

“HARMONIE 37h1 radiation sensitivity tests” Supplement 1: Mie calculations

Kristian P. Nielsen [1], Emily Gleeson [2] & Laura Rontu [3]

1. Danish Meteorological Institute, Lyngbyvej 100, DK-2100, Copenhagen Ø, Denmark.
2. Met Éireann, Glasnevin Hill, Dublin 9, Ireland.
3. Finnish Meteorological Institute, Erik Palménin Aukio 1, FI-00560 Helsinki, Finland.

Mie calculations

An accurate solution of the inherent optical properties (IOPs) that determine the scattering and absorption of spherical homogeneous particles was first derived by Mie (1908). Mie calculations require real and imaginary refractive indices of the spherical particles as input. Here we use the values for water given by Segelstein (1981) that cover the spectral range 10 nm to 40000 nm with a spectral resolution of 10 nm. The MIEV0 solver developed by Wiscombe (1980) is run for wavelengths 280 nm to 4000 nm in 10 nm steps for water droplets with radii ranging from 4 nm to 40 nm in 1 nm steps. From the MIEV0 output the IOPs: mass extinction coefficient, single scattering albedo and asymmetry factor are calculated. In Fig. 1 the resulting single scattering albedos across the spectrum are shown for five different sizes of spherical liquid water droplets.

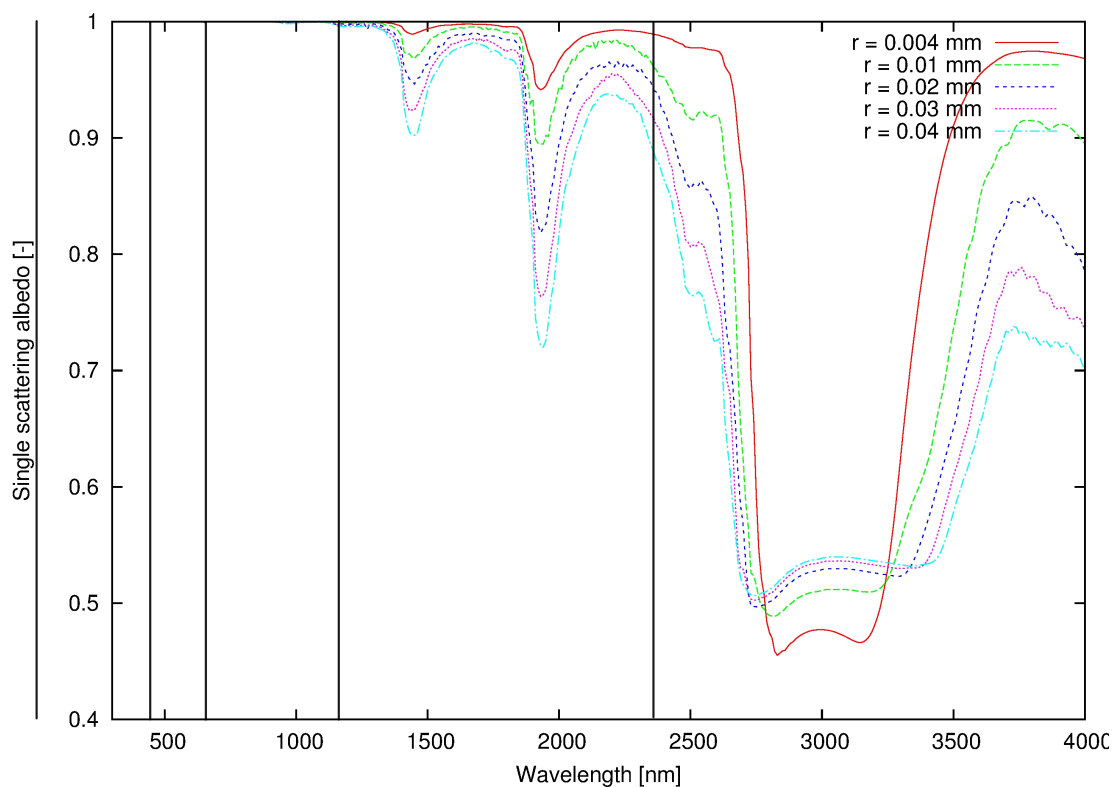


Figure 1: Mie calculations of the single scattering albedo across the solar spectrum from 280 nm to 4000 nm for five different sizes of liquid cloud water droplets.

Also marked in Fig. 1 are the divisions between the 6 SW spectral bands in the HARMONIE IFS radiation scheme as defined by the wavelengths: 185-250-440-690-1190-2380-4000 nm. As mentioned in the paper the first of these spectral bands is irrelevant. For the remaining 5 spectral bands a typical solar spectrum is used to

calculate weighted averages of each IOP. When making parametrizations for broad spectral bands it is necessary to assume a typical solar spectrum in order to account for the spectral variations within each spectral band. This assumption is a source of error in cases where the actual spectral variations within the spectral bands are very different from those assumed. It is, however, a much better assumption than using simple averages across the spectral bands.

The typical solar spectrum used for spectral weighting within the spectral bands is calculated with the pseudo-spectral LOWTRAN/SBDART option (Pierluissi & Peng 1985; Ricchiazzi et al. 1998) in the libRadtran software package (Mayer & Kylling 2005) run with 1 nm resolution using the Kurucz (1992) solar spectrum. The discrete ordinate method (DISORT; Stamnes et al. 1988) is used to solve the radiative transfer equation. Downward spectral irradiances are output at a height of 2.0 km on the 173th day of the year. The day of year determines the Sun-Earth distance. The solar zenith angle is set to 45°. The default aerosols of Shettle (1989) are used with the AFGL midlatitude summer atmosphere (Anderson et al. 1986). The ozone cross sections are given by Bass and Paur (1985).

Comparing the IOP parametrizations to the Mie calculations

In the IFS radiation scheme of HARMONIE 37h1 two IOP parametrizations of cloud liquid droplets are available: Fouquart (1987) and Slingo (1989). In the hlradia scheme IOPs are not used. The HARMONIE 37h1 IFS radiation scheme has 6 spectral bands, of which band 1 can be ignored here as solar irradiance with wavelengths below 250 nm does not reach the lower atmosphere where liquid water clouds are found.

Since the initial tests of the Fouquart and Slingo IOP parametrizations showed significant deviation from the Mie calculations, we have made a new parametrization, which we refer to as ‘Nielsen (2013)’. This new parametrization is based on empirical fits to the Mie calculations. Below these three parametrizations are given for each IOP and each spectral band. Comparisons with the Mie calculations are also plotted.

