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Geoscientific Model Development Discussions

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Interactive comment on "FaIRv2.0.0: a generalised impulse-response model for climate uncertainty and future scenario exploration" *by* Nicholas J. Leach et al.

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The paper is well written and the analysis thorough. The model is suitably described and justified. The model will serve a useful scientific purpose, and should be easy for others to use (and potentially implement). With a nice interface, and the possibility to easily vary parameters, this model could become quite well used by the scenario community.

I generally have minor comments, and I see no major impediment to publication. A few of my comments go into quite some details, though I suspect they do not require much work to address (except maybe one or two depending on the response).

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Discussion paper

I list my comments in the order they appear in the manuscript:

1. Line 45: This sort of gives the impression that there are only two main SCMs, FaIR and MAGICC, and perhaps a few others. You sort of get there in the end, mentioning a “wide range of SCMs” from Nicholls et al, but this paragraph seems to really downplay the existence of other SCMs. I would suggest rewriting more in the narrative “There are dozens of SCMs that have been in widespread usage for decades… Scenarios generated by IAMs and assessed by the IPCC have generally used one SCM (MAGICC), with FaIR additionally used in IPCC SR15. Something about RCMIP, etc.” Of course, choose your own words and framing, but this paragraph gives a very different impression than reality would have it!

2. Line 51: This is more a passing comment. FaIR might be five equations, etc, but that does not mean it is simple and transparent. And computing resources are not such a limitation for many SCM problems these days, so a more process based SCM can have advantages even if it has more equations and takes longer to solve. I don’t see the main application or even motivation of FaIR to be some IPCC SCM. FaIR was used in SR15, was available for AR6, but has not exactly taken IPCC by storm. Maybe AR7… At the end of the day, all SCMs require parameters and calibration, even FaIR has hundreds of parameters (Table S2), and there are dozens of ESMs to tune to, alternative ways to implement various processes, various ways to tune, etc, so there will always be debate about whatever SCM is used and how it is parameterised. Long story short, I would see the motivation of FaIR to do good and exciting science. If FaIR is used as a harmonising SCM across IPCC WGs, I would see that as a co-benefit (but not a motivation).

3. Figure 1: It would be useful somewhere to give equations for Gu and Ga. Also mention somewhere (caption) that terms without (t) are constant for each gas. Also, probably worth mentioning (caption), that that n=1 for most species. This figure in a way over complicates the simplicity!

4. Figure 1: It would be useful to put in numbers in each box to emphasise the sequencing ("model steps take place from left to right"), but noting, this sequencing will relate also to implementation. There is not much written about implementation, but the sequencing implies this is solved using forward differences? This is ultimately a system of differential equations, and they don't need to be solved by forward difference, so the sequencing is an artifact of the implementation?

5. Line 114: Would it be fair to say this feedback approach is a fudge? To use a non-technical term. . . This is ok, as FaIR does a good job at replicating ESMs, so don't take this as a critique. What are the physical interpretations of these r coefficients? Everything gets wrapped into alpha, and it becomes hard to disentangle. I note also that the 100 is fixed, and not given as a parameter. Does this mean that 100 is essentially arbitrary, and I could use 5, 50, and 500 years and get the same results (with different r coefficients)? Does the choice of 100 years change key parameters or just the r coefficients? For example, if I used 500 years would the TCR be different or would feedbacks be adequately represented? I am ok with the approach, just need a few more words on the implications. Would it be better, or even desirable, to have the 100 as a free floating parameter that can be determined to get the best fit?

6. Line 125: I would explicitly mention that g0 and g1 are constants for each gas, as it is not really that apparent on the first read. Also, specify the equations for Gu and Ga.

7. Line 125 and line 150 (section). I understand that this is all generalised, but as Table S2 shows, most of the parameters are zero (or 1). CO_2 and CH_4 are exceptions. It may make sense for Equation (1) to say, here is the generalised form necessary for CO_2, and here is the specific form for n=1 which applies to each other gas. What is alpha for everything other than CO_2 and CH_4? Is it just 1 (was too hard to do in my head)? A bit more information here for CO_2, CH_4, and all others is also important for implementation. If it is known that the alpha term is not used for most species, implementation could be different (CO_2 is treated as an exception). In any case, a bit more emphasis should be put on the formulation being that everything is somewhat a

structural subcase of CO_2.

8. Figure 2: Is Halon1202 correct? Seems a way off observations?

9. Line 210+: So, to be clear, I just put in anthropogenic emissions, and FaIR takes care of the rest? I don't need to specify natural emissions? (it is sort of one of these things I want to test!)

