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Transmission spectroscopy with the ACE-FTS infrared spectral atlas of Earth: A model validation and feasibility study

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Abstract

For an assessment of the detectability of molecular concentrations from transit spectra of Earth-like exoplanets, occultation spectra observed by the ACE-FTS instrument onboard the Canadian Earth observation satellite "SciSat" mission have been modeled with a line-by-line infrared radiative transfer code. For a quantitative estimate of visibility and detectability the maximum change of the residual spectrum, the relative change of the residual norm, the additional transit depth, and signal-to-noise ratios for a JWST setup are considered.

1. Introduction

With more than 3700 exoplanets known today, including some dozen Earth-likes and super-Earths, the characterization of their atmospheres has come into the focus of current research. Despite the limited quality of currently available exoplanet spectral observations, the methodology developed for Earth and Solar System Planet remote sensing can be readily applied to the analysis of terrestrial extrasolar planet data. For the retrieval of atmospheric composition, transmission spectroscopy analyzing the attenuation of stellar light along its optical path through the planet's atmosphere is particularly suited. In this contribution we use a high resolution line-by-line infrared radiative transfer code to model co-added occultation measurements in order to assess the feasibility to quantify the concentration of atmospheric constituents. (Preliminary results had been reported at EPSC 2017.)

2. Radiative Transfer Modeling

The Generic Atmospheric Radiative Transfer Line-by-Line Infrared Code — GARLIC [1] has been developed with emphasis on efficient and reliable numerical algorithms and a modular approach appropriate for simulation and/or retrieval in a variety of applications (observation geometry, instrumental spectral response and field–of–view). GARLIC has been extensively verified in several intercomparison studies, e.g. [2]. The core of GARLIC's subroutines constitutes the basis of forward models used to implement inversion codes to retrieve atmospheric state parameters from limb and nadir sounding instruments. Furthermore, GARLIC has been used for a variety of exoplanetary atmosphere studies, e.g. [3, 4, 5].

3. Earth Observation Data

Limb sounding in the microwave, infrared, and ultraviolet-visible spectral range is a well-established approach for the characterization of Earth's atmosphere. We take a limb sequence of representative cloud-free infrared (2.2 – 13.3 μm) transmission spectra [6] recorded by the space-borne ACE-FTS Earth observation mission [7] and combine these spectra to the effective height of the atmosphere. These data are compared to spectra modeled with GARLIC to study the impact of individual molecules, spectral resolution, the choice of auxiliary data, and numerical approximations. Moreover, this study can also be considered as a validation of GARLIC.

4. Results

The largest impact on the transit spectra is due to water, carbon dioxide, ozone, methane, nitrous oxide, nitrogen, nitric acid, oxygen, and some chlorofluorocarbons (CFC11 and CFC12). The effect of further molecules considered in the modeling is either marginal or absent. The best matching model with 17 molecules absorbing has a mean residuum of 0.4 km and a maximum difference of 2 km to the measured effective height. An estimate of the signal-to-noise ratios based on the model by Rauer et al. [3] for an Earth transmission spectrum seen by JWST from 10 pc distance indicates moderately good SNRs for carbon dioxide, water and ozone.

5. Summary and Conclusions

IR transit spectra of Earth's atmosphere observed by the ACE-FTS operational satellite instrument have been modelled by our high resolution code GARLIC [8]. The comparison of modelled and observed spectra clearly indicates the impact of various molecular species as well as continuum-like contributions. Varying the spectral range, spectral resolution, and noise level allows to quantify the detection level for various molecules.

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