Developing a 3D generic photochemical-climate model. Transit spectroscopy simulation and observability.

A. Y. Jaziri, F. Selsis, J. Leconte, B. Charnay

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Atmo 2021

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Outline

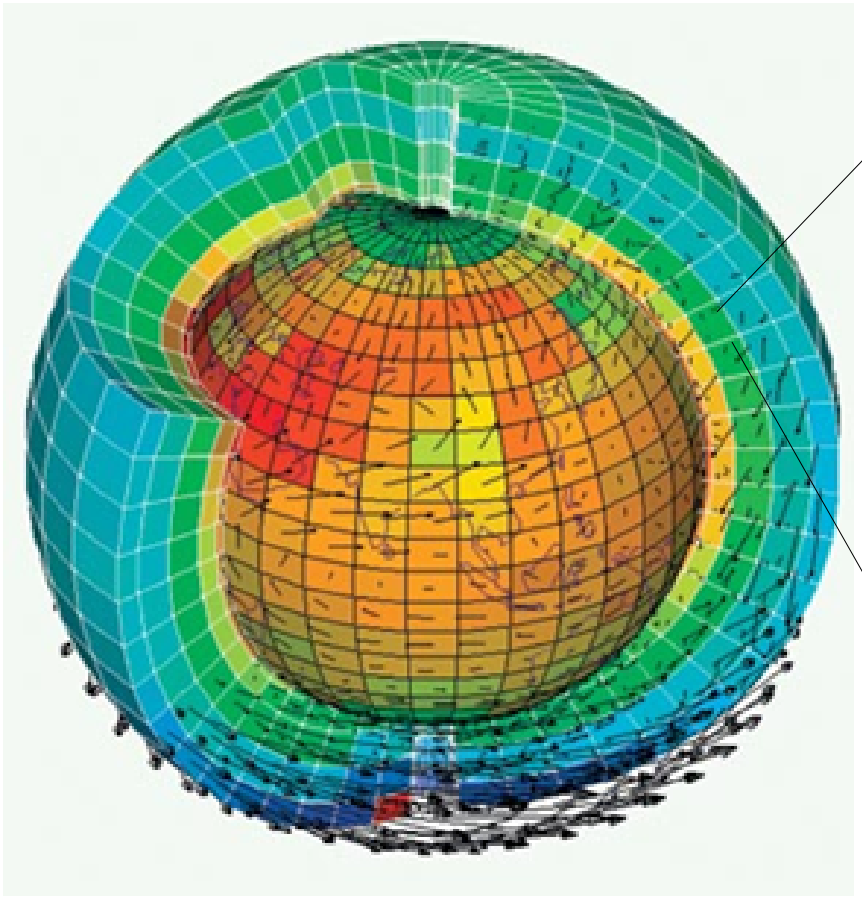
Part I

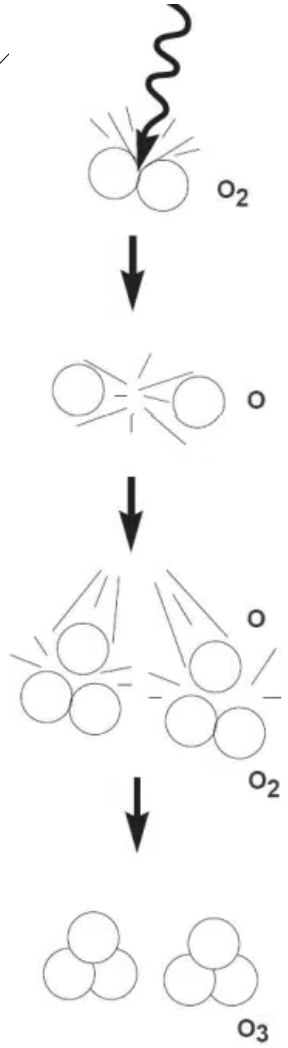
Part II

Development of a generic implementation of the (photo)chemistry in a Global Climate Model

Observability of ozone on temperate planets around red-dwarf and
2 layers retrieval model needs

The generic 3D Global Climate Model





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Developing the photochemical model

Chemistry:

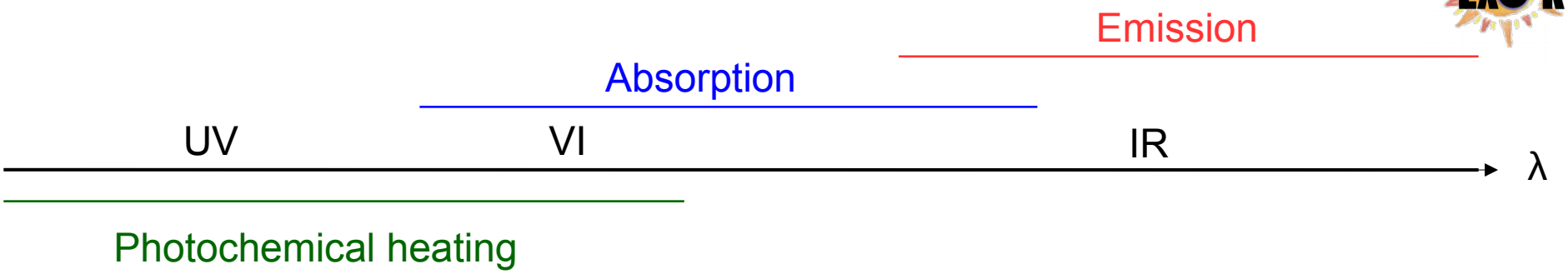
- Input network from different databases (generic read)

  → Earth chemisty
  → Early Earth chemisty
  → Warm Neptune (Roméo Veillet, Benjamin Charnay, Olivia Venot)

- Photochemistry online + photochemical heating

Leconte (2021)

Radiative transfer:



