

Global CH4 budget

General comments

Thank authors for massive compilation effort. Important product! One hopes a large community will see and use. Good product for ESSD.

Push data out to 2008-2017 decade? Various valid reasons for this but scattered somewhat randomly through the narrative. Pull all of this information into a short clear statement very near the top of the manuscript to explain time span and time lag?

I and many others will want to use this in classroom. We might assign paper as background reading. Students will loudly object - too long! This reviewer agrees. Too long by a factor of two, at least. Almost long enough to need an executive summary? See suggestion below.

In present organization, permafrost emissions sit within natural emissions. Technically, and increasingly so, permafrost emissions forced by permafrost thaw should instead account in the anthropogenic category? But if you move terrestrial permafrost sources then you also should move sub-marine permafrost emissions, boreal plant sinks or sources, etc. No easy solution but the current location will prove increasingly problematic.

Whether or not the authors intend, this reviewer concludes that we face a larger and more urgent geospatial rather chemical challenge. In short terms, we need to fix the wetland inland freshwater distribution and extent uncertainties as our highest priority, with understanding and quantification of atmospheric OH distributions, reactions and impacts as probably a second priority. If authors intend these priorities, they should state them explicitly? They can always revise in a subsequent version. If this reviewer developed a wrong impression, then authors need to reconsider information they presented and how.

Topical editor suggested that I do a full review. Finding the track-changes version somewhere between daunting and impenetrable, I agreed. After plowing through so much material, however, I almost wish I had tried instead to follow the track changes version. Fundamentally, this is way too much material. Removal of the regional details to separate papers helps a lot, but the present version still represents way too much material. You want strong interest and to serve many users, but at present the too-long, too-disorganized, too-detailed text represents a severe barrier to almost every reader and potential user. Amazing compilation effort, but you need to present it after and on the basis of an equally amazing editorial effort. The latter effort remains sadly missing.

Specific comments - long list and I know I missed some issues.

Line 304: “the relatively small and variable number of studies” Do the authors mean a small number of studies with variable results? A variable number of studies covering small regions or sectors? Confusing.

Line 317: “processed in the same way” Does this phrase mean that monthly and annual emission data, from any source, were subjected to the identical spatial 1x1 gridding? But some source data exists at higher spatial resolution? E.g. would need some form of disaggregation? Later (lines 320, 321) a reader finds that calculations of monthly and annual means came from (came after?) gridding. Confusion between spatial and temporal averaging here?

Line 332: “the regional budget presented in (Stavert, 2019)” should read as ‘the regional budget presented by Stavert (2019)’? Proofreaders will not know what to do with these punctuation errors so authors must take care to express them correctly.

Line 336: In the version I read (“the TransCom inter-comparison map ([Gurney et al., 2004](#))”, the Gurney et al reference shows as a non-functional hot link, different to all other references?

Lines 358, 35: again some references as apparently hot links, others in standard (expected) format. Why?

Line 359: “most of the inverse system the” Instead: inverse systems?

Line 373: “Methane sources and sinks” Because the (long and detailed) section 3 deals entirely with bottom-up (e.g. line 374) emissions, and because section 4 carries the explicit title of top-down (e.g. at line 1677: “Atmospheric observations and top-down inversions”), shouldn’t the title of section 3 read as ‘Bottom-up sources and sinks’? (By this point one hopes that most readers/users know that the discussion refers to CH<sub>4</sub>.) If section 3 does NOT deal solely with bottom-up sources and processes (like most readers, this reviewer loses track of bottom-up vs top-down deep in section 3, e.g. in the section on CH<sub>4</sub> lifetimes) then the reference to bottom-up at line at 374, 375 needs to change?

Line 395 to 400: good section on definitions used here vs those used by IPCC. This reviewer agrees with these choices but, more important, thanks authors for explaining the differences.

Line 436: FAOSTAT is annual or every 5 years? Annual, evidently, from Table 1?

Line 457: “Although, country emissions” Delete the comma?

Line 472: Here the reader finds FAO-CH<sub>4</sub> at annual resolution so FAOSTAT (question above) must also provide annual data? Different to FAO land use inventories with 5-year update cycles?

