A “dirty” almost-neutral surface layer

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Presentation Outline

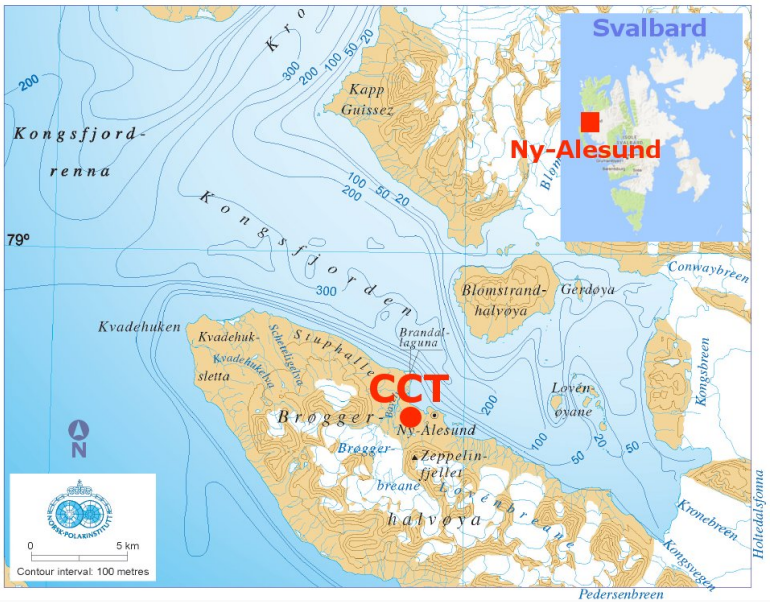
Discussion about the vertical structure of the almost-neutral surface layer at the transition between high and low winds conditions.

On the basis of a set of experimental observations:

- to what extent **similarity theories** (in particular, MOST) are applicable?
- to what extent is the **flux-gradient relationship** valid?
- some hints about **closure models** are suggested from the data analysis.

CNR - Climate Change Tower

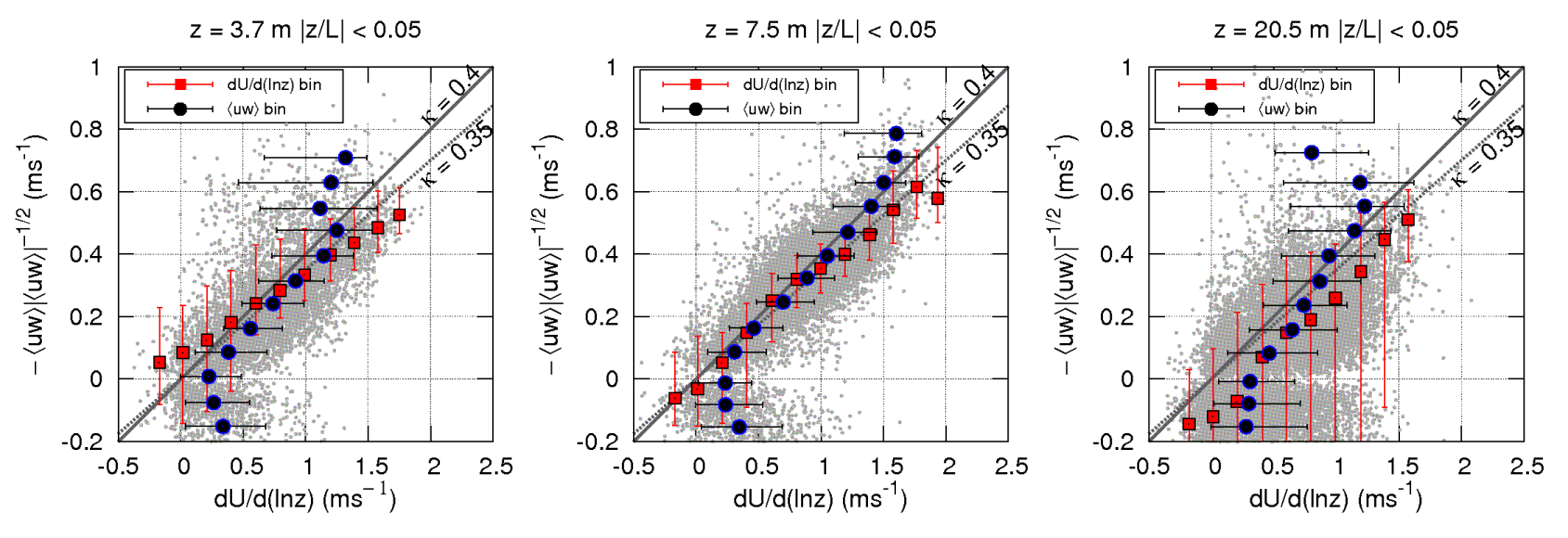
The Climate Change Tower (CCT) is located in Ny-Ålesund (79 °N,12 °E), Svalbard Islands, on heterogeneous terrain. It is operated by the Italian National Research Council (CNR). In the frame of an international collaboration, CCT hosts also KOPRI instrumentation. Observations were acquired since the end of 2009 until today.



