Author's Response to the Interactive Comments on **"Assessment of WRF-GHG Model Simulations during the CAFE-Brazil Campaign in Amazonia"**

We thank the anonymous reviewer for their constructive and valuable comments, which helped us improve the clarity and focus of the manuscript. Below, we address each point raised.

Reviewer Comment 1:

"The conclusion that meteorological uncertainty dominates the model-observation discrepancies is plausible and well argued qualitatively, but no experiment is carried out to prove it. A modest sensitivity runs, for example, perturbing wetland flux magnitude while holding meteorology fixed or having the same flux but different parameterization scheme."

Author Response:

We thank the reviewer for the insightful comment. Meteorological uncertainty primarily governs the temporal variability of CH_4, while uncertainty in wetland fluxes predominantly controls the magnitude of the model–observation bias. We have clarified this distinction in the manuscript and expanded the analysis to separately quantify the contributions of each source of uncertainty, thereby making the underlying mechanisms clearer and more transparent.

To quantify the contribution of transport errors to the CH_4 bias at ATTO, we performed a Spearman correlation analysis between absolute CH_4 bias and three transport variables (wind direction error, wind speed error, PBL height error) for all daytime events ($N = 123$). Wind direction errors show no significant correlation with CH_4 bias ($r = -0.06$, $p = 0.53$), while wind speed ($r = -0.34$, $p < 0.001$) and PBL height errors ($r = -0.39$, $p < 0.001$) contribute independently ($r\_partial = -0.33$ and -0.38). Together, the three variables explain 14% of the total CH_4 bias variance (multiple regression $R^2 = 0.14$). The remaining ~86%, combined with large residuals under correctly classified SE→SE transitions (Fig. 1B) and systematic overestimation under easterly winds (Fig. 2), points to wetland flux uncertainties as the dominant source of mean bias. This analysis was included in the manuscript as described below.

To quantify the contribution of wetland flux uncertainty to the magnitude of the CH_4 bias, we performed a flux sensitivity analysis; the eight wetland configurations — Kaplan, CAMS-Inversion, and six WetCHARTs members — were run with identical meteorological fields and boundary conditions, differing only in wetland fluxes. The bias decomposition (Fig. 3) shows that the biogenic wetland contribution ranges from 32.0 ppb (CAMS-Inversion) to 89.1 ppb (Kaplan), demonstrating that wetland flux choice is the main source of inter-inventory spread in mean bias.

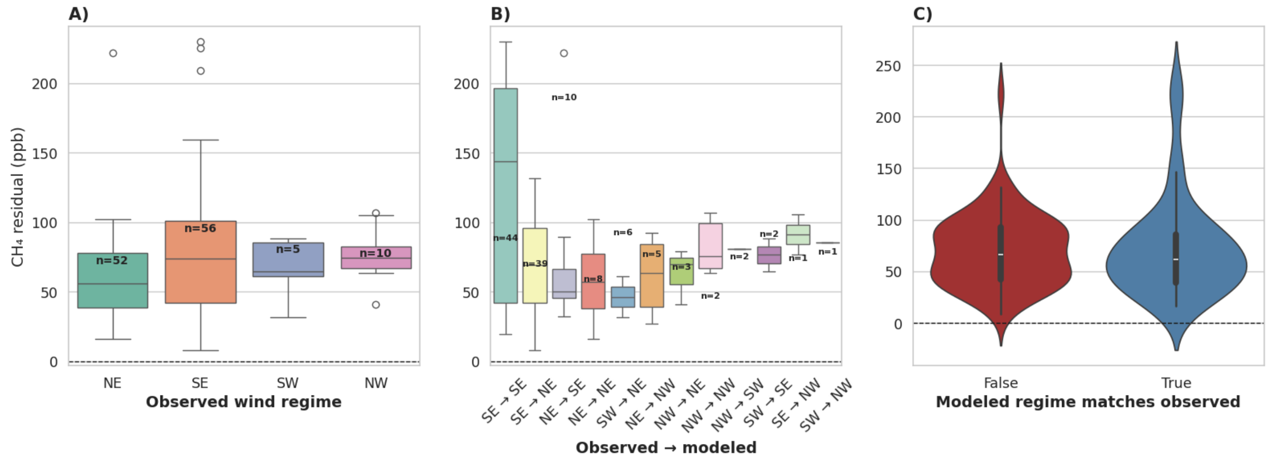

Figure 1. CH_4 residual [ppb] as a function of wind regime classification at ATTO during January 2023. (A) Box plots of CH_4 residuals grouped by observed wind regime (**NE, SE, SW, NW**) for the daytime period (N=123). (B) CH_4 residuals grouped by observed-to-modeled wind regime transitions, showing cases where the model correctly reproduces the regime (e.g., SE→SE) and cases where it does not (e.g., SE→NE). (C) Violin plots comparing CH_4 residuals for events where the modeled wind regime matches the observed (True) versus events where it does not (False), for the daytime period. The dashed horizontal line indicates zero residual. The simulated CH_4 concentration is from the Kaplan model.

