Collocated Measurements of Boundary-Layer Cloud Microphysical and Radiative Properties and Comparison with Satellite Retrievals [1]

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1. Introduction

Interaction Between Cloud Properties and Radiation

- Cloud properties (i.a. effective cloud droplet radius R_{eff}, optical thickness τ, liquid water content *LWC*, particle surface area *PSA*) highly influence the radiation budget and radiative forcing
- Precise and continuous cloud microphysical data from remote sensing applications are essential to quantify these interactions

Biases in Satellite Retrievals

- Dependent on the spectral resolution of the instrument there is a bias in the retrieval of R_{eff} and τ *due to:* 3-D radiative effects, surface albedo, absorption due to aerosol particles
- Approximations in retrieval algorithms may lead to further uncertaintes in retrievals of cloud properties

➔ Validation of cloud properties derived from satellite measurements is needed

2. Instrumentation

- Spectral radiation measurements above the cloud
- In situ measurements of microphysical properties within the cloud by instruments on Airborne Cloud Turbulence Observation System (ACTOS) [2]

➔ Truly collocated measurements
➔ Eliminates temporal + spatial displacement in inhomogeneous cloud field

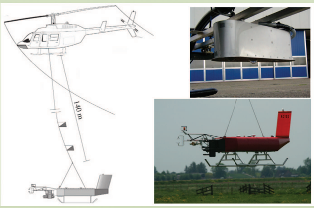


Fig. 1: The radiation instrumentation is installed underneath the helicopter and ACTOS is carried by means of a 140 m long rope. One close-up shows the housing of the optical inlets for upwelling irradiance $F_\lambda^\uparrow$ (transparent semi-spheres) and radiance $I_\lambda^\uparrow$ (flat opening). A photo of ACTOS is shown on the bottom-right side.

Radiation Measurements

- 3 grating spectrometers
- 2 optical inlets for upwelling radiance I_λ and irradiance F_λ

Measurement Quantity	Spectral range	Resolution (FWHM)
VIS – spectral upwelling irradiance $F_\lambda^\uparrow$	400 – 1000 nm	2 – 3 nm
VIS – spectral upwelling radiance $I_\lambda^\uparrow$	400 – 1000 nm	2 – 3 nm
NIR – spectral upwelling radiance $I_\lambda^\uparrow$	1000 – 2000 nm	9 – 16 nm

- cloud top reflectivity r_λ and albedo ρ_λ *are calculated*

$$\rho_\lambda = \frac{F_\lambda^\uparrow}{F_\lambda^\downarrow} \qquad r_\lambda = \frac{\pi\, I_\lambda^\uparrow}{F_\lambda^\downarrow}$$

Microphysical Properties

- Particle Volume Monitor (PVM-100A): *LWC, PSA* ➔ R_{eff}, τ ➔ time resolution 0.1s
- Phase- Doppler Interferometer for Cloud Turbulence (PICT): Droplet number size distribution dN/dD (diameter D) ➔ time resolution 1s ➔ PVM data taken

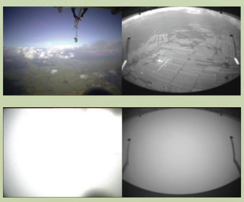
$$R_{eff} = \frac{\int \frac{dN}{dD}(D')\, D'^3\, dD'}{\int \frac{dN}{dD}(D')\, D'^2\, dD'} \sim \frac{LWC}{PSA}$$

$$\tau = \frac{3}{2} \int \frac{LWC(z)}{R_{eff}(z)\cdot \varrho} \cdot dz$$

3. Measurements during Eucaari 2008 [3]

(European Integrated Project on Aerosol Cloud Climate and Air Quality Interactions)

- boundary-layer clouds in 2000m height, cloud cover 4/8



➔ No Clouds

➔ Above Clouds

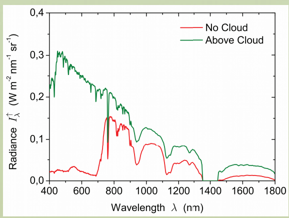


Fig. 2: Examples of spectra of upwelling radiances $I_\lambda^\uparrow$ for cloud-free conditions and above a cloud.

Two Cloud Cases on May 18

- Cloud Case 1 (CC1) with τ<10 *and geometrical thickness* Δz=20-30m, (CC2) with higher τ and Δz=60m

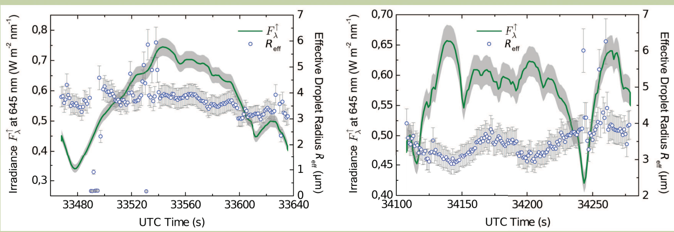


Fig. 3: Time series of in situ measured effective droplet radius R_{eff} from the PVM and upwelling irradiance $F_\lambda^\uparrow$ for CC1 (left panel) and CC2 (right panel). The grey areas and error bars indicate the measurement uncertainties for the radiation measurements and the in situ measrued R_{eff} from the PVM , respectively.