Mass extinction coefficient parametrizations

Spectral band 2 (250–440 nm)

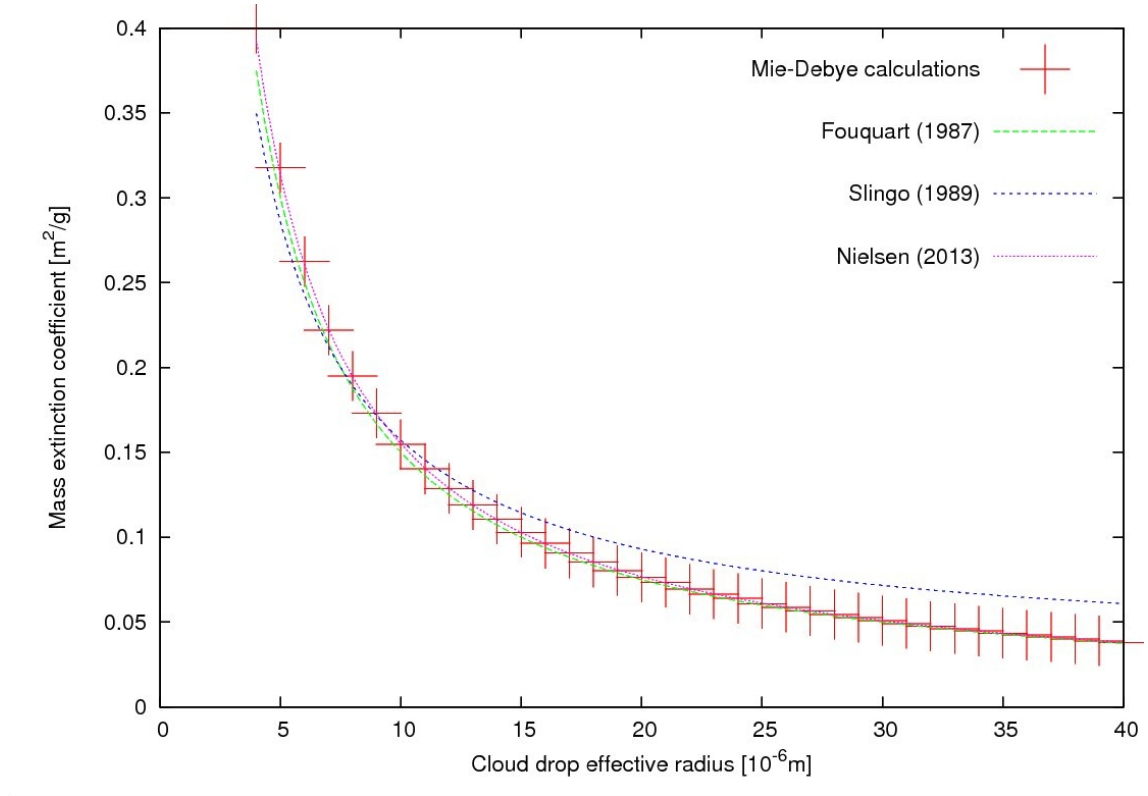


Figure 2: Comparison of mass extinction coefficient parametrizations for spectral band 2.

Fouquart (1987):

$$\frac{1.5}{r_e} \quad [m^2/g] \quad (1)$$

Slingo (1989):

$$0.02881 + \frac{1.284}{r_e} \quad [m^2/g] \quad (2)$$

Nielsen (2013):

$$1.606r_e^{-1.015} \quad [m^2/g] \quad (3)$$

Spectral band 3 (440–690 nm)

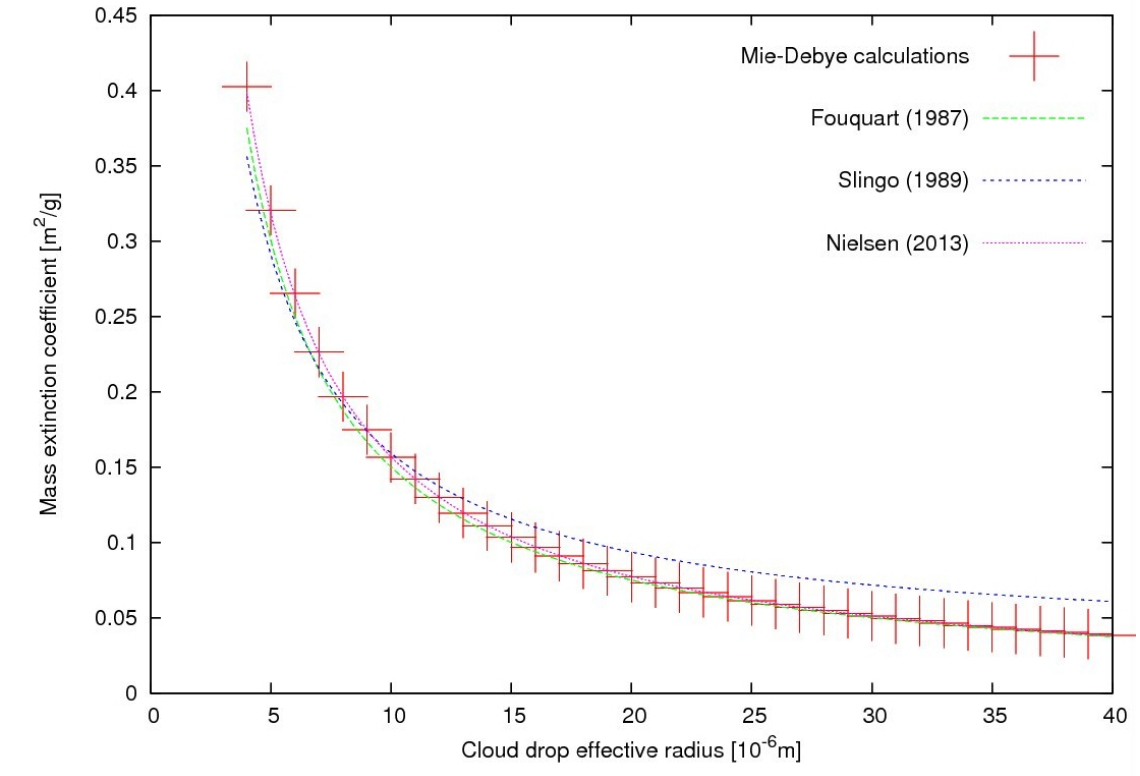


Figure 3: Comparison of mass extinction coefficient parametrizations for spectral band 3.

Fouquart (1987):

$$\frac{1.5}{r_e} \quad [m^2/g] \quad (4)$$

Slingo (1989):

$$0.02790 + \frac{1.313}{r_e} \quad [m^2/g] \quad (5)$$

Nielsen (2013):

$$1.638r_e^{-1.019} \quad [m^2/g] \quad (6)$$

Spectral band 4 (690–1190 nm)

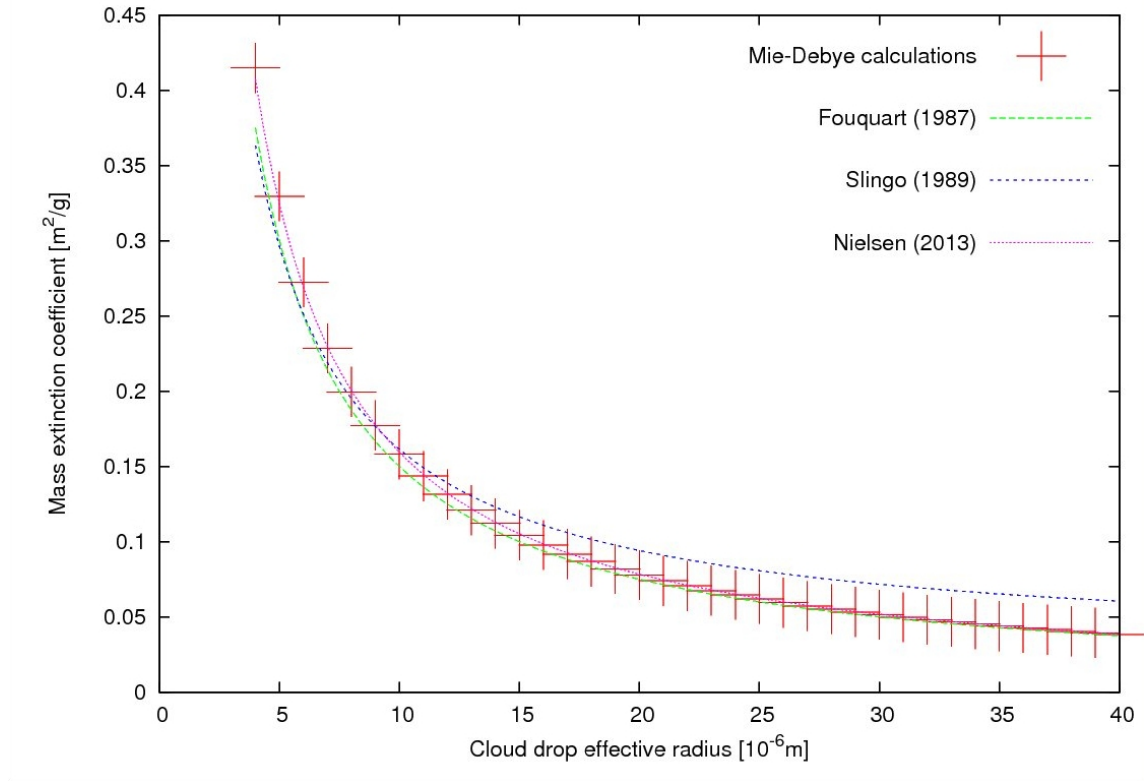


Figure 4: Comparison of mass extinction coefficient parametrizations for spectral band 4.

