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1. INTRODUCTION

The parameterization of the microphysical characteristics for low-level stratiform water clouds can be developed in terms, among others, of the *effective radius of droplets* and the *liquid water content (LWC)*. These parameters can be directly measured using aircraft mounted in-situ probes observations. The instruments used to perform these measurements, however, have an extremely small sample volume. The remote sensing methods are less direct but give much better coverage and are much less expensive.

In this paper a retrieval technique based on the relationship between the *effective radius* of cloud drops and the *radar reflectivity-to-lidar extinction ratio* is presented.

2. EXPERIMENTAL DETAILS AND INSTRUMENTATION

2.1. Observational data used

2.1.1. The CLARE'98 campaign. The Cloud Lidar and Radar Experiment (CLARE) took place near Chilbolton (United Kingdom) in October 1998. This extensive cloud campaign included airborne and ground-based radar and lidar observations as well as in-situ aircraft measurements of the drop-size distributions (DSD) (see ESA (1999) for details).

During CLARE'98 the particle size spectra in clouds were measured from a C-130 aircraft of the UK MRF with a Forward Scattering Spectrometer (FSS) and a Two-Dimensional Cloud (2DC) probes in the size ranges between 1 μm and 23.5 μm radius and between 6.25 μm and 406.25 μm radius, respectively. The available data have a 5-sec interval of averaging.

2.1.2. The DYCOMS-II campaign. The DYCOMS-II field campaign took place in July 2001 in Pacific Ocean near California (Stevens et al. (2002)). It was directed to collect data to study nocturnal marine stratocumulus. The main measuring part of campaign was made during 10 research flights of the NCAR's RAF EC-130Q. On this aircraft cloud droplet spectrums were measured using a set of probes: the PMS - PCASP 100; the PMS-FSSP-100; the PMS-FSSP-300; the PMS-260X; the PMS-2DC; and the PMS-2DP in the different size ranges between 0.045 and 786 μm radius. For in-situ measurements of LWC on aircraft two King hot-wire probes that were installed on different wings and the Gerber's Particulate Volume Monitor PVM-100A were used. The available data have a 1-sec interval of averaging.

2.1.3. The CAMEX-3 campaign. The third field campaign in the Convection And Moisture Experiment

series (CAMEX - 3) took place in Florida coastal zone in August - September 1998. The objective of the field program was data collection for research in tropical cyclone using NASA-funded aircrafts ER-2 and DC-8, and ground-based remote sensing. For this study it was important that all research flights took place in strong cumulus clouds. For measurement of the cloud drop size distributions were used FSS (the size range between 0.42 μm and 23.67 μm radius) and 2DC (the size range between 17.75 and 762.50 μm radius) probes that were mounted on the DC-8. The available data have a 60-sec interval of averaging.

2.2. In-situ clouds particle spectrum data processing and analysis

The above presented descriptions of field campaigns and their instrumentation show that in order to obtain a complete cloud DSD, the distributions that were measured by a few individual particle probes have to be merged. There are some possible techniques for such merging (e.g. Baedi et al. (1999)). For this study the simplest technique was used: all spectrum probes that had been taking into account for a given platform were analyzed on an equal basis. For every bin of every probe middle size was calculated, counted concentration was normalized by the bin's width. Then all bins for the probes were combined and rearranged in increasing order of their middle size values. The resulting grid of middle sizes was used for estimation of the values for new borders of bins - as half distance between neighbor bin's centers. Such approach gives the possibility to include in calculations all available data without any a priori assumptions about shape of DSD. Any moments of the resulting DSD can be calculated as numerical integrals for tabulated functions. Before the start of merging procedure from every probe's data first and last bins were removed as possible sources of error information.

Since this paper only deals with liquid water clouds, it was assumed that for radar observations the spherical drops act as Rayleigh scatterers, while for lidar observations they approximately act as optical scatterers. In that case, various cloud parameters can be computed from the particle size spectra using the equations for the spectral moments of 2nd, 3rd, and 6th order.

