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DELFT UNIVERSITY WIND ENERGY RESEARCH INSTITUTE

OWEZ data analysis

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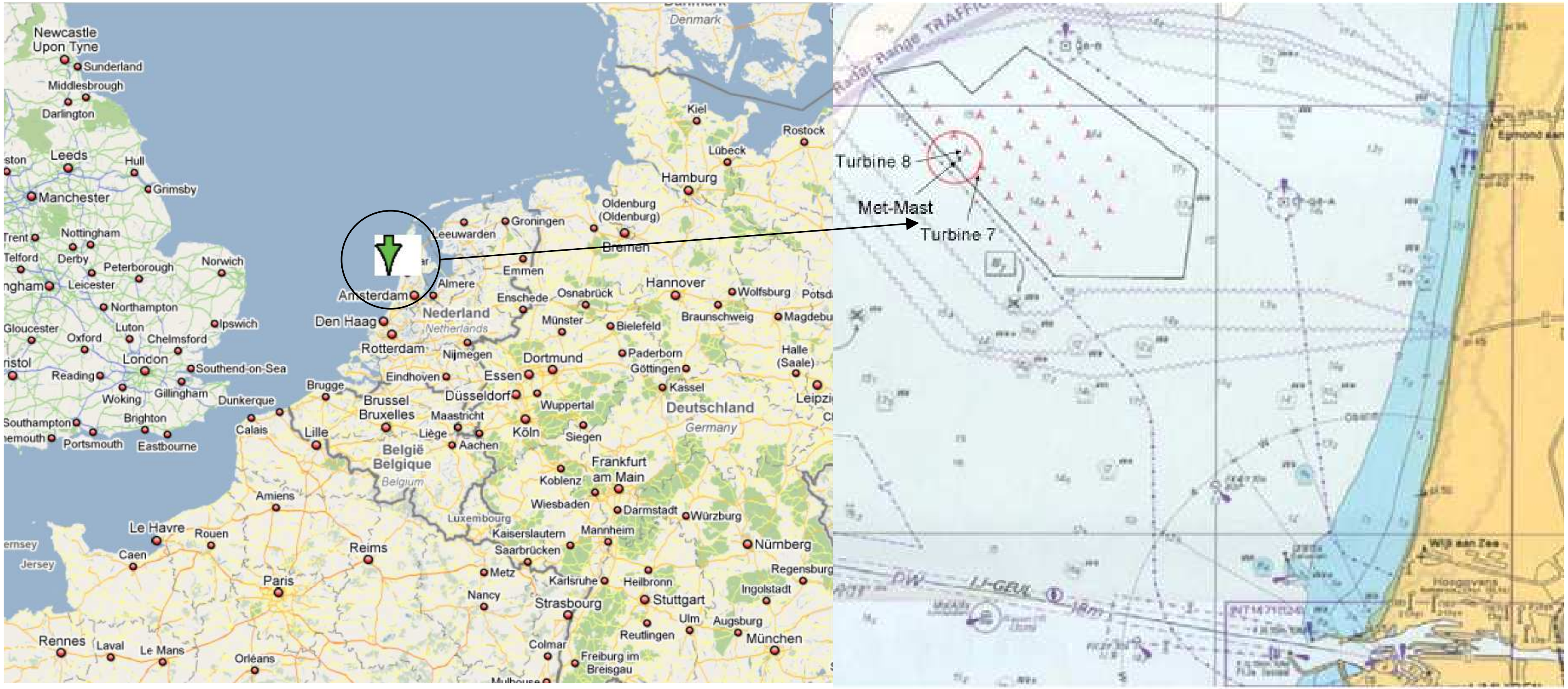
Introduction

- PhD objective – Make use of the site data and derive wind conditions relevant for loading
- Validation of wind shear with the measurements and atmospheric stability analysis
- Deriving momentum fluxes using Lidar

