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

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Introduction

- Remote sensing valuable for characterizing Earth's atmosphere, indispensible for (exo-)planetary atmospheres
- Forward models / radiative transfer crucial for successful retrievals
- Verification and validation of forward models mandatory
- ≈ 3900 exoplanets, incl. some dozen super-Earths and a few potentially habitable Earth-size planets
- Earth seen from afar as an exoplanet is an ideal testcase

$\Longrightarrow$ Use disk-averaged Earth observation data for validation

InfraRed Radiative Transfer Basics

Beer's law: transmission $\mathcal{T}$ and optical depth τ

$$\mathcal{T}(\nu, s) = e^{-\tau} = \exp\left(-\int_0^s ds' \sum_m k_m(\nu, p(s'), T(s'))\; n_m(s')\right)$$

Absorption cross section k: line-by-line

$$k(\nu, p, T) = \sum_l S_l(T)\; g(\nu;\, \hat{\nu}_l, \gamma_l(p, T))$$

Instrument: convolution of monochromatic radiance and transmission with Spectral Response Function and Field-of-View

Forward Code — GARLIC

Generic Atmospheric Radiation Line-by-line Infrared Code [1]

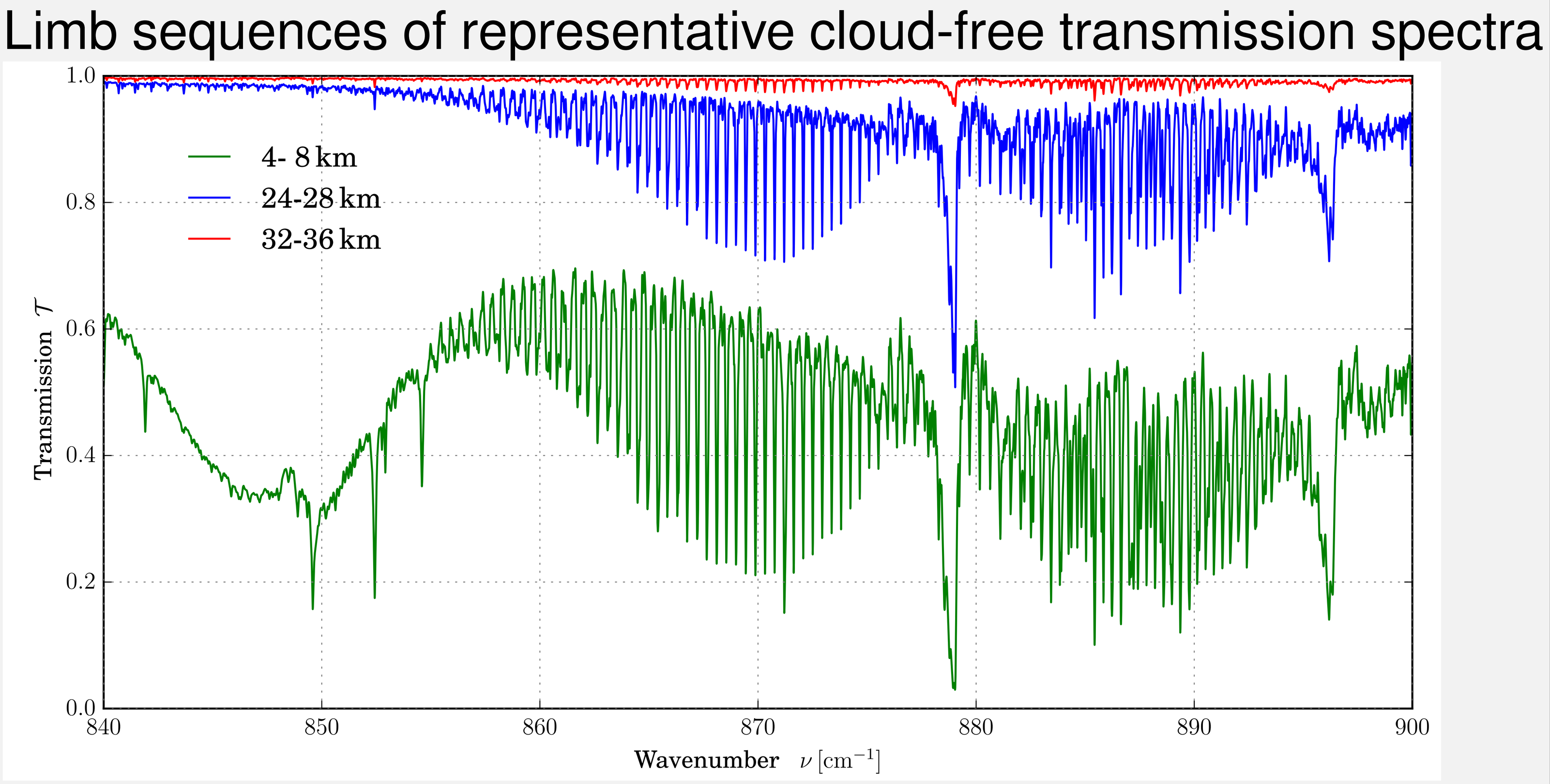
- Voigt etc. lineshapes, continua (H_2O, ...), CIA
- Limb, uplooking and downlooking geometries (refraction optional)
- Spectral response (FTS, Grating, Heterodyne, ...) and Field-of-View
- Jacobians: Automatic differentiation
- Several intercomparisons for verification
- GARLIC routines used as core of several inversion codes

