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Cloud Retrieval Using Ship-based Spectral Transmissivity Measurements

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Abstract. Within the scope of the OCEANET-Project (autonomous measurement platforms for energy and material exchange between ocean and atmosphere) on board of the research vessel Polarstern clouds have been investigated over the Atlantic Ocean under different atmospheric conditions and climate zones by active and passive remote sensing. An existing measurement platform, including lidar, microwave radiometer, all sky camera and broadband radiation sensors, has been extended by spectral radiation measurements with the COmpact RAdiation measurements System (CORAS). CORAS measures spectral downward radiances and irradiances in the visible to near-infrared wavelength region. The data were corrected to consider the movements of the ship and with it the misalignment of the sensor plane from earth's horizon. Using observed and modeled spectral transmitted radiances cloud properties such as cloud optical thickness (τ) and effective radius (r_{eff}) were retrieved. The vertical cloud structure with limitations for thick clouds is obtained from lidar and microwave radiometer measurements. The all sky camera provides information on the horizontal cloud variability. Cloud optical thickness and effective radius, will be retrieved by using a plane parallel radiative transfer model.

Keywords: Spectral radiation, Spectral transmissivity, Cloud retrieval.
PACS: 42.68.Ay

INTRODUCTION

To understand the interaction between clouds and solar radiation within the climate system ground-based observations with high temporal and spatial resolution are required. In the framework of the OCEANET-project (autonomous measurement platform for material and energy exchange between ocean and atmosphere) a measurement container was developed which is planned to be operated on freight and research vessels [1]. The container combines several measurement techniques of passive and active remote sensing applications to provide data of different cloud scenes over ocean in three climate zones in both the northern and southern hemispheres. The measurements reported here were performed during the Atlantic transfers aboard the German research vessel (RV) Polarstern. Spectral radiation measurements were used to obtain cloud microphysical properties such as cloud optical thickness τ and effective radius reff applying a spectral cloud retrieval method [2]. Furthermore, the results of different radiative transfer models will be compared with the observations.

INSTRUMENTATION

The OCEANET-Atmosphere container consists of several instruments. A microwave radiometer HATPRO (Humidity and Temperature Profiler) provides atmospheric vertical profiles of temperature, humidity and liquid water path (LWP). A full sky imager [3, 4] determines the cloud coverage and cloud type. For daytime every 15 seconds a picture is taken. Pyrano- and Pyrgoemeter were used to obtain the solar and terrestrial downward broadband irradiance [1]. A multi wavelength Raman lidar PollyXT [5, 6] measured vertical profiles of the particle extinction coefficient and aerosol microphysical properties. Spectral radiation measurements were performed with the COmpact RAdiation measurement System (CORAS). This instrument consists of two optical inlets to measure downward spectral irradiance and radiance; both inlets were mounted on the roof of the container. The inlets are connected via optical fibers to a system of spectrometers. For measurements in the visible (VIS: 290-1000 nm) and near infrared (NIR) spectral range (950-2200 nm). The spectral resolution is 2-3 nm in VIS and 15 nm in NIR. The OCEANET-container was located on the helicopter deck of RV Polarstern.

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SPECTRAL CLOUD RETRIEVAL

To obtain microphysical cloud properties from transmitted spectral radiances a cloud retrieval method [2] is applied. With the plane-parallel radiative transfer model package libRadtran [7] the transmitted radiance $I^{\downarrow}_{\lambda,\mathrm{mod}}$ at sea level z_0 is calculated. Further observations made on Polarstern (e.g., radiosonde data, temperature, wind field) were used as an additional model input. The radiative transfer calculations were performed for an ocean surface albedo and a liquid water cloud with different values of optical thickness and effective radius. The optical thickness was varied from 0.1 to 0.9 at an interval of 0.1 and from 1 to 100 at an interval of 1. The effective radius ranges from 1 µm to 30 µm in steps of 1 µm. The model results were compared to the observations of transmitted radiance $I^{\downarrow}_{\lambda,\mathrm{obs}}$. Furthermore, we calculate the spectral transmissivity at sea level z_0:

$$T^{\downarrow}_{\lambda,\mathrm{mod/obs}} = \frac{\pi I^{\downarrow}_{\lambda,\mathrm{mod/obs}}(z_0)}{\mu_0 F^{\downarrow}_{\lambda}(z_{\mathrm{TOA}})}, \tag{1}$$

where the indices 'mod' refers to the model results and 'obs' to the observations. To consider the current position of the sun the cosine of the solar zenith angle μ_0 is used along the cruise track and the incoming solar irradiance $F^{\downarrow}_{\lambda}$ at the top of atmosphere (TOA).