Results

- No significant correlation between cloud albedo and effective droplet radius R_{eff}

4. Retrieval of Microphysical Cloud Properties

Bi-Spectral Look-Up Table

- Calculation of downwelling irradiances F_λ and reflectivities r_λ : libRadtran, DISORT 2, 1-dimensional, plane-parallel ➔ Calculated reflectivities r_λ at 645 nm and 1645 nm ➔ Interpolation of r_λ ➔ R_{eff} and τ

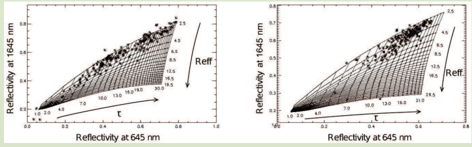


Fig. 4: Calculated r_λ grid for the 645.5 nm and 1645.3 nm wavelengths for CC1 (left panel) and CC2 (right panel). Stars indicate the helicopter measurements.

Retrieval of Microphysical Cloud Properties

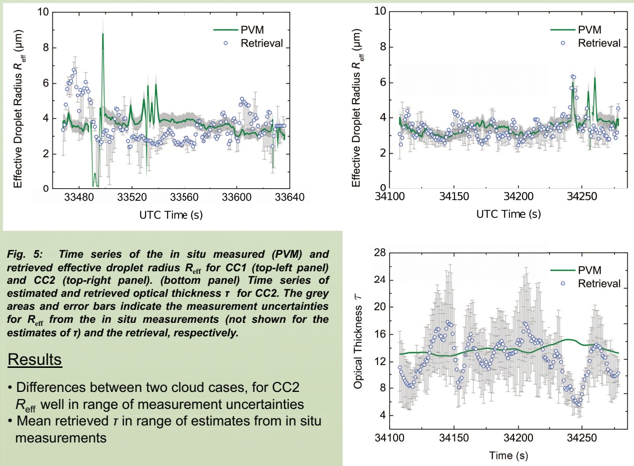


Fig. 5: Time series of the in situ measured (PVM) and retrieved effective droplet radius R_{eff} for CC1 (top-left panel) and CC2 (top-right panel). (bottom panel) Time series of estimated and retrieved optical thickness τ for CC2. The grey areas and error bars indicate the measurement uncertainties for R_{eff} from the in situ measurements (not shown for the estimates of τ) and the retrieval, respectively.

Results

- Differences between two cloud cases, for CC2 R_{eff} well in range of measurement uncertainties
- Mean retrieved τ in range of estimates from in situ measurements

➔ Including measured vertical profiles of *LWC* and R_{eff} will improve the retrieval algorithm

5. Comparison with Satellite Retrieval

- MODIS data from May 18 ➔ data from complete flight track, 45 minutes after two cloud cases

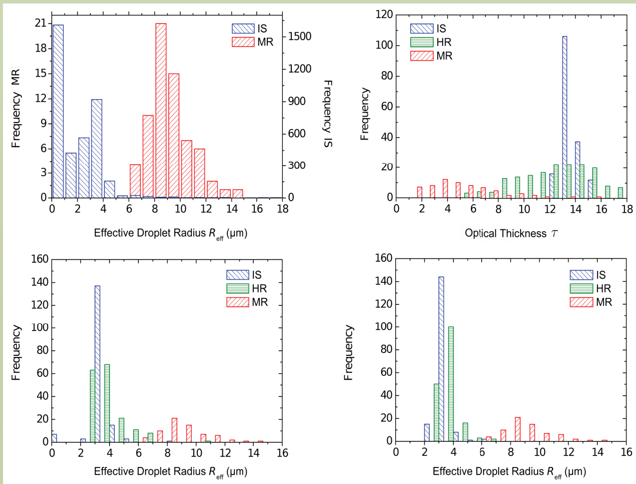


Fig. 5: Histogram of in situ measurements (IS) and MODIS retrieval (MR) of R_{eff} for the full flight track (top-left panel) and including the retrieval from the radiation measurements on the helicopter (HR) for CC1 (bottom-left panel) and CC2 (bottom-right panel).
(Top-right panel): Histogram of IS, HR and MR of τ.

Results

- Good agreement between in situ measurements and helicopter retrieval, especially for R_{eff}
- MODIS retrieval of R_{eff} 2-3 times higher than in situ measurements
- MODIS retrieval of τ 2 times lower than in situ measurements

➔ Low cloud fraction, 3D-radiative effects

6. Outlook

- Further systematic measurements are necessary
- In November 2010: Barbados Field Study

➔ New, compact radiation system + Imaging Spectrometer + 3-D Modelling ➔ Inhomogeneity Effects

[1] Henrich, F., H. Siebert, E. Jäkel, R. A. Shaw, and M. Wendisch (2010), Collocated Measurements of Boundary-Layer Cloud Microphysical and Radiative Properties and Comparison with Satellite Retrievals, in review at *J. Geophys. Res.*

[2] Siebert, H., H. Franke, K. Lehmann, R. Maser, E. W. Saw, D. Schell, R. A. Shaw, and M. Wendisch (2006), Probing finescale dynamics and microphysics of clouds with helicopter- borne measurements, *Bull. Amer. Meteorol. Soc.*, 87, 1727– 1738.

[3] Kulmala, M., et al. (2009), Introduction: European Integrated Project on Aerosol Cloud Climate and Air Quality interac- tions (EUCAARI) - integrating aerosol research from nano to global scales, *Atmos. Chem. Phys.*, 9, 2825–2841.

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