Review of MS entitled: "Soil Deposition of Atmospheric Hydrogen Constrained using Planetary Scale Observations" by Chaudhri and Stevenson

General Comments:

This manuscript presents a novel method to optimize atmospheric H_2 deposition modeling using zonal-mean seasonality from the NOAA H_2 dataset. By applying high- and low-pass filtering to perturb a prototype deposition scheme based on soil temperature and moisture dynamics, a "best-fit" scheme is identified that more accurately reproduces observed H_2 patterns. The findings reveal a necessary +3-month shift in microbial consumption seasonality in the tropics, underscoring the need for improved H_2 flux constraints in low-latitude regions.

While the proposed observation-based methodology offers valuable insights into H_2 deposition, several critical concerns must be addressed to ensure the robustness of the findings.

First, the sensitivity of the "best-fit" estimates to assumptions about the spatial and temporal distribution of the OH sink remains unclear. Given that OH chemistry is derived from a single model with prescribed H_2 and CH_4 concentrations, how can the deposition sink be effectively disentangled from the chemical sink? Could variations and uncertainties in OH fields also influence the zonal-mean seasonality? Despite H_2's relatively long lifetime with respect to OH, the spatial and temporal heterogeneity of OH should be considered interactively.

Second, beyond microbial uptake and soil diffusion, could other processes influence deposition? For instance, could atmospheric turbulence and its variability across latitudes contribute to seasonal variations?

Third, how does the 2D model compare to seasonal patterns from 3D simulations? Would leveraging 3D model outputs (e.g., Sands et al., 2023) provide a more appropriate framework for optimizing deposition?

Fourth, strengthening the manuscript's impact would require presenting site-specific seasonality for all measurement sites, not just Mace Head. This would better highlight regional differences and their connection to zonal-mean anomalies.

Finally, for the method to be reproducible, it would be best to elaborate on the rationale behind specific assumptions and thresholds, as well as describe the uncertainties on derived quantities of the filtering algorithm (e.g., phase and amplitude).

Specific Comments:

Line 55: "we assume that the general effect of these fluxes is well approximated when they are modelled in their zonal-mean monthly-mean". How valid is this assumption? Can you please elaborate.

Line 71: Can you please elaborate on the 'spatial filtering' used?

Figure 1 caption (also Line 95-97): What is the rationale behind choosing 20 ppb for the RMS error threshold for it to be an anomaly? Same for the Gaussian filter of σ=5 degrees latitude.

Line 78-84: How sensitive are your findings to assumptions on timescales (<30 days and 1 year) for these filters? How robust is this method if other filtering methods are applied (e.g., singular spectrum analysis – SSA, Seasonal Trend decomposition using Loess – STL)?

Line 101: "The seasonal H_2 signal does not depend significantly on zonal variations in local deposition." Why do you think this is?

Line 106-108: "This supports the assumption that the deposition into soils is dominated by the larger land area of the NH, where this soil sink exceeds anthropogenic emissions and the net source of H_2 from atmospheric chemistry (Paulot et al., 2021)." Can this be attributed as well to variations in OH in NH, tropics, and SH?

Line 129-140: How large is the influence of diffusion into soil on deposition relative to microbial activity? Aren't these processes coupled in reality?

Line 155-160: While the 2D model is justified, what would be the sensitivity to the best fit when 3D models are used?

Line 176-180: What is the physical rationale behind the choice of assuming that fluxes are independent to H_2 mixing ratio?

Line 197-200: Interesting finding regarding the cross-term. Why do you think this is the case?

Line 217: How sensitive would the best fit to assumptions/representations of P and rD, and M?