3. OBSERVATIONAL RESULTS

The merged drop size distribution data for all campaigns were depicted on the plane "ratio of radar reflectivity to optical extinction versus the effective radius" ($Z/a - r_{eff}$) (Fig.1). On the same figure are presented relationships for gamma-model drop size distributions with two extreme values of the shape parameter n ($n = \infty$, that corresponds to the narrow, d -function-like gamma distribution, and $n = 1$, that

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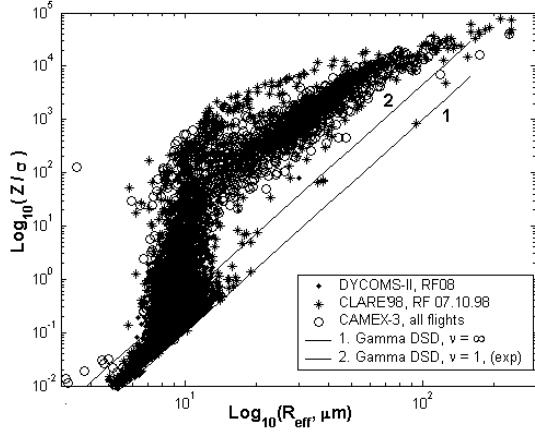


Fig. 1. The Radar to Lidar Ratio versus the Effective Radius for the CLARE'98, DYCOMS-II, and CAMEX - 3 campaigns data

corresponds to the exponential distribution). The conclusions that follows from this representation are:

- All data that were measured in different geographical regions, inside different types of water clouds, and during different field campaigns with different sets of the cloud's particle probes have the similar behavior. It means that the observed dependence has a stable character and can be used as background for the development of cloud microphysics retrieval algorithm.

- The observed data have a complicated difference with theoretical relationships. Only the part of observed DSD that are characterized by lowest value of the Z/a ratio can be described in terms of the simple statistical distributions. The complicated behavior can be described only using a mixture of different statistical distributions. It gives possibility to detect drizzle fraction in cloud and to estimate its influence on measured cloud parameters.

The reliable solution for the $r_{eff} = F(Z/a)$ dependency was found as a 4th order polynomial:

$$\log_{10}(r_{eff}) = -0.0027 \cdot (\log_{10}(Z/a))^4 + 0.026 \cdot (\log_{10}(Z/a))^3 - 0.0094 \cdot (\log_{10}(Z/a))^2 + 0.0098 \cdot (\log_{10}(Z/a)) + 0.99 \quad (1)$$

Eq. (1) is presented on Fig. 2 where it is depicted with 2D histograms of observed data for all campaigns together (Fig. 2a) and for every campaign separately (Fig. 2b, c, d). From these figures follows that (1) has reasonable good agreement with the CLARE'98 and the DYCOMS-II data for stratiform clouds. For cumulus clouds, which were observed during the CAMEX-3 campaign, the noticeable difference in the region of maximal variability of the Z/a ratio can be seen - the observed effective radii in that region for a