CCT Instrumentation

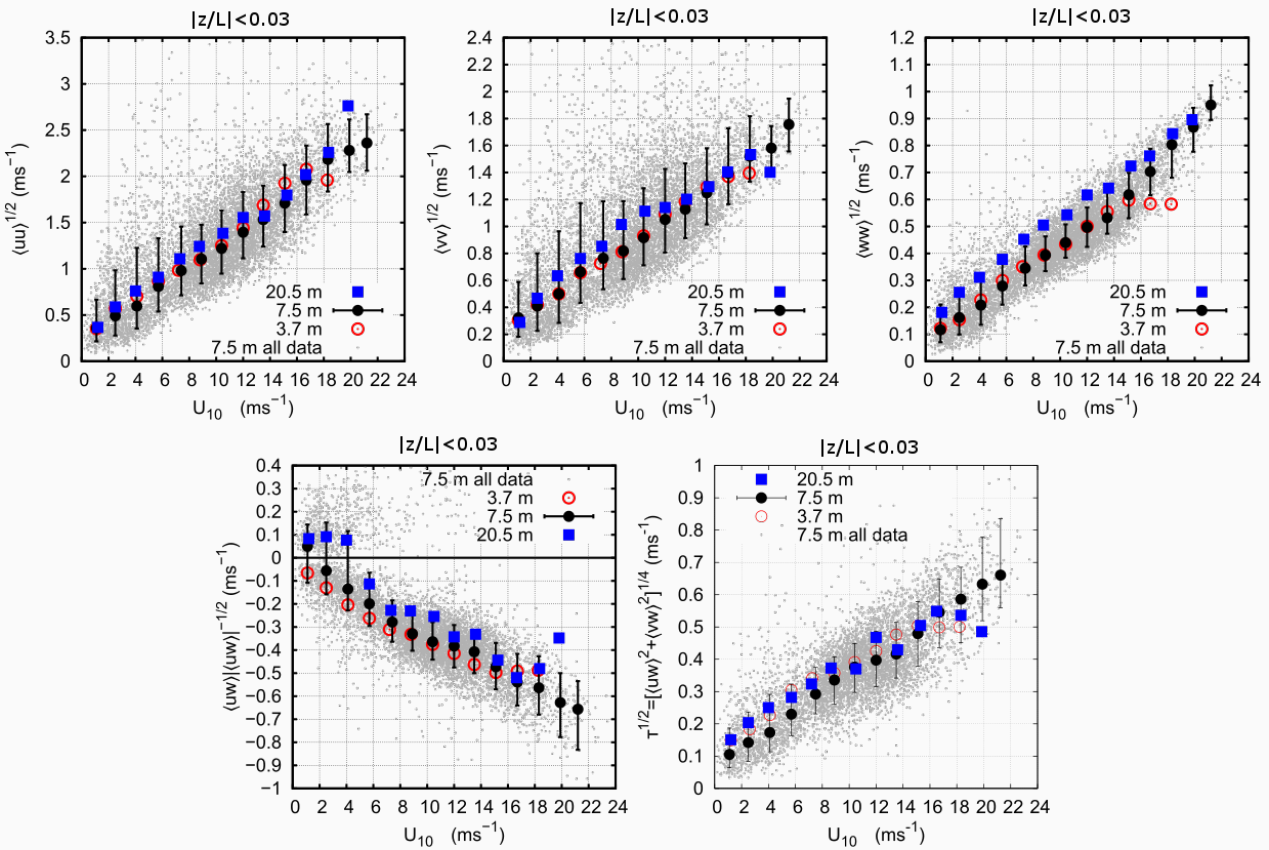
- conventional sensors at 2, 5, 10 and 33 m: 4 Vaisala thermo-hygrometers and 4 Young propeller anemometers;
- sonic anemometers at 3.7 m (R2), 7.5 m (R3) and 21 m (CS3): 2 Gill Solent (CNR) and 1 Campbell CSAT3 (KOPRI);
- radiation and snow height sensors;
- ...

