P8.6 HOW TO RELY ON TURBULENCE MEASUREMENTS IN CLOUDS

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1. INTRODUCTION

The knowledge of turbulence levels in clouds is of interest for safe aircraft operation, for the understanding of dynamical and micro physical cloud developments including precipitation formation and for estimating trace gas transports. The Doppler spectral width is an operational available product of Doppler Weather Radars. It is well known to be a measure for turbulence and shear within the radar resolution volume. Few use of that has been made up to now, possibly because of the unknown uncertainties in making quantitative estimates.

We therefore compared estimates of the eddy dissipation rates from POLDIRAD Doppler spectral width measurements in the upper parts of deep convective clouds with well co ordinated high resolution in situ turbulence measurements by the FALCON research aircraft.

2. METHODS AND MEASUREMENTS

We apply the "Doppler spectral width method" to estimate the kinetic energy dissipation rate, a measure for turbulence (Frisch and Strauch, 1976, Brewster and Zrnic, 1986, Istok and Doviak, 1986). The Doppler spectral moments are computed by autocorrelation technique (Passarelli and Siggia, 1983, Srivastava et al., 1979, Zrnic, 1979).

The errors of the radar measurements together with the uncertainties from cloud inherent processes sum up to a total error for the measured Doppler spectral width σ_M of at about 1.5 m s^{-1} (Meischner et al., 2001). The contribution of shear is subtracted according to Meyer and Jank (1989).

To relate the estimated Doppler spectral widths for the resolution volumes to the eddy dissipation rate ε, we have to assume that the turbulence is homogeneous and isotropic, and, that we cover only eddy sizes within the inertial subrange, in other words we assume a Kolmogorov spectrum throughout that volume. It has been estimated by Istok and Doviak (1986) that the outer scale of the inertial subrange must be about four to five times larger that the radar resolution volume. If this is not fulfilled, the measured Doppler spectral width σ_M will contain contributions from turbulence of scales within the input energy containing range and from shear of the ordered flow. Then σ_M cannot be related accurately to ε because eddies within the input energy containing range are not isotropic. For thunderstorms like those investigated, the ordered updraft and downdraft regions typically show scales of some km as verified by the Doppler measurements.

Then, according to Istok and Doviak (1986), for every resolution volume the turbulent kinetic energy dissipation rate ε can be estimated to

$$\varepsilon = \frac{2.4\,\sigma_T^3}{R\theta\, A^{3/2}}\,, \qquad (1)$$

with R the range from the radar in m, θ the beam width in radian, σ_T the Doppler spectral width in ms^{-1}, already reduced by shear contributions and A the Kolmogorov constant = 1.6.

The in situ measurements of the three wind components have been performed by the DLR research aircraft Falcon by a 5-hole gust probe on tip of the noseboom (Bögel and Baumann, 1991). The sensor error for the total variances $\sigma^2 = \sigma^2_u + \sigma^2_v + \sigma^2_w$ is estimated to about 20 % . The smallest detectable level (random noise) is of the order of 0.003 m^2s^{-2} . Because we calculate variances locally with limited time series to match the scales sensed by the radar resolution volume, some statistical sampling errors may add. From the time series for fluctuations of all three wind components the structure function D_{vv} is estimated (Meischner et al., 2001). According to Paluch and Baumgardner (1989) the dissipation rate ε then can be calculated as:

$$\varepsilon \approx \frac{D_{vv}^{3/2}}{(4.01\,b)^{3/2}\; r}\,, \qquad (2)$$

with $b \approx 0.2(2\pi)^{2/3}$ (Panofsky and Dutton, 1984) and $r = U_a\Delta t$, U_a the true airspeed of the FALCON.

For r = 100 m the error for D_{vv} is about 20 % and 30 % for ε. The minimum detection level is below 5×10^{-7} m^2 s^{-3} as estimated for typical frequencies and amplitudes.

