3D cloud effects on cloud retrievals using ship-based solar spectral transmissivity measurements

M. Brückner[(1)*], M. Wendisch[(2)], A. Macke[(1)], T. Kanitz[(1)], B. Pospichal[(2)]

(1) Leibniz-Institute for Tropospheric Research (IfT), Leipzig, Germany
(2) Leipzig Institute for Meteorology (LIM), University of Leipzig, Germany
* contact : mbrueck@rz.uni-leipzig.de

1. Goals

- Ship-based measurements of spectral cloud transmissivity to retrieve cloud optical thickness and effective radius
- Evaluate three-dimensional (3D) cloud radiative effects on retrieval and energy budget

2. Instrumentation

- Integrated in OCEANET-Container on RV Polarstern
- Spectral radiance and irradiance measurements with COmpact RAdiation measurement System (CORAS)
- Broadband radiation measurements for irradiance and radiance from Pyrano- and Pyrgeometer
- Vertical structure of the cloud from the Raman lidar Polly^{XT} (profiles of extinction coefficient and microphysical aerosol properties) and Microwave Radiometer HATPRO (profiles of the liquid water path (LWP))
- Full sky imager for information on the horizontal cloud variability

Ship –based	Measured Quantity	Spectral Range	Resolution
	Downward Irradiance $F_\lambda^\downarrow$	290-1000 (VIS)/950-2200 (NIR) nm	2-3 (VIS)/15 (NIR) nm
	Downward Radiance $I_\lambda^\downarrow$	290-1000 (VIS)/950-2200 (NIR) nm	2-3 (VIS)/15 (NIR) nm

Fig. 1: *Located Container on the Observation deck of RV Polarstern*

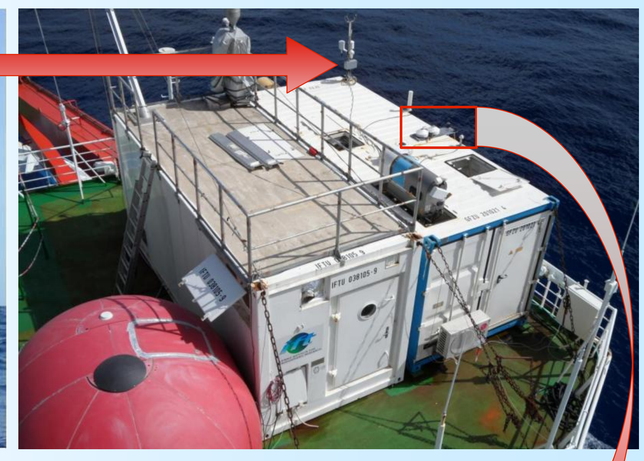

Fig. 2: *OCEANET-Container (right) aboard RV Polarstern during ANT-XXVII/4*

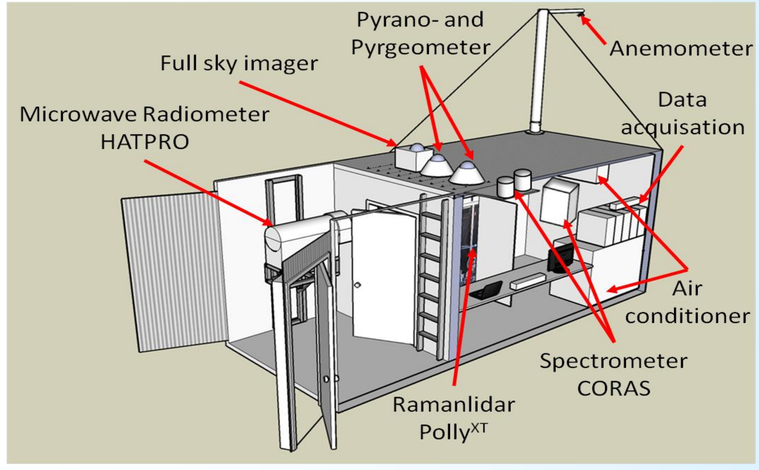

Fig. 4: *Sketch of the OCEANET-Container*

Fig. 3: *Optical inlets from CORAS and Pyrano- and Pyrgeometer*

3. Methodology

Radiative transfer model (RTM)

Plan-parallel (PP) RTM
➡ libRadtran [1]
Model $I^{\downarrow}_{\lambda,\mathrm{calc}}(z_0)\big|_{\mathrm{PP}}$ and $F^{\downarrow}_{\lambda,\mathrm{calc}}(z_0)\big|_{\mathrm{PP}}$ at sea level z_0 (using optical and microphysical observations)

