Derivation of Turbulent Structure Parameters from Large-Eddy Simulations and Comparison with Large-Aperture Scintillometer Data and Aircraft Observations

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1 Introduction

Large-aperature Scintillometers (LAS) are used to measure the turbulent fluctuations in the convective surface layer over a large footprint of several kilometres. The refractive-index structure parameter (C_n^2) is a measure for these fluctuations and can be decomposed into the structure parameters for temperature (C_T^2) and humidity (C_q^2), which in turn lead to the surface fluxes of sensible and latent heat by means of MOST. **We use large-eddy simulations (LES) of the CBL as it developed during RECAB 2002 at Cabauw (The Netherlands) in order to explore the detailed behaviour of the structure parameters and to get better understanding what a scintillometer is measuring.**

Options for deriving structure parameters:

- Path-averaged: LAS and aircraft measurements.
- 3D: LES data.

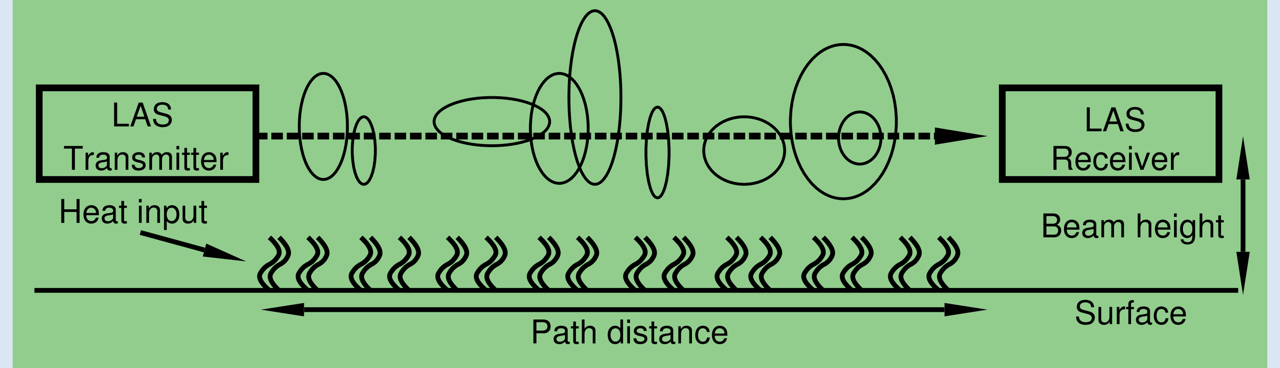
Open questions:

- **Does the LES data agree with in-situ measurements by aircraft and LAS?**
- **How large is the uncertainty in LAS measurements?**

2 The Principle of the Large-Aperture Scintillometer

An LAS measures the scattering of a transmitted optical signal due to turbulence.

- **Direct determination of C_n^2.**
- Correction for humidity leads to C_T^2.
- Path-weighting function applied.



3 Three Methods to Derive Structure Parameters

Spectral method (LES): The structure parameter of a given scalar S is related to its spectral energy Φ_S in the inertial subrange (Wyngaard et al., 1971):

$$C_S^2(k) = \frac{1}{0.2489}\Phi_S(k)k^{5/3} \quad (k \sim k^{-5/3})\,. \tag{1}$$

Wavelet method (LES, aircraft): By using a wavelet transform of the scalar fields, $\Phi_S(k)$ can be replaced by its local estimate (at location x). C_S^2 can be thus calculated by

$$C_S^2(x,k) = \frac{1}{0.2489}\,\Phi_S(x,k)\;k^{5/3}\,. \tag{2}$$

Dissipation method (LES): C_S^2 can be related to the dissipation rate of the scalar (ε_S) and TKE ($\varepsilon_{\mathrm{TKE}}$) (e.g. Peltier & Wyngaard, 1995):

$$C_S^2 = \frac{\beta}{0.2489}\,\varepsilon_{\mathrm{TKE}}^{-1/3}\,\varepsilon_S \quad (\beta \approx 0.4)\,. \tag{3}$$

Modeling ε_S and using $\varepsilon_{\mathrm{TKE}}$ from the subgrid-scale model on the LES (Cheinet & Siebesma, 2009):

$$\varepsilon_{\mathrm{TKE}} = \left(0.19 + 0.74\,\frac{l}{\Delta}\right)\frac{e^{3/2}}{l}, \qquad \varepsilon_S = 2K_S\left(\frac{\partial S}{\partial x_i}\right)^2, \tag{4}$$

where l is the mixing length, e is the TKE and K_S is the subgrid-scale eddy diffusivity.