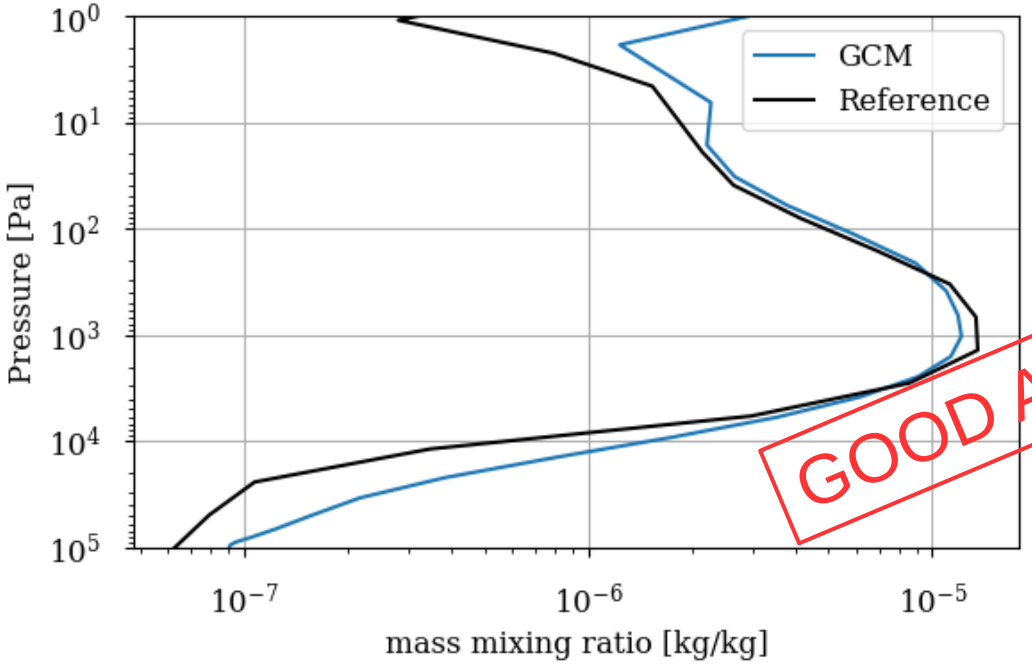
Online calculation
with cross sections

Online mixing of correlated-k for trace gas

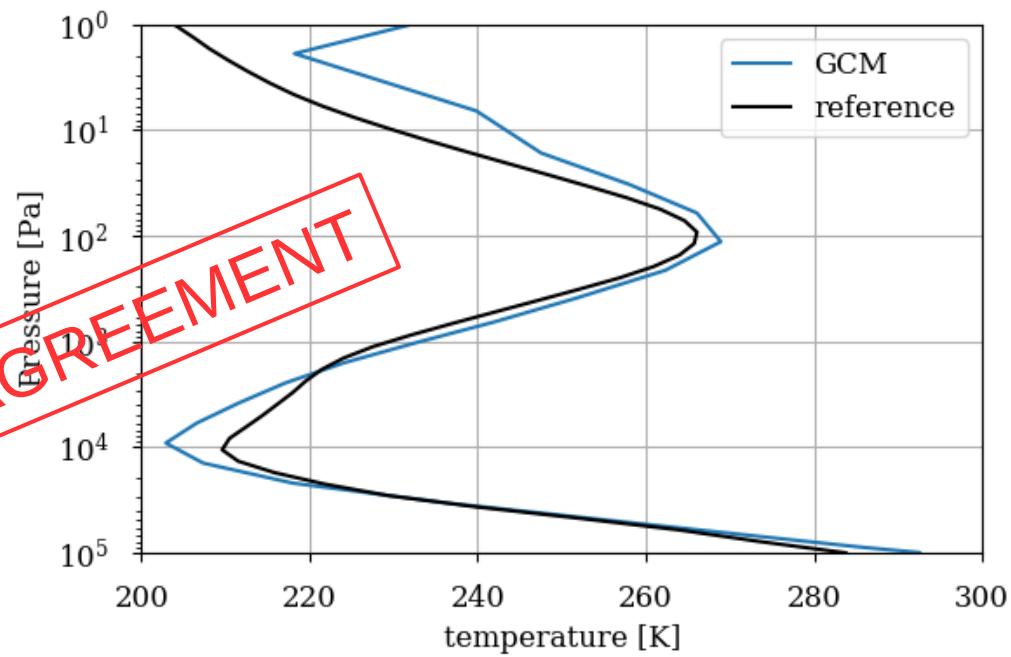
Vatant d'Ollone et al. 2018

Model validation with an Earth atmosphere

Ozone vertical profile

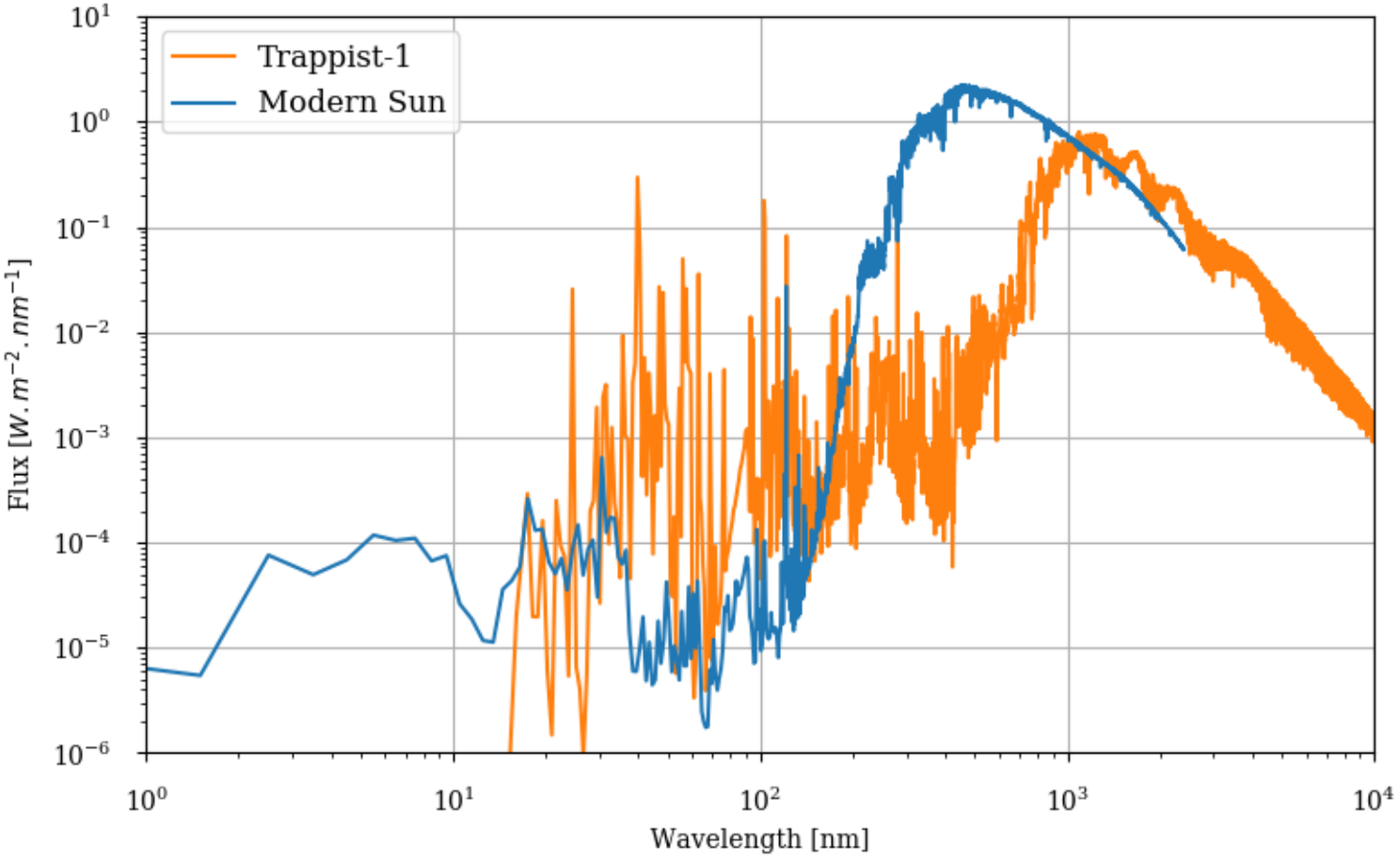


Temperature vertical profile



GOOD AGREEMENT

UV-Visible spectral balance around a red-darwf

