Clim. Past Discuss., 10, C2331–C2338, 2015
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Climate of the Past Discussions

Interactive comment on "Diminished greenhouse warming from Archean methane due to solar absorption lines" *by* B. Byrne and C. Goldblatt

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Dear Dr Wolf,

Thank you very much for the helpful review. We have addressed your comments individually below.

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

RESPONSE: We agree that we may overstate the diminished warming in the abstract and have removed the adverb "greatly" from this sentence.

COMMENT: 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], Wold 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 Archean atmosphere. Hard limits on CO2 are absent from the early Archean geological record. Thus it may indeed be possible to have 10-1 bar CO2 and 10-2 bar CH4 (or more?) during the earliest Archean. Thus the authors maximum temperature difference of 5K could feasibly occur, but more likely so for the early Archean where CO2 could have been larger, and thus the haze-free regime extends also to higher CH4. The authors may be benifitted 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 CO2 to remain warm, the haze-free, hihh-CH4 cases become more relevant.

RESPONSE: We agree that the an organic haze would likely have a more significant radiative impact than shortwave absorption by methane. However, we disagree that

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the constraints in the late Archean imply that a haze would form at low CH4, as there is still considerable uncertainty in the CO2 abundance in the middle and late Achean and the CH4 abundance required for haze formation. Furthermore, there are no CO2 constraints before 2.69 Gyr ago, thus we believe that high methane abundances are plausible without haze formation in the middle to late Archean. We have addressed these concerns in the manuscript with the following paragraph:

"Geological constraints, based on the mass balance of weathering paleosols, have suggested that the atmospheric CO2 partial pressure was in the range 0.003-0.02 bar in the late Archean [2.69 Gyr ago, Driese et. al., 2011]. Given that an organic haze could form at CH4/CO2 ratios as low as 0.2-0.3, this would imply that an organic haze would form at CH4 abundances greater than 6x10-4-6x10-3. In the presence of an organic haze, shortwave aborption by CH4 would likely be of less importance. However, at the upper limit of this range, a CH4 abundance of 6x10-3 results in a significant (3–4∼K) difference in surface warming between HITRAN versions. Thus, given the constraints on atmospheric CO2 and organic haze, the calculated reduction in surface warming due to improved line data may have been radiatively important throughout the Archean. Furthermore, atmospheric CO2 constraints only exist for the latest Archean [2.69 Gyr ago, Driese et. al., 2011]. The solar luminosity used in this study (80% of today's value) occured 2.86 Gyr ago [equation 1, Feulner, 2012] which is 170 Myr before the earliest constraint on CO2 [2.69 Gyr ago, Driese et. al., 2011]. Thus, CO2 may have been significantly higher than 0.02 bar at this time, meaning atmospheric CH4 abundance larger than 6x10-3 could have existed without haze formation."

COMMENT: Could the authors comment on the differences in CO2 and H2O 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 fairly small in the regime (<300 K, <0.1 bar CO2), but the authors may consider tating their opinion on the matter.

RESPONSE: We've added some text in section 3.3 to discuss this:

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"The difference in absorption by CO2 and H2O is quite small between the two databases. Although, many new lines have been added to both CO2 and H2O databases they do not provide a large radiative effect in the regime we examined. The differences between HITRAN versions results in a small increase to the greenhouse strength between versions, increasing the surface temperature by roughly 1 K in the regimes we examined."

COMMENT: In section 4.2, it may be noted that warming of the stratosphere from CH4 would be combined with warming from particle heating by hazes:

RESPONSE: We have added the following to section 4.2:

"However, stratospheric warming would increase the saturation vapour pressure and lower the relative humidities which would effect the formation of an organic haze, higher relative humidity may cause fractal particles to collapse into spheres, while lower relative humidity would allow the fractal shape to be better preserved (Wolf, 2014).

Wolf, E.T.: Interactive comment on "Diminished greenhouse warming from Archean methane due to solar absorption lines" by B. Byrne and C. Goldblatt, Clim. Past Discuss., 10, C2137-C2137, 2014."

COMMENT: 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.

