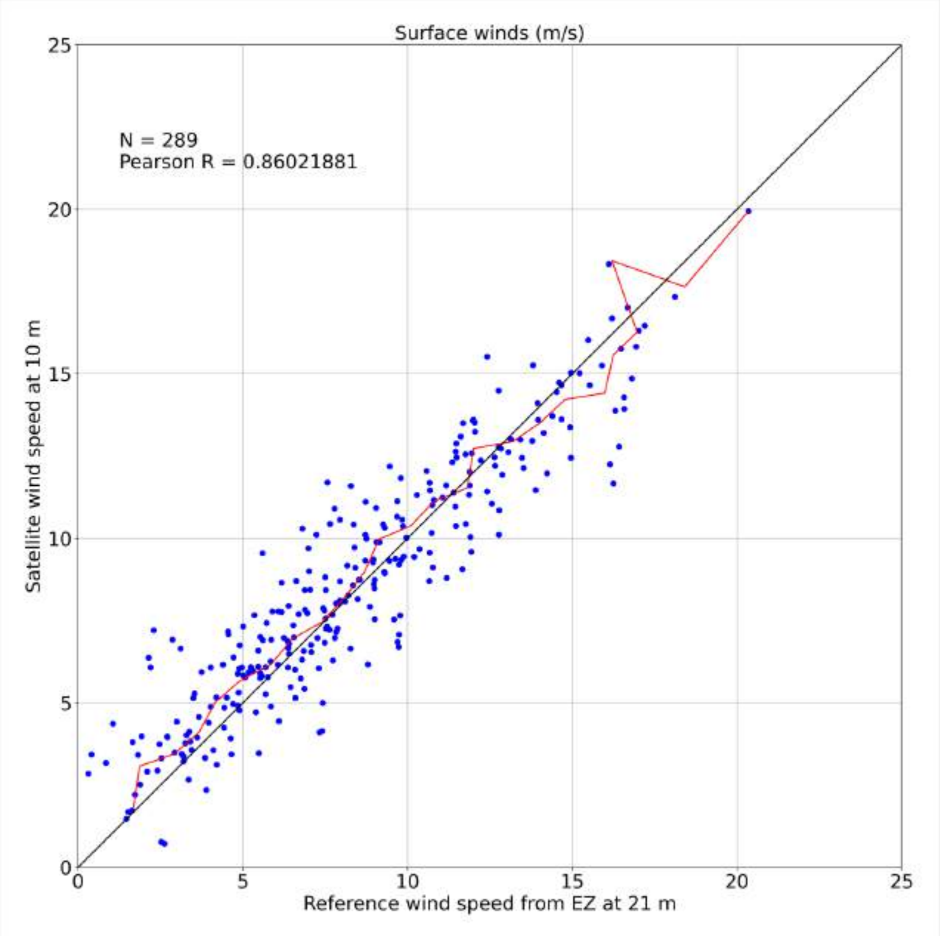
2. u* solved with C_{D10} and U_{10S} CMOD7:

$$u_* = C_{D10} \frac{<\rho_a>}{\rho_a} U_{10S}^2$$

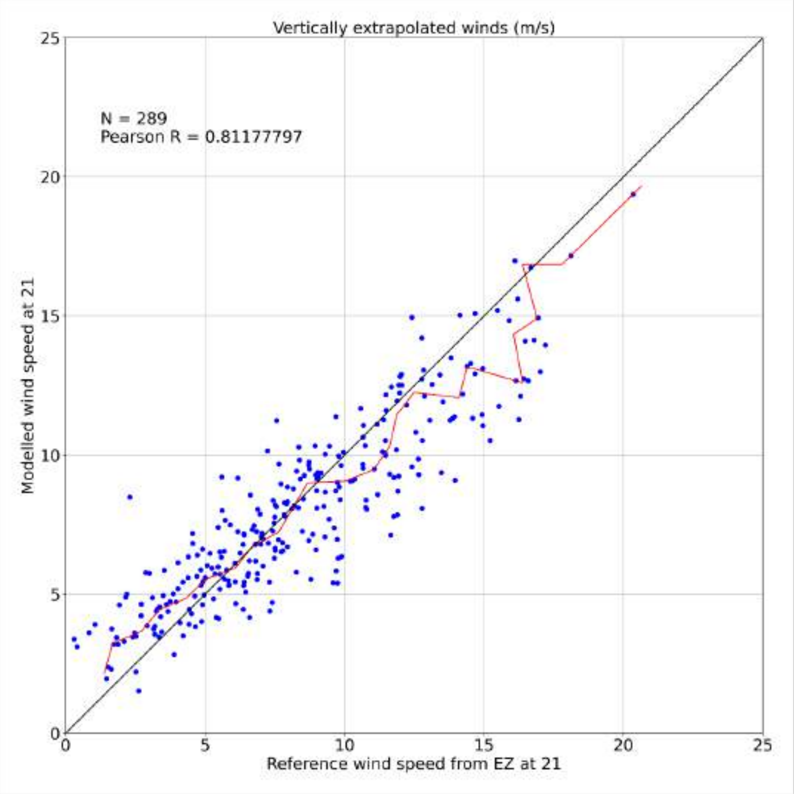
3. Now, the new OLL can be applied to determine the wind profile at different heights.

