Impact of cirrus crystal shape on solar spectral irradiance: A case study for subtropical cirrus

INSTITUTE FOR TROPOSPHERIC RESEARCH

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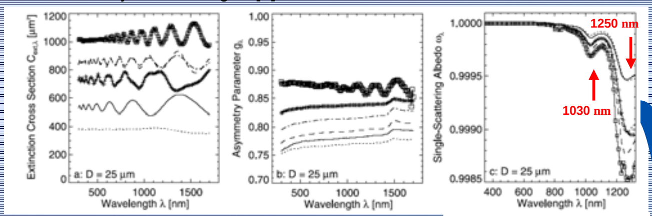
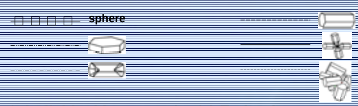
1. Introduction

- Cirrus clouds play an important role in Earth radiation budget (shortwave cooling and longwave heating effect).
- **Problem:** The net effect depends on several factors including cirrus microphysical properties such as ice crystal size and shape.
- Ice crystal size and shape determine the single scattering properties (extinction cross section $C_{ext,\lambda}$, single scattering albedo ω_λ and asymmetry parameter g_λ) of the individual crystal; see Fig.1. [1]





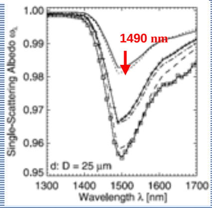


Fig. 1: Individual ice crystals: (a) Extinction cross section $C_{ext,\lambda}$, (b) asymmetry parameter g_λ, and (c and d) single-scattering albedo ω_λ as a function of wavelength λ for ice crystals with a fixed maximum dimension of D = 25 mm.

- **Goal:** - Estimate the impact of crystal shape on solar spectral irradiances with radiation transfer simulations.
  - Comparison of the results with measured solar spectral irradiances.

2. Instrumentation and Investigated Cases

- Microphysical and radiation measurements were collected during the Cirrus Regional Study of Tropical Anvils and Cirrus Layers - Florida Area Cirrus Experiment (CRYSTAL-FACE) around Florida and the Caribbean Sea in July 2002.
- Microphysical measurement: Video Ice Particle Sampler (VIPS), Cloud Aerosol Precipitation Spectrometer (CAPS), Signal Processing Package (SPP), and Cloud Particle Imager (CPI), mounted on WB-57F aircraft.
- Solar Spectral Irradiance Measurements: NASA Solar Spectral Flux Radiometer (SSFR), mounted on ER2 and Twin Otter UV-18A aircraft.
- Two cases have been investigated in detail:
  - Optical thin cirrus: 26. July 2002, Cloud Layer = 13.1 – 15.4 km, max *IWC* = 8 mg m^{-3}, τ_{vis} = 1, r_{eff} = 11 µm
  - Optical thick cirrus: 23. July 2002, Cloud Layer = 6.4 – 8.0 km max *IWC* = 550 mg m^{-3}, τ_{vis} = 7, r_{eff} = 108 µm

Fig. 2: Research aircrafts participated on CRYSTAL-FACE. ER-2 and Twin Otter measuring solar irradiances above respectively below the cloud and WB-57F measuring cloud microphysics in the cloud layer. Additionally the SPP mounted on WB-57F and the aerosol measurement instrumentation on board of the Twin-Otter is shown.

3. Calculations

- Volumetric scattering properties (Fig.3) using:
  - composite of the measured number size distributions from CAPS/SPP/CPI
  - single scattering properties library for 6 different crystal shapes (spheres, columns, hollows, plates, bullets and aggregates) covering crystal sizes between 1 and 1500 µm (40 bins) and wavelength between 300 and 1700 nm (140 bins) calculated with an Improved Geometric Optics Method (IGOM) [2]