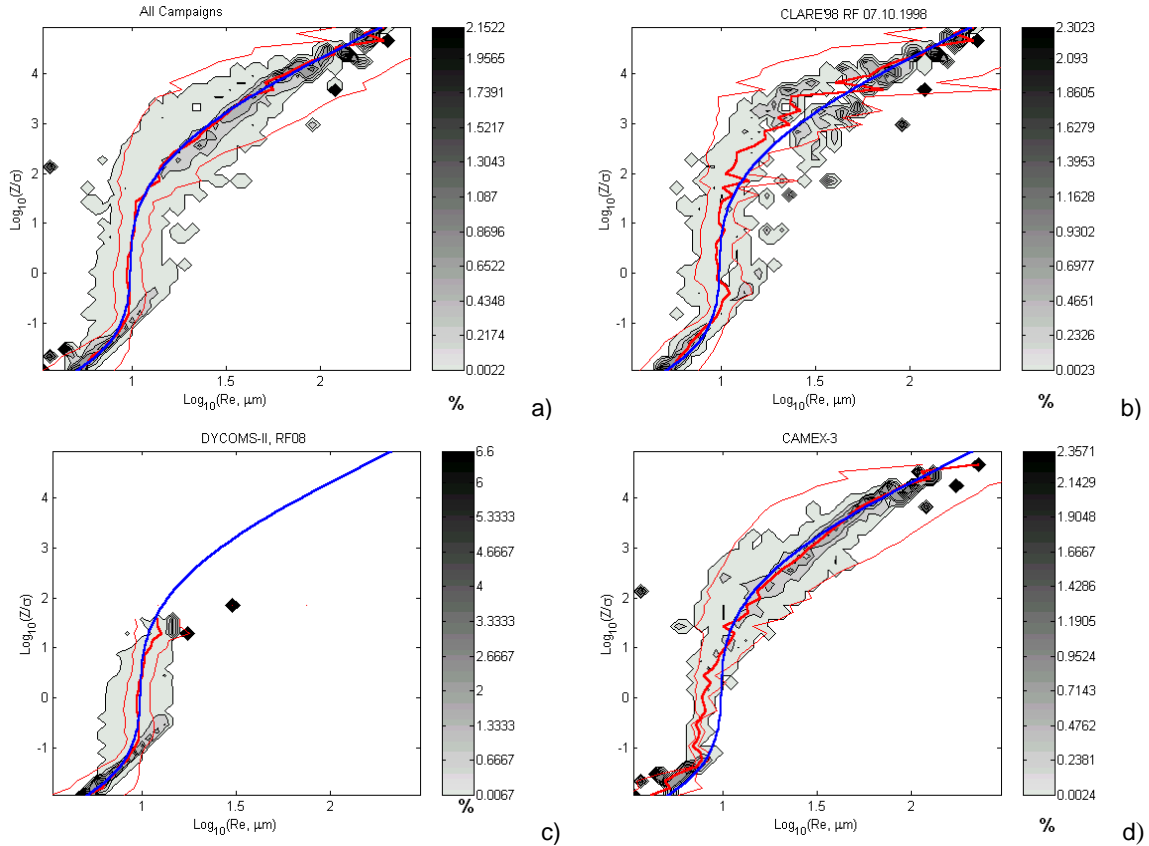


Fig. 2. Two-dimensional histograms for the observed $Z/a - r_{eff}$ relations with mean and standard deviations and their fitting using the 4th order polynomial (1): for all campaigns data (a), for the CLARE'98 RF 07.10.1998 data (b), for the DYCOMS-II RF08 data (c), and for the CAMEX-3 data (d).

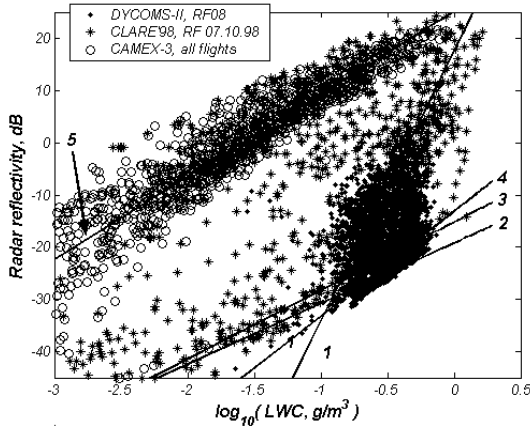


Fig.3. The relation between measured Liquid Water Content and Radar Reflectivity for different field campaigns. Lines represent the different linear fittings of this relation (see text).

given Z/a ratio are shifted to lowest values. It can be explained as natural difference between stratiform and cumulus clouds – in cumulus clouds the drizzle fraction has to be taken into account for drop size distributions that have smallest effective radii.

Another result that follows from our analysis is the possibility to classify the clouds into three types – "the cloud without drizzle", "the cloud with drizzle", and "the drizzle cloud", using their position on $Z/a - r_{eff}$ plane.

