Interactive comment on "TRAPPIST-1 Habitable Atmosphere Intercomparison (THAI). Motivations and protocol" *by* Thomas Fauchez et al.

Daniel D.B. Koll (Referee)

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This is an interesting proposal for a exoplanet GCM (global climate model) intercomparison. I am a fan of the general idea and the project's open nature – given the booming interest in the field, model intercomparisons such as this one will be playing an important ongoing role. I also think the experimental setup is generally appropriate, but clarifications on the overall design and on some of the modeling choices would be helpful. See below.

We would like to thank the reviewer Daniel D.B Koll for his kind words and his helpful and insightful review of our manuscript. We have deeply considered the points brought up by the referee in the revisions to paper. Our reply is detailed below.

***Major comments: - What plans do the authors have for an online presence to share necessary input files as well as model outputs? In particular, it is not clear to me how participants who are interested in submitting a model would obtain the necessary host star spectrum. I would also strongly encourage the authors to make their main out- put netcdfs publicly available (=not on a personal/professional website) so that model developers or graduate students will still be able to access the results five years from now. Github sounds like an easy option. Similarly some of the co-authors, e.g., the ROCKE3D team, have been doing great work in making their files available to the rest of the community, which might also be feasible here.**

We have set up this repository hosted at NASA: https://thai.emac.gsfc.nasa.gov/dataset/thai

The outputs from all the models in the intercomparison will be hosted there. The stellar spectrum used will only be in the dataset. Data will be accessible to download by anyone, and upload will be possible with authorized IP address for scientists whose want to contribute to the intercomparison with their own GCM.

We have added a statement about this in the revised manuscript:

"THAI model outputs and the TRAPPIST-1 stellar spectrum will be progressively uploaded during the intercompaison and will be available at : https://thai.emac.gsfc.nasa.gov/dataset/thai"

- To understand the likely-important impact of cloud parameterizations, what about a version of Hab1/Hab2 that still includes water vapor/latent heating effects but disables the radiative effects of clouds (see Yang et al 2019)? This setup should be easy to implement in most GCMs.

This is a very interesting suggestion that will help to interpret our differences due to cloud physical processes without having the radiative effects of clouds. However, our objective is not to fully understand all the differences between the models but to understand how the first order differences impact the observables from synthetic spectra. The co-authors have debated considerably to arrive at the five configuration chosen for this intercomparison. At this point we would rather not add more required configurations to this intercomparison. However, time permitting amongst participating parties, we encourage the exploration of different configurations and parameters not explicitly include at present.

We add this statement before the conclusion:

"Note that while additional simulations with a simple Newton cooling model, a 1-D column model, or with cloud radiative effects disabled would help to better understand the differences due to the dynamical cores and cloud physics, they will also dramatically increase the computationnal time, amount of data and effort. Yet, THAI aims to be easily reproducible and not time consuming in order to reach many GCM user groups. The five simulations propose in THAI should be enough to understand the main differences between the GCMs and their impact on the observable. THAI could also be used as a benchmark for a future GCM intercomparison that will specifically aim to understand the finest differences between the models."

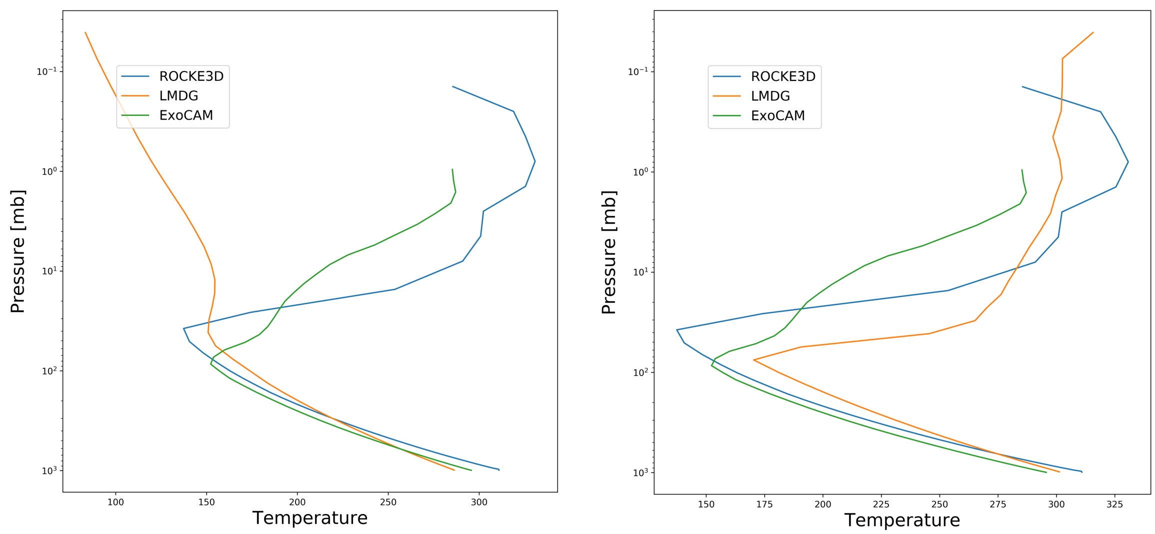
Also a THAI workshop is currently being planned around fall 2020 to discuss about THAI results and their perspectives.

- I know that this is not easily done with many GCMs, but adding a 1D single col- umn case to the intercomparison would be very useful for isolating differences due to clearsky radiative transfer. These differences can be far from negligible (see Yang et al, 2016), and at least some of the models in this study should be able to run in 1D. Even if a 1D intercomparison isn't feasible here, calling for such an option would at least be a useful sign to model developers.