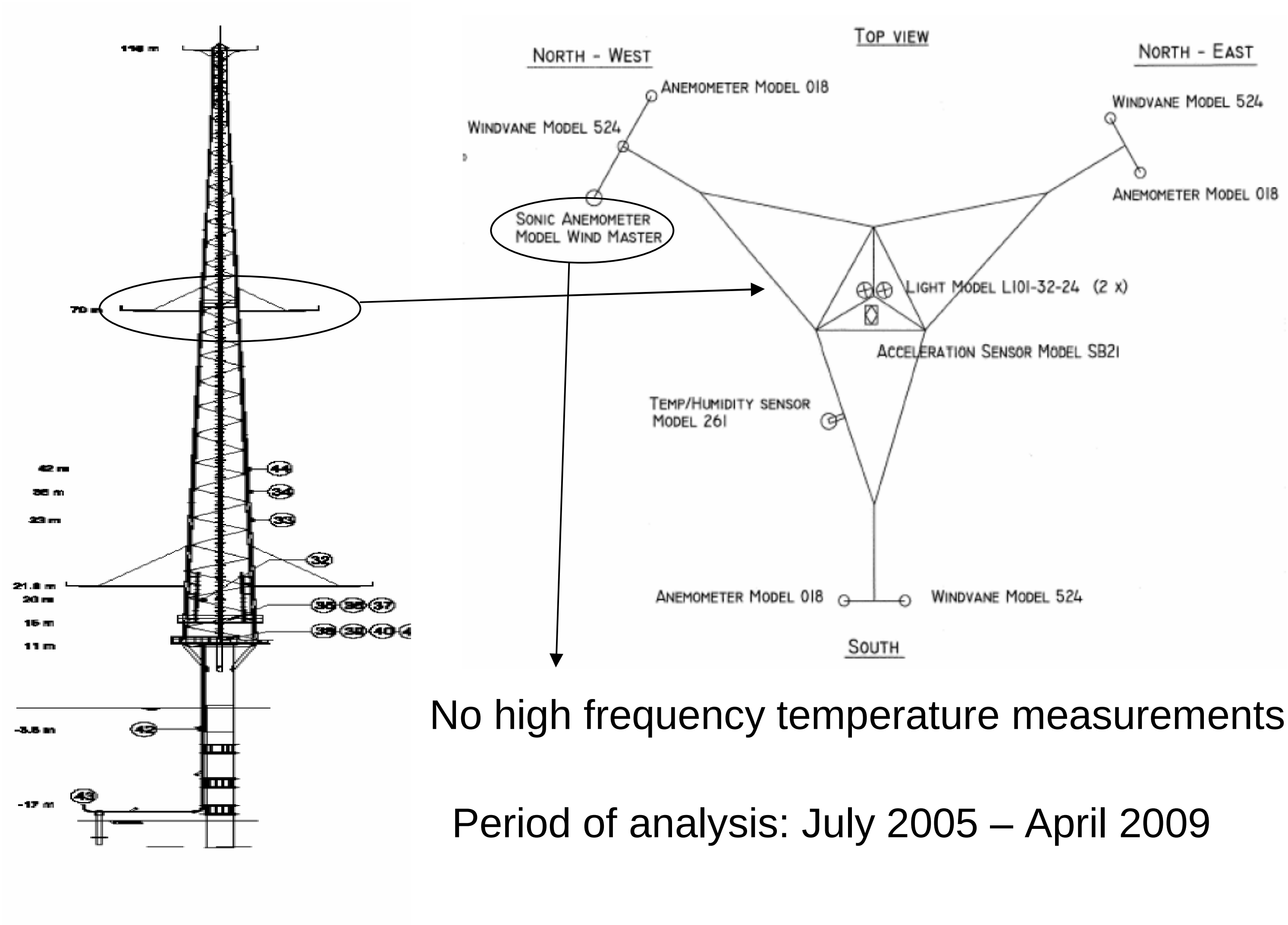
Measurement site



Henk Kouwenhoven, 2007

Site – Egmond aan Zee, Dutch North Sea, Water Depth ~ 20m
Distance to coast ~ 18 km, A dedicated met mast, 36 Vestas V90 turbines

