UNIVERSITÄT LEIPZIG
Faculty of Physics and Earth Sciences

New Helicopter-borne Retrieval of Trade Wind Cumuli under Cirrus and Verification of Indirect Aerosol Effect

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1. Introduction

Trade Wind Cumuli

- Influence on Radiation; moisture, momentum and heat transport to the free troposphere

➔ Open issues: Interaction between aerosol particles, microphysics and radiation; Giant Nuclei and their influence on droplet concentrations; warm rain problem

➔ Frequent overlying cirrus affects standard retrieval of cloud properties

Photo 1: Typical cloud scene over Barbados with trade wind cumuli over the ocean.

2. Instrumentation

CARRIBA Campaign in Barbados:

- 30 helicopter flights during November 2010 and April 2011
- Two towed platforms: (i) SMART-HELIOS : cloud top reflectivity; (ii) ACTOS : in situ measurements (cloud, aerosol, turbulence)
- Ground based measurements (LIDAR, aerosol concentrations, RADAR, sun photometer)

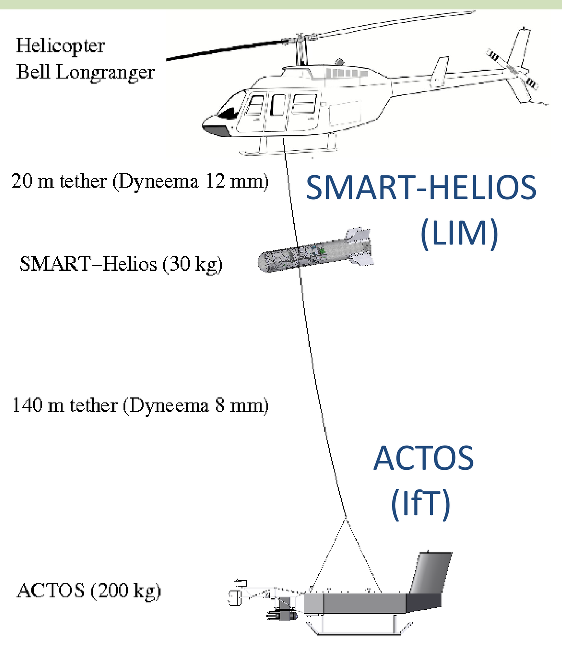

Fig. 1: Measurement setup: The radiation instrumentation is installed within the Spectral Modular Airborne Radiation measurement sysTem (SMART-HELIOS), roughly 20m below the helicopter. The Airborne Cloud Turbulence Observation System (ACTOS, [2]) is carried by means of a 160m long rope and measures cloud, turbulence and aerosol properties. Specifically, liquid water content LWC and effective droplet radius R_{eff} are measured by a PVM-100A; total aerosol concentrations are measured by a TSI CPC .

➔ **True collocation between cloud top reflectivity and in situ measurements**

➔ **Low flight speeds (17 ms^{-1}) for measuring highly inhomogeneous trade wind cumuli**

➔ **no upward looking sensor to measure incoming solar radiation**

SMART-HELIOS [1]

Photo 2: SMART-HELIOS instrument during pitch/roll angle calibration. The platform is attached via a gimbaled mounting.

- Spectral upward radiance I_λ and irradiance F_λ above trade wind cumuli
- Spectral range: 300 – 2100 nm, FWHM: 2-3 nm (visible) and 8-12 nm (nearinfrared), Δt: 0.1-1 s
- Battery: 5 h, spatial resolution of I_λ is 5 m
- Also installed: GPS, Inertia Measurement Unit, Digital Camera

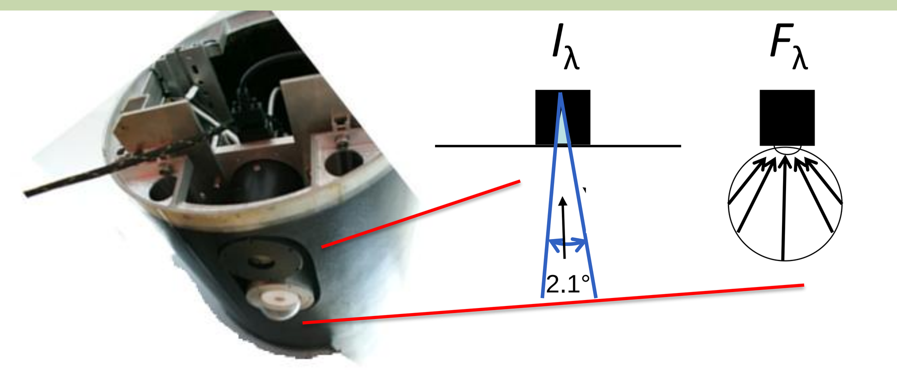

Fig. 3: Radiance and irradiance sensors at the bottom of SMART-HELIOS.