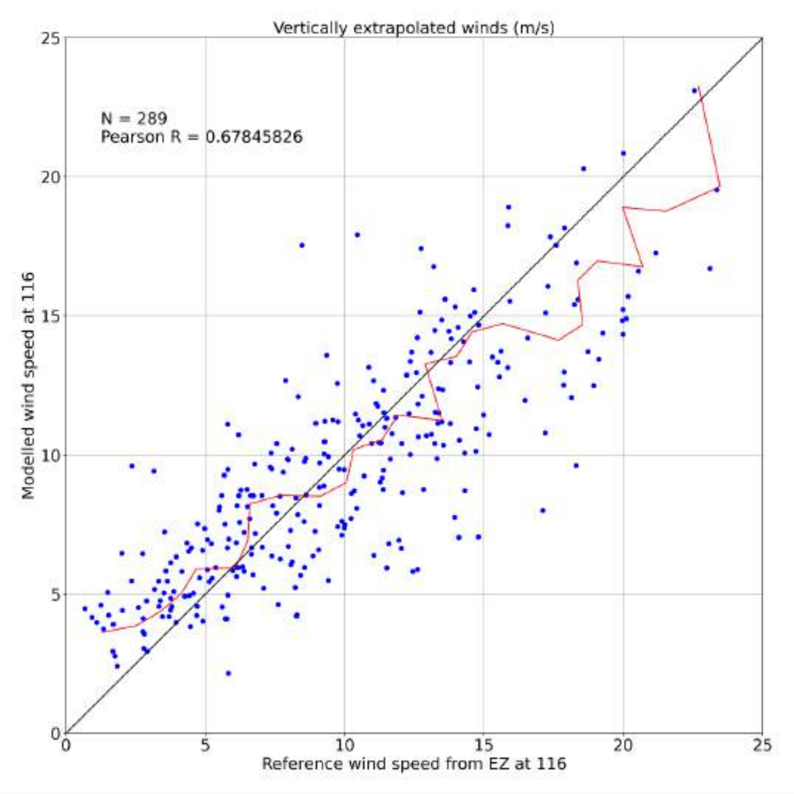
EZ mast - neutral surface winds





EZ - neutral extrapolated winds