4 LES Setup and In-Situ Measurements

LES (PALM model)

- Two simulations: morning ($z_i \approx 400\,\mathrm{m}$), afternoon ($z_i \approx 1000\,\mathrm{m}$, not shown).
- Free convective conditions.
- Initial conditions and forcing: aircraft ascends, observed surface fluxes.
- Grid resolution: 2-4 m.
- **Virtual LAS (VLAS) measurements** along horizontal paths by means of the dissipation method.

In-situ measurements

- Measurements during RECAB 2002 at Cabauw (The Netherlands).
- **LAS at 41 m above ground, path length: 9.8 km** (Kohsiek et al., 2002).
- **Sky Arrow ERA aircraft: temperature and humidity measurements at 50 Hz, path length: ca. 10 km** (de Arellano et al., 2004).

6 Horizontal Cross-sections at 41 m (LAS height)

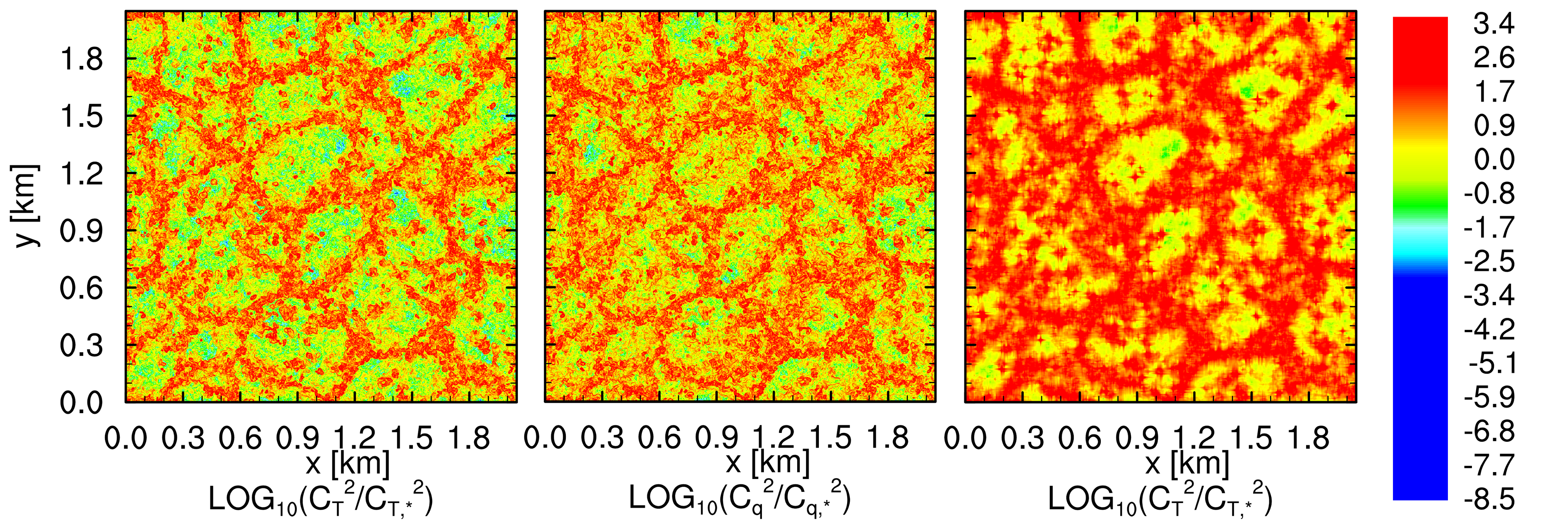


Fig. 3: C_T^2 and C_q^2 from dissipation method (left and center, respectively). C_T^2 from wavelet method (right).