Lines 475 to 503: Some deception here? None of the five sources provides actual 2017 data? Instead, authors have, by necessity, applied source-specific extrapolations to each of the five sources to reach 2017. So in fact we really only have valid bottom-up data to 2015 (perhaps, with a stretch, to 2016 for some sources) but for reasons we don't learn, authors advertise (e.g. through the title) coverage through 2017. I applaud the desire to update from Saunier 2016 but the definition of "the most recent available year" (e.g. on line 302) refers only to atmospheric concentrations but falls short on all bottom-up source data? Authors should make explicit mention of this discontinuity? Authors, knowing the UN systems, live with these inherent reporting delays but readers/users may not understand? Earlier and later the authors refer to differences between top-down total CH<sub>4</sub> emissions numbers and bottom-up numbers. This extrapolation represents an additional uncertainty factor? This discontinuity, e.g. 2017 data in some cases but extrapolations from 2015 or earlier in many other cases, impacts Figure 3?

Also, Table 2, biogeochemical models for wetland CH<sub>4</sub> emission all "were performed for the whole period 2000-2017" (Table 2) but forced with invariant wetland surface area maps? We know that wetland surface areas have changes substantially but do the data show changes specific to 2008-2017?

Line 553: "agreement Despite the offset of the SSP scenarios compared to the recent inventories" Need a period between agreement and Despite. What does 'offset' mean in this context? Divergence? Divergence from SSP2.6 or 3.4 but tracking 8.5? Not clear what authors intend with this sentence.

Line 560: "transport" here but "transportation" already mention above (line 557). In one case you mean the act or process of transportation and in the other case the actual transport of fossil fuel products (e.g. via pipeline)? For readers who do not know IPCC categories, we need clarification here.

Line 606, 607: "applying "Tier 1" approaches for coal mine emissions is not accurate enough" ?are not accurate enough?

Line 649: "and, could lead to". Delete the comma?

Lines 665 to 669: studies find emission underestimates due to inability to correctly account for CH<sub>4</sub> from fracking? Otherwise, why does reader find this particular sentence in this particular location?

Line 672: "abnormal operating conditions" abnormal = fracking? Abnormal = fracking done not according to regulations or best practices? Abnormal = some other type of fossil fuel extraction?

Lines 675 to 683: how does this section contribute to the overall or fossil-fuel-specific budget calculations? The sentence following (lines 684 to 685) provides a short sufficient summary which could replace much of the prior text?

Lines 724, 725: “the volatile solids component” This reader does not know the chemical meaning of the term ‘volatile solid’?

Lines 723 to 736: highly redundant. Could reduce to the sentence on lines 727 to 729: “Ambient temperature, moisture, and manure storage or residency time affect the amount of CH<sub>4</sub> produced because they influence the growth of the microorganisms responsible for CH<sub>4</sub> formation”. For budget purposes, we don’t need more than that?

Line 751: Start here while deleting the prior paragraph?

Line 775: “the work of (Carlson et al., 2016)” you mean ‘the work of Carlson et al. (2016)’. Please take care with punctuation, as proofreaders will not know what you want.

Line 779: “northward shift of rice cultivation”. Unless cultivation practices change with latitude, a latitudinal shift will not necessarily change or reduce emissions?

Lines 837 to 905: way too much information here! Please only include what we need to know to understand this/these budget estimates. Also we seem to have lost the useful end-of-section summary of what this budget effort concludes for this source?

Line 979: by this point the reader has encountered anaerobic conditions many times (waste water ponds, rice paddies, bovine guts, etc.). Do we really need a new definition and explanation of anaerobic metabolism at every point. Reduce, s.v.p.

Line 980: “limit oxygen availability and creates suitable redox” create, not creates?

Line 987: are these processes diffusive or advective? This reader does not understand the phrase: “molecular diffusion limited advection”

Line 992: “transportation and are further regulated by” What are ‘further regulated’? The land-surface. models? The CH<sub>4</sub> emissions? The model parameters? Very confusing, please re-write.

Line 995: “(Supplementary Material, Melton et al. (2013); Bohn et al., 2015)” Again, inconsistent and incorrect use of parentheses. Relying on bibliometrics software from various contributors evidently does not work. I have pointed out a few such errors, skipped over many, and anticipate many to come. A waste of this reviewer’s time to point them all out. Assign one of your co-authors to search for, evaluate and correct every parenthesis. Authors must take this responsibility. Proofreaders will not find nor know how to correct all of them.