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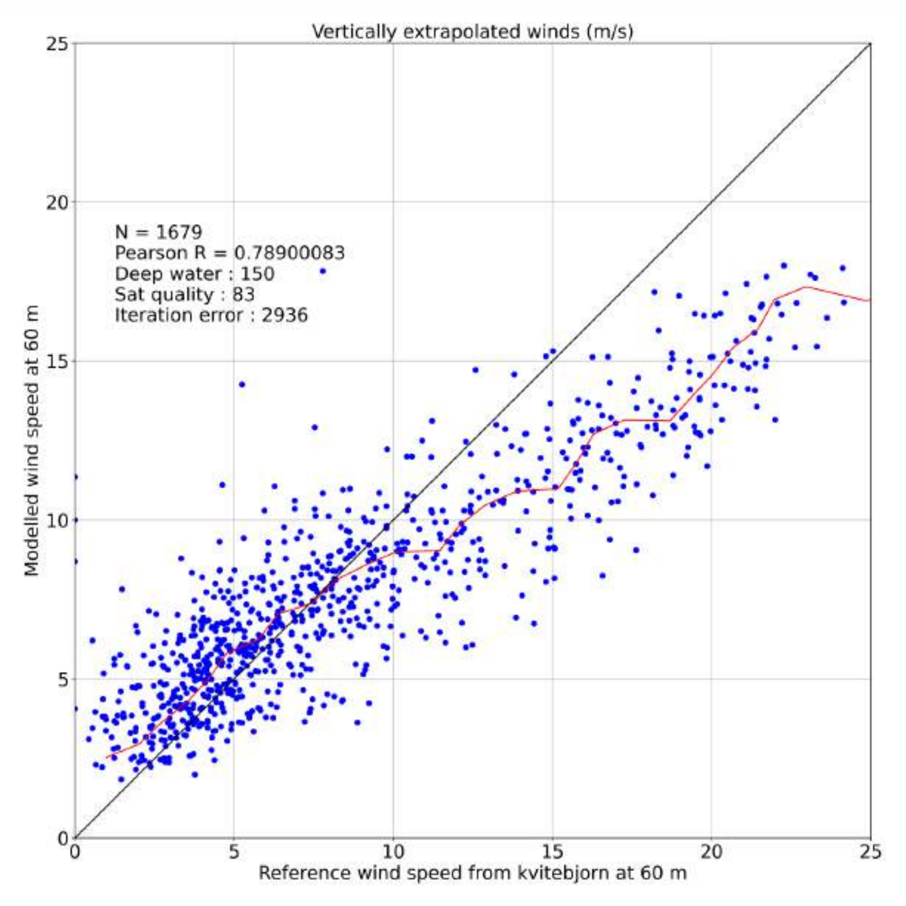
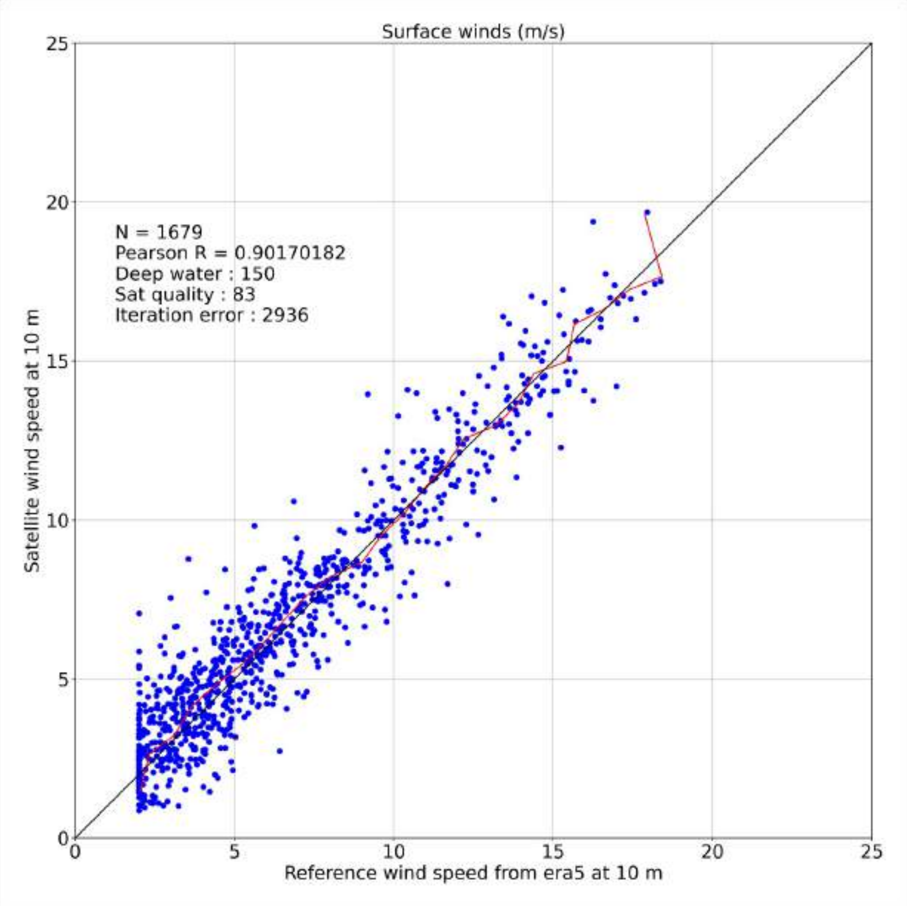
