Parameterisation of offshore turbulence

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Introduction

- This talk is about some ideas for parameterising offshore turbulence with a view to implementing this into numerical models.
- We will look at the friction velocity, u_* first...
- ...and this will then lead onto investigating the offshore Turbulent Kinetic Energy (TKE).

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Charnock's parameterisation for the roughness length

- Charnock (1955): $z_o = \alpha \frac{u_*^2}{g}$
- Logarithmic Law: $U_{10} = \frac{u_*}{\kappa} \ln\left(\frac{z}{z_o}\right)$
- Drag coefficient: $C_D = \left(\frac{u_*}{U_{10}}\right)^2$
- Hence: $C_D = \left[\frac{1}{\kappa} \ln\left(\frac{gz}{\alpha u_*^2}\right)\right]^{-2}$
- Evidence suggests this doesn't work at higher wind speeds...

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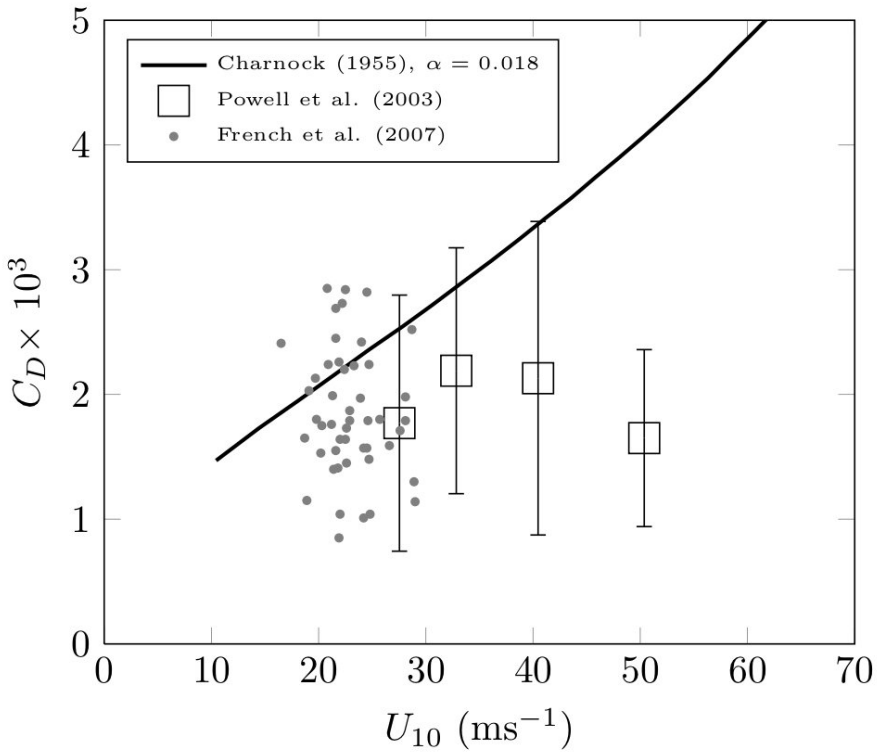
Estimates of C_D at higher wind speeds



- Powell et al. (2003) - Radiosondes in hurricanes
- French et al. (2007) - Aircraft estimates in hurricanes
- Charnock (1955) for $\alpha = 0.018$