Fouquart (1987):

$$\frac{1.5}{r_e} \quad [m^2/g] \quad (7)$$

Slingo (1989):

$$0.02682 + \frac{1.346}{r_e} \quad [m^2/g] \quad (8)$$

Nielsen (2013):

$$1.685r_e^{-1.024} \quad [m^2/g] \quad (9)$$

Spectral band 5 (1190–2380 nm)

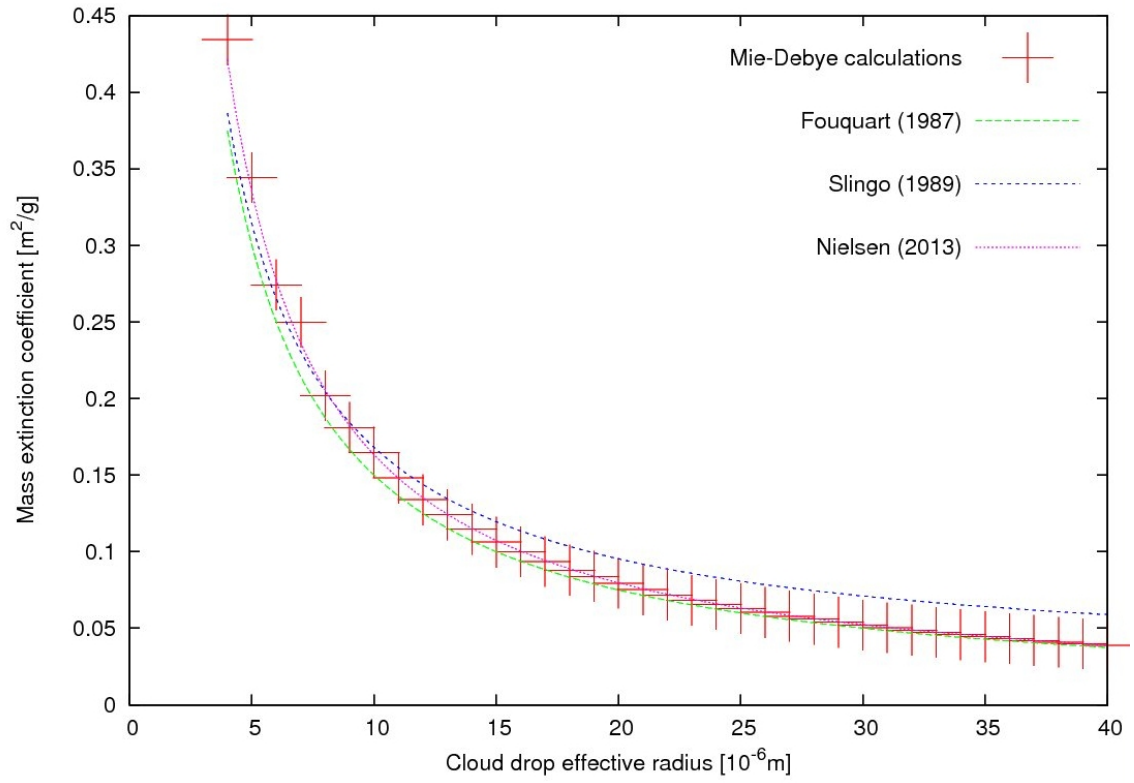


Figure 5: Comparison of mass extinction coefficient parametrizations for spectral band 5.

Fouquart (1987):

$$\frac{1.5}{r_e} \quad [m^2/g] \quad (10)$$

Slingo (1989):

$$0.02254 + \frac{1.456}{r_e} \quad [m^2/g] \quad (11)$$

Nielsen (2013):

$$1.77r_e^{-1.035} \quad [m^2/g] \quad (12)$$

Spectral band 6 (2380–4000 nm)

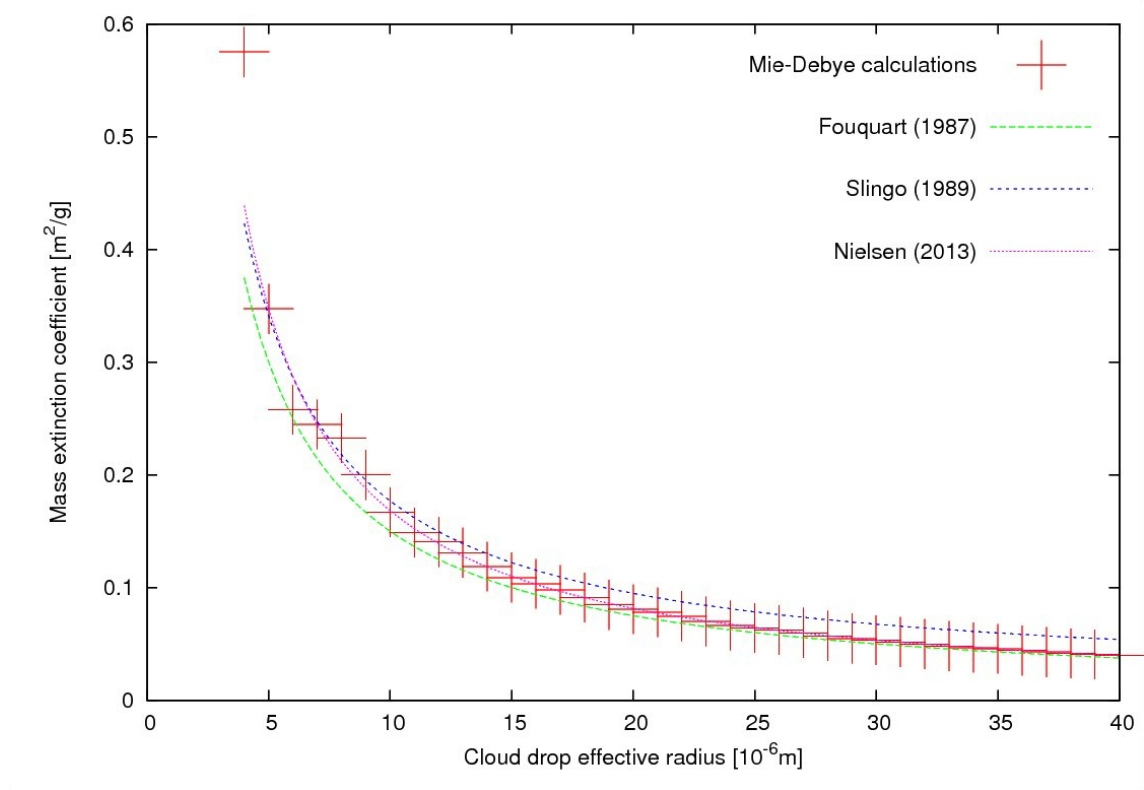


Figure 6: Comparison of mass extinction coefficient parametrizations for spectral band 6.

