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comment**

Interactive comment on "On the Future Role of the most Parsimonious Climate Module in Integrated Assessment" *by* Mohammad M. Khabbazan and Hermann Held

Anonymous Referee #2

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1   General Comments

Khabbazan and Held's paper checks the performance of a one box energy balance model (PH99), currently in use in the integrated assessment models FUND and MIND, against output from AOGCMs before suggesting a simple, improved way to use it in future. Their major conclusion is that, for strong mitigation scenarios, prescribing ECS and TCR to PH99 from Forster et al. (2013) with no further calibration implicitly causes researchers to sample much larger temperature responses than they intend to. They show that a simple fitting exercise rectifies this and validate the fit by checking PH99's performance under one other scenario. This scenario is very similar to the one they

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used for fitting. They then explore different methods to map AOGCM ECS and TCR onto 'effective' PH99 values which could provide researchers with a simple method of revealing the temperature response they are actually considering.

My major concerns focus on whether the analysis shows that PH99 is a valid energy balance model rather than a fitting tool. I also think that the writing style could be greatly improved. I think the authors point out some key errors which arise if PH99 is used without care and explore a few ways for modellers to quickly relate their parameters to AOGCM ECS and TCR values. However, given that the authors argue for mapping AOGCM properties onto 'scenario-class-specific values before using them in PH99', which appears to undermine any physical basis for PH99, I'm left wondering if this paper highlights the limitations of PH99 rather than providing strong arguments for its use.

2   Major concerns

1. The re-callibration of PH99 is only validated for RCP4.5. There is no other testing of the performance outside of RCP2.6 and RCP4.5, two very similar scenarios, nor testing of the effect of different non-CO_2 forcing pathways. Thus the authors have shown that a good fit to AOGCM GMT output can be done with two free parameters and that this fit is good for a similar scenario. I wonder if testing over a greater range of other scenarios would strengthen the justification for the use of PH99.

2. The initial testing of the performance of PH99 against AOGCMs reveals a key, hidden, bias of this model if used without validation in strong mitigation scenarios. This is a good bit of analysis. As a result of this analysis, the authors advocate mapping AOGCM climate system properties onto 'scenario-class-specific values before using them in PH99'. Whilst this seems to be necessary for accept-

able performance of PH99, it also appears to undermine any physical basis for PH99. If you have to re-callibrate PH99 every time you want to use it in a different scenario class then its parameters lose all physical meaning and instead simply become fitting parameters. Thus the authors appear to advocate shifting PH99 from an energy balance model to a function that can be fitted to AOGCM data and then used for a limited range of scenarios?

3. I don't think I am wrong in saying that this model is ultimately meant to be used by those who are looking for simple emulators of global mean temperature response and hence may not be climate modellers themselves. If this target audience can't pick up this paper and get some sense of what is going on then they will struggle to use any of the fits provided. A paper on 'the most parsimonious climate module' should have a style which reflects its title. Given that parsimonious is synonymous with 'simple' in this context, it makes sense for the communication to be as plain, clear and simple as possible too. With this goal in mind, I suggest numerous technical corrections and ask for multiple clarifications.

4. The exploration of different possible parameterisations of the relationship between AOGCM ECS/TCR and effective ECS/TCR is, in my opinion, worthwhile. My impression is that they recognise that a parameterisation would be nice but don't have strong enough evidence to recommend any of the ones they have tried and so the results here are underwhelming.

3 Specific Comments

1. As an exercise, the fitting that is done is scientifically sound re methods, assumptions, results, and reproducibility as far as I can tell. I can also see that it would be useful for modellers who wish to use a simple emulator but don't wish to do the calibration themselves.

2. I think this paper shows that PH99 is closer to a fitting tool rather than a physical model. Hence I wonder, if modellers are after computational simplicity and a fitting tool, why wouldn't they use a simple carbon budget target or emissions pathway to constrain their model. There is already research on how emissions pathways and targets map to temperature targets so this could be used to back out emissions constraints from a given temperature target for a given scenario class. This approach seems far simpler than introducing an energy balance module which requires atmospheric concentration and radiative forcing input, has little physical basis and hasn't been validated over a wide range of CO_2 and non-CO_2 scenarios so might not produce realistic temperature projections anyway.

3. The introduction calls IAMs an 'indispensable tool'. I acknowledge that this comment is made in the context of 'driving welfare-optimal climate policy scenarios' so it is accurate. However given that there are many who disagree with using economic analyses for determining 'welfare-optimal scenarios' because of the need to monetise many things which arguably can't be monetised (e.g. the environment), using this term seems to open the paper up to unwanted distractions. I think this could be avoided with a simple re-wording; calling IAMs a 'tool which are used to derive welfare-optimal scenarios' rather than an 'indispensable tool used to derive welfare-optimal scenarios'. This change would avoid opening up an economic debate (in the reader's mind) which is completely outside the scope of this paper.

