Small-Scale Turbulence in Clouds

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1. Motivation

Small scale turbulence in clouds plays a major role for mixing processes and the interaction between cloud droplets and the turbulent flow in the atmosphere. Mixing processes include internal mixing but also entrainment of dry and sub-saturated air into the cloud (so-called "entrainment"). However, the nature of cloud turbulence on sub-meter scale has not yet been investigated in more detail since most experimental data are based on fast-flying aircraft yielding a spatial resolution of about one meter.

In this paper, we present first in-situ data of the three-dimensional wind vector with a spatial resolution on the decimeter range. The data were taken during a helicopter-borne experiment with ACTOS (Airborne Cloud Turbulence Observation System) in shallow cumulus clouds of different life stages (Siebert et al. 2006c).

A special focus was devoted to the edges of freshly evolving cumulus clouds where regions of down-drafts (due to subsidence) and up-drafts are close together resulting in strong wind shear turbulence.

2. Experimental Setup

The helicopter-borne autonomous measurement payload ACTOS was used to perform turbulence measurements with a spatial resolution in the order of a decimeter. A technical description of the balloon-borne version can be found in Siebert et al. (2003), the modified helicopter-borne version is introduced in Siebert et al. (2006a) and Siebert et al. (2006c) (this issue).

3. Measurements

A data set from the first helicopter-borne cloud experiment with ACTOS is analyzed in terms of small-scale turbulence. The 20 min long record was taken on 27 April, 2005 in approximately 2200 m height near Koblenz, Germany. The true airspeed of the helicopter was 15 $\mathrm{m\,s^{-1}}$, that is, the complete record is about 18 km long. Several cumulus clouds were sampled close to cloud top with a Liquid Water Content (LWC) between 0.6 and 1.2 $\mathrm{g\,m^{-3}}$ (cf. Fig. 1).

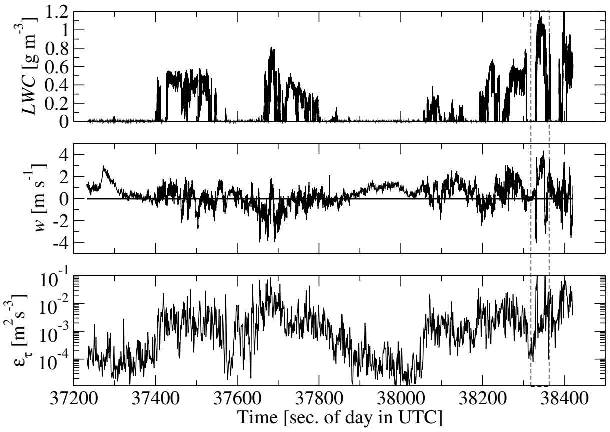

Figure 1: Time series of the LWC, w, and ε_τ. The data was taken in a height of 2200 m and a true airspeed of 15 $\mathrm{m\,s^{-1}}$.

The cloud field was inhomogeneous with several cloud holes and strong fluctuations of LWC around cloud edges. The middle panel of Fig. 1 shows the vertical ve-

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locity w corrected for payload attitude and motion. The values of w span a range of $\pm 4\,\mathrm{m\,s^{-1}}$ with highest amplitudes typically observed around cloud edges or in single cloud core regions with maximum values of LWC. The lower panel shows a logarithmic plot of local energy dissipation rates (ε_τ) as estimated from τ = 1 s long subsequences (corresponding to a length of 15 m) using second-order structure functions (Muschinski et al. 2004; Siebert et al. 2006b). The local energy dissipation rates are used as a measure for the degree of turbulence. The degree of turbulence is significantly increased in and around the clouds; ε_τ is often two orders of magnitude higher inside the cloud compared with adjacent cloud-free regions.

A 500 m long portion of the record is shown in Fig. 2 (cf. dotted box in Fig. 1). These data describe an actively growing cloud which is characterized by strong downdrafts at the cloud edges ($w \sim -4\,\mathrm{m\,s^{-1}}$) next to strong up-drafts in the cloud core region ($w \sim +4\,\mathrm{m\,s^{-1}}$) resulting in a strong wind shear zone. The horizontal gradient of w $\partial_x w$ at the first cloud edge is about 0.3 $\mathrm{s^{-1}}$.

The energy dissipation rate in this region reaches maximum values $\sim$ $10^{-1}\,\mathrm{m^2\,s^{-3}}$ compared to $10^{-3}\,\mathrm{m^2\,s^{-3}}$ in the cloud core.

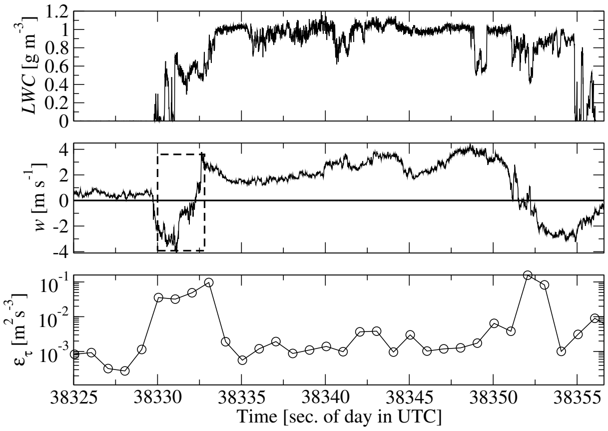

Figure 2: Enlarged portion of the data shown in Fig. 1.

4. Summary and Discussion

The small-scale dynamics of cumulus clouds has been investigated in terms of local energy dissipation rates with 15 m resolution. Actively growing cloud parts with strong down-draft and up-draft regions at the cloud edges show significantly increased values of ε_τ. In general, several different mechanisms contribute to the production/dissipation of turbulent kinetic energy (cf. budget equation for turbulent kinetic energy in Stull (1988)), however, due to the strong wind shear one might speculate that the high values of ε_τ can be explained by the wind shear term only. Assuming steady-state conditions, neglecting other terms than shear, and assuming that the horizontal gradient of w is dominating other velocity gradients, we find:

$$\varepsilon_{\mathrm{shear}} = \mathrm{K}\,\partial_x w, \qquad (1)$$

with the eddy diffusivity coefficient K which can be approximated (Hanna 1968) by K = $0.3\sigma_w l$, with l a typical length scale $\sim$ σ_w^3/ε. From our observations we found $\sigma_w \sim 1\,\mathrm{m^2\,s^{-2}}$ and $\varepsilon_\tau \sim 10^{-1}\,\mathrm{m^2\,s^{-3}}$ for the shear region, that is, K $\sim$ 1 $\mathrm{m^2\,s^{-1}}$ and $\varepsilon_{\mathrm{shear}} \sim 10^{-1}\,\mathrm{m^2\,s^{-3}}$ which was observed as local values for the wind shear region.

From this estimate we can conclude that the most ammount of energy dissipation around the cloud edge can be explained by shear generation.

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