ACE-FTS

Atmospheric Chemistry Experiment Fourier Transform Spectrometer

- On board the Canadian satellite SCISAT since 2003 [2]
- Infrared (2.2 – 13.3 μm) limb occultation (6 – 128 km)
- Hughes et al.: IR spectral atlases of the Earth's atmosphere [3]

$\longrightarrow$ Limb sequences of representative cloud-free transmission spectra



Effective height

A quantitative measure of the apparent size of a distant planet:

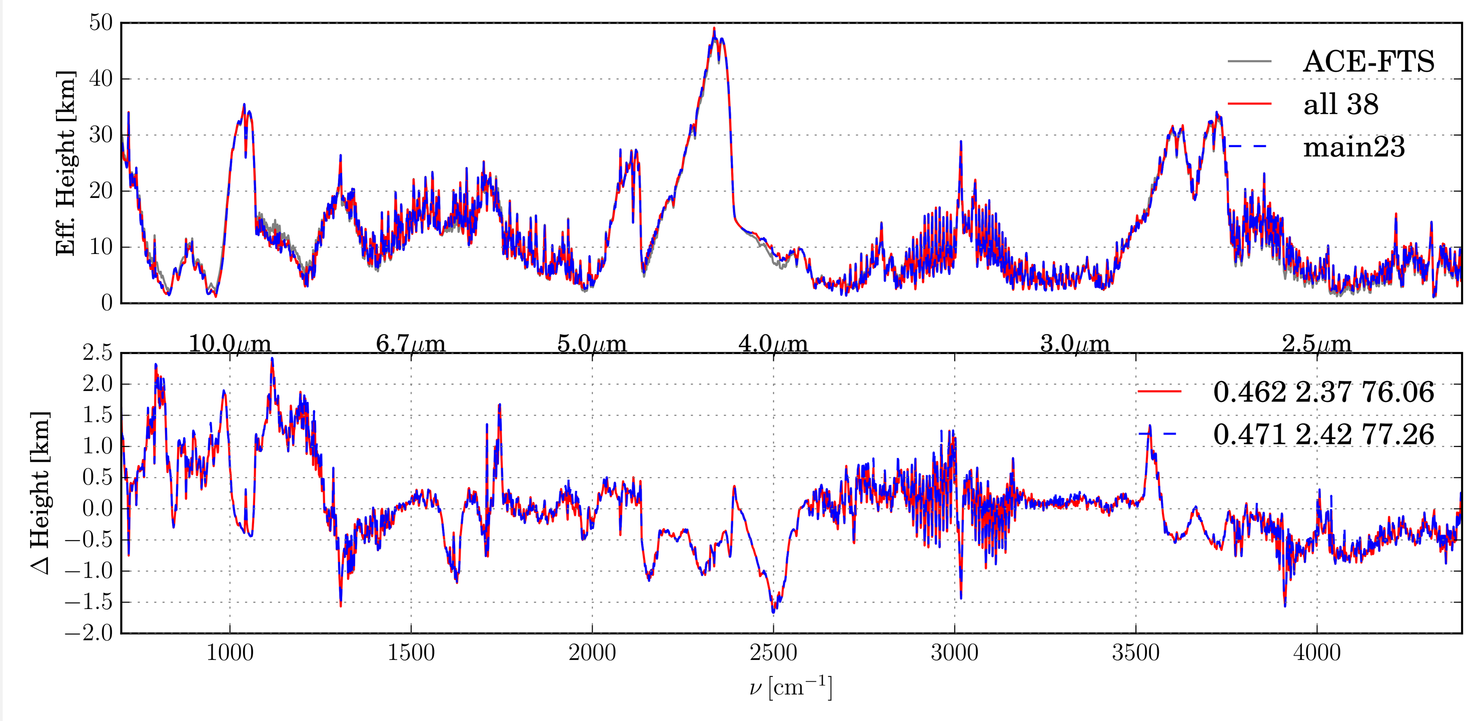
— planet is larger in optically thick regime (e.g. ozone 9.6 μm)

