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On the size dependence of the scattering greenhouse effect of CO_2 ice particles

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Abstract

In this contribution we study the potential greenhouse effect due to scattering of CO_2 ice clouds for atmospheric conditions of terrestrial extrasolar planets. Therefore, we calculate the scattering and absorption properties of CO_2 ice particles using Mie theory for assumed particle size distributions with different effective radii and particle densities to determine the scattering and absorption characteristics of such clouds. Implications especially in view of a potential greenhouse warming of the planetary surface are discussed.

1. Introduction

Clouds play an important role for the energy budget in planetary atmospheres. For Earth–like planets water droplet and water ice clouds have significant climatic effects [5]. They can scatter incident stellar radiation back to space (albedo effect), effectively cooling the surface. On the other hand they may contribute to the greenhouse effect by absorbing and emitting infrared radiation. The net effect of a specific cloud type depends on its position in the atmosphere and its optical properties. Low-level water clouds, for example, have a dominating albedo effect, thus yielding lower surface temperatures. High-level water ice clouds on the other hand have a net greenhouse effect, resulting in an increase of the surface temperature. Thus, clouds have a strong influence on the radiation budget in planetary atmospheres, which directly affects the surface temperatures and, therefore, can influence the position and the extension of habitable zones around different types of central stars.

For terrestrial planets near the outer boundary of the habitable zone, condensation of CO_2 can occur at low atmospheric temperatures. These CO_2 ice clouds may play an important role for warming the surface and, therefore, for the question of habitability of such extrasolar planets (see [4], [1], or [6]). However, the optical properties of CO_2 ice crystals differ significantly from those of water droplets or water ice particles.

2. Computational details

Assuming spherical particles, the wavelength dependent optical properties of the CO_2 ice cloud particles (absorption and scattering coefficients, scattering phase function) are calculated using Mie theory. The required corresponding refractive indices have been provided by G.B. Hansen ([2] & [3]). The calculated optical properties for single-sized particles obtained from the Mie calculations are then averaged over a considered particle size distribution function. Following the description assumed in [1] modified gamma distributions are used to describe these CO_2 ice crystal size distributions. The effective radii and densities of the particle distributions have been varied to study the size dependence of the radiative effects.

3. Studies on the scattering greenhouse effect

Due to their different optical properties the calculated absorption and scattering characteristics of CO_2 ice clouds deviate substantially from those of typical Earth clouds. Except for a small number of strong absorption bands, they are almost transparent with respect to absorption. Instead, CO_2 ice particles are highly effective scatterers at long and short wavelengths. Therefore, the net climatic effect of a CO_2 cloud will depend on how much incident stellar radiation is back-scattered to space in comparison to the amount of outgoing thermal radiation scattered back towards the planetary surface. These wavelength dependent scattering properties are largely determined by the particle size distribution and optical depth of the CO_2 cloud.

According to Mie theory the scattering phase functions for large particles are highly asymmetric. To study the effectivity of the scattering greenhouse effect these complex functions have to be included in the radiative transfer treatment in detail to obtain accurate results for scattering dominated atmospheres. Therefore, the phase functions of the CO_2 ice particles are expanded into a series of Legendre polynomials to e.g. exactly resolve the strong forward scattering peak of these phase functions in the radiative transfer calculations. For comparison, we also examine the applicability of the Henyey–Greenstein phase functions to describe the scattering behaviour of the CO_2 ice clouds, which can considerably simplify the treatment of scattering within the radiative transfer scheme. The scattering properties of small solid carbon dioxide particles approach the limit of Rayleigh scattering at large wavelengths, as expected.

4 Summary

Clouds have an important influence on the energy budget of planetary atmospheres and, therefore, also on the resulting surface temperatures which determine the (potential) habitability of the planets. The greenhouse effect of CO_2 ice clouds which can be important at the outer boundary of the habitable zone is, however, not comparable with terrestrial clouds. It is not dominated by absorption as for water ice clouds. Instead, it is largely determined by the CO_2 ice scattering properties, which are strongly wavelength and size dependent. The net climatic effect of a CO_2 cloud will consequently depend on how much incident stellar radiation is scattered back to space in comparison to the amount of thermal radiation scattered towards the surface. First results indicate that a scattering greenhouse effect can be expected for large particles at medium optical depth.

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References

[1] Forget, F., Pierrehumbert, R.T., 1997, Science, Vol 278, p. 1273

[2] Hansen, G.B. 1997, J. Geophys. Res, Vol 102, pp. 569-587.

[3] Hansen, G.B., 2005, J. Geophys. Res., Vol. 110, E11003

[4] Kasting, J.F. 1991, Icarus, Vol 94, pp. 1-13

[5] Kitzmann, D., Patzer, A.B.C., von Paris, P., et al. 2010, A&A, 511, A66

[6] Selsis, F. et al. 2007, A&A, Vol 476, pp. 1373-1387