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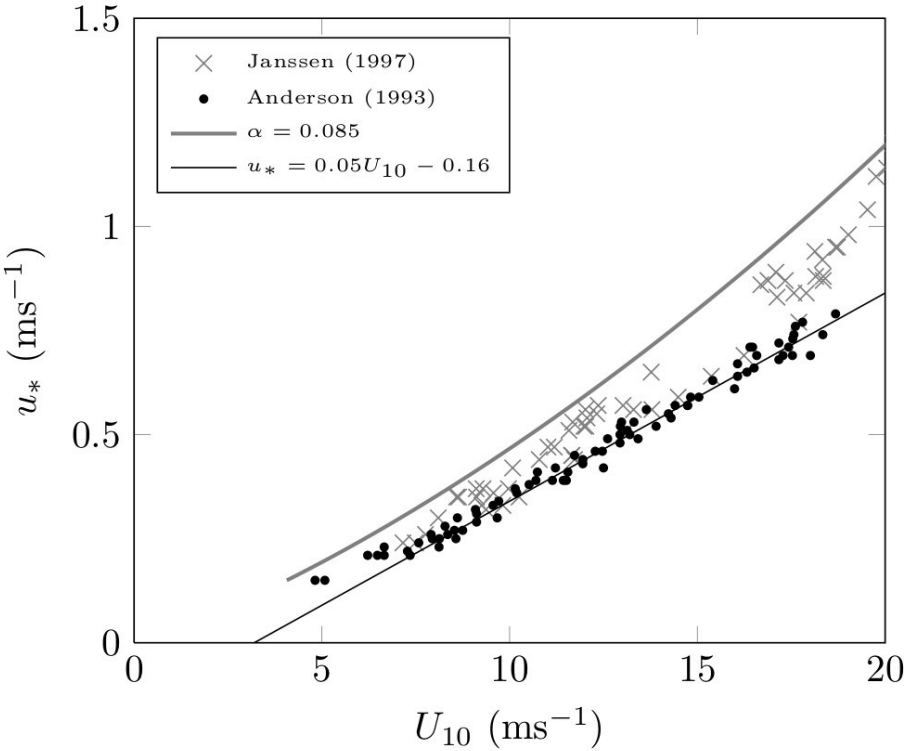
Lower wind speeds: u_* vs. U_{10}

- Are some measurements of u_* vs. U_{10} linear at higher wind speeds?



- Charnock (1955) gives non-linear u_* vs U_{10}.
- Janssen (1997) - North Sea (HEXOS)
- Anderson (1993) - North Atlantic
- Can fit $u_* = 0.05U_{10} - 0.16$ to Anderson (1993) at higher wind speeds.

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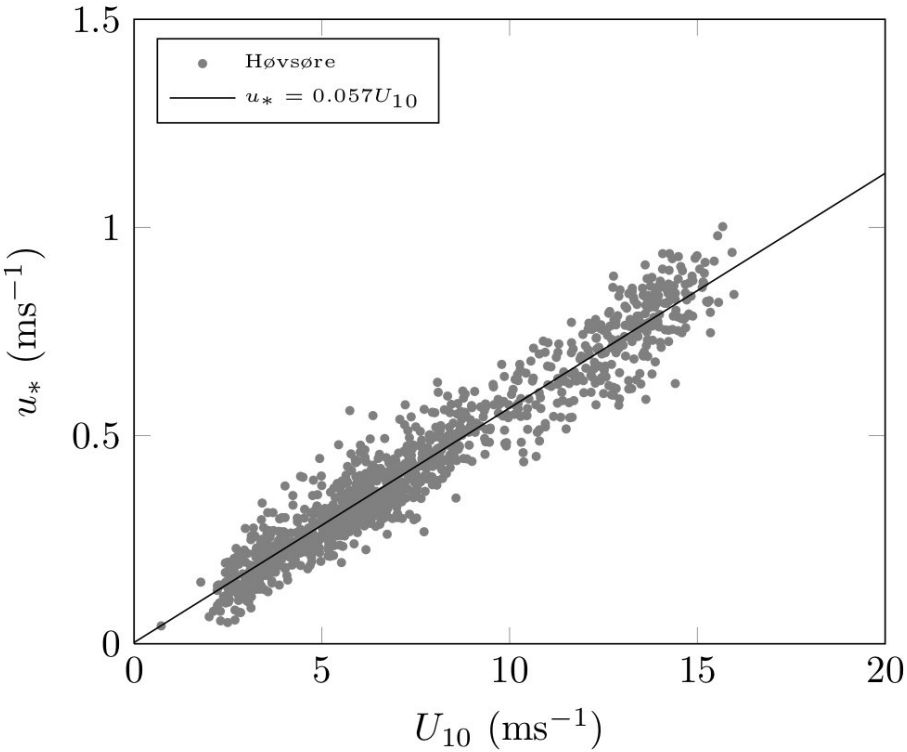
Compare u_* vs. U_{10} over land

- Is the linear regime a consequence of fully rough flow?



- Høvsøre measurements (stratification corrected) during February 2005.
- Constant surface roughness here: $u_* = 0.057U_{10}$.
- Over water: $u_* = 0.05U_{10} - 0.16$
- Is "0.16" due to low speed transition to rough flow?