Consider now the application of described above results for the parameterization of the $Z-LWC$ relation in water clouds. On Fig.3 are presented in-situ data for all three campaigns on the $Z-LWC$ plane. On the same figure are presented a few known approximations for this relationship:

1. Baedi et al. (2000):

$$\log_{10}(Z_{merged}) = 1.76 + 5.17 \cdot \log_{10}(LWC_{merged}) \quad (2)$$

2. Fox and Illingworth (1997):

$$\log_{10}(Z_{merged}) = \log_{10}(0.012) + 1.16 \cdot \log_{10}(LWC_{merged}) \quad (3)$$

3. Sauvageot and Omar (1987):

$$\log_{10}(Z_{merged}) = \log_{10}(0.03) + 1.31 \cdot \log_{10}(LWC_{merged}) \quad (4)$$

4. Atlas (1954):

$$\log_{10}(Z_{merged}) = \log_{10}(0.048) + 2.00 \cdot \log_{10}(LWC_{merged}) \quad (5)$$

5. Best fit of all data for the CAMEX-3 campaign and the CLARE'98's data for the drizzle clouds:

$$\log_{10}(Z_{merged}) = 2.51 + 1.58 \cdot \log_{10}(LWC_{merged}) \quad (6)$$

It can be seen from Fig. 3 that (3) - (5) describe only the clouds without drizzle, (2) can be applied for the clouds with drizzle, and (6) - for the drizzle clouds. The precision of these approximations is not discussed here – the dependencies are clearly visible and can be fitted using different methods. The main problem that follows from the Fig. 3 is how to separate

these cloud types with remote sensing equipment for selection of the specific dependency (2)-(6) for every observed Z . The possibility to use the $Z/a - r_{eff}$ relation for classification of water cloud can be seen from Fig. 4. On this figure two-dimensional distributions of in-situ observed DSDs that are placed on the $Z-LWC$ plane after their classification are presented. For such classification two methods were used. The first method requires the knowledge about in-situ measured parameters - r_{eff} and LWC. The second method is based only on the results of radar and lidar measurements of Z/a and Z . The criteria for classification of the cloud type and selection of the $Z-LWC$ relationship also are presented on the Fig. 4.

On the same figures linear approximations, applicable for specific situations, are placed, and it can be seen that for such methods of the clusterization the known linear approximations of the $Z-LWC$ relation are not far from reality.

From the Fig. 4 follows the conclusion about the possibility to use the Z/a ratio for clusterization of $Z-LWC$ plane into sub-regions that describe clouds with different nature and can be parameterized by different equations. Such method can be used for cloud classification and improvement of cloud microphysics retrieval technique.

4. CONCLUSIONS

The presence of stable $Z/a - r_{eff}$ relationship for the different geographical locations, different field campaigns and different cloud types was demonstrated. It is possible to use for all analyzed campaigns and cloud types a unified 4th order polynomial fitting of this relationship.

The possibility to classify water clouds into three types - the cloud without drizzle, the cloud with drizzle, and the drizzle cloud, using the Z/a ratio of radar reflectivity to optical extinction is discussed.

The algorithm for the classification of drop size distribution and cloud's type using measured radar to lidar ratio for the clusterization in the $Z-LWC$ plane were applied. It was shown that for every resulting cluster of cloud's type is possible to use specified type of the linear $Z-LWC$ relation.

The example of application of introduced cloud types classification method using real radar. lidar and radiometer data will be demonstrated during conference.

Acknowledgments. The data used in this paper were collected during the CLARE'98 campaign carried out under the auspices of the European Space Agency (ESA, (1999)). The FSSP and 2-DCP data sets for this campaign were kindly provided by P.Francis from the U.K. Met. Office. The airborne measurements obtained from the NSF/NCAR RAF EC-130Q aircraft during the DYCOMS-II project are available online from <http://www.joss.ucar.edu/dycoms/>. The access to this site was kindly provided by Bjorn Stevens. The CAMEX-3 DC-8 FSSP and 2-DC data provided by the GHRC at the Global Hydrology and Climate Center, Huntsville, Alabama. Our research received funding