Mean wind profile



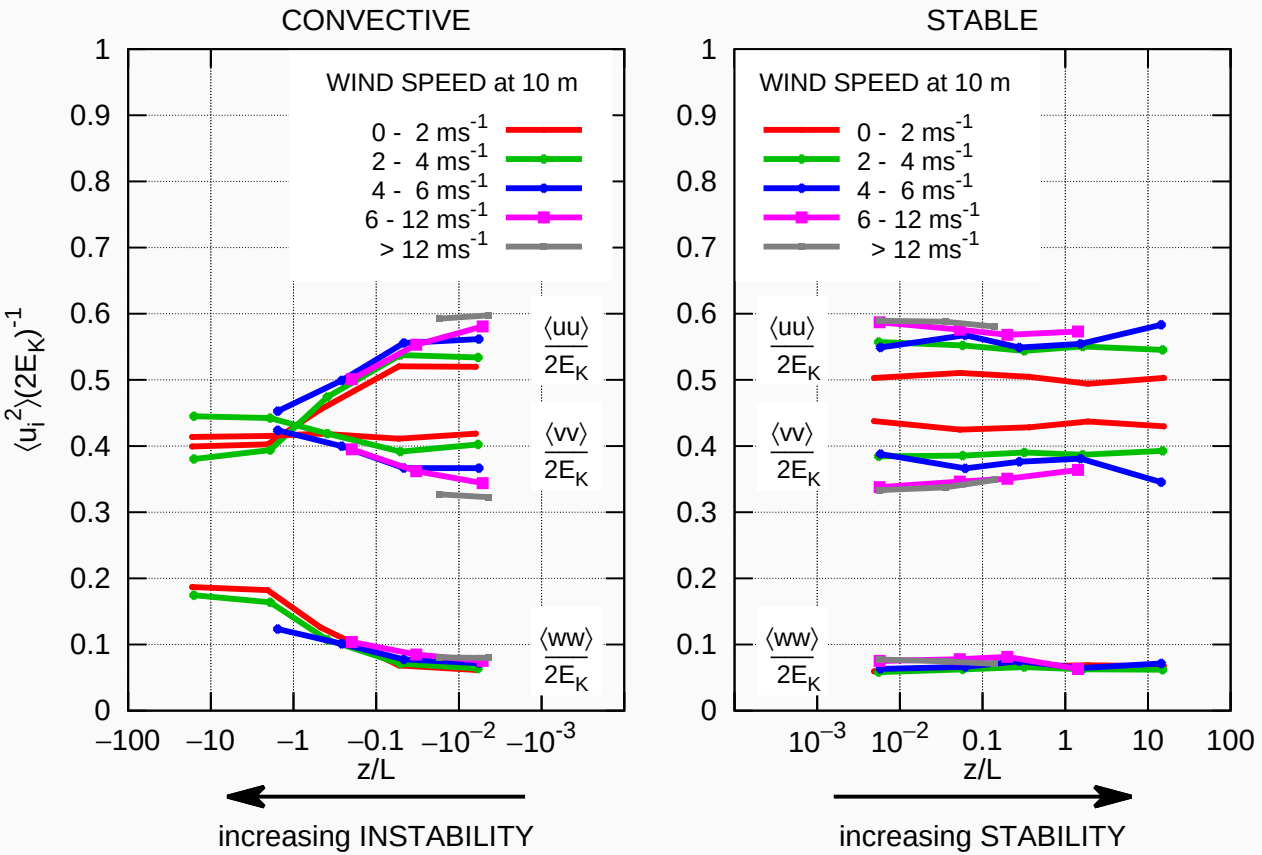
The logarithmic fit using 4 conventional anemometers gives u_* which is compared with the vertical momentum flux from the covariance measures at different heights.

Second order moments



- almost constants with height at lower levels
- increasing between second and the third sonic anemometers