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Example at FINO1 - North Sea platform

- Can try this at FINO1 but no 10 m measurement...

- Sonics at 40, 60 and 80 m - interpolate u_* to the surface.
- Use $\frac{z}{L}$ and U (ms^{-1}) at 40 m
- Monin-Obukhov similarity theory it down to 10 m

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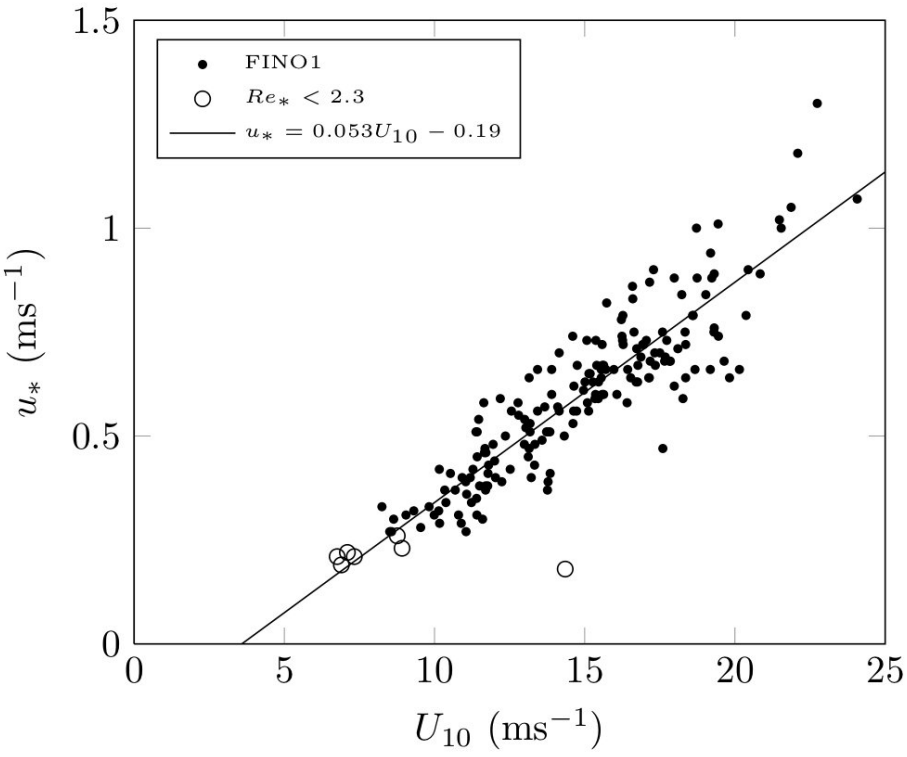
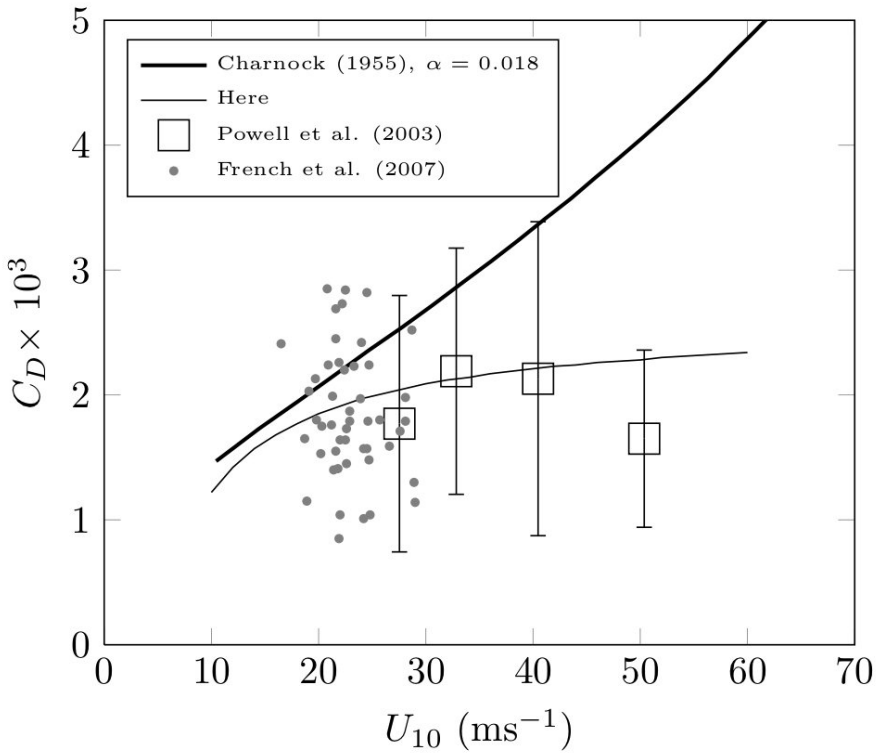
FINO1 - January 2005 - Storm "Erwin"