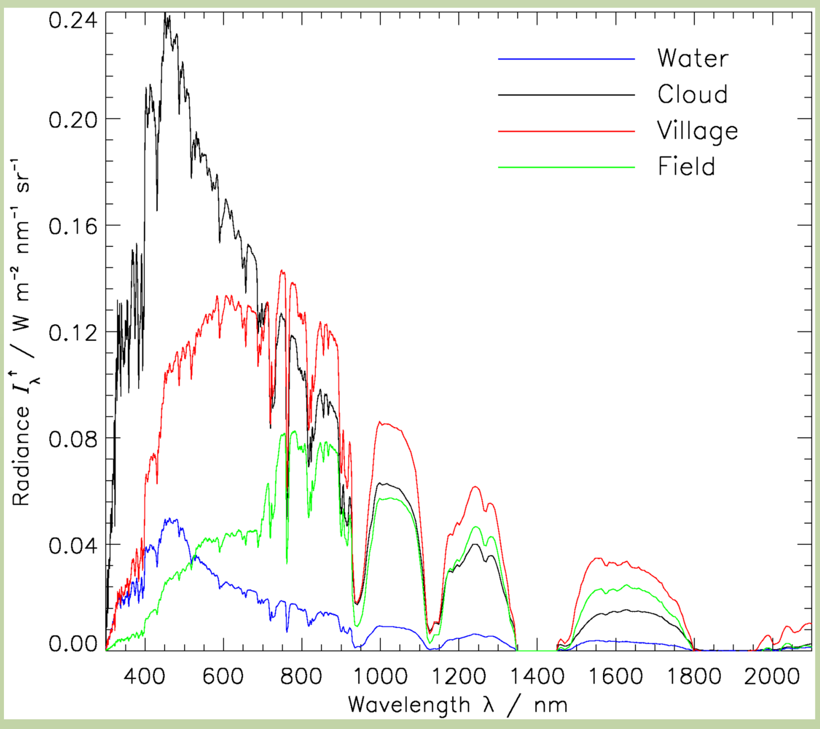

Fig. 2: Measurement example of spectral upward radiance I_λ measured on 18 April 2011. Shown are different spectra of varrying surfaces below SMART-HELIOS: The spectrum over the ocean is shown in blue, a trade wind cumulus over the ocean in black, a village with a multitude of surface albedos in red and a field on the island in green.

3. New Retrieval Under Overlying Cirrus [3]

Standard Bi-Spectral Retrieval (SBR)

- overlying cirrus present during most flights
- very inhomogeneous and comparably thin
- neglecting cirrus in retrieval: bias in results

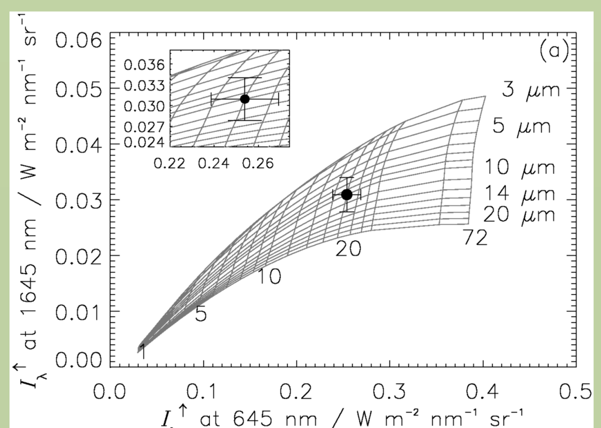

Fig. 3: Look-up table for the standard bi-spectral retrieval.