- **Localized structure parameters show cellular pattern. High (low) values are present inside (outside) the plumes. The dissipation method underestimates low values.**

5 Vertical Profiles

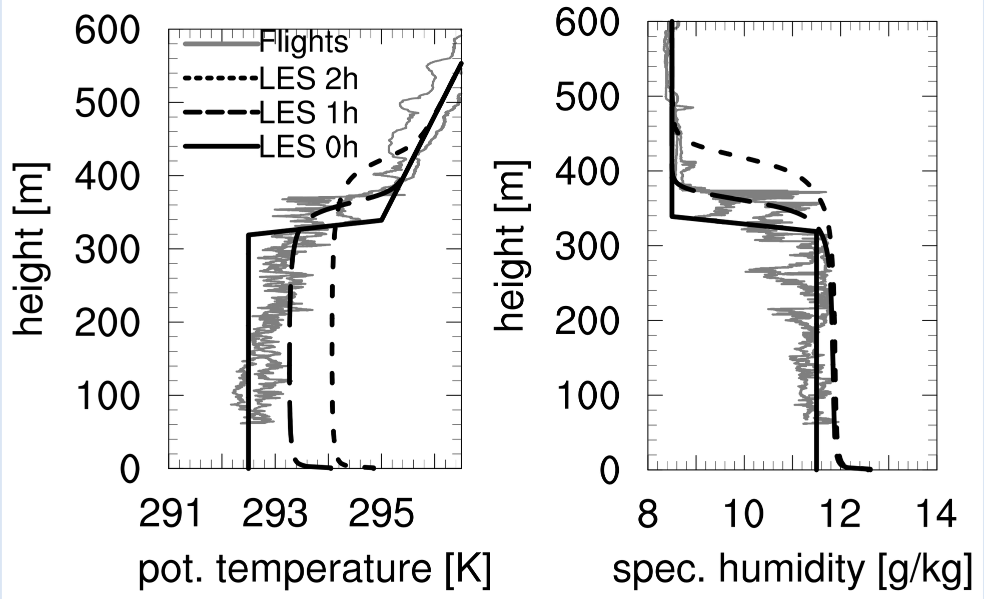


Fig. 1: Profiles of mean temperture and humidity from LES and aircraft (validation for LES after 1 h).

- LES profiles were fitted to the aircraft data .

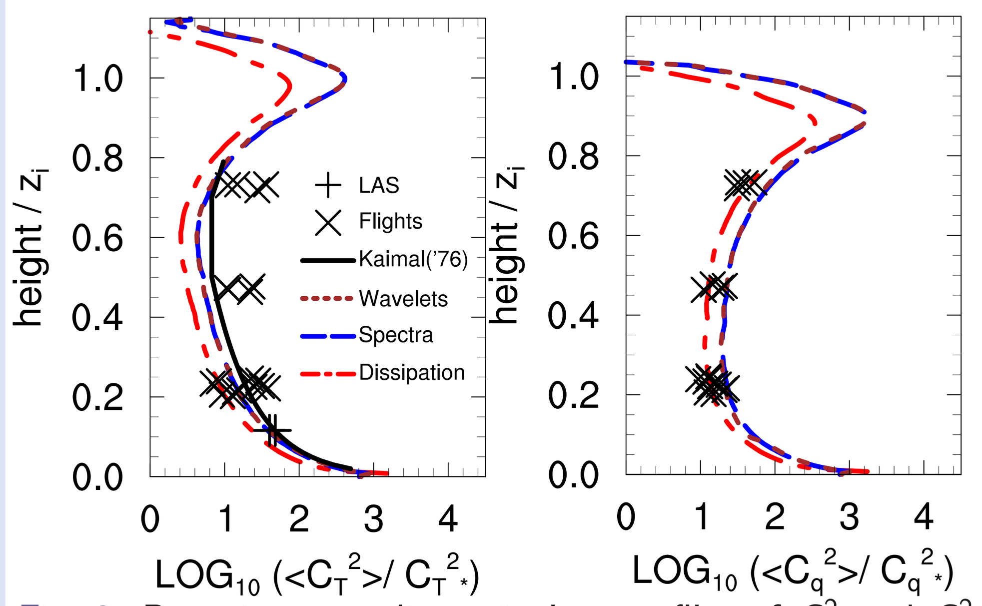


Fig. 2: Domain-mean dimensionless profiles of C_T^2 and C_q^2

- **Good agreement of LES, LAS and aircraft. The aircraft data does not show the proposed decrease with height. C_S^2 from dissipation method provides too low values (factor 1.8).**