- Circles: Rejected data using a critical roughness Reynolds number: $Re_* = 2.3$.
  - Reynolds roughness criterian has been criticised plenty before: E.g. exact Re_* uncertain...
- But...rough/linear "regime" found for wind speeds $\gtrsim$ 10 ms^{-1}?

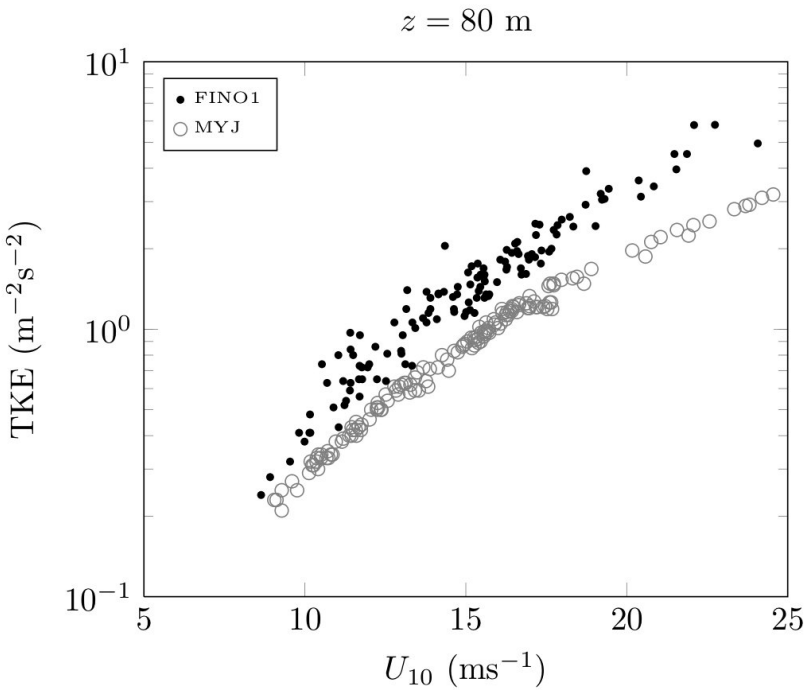
Difference between Charnock (1955) and that suggested here at higher wind speeds

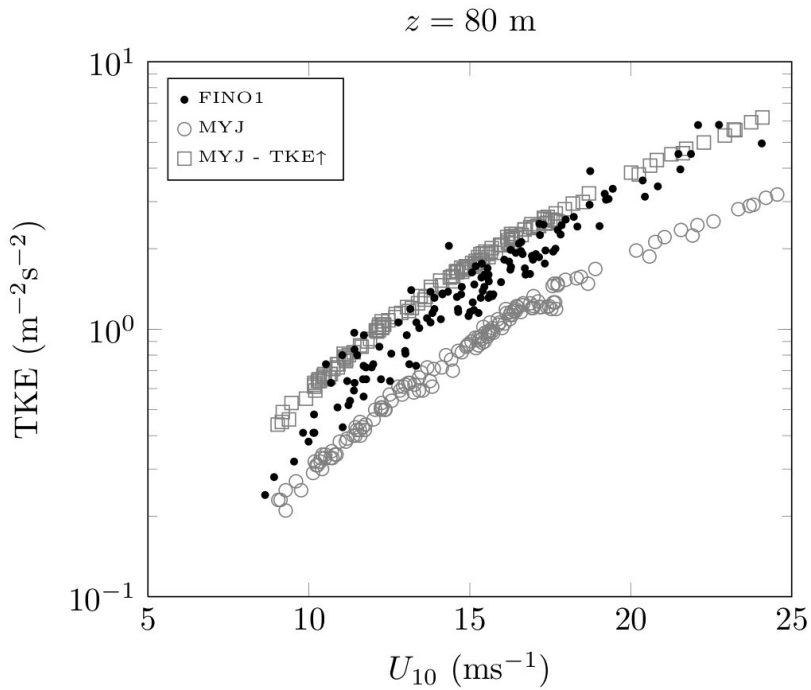
- Linear relationship between u_* and U_{10} gives $C_D \rightarrow$ constant.
- Take the Anderson (1993) results: $u_* = 0.050 U_{10} - 0.16$.
- Here: $C_D = \frac{u_*^2}{U_{10}^2} = \frac{(0.050 U_{10} - 0.16)^2}{U_{10}^2}$