Figure 1 shows the modeled spectral transmissivity for a liquid water cloud with different values of optical thickness and two values of effective radius (5µm: solid lines, and 25µm: dashed lines). The colored areas illustrate constant values of optical thickness of 5, 35, and 75. The calculation was performed for a solar zenith angle θ_0 of 30° and an ocean surface albedo using a mean surface wind speed for Cox and Munk [8, 9] ocean bidirectional reflection distribution function (BRDF) [7]. The larger the cloud optical thickness the lower the transmissivity at the surface. For wavelengths smaller than 1100 nm scattering dominates over absorption. Larger droplets have an enhanced forward scattering peak (larger asymmetry parameter) and, thus, increased transmissivity at the surface. But for wavelengths between 1100 to 1400 nm the cloud droplet absorption increases and larger effective radii result in a decreased transmissivity. The crossover between the predominant processes is determined by the magnitude of cloud absorption. Furthermore, absorption bands of different atmospheric gases (O_3, H_2O and O_2) are represented in the modeled spectral transmissivity. The lower spectral slope for larger optical thickness is related to the larger backward scattering in the upper hemisphere and larger cloud droplets.

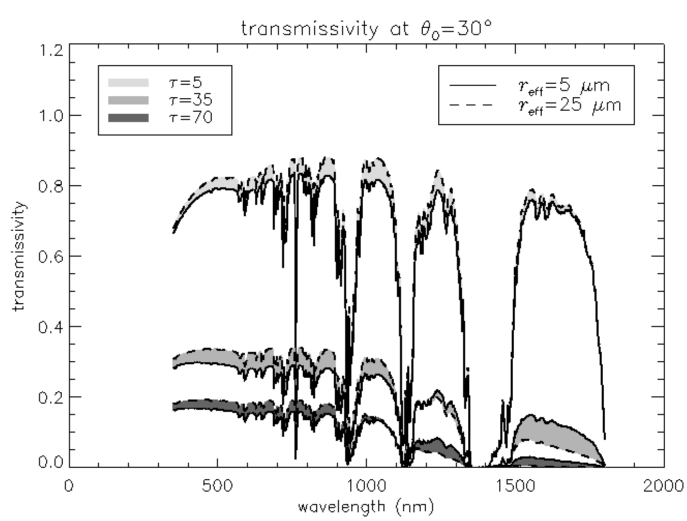

FIGURE 1. Modeled transmissivity for a water cloud with effective radius of 5 µm (solid lines) and 25 µm (dashed lines). Colored regions illustrate constant values of optical thickness. These were calculated for θ_0 of 30° and an ocean surface albedo.

The spectral cloud property retrieval uses the spectral information over a certain NIR range [2]. In this paper the spectral range between 1550 nm and 1700 nm is used to apply the retrieval. This wavelength range was chosen because transmissivity has a nearly linear behavior over a wide range of values of optical thickness and effective radius. Furthermore, it is outside of bands with enhanced molecular absorption bands. In this spectral range the slope of transmissivity normalized to the transmissivity at 1700 nm is calculated. The normalization removes the effect of spectrally correlated errors such as radiometric uncertainties.

Figure 2 shows the modeled normalized transmissivity for a water cloud with an optical thickness of 35 and two values of effective radius over the spectral range. The slope is derived with a least square linear regression. For water cloud the slope for larger effective radius (dashed line) is smaller than for smaller effective radius (solid line). The spectral slope carries information on microphysical properties, cloud optical thickness and effective radius.

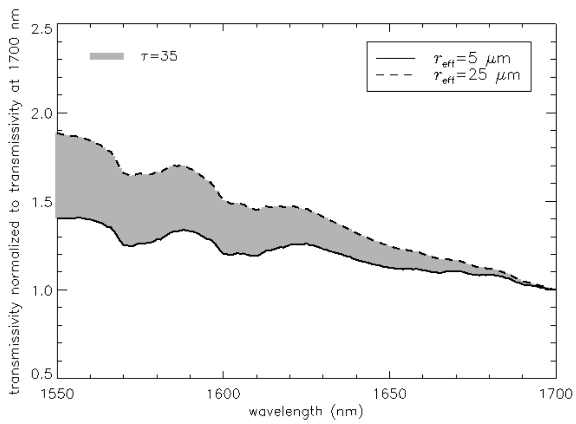

FIGURE 2. Modeled normalized transmissivity for an optical thickness of 35 and an effective radius of 5 µm (solid line) and 25 µm (dashed line).