— planet is smaller in "atmospheric windows" (e.g. 8 – 12 μm)

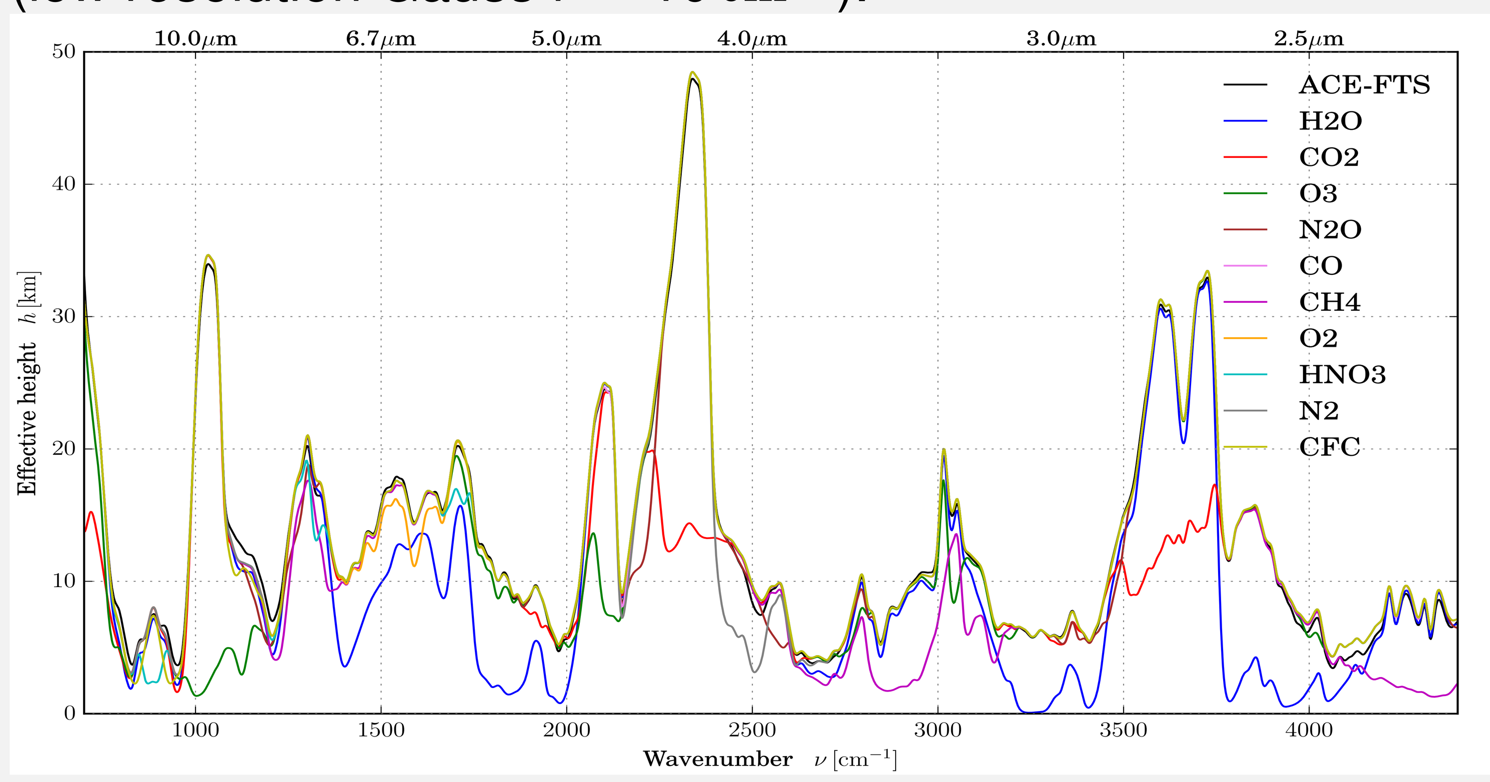
$$h(\nu) = \int_0^\infty \left(1 - \mathcal{T}(\nu, h_t)\right) dh_t \qquad \text{with limb tangent height } h_t$$

Impact of molecules

- Comparison of transit spectra modeled with the 23 "main" gases or with 38 gases. Arctic winter, moderate resolution $\Gamma = 1\,\text{cm}^{-1}$