Fouquart (1987):

$$\frac{1.5}{r_e} \quad [m^2/g] \quad (13)$$

Slingo (1989):

$$0.01281 + \frac{1.641}{r_e} \quad [m^2/g] \quad (14)$$

Nielsen (2013):

$$1.87r_e^{-1.046} \quad [m^2/g] \quad (15)$$

Single scattering albedo

Spectral band 2 (250–440 nm)

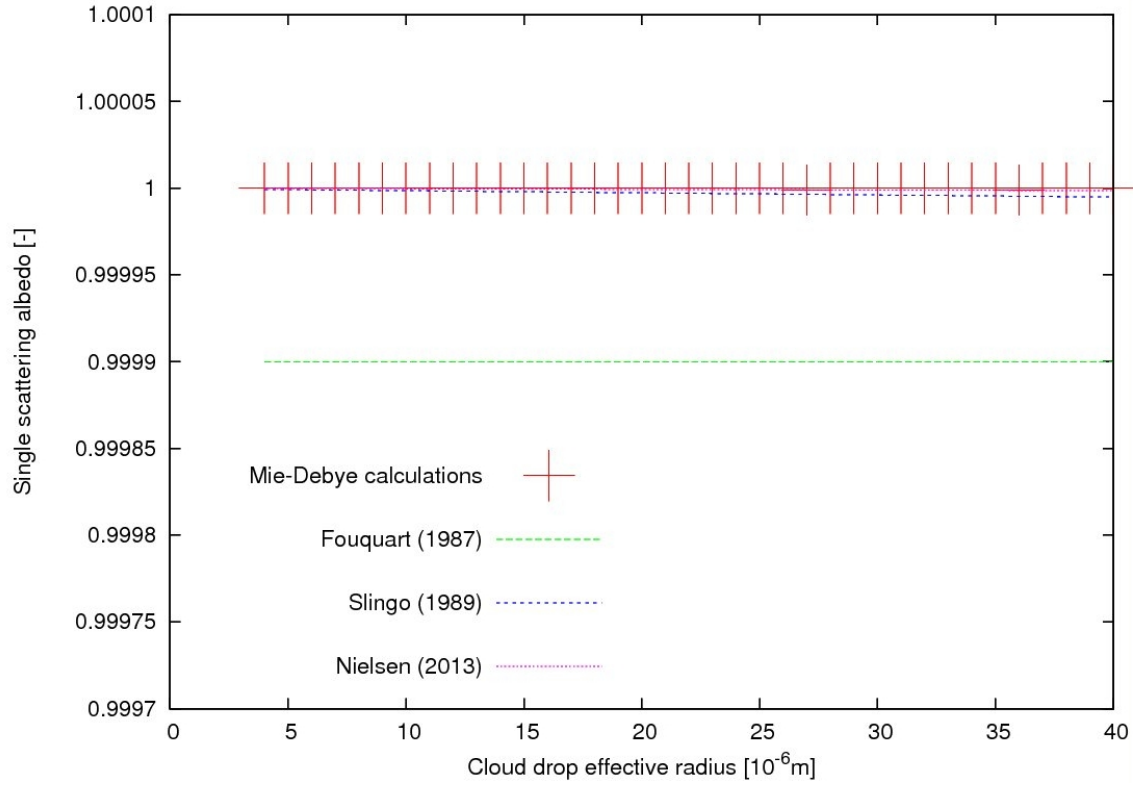


Figure 7: Comparison of single scattering albedo parametrizations for spectral band 2.

Fouquart (1987):

$$0.9999 - 5 \cdot 10^{-4} \exp\left(-0.5 \frac{1500}{r_e}\right) \quad [-] \quad (16)$$

Slingo (1989):

$$1 - 1.77 \cdot 10^{-7} - 1.23 \cdot 10^{-7} r_e \quad [-] \quad (17)$$

Nielsen (2013):

$$1 - 3.3 \cdot 10^{-8} r_e \quad [-] \quad (18)$$

Spectral band 3 (440–690 nm)

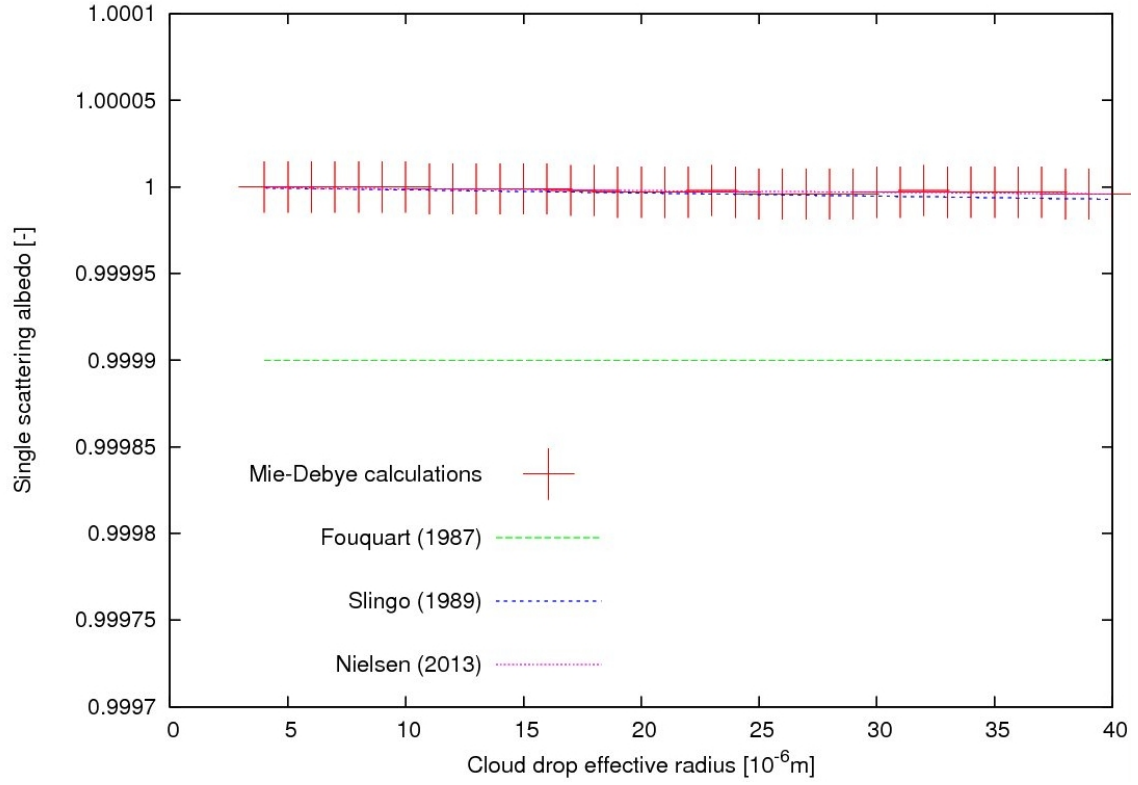


Figure 8: Comparison of single scattering albedo parametrizations for spectral band 3.