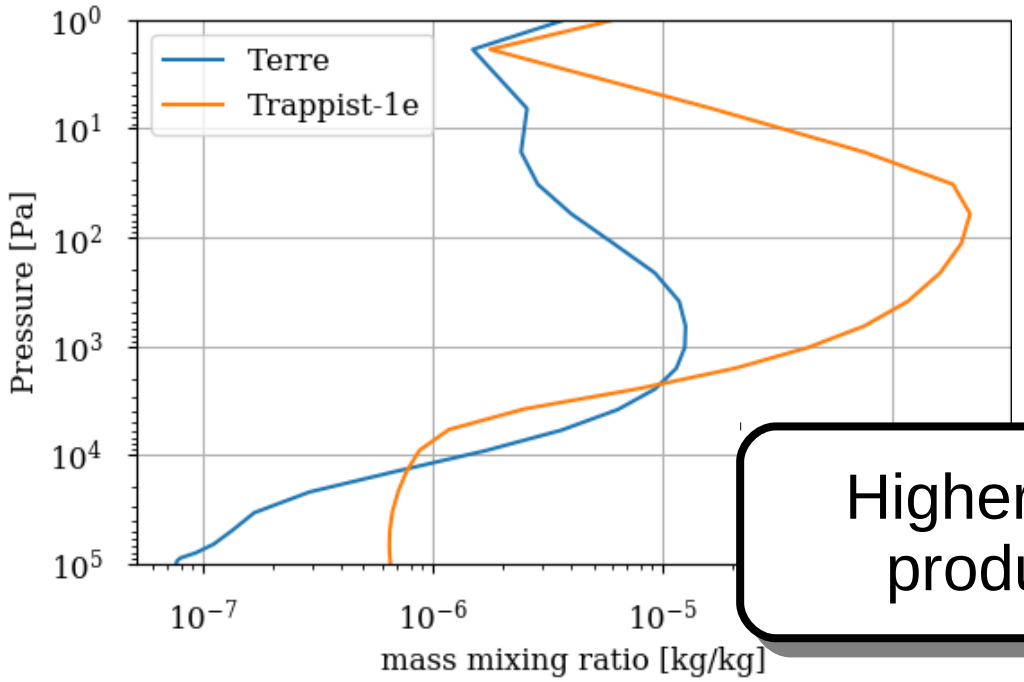


Peacock et al. 2018

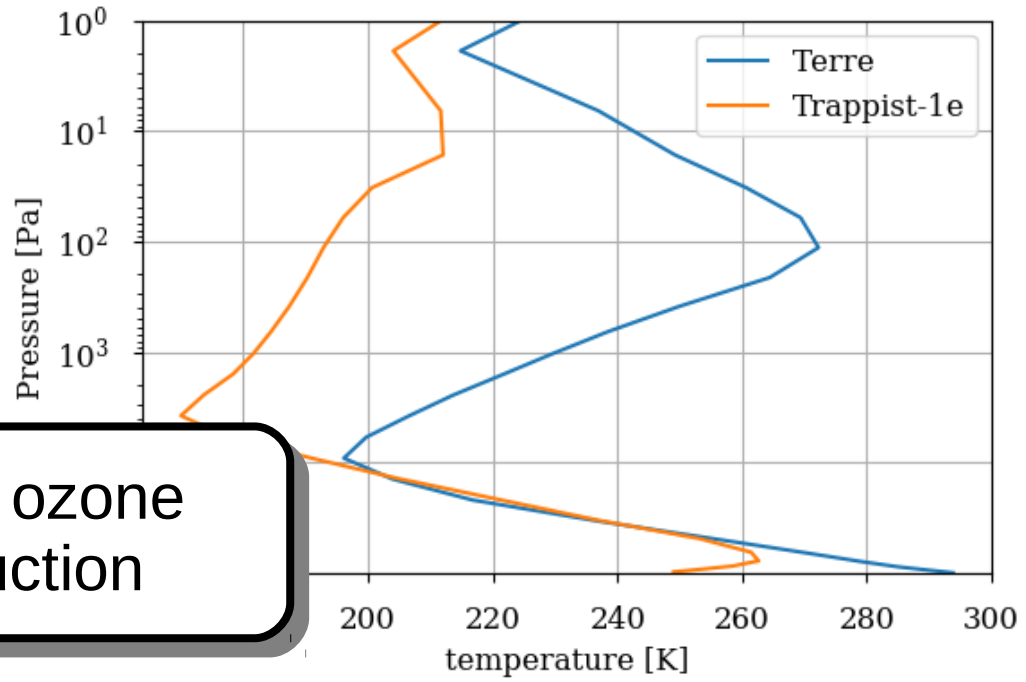
Ozone and temperature on Trappist-1e

Parameters	Trappist-1e	Terre
Surface gravity [m.s^{-2}]	9,12	9,81
Radius [m]	5855130,0	6378137,0
Obliquity [°]	0,0	23,44
Angular rotation [rad.s^{-1}]	1.212×10^{-5}	7.272×10^{5}
Irradiation [W.m^{-2}]	904,0	1366,0