Line 1008: “a monthly global wetland area dataset” Does wetland surface area vary only seasonally or does it also evolve with time over several years?

Line 1056 to 1074: a hard-nosed editor could re-write this entire section in two sentences or perhaps even one sentence. How much of this is relevant to this current version of a CH<sub>4</sub> budget?

Line 1107: “south of 60°N) with. Tan and Zhuang” something wrong with punctuation here?

Lines 1165 to 1174: here we get expert opinion on what next and what needed for lakes and rivers. Good! But doesn't this section belong elsewhere/later?

Line 1234: why specify exact (and proprietary) GIS software here? Same scale up would have worked in any GIS environment?

Line 1341: “which allows very little methane; even from established”. Punctuation error?

Line 1376, 1377: Authors already defined marine clathrates earlier (line 392). Reader does not need redundant definitions?

Line 1398: In earlier sections readers found summaries first, then itemization of individual components following. Here we get the opposite: components first followed by summary. Chose one or the other but do not confuse us with both?

Line 1455: Many references in this section appear as (non-functional) hot links. Many other references do not. Please fix this!

Line 1511: Finding the (strange) unit here of “molec” and having earlier seen reference to mole fractions (strictly, in an SI units sense moles per mole but more casually expressed as ppb), one wishes the authors had provided a conversion table as in the global carbon budget. They have done a very good job of keep flux units consistent as Tg CH<sub>4</sub> yr<sup>-1</sup>, but they could help readers by cross-referencing the various concentration units.

Lines 1498 to 1558: do we need an extensive discussion of OH concentrations, reactions, hemispheric distributions and lifetimes to understand the magnitude and validity of the present CH<sub>4</sub> budget? This review thinks not. One could summarize this entire section in two or three lines?

Line 1526: Pinatubo eruption represented a climate variation? Hardly.

Line 1530: “enhances CH<sub>4</sub> consumption”? You mean ‘enhances the CH<sub>4</sub> sink’ or ‘enhances CH<sub>4</sub> oxidation’?

Line 1548: “consistent, albeit lower, than the value deduced from”? Very sloppy wording, leaves a reader guessing at what you mean here.

Lines 1577 to 1579: This sentence summarizes the entire stratospheric dynamics and photochemistry section. Why do we need all the rest of this?

Line 1590: Should CH<sub>4</sub> sink terms use a different sign than source terms? I suspect carbon budget has already wrestled with this flux direction issue. What did they decide? Does GCP adhere to a consistent sink/source nomenclature convention?

Line 1606: “the KIE approach” KIE = kinetic isotope effect, but you have’t defined it yet?

Line 1679: ~~The first~~ systematic atmospheric?

Line 1695: A couple TCCON sites, perhaps Australia or NZ or both, have published CH<sub>4</sub> data in ESSD?

Lines 1699 to 1711, other data. If not useful or used for this global CH<sub>4</sub> budget, why mention it/them?

Lines 1713 to 1716: a reader just saw this identical list a few lines earlier. We don’t need to see two mentions of the same information?

Line 1739: And you show G<sub>ATM</sub> for the previous version of global CH<sub>4</sub> budget (e.g. in Table 3) but not for this version. Why not?

Line 1745: By definition, a growth rate can not be both positive and stable. Instead of stable, you mean consistent or persistent?

Line 1751 to 1755: Here a reader finds the recent growth values, nicely documented with appropriate uncertainties. Why do these values not also appear in Table 3?

Lines 1756 and following, Satellite data. Important to show command of this data for budget purposes but way way too much information here. Why write four or five sentences of description about a source that you - for valid reasons - can not use? Is this a budget discussion or narrative about the history of SWIR sensors? You define SWIR at least twice in this section. Compilation - good - but not followed by tight budget-focussed editing - bad.

Line 1778: “retrieval approaches, Proxy and Full Physics. The proxy method retrieves” ????. A former sub-heading now buried in this text? We do not need all this information?

Line 1792: “only inversions using GOSAT retrievals are used.” After nearly 40 lines of text a reader finally finds this short conclusion. Please can someone apply a sharp red pencil to this manuscript - focus on the CH<sub>4</sub> budget!

