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Influence of clouds on the reflection spectra of Earth-like extrasolar planets

D. Kitzmann (1), M. Vasquez (2), A.B.C. Patzer (1), F. Schreier (2), H. Rauer (1,3) and T. Trautmann (2)
(1) Zentrum für Astronomie und Astrophysik, Technische Universität Berlin, Germany, (2) Institut für Methodik der Fernerkundung, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Germany, (3) Institut für Planetenforschung, Deutsches Zentrum für Luft- und Raumfahrt (DLR), Germany (kitzmann@astro.physik.tu-berlin.de)

Abstract

The effects of multi-layered clouds in the atmospheres of Earth-like planets orbiting different types of stars are studied in this contribution. The radiative effects of cloud particles are directly correlated with their wavelength-dependent optical properties. Therefore, the incident stellar spectra does play an important role for e.g. the scattering of radiation by clouds. In particular we study here the impact of multi-layered clouds on the planetary reflection spectra in the atmospheres of Earth-like extrasolar planets orbiting different types of main sequence dwarf stars.

1. Introduction

The climate of Earth-like planets results from the energy balance between absorbed starlight and radiative losses of heat from the surface and atmosphere to space. Clouds reflect sunlight back towards space, reducing the stellar energy available for heating the atmosphere (albedo effect), but also reduce radiative losses to space (greenhouse effect). Clouds do also have a large effect on reflection spectra of planetary atmospheres, by increasing the amount of backscattered stellar radiation. Because the climatic effects (e.g. changes in the surface temperature) and the impact on the reflection spectra are both correlated, an atmospheric model is needed, which takes the climatic effects caused by the presence of clouds directly into account and a radiative transfer treatment, which considers the scattering and absorption properties of cloud particles.

2. Model description

2.1. Cloud parametrisation

Two different cloud layers are considered in this work: low-level water droplet clouds and high-level ice clouds. The ice crystals are assumed to be hexagonal columns. For these cloud layers analytic size distributions are used, based on in-situ observations in the Earth atmosphere. The altitude of each cloud layer is iteratively adjusted to match measured pressure values. Optical properties of the cloud particles (absorption coefficient, scattering coefficient, asymmetry parameter) have been calculated with Mie theory. For the hexagonal ice columns an equivalent sphere approach is used. Further details about the cloud description and the calculation of the particle size and wavelength dependent optical properties are given in [5].

2.2. Atmospheric model

A one-dimensional steady state radiative-convective atmospheric climate model is used here to study the effects of clouds on the climate and emission spectra of Earth-like planets orbiting different types of central stars (see [2], [3], and [5] for details of the model). In particular, the influence of two different cloud layers (low-level water and high-level ice clouds) are included in the model. The model uses the measured value of the Earth surface albedo. The chemical composition of the atmospheres is chosen to represent the modern Earth atmosphere and was calculated using a photochemical model (see [1]). Four different types of central stars are considered: F2V, G2V, K2V, and M4.5V-type stars. The incident stellar fluxes are scaled by orbital distance variations, such that the energy integrated over each stellar spectrum equals the solar constant at top of the atmosphere of the corresponding Earth-like planet. The atmosphere model uses a broadband two-stream radiative transfer scheme, optimised for the energy transport in Earth-like atmospheres, which takes apart from gas opacities also the frequency dependent optical properties of clouds including multiple scattering into account (see [5]).

2.3. Line-by-line radiative transfer

A Line-by-Line (lbl) radiative transfer model is used to study the high resolution reflection spectra of Earth-like planets. The model computes radiative transfer in one-dimensional spherical atmospheres for up-, down- and limb-viewing geometry. Instrument effects, important for remote sensing, are modelled by convolution with spectral response and field-of-view functions. The lbl model also considers cloud effects by taking into account the single scattering source term [4]. The profiles obtained from the atmospheric model calculations of Earth–like extrasolar planets, molecular spectroscopic line parameters from the HITRAN database, and the clouds optical properties of the low-level water droplet and high-level ice droplet have been used as input parameters for the spectra calculations in the near infrared (IR). Various molecular concentrations (e.g. H_2O, CO_2, ...) in the planetary atmospheres were considered as well as two different viewing geometries: up- and down-looking.

3. Results

The albedo effect of the low-level clouds leads to a decrease in surface temperature, while the net greenhouse effect of the high-level clouds have a heating effect on the surface. Because of these two competing effects several combinations of the two cloud coverages can result in a mean Earth surface temperatures (288.4 K). The range of possible parameter combinations, however, depends strongly on the considered central star (see [5] for details).
Clouds have also a huge effect on the reflections spectra of terrestrial planets. They increase the amount of reflected light, which also leads to deeper absorption bands of atmospheric molecules. The reflection spectra, however, do also strongly depend on the spectral distribution of the incident stellar radiation. Depending on the type of the central star, different molecular absorption features can be found in the reflectance[1] spectra.

[1] spectrum of light reflected by the planet normalised to the stellar spectrum

4. Conclusions

Clouds have a strong impact on the reflection spectra of Earth–like planets. However, this contribution is quite complex, because (multiple) scattering of cloud particles affects in several ways the radiation path–length through the planetary atmosphere and, thereby, the molecular absorption characteristics in the visible and near IR spectral region. Our calculations of the reflectance spectra of Earth–like planets with cloudy atmospheres orbiting different types of central stars revealed the significant enhancement of atmospheric molecular signatures (e.g. O_2) due to the presence of clouds.

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