Dear Jens-Uwe Grooß and Referees,

Thank you for reviewing our revised manuscript and offering your support for its publication.

We have made changes following the referee suggestions and included (below) is a line-by-line response to Referee #2.

Yours sincerely,

Alex Tardito Chaudhri and David Stevenson

Responses to Referee #2:

RC: The authors may wish to discuss whether the mismatches observed in tropical regions are partly driven by uncertainties in input data (in addition to parameter choice and process representation), which can significantly influence modeled seasonal cycles. Paulot et al. (2024), for example, show (Fig. 3a) that the GFDL moisture dataset produces a single harmonic in the tropics, similar to the authors' prototype scheme using ERA5, whereas the GLDAS dataset yields a double harmonic, consistent with the best-fit scheme. These double peaks likely correspond to the transitions between dry and wet seasons, which align well with the authors' best-fit findings.

ATC: This is an insightful connection to make between these works. Some extended explanation added:

(ln 283) The double peak in the deposition seasonality of BF1 in the tropics (Figs. 8d, e) suggests that the fastest uptake may occur coincidentally with the ITCZ crossing the equator at the equinoxes (Fig. 8) rather than when the ITCZ is furthest from the equator, as in the prototype scheme. This implies that BF1 may reflect soil-moisture processes not captured in the prototype scheme. Paulot et al. (2024) have recently shown how a deposition scheme driven by three-hourly varying soil parameters from the Global Land Data Assimilation System (Rodell et al., 2004), and a low soil moisture activation threshold for bacterial uptake, produced a double-peak in H_2 in the tropics and better captured NH H_2 seasonality. This is distinct from their base simulation driven by monthly soil moisture, where NH sub-tropical H_2 peaked three months earlier than observations, comparable with the prototype scheme driven with monthly-mean ERA5 data in this work (Fig. 4b).

Minor:

RC: Line 19: consider rephrasing as "...contributes to the formation of the greenhouse gas ozone...".

ATC: Thank you for this suggestion, this is a clearer statement as the contribution to ozone formation involves a series of reactions. Becomes:

(ln 19) Hydrogen oxidation by OH additionally contributes to the formation of the greenhouse gases ozone and water, with the latter having a significant warming effect in the otherwise dry stratosphere (Sand et al., 2023; Warwick et al., 2023).

RC: Lines 27–31: This doesn't read clearly at the moment. The long-term H_2 trend linked to CH_4 is clear; what remains less clear are shorter-term fluctuations, likely reflecting anthropogenic emissions and soil uptake increase/reduction.

ATC: Thank you for pointing out this distinction between explanations for long-term trends and sub-decadal fluctuations. I think it is useful to refer to Derwent et al. (2023, Atmospheric Environment) and Paulot et al. (2024, ACP) here:

(ln 29) Multi-decadal increases in H_2 can mainly be attributed to increases in methane oxidation, while sub-decadal variations are more related to changes in the soil sink and H_2 emissions (Derwent et al., 2023; Paulot et al., 2024).

RC: Line 68: clarify that "diffusion" refers to atmospheric (turbulent) dispersion, not soil diffusion.

ATC: for clarity this is changed to:

(ln 67) … and atmospheric dispersion parameters tuned based on reproducing the observed SF_6 distribution.

RC: Line 74: the estimate that only ~1% of bacterial biomass is hydrogen-oxidizing may be outdated. Greening and Grinter (2022, Nat. Rev. Microbiol) report up to 40% in forest soils and up to 90% in deserts.

ATC: these new results are very important, in particular the recent findings of the ubiquity of the hydrogen oxidising community needs to be recognised clearly (Bay et al. 2021 and Greening and Grinter (2022) added as references). Becomes:

(ln 71) H_2 oxidising bacteria are ubiquitously distributed in soils (Schlegel, 1974; Khdhiri et al., 2015; Greening et al., 2016; Ji et al., 2017; Bay et al., 2021; Greening and Grinter, 2022).