Ozone vertical profile

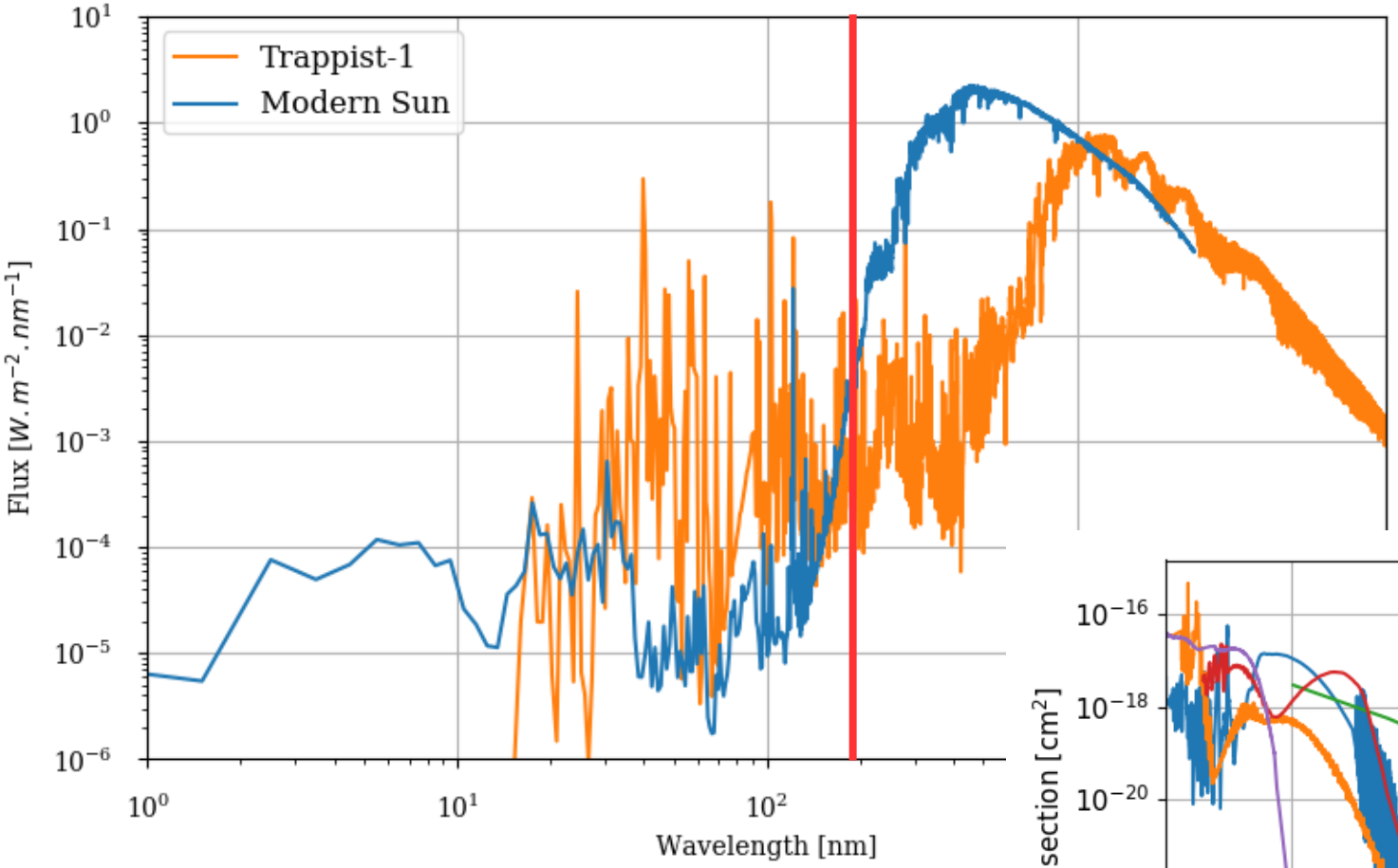


Temperature vertical profile

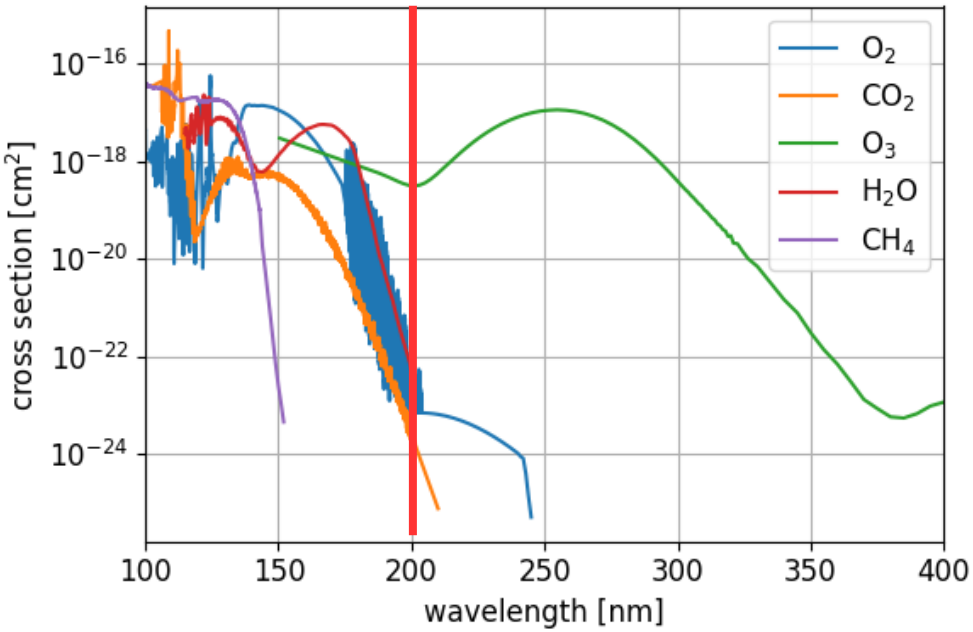


Higher ozone production

Reduced ozone photolysis

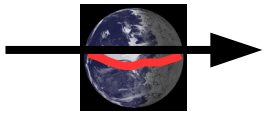


200 nm

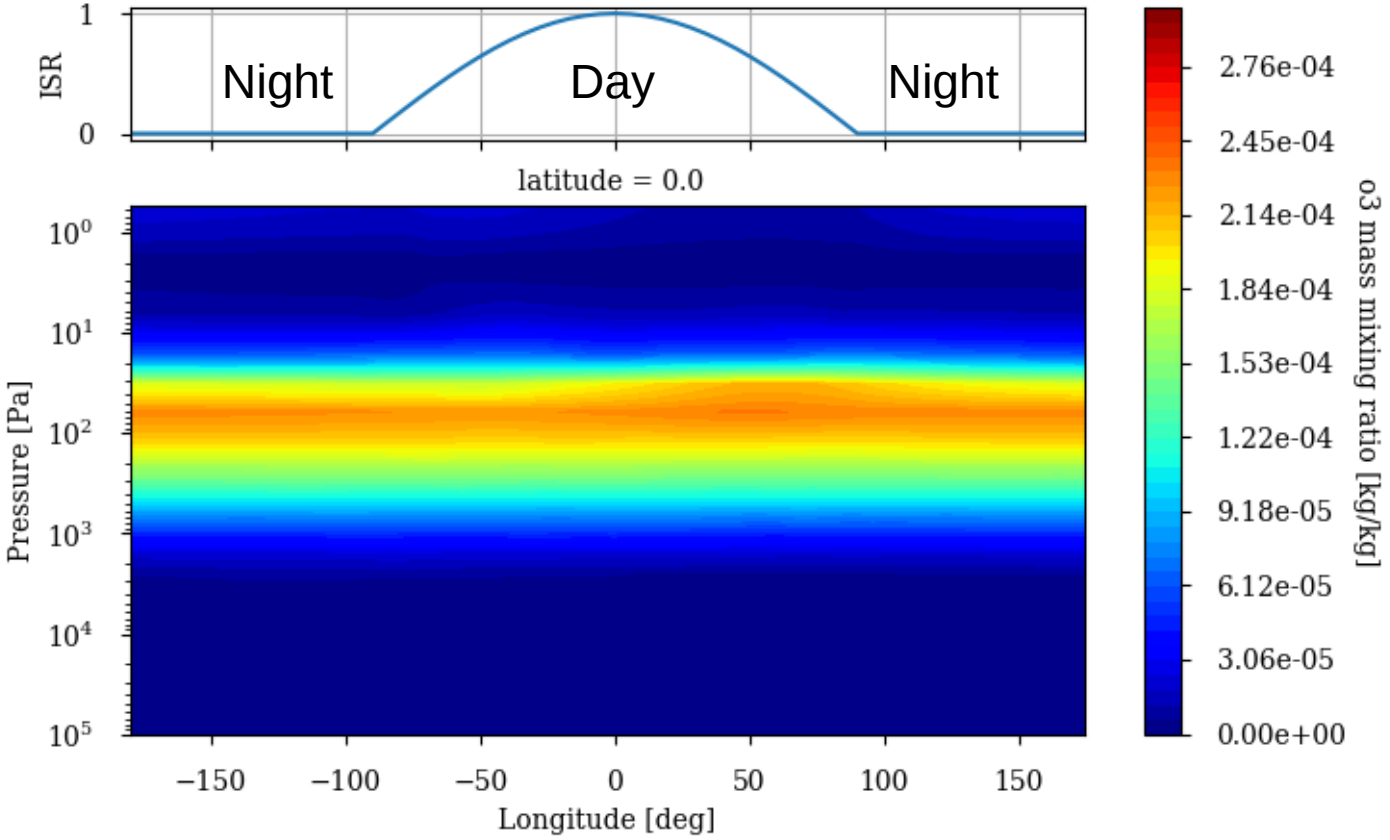


Homogeneous ozone layer

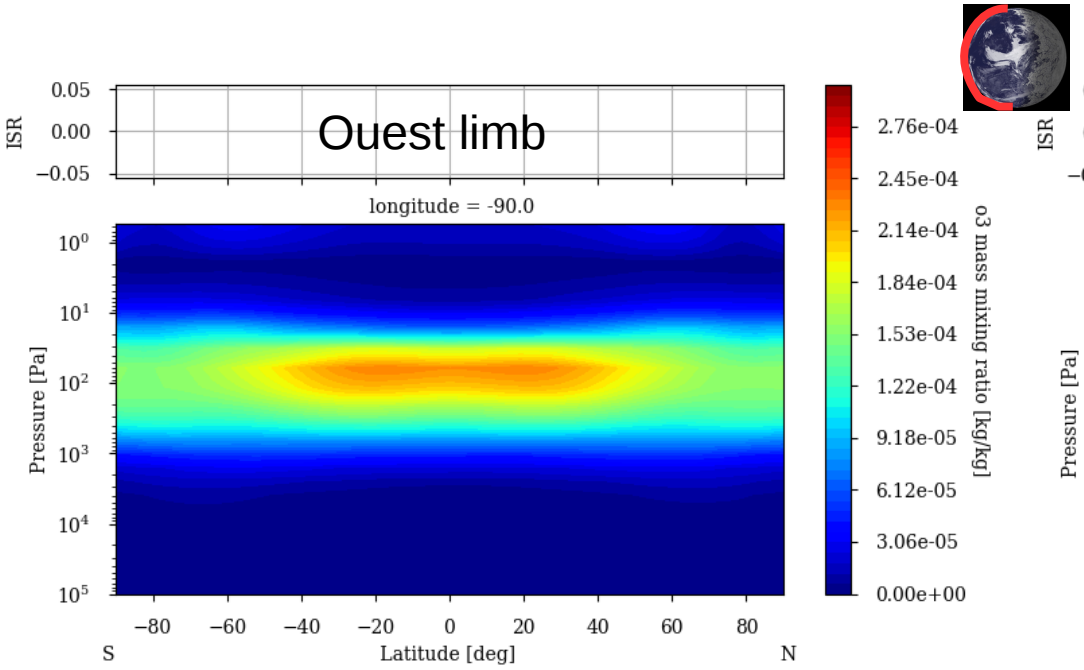
Fast rotation

