Comment on "Diminished greenhouse warming from Archean methane due to solar absorption lines." By Byrne and C. Goldblatt

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Summary:

In this paper the authors study the differences in Archean climate that arise between (1D) simulations using HITRAN 2000 and HITRAN 2012, assuming radiatively active gases of CO_2, H_2O, and CH_4. They focus on the effects of increasing CH_4, though CO_2 and H_2O are also included. For $CH_4 < 10^{-3}$ bar, HITRAN 2012 simulations are slightly (<1 K) warmer owing to additional longwave absorption lines. For $10^{-3} < CH_4 < 10^{-2}$ bar, HITRAN 2012 simulations becomes cooler by up to ~6 K due to significantly increased shortwave absorption by CH_4 in the upper atmosphere, thus preventing the solar energy from warming the surface.

This paper is well constructed and presents an interesting development in light of numerous models that require CH_4 at or above 10^{-3} bar to achieve warm temperatures in the late Archean. However, the significance of their result may need stronger qualifications to identify when differences become significant. It is expected that Titan-like organic hazes form at high CH_4 concentrations. This will obscure the direct effect of enhanced methane absorption (see General Comments).

General Comments:

I feel that the word choice of "Surface warming is *greatly* diminished relative to HITRAN 2000 line database," in the abstract and elsewhere may be somewhat misleading.

For the late Archean, the most recent constraints on CO_2 place its value near $~10^{-2}$ bar (Sheldon, 2006; Driese *et al.* 2011). Thus, *if* we assume these CO_2 constraints are appropriate, hazes may be expected to begin forming during the late Archean when $CH_4 \geq 10^{-3}$ bar. Additionally Haqq-Misra (2008), Wolf and Toon (2013) and Charnay (2013) all find marginally warm solutions for the late Archean with $~10^{-2}$ CO_2 and $~10^{-3}$ methane. Thus for the currently accepted most likely atmospheres for the late Archean, differences in T_s due to differences between HITRAN 2000 and HITRAN 2012 only appear to be $~1–2$ K cooling (small!). This is explicitly illustrated in Figure 4, panel 2. Any further increases in CH_4 above $~10^{-3}$ pushes climate into the haze forming regime. Likewise, for assumed CO_2 amounts of 10^{-3} bar, the change to HITRAN 2012 only serves to *warm* climate in haze free regime. This is illustrated in Figure 4, panel 3. Methane-hazes on Titan significantly warm the stratosphere and cool the surface and it would be expected that such hazes would act similarly if they existed on the Archean Earth. Thus results that lie within the expected haze forming regime must be taken with a grain of salt, as the climatological effects of the haze may be significant and thus outweigh HITRAN differences.

However, importantly, one can imagine that the larger temperature differences found in this study may indeed be possible for a hypothetical *early* Archean atmosphere. Hard limits on CO_2 are absent from the early Archean geological record. Thus it may indeed be possible to have 10^{-1} bar CO_2 and 10^{-2} bar CH_4 (or more?) during the earliest Archean. This case is approximately illustrated in Figure 4, panel 1, albeit here with a solar constant of 80% S (instead of say 75% S, more appropriate for the early Archean). Thus the authors maximum temperature difference of ~5 K could feasibly occur, but more likely so for the early Archean where CO_2 could have been larger, and thus the haze-free regime extends also to higher CH_4.

The authors may be benefitted from qualifying their conclusions with the notion that for currently proposed late Archean atmospheres, temperature differences may not be large. However, for early Archean conditions that indeed require 10^{-1} bar of CO_2 to remain warm, the haze-free, high-CH_4 cases become more relevant.

Specific Comments:

I found the error estimate approach to be reasonable. I recognize the devil in the numerical issues and that sometimes increasing the number of iterations amounts to gaining very little knowledge in exchange for many computer hours.

Could the authors comment on the differences in CO_2 and H_2O that arise from switching between HITRAN 2000 and HITRAN 2012, within the temperature and concentration regimes studied in this paper? At first glance at Figure 4, I assume that going between HITRAN 2000 and HITRAN 2012 must be fairly small in regime studied (<300 K, ≤0.1 bar CO_2), but the authors may consider stating their opinion on the matter.

In section 4.2, it may be noted that warming of the stratosphere from CH_4 would be combined with warming from particle heating by hazes. Higher relative humidity may cause fractal particles to collapse into spheres, while lower relative humidity would allow the fractal shape to be better preserved.

Technical corrections:

Figure 4 appears to have error bars, I am assuming from the expanded convergence criteria discussed in section 3.2. Can you make reference to the error bars in the caption to Figure 4? Clearly the error bars do *not* affect the authors' main conclusions.

The axis on Figure 5 and Figure 6 is slightly confusing. Can you also label the vertical axis (pressure) and the horizontal axis (water vapor mixing, temperature)? Also it appears that the vertical axis in Figure 5 and 6 are in bar, while the analogous axis is in figure 2 is in Pascal. Can this be made consistent?