More practical matters: FINO1

- TKE in existing MYJ too low...increase TKE and...
- Is there a wind speed (Reynolds number) dependence?





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Increasing TKE in the Mellor-Yamada-Janjic scheme

- You can increase the TKE in the Mellor-Yamada-Janjic (MYJ) scheme by bumping up B_1 (see Mellor & Yamada (1982)) to what you think it should be, while relaxing the specification for γ_1 and adding an explicit dependence of ℓ (master length scale) on surface stratification: $\ell_s = \left(1 + c\frac{z}{L}\right)$ for $\frac{z}{L} > 0$.
- How big should B_1 be and is it even constant? - The model assumes Reynolds number independence
  - $B_1 = \frac{q^3}{u_*^3}$, $\gamma_1 = \frac{1}{3} - \frac{2A_1}{B_1}$
  - Laboratory measurements are conflicting but suggest B_1 is not Reynolds number independent as $Re \rightarrow \infty$
  - Atmospheric measurements?

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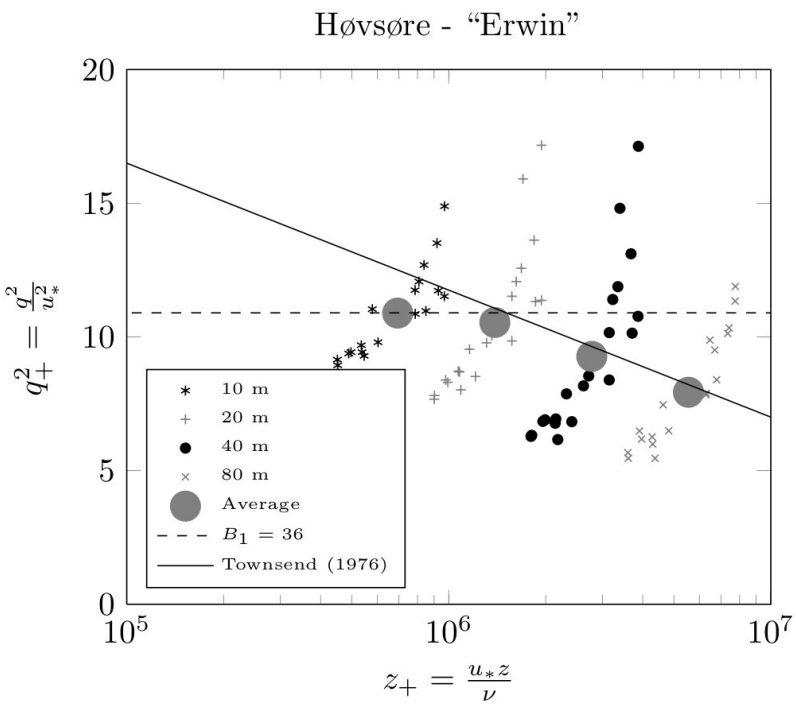
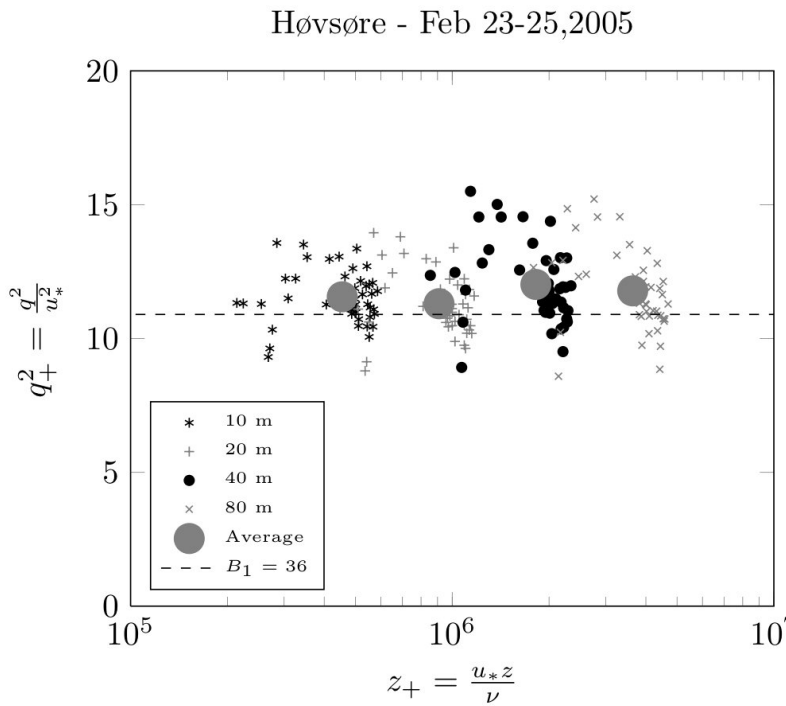
TKE ($\frac{1}{2}q^2$) at Høvsøre - Wall coordinates