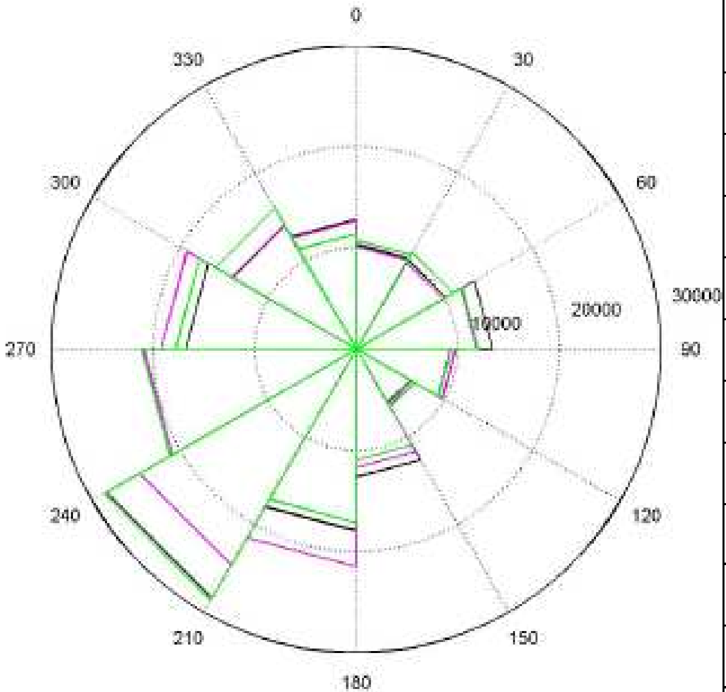
Measurements



No high frequency temperature measurements

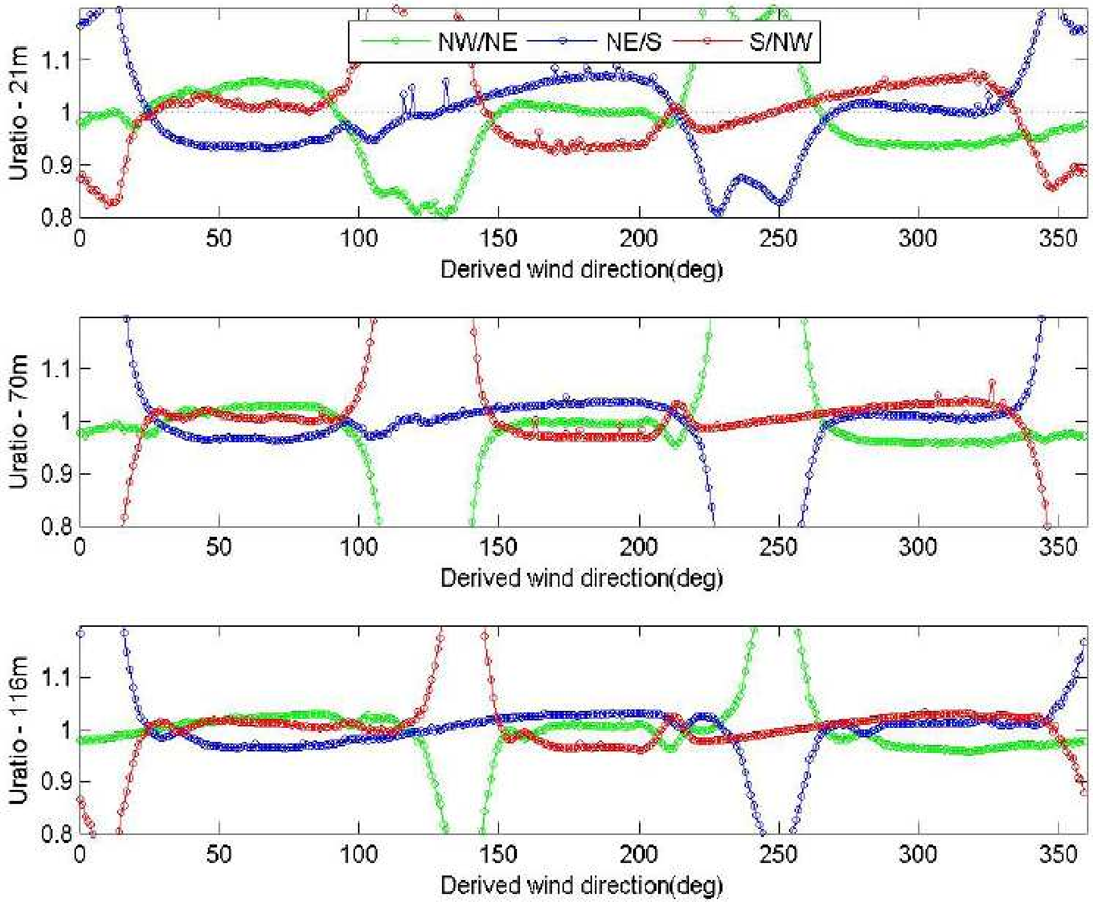
Period of analysis: July 2005 – April 2009