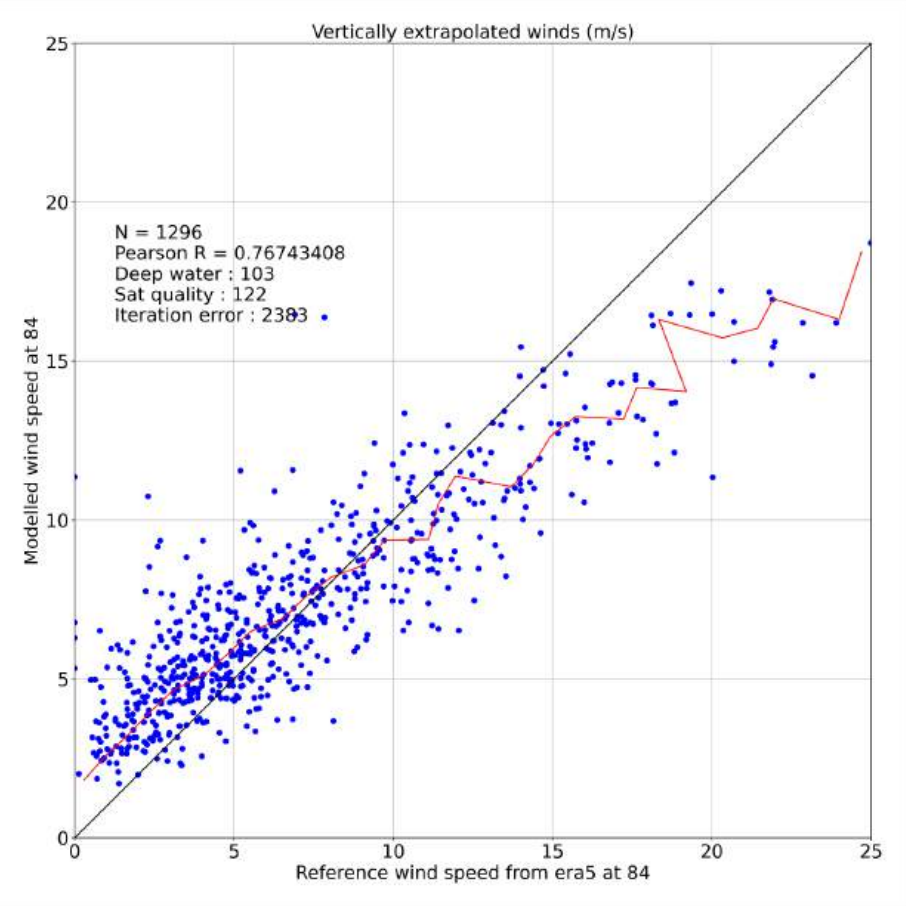
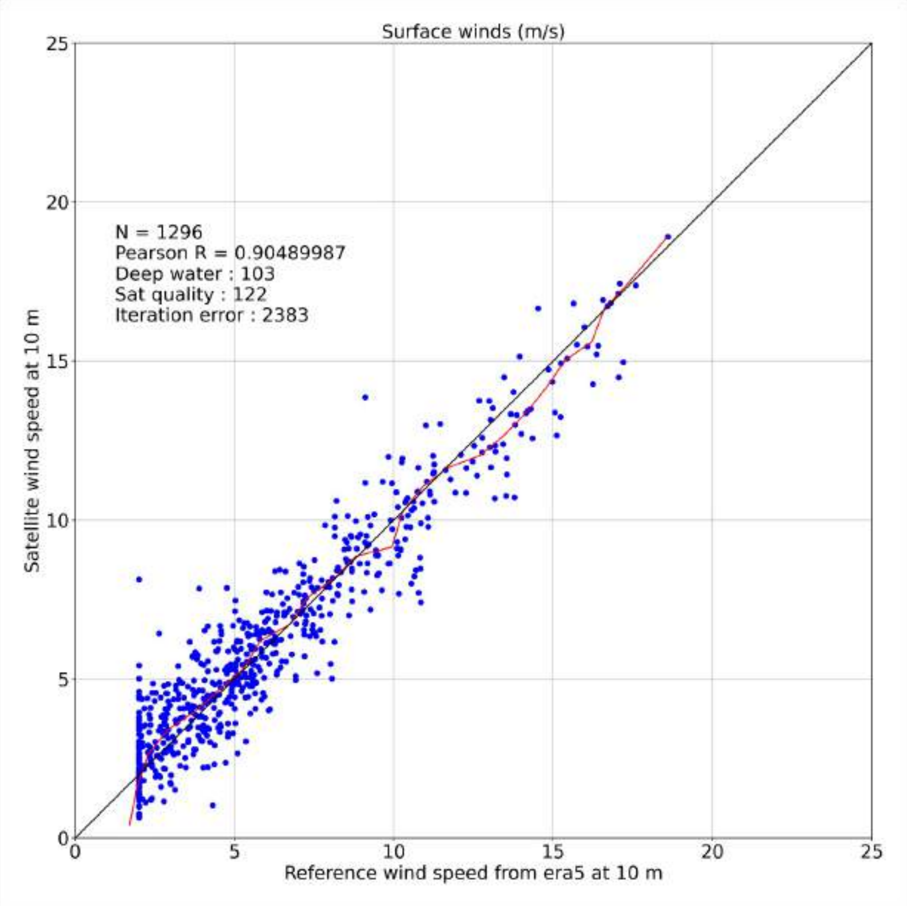
Results - Oil platform - Kvitebjorn (60m)



