Ice clouds exhibit a cooling impact on Earth’s climate by reflecting incoming solar radiation and a warming impact through absorption of infrared radiation and thermal emission towards Earth’s surface. Ice clouds consist of non-spherical ice crystals with various shapes and sizes. To determine the influence of ice clouds on Earth’s radiation budget and hence climate, knowledge of how they scatter and absorb radiation, henceforth called their single-scattering properties, is required. A geometric optics method (GOM), an asymptotic solution that is appropriate when a particle is much larger than the wavelength of incident light, has been widely used to calculate the single-scattering properties of ice crystals. However, the exact size range of applicability of GOM has not been well established and should be determined through comparison against numerically exact methods.

In this study, single-scattering properties of ice crystals were calculated using both GOM and a numerically exact method to determine the range of applicability of GOM.

**METHODS & RESULTS**

In order to determine the applicability of GOM, the single-scattering properties of randomly oriented hexagonal ice crystals were calculated using the Amsterdam DDA (ADDA) [1] and conventional GOM [2] at a non-absorbing wavelength λ=0.55 μm. Observations of naturally occurring ice crystals were used to determine the range of morphological features of the crystals used in the calculations [3]. A width (W) of up to 20 μm and a length (L) of up to 48 μm of hexagonal ice crystals with aspect ratios (AR=L/W) of 0.5, 1.0, 2.0, and 4.0 were thus used in the simulations.

The most notable differences in P11 are in the asymmetry parameter g and the extinction efficiency (Qext) became smaller as the crystal size increased. The errors in the conventional GOM compared to ADDA were ~1.5% (7.0%) for g (Qext) of hexagonal crystals with χ=90 for all ARs, whereas they were ~1.2% (1.3%) for hexagonal crystals with χ=100. The GOM simulations (i.e. P11, g, and Qext) for hexagonal crystals with compact shapes (i.e. AR=1.0) were closer to the ADDA simulations for smaller sizes compared to the simulations for oblate and prolate hexagonal crystals. This indicates that the lower size limit of applicability of GOM depends on the crystal shape (i.e. habit) and on its morphological features (e.g., aspect ratio).

Since methods that directly solve Maxwell’s equations (e.g., DDA) are computationally expensive for large particles, while GOM is a fast and flexible method to calculate scattering properties of non-spherical particles, inevitably GOM will continue to be used for scattering calculations. This work provides guidance on where errors in GOM are small enough that its use is appropriate. The wide variety of shapes, sizes, and habits of ice crystals mean the development of more databases on scattering properties will continue to be needed.