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

Eric T. Wolf

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 CO₂, H₂O, and CH₄. They focus on the effects of increasing CH₄, though CO₂ and H₂O are also included. For CH₄<10⁻³ bar, HITRAN 2012 simulations are slightly (<1 K) warmer owing to additional longwave absorption lines. For 10⁻³<CH₄<10⁻² bar, HITRAN 2012 simulations becomes cooler by up to ~6 K due to significantly increased shortwave absorption by CH₄ 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 CH₄ 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 CH₄ 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 CO₂ place its value near ~10⁻² bar (Sheldon, 2006; Driese et al. 2011). Thus, if we assume these CO₂ constraints are appropriate, hazes may be expected to begin forming during the late Archean when CH₄≥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 CO₂ and ~10⁻³ methane. Thus for the currently accepted most likely atmospheres for the late Archean, differences in Tₛ 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 CH₄ above ~10⁻³ pushes climate into the haze forming regime. Likewise, for assumed CO₂ 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 $\sim$5 K could feasibly occur, but more likely so for the early Archean where CO$_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$_2$O 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, $\leq$0.1 bar CO$_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?