Fouquart (1987):

$$0.9999 - 5 \cdot 10^{-4} \exp\left(-0.5 \frac{1500}{r_e}\right) \quad [-] \quad (19)$$

Slingo (1989):

$$1 - 1.55 \cdot 10^{-7} - 1.8 \cdot 10^{-7} r_e \quad [-] \quad (20)$$

Nielsen (2013):

$$1 - 1 \cdot 10^{-7} r_e \quad [-] \quad (21)$$

Spectral band 4 (690–1190 nm)

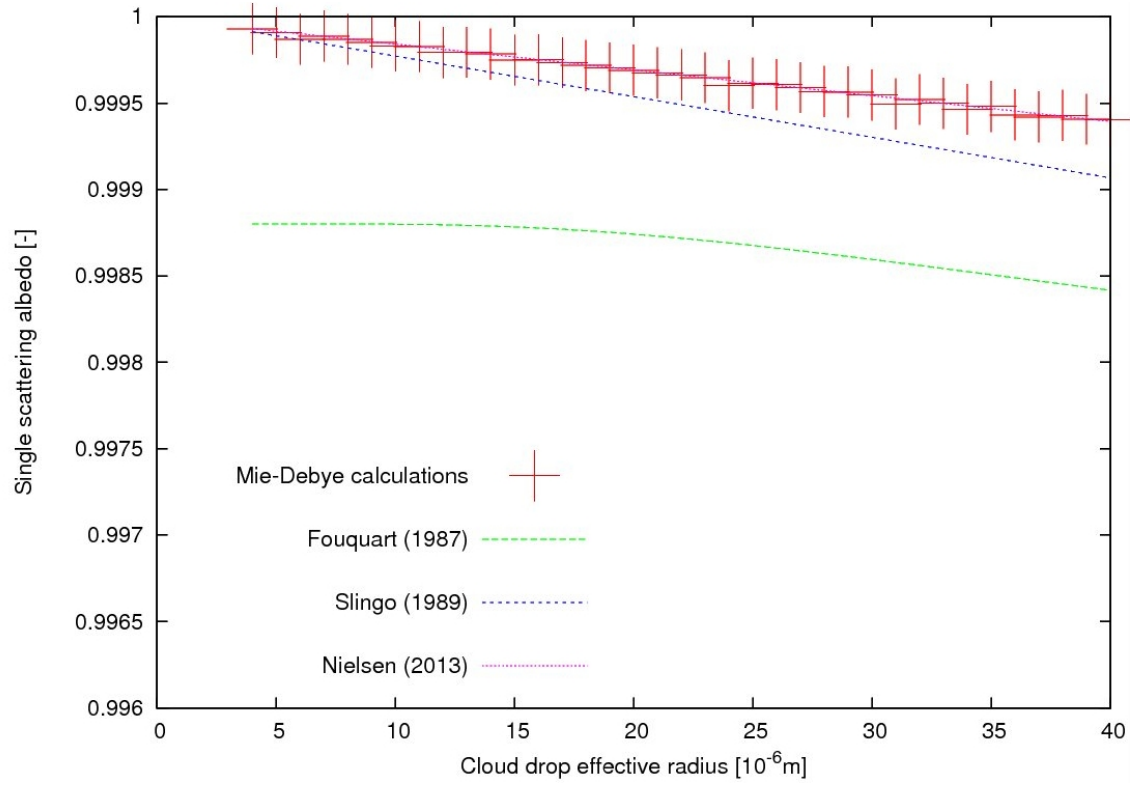


Figure 9: Comparison of single scattering albedo parametrizations for spectral band 4.

Fouquart (1987):

$$0.9988 - 2.5 \cdot 10^{-3} \exp\left(-0.05 \frac{1500}{r_e}\right) \quad [-] \quad (22)$$

Slingo (1989):

$$1 - 6.94 \cdot 10^{-6} - 2.35 \cdot 10^{-5} r_e \quad [-] \quad (23)$$

Nielsen (2013):

$$0.99999 - 1.49 \cdot 10^{-5} r_e \quad [-] \quad (24)$$

Spectral band 5 (1190–2380 nm)

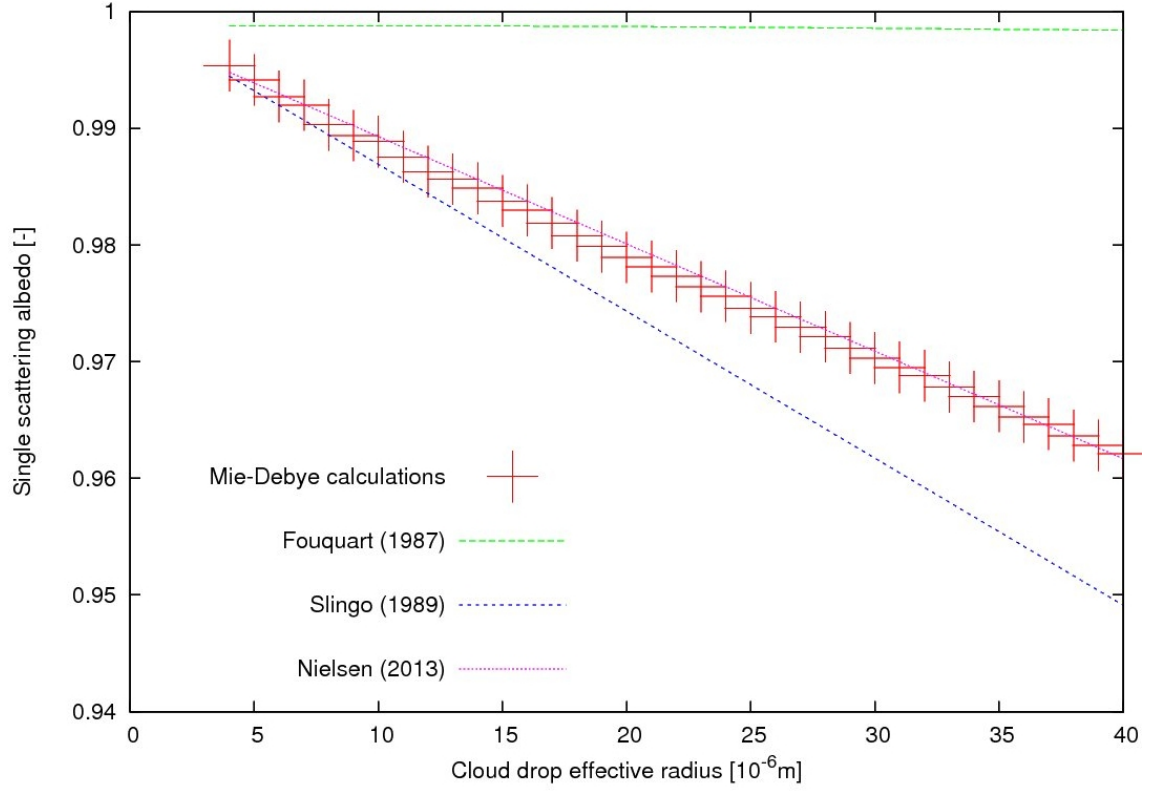


Figure 10: Comparison of single scattering albedo parametrizations for spectral band 5.