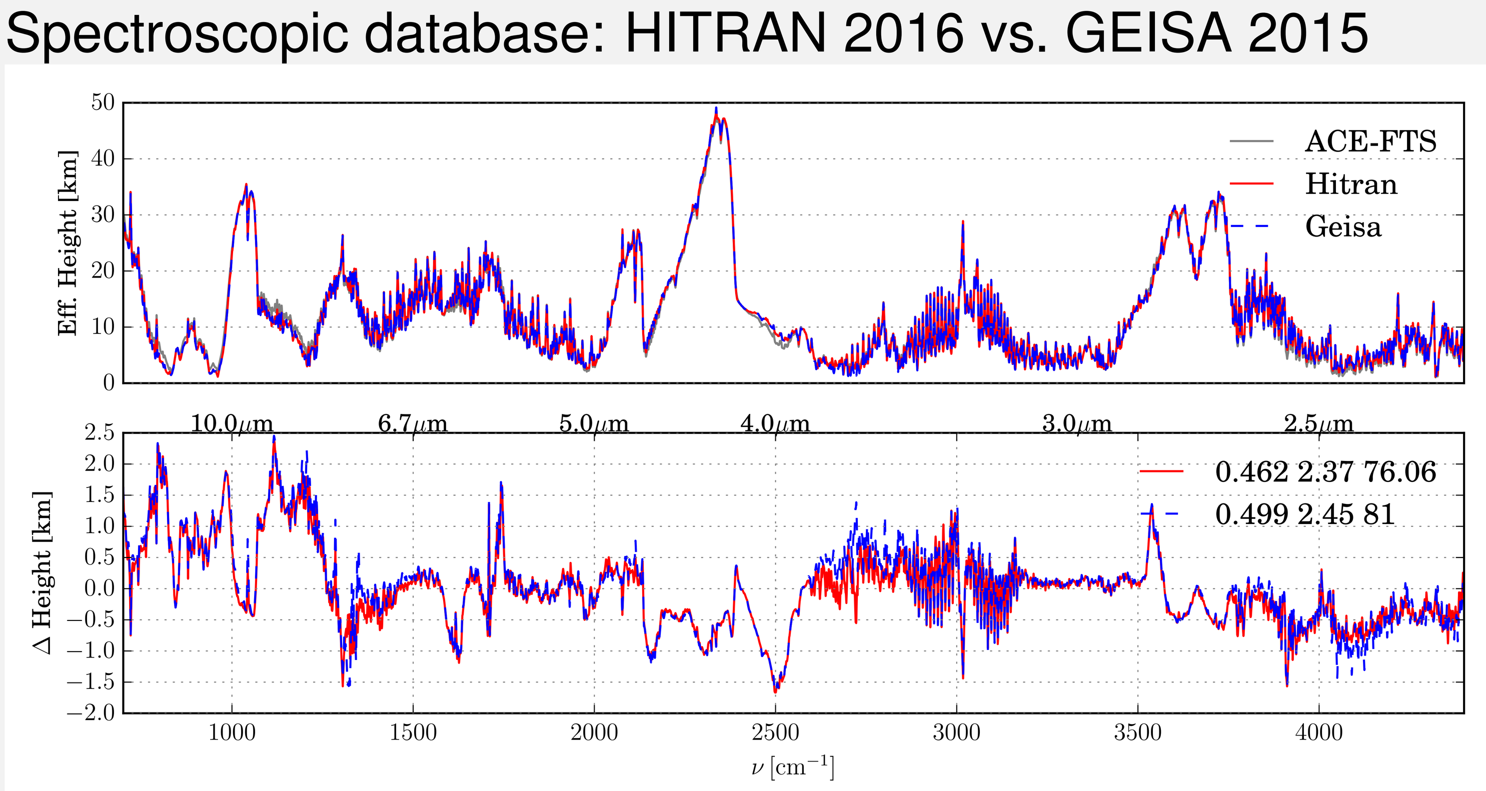


- Impact of a missing species on the global (tropical and arctic & midlatitude summer & winter combined) effective height spectrum (low resolution Gauss $\Gamma = 10\,\text{cm}^{-1}$).