RC: Line 95: you may want to comment that you assume proportionality to h·f·g, but in the widely used formulation of Ehhalt and Rohrer (2013), deposition velocity scales as (h·f·g)^0.5.

ATC: Thank you for pointing out that this is a useful note for the reader, their scaling with (fgh)^1/2 solution comes about for moist soils where the diffusive depth is limited. This paragraph becomes:

(ln 88) Analytically, the resultant H_2 uptake is the parallel sum of the potential flux limited by biological activity with the potential flux limited by diffusion (Bertagni et al., 2021). However, that formulation would require accurate quantification of each flux. Alternately, Ehhalt and Rohrer (2013) have formulated deposition velocity in moist soils to vary with (fgh)^1/2. However, in this work, the objective of the prototype scheme is to capture the seasonality in these processes while facilitating an analysis of how these processes drive the planetary H2 distribution. Therefore, we adopt an idealised formulation where the total uptake is proportional to the product of the normalised terms, fgh, and is scaled to achieve a total 57.2 Tg yr−1 average deposition (following Sand et al., 2023).

RC: Figure 2: H_2 should not be italicized.

ATC: fixed in figure.

RC: Line 109: suggest rephrasing "carefully handled"

ATC: rephrased for style improvement:

(ln 108) The effects of diffusive barriers are diagnosed by Bertagni et al. (2021). Their presence has the strongest limiting effect where the underlying soil diffusivity is highest but this is masked where the biological uptake is strongly limited due to lack of soil moisture, or by cold temperatures where there is snow cover.

RC: Table 2: h, f, and g are dominant not only in Bertagni's formulation but also in that of Ehhalt and Rohrer.

ATC: E+H (2013) now cited in Table 2.

RC: Figure 8: the hatched regions in panel a are hard to distinguish when printed; also, I couldn't understand if the arrows should reach the "target" values, as these don't match those in panel c.

ATC: hatches now produced in red (more clear on the blue-green-brown colouring) and figure caption re-written for clarity:

Figure 8. (a-c) Colours show R_{BF} (Equation D1), which measures the performance of adjusted versions of the prototype deposition scheme at reproducing the best-fit deposition scheme, BF1. R_{BF} = 1 when the adjusted scheme performs as well as annual mean deposition with no seasonality, and R_{BF} = 0 when the deposition scheme reproduces BF1. In (a), only the amplitude of the deposition seasonality is adjusted, by scaling with a multiplier, α. In (b), only the timing of the deposition seasonality is adjusted, by including an offset, Δt. Arrows indicate optimal adjustments at the latitudes of peaks in deposition seasonality in the prototype scheme (annotated A: 18◦S, B: 13◦N and C: 52◦N in each panel, see Fig. 7a) when α and Δt are adjusted individually. (c) the optimal R_{BF} achieved at latitudes A, B and C when α and Δt are adjusted jointly. Seasonality of deposition for the prototype and BF1 schemes, integrated across three latitude bands: (d) 0-30°S; (e) 0-30°N; and (f) 30-60°N.