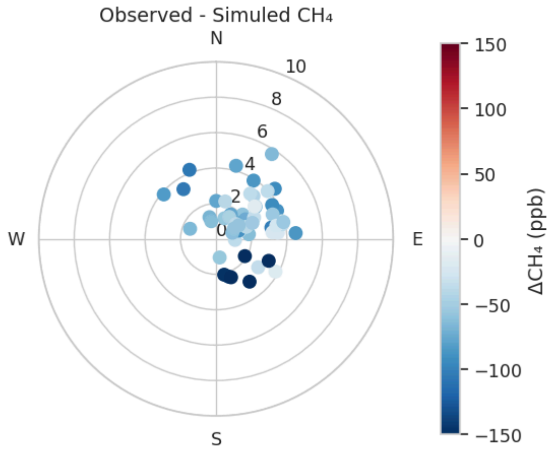

Figure 2. Polar plot of the difference in CH_4 mole fractions (ΔCH_4 = observed − simulated, ppb) as a function of wind direction and wind speed at ATTO during January 2023 for the daytime period. Each point represents an hourly mean, with radial distance indicating wind speed (m s^{-1}) and color indicating the CH_4 difference. Positive values (warm colors) indicate that observations exceed model simulations, whereas negative values (cool colors) indicate model overestimation. The largest negative residuals occur under easterly wind conditions (approximately 80°–120°), suggesting a systematic model overestimation associated with air masses transported from wetland source regions upwind of ATTO.

However, flux differences do not explain the excessive simulated CH_4 variability. CAMS-Inversion and WetCHARTs prescribe constant monthly fluxes, while Kaplan includes a diurnal emission signal, yet all configurations produce similar diurnal concentration cycles. To quantify this, we calculated the daily CH_4 diurnal range by atmospheric stability using observed PBL height. Simulated variability was ~6–13 times larger than observed across all stability classes (Stable: 69 vs. 12 ppb; Moderate: 85 vs. 15 ppb; Convective: 71 vs. 6 ppb). Neither observed PBL height nor PBL-height bias correlated significantly with simulated variability ($r = -0.03$, $p = 0.89$; $r = +0.05$, $p = 0.84$). The model also misclassified stability on 65% of days and overestimated PBL height by ~400–600 m across stability classes.

These results indicate that the excessive CH_4 variability is not explained by PBL-height errors or emissions and is more consistent with episodic horizontal transport, particularly nocturnal advection of CH_4 from the Amazon River. For example, on 20 January, the simulated diurnal variability was 176 ppb compared with only 6 ppb observed (Fig. 7). Thus, adjusting wetland flux magnitude alone is unlikely to correct the temporal variability. The role of canopy–atmosphere coupling and surface parameters such as canopy height and roughness length, which may affect turbulent mixing and the vertical distribution of transported CH_4, should be investigated in future work.

