Geosci. Model Dev. Discuss.,
https://doi.org/10.5194/gmd-2018-60-RC2, 2018

Geoscientific Model Development Discussions
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Interactive comment on "Computationally Efficient Emulators for Earth System Models" *by* Robert Link et al.

Anonymous Referee #2

Received and published: 13 August 2018

1 General comments

This paper describes an earth system model "emulator" for quickly simulating multiple realistations of earth system model output. This model will be useful for studies in which large ensembles are necessary to evaluate effects, or for probabilistic evaluations such as how likely a given emissions pathway results in a global mean temperature exceeding some pre-defined threshold. The spatial nature of the model also allows investigations into regional effects. As suggested by the authors I can see an application where this model could be applied to the output of simple climate models to introduce temporal and spatial variabilty.

In general the paper is well-written and reasonably easy to follow. The software itself is

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publicly available and the examples given in the paper are reproducible. However, the language used is quite mathematical for a GMD paper. I think this could be addressed without loss of quality or conciseness.

Also, as suggested by the first reviewer, this is not an emulator in the strict sense. See Lee et al 2011 https://www.atmos-chem-phys.net/11/12253/2011/acp-11-12253-2011.pdf, fig. 2 for a graphical representation of an emulator in the 1-dimensional case.

I also agree with the first reviewer in that, ESM outputs are not "observations". "ESM outputs" would suffice. A related point is that the model simulates global mean surface temperature from GCMs (general circulation models/global climate models - choose your favourite acronym) rather than ESMs. The CMIP5 definition of an ESM includes an interactive carbon cycle, going from emissions to concentrations to forcing to temperature. GCMs skip the emissions step, running from prescribed concentrations that have been calculated from a simple model, e.g. MAGICC, as they were in CMIP5.

2 Specific comments

In the introduction, the application of the model to extreme events is given as a justification for its creation. However, the model only produces annual mean temperature output in each grid cell. I am not aware of an extreme indicator that uses annual mean temperatures. Such indicators are usually calculated from daily climate model output (see Zhang et al 2011, 10.1002/wcc.147). This would be a natural extension to this model, but in its current form it is not capable of analysing "extremes" in the usual sense.

Section 2.3: I don't disagree with the authors about the notation convention: I understand the broadcasting concept used in their convention and agree it aids readability. I do find it hard to follow the equations though. If we have

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$|T_g >= \mathbf{O}|\lambda >$

then this suggests to me that $|T_g >$ is a column vector of shape 855 x 1 formed by multiplication of $\mathbf{O}$ (855 x 55296) by $|\lambda >$ (55296 x 1). In eq(2) you have $T_g|w > +|b >$. Is T_g (not bracketed in eq(2)) times $|w >$ a column vector times a column vector? How is this defined? And then in equation 3, there is $|T_g >$ (a column) times w (a row), which I think is 855 x 855, then added to $|b >$ (855 x 1)? and subtracted from $\mathbf{O}$ (55296 x 855 - but how is this broadcasted?) If there are no typos in these equations, it would be helpful here to put in a diagram of the matrix dimensions in the equations 1 to 3.

σ values in table 1 and p5 line 9. I think these are the singular values of $\mathbf{R}$, but it is not really explained what these are or what they mean. This paragraph could do with some expansion of the key terms (rank deficient, discrete Fourier transform). Does dropping EOFs where $\sigma < \sigma_{threshold}$ guarantee full rank?

Section 3: Can the four images in figure 1 be interpreted as ensemble members? If so, it would be good to state this.

figures 4-6 and associated discussion in lines 24-28 on page 6: The periodic variability in EOFs 2, 3 and 5 - could these have a physical interpretation? For example there seems to be an El Nino style feature in EOFs 3 and 5. On the other hand, is there any evidence that the lower EOFs are not just noise?

Section 4.2 got me thinking that as the model is trained on the RCP outputs, is there any difference in the results when taking just the set of realisations from RCP2.6 and RCP8.5? Certaintly across ESMs, the variance across models increases with increasing global mean temperature. It would therefore not be correct to use a variability model that is trained on RCP8.5 for low forcing scenarios or those with a peak and decline. I note the authors address this in section 4.3, but I wonder if they have tested this.

3 Technical corrections

page 5, line 3: allow > allows

page 6, line 3: 143 seconds. What is the machine architecture here?

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