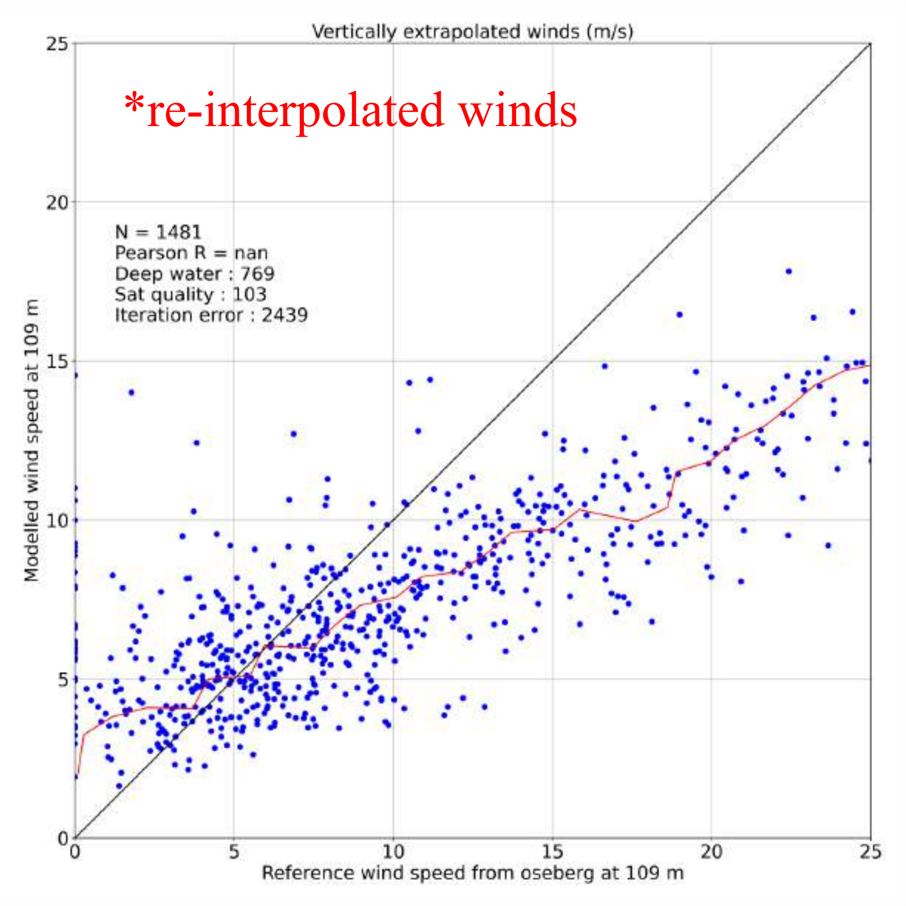


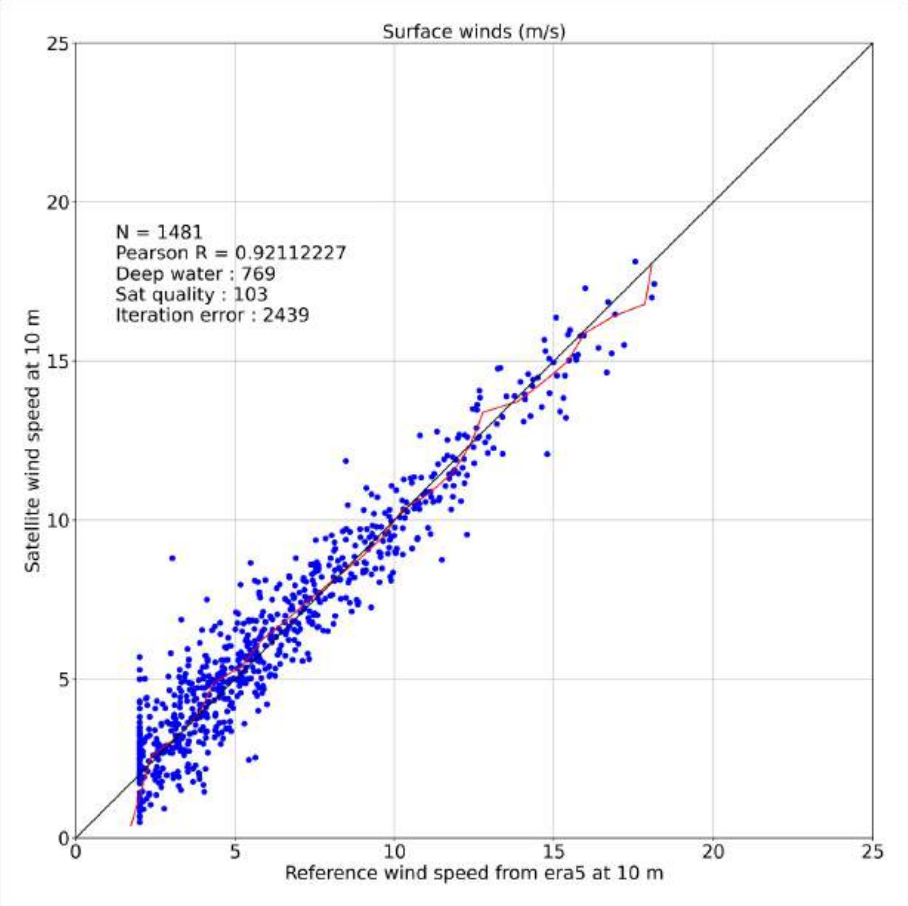
Results - Oil platforms - Troll (84m)