7 VLAS Measurements at 41 m

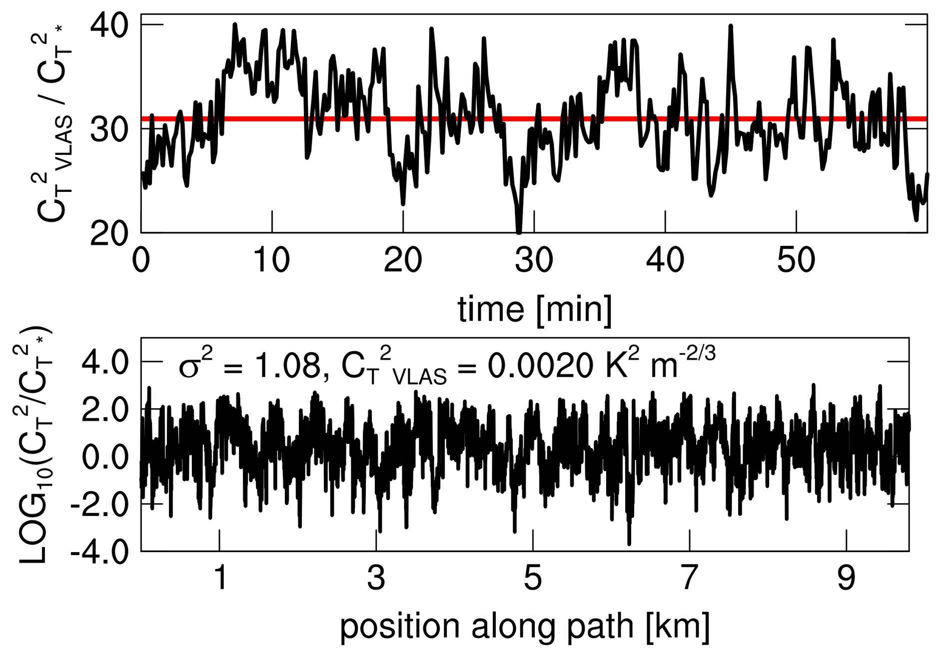


Fig. 4: Temporal variability of a scaled VLAS measurement (top) and instantaneous spatial variability along this VLAS path (bottom).

- **Sufficient averaging is necessary.**

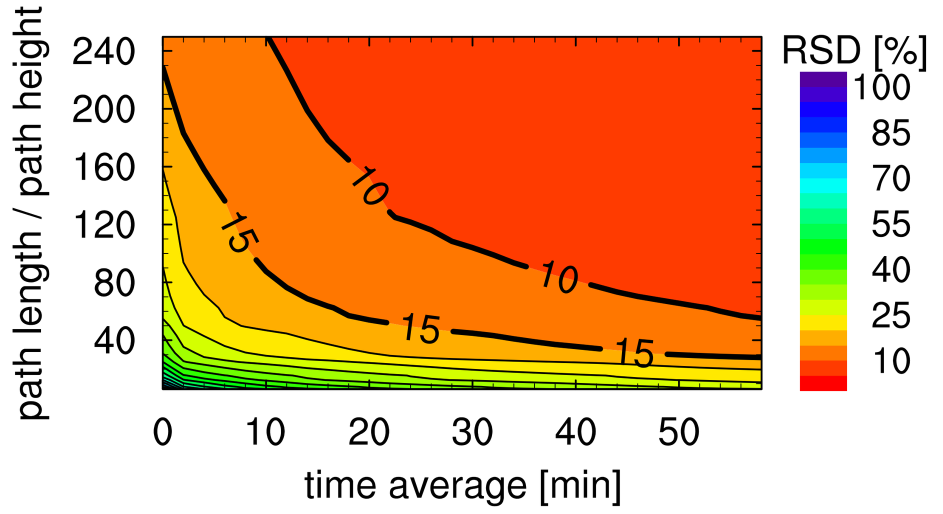


Fig. 5: Relative standard deviation (RSD) of VLAS measurements. The RSD was calculated from more than 2000 single VLAS measurements.

- **Uncertainty depends on the system setup only! Appropriate time-averaging is required.**

Future Research

- Investigating the MOST relationships for structure parameters.
- What is the effect of surface heterogeneity on the structure parameters?
- Does a blending height exist for structure parameters over heterogeneous terrain?

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