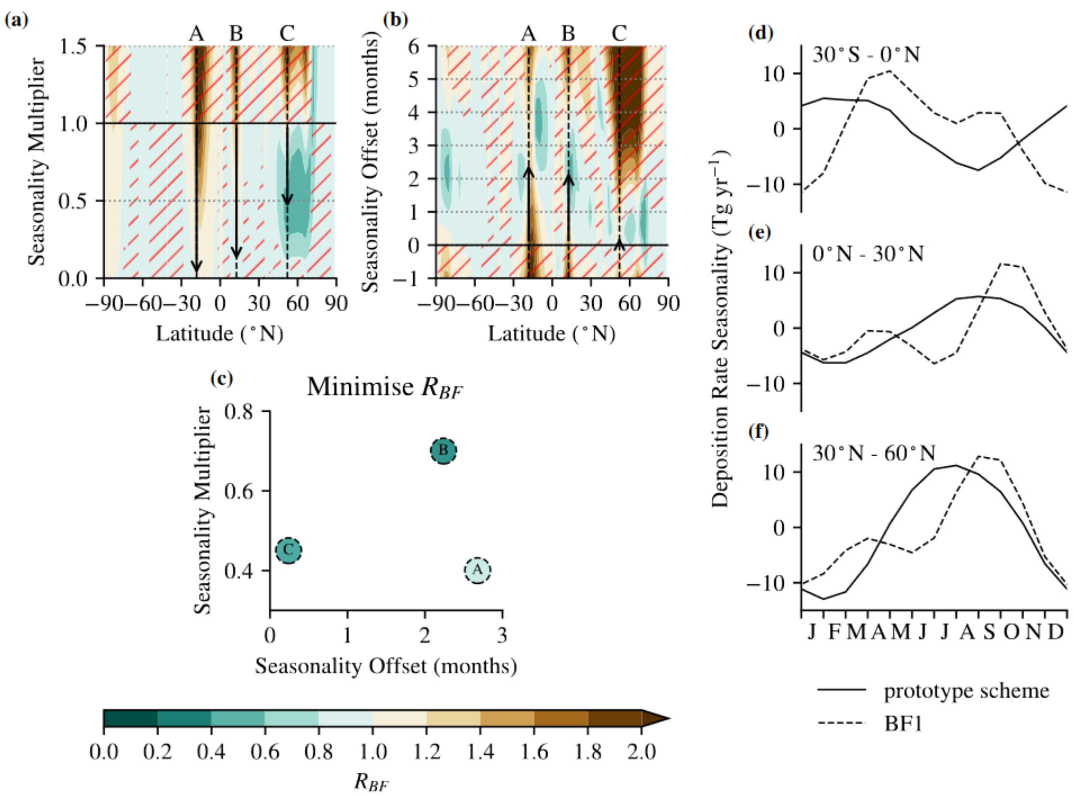

Figure 8. (a-c) Colours show R_{BF} (Equation D1), which measures the performance of adjusted versions of the prototype deposition scheme at reproducing the best-fit deposition scheme, BF1. $R_{BF} = 1$ when the adjusted scheme performs as well as annual mean deposition with no seasonality, and $R_{BF} = 0$ when the deposition scheme reproduces BF1. In **(a)**, only the amplitude of the deposition seasonality is adjusted, by scaling with a multiplier, α. In **(b)**, only the timing of the deposition seasonality is adjusted, by including an offset, Δt. Arrows indicate optimal adjustments at the latitudes of peaks in deposition seasonality in the prototype scheme (annotated A:18°S, B:13°N and C:52°N in each panel, see Fig. 7a) when α and Δt are adjusted individually. **(c)** the optimal RBF achieved at latitudes A, B and C when α and Δt are adjusted jointly. Seasonality of deposition for the prototype and BF1 schemes, integrated across three latitude bands: **(d)** 0-30°S; **(e)** 0-30°N; and **(f)** 30-60°N. ~~The ratio R_{BF} (Equation D1) measuring how well adjusted versions of the prototype deposition scheme perform at reproducing the best-fit deposition scheme, BF1. (a) the prototype deposition seasonality is scaled by a multiplier, α; (b) the deposition seasonality is offset in time by Δt; and (c) minimum R_{BF} achieved when α and Δt are varied at the latitudes of peaks in deposition seasonality in the prototype scheme (annotated A:18°S, B:13°N and C:52°N in each panel, see Fig. 7a). Arrows indicate adjustments that improve the performance at latitudes A,B and C, hatches indicate where the adjusted deposition schemes perform worse than the prototype scheme.~~

RC: Figure 8e: I like this panel, showing a clear double peak instead of the expected single maximum, consistent with the comment above.

ATC: this shows that the best-fit in broad bands that are unconstrained by the theoretical seasonality reproduce a deposition seasonality reflecting the dry-wet tropical seasons. Please see main response above.

RC: Lines 389–390: I strongly support the authors' call for more hydrogen observations in tropical environments (atmosphere and soil both).

ATC: I am optimistically looking forward to efforts from the observation community to achieve this.