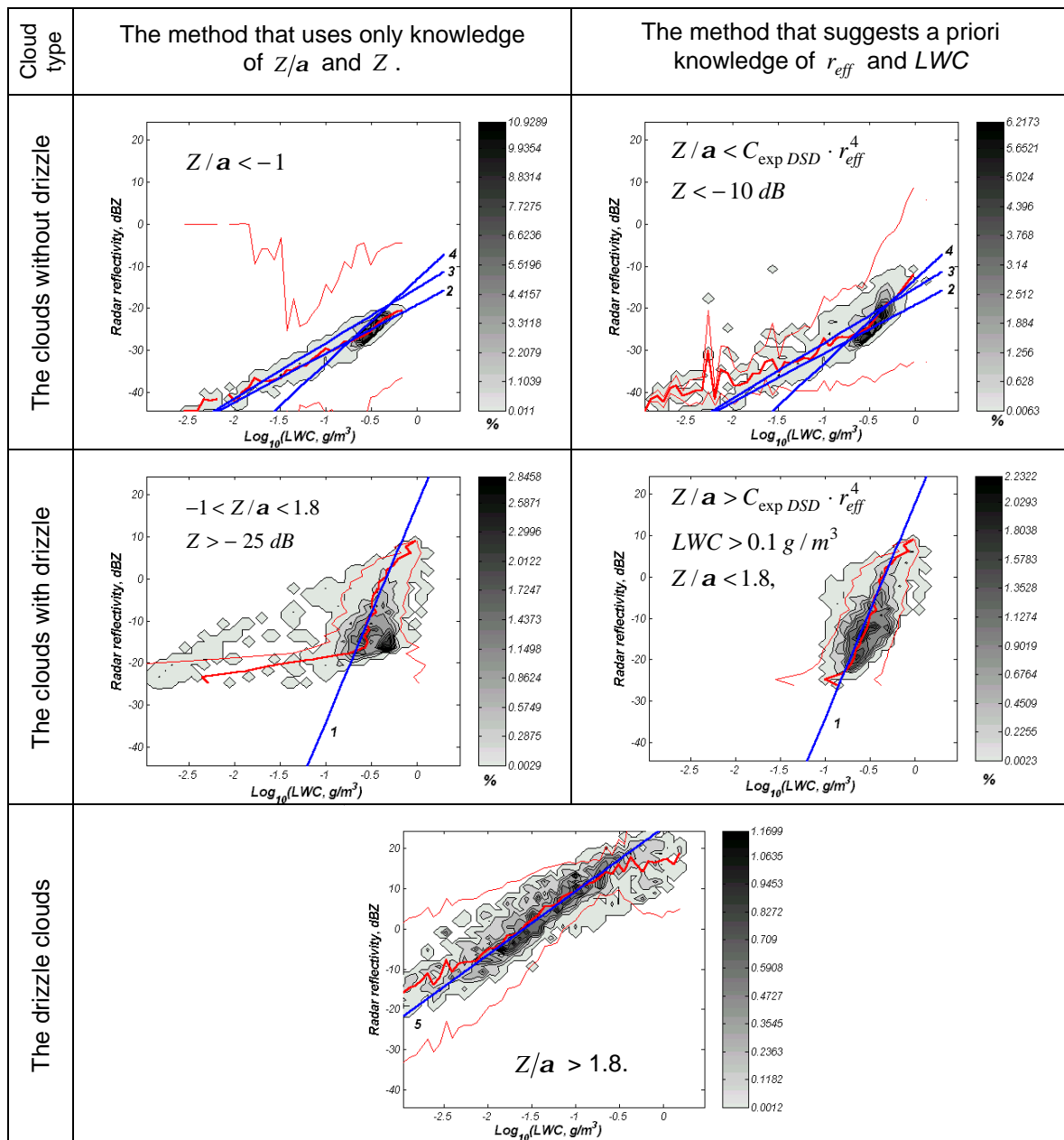


Fig. 4. Two-dimensional histograms for the Z - LWC relation (with mean, standard deviations, and linear fittings) for different criteria and methods of cloud's type classification

from the Netherlands Space Agency (SRON) under project EO - 035.

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