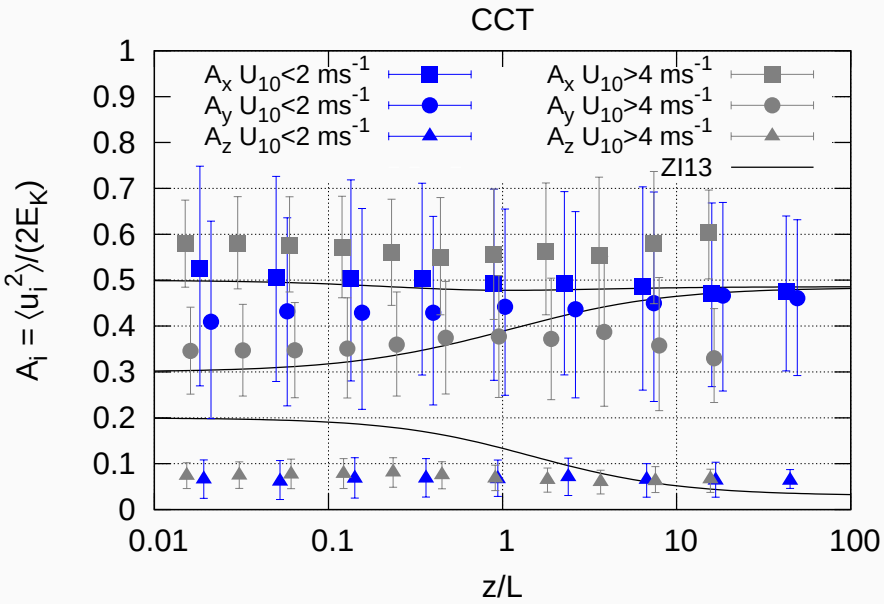
Share of TKE among components – CCT data

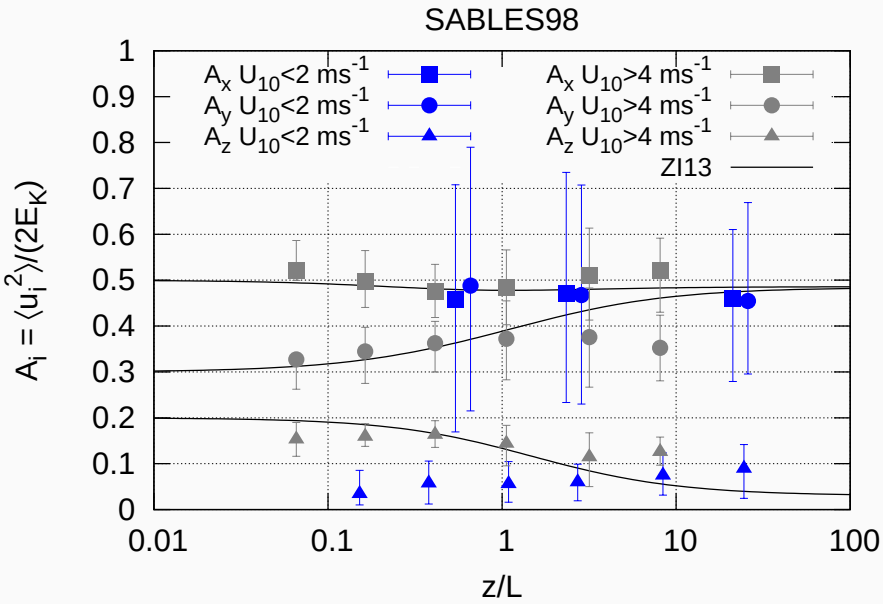


- Weak dependence on stability for $-0.03 < z/L < 1$
- Dependence on wind velocity for $U_{10} < 5\,\mathrm{ms}^{-1}$

Share of TKE – CCT vs SABLES98

C. Yagüe (per. comm.)





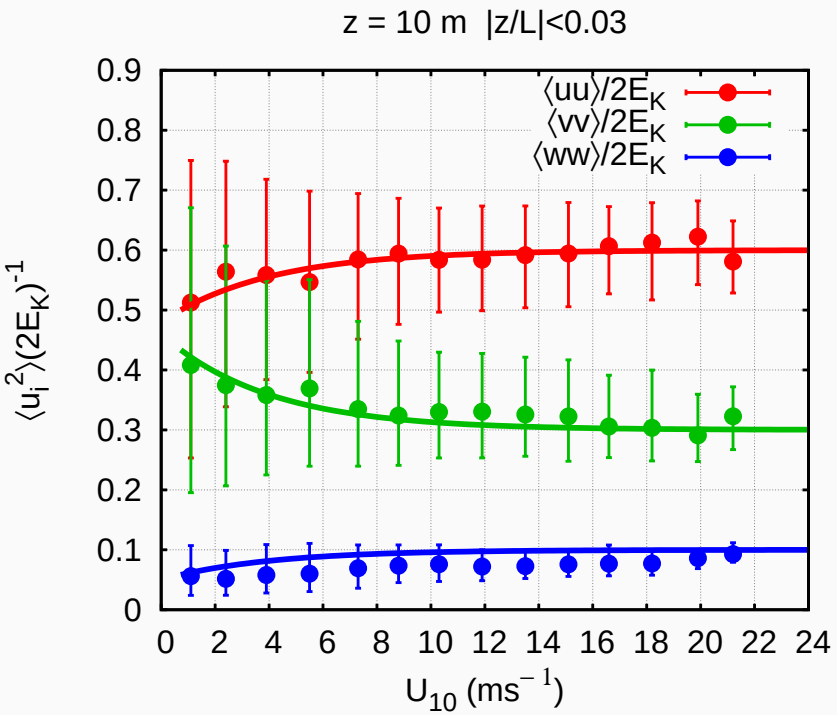
For **low winds**, **similar behaviour**:

- slight or no dependence on z/L;
- horizontally isotropic turbulence: $A_x \simeq A_y \simeq 0.45$, $A_z \simeq 0.1$

For **higher winds**, **main differences**:

- SABLES98 following ZI13 parameterizations for $z/L \lesssim 1$:
  - exchange between A_y and A_z for SABLES98 but not for CCT;
  - A_z increasing with wind speed for SABLES98, but not for CCT.

Dependence on wind velocity – CCT



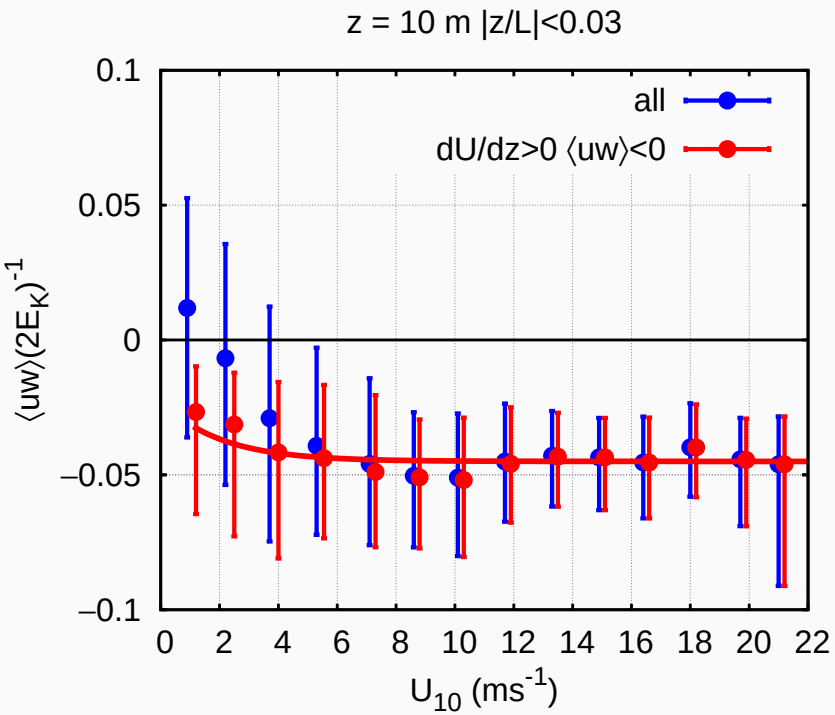
CCT data

$$\langle uu\rangle/(2E_K) = 0.6 - 0.115\exp(-U_{10}/4)$$

$$\langle vv\rangle/(2E_K) = 0.3 + 0.165\exp(-U_{10}/4)$$

$$\langle ww\rangle/(2E_K) = 0.1 - 0.05\exp(-U_{10}/4)$$

$$\langle uw\rangle/(2E_K) = -0.045[1 - 0.5\exp(-U_{10}/2)]$$



Zilitinkevich et al. (2013)