With this information a look up table for transmissivity is obtained (Figure 3). The spectral slope fit to normalized transmissivity at 1700 nm is plotted against the transmissivity in the VIS range at 532 nm. The slope is shown on a logarithmic axis. There is less sensitivity to effective radius for an optical thickness lower than 5 because there are two opposing effects. Larger droplets increase forward scattering but additionally cloud droplet absorption dominates for optical thin clouds. But for optical thickness larger than 5 the lines of different values of effective radius are clearly separated. The shape of the look up tables results from the ambiguous behavior of transmitted radiance. On radiance value corresponds to two different values of optical thickness.

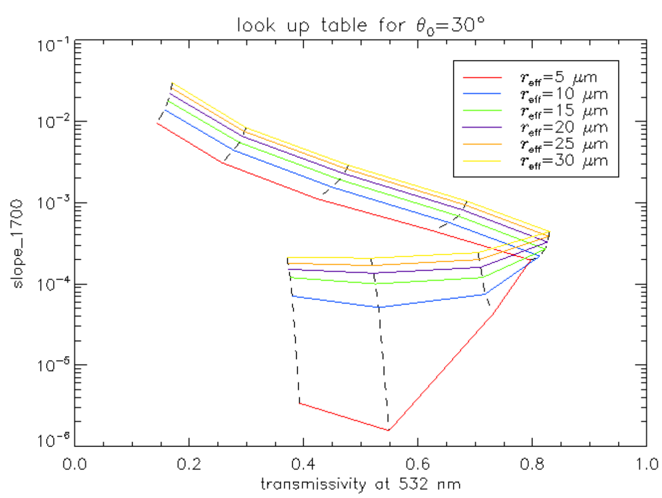

FIGURE 3. Look up table for transmissivity at a solar zenith angle θ_0 of 30°. Transmissivity was calculated with modeled transmitted radiances and the spectral slope fit through normalized transmissivity in the NIR range from 1550 nm to 1700 nm for different values of optical thickness (dashed lines) and effective radius (colored solid lines).

SUMMARY AND OUTLOOK

This paper introduces a spectral cloud retrieval to obtain cloud optical thickness and effective radius from ship-based spectral transmissivity measurements. The measurements of spectral radiation were performed in the scope of the OCEANET project during the Atlantic Ocean transfers of RV Polarstern. The spectral information of transmitted radiance is used to obtain the spectral transmissivity at the surface. The slope of transmissivity normalized by the transmissivity at 1700 nm and the transmissivity in the VIS spectral range at 532 nm were calculated to retrieve cloud microphysical properties.

It is planned to improve the spectral cloud retrieval by a zooming retrieval technique, which makes it unnecessary to calculate the whole grid for each time step of the observation. A better way is to limit the value range of optical thickness and effective radius. By zooming iteratively into optical thickness by keeping the effective radius constant the possible range for observed optical thickness is contained. Using this new optical thickness range the value range for effective radius is searched in the same way. After limiting the possible value range for the observation the whole retrieval (step by step) is applied. This will accelerate vastly the retrieval algorithm.

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REFERENCES

1. A. Macke, J. Kalisch, Y. Zoll, and K. Bumke, *EPJ Web of Conferences* **9**, 83-94 (2010).
2. P. J. McBride, K. S. Schmidt, P. Pilewskie, A. S. Kittelman and D. E. Wolfe, *Atmos. Chem. Phys.* **11**, 7235–7252 (2011).
3. J. Kalisch and A. Macke, *Meteorol. Z.* **17**, 603-611 (2008).
4. J. Kalisch, "Der Einfluss von Wolken auf den Strahlungsantrieb der Erde", Ph.D. Thesis, Leibniz Institute for Ocean Research IFM-GEOMAR, Kiel, 2011.
5. D. Althausen, R. Engelmann, H. Baars, B. Heese, A. Ansmann, D. Müller and M. Komppula, *J. Atmos. Oceanic Techno.* **26**, 2366–2378, doi:10.1175/2009JTECHA1304.1 (2009).
6. T. Kanitz, P. Seifert, A. Ansmann, R. Engelmann, D. Althausen, C. Cassicia and E.G. Rohwer, *Geophys. Res. Lett.* **38**, L17802, doi:10.1029/2011GL048532 (2011).
7. B. Mayer and A. Kylling, *Atmos. Chem. Phys.* **5**, 1855-1877 (2005).
8. C. Cox and W. Munk, *J. Opt. Soc. Am.* **44**, 838–850 (1954).
9. C. Cox and W. Munk, *J. Marine Res.* **13**, 198–227 (1954).