4. page 8, line 22: 'personal conviction'. I don't think personal convictions have any place in scientific papers. Either the evidence is there to support using log-normal distributions or it's not. I also don't understand what the sentence beginning with 'This conviction rests' means. Does it mean 'Schneider von Deimlinig et al. show that constraining ECS by paleo data results in thin-tailed distributions'? If yes, then there is no need for a 'personal conviction', circling back to my first point.

5. I really appreciated the discussion of low pass filtering and think this was well done.

6. In section 4 (page 7, lines 32-34), the authors state that 'regressing both inferred effective ECS and TCR solely against AOGCMs' ECS obviously is the overall better approximation'. Whilst this is borne out by taking a pure average of all the results, there are clearly two strong outliers which are having a major effect on the performance of the ECS-ECS & TCR-TCR mapping. I wonder what is causing such large outliers (they seem hugely anomalous) and if removing them would be justified. If they are removed, how much does this change the conclusions.

4 Technical Corrections

4.1 Graphs

Labelling of axes and units could be greatly improved on all figures

Figure 1: Adding something to indicate that 2071-2100 was the most important region for validating the model might be useful for the reader

Figure 2: Is the legend covering part of the figure?

Figure 4: Is the legend covering part of the figure?

Figure 5: Would it be worth adding fitting parameter values to the figure or caption?

Figure 6: Would it be worth adding fitting parameter values to the figure or caption?

Figure 7: Please add more explanation of the caption to the figure e.g. what do the different colours on the right hand side of the figure represent?

4.2 Text

Abstract: It might be worth swapping sentences 2 and 3 with sentences 4 and 5?

page 1, line 6: This is effectively an 'energy balance' model, I don't think the term 'climate' model is appropriate for one box models

page 1, line 15: replace 'effective' with 'equivalent'?

page 1, line 15: delete 'intrinsic'

page 1, line 16-17: 'in particular when computationally demanding decision-making under climate response uncertainty continues to be modelled' should either be 'in particular as computationally demanding decision-making under climate response uncertainty continues to be modelled' or 'in particular when computationally demanding decision-making under climate response uncertainty is modelled'

page 1, line 18: delete 'thereby'

page 1, line 18: 'determined effective' should match with whatever language is used to describe these ECS values in line 15

page 1, line 19: delete 'now'

page 1, line 24: 'emulating' → 'to emulate'

page 1, line 27: 'reduced time' → 'reduced amount of 'time'

page 1, line 28-29: "SCMs are indispensable as those IAMs' numerical solvers would call the climate module from ten thousands to hundred thousand times before numerical convergence is flagged." → "whose numerical solvers would call the climate module from ten to a hundred thousand times before numerical convergence is flagged, SCMs are indispensable."

page 2, line 6: 'capable of emulating the behavior of AOGCMs regarding GMT change,

deviations being a function of spread of forcing,' → 'capable of emulating the GMT change behavior of AOGCMs with observed deviations being a function of the spread of forcing,'

page 2, line 7: 'callibration' please provide reference

page 2, line 10: delete commas and 'utilized'

page 2, line 13: 'Here we address the most extreme opposite end of scale of complexity within the model category of SCMs' → 'Here we address the opposite end of the SCM scale'

page 2, line 14: delete 'Its role is as described in the following.'

page 2, line 15: add comma after 'diagnostic instrument'

page 2, line 17: comma after '(1999))'

page 2, line 27: 'further validation is both necessary and possible on a higher level of consistency' → 'further validation is necessary and results in a higher level of consistency'

page 2, line 29: 'scenario generation' → 'generating scenarios'

page 2, line 29: comma after '(UNFCCC, 2016)'

page 2, line 30: 'scenarios is crucial, displaying' → 'scenarios is crucial because they display'

page 2, line 32: 'we utilize' → 'we instead utilize'

page 2, line 33: 'Finally we find current practice, directly' → 'Finally we find that the current practice of directly'

page 2, line 33-34: 'and a second, time- scale relevant property for calibrating PH99,' → 'and a second, time- scale relevant, property for calibrating PH99'

page 3, line 1: 'in' → 'by' and 'on' → 'onto'

page 3, line 16: I don't understand what 'generically' means in this context, is it meant to be 'generally'?