We agree with referee #1 that comparison using a 1D single column model could be useful to isolate difference due to clearsky radiative transfer. However, all GCMs do not have a 1d single column version. Also the cloud-free cases Ben1/Ben2 can also allow such radiative transfer comparison.

- For the pure N2 case, do the authors still want models to include N2-N2 collision- induced absorption or is this supposed to be an atmosphere that is completely trans- parent? For an intercomparison, the latter case would presumably be interesting. How- ever, I'd think that a zero-opacity atmosphere might easily lead to numerical issues (first, some radiation codes just crash if run with zero optical thickness; second, a zero- or low-opacity atmosphere might become extremely warm, because it is still heated by sensible heat fluxes on the dayside but can't easily shed the heat via radiative cooling, leading to potential further numerical issues). If such issues arose during the study, it would be worth discussing how participating models have dealt with them.

Yes we have included N2-N2 CIA in our simulations otherwise the atmosphere is indeed transparent and numerical issue arise. Also, we have noticed that when lacking an efficient radiative coolant in the high atmosphere like CO_2, N_2-N_2 mid-IR absorption warms the stratosphere and creates an inversion. The figure below shows a comparison between LMD-G, ROCKE-3D and ExoCAM average temperature profiles. In the left panel mid-IR N_2-N_2 was omitted in LMD-G, but included in the two other models. In the right figure N_2-N_2 has been included in the three models and we can see the temperature inversion occurring between 30-100 mb.



In section 3.1, when presenting Ben2 we have added: *"Note that N_2 -N_2 CIA should be included to avoid a fully transparent atmosphere and associated numerical instabilities."*

***Minor comments: - Figure 1, bottom row: add global-mean albedos somewhere on this figure?**

- Page 7: the intercomparison fixes albedos, but what about sea ice dynamics?

There is no dynamic ocean nor dynamic sea ice included since only ROCKE-3D is able to use such parameterizations.

- Page 7: do the Hab1 and Hab2 cases with a zero-ocean-heat-transport slab ocean reach steady state on the nightside? In particular, does the sea ice thickness asymp- tote to a finite value?

This is a level of details we reserve for the second part of the study when we will compare the outputs of each of the models.

- Page 9 "should have reached radiative equilibrium" To what precision, in W/m2? Also, the global-mean top-of-atmosphere radiative equilibrium will be dominated by the warm dayside. The nightside could take much longer to reach equilibrium (smaller flux = longer equilibration timescale). Have the authors looked at the nightside surface bud- get, to see if it reaches equilibrium?

This is an important question, however this question depends on the model itself. As described in Way et a.l, (2017), ROCKE-3D considers radiative equilibrium at a precision of 0.2 W/m^2. But other models may never reach such level of radiative equilibrium. Also, sometimes it requires other diagnostics such as surface temperature, sea ice extension, etc. to determine whether or not the model reached convergence. Therefore, we prefer to remain agnostic concerning the threshold for radiative equilibrium and leave it up to the user to determine the convergence.

- Page 11 "LMD-G is available upon request." From whom?

We add: "LMD-G is available upon request from Martin Turbet (martin.turbet@lmd.jussieu.fr) and François Forget (francois.forget@lmd.jussieu.fr)"

***Technical comments: - Abstract, l.3: "... may soon be able to characterize, through transmission spectroscopy, the atmospheres of rocky exoplanets..." Why emphasize transits over other techniques that the manuscript mentions later on (e.g., emission spectra or phase curves)? The results of this work will be interesting more broadly.**

We modify this sentence into: *"through transmission, emission and reflection spectroscopy, the atmospheres of rocky exoplanets"*

- Abstract, l.14 "The four test cases included two land planets composed of pure N2 and pure CO2, respectively..." ... pure N2 and pure CO2 *atmospheres*, ...

Done

- P2, l.6-7: "... and represent nearly 20% of astronomical objects in the stellar neigh- borhood of the Sun. " Interesting! Citation?

it is actually 15 %: "Cantrell, J. R., Henry, T. J. & White, R. J. The solar neighborhood XXIX: the habitable real estate of our nearest stellar neighbours. *Astron. J.* **146,** 99 (2013). "

We have updated the 20 % to 15 % and added (Cantrell et al., 2013) as a reference.

- P6, l.7: "because all the models do not include CO2 condensation" - because not all the models include X, or because all the models do not include X?

"because not all the models include X" thank you.

- P7, l.29: " to much the model" - typo, too.

Done.

- P7, l. 30: "disable the gravity waves" - the gravity wave parameterization in the strato- sphere? The dynamical cores should still be resolving some internal gravity waves.

Yes, the gravity wave parameterization in the stratosphere (sub-grid). Thank you for pointing this out, we have modified the paragraph in:

"We also ask the contributing scientists to disable the sub-grid gravity wave parameterizations in their model. Indeed, all the models do not have implemented a gravity wave parameterization and some have prescribed or predicted gravity wave formation, tuned for Earth topography and meteorology. Therefore, to avoid differences in atmospheric dynamics especially above the tropopause, we recommend to not include the sub-grid gravity wave parameterizations in this

intercomparison. Gravity waves whose wavelengths are greater than the model grid are explicitly resolved in the models and do not need to be modified."

- Page 8, Table 2: molecular air mass is referring to the dry background gases only?

Yes only for dry gases, we add "(dry)" in the "molecular air mass" row of Table 2.

- Page 8, Table 2: momentum roughness length and heat roughness length are missing units.

Good catch. Both are in meter.

Done.