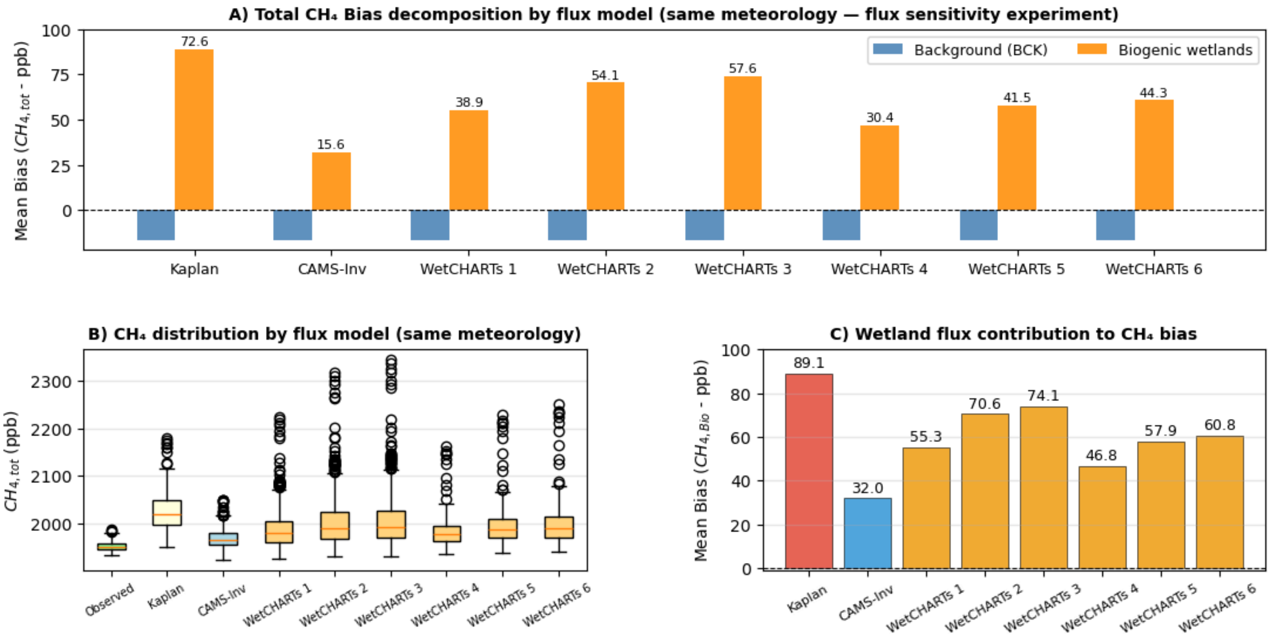

Figure 3. CH_4 bias decomposition by wetland emission inventory at ATTO during January 2023. (A) Mean bias decomposition showing the contributions of the prescribed large-scale background (CAMS boundary conditions, blue) and the biogenic wetland component (orange), for each inventory configuration. All simulations share identical meteorological fields, boundary conditions, and non-wetland flux components — the only difference between experiments is the wetland CH_4 flux magnitude. (B) Distribution of total simulated CH_4 mole fractions by inventory compared to observations (green), showing the dispersion introduced by flux choice alone. (C) Mean biogenic wetland contribution to CH_4 bias by inventory, with transport held fixed across all configurations.

<u>Changes in the manuscript:</u>

The attribution analysis and the bias decomposition analysis presented in Fig. 1 have been incorporated into Section 5.2.2 of the revised manuscript (lines [402-451]), while Fig. 1, Fig. 2, and Fig. 3 are provided in the Supplementary Material as Fig. S16, Fig. S17, and Fig. S19, respectively.

Current text to be replaced (Section 5.2.1, lines ~418-429):

"Discrepancies between observed and simulated CH4 mole fractions may also have a contribution of the simulated wind field…"

Replaced text:

To quantify whether the excessive simulated variability could be explained by differences in atmospheric stability, we calculated the daily CH_4 diurnal range as a function of observed PBL height. The simulated diurnal variability was approximately 6-13 times larger than observed across all stability classes (Stable: 69 vs. 12 ppb; Moderate: 85 vs. 15 ppb; Convective: 71 vs. 6 ppb). Neither observed PBL height nor PBL-height bias showed a significant correlation with the simulated CH_4 diurnal range ($r = -0.03$, $p = 0.89$ and $r = 0.05$, $p = 0.84$, respectively). These results indicate that the excessive temporal variability cannot be explained solely by the representation of boundary-layer depth. The model also misclassified the observed stability regime on approximately 65% of days and overestimated PBL height by approximately 400-600 m across the stability classes. Although this systematic PBL-height bias can affect atmospheric dilution and therefore contribute to the mean CH_4 bias, its lack of correlation with the simulated diurnal range indicates that it does not explain the excessive sub-daily variability.

To quantify the relative contributions of background, wetland emissions, and atmospheric transport to the CH_4 bias at ATTO, we performed two complementary analyses for all daytime events ($N = 123$). First, a bias decomposition across the eight inventory configurations, which share identical meteorological fields, shows that the background contributes a consistent -16.4 ppb across all simulations, while the wetland biogenic component is the dominant and most variable term, ranging from 32.0 ppb (CAMS-Inversion) to 89.1 ppb (Kaplan; Beck et al. 2013), with WetCHARTs members spanning 46.8 - 74.1 ppb (Fig. S19). econd, a Spearman correlation analysis between absolute CH_4 bias and three transport variables shows that wind direction errors are not significant ($r = -0.06$, $p = 0.53$; Fig. S16c), while wind speed ($r = -0.34$, $p < 0.001$) and PBL height errors ($r = -0.39$, $p < 0.001$) both contribute independently ($r_{partial} = -0.33$ and -0.38, respectively), explaining 14% of the total CH4 bias variance (R2 = 0.14). Together, these results indicate that wetland flux uncertainties are the dominant source of inter-inventory spread in mean bias, while transport errors contribute a modest but significant fraction of the residual variance. The remaining ~ 86% of unexplained variance, combined with large CH_4 residuals under correctly classified SE→SE transitions (Fig. S16b), further supports wetland flux uncertainties as the primary source of the mean CH_4 bias.

The polar plots in Fig. S17 provide additional support for this interpretation. The largest CH_4 overestimation occurs under easterly winds, which are associated with upwind wetland sources, despite the absence of a systematic wind-direction error under these conditions. Thus, while errors in wind speed and PBL height contribute to the simulated CH_4 bias, their relatively modest explanatory power suggests that improving the magnitude and spatial distribution of wetland emissions is likely to have a larger impact on reducing the mean model–observation discrepancy. In contrast, the excessive sub-daily variability appears to be more closely associated with episodic horizontal transport, particularly the modeled advection of CH_4 from upwind wetland and riverine regions.

