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## Comment on gmd-2021-252

Christopher Smith (Referee)

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Referee comment on "From emission scenarios to spatially resolved projections with a chain of computationally efficient emulators: coupling of MAGICC (v7.5.1) and MESMER (v0.8.3)" by Lea Beusch et al., Geosci. Model Dev. Discuss., <https://doi.org/10.5194/gmd-2021-252-RC1>, 2021

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In this paper the authors couple a global emulator (MAGICC) with a regional ESM emulator (MESMER) to create simulated fields of regional surface temperature anomalies from pre-industrial under different future climate scenarios. The combined emulator can be run either to simulate the response to particular CMIP6 models, or in an "observationally constrained" manner in which the global mean response ensemble from MAGICC has been pre-selected to be consistent with observed temperature and global mean uptake. This framework will be very useful to provide regional projections of climate change to future scenarios. Most importantly, and possibly a point that the authors undersell, is that the regional climate projections from *any* scenario can be produced, not just those that were run by ESMs (e.g. the SSPs). This would allow specific scientific questions to be answered such as the regional responses to different pre-defined levels of global mean warming, forcing, or total carbon budgets, and regional climate change commitments. The cheap computational framework, allowing millions of ensemble members to be run (memory is suggested as a limiting factor, but not processing speed), allows for statistically robust projections of climate risk in different regions and can aid adaptation planning. The modular, open-source framework appears to be flexible and extensible: while only annual mean regional temperature anomalies are included at the moment, the opportunity to include precipitation and other climate variables (provided robust predictors are found), or higher simulated time resolution, should be possible without redesigning the whole framework.

This paper does something important and useful, and does it well, so my comments are limited to being quite minor.

lines 19-20: I assume IPCC 2021 also says this - though given the increased roles of emulators in the Sixth Assessment, perhaps ESMs are not our primary tools any more!

figure 2: It took me a few minutes to fully decipher what the right side was showing here. Faint horizontal lines that separate the four rows would make it clearer that the spatial plots correspond to the same rows as the time series plots. In the first map in row (b) I think it is taken that the pink, purple and orange lines are very similar and the forced GSAT plot from the blue line is a bit warmer. I would also take from this that in (b) and (c), dividing any of the four scenarios by any of the others would give a constant pattern scaling ratio of local to global GSAT that is the same everywhere.

lines 139-140: more for my interest, but what regression coefficient did you determine for the stratospheric aerosol optical depth? Also, if you wanted to be totally CMIP6-consistent you could use the CMIP6 SAOD time series ([ftp://iacftp.ethz.ch/pub\\_read/luo/CMIP6/CMIP\\_1850\\_2014\\_extinction\\_550nm\\_strat\\_only\\_v3.nc](ftp://iacftp.ethz.ch/pub_read/luo/CMIP6/CMIP_1850_2014_extinction_550nm_strat_only_v3.nc)) rather than NASA-GISS one.

lines 193-194: of course, more predictors will reduce error. I was satisfied that the possibility of overfitting is addressed later on (lines 216-218). Still, I think the flow of the paper is a bit disjointed: we have a standard MESMER config (Beusch et al. 2020), then we introduce a relationship with more predictors and shows it performs slightly better (fig 3 and 4), but actually we don't use it for the main MESMER-MAGICC coupling in section 3.3 (explained in lines 249-255) that is the main subject of the paper. Perhaps a reordering to put the "additional predictors" section later on could be explored.

line 247: I'm in general agreement with the authors' opinion on the implausibility of SSP5-8.5 but I think Hausfather & Peters 2020 gets abused a bit - particularly as we're running everything concentration driven here and high-end climate responses to a SSP3-7.0 (or even SSP4-6.0) like emissions pathway can't be ruled out.

line 268: MESMER (typo)

lines 285-286: "however, most CMIP6 ESMs perform in an observationally-consistent manner in most regions (Beusch et al. 2020b)." For the ignorant such as me, you might want to briefly explain the discrepancy between poorly performing global GSAT and well-performing regional GSAT in ESMs. I don't know if it is true, or covered in Beusch et al. 2020b, but is it because the regions are mostly land regions and cover 30% of the surface, so much of the poorly performing regions with respect to observations are over the ocean?

line 301: minor style typo: 360,000

lines 304-306 (remark only, no need to respond): I believe this sparse sampling would be sufficient actually. We did some pattern scaling with FaIR where the global delta T from FaIR was combined with one of 10 ESM simulations chosen at random where the ESM performed well over the UK domain. Indeed, the full span of uncertainty was well sampled.

figure 5: it could be a PDF rendering issue, but it would look nice if the alpha (1 - transparency) value for the shaded regions was  $< 1$  to see the overlapping regions between blue and orange.

line 311: SSP1-1.9

section 4.2: is it worth saying where these 600 constrained ensemble members came from? Is it the MAGICC AR6 WG1 config, or is it from one of the RCMIP papers - Nicholls et al. 2020?

lines 336-337: optionally, you could hammer this home by giving the mean and range of ECS of these 6 models, compared to the full CMIP6 ensemble and/or the AR6 assessed range.

line 338: "is clearly incompatible ... (Fig. 6)." Well, only for 2 out of the 6 models - the other 4 look reasonable to me

lines 358-360: Indeed, there was a whole unofficial MIP (PDRMIP) devoted to this behaviour in ESMs. Tom Richardson derived a global precipitation emulator based on emissions of different GHGs, aerosols and GSAT: <https://doi.org/10.1175/JCLI-D-17-0240.1>. He had a regional one somewhere too but don't think it ever made it into a publication. Definitely something to explore.