Review of 'The Oxygen Valve on Hydrogen Escape Since the Great Oxidation Event'

Summary

This study uses a 3-D Earth System Model (WACCM6) to investigate the effect on hydrogen escape of varying the atmospheric O_2 mixing ratio. The study finds that, to first order, atmospheric warming due to increased ozone concentrations with increased O_2 results in a weakening of the H_2O cold trap. This allows more hydrogen to be lifted into the upper atmosphere, where it can escape to space. However, changes in O2 level alone are unlikely to have been a significant factor affecting H escape rate variations over geological time. The article ends with a comprehensive discussion of the applicability of the results to the water loss and atmospheric composition of both early Earth and other (exo)planetary bodies.

Overview

This work is a very interesting and important contribution to the field, as it thoroughly explores the effects of varying O_2 levels on other atmospheric processes. The WACCM6 Earth System Model is an excellent tool to explore the research question. The simulations are well-designed and the model results explored carefully and in sufficient detail to thoroughly assess the effect of one factor (O_2 mixing ratio) on another (H escape) and explain the relevant causes and effects. For the most part, the figures are well-chosen and illustrate the key points well.

The discussion section is comprehensive and relevant, and demonstrates the wide applicability and importance of the results to different aspects of the field. It achieves a great balance of evidence-based speculation without stretching too far. The abstract and conclusion summarize the study very helpfully.

The overall article is well structured and easy to follow. Key terms and ideas are well explained and defined (e.g., TTL, cold trap).

I have only minor comments and suggestions for improvement or consideration, as follows. A number of them could help the reader to match descriptions of the results in the text with the corresponding figures.

1. Introduction

L34: "the GOE… has been proposed to have **halted** hydrogen escape." I suggest a different word/phrase is used, e.g., "significantly reduced," as hydrogen escape will have persisted, even if at a much smaller magnitude. If I'm mistaken and the word "halted" is kept, I suggest a reference is needed at the end of this sentence.

L41: Suggestion: "through several mechanisms, **including** Jeans escape…" (as I don't think this is a fully exhaustive list).

L67: Typo: "though**t**"

L73: The comparison to the deepest point in the Earth's ocean is helpful for providing context to the water loss rate, but I think that the global equivalent layer of the Earth's current oceans (~3.6 km) might be an even more helpful comparison. This would also provide consistency and ease of comparison with L76.

L88-93: This is a really helpful paragraph summarizing a clear aim.

2. Numerical methods

I think a sentence on the model's lower boundary condition for H_2O would be helpful to note, even if it is in the referenced literature; e.g., is an infinite ocean reservoir assumed?

L105: "that have been estimated to have existed on the Earth over…" I suggest a very minor rewording to something like "within estimates for the Earth over…"

L118: suggest, for clarity and conciseness: "The diffusion-limited hydrogen escape rate (Hunten, 1973; Kasting and Catling, 2003), Φ_{esc}, is proportional to the total mixing ratio of hydrogen components at the homopause:

$$\Phi_{esc} \propto f_T(H),$$

$f_T(H)$ can be written…"

3. Results

L162: "measured" is perhaps slightly misleading, as the text is referring to model results. Suggest "< 3K in terms of global averaged surface temperature" or something similar, instead.

L164: "PI, **1%,** and 0.1% PAL

L168: There is no explanation of how low and medium clouds are defined.

L170: Suggest that "±**0–**60°" might be clearer than "±60°."

L171: Suggest "ice content **(blue shading)** and a lower amount of H_2O **(colored contours)**," for ease of understanding Fig. 4 quickly.

L194: It is not clear what is meant by "visual discernment," as this depends on the scale used on the figure. Suggest "a visual discernment on the scale of Fig. 4" or equivalent.

L201: A brief explanation of the focus on 88 hPa (and also 100 hPa on L207) in particular might be helpful. In general, if there is a way to contextualize these pressure levels with altitudes or atmospheric levels (e.g., tropopause, homopause, etc.) a little more often, that might be helpful to the reader.

L204: “A positive correlation is not present when comparing $f_T(H)$ with global mean temperature alone.” Is this referring to global mean temperature in the tropics (at all pressures) or at 88 hPa (in the tropics) or at all latitudes and pressures?

L218-219: “Above the cold trap in the TTL… due to CH_4 reacting with OH.” It is unclear where the 5 ppmv value comes from and how it corresponds to Fig. 7. I suggest that some further description is given of where in Fig. 7 we see this, as I am looking at the solid black line (for H_2O) in the lower left subpanel, where the maximum above 1 hPa is ~10 ppmv rather than 5 ppmv. In addition, I suggest moving this sentence to the below paragraph, after the lower panels of Fig. 7 have been introduced.

L222: Suggest specifying in parentheses which species are being referred to, e.g., “…the lighter atmospheric constituents **(H)** increase…” It seems from the figure that this is only the case for H, rather than multiple species. I also suggest that this sentence is moved to the paragraph below, as it is more connected to the discussion of the different species’ mixing ratios.

Discussion

Another point that could have been discussed in Section 4 is whether there is any feedback whereby a change in H escape affects the O_2 mixing ratio (as H escape can be considered a source of oxygen).

Figures and Tables:

Table 1: I think this table is unnecessary, as the mixing ratios (right hand column) are clear from the names of the simulations alone (left hand column). I suggest that the mixing ratio column is included in Table 2 between the ‘Simulation’ and ‘$f_T(H)$’ columns instead. The text in the caption can then be folded into the main text, e.g., around line 104, such that the number of simulations, the full definition of PAL, the model surface pressure, and the information about the other boundary conditions is not lost.

Figure 2 caption: Suggest “against the atmospheric mixing ratio of O_2 **at the surface** in terms…”

Thank you for the opportunity to review this paper, and I look forward to seeing it published in due course.