Reviewer Comment 2:

“In result or conclusion manuscript reports: VPRM-cal substantially improves simulated CO2 concentrations, but it does not adequately discuss whether this improvement results from a more realistic representation of biospheric fluxes or from compensation for known transport biases (e.g., overestimated PBL depth and wind speed). Authors should discuss the possibility of error compensation.”

Author Response:

We thank the reviewer for raising these questions, which provide an opportunity to clarify these aspects. In the WRF-GHG model, the interaction between meteorology and biogenic carbon fluxes is a one-way influence only. While the meteorology simulated by WRF dynamically drives the VPRM biogenic fluxes (via temperature and radiation), the calculated CO_2 fluxes and concentrations do not feed back to alter the weather or climate variables within the model. Error compensation in the strict physical sense is therefore not possible within this framework. The calibrated VPRM substantially reduces the mean CO_2 bias by modifying the simulated GPP and respiration. In particular, the calibrated VPRM increases the respiration rate, leading to a larger amount of CO_2 being retained within the canopy and thereby reducing the underestimation of CO_2 mixing ratios.

However. it does not correct the temporal offset in the diurnal cycle. As shown in Fig. 5 of the manuscript, both VPRM configurations exhibit a lag of approximately one hour in the morning CO_2 flushing peak, more pronounced at lower altitudes (24 m and 38 m) and less so at 81 m. This timing error suggests that the model builds the convective boundary layer and erodes the nocturnal stable layer on a different timescale than observed, delaying the morning ventilation of accumulated CO_2 (de Araújo A., 2008). This limitation is independent of the flux parameterization and therefore cannot be corrected through VPRM calibration alone. It does not reflect a compensation between surface emissions and atmospheric dynamics. Rather, the offset is primarily associated with the sensitivity of simulated near-surface mixing to canopy structural parameters, particularly canopy height and roughness length, which control the onset and depth of turbulent mixing within and above the canopy. Although improved estimates of ecosystem respiration can reduce the overall CO_2 bias, they cannot fully compensate for biases arising from the representation of canopy structure and turbulent mixing.

<u>Changes in the manuscript:</u>

The discussion of the one-way coupling between meteorology and biogenic CO_2 fluxes, as well as the diurnal timing offset, was already addressed in the original manuscript. However, some modifications were made. (lines [356-3]).

Current text to be replaced (Section 5.2.1, lines ~356-366):

"The diurnal cycle …"

Replace with:

The diurnal cycle (Fig. 4b) reveals a characteristic early-morning "flushing peak" in observed CO_2 concentrations, corresponding to the rapid release of CO_2 accumulated overnight within the sub-canopy layer (de Araújo A., 2008). WRF-GHG simulates this peak with a lag of approximately one hour, more pronounced at lower altitudes (24 m and 38 m) and diminishing at 81 m (Fig. 5). This altitude-dependent lag reflects a physical process that WRF-GHG does not fully represent: during the night, CO_2 produced by ecosystem respiration accumulates within the sub-canopy layer (<37 m), which remains decoupled from the atmosphere above due to strong thermal stratification and suppressed turbulence (de Araújo A., 2008). At dawn, solar radiation penetrates the canopy progressively from the top downward, so that the sub-canopy air — which holds the largest CO_2 reservoir —is ventilated later than the air above. The WRF-GHG model represents the canopy as a single surface layer without resolving this vertical gradient of light penetration. As a result, all atmospheric layers are ventilated simultaneously at the onset of convection, producing a morning peak that occurs earlier than observed and lacks the altitude-dependent delay seen in measurements. This limitation is independent of the flux parameterization — it cannot be corrected through VPRM calibration alone — and is sensitive to canopy structural parameters, particularly canopy height and roughness length, which govern the onset and depth of turbulent mixing within and above the canopy.

Discrepancies between observations and CO_2 simulations also reflect meteorological limitations identified in Section 5.1. Overestimating PBL depth can dilute near-surface CO_2 during the day, while nighttime mixing biases may reduce CO_2 buildup. Inaccuracies in shortwave radiation affect photosynthesis rates and the daily cycle of CO_2 uptake and release. These transport-related errors contribute to the residual bias in both VPRM configurations, beyond what can be corrected by flux calibration alone.