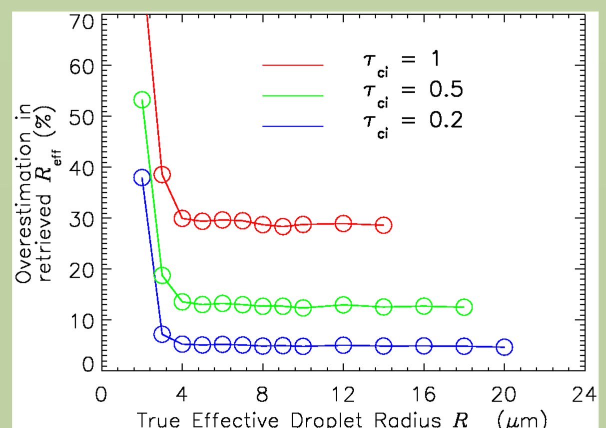

Fig. 4: Influence of overlying cirrus, with different cirrus optical thickness τ_{ci}, on the retrieval of the effective droplet radius R_{eff} of the trade wind cumuls.

➔ **Overestimation of R_{eff} of 6, 13 and 31 %**

➔ **Underestimation of τ of 1,2 and 5 %**

New Radiance-Ratio Retrieval (RRR)

- Retrieval with radiance-ratios $\mathcal{R} = I_{\lambda 1} / I_{\lambda 2}$
- λ1 and λ2 where $I_{\lambda 1} / I_{\lambda 2}$ under cirrus = $I_{\lambda 1} / I_{\lambda 2}$ cirrus-free
- Radiance-ratios decrease measurement uncertainty

➔ **Mitigates effect of cirrus on retrieval**

➔ **Measurement uncertainties decrease**

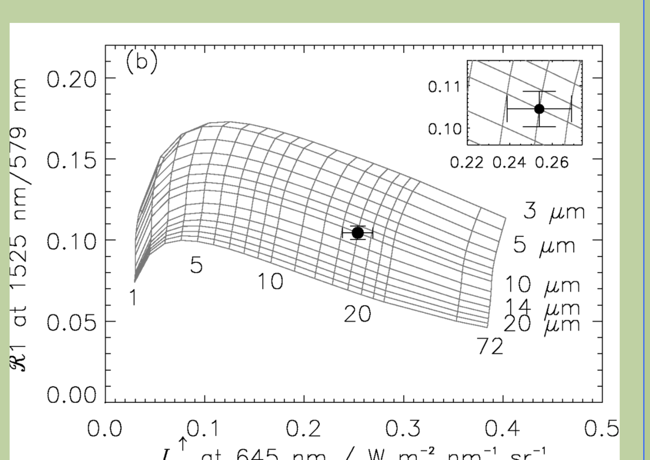

Fig. 5: New look-up table with radiance-ratio at 1525 nm / 579 nm and single radiance at 645 nm.

[1] Henrich, F., H. Siebert, E. Jäckel, R. A. Shaw, and M. Wendisch (2010), Collocated measurements of boundary layer cloud microphysical and radiative properties: A feasibility study *Journal of Geophysical Research-atmospheres*, 2010, *115*, D24214

[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 measurement.s, *Bull. Amer. Meteorol. Soc.*, 87, 1727– 1738.

[3] Werner, F., H. Siebert, P. Pilewskie, M. Wendisch (2012), Helicopter-borne Passive Remote Sensing and In Situ Observations of Microphysical and Optical Properties of Trade Wind Cumuli., in preparation

