We thank the editor for her constructive comments on this article. We provide a point-by-point response to the comments below.

Editor comments

1. Reviewer #1 suggested a comparison between the derived deposition velocities with observations. You indicate that this comparison was previously done in Paulot et al. (2021) and that you are using the same soil sink scheme. However, the input data being used here differs from that in Paulot et al., and hence the performance may differ. I agree with the reviewer here that a comparison with observations and/or Paulot et al. is warranted.

Indeed, due to differences in the input data, resolution, and time period, differences in the resulting deposition velocity are to be expected. It is not possible to make a direct comparison with the results of Paulot et al. (2021) and related studies, as none of the data presented in that manuscript are publicly available. However, we have now included a map showing our average deposition velocity with the same colour scale as in Figure 2 of Paulot et al. (2021). This map can be found in the supplement, alongside a plot of the zonal mean deposition velocity that allows further comparison with the results presented by Paulot et al. (2021). We added a paragraph to section 2.2 in the main text briefly discussing these figures: namely, that

'The global distribution of the H_2 deposition velocity averaged over the 2012 to 2021 period resembles the maps presented by Paulot et al. (2021), but with more pronounced extrema (Figure S1 in the supplement). The zonal mean of the H_2 deposition velocity over land also falls within the range of results reported by Paulot et al. (2021). However, the local minimum around 20°N, due to the Sahara, and the maximum around 10°N, where the transition to more humid regions favours soil uptake, are more distinct in this study than in most of those shown by Paulot et al. (2021) (Figure S2 in the supplement). Thanks to extensive observational records of atmospheric hydrogen concentrations at stations around the world, it is possible to carry out detailed validation of hydrogen deposition based on the resulting concentrations. This method, presented in the following sections, is more informative than local deposition analysis because it is less susceptible to significant variations in surface conditions and is based on a much larger database.'

The deposition data used in our simulations and presented in the figures is now available in the Edmond Open Research Data Repository of the Max Planck Society. We now also emphasise that validating the resulting atmospheric concentrations is more informative than analysing the local deposition, since the former is less affected by strong variations in surface conditions and has a much larger observational database.

2. Reviewer #2 made a comment on the use of the wording "long term" in the title, given that the simulation performed here is a timeslice (albeit with time-varying meteorology). With respect, I do not agree with the statement "We think that the wording long-term is still justified, since we are using flux boundary condition for H_2 and CH_4 emissions." The emissions and the soil sink used are representative of only a single year and used repeatedly throughout the equilibrium simulation. As a result, the simulation performed for this study will not capture changes in secondary production of hydrogen, for example, as would arise if the simulation was transient and using time-varying emissions. Therefore, I kindly ask that you adjust your title

accordingly and that you remove "long term" in the main text based on Reviewer #2's second comment (i.e., about Line 4 of original manuscript).

We thank the editor for this comment. The title has been changed accordingly: 'Global atmospheric hydrogen chemistry and source-sink budget equilibrium simulation with the EMAC v2.55 model'. The abstract has been modified: 'Extensive global equilibrium simulations were performed with a horizontal resolution of 1.9 degrees. The results of this simulation are compared with observational data from 56 stations'. We think that the formulation extensive is justified, since the simulation, including spin-up time, covers 18 years (2006 - 2023). Actually, if we would here also account for the time to gain improved initial conditions for the atmospheric methane concentration, this time is even longer (34 years, 1990-2023). In the paper the spin-up time (2006-2009) refers to the time that is needed to adjust the hydrogen ocean source according to literature recommendations and the slight scaling of the soil sink (in comparison to Paulot et al. (2021)).

3. Linked to the request above is a request to add greater clarity around the simulation set up. For example, the text states "the model experiment covers the time period 2006–2023". This is misleading and should be changed to something like "The model experiment is representative of the present-day (Year 2020) and uses meteorology for the years 2006-2023, with the first three years used as spin-up time."

We follow the suggestion and have changed accordingly: 'The model experiment is representative of the present-day (i.e. the year 2020) and uses meteorology for the years 2006-2023, with the first four years used as spin-up time'. The spin-up time has been corrected. It is four years 2006-2009.

4. It is still unclear what criteria were used to determine which sites fall into which categories (i.e., well mixed polluted/unpolluted) based on Reviewer #2's request – may I please ask that you expand on this?