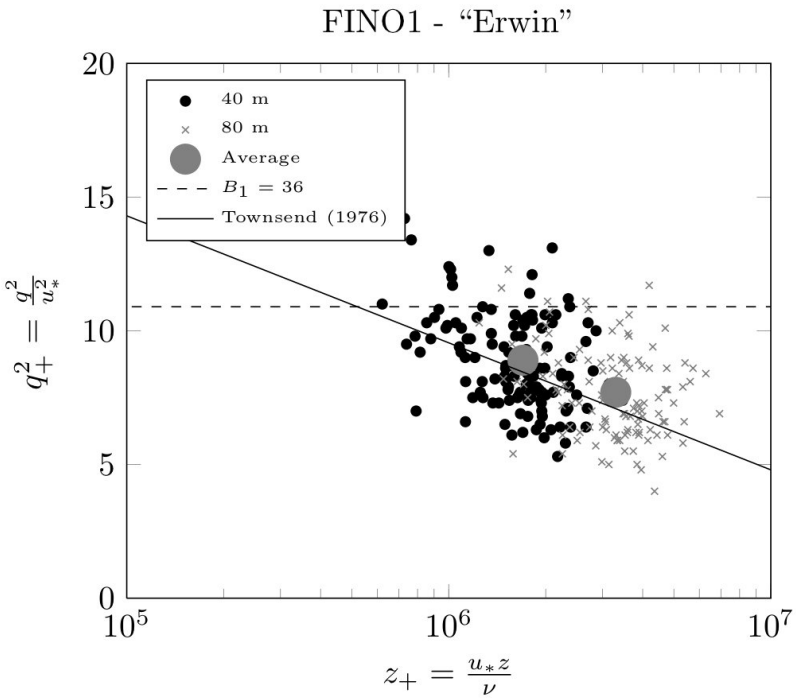
- High wind speed periods: "Erwin" (sea $\rightarrow$ land) and February 2005 (land).
- LHS: Constant stress layer up to 10 m? RHS: constant stress layer up to 80 m?
- LHS agrees better with Townsend's (1976) scaling?