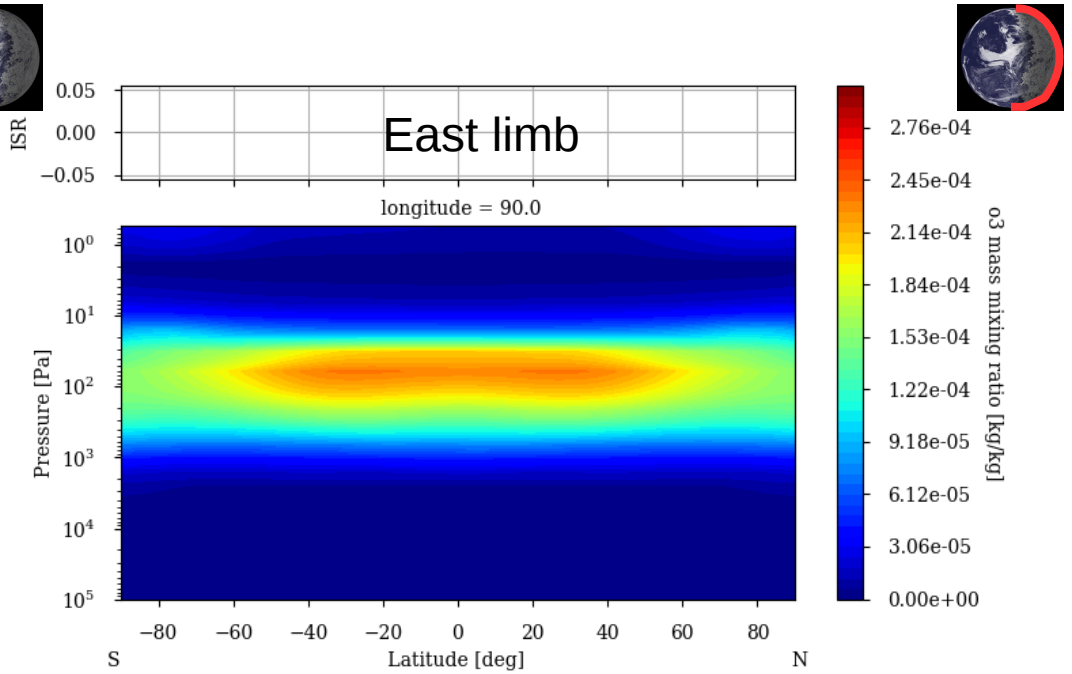


Good mixing



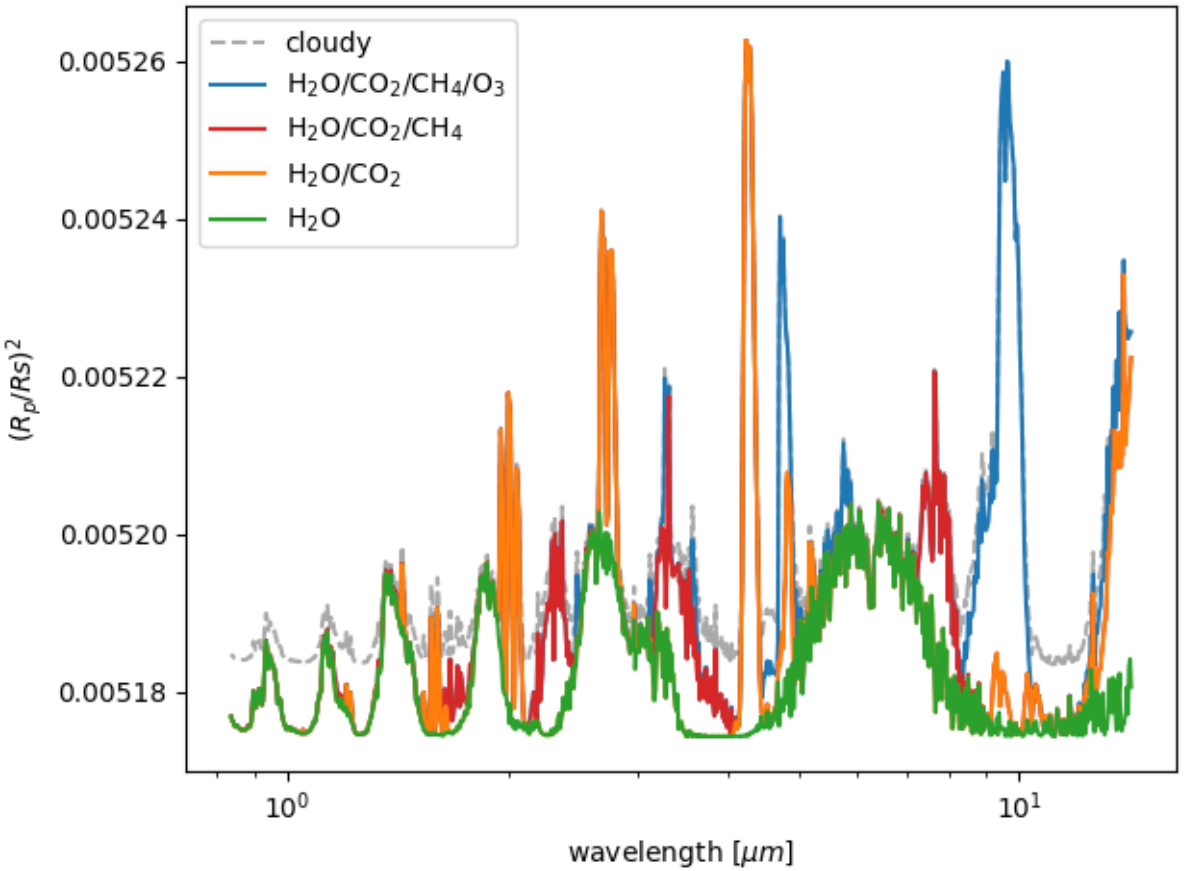
Limbs vertical profil



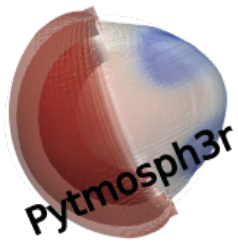


Only significant vertical variations

Transmission spectra contributions

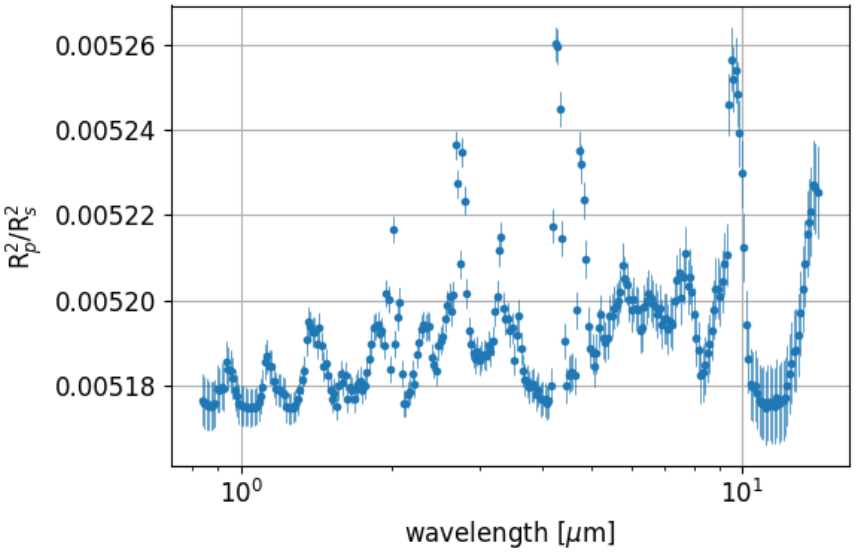


Idealistic low photon noise uncertainty



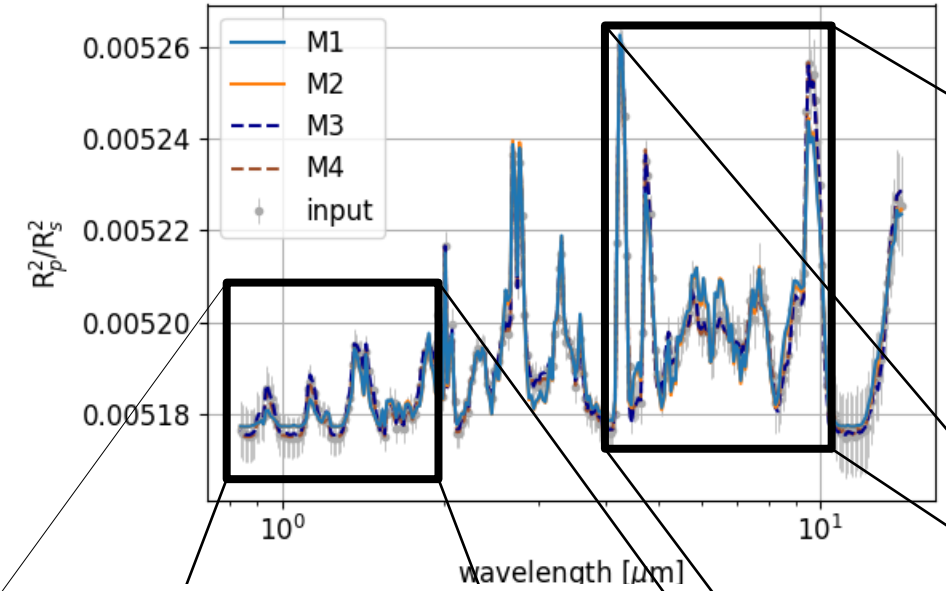
Caldas et al. (2019)