Preliminary data analysis

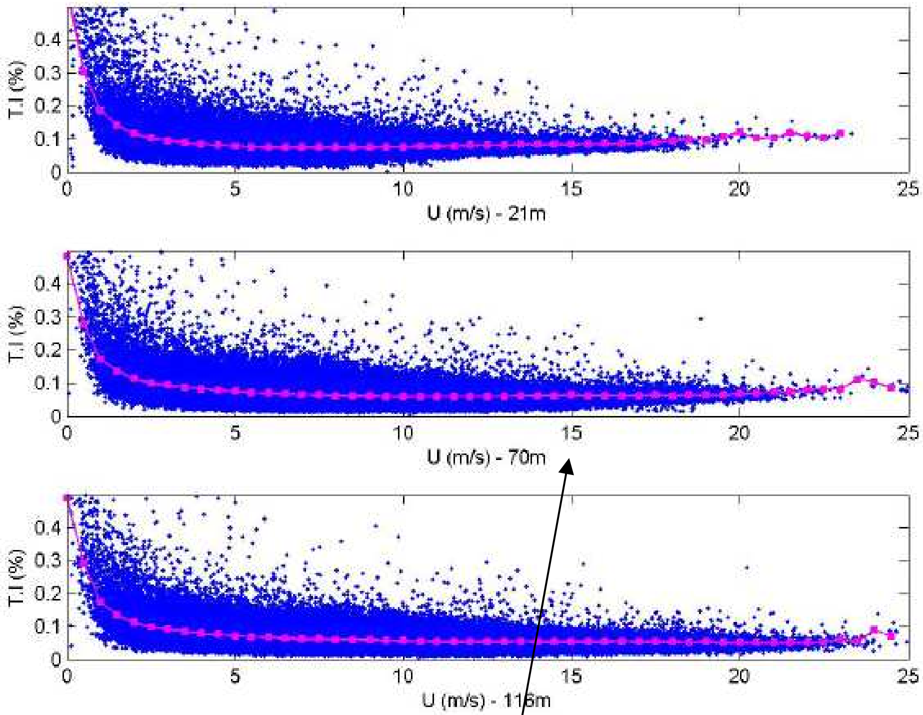


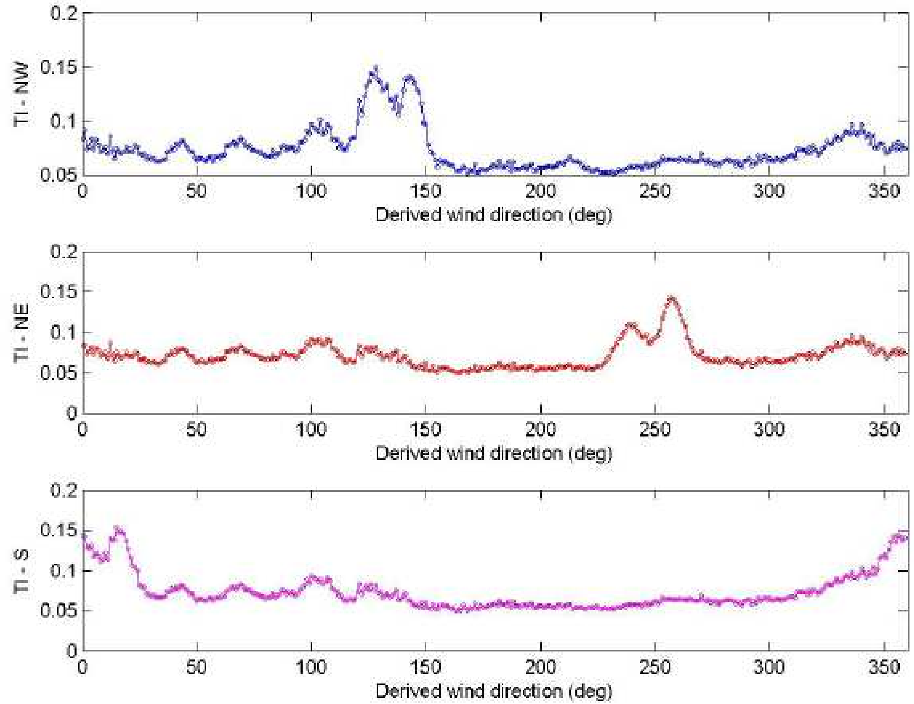
Reference Directional Sectors	Sensors used at each height		
	$21m$	$70m$	$116m$
0° – 30°	NW,NE	NE,S	NW,NE
30° – 60°	NW,NE	NW,S	NW,NE
60° – 90°	NE,S	NW,S	NE,S
90° – 120°	NW,S	NW,S	NE,S
120° – 150°	NE,S	NE,S	NE,S
150° – 180°	NE,S	NW,NE	NE,S
180° – 210°	NW,S	NW,S	NW,S
210° – 240°	NW,S	NW,S	NW,S
240° – 270°	NW,S	NW,NE	NW,S
270° – 300°	NW,S	NE,S	NE,S
300° – 330°	NW,NE	NW,NE	NW,NE
330° – 360°	NW,NE	NW,NE	NW,NE