Fouquart (1987):

$$0.9988 - 2.5 \cdot 10^{-3} \exp\left(-0.05 \frac{1500}{r_e}\right) \quad [-] \quad (25)$$

Slingo (1989):

$$1 - 4.75 \cdot 10^{-4} - 1.26 \cdot 10^{-3} r_e \quad [-] \quad (26)$$

Nielsen (2013):

$$0.9985 - 9.2 \cdot 10^{-4} r_e \quad [-] \quad (27)$$

Spectral band 6 (2380–4000 nm)

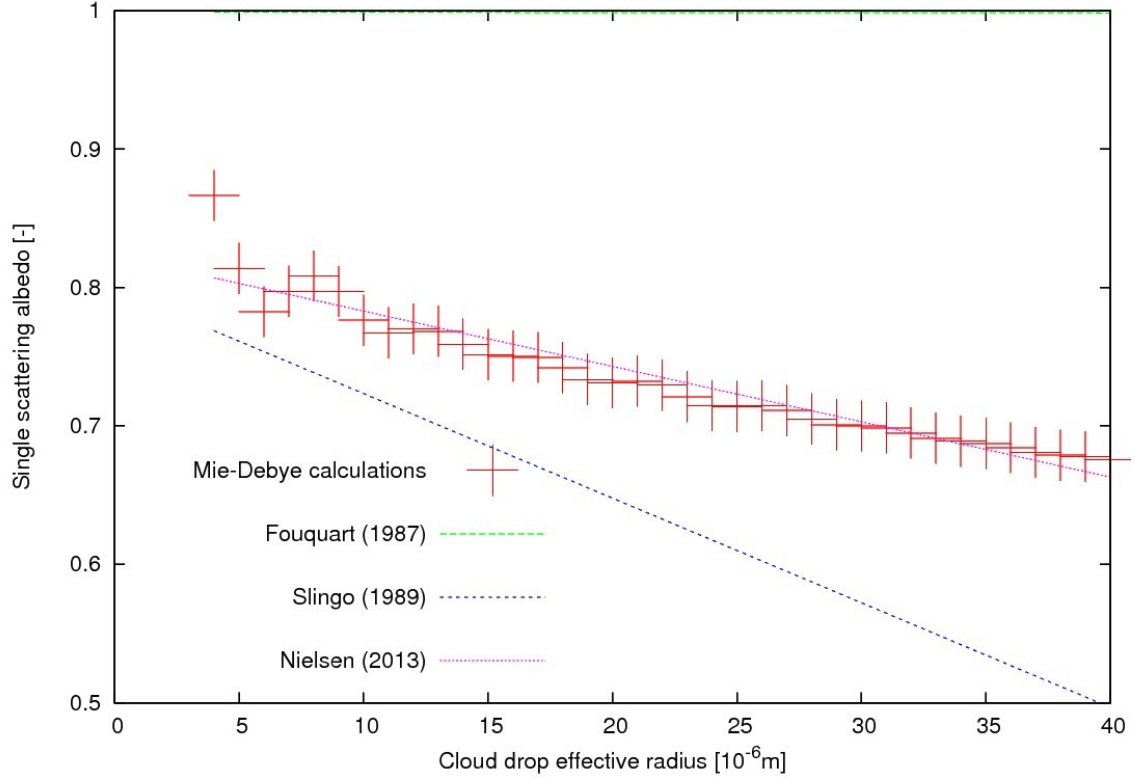


Figure 11: Comparison of single scattering albedo parametrizations for spectral band 6.

Fouquart (1987):

$$0.9988 - 2.5 \cdot 10^{-3} \exp\left(-0.05 \frac{1500}{r_e}\right) \quad [-] \quad (28)$$

Slingo (1989):

$$1 - 0.201 - 7.56 \cdot 10^{-3} r_e \quad [-] \quad (29)$$

Nielsen (2013):

$$0.823 - 4 \cdot 10^{-3} r_e \quad [-] \quad (30)$$

Asymmetry factor

Spectral band 2 (250–440 nm)

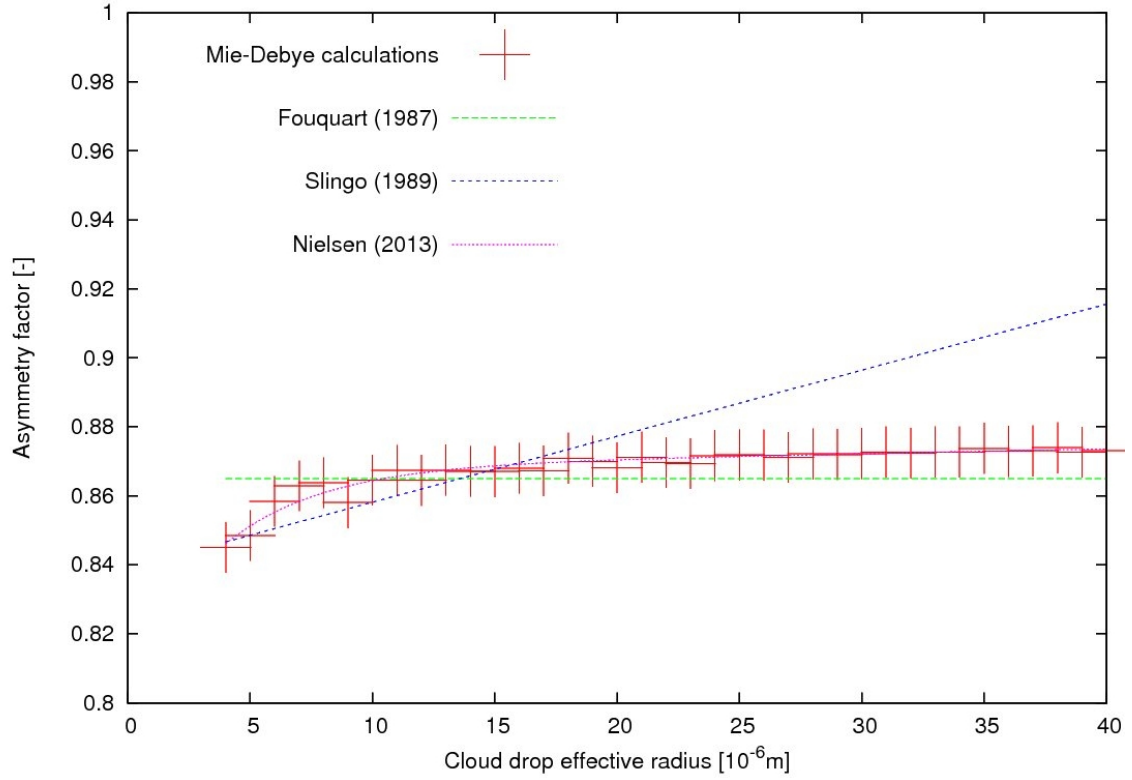


Figure 12: Comparison of asymmetry factor parametrizations for spectral band 2.

$$\text{Fouquart (1987):} \quad 0.865 \quad (31)$$

$$\text{Slingo (1989):} \quad 0.839 + 1.914 \cdot 10^{-3} r_e \quad (32)$$

$$\text{Nielsen (2013):} \quad 0.868 + 1.4 \cdot 10^{-4} r_e - 6.1 \cdot 10^{-3} \exp(-0.25 r_e) \quad (33)$$

Spectral band 3 (440–690 nm)

