

Dear Dominik, we thank you for the guidance and correction to the manuscript. We have addressed each one and made the necessary changes.

Thank you for your responses to the reviewer's comments and further amendments to the manuscript.

I am not yet entirely satisfied and would like to suggest some further changes as described below.

The general idea of updating prior information using GHGSat observations is good, but the method of up-scaling the limited observations to the whole study domain is still not clear enough. There is also quite a large number of typos and grammatical issues remaining, which should have been eliminated in previous iterations.

Please find below my comments and suggestions. I don't consider them critical, but they are important to address.

Page 1, Line 28: Why should recent budgets be "significant"? Or did you simply put the comma at the wrong place?

The comma has been moved to after “significant” to correctly modify wetland/water emissions.

P1, L30: ecosystem -> ecosystems

Made the change.

P2, L35: really only the past two years?

Changed to last decade to better reflect the previous airborne and developmental period these satellite approaches underwent.

P2, L40: There are 2 different sentences here that are not properly separated.

We have split the sentence into two and adjusted them for clarity. “This study employs the Western Siberian Lowlands as a case study for the extrapolation of observed emissions to regional priors. Furthermore, the incorporation of plume estimates into our modelling framework can improve our understanding of potential sectoral misattribution between anthropogenic and wetland methane sources.”

P2, L50: Please explain what is meant by "collocated"? Do you use a certain radius to define this? The value of 75% cannot be understood without such information. What is the resolution of the OGIM and GLWD data sets? I do not question the fact that O&G infrastructure and wetlands are often in proximity, but providing hard numbers for collocation and overlap requires more detail.

Oil and gas fields in the OGIM are a polygon spatial feature, these extents were used to extract the land cover from the GLWD dataset. We have revised the sentence to hopefully be more clear but are open to further revision “We found that 75% of oil and natural gas fields have wetlands or water within their extent and on average 35% (SD: 41%) of oil and natural gas field area was wetland land cover. “

P2, L52: How do you get an SD of 38%. Is this the uncertainty of the fraction? If that's the case, then the fraction could also be 100% or it could only be 35%. I can't imagine that the uncertainty of this number is so large. You are only comparing the number of O&G fields being classified as wetland to the total number of O&G fields. How do you get an SD from this?

The percentage is being calculated by treating each oil and gas field on its own and getting the average wetland and waterbody area within each oil and gas field to calculate an average percent wetland and waterbody and standard deviation. We think this provides a good comparison with the global numbers in showing that That Russia and WSL in general have a very high rate of wetland and waterbodies co-occurring with oil and gas fields. We have adjusted the sentence to hopefully make this clear “In Russia this rises to 98% of oil and natural gas fields being co-located with wetlands and an average of 73% (SD: 38%) of individual oil and natural gas fields area being classified as wetland or water.”

P2, L56: flux -> fluxes

Made this change and removed a

P2, L57: "land-surface model" is not precise enough to describe this type of models. There are many land-surface models coupled to weather prediction models that only simulate energy and water exchange between land and atmosphere but no methane emissions.

Changed to chemical-transport model to better capture these specialized models.

P3, L68: Change "in ... grid" to "on a .. grid". Same line: replace "TRACE." By "TRACE,"

Made these changes.

P3, L74: "Methane" -> "methane"

Change made.

P3, L75: Maybe it would be better to state "remains unchanged" instead of "is consistent".

Agree, we have made this change.

P3, L82: I wouldn't agree that this is a "large portion". To my knowledge the sources detected by GHGSat only represent about 12%-24% of the total emissions from the energy

sector (see Jarvis et al., DOI: 10.1126/science.adv3183), which is only a few percent of global CH₄ emissions from all natural and anthropogenic sources.

We meant super emitters in general contribute a large portion. However, for simplicity and clarity we have simplified the definition to "...super emitters i.e. point sources with high emission rates."

P4, L101: Change "the domain" to "the model domain" or similar.

Changed in this instance and throughout the text.

P4, L103: This is the first time the reader learns about "three GHGSat observations" sites. Since the GHGSat observations are essential, they need to be introduced more clearly. Why was there only 3 sites observed? Or is this simply what was available to you?

We agree this is jarring. Added, a sentence to the GHGSat section that clarifies the 3 observation sites. "GHGSat observations were acquired over three areas of oil and gas infrastructure in the WSL, as part of the NASA Commercial Satellite Data Acquisitions program's GHGSat evaluation." We shared targeting quota's with a number of other teams and priorities. Three sites was the maximum available to us.

P4, L111: "amd" -> "and"

Change made.

P4, L111: What do you mean by "each model"? There is only one model, GEOS-Chem.

Updated to reflect that each version of the model was run three times. "Uncertainty was estimated by running both the updated prior and default models three times, each with a different set of prior and observation error parameters: 0.75 and 0.2, 0.5 and 0.15, and 0.25 and 0.1, respectively."

P4, L115: It is not clear to me how EDGAR and GFEI were combined. EDGAR includes emissions from fuel exploitation. Did you simply replace that sector by GFEI emissions, or did you perform simulations with both?

This is a standard approach the IMI 1.0 uses. We performed no special analysis with EDGAR and GFEI. The IMI utilizes GFEI for fuel exploitation and EDGAR for other anthropogenic emissions.

"The priors for global modelling included in the IMI are 1) fuel exploitation from EDGAR v6.0 (Crippa et al. 2021), 2) other anthropogenic emissions from Global Fuel Exploitation Inventory..."

Section headers (e.g. sections 2.2 and 2.3) should not end with a ":"

Removed from all section headers.