Preliminary data analysis



Preliminary data analysis





IEC, T.I, 15 m/s >> 0.066 at hub height

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Theory of wind profiles

$$U = \frac{u_*}{k}\left[ln(\frac{z}{z_0}) - \psi_m(\frac{z}{L})\right] \qquad \theta_2 = \theta_1 + \frac{\theta_*}{k}\left[ln(\frac{z}{z_t}) - \psi_t\right]$$

$$\psi = 2ln\left(\frac{1+x}{2}\right) + ln\left(\frac{1+x^2}{2}\right) - 2tan^{-1}(x) - \frac{\pi}{2} \; ...for \; \frac{z}{L} < 0$$

$$\psi = -\beta\frac{z}{L} \; ...for \; \frac{z}{L} > 0$$

$$z_0 = \alpha\frac{u_*^2}{g} \qquad L = -\frac{u_*{}^2\theta_v}{kg\theta_{*v}} \qquad z_s = 0.025\frac{u_*}{f_c}$$

Crucial parameters

Methods used to estimate L

- Profile methods
  - 3 variants
  - Iteration of wind profile equation
- Richardson number
  - Gradient $$Ri_g = \frac{g\overline{\triangle\theta_v}\triangle z}{\overline{\theta_v}(\triangle\overline{U})^2}$$
  - Bulk $$Ri_b = \frac{g\overline{\triangle\theta_v}z}{\overline{\theta_v}(\overline{U})^2}$$