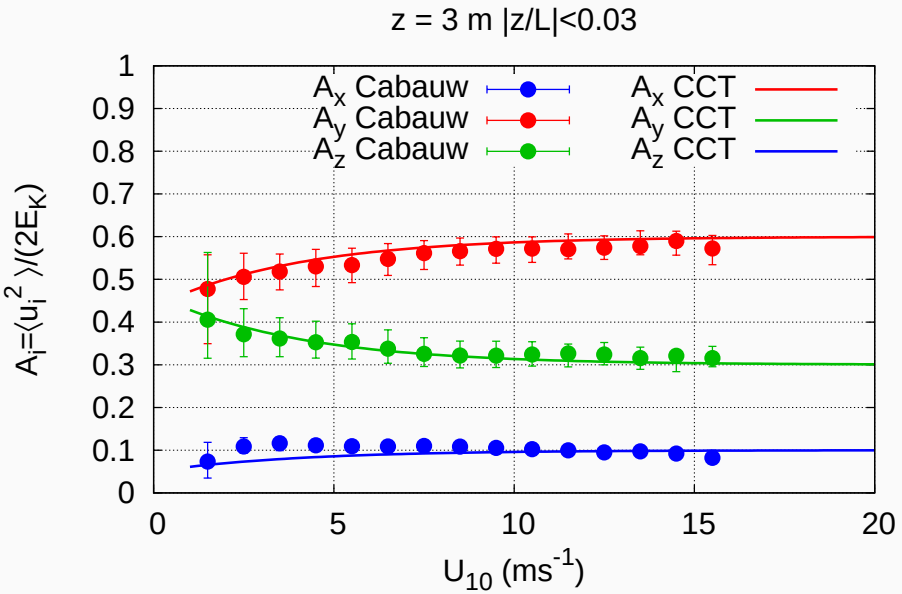
$$\langle uu\rangle/(2E_K) = 0.5$$

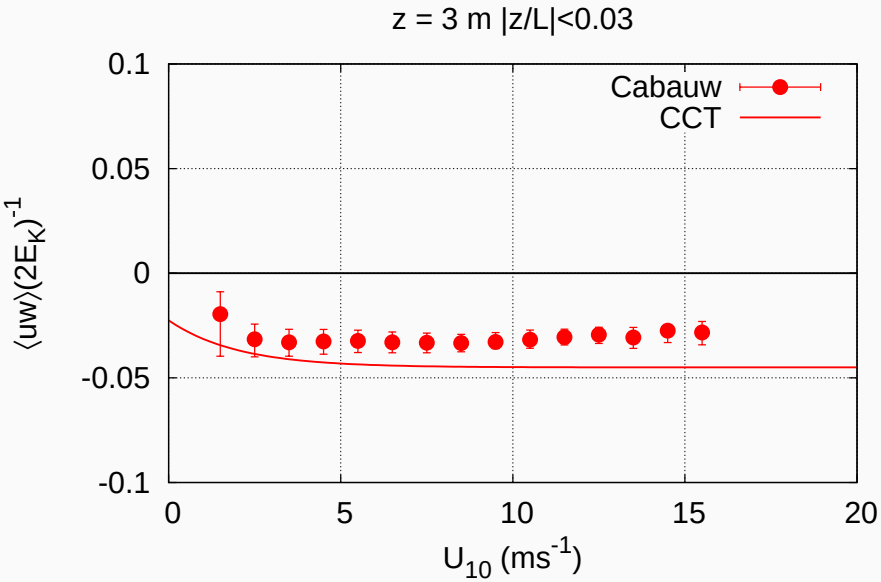
$$\langle vv\rangle/(2E_K) = 0.3$$

$$\langle ww\rangle/(2E_K) = 0.2$$

$$\langle uw\rangle/(2E_K) = -0.1$$

Dependence on wind velocity – Cabauw F. Bosveld (per. comm.)





- similar behaviour for $U_{10} \gtrsim 1\,\mathrm{ms}^{-1}$
- for $U \to 0$ $A_z \to 0$? For $U_{10} \lesssim 1\,\mathrm{ms}^{-1}$, few data points

- similar behaviour of $\langle uw \rangle / (2E_K)$
- smaller asymptotic value

Modeling implications

Zilitinkevich et al. (BLM 2010,2013)

Master equations: budget of 2nd order velocity moments

$$
\begin{aligned}
-2\langle uw\rangle \frac{dU}{dz} - Q_{xx} - \frac{2}{3}\epsilon = 0 \quad & \langle uu\rangle \\
-Q_{yy} - \frac{2}{3}\epsilon = 0 \quad & \langle vv\rangle \\
-Q_{zz} - \frac{2}{3}\epsilon = 0 \quad & \langle ww\rangle \\
-\langle ww\rangle \frac{dU}{dz} - \epsilon_{uw} = 0 \quad & \langle uw\rangle \\
-\langle uw\rangle \frac{dU}{dz} - \epsilon = 0 \quad & \text{TKE}
\end{aligned}
$$

Hypotheses:

- neutral stratification
- steadiness
- horizontally homogeneity
- negligible divergence of 3rd order terms and pressure-velocity correlation
- isotropic turbulence at dissipation scales

