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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Technical note: On comparing greenhouse gas emission metrics" *by* Ian Enting and Nathan Clisby

Ian Enting and Nathan Clisby

ian.g.enting@gmail.com

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Author comment: Response to referee 2

We are not proposing a continuous metric. $\Delta S_{CO2}(t)$ is not a metric. It is the result, for a particular time t, of applying a metric. The metric is the process of going from $\Delta S_{CH4}(.)$ to the CO2-equivalent. In general mathematical terms this would be a functional. Restricting such functionals to time-invariant linear operators whose Laplace transforms are rational functions restricts consideration to metrics defined as linear integro-differential operators. The full inversion of the Wigley FEI relation can be expressed in this way (most easily by using Laplace transforms) if the CH_4 and CO_2 responses are sums of exponentials. However, our analysis suggests that useful ap-

proximations can be obtained using much simpler expressions.

The various metric processes that we consider for generating $\Delta S_{CO2}(t)$, each applicable at any single time t, are

- multiply $\Delta S_{CH4}(t)$ by a constant (ie, GWP approach)
- multiply $\frac{d}{dt}\Delta S_{CH4}(t)$ by a constant — in practice this would require a specification of how the derivative is defined
- combine current $\Delta S_{CH4}(t)$, with the 20-year difference $4\Delta S_{CH4}(t) - 3.75\Delta S_{CH4}(t-20)$
- take current $\Delta S_{CH4}(t)$ offset by weighted integral over past emission perturbations.

Line by line comments

Line 16 the use of 'so-called' captures the fact that actual greenhouses don't work by changing radiation balance. Our bending over backwards for correctness reflects the politicisation of climate science, particularly in Australia and the USA.
Proposed change: *Leave decision to editor.*

Line 21 noted
Proposed change: *where a_X is the radiative efficacy in mass units: the amount of change in radiative forcing per unit mass increase for constituent X in the atmosphere.*

Sec 3.2, 3.3 agreed
Proposed change: *'insert as shown by the *** line,' after lines 82, 93, 104, 114. Similar change also made in Section 4.*

Sec 3.4 We regard the parameter b as being an empirical fit that has no specific physical meaning. The reduced model is fitting the ratio of two response functions whose parameters are themselves empirical fits whose parameters have only distant connection to the underlying processes involved. However, the important point is that b is independent of the growth rate used in the example.
Proposed change: *Propose inserting, after line 65:*
A general linear, time-invariant equivalence relation defined by

$$a_{CO2}\Delta\tilde{S}_{CO2-eq}(p) = a_{CH4}\tilde{\Psi}(p)\Delta\tilde{S}_{CH4}(p) \qquad AC2.1$$

can be assessed in radiative forcing terms by the accuracy of the approximation

$$a_{CO2}\tilde{R}_{CO2}(p)\Delta\tilde{S}_{CO2-eq}(p) = a_{CH4}\tilde{R}_{CO2}(p)\tilde{\Psi}(p)\Delta\tilde{S}_{CH4}(p) \approx a_{CH4}\tilde{R}_{CH4}(p)\Delta\tilde{S}_{CH4}(p) \qquad AC2.2$$

If the global temperature response is linearised using a response function $U(t)$, as in done for example in AR5-WG1-Ch8, then equivalence in temperature perturbations can be analysed in terms of the approximation

$$\tilde{U}(p)a_{CO2}\tilde{R}_{CO2}(p)\Delta\tilde{S}_{CO2-eq}(p) = \tilde{U}(p)a_{CH4}\tilde{R}_{CO2}(p)\tilde{\Psi}(p)\Delta\tilde{S}_{CH4}(p)$$
$$\approx \tilde{U}(p)a_{CH4}\tilde{R}_{CH4}(p)\Delta\tilde{S}_{CH4}(p) \qquad AC2.3$$

In each case, removing the common factors reduces the comparison to one of considering the accuracy of the approximation

$$\tilde{R}_{CO2}(p)\tilde{\Psi}(p) \approx \tilde{R}_{CH4}(p) \qquad AC2.4$$

Because of the commutative and associative properties of such transformations, a transformation of the CH_4 source to give an equivalent CO_2 source can be described in terms of how well the metric transformation, acting on the CO_2 impulse response, reproduces the impulse response for CH_4. The application of this relation in the frequency domain (i.e. $p = 2\pi if$) is noted in the appendix.

Following this insertion, we propose to use the symbol Ψ, with special cases Ψ_{FEI}, Ψ_{GWP}, Ψ_{Deriv}, Ψ_{Diff} and Ψ_{RM}, throughout the rest of the section and in the appendix.

Line 129 Noted. We propose adding an appendix on a frequency domain analysis. The reason in favour is that Fourier analysis and Fourier transforms are more familiar than Laplace transforms for many scientists. The negatives (which are reasons to use an appendix) are that the analysis is based on complex numbers (as shown in the R code in the supplement) and its formal definition requires limiting processes to ensure convergence of the defining integrals.
Proposed change: *Add appendix*

Line 136 A major reason for considering GWP* and related metrics is because GWP is a poor metric for efficient stabilisation. Nevertheless, a metric that gives perverse behaviour in the short-term is unlikely to gain political acceptance.
Proposed change: *Propose adding extra section on practical issues.*

Line Figs 2,3 These were split for ease of layout in a 2-column journal.
Proposed change: *Combine as suggested.*

Line 164 Propose to rephrase,
Proposed change: *Response to reviewer 1 proposes moving this paragraph into new section discussing practicalities. The new section, with rephrasing of line 164, is in a separate post.*

Conclusions OK
Proposed change: *Proposed re-write posted separately.*

Line 174 agree.
Proposed change: *faster growth rate*

Line 177 We agree that ratio of airborne fractions is good for all timescales, but approximating this as e-folding rate is not.
Proposed change: *....approximating the ratio of airborne fractions as a multiple of the e-folding rate. This approximation can provide a good ....*

Supplement Reading the supplement as 'text broken up by code' is, we agree, confusing. It is intended as 'code broken up by text', where the text is inserted in connection with particular parts of the code (i.e. annotated code, as we describe it on line 183). As described, the role of the supplement is to document the code (for review purposes). In the event of acceptance of the paper, we intend to lodge the code in an archive (probably figshare) once we have made any changes as a result of the review process. (We expect that such changes will be confined to the axis rescaling noted in our first post and cosmetic aspects of the graphs.)

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