We thank the editor for this comment. The stations are now characterised as marine, polar, mountain, or none of these categories. Generally, the nature of the measured air masses is discussed along the line of the sites characterisations. It is clarified that the station network is predominantly measuring remote or free tropospheric air masses. Furthermore, sites impacted with high air pollution are more clearly identified. The terms well-mixed and unpolluted are completely omitted from the manuscript. It's briefly discussed that the very low number of continental, non-mountain sites limits the networks ability to evaluate the H_2 soil sink in more detail.

We modified lines 9-12 as: ' Time series comparison of EMAC and observational data produces Pearson correlation coefficients (r) in excess of 0.9 at eight remote stations located in polar region and on high mid latitude islands. A further 23 sites yielded correlation coefficients between 0.7–0.9, predominantly located in remote marine stations across all latitudes and also in polar regions.'

We replaced lines 182-192 by: '38 of the 56 stations have marine characteristics (Table A1 and Fig. 1), i.e. are located coastally or on islands. 11 sites can be described as polar (latitude $\geq |60°|$), and 14 stations are positioned on mountains (i.e. a single site might have several characteristics). These stations usually measure remote, often marine air masses or free tropospheric concentrations. Just 8 sites Hungary (HUN), Mongolia (UUM) , CIBA (CIB, northern central Spain), Shangdianzi (SDZ, China), Wendover (UTA, Utah), Southern Great Plane (SGP, Oklahoma), Israel (WIS), and Gobabeb (NMB, Namibia) fall in neither of those categories. Inner continental non-mountain stations are sparse, with none in South America and Australia. The two continental stations in Africa (ASK, and NMB) are located in the desert. There are also no sites in Central Asia. The three Mediterranean stations (CIB, LMP, and WIS) and the continental Chinese (SDZ) and Mongolian (UUM) sites are located in or close to areas with high air pollution (Lelieveld et al. (2002); Silver et al. (2025)). The Bukit site (BKT, Indonesia) is regularly impacted by biomass burning and peat fires (Yokelson et al. (2022)).

Across these 56 observational stations, the Pearson correlation coefficient (r) exceeds 0.9 for eight remote stations located either in the Arctic or Antarctic regions and on islands on high mid latitude. In such cases, the annual cycle of H_2 is modelled excellently in terms of magnitude, amplitude and seasonality. In contrast 9 stations produce correlation coefficients below 0.5. The three stations in the Mediterranean region CIB (-0.17), LMP (0.05) and WIS (-0.29) and the Chinese and the Mongolian sites SDZ (-0.2) and UUM (0.03) show coefficients close to zero or even negative. Negative r values suggest that the EMAC model does not correctly capture the phasing of the annual H_2 cycle which results in pronounced phase mismatches or anti-correlation in Table B1 and Figures 2, B1, and B2. These sites are located in regions known for levels of high air pollution. The two tropical coastal stations BKT (0.14) and Natal (Brazil, NAT 0.14) do show rather low r values compared to other tropical stations. They are impacted by biomass burning (i.e. NAT) and peat fire emissions (i.e. BKT). The comparison at the Hungarian station (HUN, 0.39) shows a considerably lower r value compared to the other two central European stations Hohenpeissenberg (HPB, 0.56) and Ochsenkopf (OXK, 0.64). HPB and OXK are mountain stations and less susceptible to local mismatch in H_2 soil deposition, as can be seen from the much better match of amplitude and phase. The Christmas Island site (CHR, 0.43) is the only very remote tropical island station, which has a considerably low r value. There the observational time series is relatively short with hardly any annual cycle. '

We modified lines 194-195 as: 'The remaining 16 stations produce correlation coefficients between 0.5–0.7'

We changed line 221 to: 'experience remote air masses'

We added in line 243: 'As mentioned above, the H_2 observational stations do not represent the inner region of continents well. Especially, the small number (UTA, SGP, UUM) of remote non-mountain, non-hyperarid sites, placed away from highly anthropogenically influenced regions limits its usage in looking in more detail on the parametrisation of the soil sink. At Wendover (UTA, Utah, arid cold climate, $r = 0.82$) and the Southern Great Planes (SGP, Oklahoma, humid subtropical climate, $r = 0.77$) shown in Figure 2, the model performs well. By realistically representing the magnitude, amplitude and seasonality, of the measurements this indicates that the soil sink parametrisation of H_2 is realistic in those regions. The poor results at the Mongolian site (UUM, arid cold climate, $r = 0.03$), Fig. B2, might be partly attributed to a resolution effect (see above).'

We modified line 307 as: 'remote observational stations and for sites measuring remote and free tropospheric air'

Furthermore, Tables A1 and B1 are supplemented with site characterisation details.

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