3D Monte-Carlo RTM
➡ MCUNIK [2]
Model $I^{\downarrow}_{\lambda,\mathrm{calc}}(z_0)\big|_{\mathrm{3D}}$ and $F^{\downarrow}_{\lambda,\mathrm{calc}}(z_0)\big|_{\mathrm{3D}}$ at sea level z_0 (using optical and microphysical observations)

$$I^{\downarrow}_{\lambda,\mathrm{calc}}(z_0)\big|_{\mathrm{PP,3D}} \cong I^{\downarrow}_{\lambda,\mathrm{meas}}(z_0);$$
$$F^{\downarrow}_{\lambda,\mathrm{calc}}(z_0)\big|_{\mathrm{PP,3D}} \cong F^{\downarrow}_{\lambda,\mathrm{meas}}(z_0)$$

Quantify 3D cloud effects

Observations of $I^{\downarrow}_{\lambda,\mathrm{meas}}(z_0)$ and $F^{\downarrow}_{\lambda,\mathrm{meas}}(z_0)$ at sea level z_0 from CORAS

Calculate modeled spectral transmissivity $T_{\lambda,\mathrm{calc}}\big|_{\mathrm{PP}}$ using a PP-RTM

$$T_{\lambda,\mathrm{calc}}\big|_{\mathrm{PP}} = \frac{\pi I^{\downarrow}_{\lambda,\mathrm{calc}}(z_0)\big|_{\mathrm{PP}}}{\mu_0 I^{\downarrow}_{\lambda}(z_{\mathrm{top}})}$$

Calculate modeled spectral transmissivity $T_{\lambda,\mathrm{calc}}\big|_{\mathrm{3D}}$ using a 3D Monte-Carlo RTM

$$T_{\lambda,\mathrm{calc}}\big|_{\mathrm{3D}} = \frac{\pi I^{\downarrow}_{\lambda,\mathrm{calc}}(z_0)\big|_{\mathrm{3D}}}{\mu_0 I^{\downarrow}_{\lambda}(z_{\mathrm{top}})}$$

Quantify 3D cloud effects on spectral transmissivity

Calculate observed spectral transmissivity $T_{\lambda,\mathrm{meas}}$ using ship-based measurements at sea level

$$T_{\lambda,\mathrm{meas}} = \frac{\pi I^{\downarrow}_{\lambda,\mathrm{meas}}(z_0)}{\mu_0 I^{\downarrow}_{\lambda}(z_{\mathrm{top}})}$$

cloud retrieval[3] using spectral transmissivity

Spectral cloud retrieval with modeled transmissivity $T_{\lambda,\mathrm{calc}}\big|_{\mathrm{PP}}$ and $T_{\lambda,\mathrm{calc}}\big|_{\mathrm{3D}}$ to retrieve optical thickness τ and effective radius r_{eff}

Classify differences in retrievals by cloud fraction and vertical inhomogenieties

$\tau\big|_{\mathrm{PP}}, r_{\mathrm{eff}}\big|_{\mathrm{PP}}$ $\qquad$ $\tau\big|_{\mathrm{3D}}, r_{\mathrm{eff}}\big|_{\mathrm{3D}}$

top = top of cloud

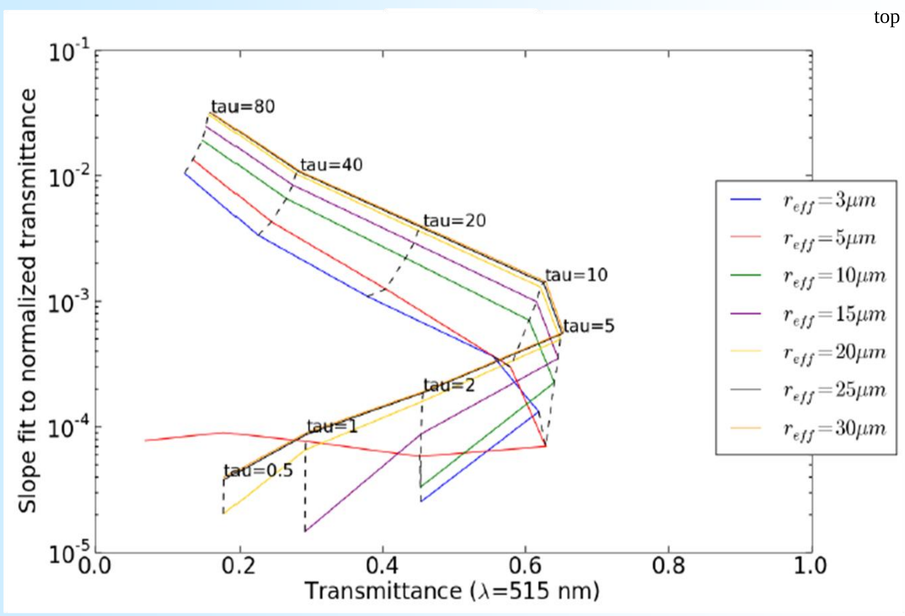

Fig.5: *Look up table for spectral cloud retrieval using modeled transmissivity (PP-RTM) and spectral slope fit through normalized transmissivity. Figure taken from [3].*