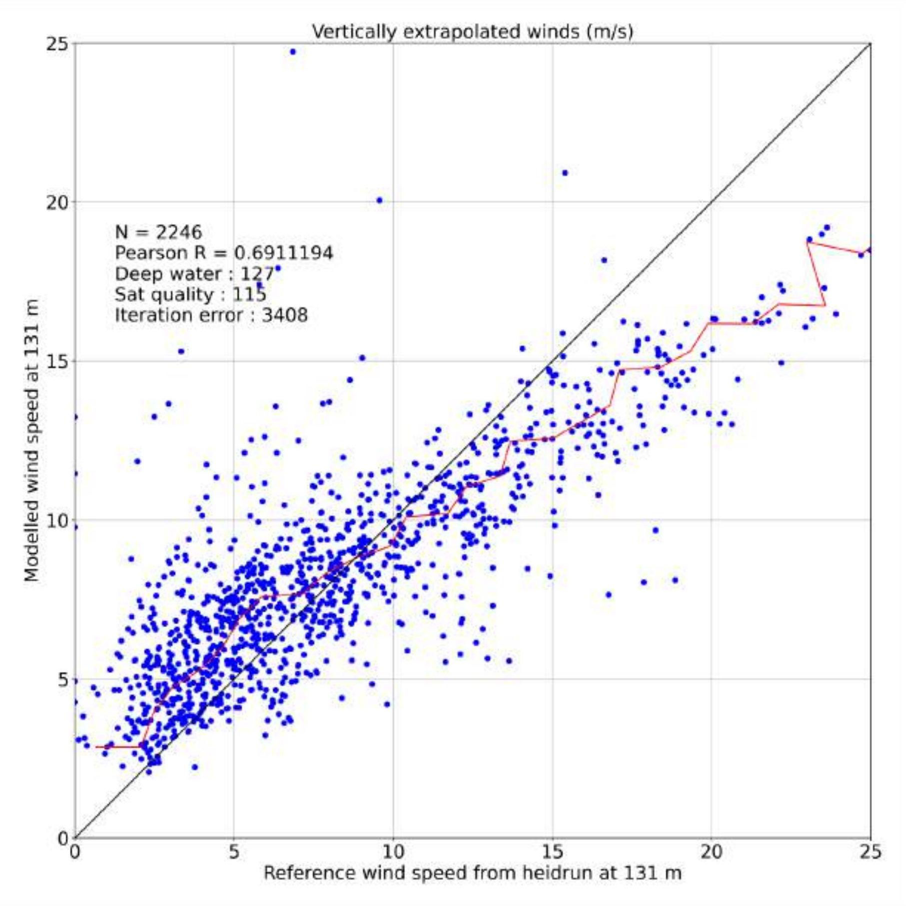


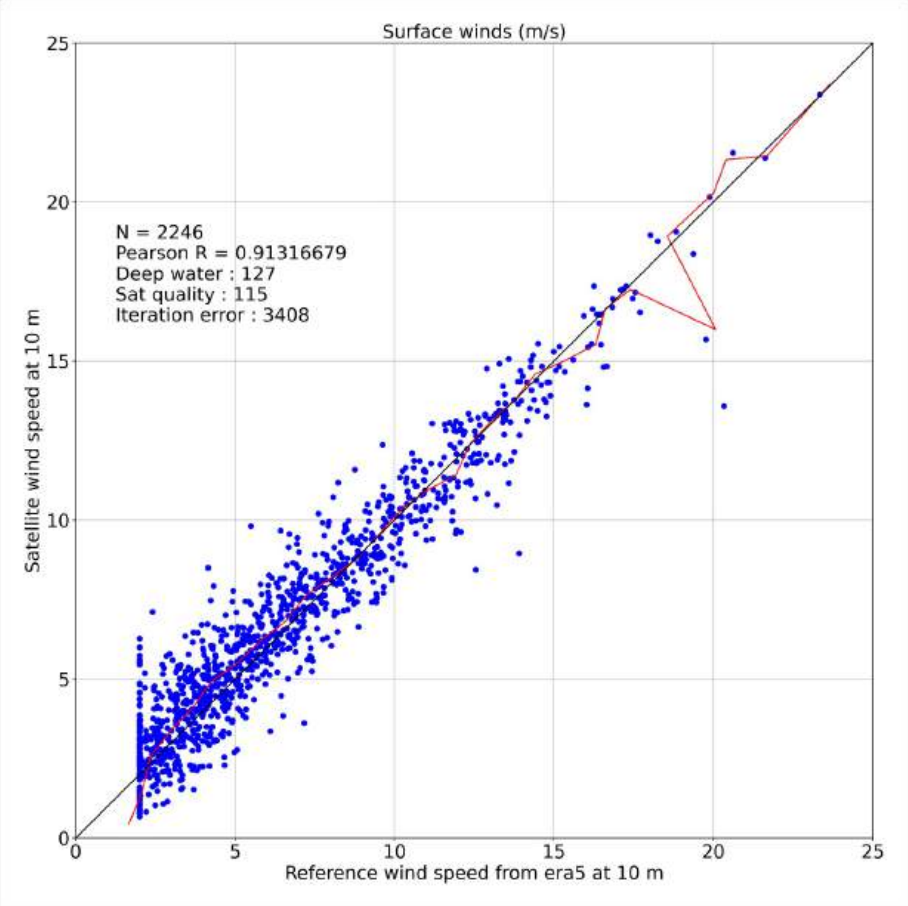
Results - Oil platform - Oseberg (109m)





Results - Oil platforms - Heidrun (131m)





Summary

Lessons learned

- When applying the log law (or COARE):
  - The lower the level the smaller the error
  - A under/overestimated z_0 is compensated with an over/underestimated u*
- Good validation: calculate surface parameters and extrapolate vertically
- Ideal validation: modelled u* against a u* sonic anemometer, but at what height??

Future steps

- Is ε_k really dependant on z ??
  - If yes, find the relationship
  - If not, recalculate ε_k empirical parameters for an z-independent ε_k
- Use insitu sea state measurements instead of model for sea state input
- Perhaps, apply readjustment to scatterometers high winds ??
- Extent the study to radiometers and SAR