http://perso.astrophy.u-bordeaux.fr/~jleconte/pytmosph3r-doc/index.html

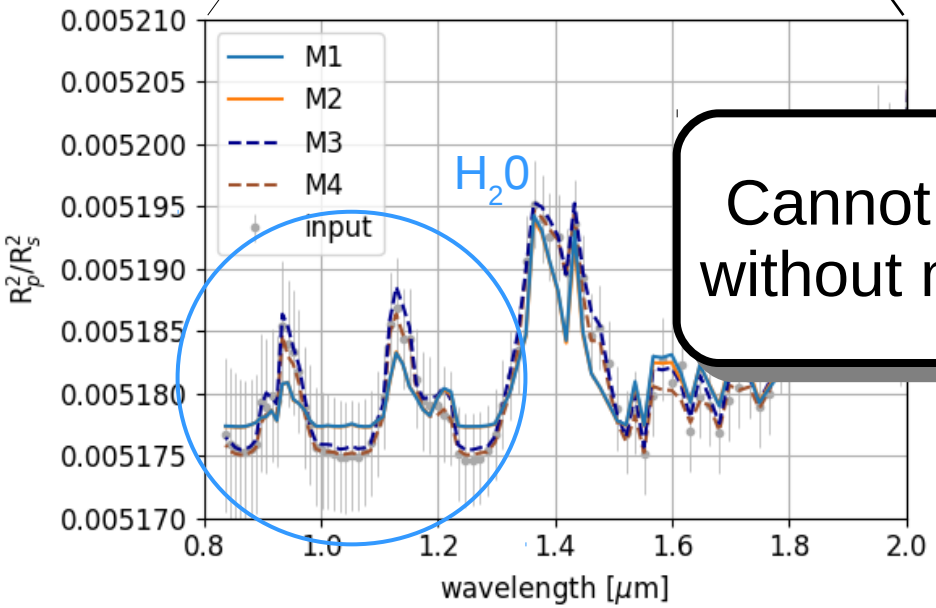


Vertical effects → 2 layers retrieval

Al-Rafaie et al. (2019)

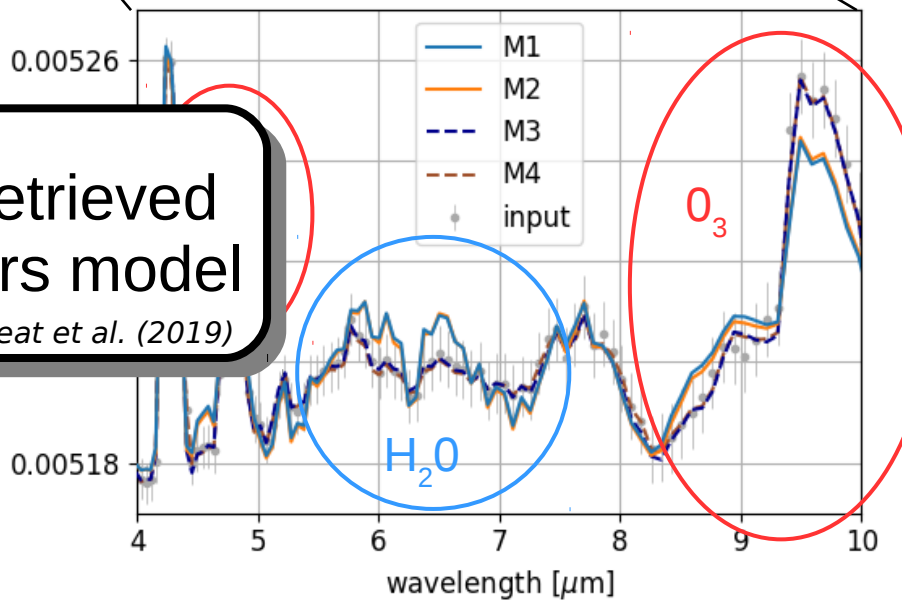


Models	Temperature	Species	ADI	Δ_{cst}
M1	isothermal	constant	1632.50	0.0
M2	4 points	constant	1632.95	0.4545
M3	isothermal	2 layers	1694.81	62.31
M4	4 points	2 layers	1697.87	65.37



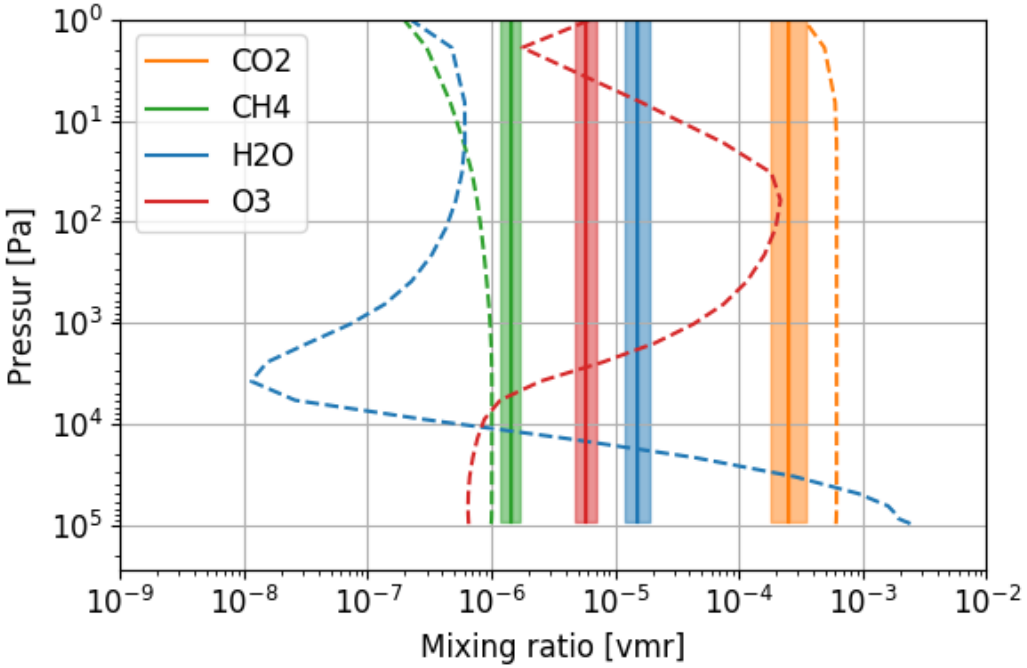
Cannot be well retrieved without multi-layers model

Changeat et al. (2019)

