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Climate modelling of an Earth-like extrasolar planet orbiting a K-type star

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Abstract

We investigate the atmospheric response of an Earth-like extrasolar planet orbiting a K-type star, analysing the interaction of the stellar radiation and its spectral distribution with atmospheric and surface properties.

Introduction

The more than 500 extrasolar planets and planet candidates found until today are orbiting various types of stars. For terrestrial planets the energy provided by the central star is usually the main energy source. The total amount of energy received at the top of the planetary atmosphere depends on the stellar luminosity and the planet to star distance. If a terrestrial planet receives an appropriate amount of energy from its central star, and holds an appropriate atmosphere, liquid water on the planetary surface is in principle possible, which is the prime requirement for life as we know it.
Nevertheless, surface temperatures not only depend on the total amount of the incident energy, but also on the spectral distribution of the stellar radiation and the concentrations of radiative gases and particles. They furthermore depend on the planetary location, the corresponding surface properties, such as albedo and heat capacity, as well as on the heat transport by atmospheric dynamics.
The influence of the total amount of energy, the spectral distribution of the stellar energy and the concentration of some radiative species on global mean atmospheric and surface temperatures has been investigated with one-dimensional (1D) radiative convective models (e.g. [2], [5], [6], [3]) and with a three-dimensional (3D) climate model for the special case of Gliese 581d [7], for example.

Modelling details

To improve the understanding of the interaction between stellar radiation characteristics, atmospheric dynamics and local planetary conditions, we make use of the 3D general circulation model EMAC (ECHAM/MESSy Atmospheric Chemistry model, [1]), which has been developed for Earth climate studies to calculate the climate of an Earth-like extrasolar planet around a K-type star.
EMAC-FUB offers the possibility of a high spectral resolution scheme ([4]) in the stellar radiative transfer, which is important for studying the influence of the stellar spectral distribution. Besides the radiative transfer in the stellar and in the thermal wavelength regime, we restrain the processes included in the calculations to the basics, i.e. convection, cloud processes, water transport and feedback on specific humidity. Thus, chemistry is not calculated interactively.

Planetary scenarios

As a first step we investigate the influence of a K-type stellar spectral energy distribution upon atmospheric dynamics, focusing on the stratosphere, since the radiation has its largest impact here. Therefore, we prescribe the sea surface temperatures (SSTs) and sea ice concentrations to present Earth's values, scale the K-type stellar spectrum to a total energy input of the present total solar irradiance (TSI, $1366 \mathrm{Wm}^{-2}$), and retain other surface properties and concentrations of radiative gases and aerosols to Earth conditions.
In a second step, we couple a mixed layer ocean to the atmosphere, to investigate the influence of the surface properties upon surface temperatures, e.g. the change in surface albedo due to melting surface ice. The stellar irradiance and concentrations of radiative species are again kept at Earth's values.

Since the total stellar irradiance depends on the planet to star distance, we consider in a third scenario consistent values for the stellar radiation and the length of year. The response of the surface temperature and other atmospheric properties is analysed.

Concluding remarks

The 3D model results are compared to those of a 1D radiative convective model to evaluate the importance of atmospheric dynamics and surface properties for the global mean climate state of Earth-like extrasolar planets yielding information about the potentail usability of 1D modelling results in view of the search for especially habitable extrasolar planets.

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