The measurements have been performed during the experiments LINOX,1996 (Huntrieser et al., 1998, Höller et al., 1999a) and EULINOX, 1998 (Höller et al., 1999b). The FALCON collected chemical, meteorological and turbulence data within the anvils of active storms where their structures was observed by radar and satellite.

We here compare the eddy dissipation rate estimated from the aircraft measurements with those from the simultaneous radar observations.

There are up to five minutes time difference between radar samplings and aircraft measurements of individual volumes. We correct for the time difference under the assumption that the cloud characteristics did not change during that time. We shift the coordinates of the true aircraft position by that distance, a sample would flow with the mean local horizontal wind speed during the time between the radar and aircraft measurements.

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3. RESULTS

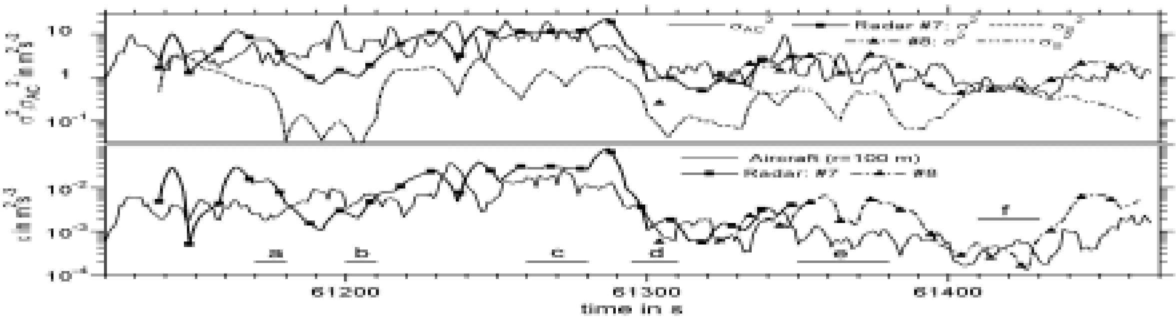

Fig. 1 Time series of estimated turbulende data of 21 July 1998.

Fig. 1, as an example, displays results from the anvil of a complex of moderate intense cells. The radar estimated and aircraft estimated variances σ^2 and σ_{AC}^2 respectively, are in general agreement when averaging more than 30 s, corresponding to a flight path of 6 km. Fine scale structures for less than 10 s or 2 km are less correlated. The dissipation rates as estimated from radar are systematically above the aircraft estimates. Large scale features however, especially the drop at 61290 s and the minimum at 61420 s agree quite well. For sections (b), (d) and (f) agreement with the radar data is best. In section (f) the estimated dissipation is as low as 3×10^{-4} m^2s^{-3}, in agreement with the aircraft estimates. This is the lowest value measured with radar in this study. Fig. 1 underlines that, although σ^2 and σ_{AC}^2, agree quite well, the radar estimates of ε usually exceed those from aircraft. The bars (a) to (f) indicate sections of more detailed analysis of the in situ measurements. Here we look for the power spectra of all three wind components giving us indication for isotropy of the turbulence and whether sensing an area of energy dissipation.

For these sections we further show how the estimated mean values for the energy dissipation rate depend on the scale parameter r. This indicates the length scales contributing most to the energy dissipation. Within the inertial subrange, where the power spectra follows the $k^{-2/3}$ law, ε should not depend on r . Such, "flat" regions indicate the inertial subrange. Fig. 2 summarizes all measurement of this study for three different days. The horizontal lines at the right mark the corresponding means of ε as estimated by radar. For (h) and (i) the flight was above the cloud, hence no radar data were available.