P5, L142: The equation does not look like an equation (there is no "="), and it certainly does not look like an error propagation equation. This needs to be strongly revised. You should first define the target quantity (maybe average emission per infrastructure? Or average emission per (flaring) site?) and then explain, how the error of that quantity was determined by error propagation or Monte Carlo sampling.

Equation and description of propagation were updated.

P5, L152: The sentence "Consequently, the calculated occurrence rate was applied uniformly across all flaring locations." Still raises questions. Obviously, the occurrence rate was determined was determined at the level of infrastructure (e.g. the approx.. 1% for infrastructure in site 1). So it remains unclear how this occurrence is applied to all flaring locations without knowing how much infrastructure those flaring locations are assumed to represent.

This sentence was removed and replaced with a sentence at line 170 "We treated each flaring location as a proxy for a complex of oil and gas infrastructure, consistent with the GHGSat observation sites." These better fits the flow of the section. Each of our observation sites had multiple oil and gas infrastructure and flares likely represent a similar pattern as is common throughout the region.

P5, L156: Why did you convert to kg s⁻¹? In the text, there are numbers in kg/hr, Tg/yr and now also in kg/s. This makes the sections hard to read.

This was necessary for incorporating into the updated priors. We removed this detail to increase readability.

P5, L157: Is an emission site comparable to one of the three GHGSat sites or should it be understood as a single facility. This remains confusing.

We clarify that these are to be understood as analogous to GHGSat observation sites. Due in part to the spatial resolution of the VIIRS sensor. "OGIM oil and gas flaring utilizes VIIRS data which 750 m spatial resolution making facility clusters a likely occurrence, therefore we consider these sites to be analogous to our GHGSat observation sites and the likelihood for entire sites is applied to flaring"

P6, L159: It is unclear whether each of the 869 sites was assigned the same (mean) emission rate or whether each one was assigned a different rate estimated from a random distribution with mean = mean emission rate and sd = sd determined from the Monte Carlo

sampling. If it was a random sampling, what is the consequence of this on the inversion results? Would a different sampling have changed the results?

Clarified that it random. Yes, this is likely a major reason for the low performance of the added emissions. If running this again, a priori, information from the TROPOMI XCH₄ could be used to distribute the updated oil and gas priors so higher emission values correspond with the TROPOMI XCH₄.

P7, L187: "consistent" -> "consistently"

Change made.

P8, L197: Previously you were talking of "869 possible emission sites", now of "452 facilities" and "158 within the domain". It is impossible for the reader to bring these numbers together. They are extremely confusing.

Agreed, and we have clarified. 869 facilities across the model domain and 4° boundary with 452 of these having predicted emissions of those 152 fell within the model domain.

“Emissions were estimated for 452 of the possible 869 facilities within the model domain and 4° boundary region of which 158 were within the model domain.. Our probabilistic emissions increased the oil and gas prior by 4.48 Tg CH₄ yr⁻¹ in the model domain (Figure 1).”

P9, L205-206: The rate of occurrence as defined in Eq. 2 relates to the occurrence for an individual facility, but in the next sentence you suggest using this as a rate of occurrence per site. It should be made clear through-out that the occurrence rate is at facility level, not at (flaring) site level.

Adjusted the equation to be clearly site related, i.e. we are talking about # of site plumes, facilities at the site, # of observations of the site. It is calculated for each of the three sites and is not by facility. Each site had multiple facilities. The equation and related text is moved to the methods. Individual facility likelihood would be much lower and could have been used.

P9, L210: I assume the mean emission of 0.22 kg s⁻¹ refers to the emission from a single facility, right? If Eq. 1 would be defined accordingly, this would be much clearer. You should state the emissions in terms of kg hr⁻¹ and then maybe in addition in terms of kg s⁻¹, which is probably the units required for the modeling.

Updated the sentence accordingly, “Following the propagation of these error terms using equation 1, we found a mean of 792 kg hr⁻¹ and standard deviation of 4032 Kg hr⁻¹ (0.22 SD 1.12 Kg s⁻¹).”

P10, L232: Please explain what a low scale factor means. Up to this point, it wasn't clear that the inversion method optimizes scaling factors (rather than emission fluxes, which would be another possibility).

Added a few sentences discussing scaling factors. The model optimizes emissions estimates by comparing prior driven GEOS-Chem outputs to TROPOMI XCH₄ observations. If the TROPOMI estimates are substantially different than the modelled, a scaling factor is applied to align the modelled emissions with the TROPOMI data. Therefore, a low-scale factor occurs when TROPOMI emissions are low and the modelled emissions are high.

P12, L255-257: It is surprising that the bias is not reduced in the posterior, since not only the emission fluxes are scaled but also the background XCH₄ at the inflow boundaries of the domain. Did you really apply also the corrected posterior scaling factors for the boundary conditions when computing the posterior XCH₄ values? I am thus not convinced that "additional emissions are feasible". I would actually delete that sentence, as it questions the inversion results.

We deleted the "...suggesting that additional emissions are feasible."

P12, L259: The sentence starting with "Suggesting that" is not a proper sentence.

Updated the sentence to "The combination of clustering and extrapolation failed to capture the spatial pattern of emissions."

P12, L262: An increase in 2020 relative to what? Relative to the year before?

Add "from 2019 to ..."

P15, L333: Shouldn't "removes" be replaced by "would remove"?

Adjusted the sentence as suggested.

P15, L335: The sentence starting with "Possibly due to .." is incomplete (in grammatical terms).

Changed sentence to "Tanager's lower average emission rate could be due to the additional categories of CH₄ emissions being tracked by Tanager."

P16, L360: "This" -> "These" new versions.

Best wishes
Dominik Brunner