Master equations:

$$-2\langle uw\rangle\frac{dU}{dz} - Q_{xx} - \frac{2}{3}\epsilon = 0 \quad \langle uu\rangle$$

$$-Q_{yy} - \frac{2}{3}\epsilon = 0 \quad \langle vv\rangle$$

$$-Q_{zz} - \frac{2}{3}\epsilon = 0 \quad \langle ww\rangle$$

$$-\langle ww\rangle\frac{dU}{dz} - \epsilon_{uw} = 0 \quad \langle uw\rangle$$

$$-\langle uw\rangle\frac{dU}{dz} - \epsilon = 0 \quad E_K$$

Closures:

$$Q_{xx} = -\frac{c_R+1}{t_T}\left[\langle uu\rangle - \frac{2}{3}E_K\right] - \frac{2}{3}\frac{c_R c_1}{t_T}E_K$$

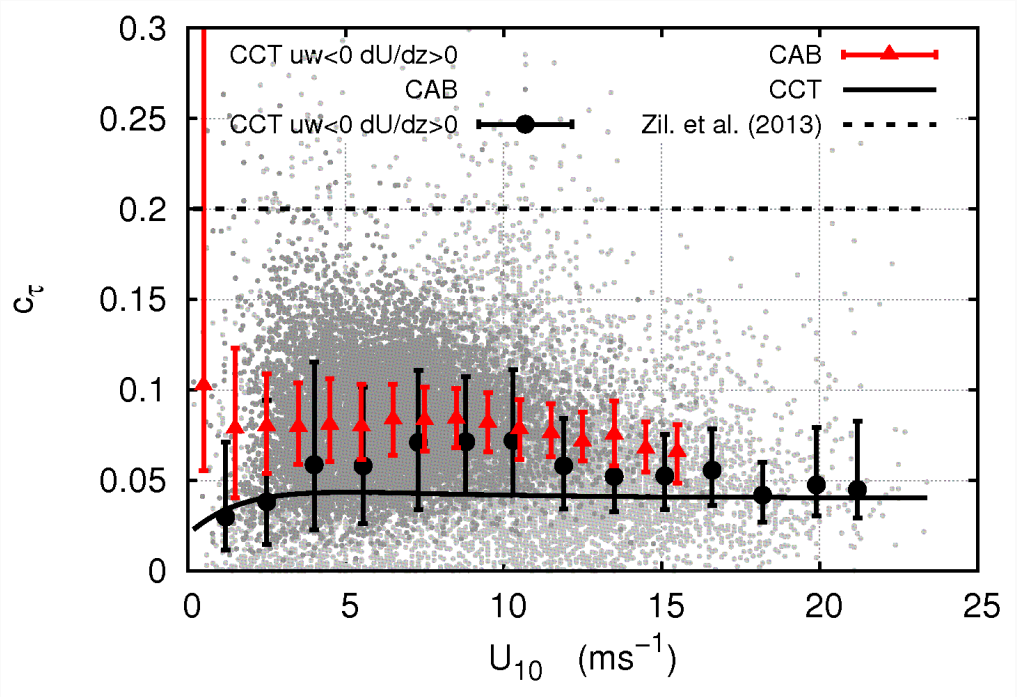
$$Q_{yy} = -\frac{c_R+1}{t_T}\left[\langle vv\rangle - \frac{2}{3}E_K\right] + \frac{2}{3}\frac{c_R c_1}{t_T}E_K$$

$$Q_{zz} = -\frac{c_R+1}{t_T}\left[\langle ww\rangle - \frac{2}{3}E_K\right]$$

$$\epsilon = \frac{E_K}{t_T}, \quad \epsilon_{uw} = \frac{\langle uw\rangle}{c_\tau t_T}$$

Where $c_R = c_R(U)$, $c_1 = c_1(U)$ and $c_\tau = c_\tau(U)$.

The effective-dissipation time-scale constant: c_τ



From

$$-\langle ww \rangle \frac{dU}{dz} - \epsilon_{uw} = 0, \quad \epsilon_{uw} = \frac{\langle uw \rangle}{c_\tau t_T}$$