Data used
Mean wind speed,
Sea temperature
Air temperature

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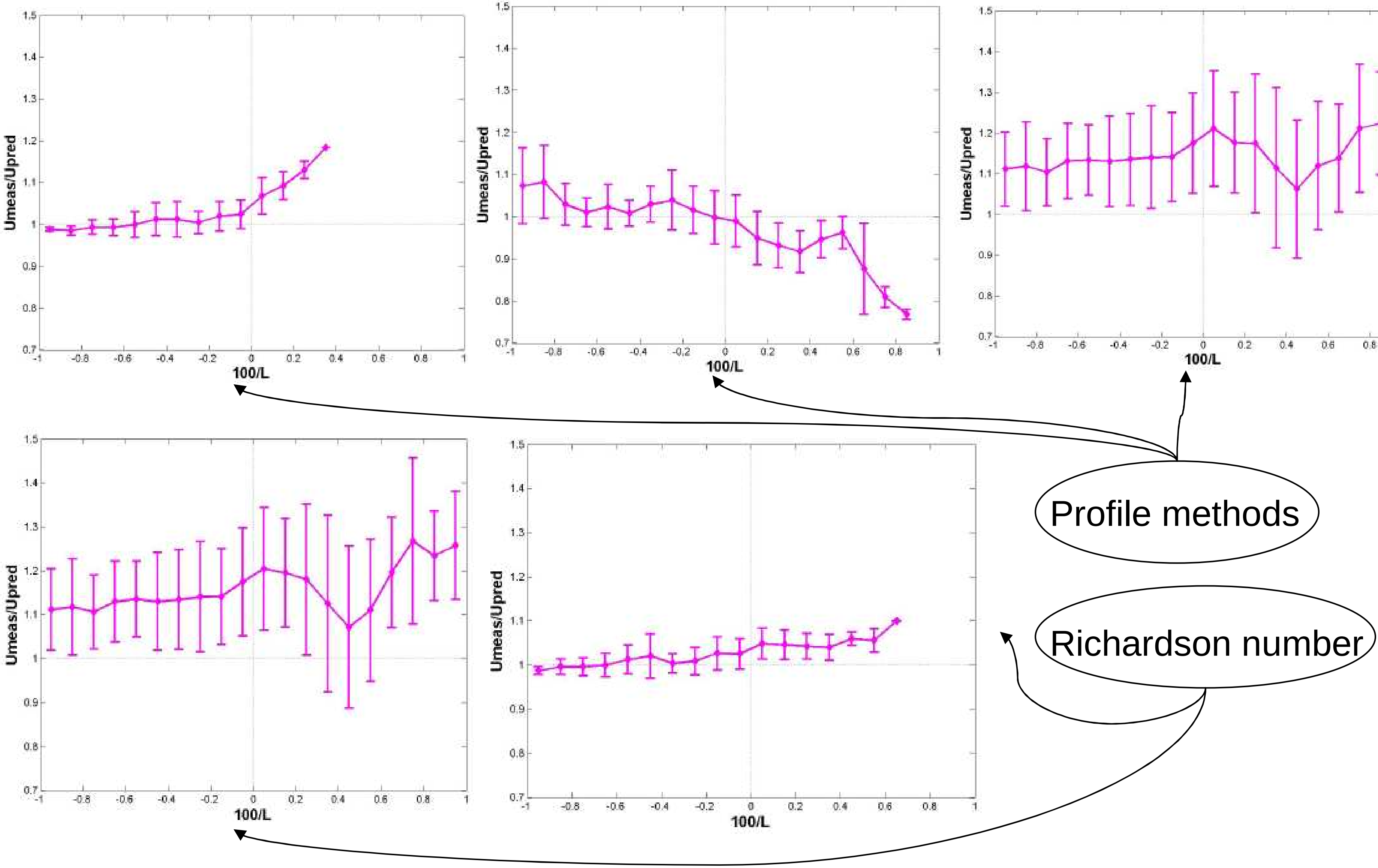
Validation of wind shear