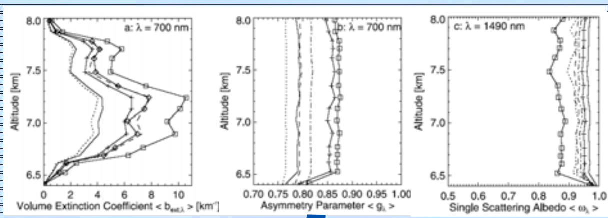
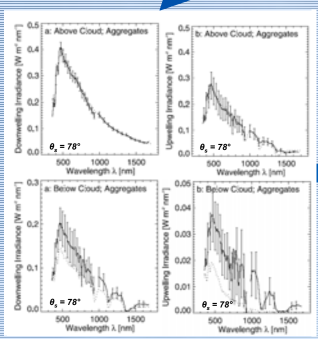


Fig. 3: Ice particle number concentration (left) and ice water content (right) for the measurements on 26 July. Size distribution measurements of the CAPS/SPP/CPI instruments on board the WB-57F aircraft were used for the integration. The curve notation is the same as in Figure 1.



- Radiative transfer simulations using:
  - libRadtran code by A. Kylling and B. Mayer [3]
  - discrete ordinate solver DISORT version 2.0
  - volumetric scattering properties (Fig.3), including Henyey-Greenstein volumetric phase function represented by the asymmetry parameter
  - solar zenith angle averaged over flight track

Fig. 4: Measured (solid lines) and calculated (dashed lines) (left) downwelling irradiance $F_\lambda\downarrow$ and (right) upwelling irradiance $F_\lambda\uparrow$ for the flight level (20.7 km, ER-2) above the cloud and (3.6 km, Twin-Otter) below the cloud for 23 July. The vertical bars represent the standard deviations of the measurements along the flight track. Aggregates have been assumed as ice crystal shapes.

4. Conclusions

- Measured and calculated solar irradiances above the cirrus were in close agreement (within ±5-10%) for the most of the assumed crystal shapes.
- Poor agreement for irradiances below the cloud, caused by variable surface albedo and nonideal coincidence in time and space between microphysical and radiation measurements.

- Outside the ice absorption bands: If multiple scattering becomes dominant (higher cloud optical thickness, or larger zenith angle) the impact of nonspherical ice crystal shape is more and more diminished.
- Inside the ice absorption bands: Multiple scattering magnifies the impact of nonspherical ice crystal shape.

- Effect of nonsphericity on the spectrally integrated radiative forcing ranges between ±8 % for large and -16% to +26% for small solar zenith angles.

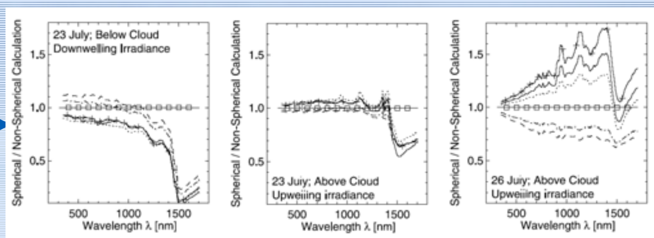


Fig. 5: Ratio of calculated irradiances assuming spherical and nonspherical ice crystal shapes. (a) downwelling irradiances for the flight level of the Twin-Otter (3.6 km, θ_s = 78°) below the cloud on 23 July; (b) and (c) upwelling irradiances for the flight level of the ER-2 (20.7 km, θ_s = 78° (b) and 19.2 km, θ_s = 21° (c)) above the cloud on 23 July (b) respectively 26. July (c). The curve notation is the same as in Figure 1.

Physics Department

[1] Wendisch, M., P. Pilewskie, J. Pommier, S. Howard, P. Yang, A. J. Heymsfield, C.G. Schmitt, D. Baumgardner, and B. Mayer (2005), Impact of cirrus crystal shape on solar spectral irradiance: A case study for subtropical cirrus, J. Geophys. Res., 110, D03202, doi:10.1029/2004JD005294
[2] Yang, P., and K. N. Liou (1996), Geometric-optics-integral-equation method for light scattering by nonspherical ice crystals, Appl. Opt., 35, 6568 –6584.
[3] Mayer B., and A. Kylling (2005), Technical Note: The libRadtran software package for radiative transfer calculations: Description and examples of use, Atmos. Chem. Phys., 5., 1855-1877