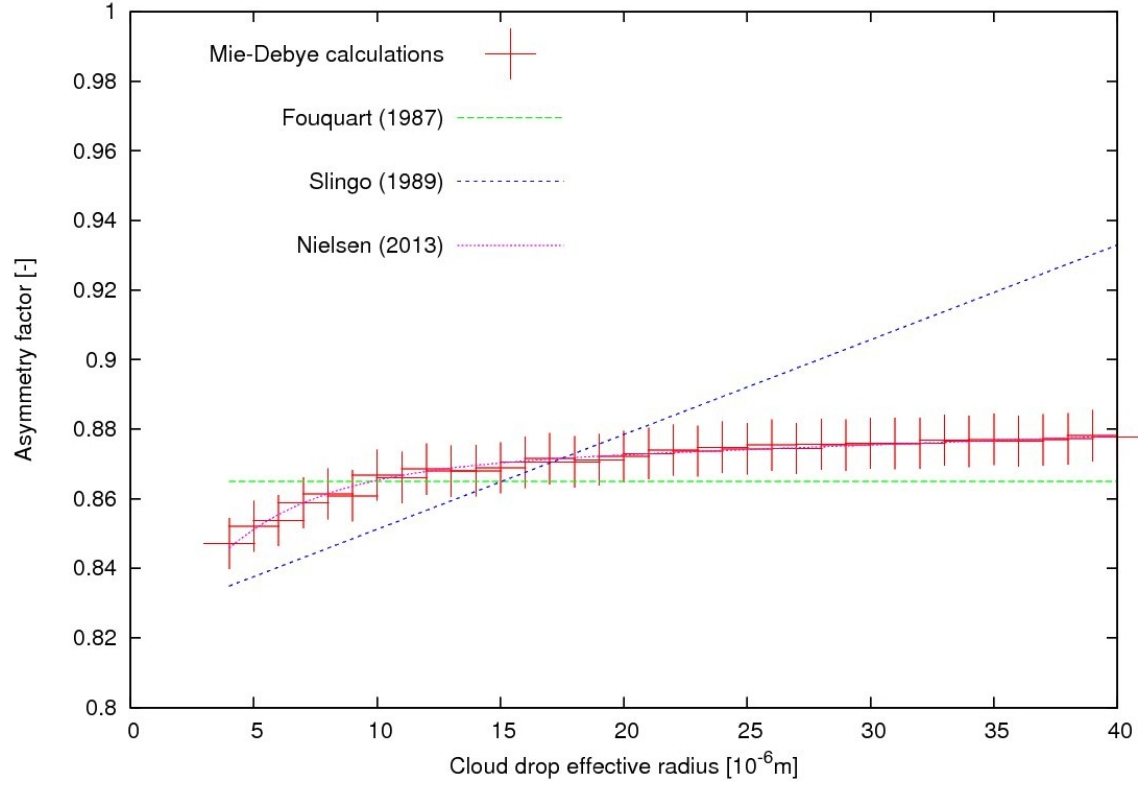


Figure 13: Comparison of asymmetry factor parametrizations for spectral band 3.

$$\text{Fouquart (1987):} \quad 0.865 \quad (34)$$

$$\text{Slingo (1989):} \quad 0.824 + 2.723 \cdot 10^{-3} r_e \quad (35)$$

$$\text{Nielsen (2013):} \quad 0.868 + 2.5 \cdot 10^{-4} r_e - 6.3 \cdot 10^{-3} \exp(-0.25 r_e) \quad (36)$$

Spectral band 4 (690–1190 nm)

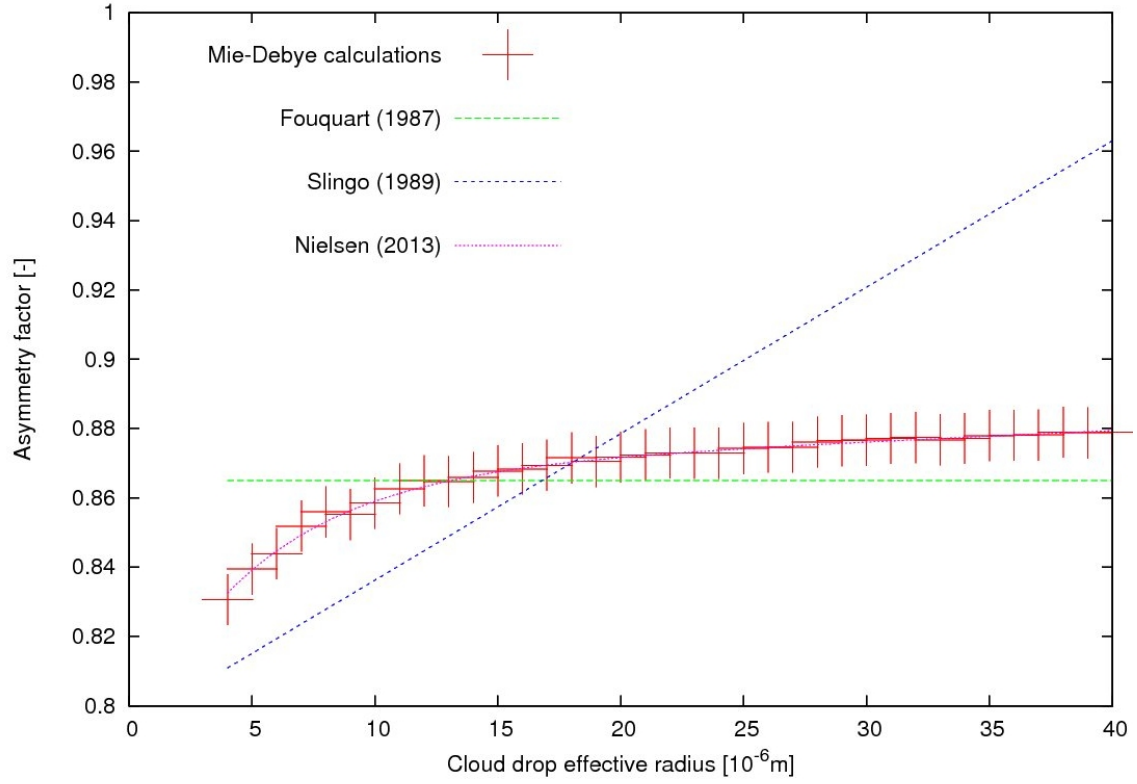


Figure 14: Comparison of asymmetry factor parametrizations for spectral band 4.

$$\text{Fouquart (1987):} \quad 0.865 \quad (37)$$

$$\text{Slingo (1989):} \quad 0.794 + 4.226 \cdot 10^{-3} r_e \quad (38)$$

$$\text{Nielsen (2013):} \quad 0.867 + 3.1 \cdot 10^{-4} r_e - 7.8 \cdot 10^{-3} \exp(-0.195 r_e) \quad (39)$$

Spectral band 5 (1190–2380 nm)