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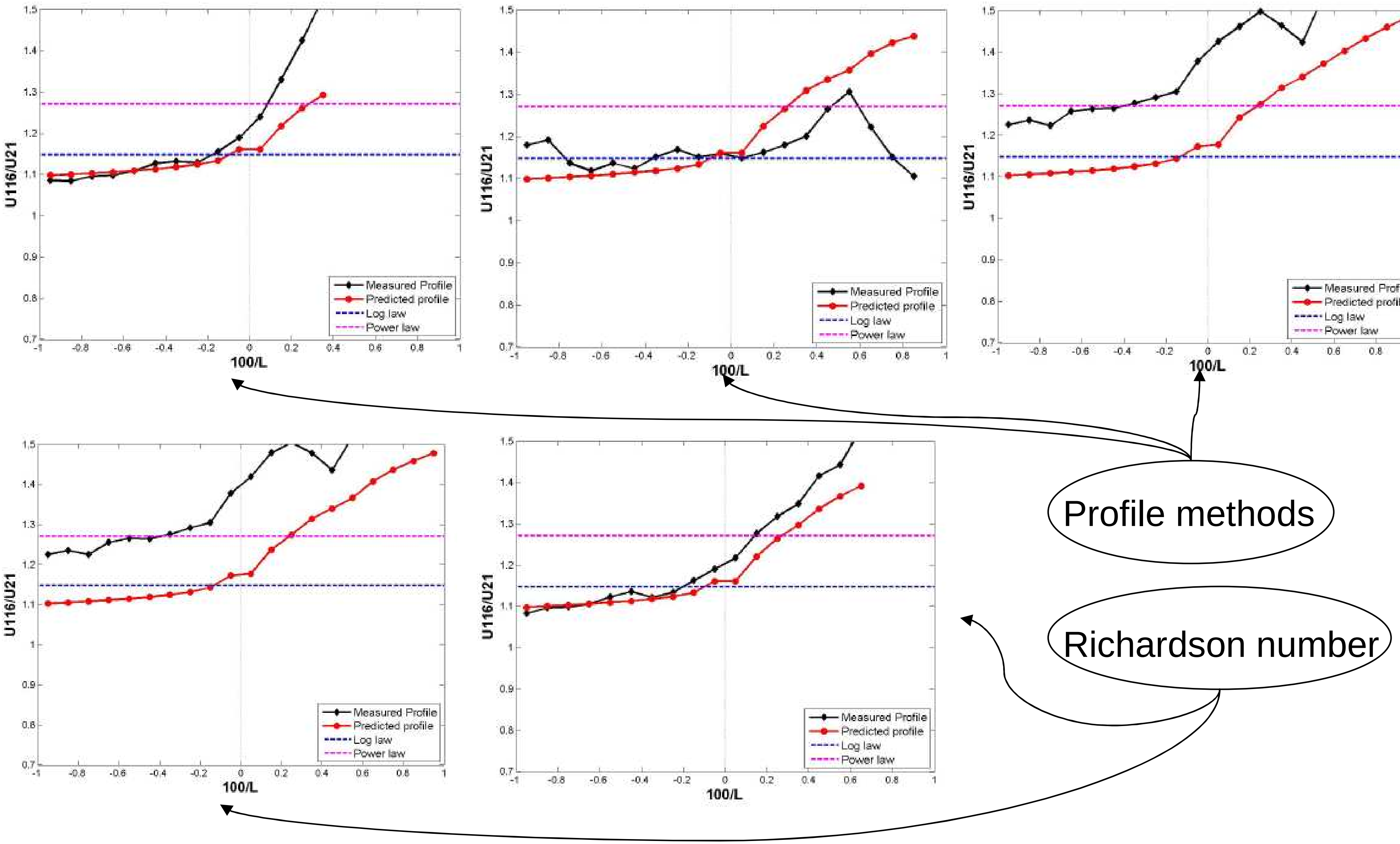
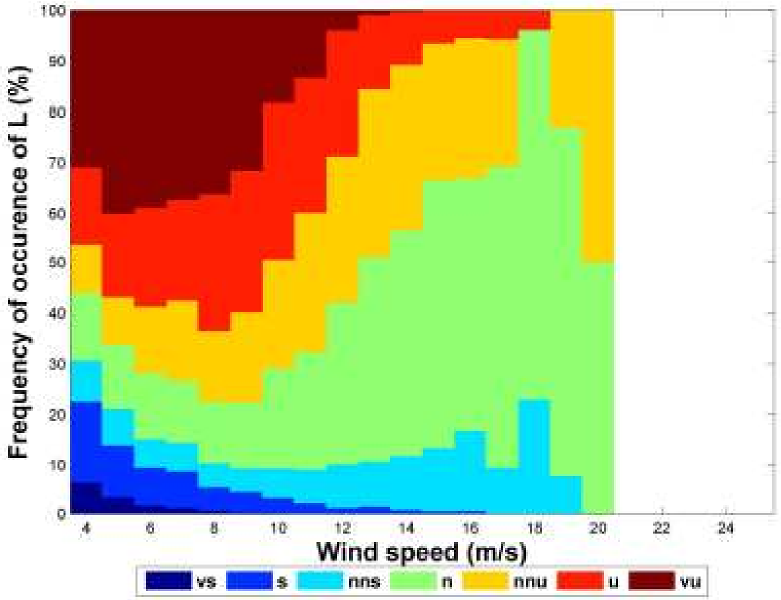
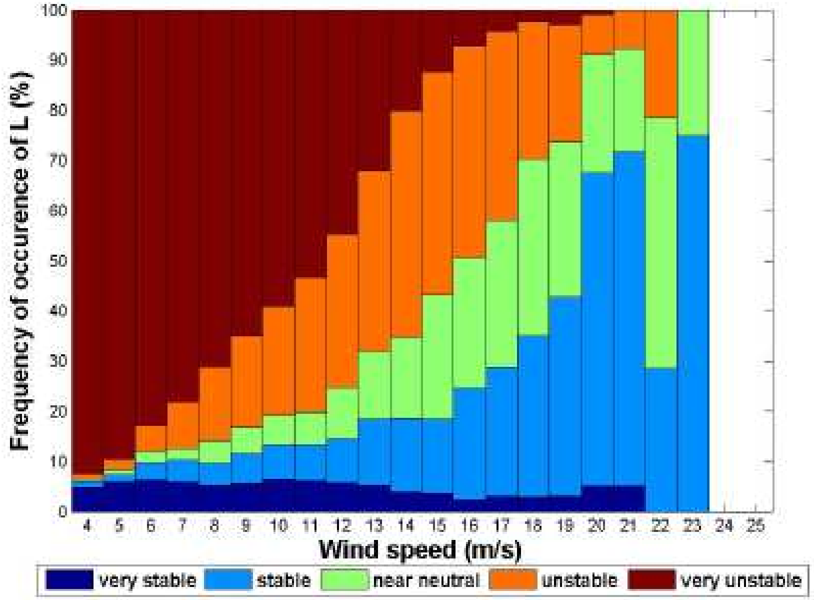
Validation of wind shear