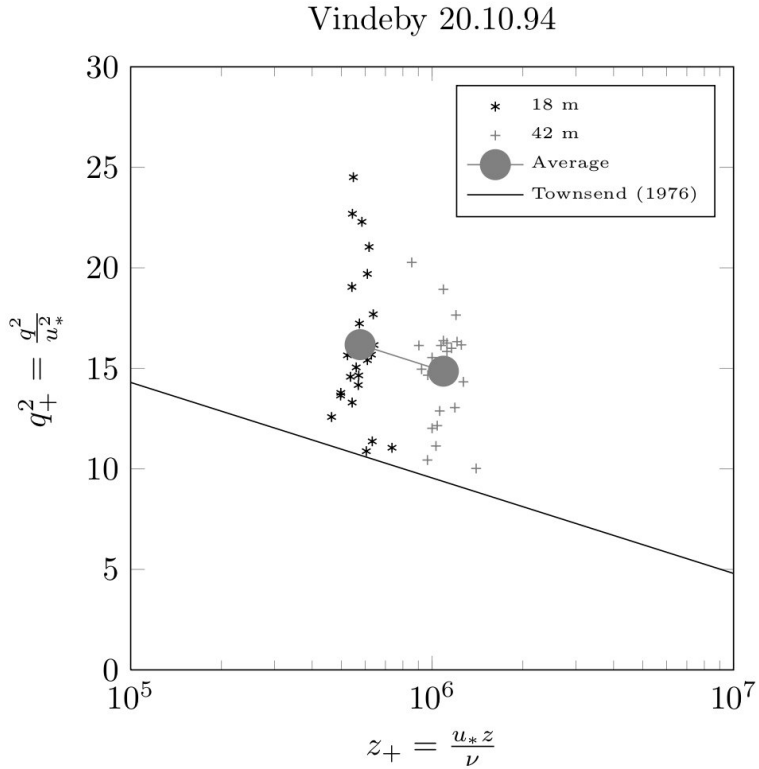




q_+^2 vs. z_+ at FINO and Vindeby

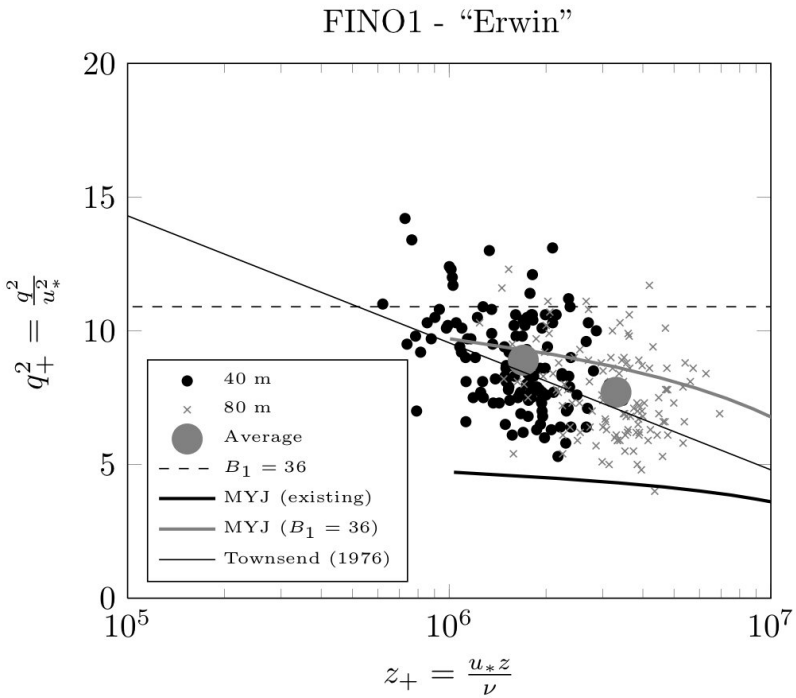
- Townsend (1976), Kunkel & Marusic (2006, JFM): Outer layer eddies scale with $\frac{\overline{u'^2}}{u_*^2} = B - A \ln\left(\frac{z_+}{\delta_+}\right)$
- $A = 1.03, B = 2.39$, assume $\frac{q^2}{u_*^2} \approx 2\frac{\overline{u'^2}}{u_*^2}$ in neutral stratification and $\delta_+ = \mathrm{O}(10^7)$.





Result:

- Assume $\frac{\overline{u'^2}}{u_*^2} = B - A \ln\left(\frac{z_+}{\delta_+}\right)$ applies (and hence there is a Reynolds number dependence), then...
- In practice, ability to model TKE with Mellor-Yamada model will depend on wind speed, vertical resolution, boundary layer thickness.



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Conclusions

- Presented idea to explain levelling-off of C_D for higher wind speeds based on lower wind speed measurements.
- Currently working on wave parameterisation to better explain this result.
- Offshore measurements could agree readily with the Townsend (1976) and Kunkel & Marusic (2006) appoach but need independent estimate of the Reynolds number.

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