RESPONSE: We have added the following text to the caption: "Error bars are plotted corresponding to the error estimates from section 3.2"

COMMENT: 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 bars, while the analogous axis is in figure 2 is in Pascal. Can this be made consistent?

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RESPONSE: We have labeled the axis and all pressure units are now in bars.

Interactive comment on Clim. Past Discuss., 10, 4229, 2014.

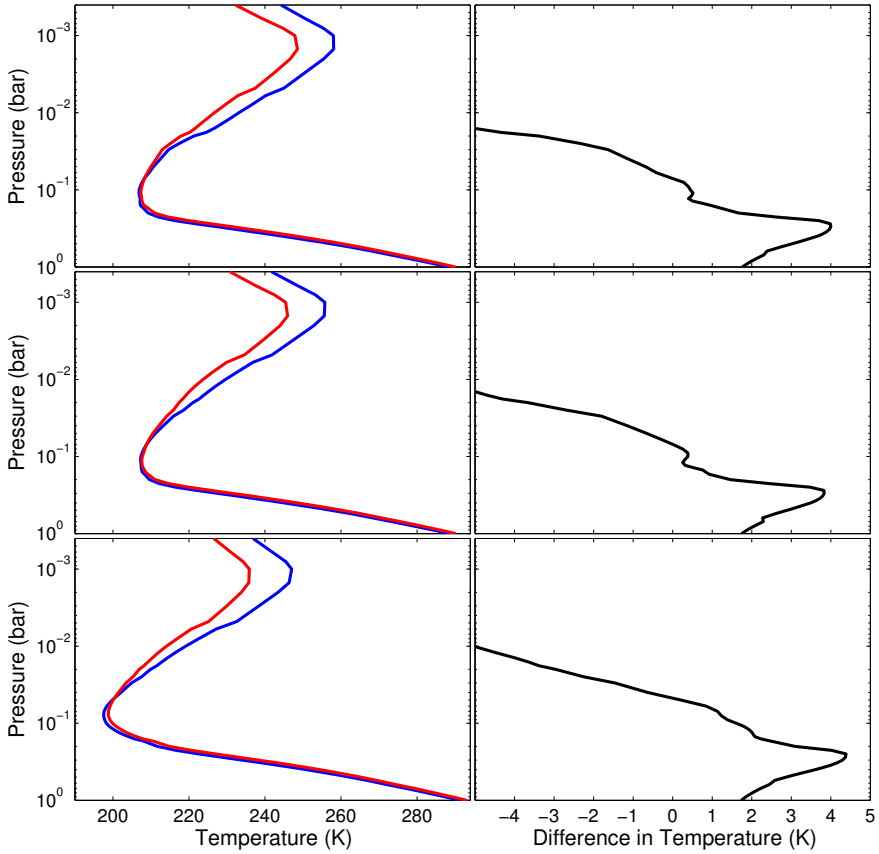

Fig. 1. figure 2 from manuscript

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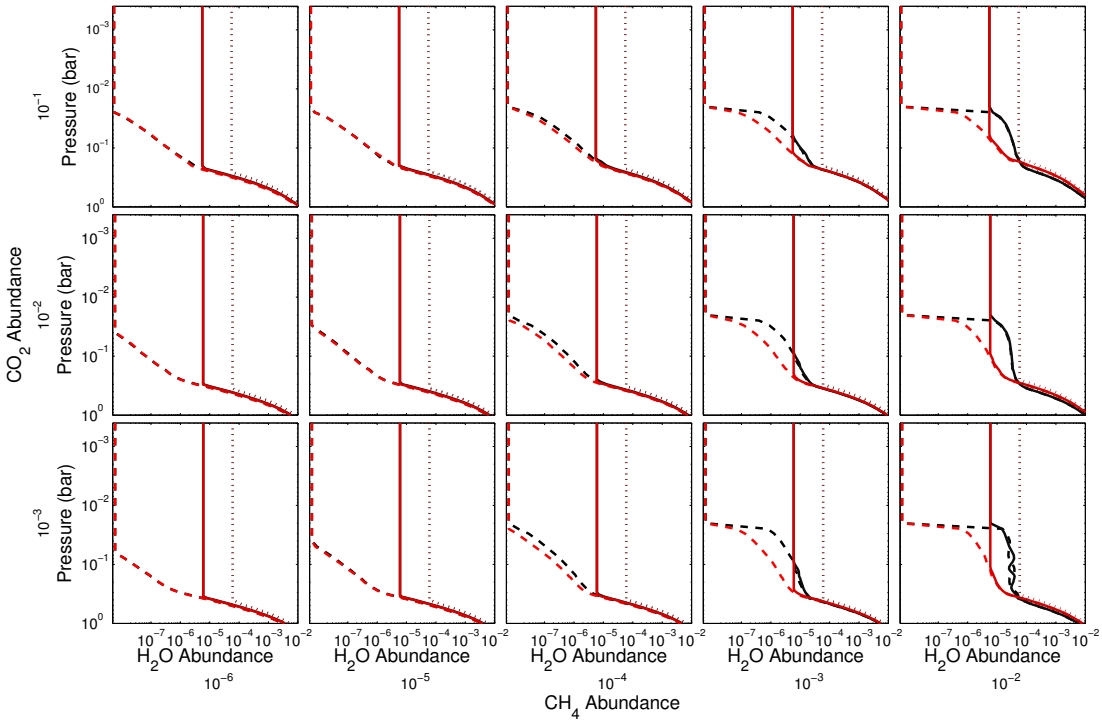

Fig. 2. figure 5 from manuscript

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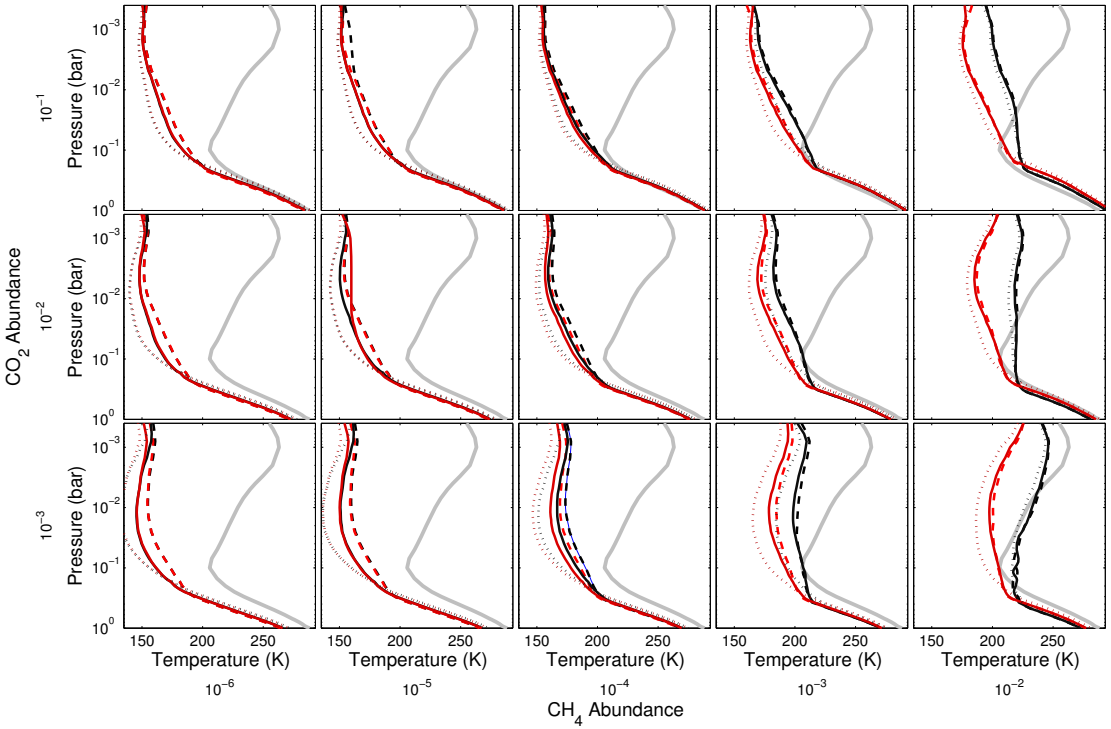

Fig. 3. figure 6 from manuscript

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