Reviewer Comment 3:

"The abstract section needs to be rewritten to better highlight the main results of this study. Right now, 30% of the abstract is filled with general information. One recommendation is to emphasize the statistics showing how well the study's observations were reproduced by the WRF-GHG model. Also, highlight the limitation like possibility of error compensation. "

Author Response:

We thank the reviewer for this comment. The abstract has been rewritten to reduce general background information and emphasize quantitative results. The revised abstract now includes: meteorological skill statistics (temperature r = 0.77, wind speed MB = +1.28 m s^{-1}, PBL MB = +93.7 m); CO_2 performance metrics for both VPRM configurations (MB reduced from −16.62 to −1.60 ppm; RMSE from 20.31 to 10.25 ppm); results of the error compensation test (r = −0.20, p = 0.013) with explicit acknowledgment that partial compensation during morning hours cannot be excluded; CH_4 bias range across inventories (+15.6 to +72.6

ppb); aircraft comparison statistics; and the quantitative transport versus flux attribution (~14% transport, ~70 ppb flux dispersion). The revised abstract contains 248 words.

Revised Abstract:

The Amazon Basin plays a pivotal role in the global carbon cycle, yet accurate simulation of greenhouse gas (GHG) transport and surface fluxes remains a major challenge. We evaluate the WRF-GHG model using CO_2 and CH_4 measurements from the Amazon Tall Tower Observatory (ATTO) and aircraft observations from the CAFE-Brazil campaign (January 2023), incorporating MapBiomas land cover, regionally calibrated CO_2 fluxes, and three wetland CH_4 configurations: Kaplan (process-based), CAMS-Inversion (top-down), and WetCHARTs (ensemble). The model captured surface temperature and humidity well but exhibited systematic biases in wind speed and planetary boundary layer height, which affected tracer transport. The regional calibration of VPRM reduced the CO_2 mean bias at ATTO from −16.62 to −1.60 ppm and improved the overall diurnal pattern. However, a persistent ~1-hour timing offset in the morning flushing peak remains, indicating that the model's representation of nocturnal CO_2 accumulation and the transition to turbulent mixing within the boundary layer is still inadequate. For CH_4, all simulations overestimated concentrations at ATTO (biases ranging from +15.6 ppb for CAMS-Inversion to +72.6 ppb for Kaplan), primarily due to limitations in the emission inventories. Furthermore, the temporal variability, particularly the representation of the diurnal cycle, is largely driven by overestimated wind speeds and boundary-layer dynamics, which enhance the transport of CH_4 from upwind wetlands. In the free troposphere, simulated CH_4 was consistent with aircraft observations and dominated by background levels. Within the boundary layer, elevated concentrations reflected biogenic emissions and transport influences. CAMS-Inversion and WetCHARTs best captured regional CH_4 variability. Wetland flux uncertainties accounted for ~70 ppb of the inter-inventory spread, while transport errors explained ~14% of residual bias variance. These results underscore the critical importance of regionally calibrated fluxes and improved boundary-layer representation for accurate GHG modeling in tropical environments.

Reviewer Comment 4:

"The manuscript reports that background accounts for ~95% of simulated CH4 at ATTO, yet all metrics are computed on total mole fractions. Skill statistics therefore largely reflect the quality of the prescribed CAMS fields rather than the model's regional transport or the wetland inventories. I strongly encourage evaluating the background tracer against the above-boundary-layer aircraft legs."

Author Response:

We thank the reviewer for highlighting this important point. We agree that skill statistics on total CH_4 mole fractions, where the background accounts for ~95% of the signal, primarily reflect the quality of the CAMS boundary conditions rather than regional transport or wetland inventories. We evaluated the background tracer against above-PBL legs from the RF15 mission (14 January 2023), identifying 6 valid above-PBL data points (mean PBLH = 496 m) (Fig. 4).