10. Section 2.2: As for the concentration equations, the general form is only needed for CO_2, CH_4, and N_2O? Worth mentioning the simplifications otherwise it all looks so complex. . .

11. Line 319: Table S5 has the parameters C, kappa, etc. (it took me a while to find these). The C, kappa, etc, are the physical ones that are more important than d and q? Do these values make physical sense? I see in the table some values differ quite some from others. Do these differences indicate something with the calibration or other ESM specific issues? It also looks like C3 can take on many values? d3 seems to not add much value to the times, it could be 70 years to 1000s of years. Since the experiments used for calibration have short run times, is there really enough data to fit three exponentials? Time scales of 1000s of years in a fit over a few hundred is meaningless. Perhaps two exponentials are more than sufficient? Dropping the third exponential may not change the quality of the fit. Was there a reason to take 3 terms?

12. Line 319: I don't think the paper gives default values for the climate system? Table S2 has all the default values for the atmospheric response and forcing, but what are the default climate parameters?

13. Section 2 overall: There is nothing mentioned about implementation. It would be useful to write something about how you implemented this. Was it a simple forward difference (as implied by Figure 1)? Did you calculate all equations for all components, or simplify for non-CO_2 and non-CH_4 species? You note how fast the code solves, but from experience, fast code usually requires smart implementation. Another key

aspect for solution times is the time step. If you used an explicit method, the time step would need to satisfy some constraints. I think of these as all quite important points to discuss, if one hopes to implement the code. . . And you note one key advantage of the model is that it is so simple and easy for others to implement. . .

14. Table 2: Each column seems to have different significant digits? Is there a rationale?

15. Figure 3: I guess the figure is from 1850 (axis label not that great)

16. Figure 4: What happens with GFDL? FaIR seems to have variability?

17. Table 5: How would these parameters change if 100 years was not used for the feedback? What about 50 years, 200 years, etc?

18. Section 4: You often write “are given below” when it should say “are given in Table X” or something.

19. Figure 7: The 2010-2019 warming seems like the key constraint? On a 10 year time scale, variability could still be at play, so this constraint is locking in some variability? Would it be better to take a climatology of say 30 years? What happens if this constraint is removed altogether? You did some analysis for the alternative ECS priors, but I think it makes sense to remove some of these constraints to see how they effect the solution.

20. Figure 8d: It is a bit unclear what the reference to GCP is here? Is this the period over which the airborne fraction is calculated? Might need a word or two extra. . .

21. Section 4.5: Does the Table miss a caption?

22. Section 4.5, Table: For ssp119/26, does it make sense to show two additional rows for peak warming?

23. Figure 10: By eye, it looks like MAGICC and FaIR differ by around 0.2°C (for the high and low pathways)? This is not trivial for 1.5°C! And the difference to CMIP6 is rather significant. This comes all the way back to my 2nd comment. . . How do I deter-

mine if MAGICC or FaIR is a better representation? Maybe MAGICC performs better across all scenarios, maybe not, but how would I assess this? If MAGICC performs better, would I use FaIR if it only has five equations and solves in a microsecond? And is the performance related to structural issues or parameterisations? Maybe FaIR would perform better overall with some tweaks to the calibration? There is also the question of whether the task of FaIR is to represent the CMIP6 ensemble, or to represent a constrained version, or both (of course). I know this figure is illustrating the model, but it opens many questions in the context of how the paper was framed. In any case, these are all points for the discussion! And these points are why it is so nice to have such a "simple and transparent" SCM, as you can do so many quick analyses to answer these sorts of rather fundamental questions!

24. One issue not mentioned is the paper is additivity and nonlinearities. It is not uncommon to want to know what the effect of a given sector or gas is? How much is CO2, or SO2, or transport, or China, etc of the total? In that case, it would be nice to know how non-linear the model is. If I ran all the components separately (Table S2) and added together, how close to the total is it? What about if I added sectors or countries, would the sectors and countries add to the global total? If not, how big or important is the difference? Since you hope this model will be widely used, and even has an EXCEL version, the additivity and nonlinearity issues really need to be discussed and quantified.

25. Just to mention again, it would be good to have a section where the implementation is discussed. The paper mentions this can run in EXCEL and is easy for others to implement, but just running through my head, it doesn't necessarily seem completely trivial! It would be great to explain how it was implemented and how the solution time was optimised given time steps, etc. You mention there are also memory issues too, so mentioning these sorts of issues is important if people want to implement the model. It would also be useful for implementation purposes to provide some standardised input and output data, so people can test their implementation and problem solve any

implementation errors.

26. Table S2: I guess that is a r_tau, not tau?

27. Table S2: Great if this data, and similar data for the temperature model, are easily to download as csv or something as these are key parameters for people to implement the model.

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