Line 1799: “ensemble of inversions gathering various chemistry transport” Why? To reduce uncertainties or provide independent validation for the CH<sub>4</sub> budget terms (e.g.

use top-down to constrain bottom-up) or to ensure that a long list of inversion modelers get their work listed and recognized via this global CH<sub>4</sub> budget paper. I apologize if this reviewer's questions seem uniformed, irrelevant or even rude. But pity the poor readers / users. They want to use this product to understand CH<sub>4</sub> budgets! Instead, they confront pages of tangential descriptions replete with (obscured by) more and more acronyms. Seriously, am I reading the CH<sub>4</sub> budget or a narrative recount of every CH<sub>4</sub> activity that has occurred?

Lines 1801, 1802: "assume that this model range is sufficient to cover the range of transport model errors in the estimate of methane fluxes". You 'assume'? This assembly of world experts on CH<sub>4</sub> uses an ensemble approach because they can't (or won't) distinguish useful from not useful inversions? Again, does this approach help quality of the budget? If so, quantify that. Does it help users? If so, tell us. Show us! Did the inversions prove useful in the previous CH<sub>4</sub> budget? If so, how? Although these authors claim (lines 1807, 1808) intention to do flux assessment rather than a MIP, the section in its present description looks, smells and sounds like a MIP to this reader.

Lines 1844 to 1846: Here, deep in the manuscript where few readers will notice, we finally read a justification of costs and benefits of time span and time lag of the current product. Good discussion! But we should have read it in the introduction? It sets out temporal goals that guide the entire product!

Lines 1850 and following: This is a good useful orderly section! But: a) it repeats a lot of material from earlier; and b) a reader needed to work through - or, more likely, skip through - an unusually large amount of text to get here. Authors could argue that this section depends on all the prior detail. This reader/reviewer asks authors to consider how to make the user's 'life' easier rather than putting priority on including all details. Details can and should go in individual research papers. The budget should not replay, only summarize?

Line 1882: Introductory sentence implies treatment by the five source categories but discussion/summary that follows treats natural vs anthropogenic (with wetlands called out separately) but does not follow the five-category organization that you used earlier, for example. Revise this opening sentence to better convey what will follow?

Line 1914; "study derive significant changes in wetland emissions" derive? I think you mean 'identify' or 'reveal' or 'point to'?

Line 1919: We just read (lines 1875) that uncertainty ranges for, e.g. ocean, termites, geological sources have reduced (improved) in this version, but here the authors point to those same specific sources as plausible reasons for the top-down bottom-up discontinuity? Uncertainty goes down but discrepancy goes up? Mathematically I think that works but this discussion implies a substantial weakness in our understanding. This reader particularly wonders about permafrost in this regard (see opening comments above), not so much about the permafrost numbers but more about whether assigning

permafrost emissions as natural emissions doesn't presently or won't in the future exacerbate this discrepancy?

Line 1930: "Improved area estimates ..." By this point reader has seen this recommendation at least twice. It really rather belongs in a summary or future work section, not here? This entire paragraph repeats earlier text and belongs instead in a summary section?

Line 1948: "which is about 30% (23%) of global methane" What does the 23% indicate here? About 30% but actually 23%? 23% of global but 30% of anthropogenic? Some plus minus 23% uncertainty? I find the answer to my question in line 1949, 30% of top-down but only 23% of bottom-up. Readers should encounter definition before data, not the other way around?

Line 1958: "partition of methane emissions between wetlands and freshwater systems should still receive a high priority" this includes the thawing permafrost freshwater confusion?

Lines 1982, 1983: Valid caution but a reader should have encountered it earlier?

Lines 1997 to 1999: Very confusing here, again the source/sink flux direction problem. The text says 'model inputs somewhat higher' but what you mean is some models show a higher value for total sink because they include a larger land sink term? For a known atmospheric CH<sub>4</sub> concentration, that larger sink term must lead to a correspondingly larger source term! Here, we read about a larger central top-down estimate. Authors intend this phrase to refer to the larger sink term, or to a larger total CH<sub>4</sub> emissions term? The authors, no doubt, know various sink, source and net terms, but here they fail to express themselves in clear language, leaving readers therefore confused. This statement occurs within the section on CH<sub>4</sub> sinks, so one wonders ...