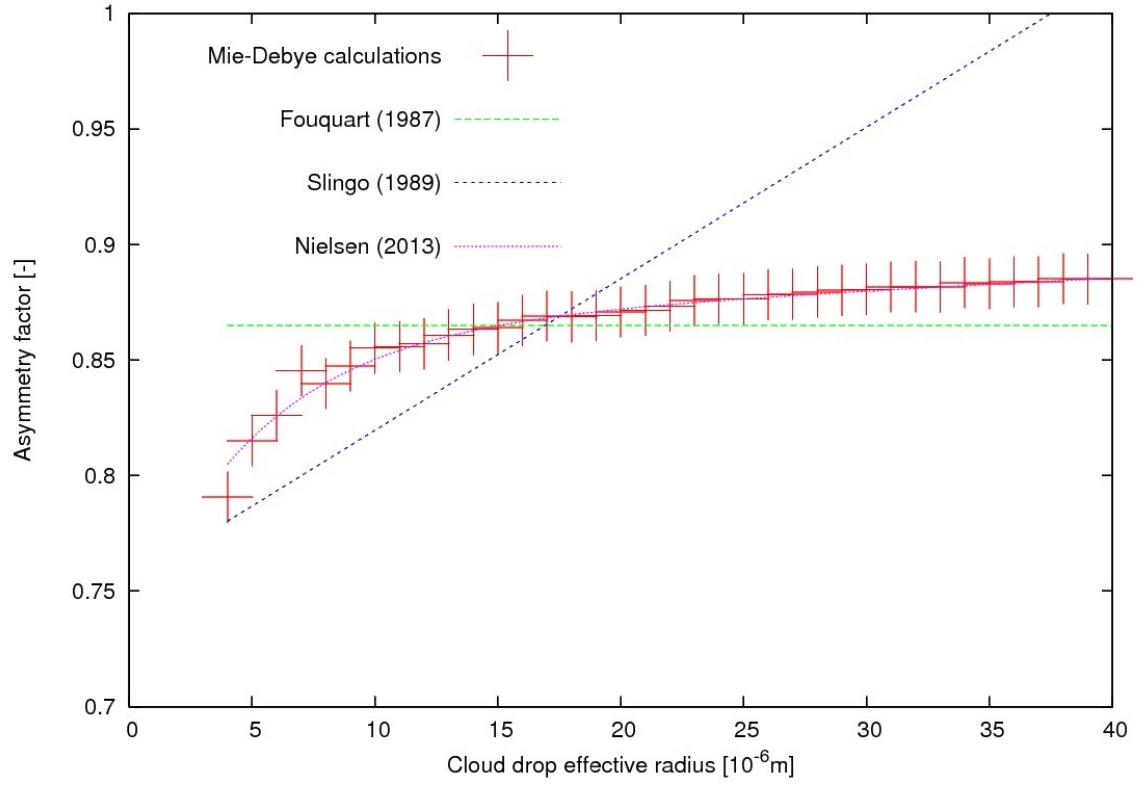


Figure 15: Comparison of asymmetry factor parametrizations for spectral band 5.

$$\text{Fouquart (1987):} \quad 0.865 \quad (40)$$

$$\text{Slingo (1989):} \quad 0.754 + 6.561 \cdot 10^{-3} r_e \quad (41)$$

$$\text{Nielsen (2013):} \quad 0.864 + 5.4 \cdot 10^{-4} r_e - 0.133 \exp(-0.194 r_e) \quad (42)$$

Spectral band 6 (2380–4000 nm)

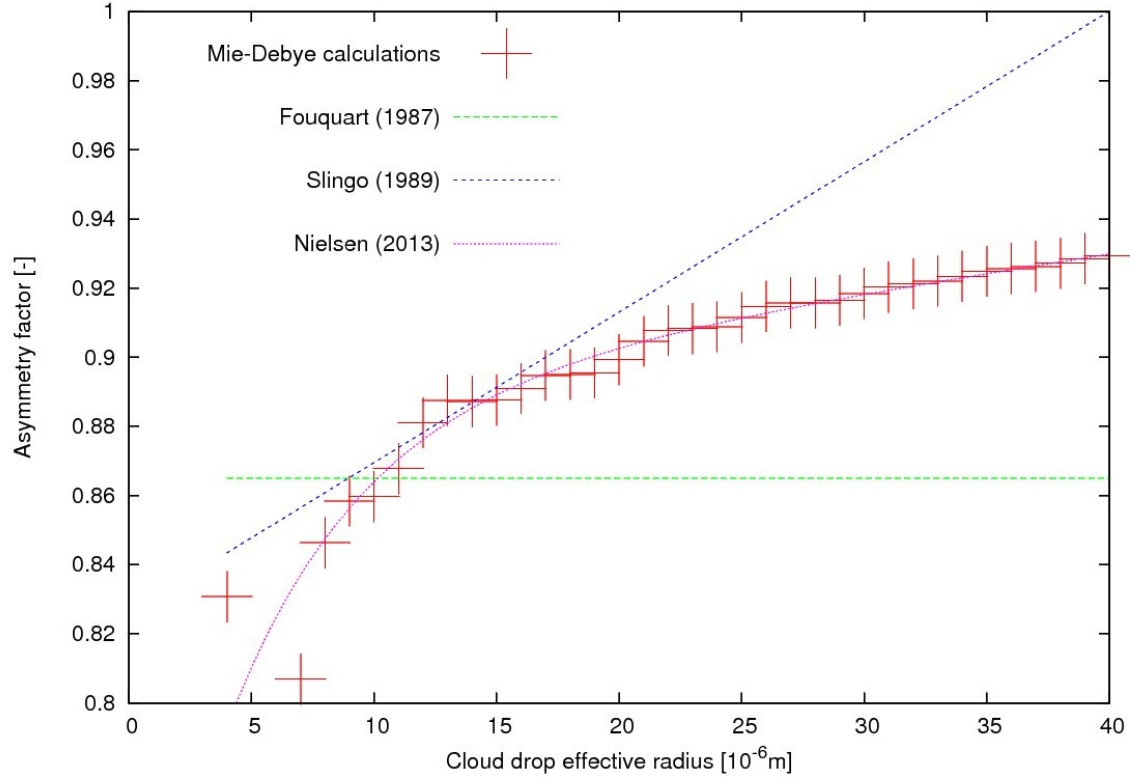


Figure 16: Comparison of asymmetry factor parametrizations for spectral band 6.

$$\text{Fouquart (1987):} \quad 0.865 \quad (43)$$

$$\text{Slingo (1989):} \quad 0.826 + 4.353 \cdot 10^{-3} r_e \quad (44)$$

$$\text{Nielsen (2013):} \quad 0.886 + 1.1 \cdot 10^{-3} r_e - 0.20 \exp(-0.18 r_e) \quad (45)$$

References

- [1] Anderson, G. P., Clough, S. A., Kneizys, F. X., Chetwynd, J. H., and Shettle, E. P.: AFGL Atmospheric Constituent Profiles (0–120 km), Tech. Rep. AFGL-TR-86-0110, Air Force Geophysics Lab Hanscom AFB, MA, USA, 1986.
- [2] Bass, A. M. and Paur, R. J.: The Ultraviolet Cross-Sections of Ozone: I. The Measurements, in: *Atmospheric Ozone*, edited by Zerefos, C. S. and Ghazi, A., pp. 606–610, Springer, Netherlands, 1985.
- [3] Fouquart, Y.: Radiative transfer in climate modeling, in: *NATO Advanced Study Institute on Physically-Based Modeling and Simulation of Climate and Climatic Changes*, edited by Schlesinger, M. E., pp. 223–283, 1987.
- [4] Kurucz, R. L.: Synthetic infrared spectra, in: *Infrared Solar Physics*, IAU Symp. 154, edited by Rabin, D. M. and Jefferies, J. T., Kluwer, Acad., Norwell, MA, USA, 1992.
- [5] Mayer, B. and Kylling, A.: Technical note: The libRadtran software package for radiative transfer calculations – description and examples of use, *Atmos. Chem. Phys. Discuss.*, 5, 1319–1381, 2005.
- [6] Mie, G.: Beiträge zur Optik trüber Medien, speziell kolloidaler Metallösungen, *Ann. Physik*, 25, 377–445, 1908.
- [7] Pierluissi, J. H. and Peng, G.-S.: New molecular transmission band models for LOWTRAN, *Opt. Eng.*, 24, 541–547, 1985.
- [8] Segelstein, D. J.: The complex refractive index of water, Master’s Thesis, University of Missouri-Kansas City, 1981.
- [9] Shettle, E. P.: Models of aerosols, clouds and precipitation for atmospheric propagation studies, in: *Atmospheric propagation in the UV, visible, IR and mm-region and related system aspects*, 454, AGARD Conference Proceedings, 1989.
- [10] Slingo, A.: A GCM parameterization for the shortwave radiative properties of water clouds, *J. Atmos. Sci.*, 46, 1419–1427, 1989.
- [11] Stamnes, K., Tsay, S.-C., Wiscombe, W., and Jayaweera, K.: Numerically stable algorithm for discrete-ordinate-method radiative transfer in multiple scattering and emitting layered media, *Appl. Opt.*, 27, 2502–2509, 1988.
- [12] Wiscombe, W. J.: Improved Mie scattering algorithms, *Appl. Opt.*, 19, 1505–1509, 1980.