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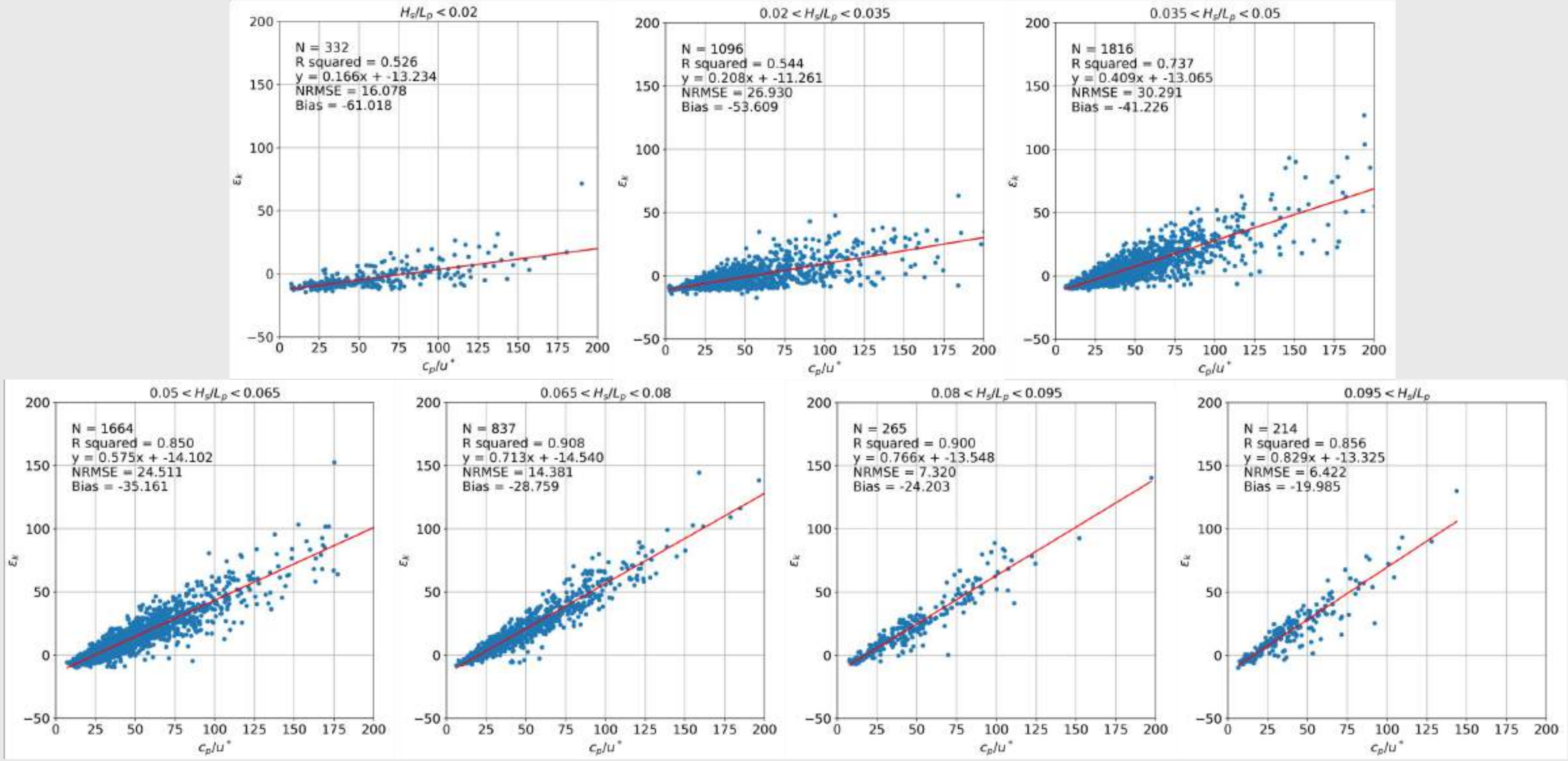
Questions?

Bonus slide



$H_s/L_p < 0.02$
N = 332
R squared = 0.526
y = 0.166x + -13.234
NRMSE = 16.078
Bias = -61.018
$0.02 < H_s/L_p < 0.035$
N = 1096
R squared = 0.544
y = 0.208x + -11.261
NRMSE = 26.930
Bias = -53.609
$0.035 < H_s/L_p < 0.05$
N = 1816
R squared = 0.737
y = 0.409x + -13.065
NRMSE = 30.291
Bias = -41.226
$0.05 < H_s/L_p < 0.065$
N = 1664
R squared = 0.850
y = 0.575x + -14.102
NRMSE = 24.511
Bias = -35.161
$0.065 < H_s/L_p < 0.08$
N = 837
R squared = 0.908
y = 0.713x + -14.540
NRMSE = 14.381
Bias = -28.759
$0.08 < H_s/L_p < 0.095$
N = 265
R squared = 0.900
y = 0.766x + -13.548
NRMSE = 7.320
Bias = -24.203
$0.095 < H_s/L_p$
N = 214
R squared = 0.856
y = 0.829x + -13.325
NRMSE = 6.422
Bias = -19.985
ε_k
c_p/u^*