The plots for (a)-(g), 21 July 1998, show moderate slopes with *r*. (a) shows the weakest dependence on *r*, it corresponds to an area without significant vertical wind. The local maxima of $\varepsilon(r)$ lie between $r = 20$ m and $r = 300$ m. With the exception of (e), ε decreases below and above the flat section. For (e) ε increases with r^2 for *r* above 700 m due to nearly constant shear along that path. The radar estimated means of ε differ to the maxima of the in situ means, by a factor of 4.5 for (a), 4.2 for (e), 1.61 for (c), 1.24 for (g), 1.19 for (d), 0.65 for (f) and 0.47 for (b). Cases (a), (b), (c) and (e) are areas of strong shear, (b) and (c) additionally are within updrafts. Cases (d), (g) and (f), which show the best agreement are areas of weak shear.

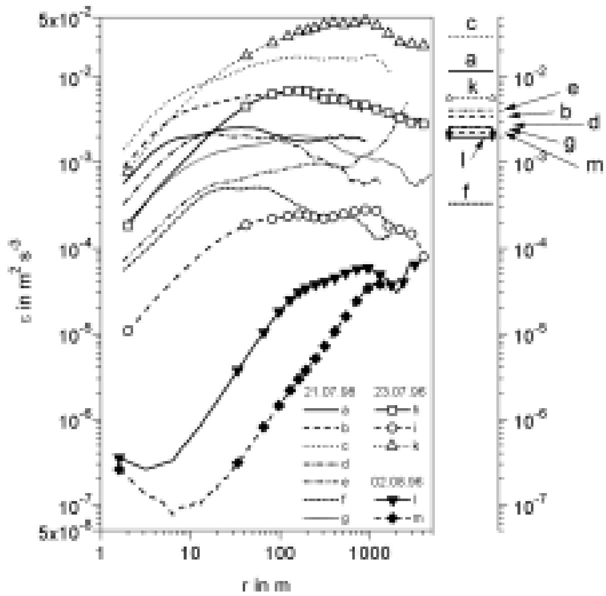

Fig. 2 Estimated energy dissipation rate ε with scale parameter r and mean radar estimates.

For the cases (h), (i), 21 July 1996, the flat part starts at higher values of *r*, around 60 m. In case (k), which is within a strong updraft region ε increases with *r* up to $r = 300$ m. The estimates of ε for $r = 100$ m are about 40 % below the maximum. This indicates, that the inertial part of the turbulence spectrum covers larger scales than for the 1998 cases. This can also be recognized from the power density spectra, not shown here. There the slope of the spectra (h), (i), (k) increases for upper frequencies. For (k) the radar estimate of ε is about a factor of 8 below the maximal in situ estimate.

The measurements from 2 August 1996, (l) and (m), show a significant different behaviour. This cloud was not an active thunderstorm. The increase below $r = 6$ m is due to instrumental noise showing the limits of the a/c measurements. The radar estimates are several orders of magnitude above the highest in situ estimates. These measurements clearly do not represent the inertial subrange, such, the estimates of ε are not reliable.

4. CONCLUSION

The comparison of radar estimated energy dissipation rates in thunderstorms from Doppler spectral width measurements with high resolution and high precision in situ aircraft measurements show:

Doppler weather radar is well suited to estimate energy dissipation rates above a certain level of turbulence. For operational C-band systems this will be around 10^{-3} m^2s^{-3} for ε. The method however assumes measurements within the inertial subrange. From Doppler radar measurements alone, no direct distinction between energy production areas and energy dissipation areas however will be possible. Further, information on isotropy might only be estimated from volume measurements, not commonly available by operational radars. Such, care is necessary for use of estimated values of ε.

For general warning applications however, the available information will be sufficient and of high value. This especially is underlined by the general agreement of radar estimated variances σ^2 with the in situ estimates σ_{AC}^2. The Doppler spectral width as measured, includes turbulence and shear, for outer scales too. Both affect aircraft handling and reduces aircraft passenger comfort.

Detailed comparisons between the high precision and high resolution aircraft measurements and carefully interpolated radar measurements indicate some overestimation of both, eddy dissipation rate and variances by radar compared to the more accurate in situ measurements.

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