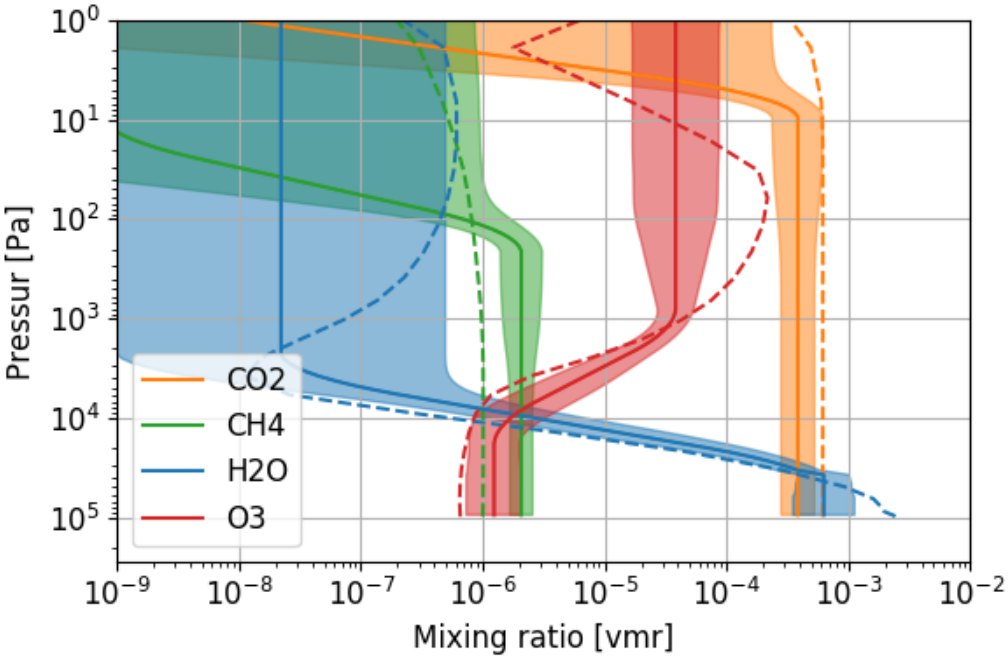


Species vertical profiles

One layer retrieval



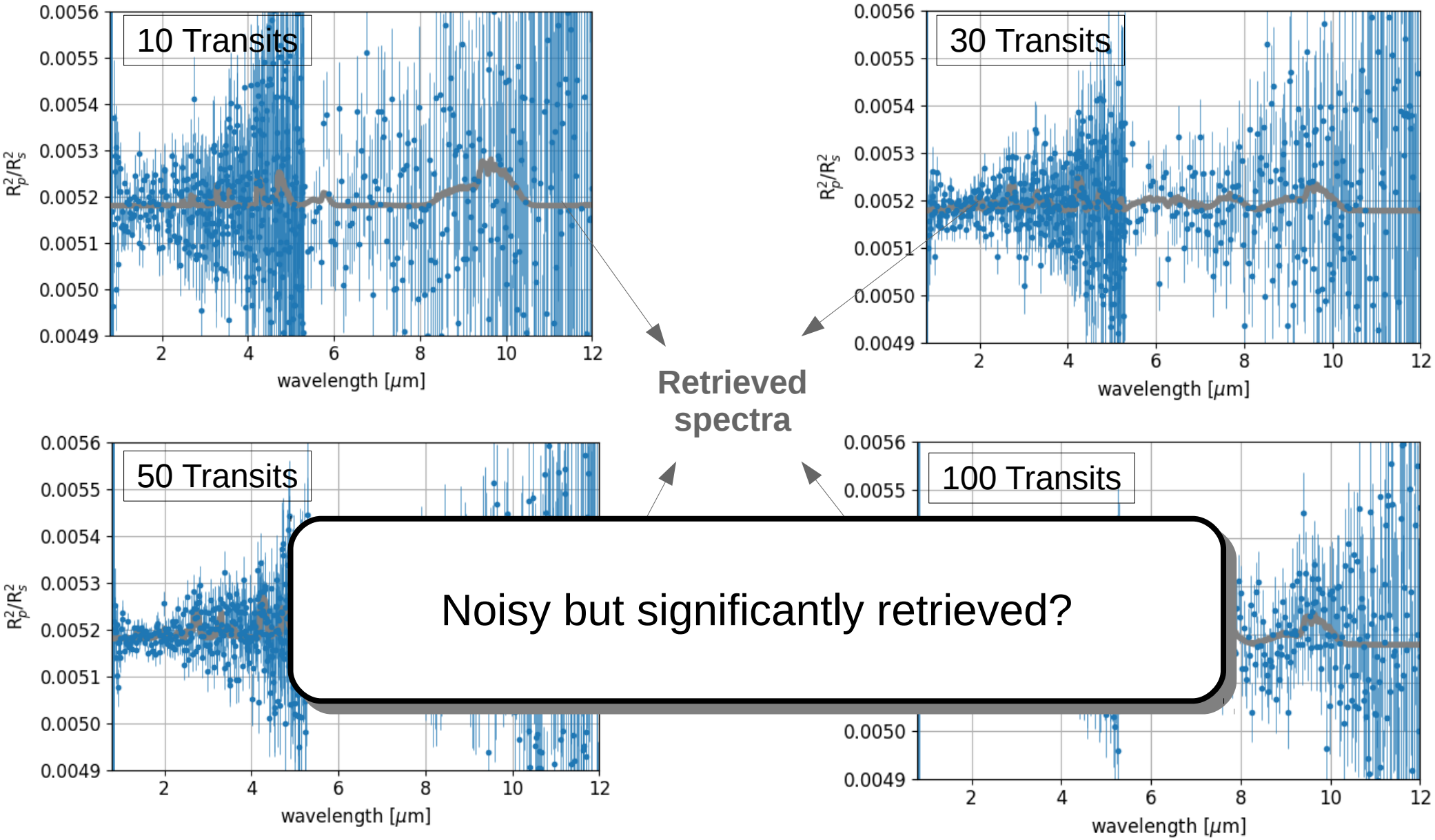
Two layers retrieval



Good agreement of a 2 layers model

JWST noise simulation

Batalha et al. (2017)



Noisy but significantly retrieved?

JWST noise simulation

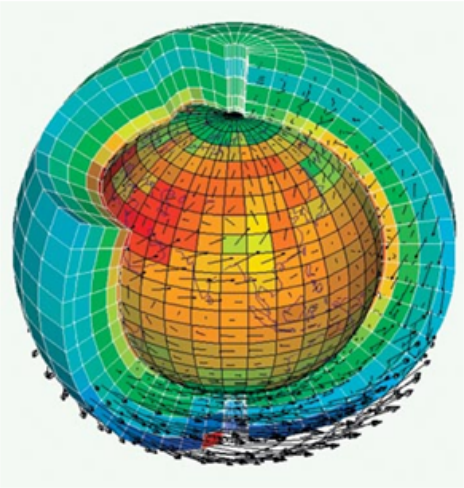
Retrieved parameters	bounds	**Trappist-1e** 10 transits	**Trappist-1e** 30 transits	**Trappist-1e** 50 transits	**Trappist-1e** 100 transits
T_P (K)	[50 ; 450]	unconstrained	105^{+44}_{-26}	198^{+57}_{-40}	152^{+42}_{-32}
R_P (R_J)	±25% R_P	$0.083763^{+0.000037}_{-0.000044}$	$0.083771^{+0.000029}_{-0.000038}$	$0.083782^{+0.000022}_{-0.000024}$	$0.083762^{+0.000019}_{-0.000023}$
$\log_{10}[H_2O]$	[-12 ; -1]	unconstrained	$-5.8^{+1.9}_{-3.7}$	$-5.4^{+0.5}_{-0.5}$	$-5.5^{+0.8}_{-0.9}$
$\log_{10}[CO_2]$	[-12 ; -1]	unconstrained	$-3.4^{+1.5}_{-1.4}$	$-5.1^{+0.9}_{-1.2}$	$-3.8^{+1.1}_{-1.0}$
$\log_{10}[CH_4]$	[-12 ; -1]	unconstrained	$-5.6^{+1.1}_{-1.6}$	$-6.4^{+0.5}_{-0.9}$	$-6.1^{+0.5}_{-0.5}$
$\log_{10}[O_3]$	[-12 ; -1]	$-5.3^{+1.3}_{-1.7}$	$-5.7^{+1.4}_{-2.5}$	$-5.4^{+0.6}_{-0.6}$	$-6.0^{+0.6}_{-0.5}$
μ (derived)		$28.0138^{+0.0180}_{-0.0003}$	$28.019^{+0.173}_{-0.006}$	$28.0136^{+0.0010}_{-0.0002}$	$28.016^{+0.025}_{-0.002}$
ADI	-	1.21	5.41	20.69	34.01
Δ_{O_3}	-	1.28	0.27	7.69	5.73

Good detection

Benneke and Seager (2013)

Summary

Global Climate Model
Generic 3D



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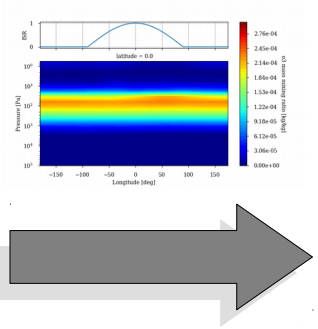
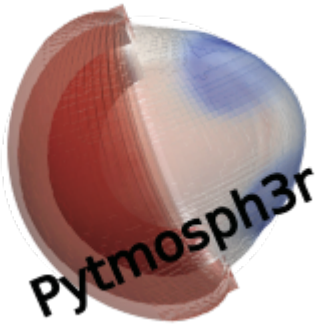
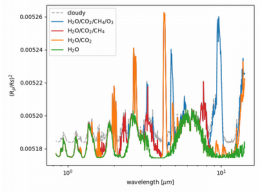


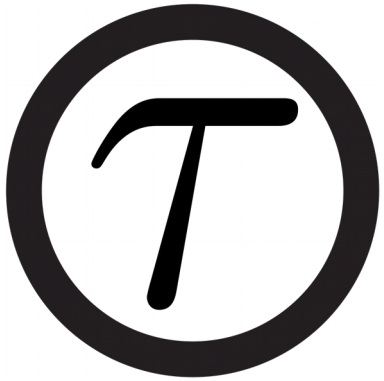
Pytmosph3r
Transit 3D



Caldas et al. (2019)