4. New Retrieval and CARRIBA 2011 Data

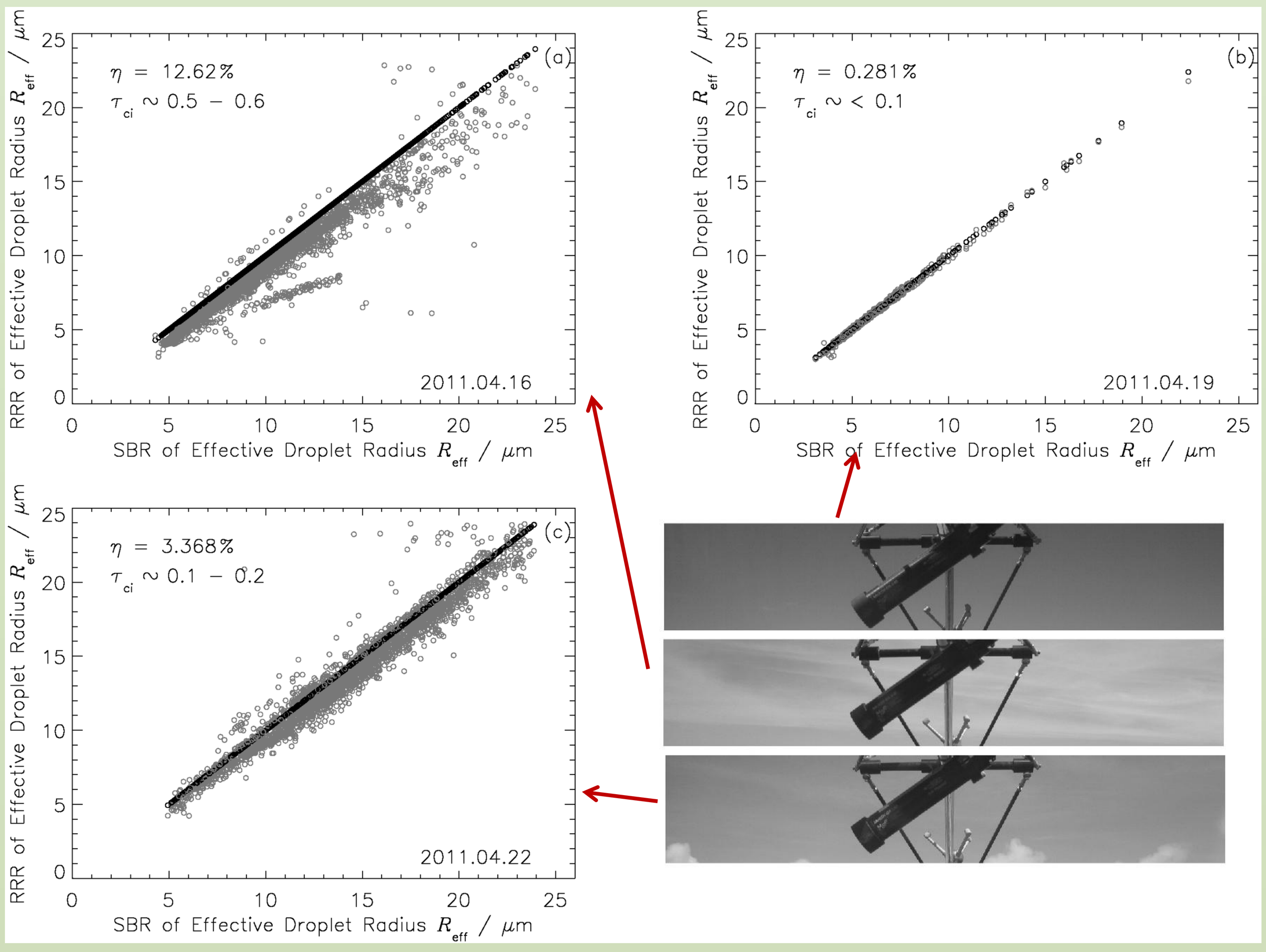

Fig. 6: (a) Radiance-Ratio Retrieval (RRR) as a function of Standard Bi-Spectral Retrieval (SBR) of the effective droplet radius R_{eff} on 16 April 2011. (b) RRR as a function of SBR of R_{eff} on 19 April 2011. (c) RRR as a function of SBR of R_{eff} on 22 April 2011.

On the bottom right 3 photos from the front-facing camera on ACTOS are shown, illustrating the overlying cirrus scene during each day (from top to bottom: 16, 19 and 22 April 2011.)

➔ **Increasing cirrus optical thickness ➔ increasing overestimation in the SBR of R_{eff}**