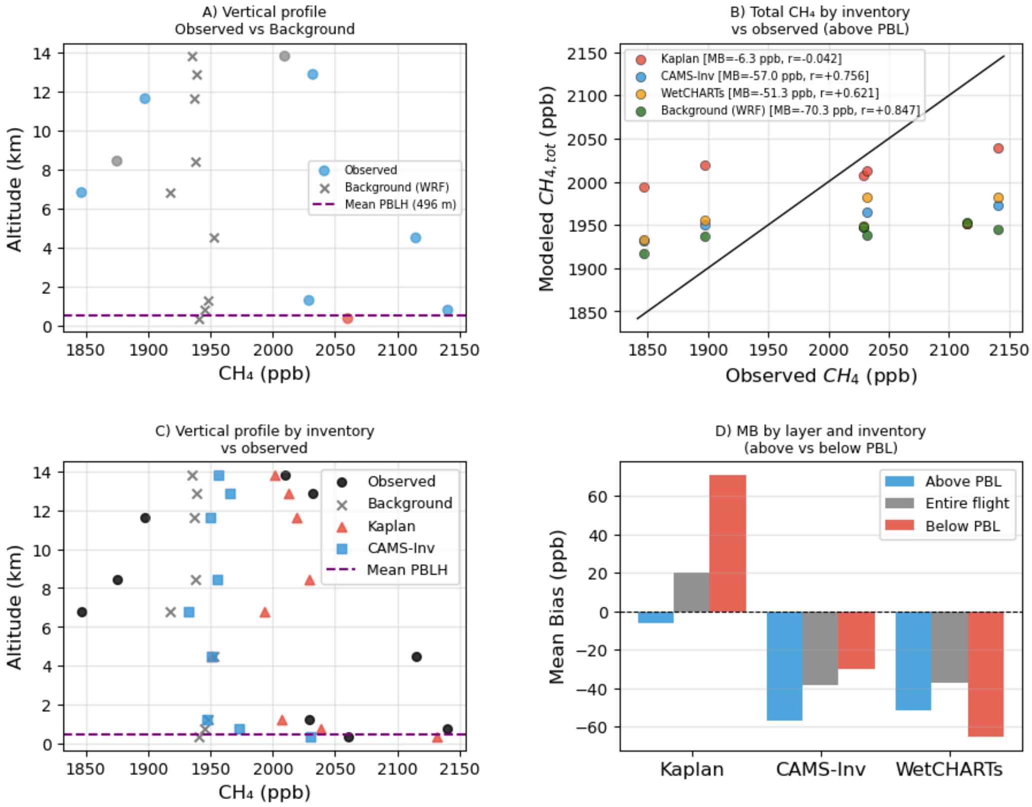

Figure 4. Evaluation of the WRF-GHG CH_4 background tracer against CAFE-Brazil RF15 aircraft observations (14 January 2023). (A) Vertical profile of observed CH_4 and simulated background tracer; dashed purple line indicates mean modeled PBL height (496 m). (B) Simulated total CH_4 by inventory versus observed CH_4 for above-PBL legs (altitude > 1.1 × PBLH); statistics are shown in the legend. (C) Vertical profiles of simulated CH_4 by inventory compared to observations. (D) Mean bias by layer (above PBL, entire flight, below PBL) and inventory. Note that the above-PBL evaluation is based on N = 6 data points.

As shown in Fig. 8 in the main manuscript, the simulated background lies within the observational spread at most trajectory points, including T4 and T5, where it exceeds the observed mean, suggesting that CAMS provides a reasonable large-scale CH_4 representation for this period. Beyond the mean bias, the model shows limited spatial variability compared to observations, a known limitation of regional models in capturing convective vertical motions in the tropics (Beck et al., 2013). A more robust evaluation requires multiple flight days; analysis of the full CAFE-Brazil dataset is currently underway for another student.

<u>Changes in the manuscript:</u>

Discussion revised in Section 5.3 to acknowledge the ~95% background contribution to total CH_4 metrics and to clarify the compatibility of the background with above-PBL observations from RF15. No new figure added

Current text to be replaced (Section 5.3, lines ~465-475):

"Among the different wetland emission inventories, the simulation using WetCHARTs emissions shows the best agreement with the observed data (r = 0.50; MB = -27.1 ppb; RMSE = 92.6 ppb), capturing both the magnitude and the spatial variability of CH_4. Simulations based on CAMS-Inversion also show a reasonable agreement with the observed values (r = 0.45; MB = -38.2; RMSE = 97.9). In contrast, the Kaplan emission model yields poorer results, with simulated CH_4 concentrations that overestimate the observed values (r = 0.09; MB = 19.9 ppb). This discrepancy was already observed in the CH_4 analysis at 81 meters above the

ATTO site, where simulations using the Kaplan inventory produce abnormally high CH_4 concentrations (see Fig. 6). The overestimation can be attributed to the Kaplan inventory's higher methane fluxes, which are based on a larger percentage of inundated areas. This leads to higher CH_4 emissions compared to the other inventories. The simulated background CH_4 concentration component remains nearly constant along the flight path, confirming that the observed CH_4 has reduced vertical stratification and that above the boundary layer, the concentration is homogeneous. A key observation is that the background CH_4 concentration dominates along most of the flight trajectory."

Replace with:

*Among the different wetland emission inventories, WetCHARTs shows the best agreement with observed data (r = 0.50; MB = −27.1 ppb; RMSE = 92.6 ppb), followed by CAMS-Inversion (r = 0.45; MB = −38.2 ppb; RMSE = 97.9 ppb). Kaplan overestimates observed values (r = 0.09; MB = +19.9 ppb), attributable to the larger inundated area extent prescribed in that inventory. We note that these statistics primarily reflect the quality of the CAMS boundary conditions, which account for ~95% of the simulated signal. Evaluation of the background tracer against above-PBL aircraft legs (N=6, mean PBLH = 496 m) shows that simulated concentrations lie within the observational spread at most trajectory points (Fig. 8B), confirming that the background is reasonably represented and that the total model-observation discrepancy at ATTO is not primarily attributable to errors in the prescribed boundary conditions. The model nonetheless shows limited spatial variability compared to observations, consistent with known difficulties in representing convective vertical motions in the tropics (*Beck et al., 2013*). Analysis of the complete CAFE-Brazil flight dataset is currently underway and will provide a more comprehensive background evaluation in future work.*

Response to specific points — Line 70:

"A secondary objective is to evaluate and refine the WRF-GHG model configuration for application in regional modelling over tropical regions, including e.g. downscaling of future climate scenarios, which will be addressed in subsequent work" - Not clear because it is not discussed it at a later stage. Also, the next sentences need a logical connection, right now they highlight separate ideas.