page 3, line 26: 'Hereby' → 'where'

page 3, line 26: 'GMT' → 'GMT anomaly'

page 3, line 26: 'in units' → 'as a fraction' (?)

page 3, line 31: delete 'also in line with Petschel-Held et al. (1999) and Kriegler and Bruckner (2004).'

page 4, line 3: Would it be worth pointing out that for an increase rate, r, in %/yr, $\gamma = \ln(1 + \frac{r}{100})$?

page 4, line 4: add comma after 'In the following'

page 4, line 8: 'We address this difficulty by a chain of arguments along the equations as given below' → 'We address this difficulty now'

page 4, line 9: 'As starting point' → 'As a starting point,'

page 4, line 13: delete 'so derived'

page 4, line 13-28: I found this section very hard to understand, is it possible to simplify the language and process, perhaps?

1. convert equation 1 into an equation for heat flux by multiplying by h so it reads

$$hTt = \mu h \ln(c) - \alpha h T(t)$$

2. recognise that $\mu h \ln(c)$ is radiative forcing due to CO_2

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3. recognise that radiative forcing due to CO_2 is also given by $\frac{Q_2}{\ln 2}\ln(c)$ so

$$\mu h = \frac{Q_2}{\ln(2)} \Rightarrow \mu = \frac{Q_2}{h\ln(2)}$$

4. use equations 2, 3 and 6 with input ECS, TCR and Q_2 to determine α, μ and h and hence be able to time-integrate equation 5

page 4, line 27: 'Thereby' $\rightarrow$ 'Thus'

page 4, line 28: 'are projected' $\rightarrow$ 'can be projected'

page 4, line 29-: Sentence is too long: 'To derive the initial levels (2006) of the temperature anomaly with respect to the preindustrial value, for each AOGCM we calculate the mean temperatures over the period 1881-1910 and 1991-2020, respectively, as the preindustrial level of temperature and indicator for 2006 temperature level. The difference between these two is fixed as the initial temperature anomaly.' $\rightarrow$ 'Finally, to avoid differences occurring over the historical period (pre-2006 for the RCPs), we need to initialise PH99 with each AOGCM's 2006 temperature anomaly with respect to the pre-industrial value. To do this, for each AOGCM we calculate the mean temperature over the period 1881-1910 and set this as the pre-industrial value. We then calculate the mean temperature over the period 1991-2020 and use this as an indicator for the 2006 temperature level. The difference between these two values is fixed as the initial temperature anomaly for PH99.'?

page 5, line 3: 'As for' $\rightarrow$ 'For'

page 5, line 4: I can't find the Edenhofer et al. reference in the reference list and I don't think I'm being completely stupid...

page 5, line 5-6: 'is of special importance, as an error metric, the respective 2071-2100 GMT time averages of PH99 and AOGCM are subtracted.' $\rightarrow$ 'is of special importance.

Hence we use the difference between the respective 2071-2100 GMT time averages of PH99 and the AOGCM as an error metric.'

page 5, line 9: 'the deviations from the annual temperature data of' → 'the difference between PH99 and the AOGCM GMT anomaly for the'

page 5, line 10: 'are' → 'is'

page 5, line 11: '30-year means' → '2071-2100 means'

page 5, line 12: 'APGCM' → 'AOGCM' (this typo happens a few times, find and replace all 'APGCM' with 'AOGCM' should eradicate it)

page 5, line 22: delete 'needed to be run'

page 5, line 22: 'to check whether the trained climate module can' → 'of the trained climate module's ability to'

page 5, line 23: 'in PH99 the latter then being driven' → 'in PH99. PH99 is then'

page 5, line 24: 'final 30-year' → '2071-2100'

page 5, line 25: 'APGCM' → 'AOGCM'

page 5, line 27: 'time $1/\alpha$ calculated' → 'time, $1/\alpha$, calculated' or maybe 'time ($1/\alpha$) calculated' to be consistent?

page 5, line 28: (being pedantic) units of 2.11 and 4.67

page 6, line 6: 'the' → 'from a'

page 6, line 6-8: "Paris 2015 agreement (UNFCCC, 2016) stated goal is '...holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels...'" → "2015 Paris agreement stated goal is '...holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels...' (UNFCCC,

2016)"

page 6, line 8: 'difference in 0.5K does matter' → 'difference of 0.5K matters'

page 6, line 10: 'deviations' → 'GMT deviations'

page 6, line 10: delete 'actual temperature'

page 6, line 11: delete 'thereby'

page 6, line 18: 'any' → 'each' and 'whereby' → 'where'

page 6, line 20: ', hence' → 'i.e.'