TauREx
Retrieval 1D



Al-Rafaie et al. (2019)

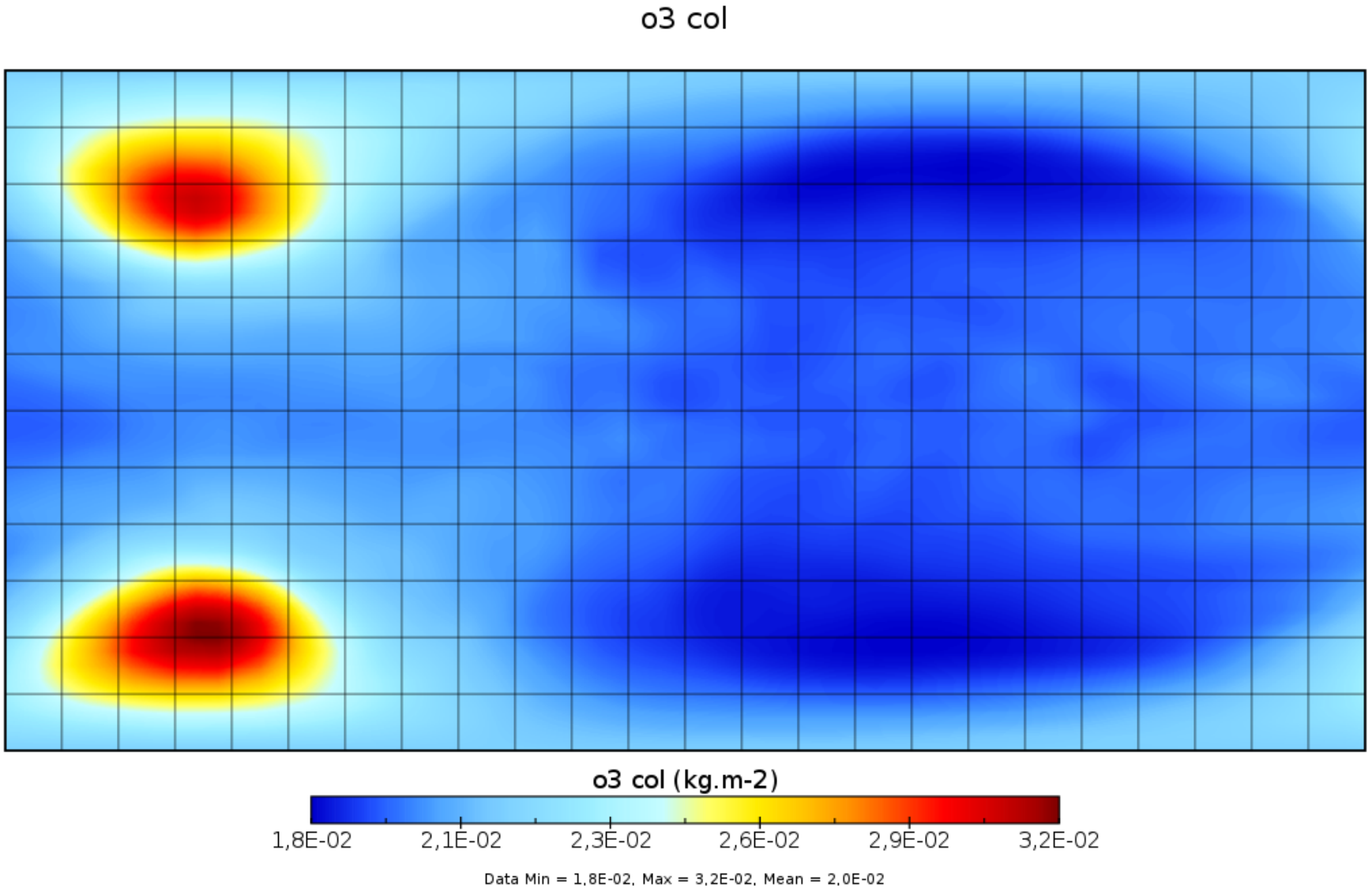
Leconte (2021)

Conclusion

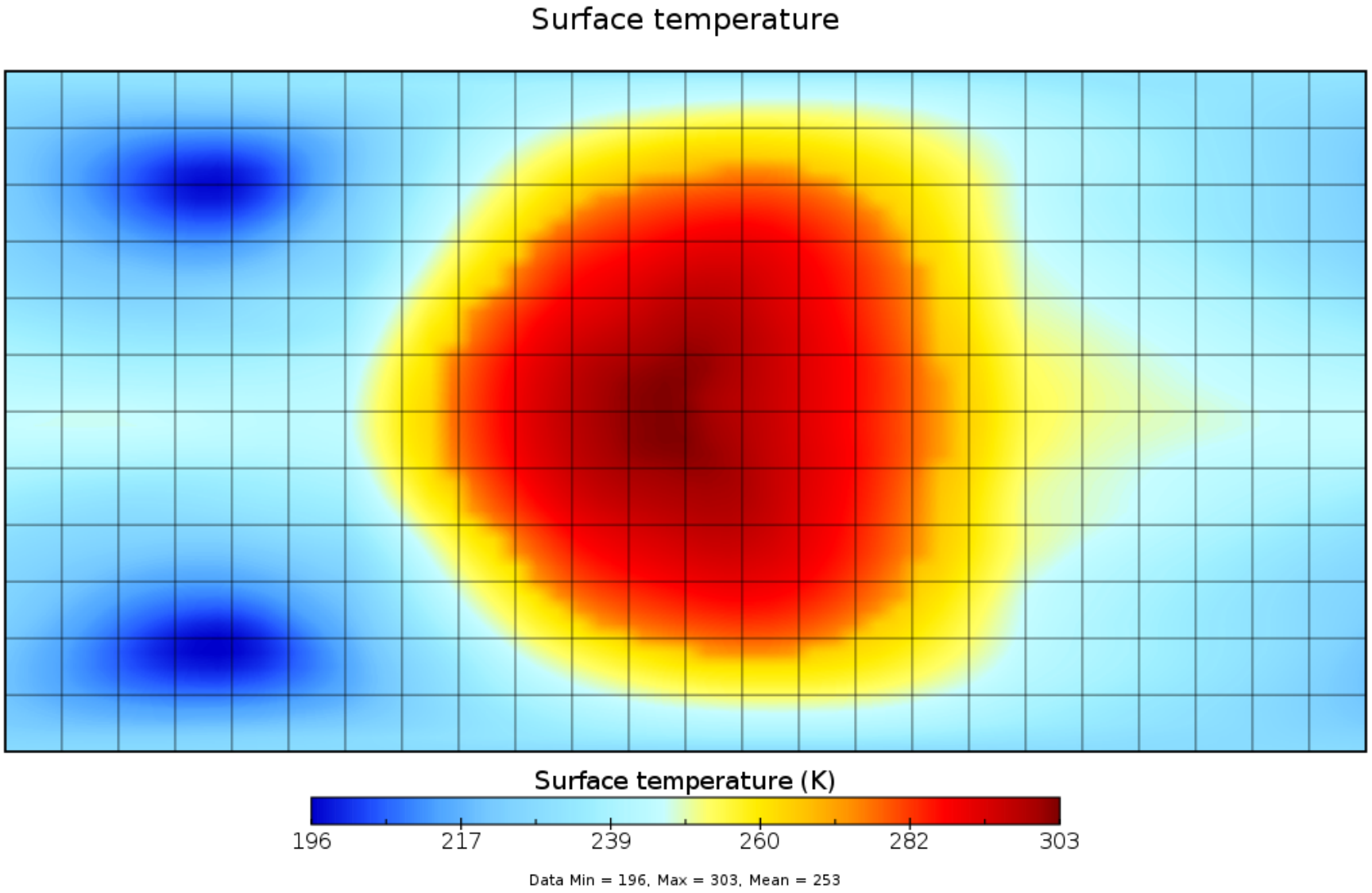
- A generic 3D photochemical-GCM for exoplanet atmosphere
- Ozone increasing productivity around Trappist-1e (red-dwarf M8)

- Multiple application for molecules detectability
- Detectability challenging and vertical model needed to constrain the abundance on temperate planets

Column ozone



Tsurf


Surface temperature
Surface temperature (K)
196
217
239
260
282
303
Data Min = 196, Max = 303, Mean = 253