Comments

This manuscript presents a Bayesian inversion of the global methane budget based on a harmonized 35-year dual-isotope dataset ($\delta^{13}C–CH_4$ and $\delta D–CH_4$). By combining a two-box model with a discrete parameter tuning (DPT) approach, the study demonstrates the added value of $\delta D–CH_4$ in constraining methane sources and sinks. The work is methodologically innovative and addresses the ongoing debate on the drivers of global methane growth since 2006. The manuscript is clearly structured and merits publication after consideration of the points raised below.

Major Comments

1. Tropical and low-latitude regions dominate global methane emissions and oxidation. The division of the globe into two hemispheric boxes at the equator (Fig. 1), together with the markedly different hemispheric source isotopic signatures listed in Table 1, implies that the same source type in the tropical region may be assigned substantially different isotopic values north and south of the equator. Given the large contribution of tropical methane to the global budget (some studies suggest on the order of 60–65%), the authors should discuss whether this structural simplification could introduce biases or otherwise influence the inferred global emissions and their temporal trends.

2. The posterior emissions shown in Figures 3 and 4 exhibit substantial interannual variability, particularly for wetlands, where year-to-year changes can exceed 50 Tg. It would be helpful to clarify whether these fluctuations are interpreted as reflecting true physical variability (e.g., climate-driven wetland dynamics), compensatory adjustments among sources within an underdetermined inversion, or artefacts arising from the two-box framework or the adopted prior uncertainty settings.

3. The DPT methodology is a key strength of the study. However, the physical basis for the chosen acceptance threshold (mean normalized RMSE < 0.1) requires further clarification. Please indicate what typical absolute residuals (in ‰) for $\delta^{13}C–CH_4$ and $\delta D–CH_4$ this threshold corresponds to, and discuss whether modest adjustments to this cut-off value would materially affect the main conclusions regarding source partitioning and long-term trends.

4. The adopted fossil fuel δD signatures (–192‰ for the Southern Hemisphere and –191‰ for the Northern Hemisphere) are consistent with a global average, yet regional variations are known to exist (e.g., with latitude, and among conventional gas, coal, and shale gas). Given that a key conclusion of the study is that including $\delta D–CH_4$ reduces the inferred growth in fossil fuel emissions, a brief discussion of the sensitivity of this conclusion to potential systematic shifts in the assumed fossil δD signature would be valuable. For example, could a systematically heavier fossil δD signature permit a larger fossil fuel contribution while still reproducing the observed atmospheric δD trend?

5. $\delta D–CH_4$ is highly sensitive to oxidation kinetics, yet the two-box model aggregates tropospheric oxidants (e.g., OH and Cl) and does not resolve their latitudinal gradients. While these limitations are acknowledged in Section 4.6, the manuscript would be strengthened by more clearly distinguishing which major conclusions (such as the dominance of biogenic

methane growth after 2006) are likely robust at the global scale, and which may be more sensitive to the simplified representation of hemispheric transport and oxidation processes.

Minor Comments

1. Please clarify the usage and grouping of the terms thermogenic, pyrogenic, and fossil throughout the manuscript to ensure consistency (e.g., specifying whether "fossil" is treated as a subset of "thermogenic").

2. Line 252: "GIANS" should be corrected to "GAINS".

3. Line 366: "DTP" should be corrected to "DPT".

4. Upon first use, please spell out "RMSE" before using the abbreviation.

5. Given that the isotope dataset is dominated by high-latitude monitoring sites, a brief discussion of how representative these constraints are for tropical emissions would further strengthen the interpretation.