Line 2006: "chemical lifetime and to narrow it down in" Authors have addressed the issue of lifetime many times and in great detail prior to this statement. A reader knows at this point a lifetime of 9 years, plus or minus perhaps 0.5 years. How would refinement of this lifetime calculation improve the overall budget calculation, much less mitigation planning? E.g. does a lifetime of 8 years or 10 years really make a difference at this point? This reviewer suspects not. This section represents an(other) example of everyone's scientific priority gaining equal weight in the compiled budget. This (small, to this reviewer) remaining uncertainty has larger overall priority than fixing the distribution and extent uncertainties of freshwater (also mentioned numerous times)? Organizationally, this entire section (lines 2005 to 2012) belongs in a summary / future work section.

Line 2024: A reader has now seen this statement at least four times?

Line 2033: Readers already know, at least twice, why SCIAMACHY data not used.



Lines 2024 to 2053: Good knowledgeable expert discussion of impact of satellite vs in situ data on inversions and emissions. But, of what relevance, in specific plus/minus Tg CH<sub>4</sub> terms, to the global CH<sub>4</sub> budget? A reader sees “clearly show” but at the same time “not systematically consistent”. I almost used a profane shorthand here: what do the authors want readers to learn, and how does it matter to the CH<sub>4</sub> budget? No clue in this section. More “further investigation” ....

Line 2082: Section 6, developments, missing elements, remaining uncertainties. Important section. Readers will not disagree with topics raised here. But the section reads more as a recitation of the previous CH<sub>4</sub> budget issues while omitting issues raised in this version. Ebullition, for example, mentioned repeatedly in the text, does not emerge here. The entire tension between spatial uncertainties and chemical uncertainties, a theme of this paper, does not emerge here, at least not in those recognizable terms. Pages of text on the need to improve distribution or lifetime of OH, but only one faint mention here, that basically repeats what we already read? We could get a list: previous but now resolved, previous but not yet resolved, new. Here a reader finds no sense of priority, just a large wish list not much changed from the prior budget. Use the GWP of CH<sub>4</sub>, find the largest or most tractable uncertainties, convert those to climate urgency: where should we put our efforts? If we know new satellites have recently or will soon come on line, what do we need for validation? Where will that data have most impact in this budget? More, more, more. More systematic. More integrated. Just another wish list. After all the work to compile this information, the world-wide experts then throw up their hands - they don't know what they need next? They need everything? Not helpful.

After working to assimilate all the details provided to this point, this reader basically glazed over this section. It seemed only vaguely related to what we just learned, a white-paper level of what we should do to better understand CH<sub>4</sub> but not well connected to all that we just read about efforts and information need to assemble this budget.

Line 2089: “Knox and al., 2019)” ??

Lines 2209 to 2219: a short clear paragraph of budget outcomes - thank you! Notable, unfortunately, because it differs so much in style, brevity and clarity from most of the preceding text.

Lines 2226 to 2231: weaknesses and cautions about extracting regional information from satellites. Important, clear, useful. But link this to specific recommendations in Section 6, where now we just find a wish list for more of everything?

Line 2237: a “clear priority”! Finally! First one? Does permafrost fit into this inland freshwater priority?

Line 2242: “also place importance in” Should a reader conclude here that authors consider improvements in OH distributions as second in importance to the freshwater extent problem?

Line 2246 to 2253: Short clear paragraph, contains a bit of the unhelpful 'need everything' philosophy, but if we have these topics listed here we could get rid of much of Section 6?

Lines 2254 to 2257: Good statement, good motivation, good summary of forward plans, but repeats almost verbatim what readers saw earlier (lines 1844 to 1846)? Some repeat expected in a good summary but not clear here why we need this detail twice?

Line 2268: "a negative contribution (from biomass burning)" You really do not want punctuation errors in such an important paragraph?

Line 2299 and following, Acknowledgements. Interesting section. I think global carbon budget does something like this but through a table instead? Nothing wrong with this approach but text includes several (perhaps many) punctuation and tense errors. Someone of the author team should read this carefully?

Page 126, 127, Table 3. Cells need reformatting, presumably will happen during typesetting. Authors will need to check text wraps. Repeat the question raised above about why no  $G_{ATM}$  rate information for current version(s)?