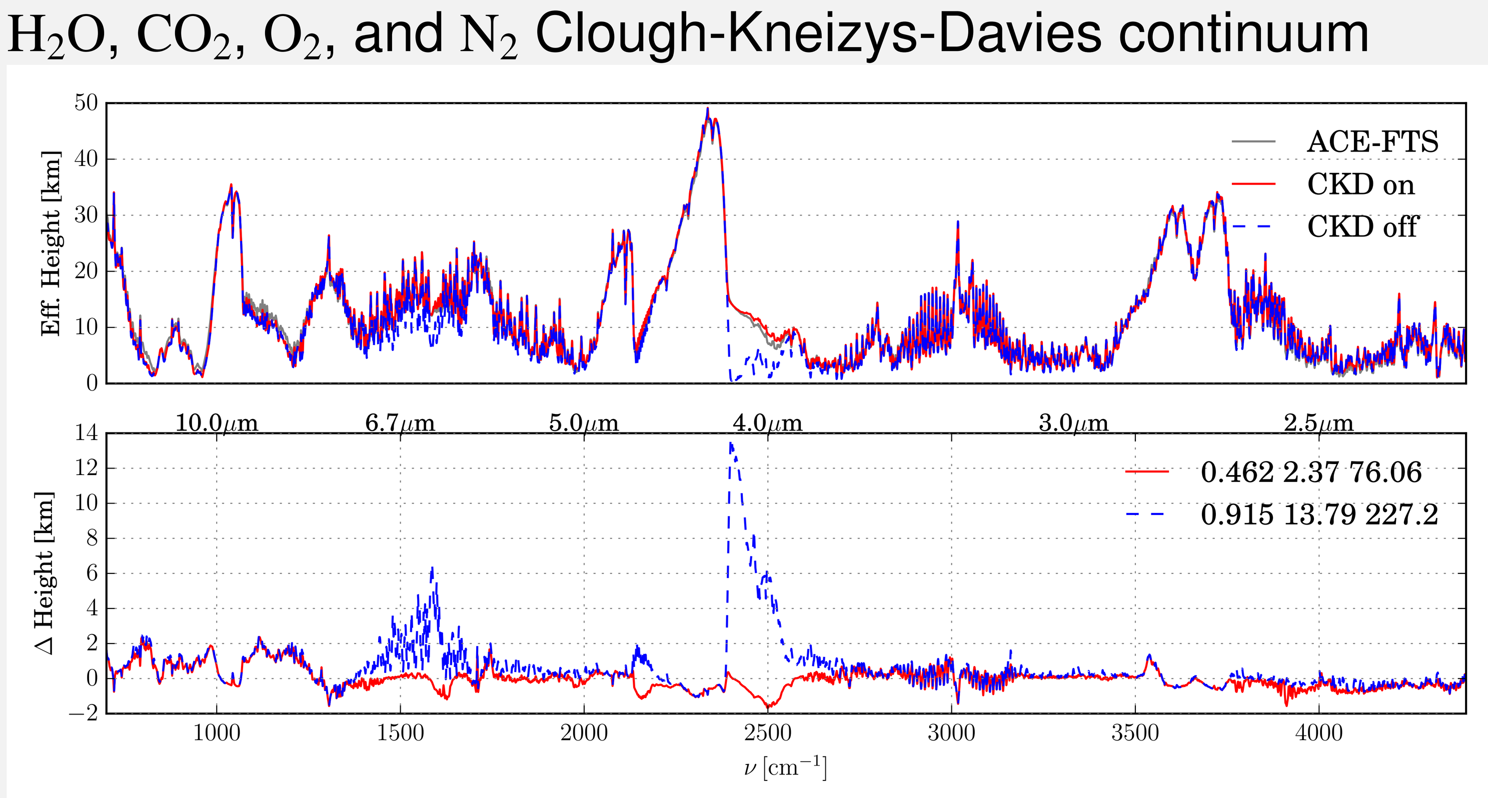


Impact of auxiliary data

- Spectroscopic database: HITRAN 2016 vs. GEISA 2015



- H_2O, CO_2, O_2, and N_2 Clough-Kneizys-Davies continuum



Further reading

[1] F. Schreier et al. *GARLIC – A General Purpose Atmospheric Radiative Transfer Line-by-Line Infrared-Microwave Code: Implementation and Evaluation.* JQSRT, 137, 29-50, 2014

[2] P. Bernath. *The Atmospheric Chemistry Experiment (ACE).* JQSRT, 186, 3–16, 2017

[3] R. Hughes, P. Bernath and C. Boone. *ACE infrared spectral atlases of the Earth's atmosphere* JQSRT, 148, 18–21, 2014

[4] F. Schreier, S. Städt, P. Hedelt, and M. Godolt. *Transmission spectroscopy with the ACE-FTS infrared spectral atlas of Earth: A model validation and feasibility study.* Molec. Astrophysics, 11, 1–22, 2018