Stability conditions

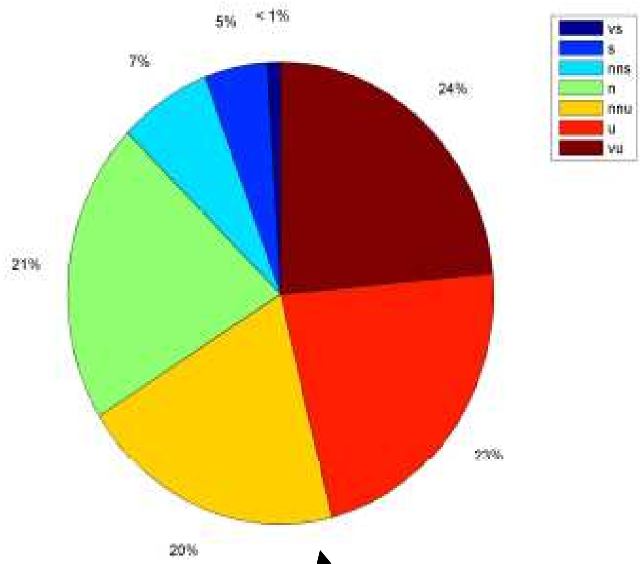


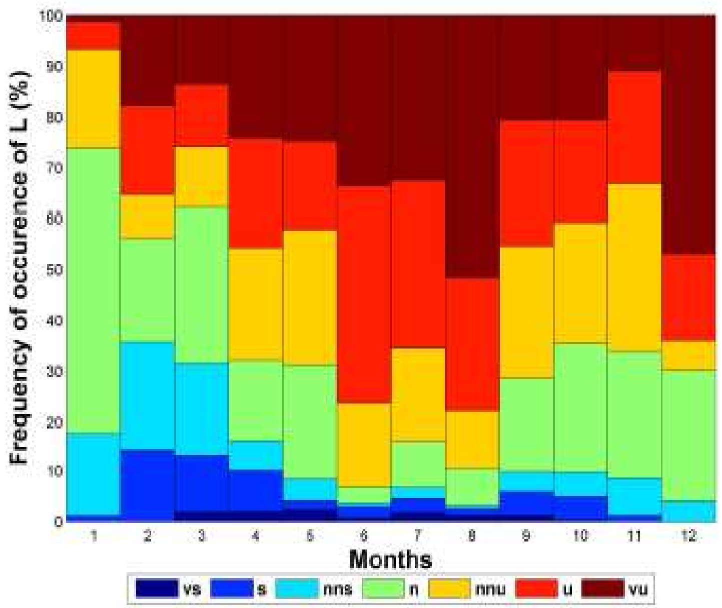


Stability condition	Range
very stable (vs)	$10 < L < 50$
stable (s)	$50 < L < 200$
near-neutral stable (nns)	$200 < L < 500$
neutral (n)	$\mid L \mid > 500$
near-neutral unstable (nnu)	$-500 < L < -200$
unstable (u)	$-200 < L < -100$
very unstable (vu)	$-100 < L < -50$

very stable	$0 < L < 200$ m
stable	$200 < L < 1000$ m
near-neutral	$\mid L \mid > 1000$ m
unstable	$-1000 < L < -200$ m
very unstable	$-200 < L < 0$ m

Stability conditions





Compares well with the work of Coeling et al, 1996

Conclusions

- Method to estimate L is crucial, Bulk Ri is the best
- MO-theory restricted to surface layer and hence large reduction in data
- Conditions at Egmond aan Zee are mainly unstable
- Classification of L has a major impact on the interpretation of stability conditions
- Better wind shear models are required that go beyond the surface layer

Future work

- Estimation of u* with sonic data and comparison with other methods
- Use of model devoloped by Gryning et al to extrapolate wind profiles beyond the surface layer
- (Possibly) estimate the uncertainty in the analysis

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Thank you