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Spectra of Earth-like extrasolar planetary atmospheres affected by cloud layers

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Abstract

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

1. Introduction

The energy balance between absorbed starlight and radiative losses of heat from the surface and atmosphere to space determines the climate of Earth-like planets. Clouds reflect the stellar light back towards space thereby reducing the stellar energy available for heating the atmosphere (albedo effect), but lower the radiative losses of thermal radiation to space (greenhouse effect) as well. Clouds have also a large impact on the IR emission spectra of planetary atmospheres by concealing the thermal emission from the surface and dampening the spectral features of molecules. In addition, they strongly affect the reflection spectra of planetary atmospheres by increasing the amount of backscattered stellar radiation, thereby enhancing the spectral molecular signatures. Since the climatic effects (e.g. changes of the surface temperature) and the impact on the spectra are both correlated, the scattering and absorption properties of cloud particles have to be taken adequately into account in the atmospheric model.

2. Computational details

A one-dimensional steady state radiative-convective atmospheric climate model is used here to study the effects of clouds on the climate and spectra of Earth-like planets orbiting different types of central stars (see [6], [7], [8], and [3] 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. In clear sky model calculations of Earth-like planets the surface albedo has to be tuned to mimic the climatic effects of clouds by prescribing the resulting surface temperature (see e.g. [7], [8]). In contrast, the surface temperatures are direct results of our atmospheric model calculations including the effects of clouds. Details about the developed cloud description and the calculation of the particle size– and wavelength–dependent optical properties of both cloud types are given in [3]. The chemical composition of the atmospheres is chosen to represent the modern Earth atmosphere and was calculated using a photochemical model (cf. [1]). Four different types of central stars are considered in this study: F2V, G2V, K2V, and M4.5V-type stars. The incident stellar fluxes are scaled by varying the orbital distances, such that the frequency integrated energy of each stellar spectrum at the top of the atmosphere of the corresponding Earth-like planet equals the solar constant. In the model broadband two-stream radiative transfer schemes, optimised for the energy transport in Earth-like atmospheres, is used, which takes apart from gas opacities also the frequency dependent optical properties of clouds including multiple scattering into account (see [3]).

3. Results

The net greenhouse effect of the high-level clouds has a heating effect on the planetary surface, while the albedo effect of the low-level clouds leads to a decrease in surface temperature. Due to these two competing effects several combinations of the two cloud coverages can result in a global mean Earth surface temperature of 288 K, i.e. habitable conditions. The range of possible parameter combinations, however, depends strongly on the considered central star (see [3]).

Due to enhanced cloud absorption and scattering of the outgoing radiative IR flux, the presence of clouds generally results in an overall decrease of IR emission at the top of the atmosphere compared to the respective clear-sky conditions. These results have been confirmed by measurements of the emission spectra of Earth published by e.g. [2]. Apart from the overall decrease of IR emission, the presence of clouds dampens also the individual spectral features of molecules (see also [4] for a more detailed discussion). For example, the spectral absorption band feature of the biomarker ozone (at $\sim 9.6\ \mu\mathrm{m}$) in the low resolution IR emission spectra is especially affected by the cloud layers as discussed by [4]. In general, the depths of the molecular IR features decrease with increasing cloud cover.

Clouds have also a large effect on the reflection spectra of Earth–like planets. They increase the amount of reflected light, which leads to deeper absorption bands of atmospheric molecules. The reflection spectra, however, do 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 reflection spectra even at low resolution (see [5] for details).

4. Summary

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 low resolution reflection spectra of Earth–like planets with cloudy atmospheres orbiting different types of central stars revealed the significant enhancement of atmospheric molecular signatures due to the presence of clouds. According to our studies of the thermal emission spectra the detectability of molecular absorption signatures in the IR spectral region is as well strongly influenced by the presence of clouds and may become impossible at low resolution for high cloud coverages.

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