page 6, line 23: '4 A mapping of α, μ, and ECS onto their PH99-specific counterparts' → '4 A mapping of ECS onto its PH99-specific counterparts α and μ'

page 7, line 3: 'on ECS' please provide reference

page 7, line 5: 'hereby' → 'here'

page 7, line 6: 'as of' → 'in'

page 7, line 7: 'by means of' → 'with'

page 7, line 8: 'as' → 'as a'

page 7, line 10: 'needed' → 'need about'

page 7, line 13: 'exploits' → 'exploits the fact'

page 7, line 21: 'extrapolate from the 14 utilized AOGCMs on any ECS' → 'extrapolate ECS and TCR from the 14 utilized AOGCMs'

page 7, line 21-22: Is line 22 meant to read 'Fig. 5'? as saying 'going beyond the scheme displayed' contradicts with figure 4 which actually does show all the schemes you discuss and the text on page 4, line 32 'are shown in Fig. 4'.

page 8, line 4: 'use of broader' → 'use of a broader'

page 8, line 5: 'use of' → 'using'

page 8, line 5: delete 'not only it projects a better approximation, but also'

page 8, line 6: 'on' → 'of'

page 8, line 13: 'This means, that, firstly' → 'For example'

page 8, line 14: 'on' → 'onto'

page 8, line 15: 'active' → 'forcing' or 'forcing active'

page 8, line 19: 'announced' → 'thought' or 'intended'

page 8, line 24: 'at' → 'to'

page 8, line 27-28: ', hence expresses' → '. It indicates that one is'

page 8, line 29: 'accepted above' → 'accepted the above'

page 8, line 29: 'boefore' → 'before'

page 8, line 30: 'on ECS' → 'of ECS'

page 8-9, line 30-1: 'When interpreting these values as PH99 values, as they have been in fact utilized in PH99 since Lorenz et al. (2012) for the MIND model,' → 'When interpreting these values as PH99 values (as they have in fact been utilized in PH99 since Lorenz et al. (2012) for the MIND model)'

page 9, line 2: 'From Fig. 7, from' → 'Fig.7 from' and '(Bindoff et al., 2013) we see' → '(Bindoff et al., 2013), shows'

page 9, line 21: 'Quite' → 'On'

page 9, line 27: 'Hereby' → 'Here'

page 9, line 29: 'those' → 'the'

page 9, line 30-32: Unclear. The only thing that made sense to me was to re-write as

'deviations from the RCP2.6 scenario are most relevant so we expect sufficiency for scenarios approximately in-line with the 2° target.'

page 9, line 32: 'approximantely' → 'approximately'

page 10, line 6: delete 'when'

page 10, line 7: 'AOGCMs to the emulator PH99, generally leads to an overestimation of global mean temperature (GMT) by 0.5 K. Quite' → 'AOGCMs to the emulator PH99 generally leads to an overestimation of global mean temperature anomaly (GMT) by 0.5 K. On'

page 10, line 8: 'by' → 'with'

page 10, line 10: 'AOGCM' → 'AOGCMs'

page 10, line 10: Is it worth pointing out that the 'several explanations' are all in the discussion as only one is presented in the conclusion?

page 10, line 12: 'as already' → 'as is already'

page 10, line 13: Add comma after 'However'

page 10, line 14: 'are re-interpreted as effective, 2°C-scenario-class specific values and mapped from original ECS and TCR values' → 'are mapped from original ECS and TCR values onto effective, 2°C-scenario-class specific values'

page 10, line 17: 'operated' → 'used'

page 10, line 17: 'For the' → 'Nonetheless, for the' may read better

page 10, line 19: 'It has to be checked to what extent the transformations on ECS and TCR' → 'check the extent to which the transformations of ECS and TCR'

I would suggest

page 10, line 20: '. (ii) By' → ' (ii) by'

page 10, line 22: '. (iii) F' → ' (iii) f'

page 10, line 23: '. (iv) A' → ' (iv) a'

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page 10, line 23: 'mapping from ECS/TCR' → 'mapping from desired ECS/TCR values' or some other words to clarify?

page 10, line 28: 'parsimoneous' → 'parsimonious'

page 17, line 3: 'before' → 'at their RCP2.6 fitted values'

page 18, line 6: Delete 'Hence the validation is successful'. That's for the reader to decide.

page 19, line 1: 'over the last 30 years' → 'over the period 2071-2100'

page 19, line 1: 'vs.' → 'from'

page 21, line 2: 'discussion' → 'discussion of'

page 21, line 3: delete 'effectively lower'