Author Response:

We thank the reviewer for this comment. We agree that the reference to future climate downscaling is beyond the scope of the present study and creates a logical disconnect. We have removed this statement and revised the paragraph to focus on the evaluation and refinement of the WRF-GHG configuration for regional GHG simulations over the Amazon, with an explicit connection between the stated objectives and the three core scientific questions guiding the study.

Current text to be replaced (Section 1, lines ~74-80):

"A secondary objective is to evaluate and refine the WRF-GHG model configuration for application in regional modelling over tropical regions, including, e.g., downscaling of future climate scenarios, which will

be addressed in subsequent work. By adjusting physical parameterizations to better represent the Amazon region, this study proposes a recommended model setup for simulating future conditions and explicitly documents its limitations. This framework provides a robust foundation for modeling net ecosystem exchange under future scenarios and supports further investigations within the context of Shared Socioeconomic Pathways (SSPs)."

Replace with:

In addition, we evaluate key aspects of the model configuration that control the representation of regional GHG variability, including land-surface representation, biogenic CO_2 fluxes, wetland CH_4 emissions, and atmospheric transport. By identifying the strengths and limitations of these components under Amazonian conditions, this study provides a documented modeling framework for subsequent regional applications and sensitivity experiments.

Response to specific points — Line 170:

"For this study, daily emission factors were applied to represent diurnal variations in CO2 and CH4 emissions." -Which emission factor dataset is used here?

Author Response:

We thank the reviewer for pointing out this ambiguity. The term "daily" was imprecise — hourly emission factors were applied specifically to anthropogenic CO_2 and CH_4 emissions from EDGAR v6.0, following the sector-averaged diurnal profile implemented in the PRE-CHEM preprocessor (Freitas et al., 2011). Wetland CH_4 fluxes from CAMS-Inversion and WetCHARTs were prescribed as monthly mean values, constant throughout the day. The Kaplan wetland model calculates emissions online at hourly resolution, responding dynamically to WRF meteorological fields. The manuscript has been corrected accordingly.

Current text to be replaced (line ~170):

"For this study, daily emission factors were applied to represent diurnal variations in CO_2 and CH_4 emissions."

Replace with:

Hourly emission factors from the PRE-CHEM preprocessor (Freitas et al., 2011) were applied to distribute annual EDGAR v6.0 anthropogenic CO_2 and CH_4 emissions into diurnal cycles, using fixed sector-averaged temporal profiles in UTC. Wetland CH_4 fluxes from CAMS-Inversion and WetCHARTs were prescribed as monthly mean values, constant throughout the day, while the Kaplan model calculates wetland emissions online at hourly resolution, responding dynamically to WRF meteorological fields.

Response to specific points — Line 190:

"The full set of VPRM parameters also includes Tmin, Tmax, Topt, and Tlow, which are drawn from the literature to avoid numerical instabilities" Which literature needs citation?

Author Response:

The parameters Tmin, Tmax, Topt, and Tlow were taken from the original VPRM formulation *(Mahadevan et al., 2008)*, which provides default values by vegetation type. The citation has been added to the revised manuscript.

Response to specific points — Line 341:

"VPRM-Ca..resulting in improved representation of temporal variability in CO2 concentrations" More discussion on which specific calibrated parameters (e.g., λ_0, PAR_0, α, or β) are primarily responsible for the observed improvements or how the calibration modifies the representation of different vegetation classes would strengthen the interpretation of the results.

Author Response:

Regarding the specific calibrated VPRM parameters responsible for the improvement: the primary change between VPRM-default and VPRM-cal is the regional calibration of the light-use efficiency parameter (λ_0) and the half-saturation PAR parameter (PAR_0) for Amazonian evergreen vegetation, following Botía et al. (2025). These parameters directly control the magnitude and light-response of GPP, which is the dominant term driving the daytime CO_2 drawdown. The improved agreement with observations under VPRM-cal therefore primarily reflects a more realistic representation of canopy-level photosynthesis rather than transport error cancellation.