Comparison of retrieval with in situ results

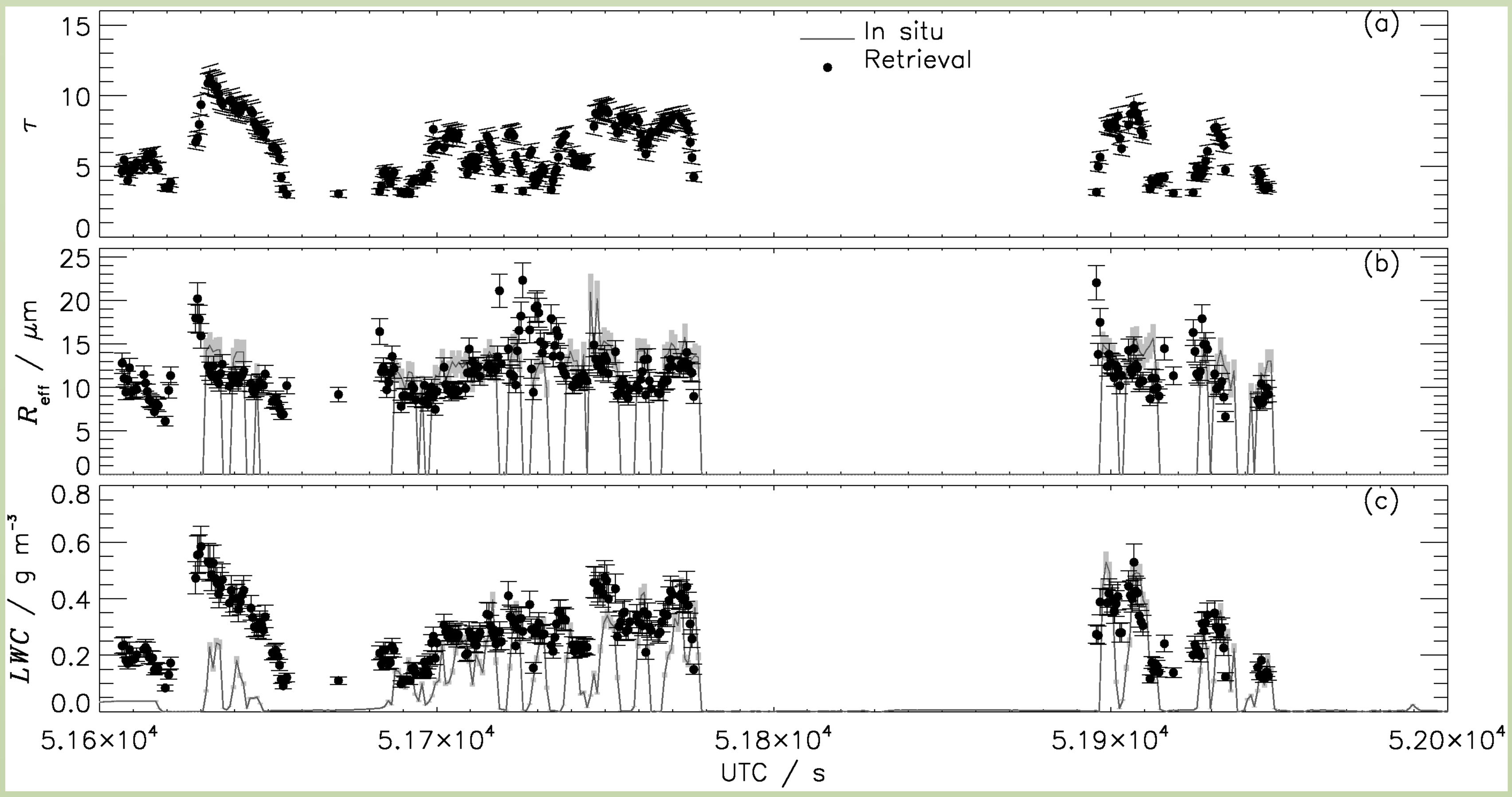

Fig. 4: Time Series of (a) retrieved cloud optical thickness τ, (b) retrieved and in situ measured effective droplet radius R_{eff} and (c) retrieved and in situ measured liquid water content LWC. The data set is a 400 s measurement interval on 22 April 2011. In situ measurements are shown in solid lines and the retrieved results are shown in filled circles with the respective uncertainties.

➔ **retrieval of τ, R_{eff} and LWC comparable to in situ values**

➔ **differences due to different probe volumes, ACTOS up to 100 m within cumuli, 3-D effects**

