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# Interactive comment on "A modified impulse-response representation of the global response to carbon dioxide emissions" *by* Richard J. Millar et al.

Anonymous Referee #2

"A modified impuse-response representation of the global response to carbon dioxide emissions" by R.J. Millar et al., describes a simplified impulse-response model to simulate the airborne fraction of CO2 and subsequent temperature response to CO2 emissions. The goal of a simple model with which to examine probabilistic responses to CO2 emissions is worthwhile, but the paper has major deficits that must be reconciled before the work is accepted for final publication. Given the current state of the paper, it is difficult to assess the scientific significance of this model.

First, the authors must provide a better literature review that contains brief descriptions of the other models to which their FAIR model is compared, including the IPCC simple model and the BEAM model, which is introduced rather abruptly in the results section.

The type of research that would be enabled by such a simple representation of climate-carbon couplings is likely to be interdisciplinary in nature, and therefore the tools that are introduced in this manuscript must be better explained for their paper to be of broad utility to the climate community. At the end of the introduction, the authors propose to "extend" on the IPCC-AR5 model, but I don't think they have fully introduced this model, or described why they think it is deficient.

Second, the authors must provide a better description of their own FAIR model. The time constants should be better described, the carbon reservoirs used in the model should be named, and all the variables used in equations 1-5 should be described and the appropriate units should be listed. Although a table would be helpful for this, the authors do not even describe all the variables in-line. The authors need to provide a brief explanation as to how the new values for ECS and TCR were arrived at, rather than assuming readers of this paper will consult the author's 2015 paper.

Third, the discussion of the figures, which is the bulk of the manuscript, needs to be enhanced. The Results section reads like a laundry list of the figures, so you might consider structuring your results around the scientific questions each figure answers rather than beginning each paragraph with "Figure N shows...". Given the current state of the Results section, I have a hard time knowing whether you think the model shows good agreement with some benchmark or plausible agreement with other model output. I also have no idea why you think the benchmarks you selected are the best ones to use (and whether they are sufficient), or which models you are trying to show that yours agrees with.

Fourth, I think that Fig. 4c merits a bit more attention. The authors contrast their FAIR model with the BEAM model by stating that FAIR includes some parameters for terrestrial uptake, rather than just marine uptake. Variations in terrestrial uptake largely drive variations in the airborne fraction, yet the FAIR model shows variability in the airborne fraction that is maybe 25% of the observations. So is FAIR really capturing climate-terrestrial uptake interactions? If variations don't show much semblance to

reality at shorter timescales, how can we trust the longer timescales? Given high profile recent papers that have tried to use interannual variability in the CO2 growth rate in ESM ensembles to constrain long-term temperature sensitivity of terrestrial uptake, I think this merits a bit more discussion.

The paper would also benefit from paying a bit more attention to details in the figures. For example, the legends for the figures are often incomplete and rely on information buried in the caption. Please help your reader by including this in the figure panels. The legend in Fig. 2 is incomplete (should include solid vs dash trendlines), as is the legend in Fig. 3 (should include red vs blue). There is no legend for Fig. 4. For Fig. 5, please consider using different colors since the purple and red are hard to distinguish. For Fig. 7 – I am not sure what are the brown dashed lines. It is possible that the purple shade and the brown shade are also too close.

In the revised paper, I think it is necessary to include more discussion of how do we know this simplified model is "good enough". The figures show comparisons against other, "wrong" models. Why is this model sufficient? Perhaps better discussion of the variables that comprise the model itself would and their physical significance/relationship to variables that exist in full-physics and full-BGC models would accomplish this, but the authors might also consider adding an additional section to the paper.

I would also like to see some discussion of how the FAIR model can be improved/extended in the future. Will variables simply be re-tuned when AR6 models come back with different emergent responses? Are there clear steps that would better emulate the physics, biology, and chemistry that govern the airborne CO2 feedbacks that can be added independent on next generation ESM simulations?

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