Current text to be replaced (line ~341):

"VPRM parameters were optimized by Botía et al. (2025a) (parameters listed in Table S4, supplementary material), resulting in improved representation of temporal variability in CO_2 concentrations. With this calibration, the mean model–observation difference decreased from -16.62 ppm to -1.60 ppm, while maintaining a similar moderate correlation (r = 0.59). Notably, VPRM-cal better captures the nighttime accumulation and daytime drawdown driven by photosynthesis, whereas VPRM-default continues to underestimate both nighttime buildup and daytime mixing ratios (Fig. 4). The effect of VPRM calibration impacts not only the concentration baseline, but also the diurnal amplitude of CO_2 concentrations. The amplitudes estimated by VPRM-cal are closer to the observations."

Replace with:

VPRM parameters were optimized by Botía et al. (2025a) (parameters listed in Table S4, supplementary material), resulting in improved representation of CO_2 temporal variability at ATTO. With this calibration, the mean model–observation difference decreased from -16.62 ppm to -1.60 ppm, maintaining a moderate *correlation (r = 0.59). The primary parameters responsible for this improvement are λ_0 and PAR_0, which directly control the magnitude and light-response of daytime GPP — the dominant term driving the observed diurnal CO_2 drawdown.*

Response to specific points — Line 375:

Many statements are made without proper justification or clear explanation. Like "possibly caused by limitations in the representation of canopy conductance, soil respiration dynamics, or carbon allocation under Amazonian conditions."

Author Response:

The speculative language has been revised. The residual underestimation of daytime carbon uptake by JULES is now attributed to known limitations in the representation of canopy-level processes under Amazonian conditions, as discussed in the site-specific calibration study (Prudente Junior et al. 2025), rather than to an open-ended list of possibilities.

Current text to be replaced (Section 5, lines ~372-375):

"However, VPRM-default underestimated nighttime respiration. Comparing the three carbon flux modeling approaches, JULES showed the best performance, despite the underestimation in the diurnal carbon uptake, possibly caused by limitations in the representation of canopy conductance, soil respiration dynamics, or carbon allocation under Amazonian conditions. Optimization of the parameters of the JULES model for the ATTO site by Prudente Junior et al. (2025) may have contributed to decreasing the bias against observations. This highlights the importance of site-specific tuning of model parameters. Although VPRM-cal used calibrated parameters for the Amazon forest, they were not specific for the ATTO site."

Replace with:

Compared to observations at ATTO, both VPRM-cal and JULES underestimated the diurnal carbon sink, though they correctly reproduced nighttime respiration magnitude. JULES showed the best overall performance, likely benefiting from site-specific parameter optimization at ATTO (Prudente Junior et al., 2025). The residual underestimation of daytime carbon uptake by JULES likely reflects limitations in the representation of canopy conductance and light-use efficiency under the high-radiation, high-humidity conditions of the wet-season Amazon (Prudente Junior et al., 2025). VPRM-default, in contrast, underestimated nighttime respiration. Although VPRM-cal used parameters calibrated for Amazonian forests, they were not site-specific for ATTO, which likely contributes to its larger residual bias relative to JULES.

<u>The following comment was added to the main text, clarifying these aspects</u>

Grammatical mistakes

- Line 45: “proper representation … are important” → “proper representation … is important”
- Line 63: “including online process-based…” → “including an online process-based…”
- Line 105: “from end of November … until end of January” → “from the end … until the end…”
- Line 111: “traces gases” → “trace gases”
- Line 135: “intital” → “initial”
- Line 277: “session 5.2.2” → “Section 5.2.2”
- Line 291: “patterns …reveals” → “patterns … reveal”
- Line 297: “parameterizations operates” → “parameterizations operate”
- Line 381: “VRPM-default” → “VPRM-default”
- Line 401: “along the day” → “throughout the day”
- Line 434: “boundary-layer” → “boundary-layer mixing”??
- Line 442: “winds flow from different direction” → “winds flow from different directions”
- Line 449: “does not means” → “does not mean”
- Figure 7 captions: “The Blue rectangle correspond” → “The blue rectangle corresponds”
- Line 462: “as function of” → “as a function of”

Author Response:

We thank the reviewer for carefully identifying these grammatical inconsistencies. The suggested corrections have been implemented throughout the revised manuscript.

<u>Reference</u>

de Araújo, A.C., Kruijt, B., Nobre, A.D., Dolman, A.J., Waterloo, M.J., Moors, E.J. and de Souza, J.S. (2008), NOCTURNAL ACCUMULATION OF CO_2 UNDERNEATH A TROPICAL FOREST CANOPY ALONG A TOPOGRAPHICAL GRADIENT. Ecological Applications, 18: 1406-1419. https://doi.org/10.1890/06-0982.1

Freitas, S. R., Longo, K. M., Alonso, M. F., Pirre, M., Marecal, V., Grell, G., Stockler, R., Mello, R. F., and Sánchez Gácita, M.: PREP-CHEM-SRC – 1.0: a preprocessor of trace gas and aerosol emission fields for regional and global atmospheric chemistry models, Geosci. Model Dev., 4, 419–433, https://doi.org/10.5194/gmd-4-419-2011, 2011.