4. Examples

[+] using the NASA SSFR

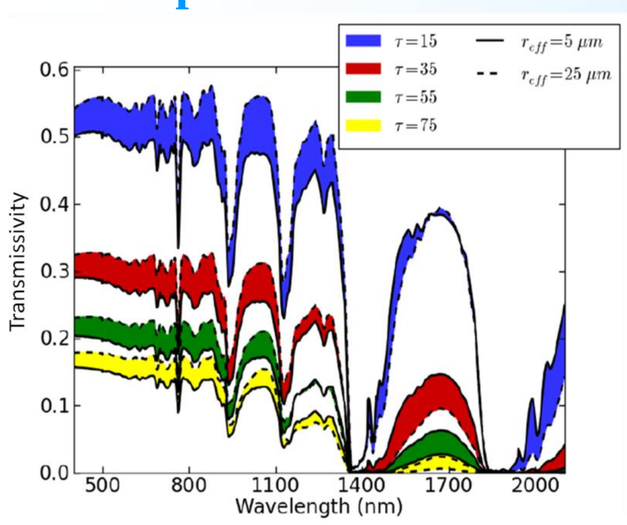

Fig. 6: *Modeled spectral transmissivity (PP-RTM) for a liquid water cloud in dependence on optical thickness and effective radius. Figure taken from [3].*

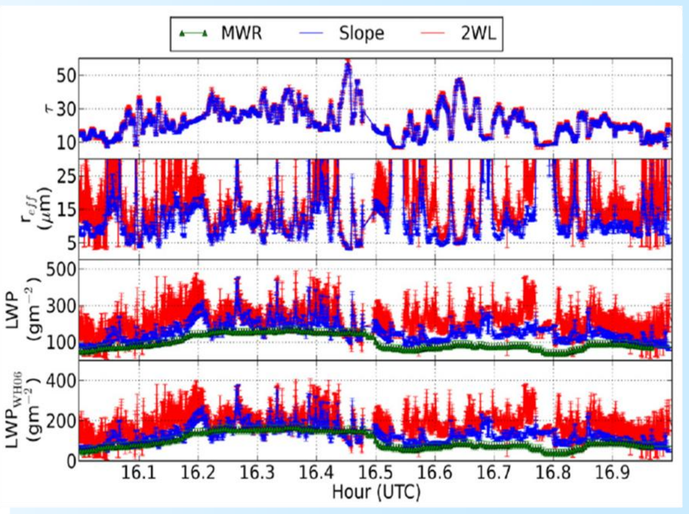

Fig. 7: *Time series from ICEALOT[+] campaign of retrievals of optical thickness and effective radius with spectral cloud retrieval (slope) and 2-wavelength (2WL) method. LWP retrievals from NOAA Microwave radiometer (MWR) and from spectral radiation measurements. Figure taken from [3].*

5. Outlook

- Quantify 3D cloud effects on ship-based and modeled spectral transmissivity using PP-RTM and 3D Monte-Carlo RTM
- Retrieve cloud optical thickness and effective radius using PP-RTM and 3D Monte-Carlo RTM to quantify 3D cloud effects on spectral transmissivity for different cloud types
- Classify systematically differences in retrieved cloud parameters by cloud fraction and cloud vertical inhomogeneities from full sky imager, lidar and microwave radiometer
- Determine dependence on solar zenith angle (SZA) for spectral radiation quantities
- quantify retrieval sensitivity to model assumptions

References: [1] Mayer, B. and Kylling, A.: Technical note: The libRadtran software package for radiative transfer calculations - description and examples of use, Atmos. Chem. Phys., 5, 1855–1877, 2005, http://www.atmos-chem-phys.net/5/1855/2005/.
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[3] McBride, P.J. et al.: A spectral method for retrieving cloud optical thickness and effective radius from surface-based transmittance measurements, Atmos. Chem. Phys. Discuss., 11, 1053-1104, 2011

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