and

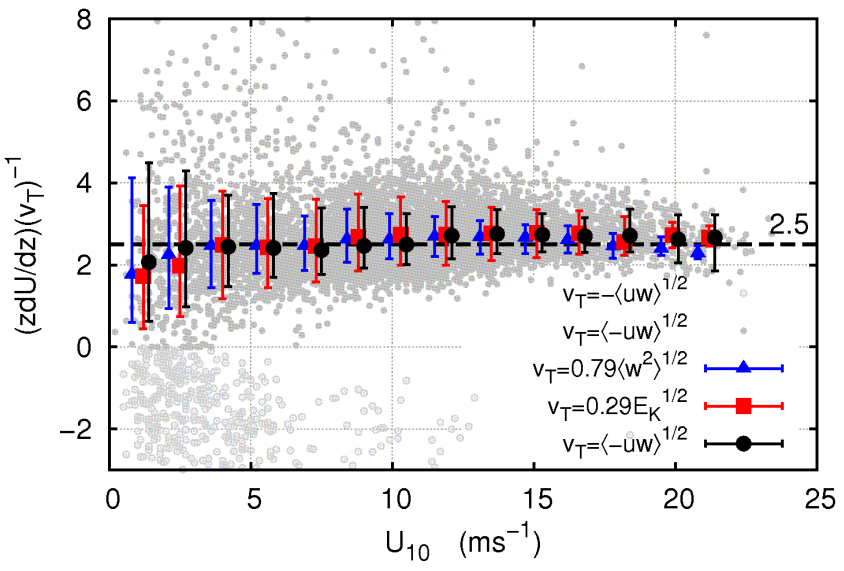
$$-\langle uw \rangle \frac{dU}{dz} - \epsilon = 0, \quad \epsilon = \frac{E_K}{t_T}$$

we have

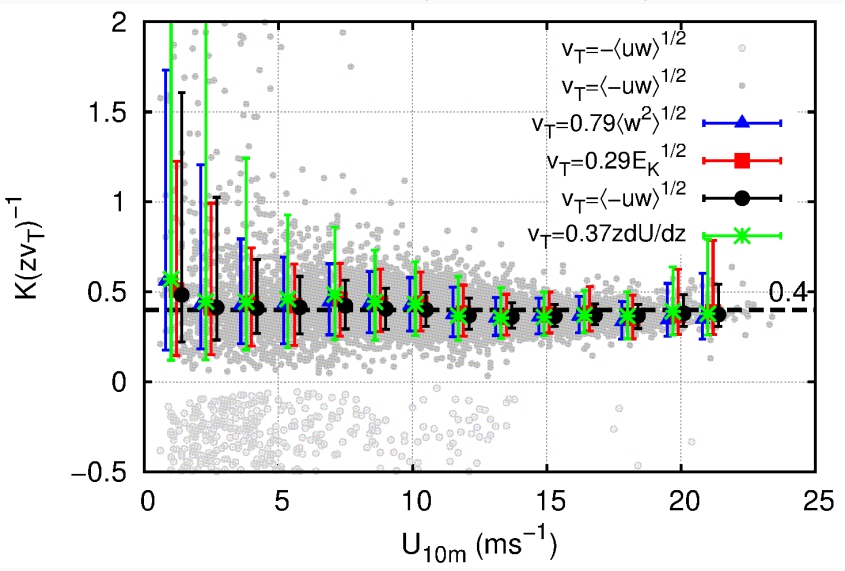
$$c_\tau = \left(\frac{\langle uw \rangle}{E_K} \right)^2 \left(\frac{\langle ww \rangle}{E_K} \right)^{-1}$$

Eddy diffusivity – Mixing lengths

How does the wind profile scale?



How does the eddy diffusivity scale?



From

$$-\langle uw\rangle = K\frac{dU}{dz} \quad \text{and} \quad K = \ell v_T$$

$$\frac{K}{zv_T} = \frac{\ell}{z} = \frac{-\langle uw\rangle}{(zdU/dz)v_T}$$

Turbulent velocity scales:

- $v_T = \langle -uw\rangle^{1/2}$
- $v_T = \langle w^2\rangle^{1/2}$
- $v_T = E_K^{1/2}$
- $v_T = zdU/dz$

Conclusions: Wind and turbulent transport

- the log profile gives a robust description of the wind observed on average (single realizations may depart) for changing U_{10};
- the measured vertical momentum flux is in equilibrium with the profile (a flux-gradient relationship holds) in the observed velocity range
- the mixing length depends on U_{10};
- for low winds, does the equilibrium hold for each realization?

Conclusions: Closures

At the level of the present (preliminary) investigation, and without the claim of universality of numerical values:

- $0.2 < c_r < 0.4$
- $c_1 \simeq 2$ for $U_{10} > 10\,\mathrm{ms}^{-1}$ increasing for $U_{10} \to 0$
- $c_\tau \simeq 0.04$ for $U_{10} > 10\,\mathrm{ms}^{-1}$ decreasing for $U_{10} \to 0$
- In models using a E_K-based eddy diffusivity, the mixing length depends on wind velocity.
- hint for future research: U or dU/dz?

Questions?