5. Influence of Aerosol Particles on τ and R_{eff}

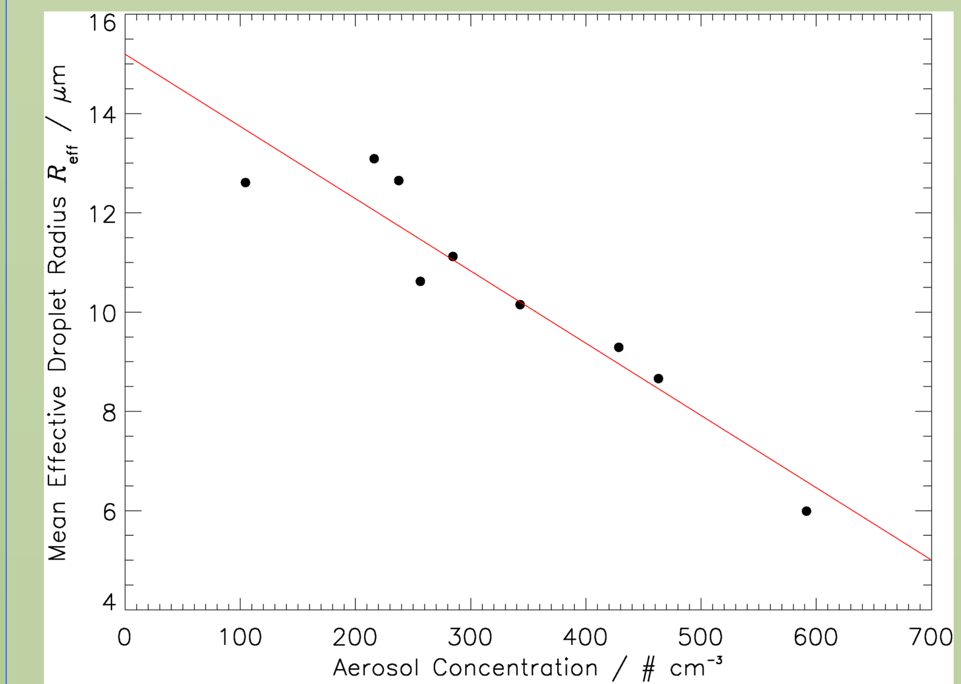

Fig. 7: Retrieved daily mean values of effective droplet radius R_{eff} as a function of total aerosol concentration data from the CPC on ACTOS. Data is from April 2011. The red line indicates a linear fit trough the data.

➔ **Strong linear relation between total aerosol concentration and R_{eff}**

➔ **Decreasing R_{eff} with increasing aerosol concentration**

22 April 2011: low aerosol load
19 April 2011: high aerosol load (biomass burning)

➔ evaluate mean values for measurements with the same *LWC* ➔ discrete *LWC* bins

➔ **Increasing aerosol concentration: smaller R_{eff} and higher τ for same *LWC***

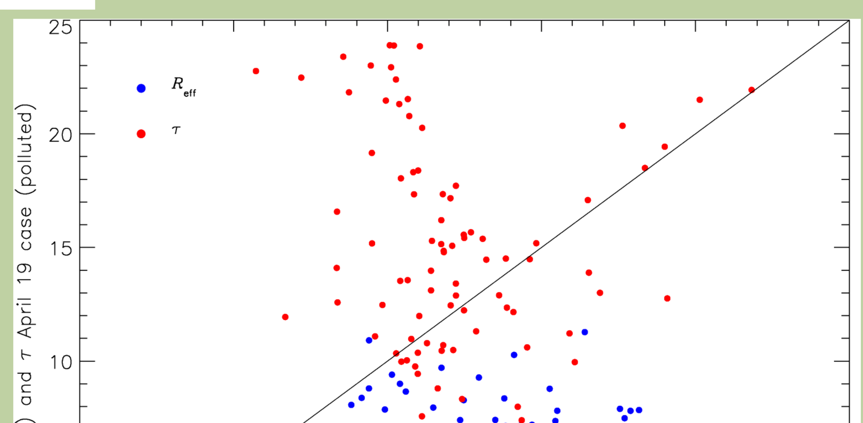

Fig. 8: Retrieved cloud optical thickness τ and effective droplet radius R_{eff} on 19 April 2011 (total aerosol concentration of 710 cm^{-3}) as a function of retrieved results on 22 April 2011 (total aerosol concentration of 125 cm^{-3}). Each data point represents the mean within a 0.01 LWC bin (e.g. within a LWC-range LWC = 0.2 - 0.21 g m^{-3}). LWC data is from the PVM-100A on ACTOS.

6. Summary

- Collocated measurements of cloud microphysics and radiation
- New Radiance-Ratio Retrieval allows for τ and R_{eff} retrievals under overlying cirrus
- linear relation between R_{eff} and aerosol particle concentrations, observed Twomey effect

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