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Interactive comment on "An update of IPCC climate reference regions for subcontinental analysis of climate model data: Definition and aggregated datasets" *by* Maialen Iturbide et al.

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Along the next lines, the different comments posed by the reviewer RC2 are reviewed point by point.

Comment: This dataset, and therefore manuscript, is clearly an important contribution to the field. I appreciate the openness of the process this time around to define the regions, and that this allows the community a chance to comment on the choice of them. Previously the regional definitions have been either mandated from the top-down or decided by in- dividual researchers for their own purposes. Having said that I feel that the manuscript would benefit from some revisions before it can be published.

Response: We thank the referee for the time devoted to review our manuscript, and for the positive feedback provided.

Comment: This manuscript has multiple different aims. I interpret these as:

1. Justifying any changes in the pre-existing regions
2. Analysing the homogeneity of the regions (this is explicitly stated in the abstract)
3. Providing detailed information to allow researchers to apply the regions themselves
4. Presenting 2 codes to permit regional analyses to be performed
5. Describing a dataset of precomputed time series from the CMIP5 (and CMIP6) simulations

This is an ambitious, but really useful, set of goals. Unfortunately, I find some of the presentation in the manuscript is sub-optimal for these aims. There are some questions that arose from my reading of the manuscript and I have some suggestions that would strengthen the manuscript. I've decided to separate my comments into ones relating to the regions themselves, and ones relating the manuscript. For the purpose of peer-review I feel that only the manuscript comments must be addressed. I do not really mind whether the authors alter the regions in light my comments – rather that they justify the choices they have made.

Response: Again we thank the referee by the positive comments and have included point by point responses to the comments below. We will take into account comments related to both the manuscript and the regions, as explained in the point by point responses below.

Comment: I would also like to mention that I have forked their repository and started to look at the python code. I work mainly in NCL myself, and have added an equiv-

alent function I've written to compute the area-statistics for the AR5 regions into my version. When this manuscript is revised, I should be able to update the definitions in this function as a contribution to the effort.

Response: We are glad to see that the GitHub repository and the code are useful for the community. We would be happy to have your contributions in the package; you can just send a pull-request to our repository from the forked one.

1 Comments about the manuscript

Comment: I often found the justifications for the sub-divisions to be criticisms of the earlier regions, rather than providing an argument for the new choices. For example, in Africa (P5, L12-20) you convincingly demonstrate that the AR5 regions have failings. But there is no acknowledgment the new boundary is different in the Central/Northern compared to the Southern region, let alone justification for it.

Response: We agree with the referee that in some cases the focus is given to deficiencies of the old regions and a description of the reasons for the new choices is missing. This will be clarified in the revised version of the manuscript.

Comment (a): I was surprised by the fact the manuscript only uses the (somewhat arbitrary) interpolated grids for any discussion about whether there are sufficient grid boxes in the regions. This use was exemplified by Fig. 3, whose findings are strongly reliant on the presumed 1° or 2° grid resolution. This component of the manuscript would be much more convincing if you used actual GCM grids. [I believe that an easy way to compute this would be to apply the region masks to the areacella variable. You could then back out the number of grid boxes by dividing the sum of areacella by the mean of areacella.]

Response: The resolution (2° and 1°) of the reference grids used for CMIP5 and CMIP6 ensembles correspond (approx.) to the mean resolution of the models forming

the ensemble and are therefore used as representative grids for generating the the corresponding ensemble products interpolating the individual models. However, we agree with the referee that it would be much informative having the numbers of gridboxes falling in each of the reference regions considering the original model resolutions as well. We will include this information in the revised manuscript. In particular, in the figure we calculate the number of land gridboxes which fall in each of the reference land regions (since those gridboxes are the ones used to interpolate the model values over land); for the individual models we calculate those numbers individually and then represent the mean (and the deviation among models).

Comment: It was unclear to me from either the manuscript, or the provided codes, whether interpolation onto a common grid is/was performed in the computation of the regional averages. Whilst I accept the necessity of using a common grid for any ensemble averaging - such as in Fig 2(d,e) – it would appear to introduce unnecessary computation in determining an area mean, and may even introduce errors in computing higher order statistics.

Response: The reference grid is used to compute the areal aggregated values. Only land model gridboxes are used in the interpolation (using conservative remaping for precipitation) to land reference gridboxes (and ocean gridboxes for the oceanic ones). Therefore the regional mean values computed from the reference grid are representative of the ensemble and do not include artifacts due to different model land/sea masks.

Comment: I did not notice any analysis of the homogeneity of the new regions in the manuscript. You discuss Fig. 2 as if it presents such analysis. But this figure solely presents some key spatial fields and requires the reader to make their own qualitative assessment about the homogeneity. I suspect the box and whiskers in Fig. 5 conventionally presents the spread with time of the monthly values. Therefore, it does not demonstrate that all the grid points within a region have a homogeneous climate. Rather Fig 5 shows that the area averages of the regions follow different structures, which does not allow a reader to identify where 3 different rainfall regimes exist, but

are being shoehorned into 2 boxes. (I note that Fig. 5 may instead use the box and whiskers to measure the spatial variance in the climatological monthly rainfall over the region, but this not mentioned in the caption – nor would it be necessary if an alternate method of demonstrating the homogeneity is used).

Response: As the referee notes in the last sentence, the box-and-whiskers plots in Figures 4 and 5 represent the spatial (gridbox) spread of climatological monthly means over the region; therefore it provides a view of the spatial consistency of the seasonal cycle regimes. We are sorry that was not clear enough in the manuscript. We will clarify that and extend the analysis on the homogeneity (and inhomogeneity in some) of the new regions in combination with Figure 2 in the revised manuscript.

Comment: Please be careful about using the term (inter)annual variability (e.g. P5, L15). This phrase relates to things like the North Atlantic Oscillation and El Niño. You are using it to discuss the climatological seasonal cycle.

Response: Thank you for pointing this out. We will modify the terminology accordingly.

Comment: In light of my own efforts to apply the AR5 regions in NCL, can you please explicitly mention that the regions are defined by straight lines on a projected plane – rather than great circles over a sphere.

Response: We will clarify that in the revised version. Thank you.

Comment: Can you please be more explicit about your treatment of coastal ocean? P6, L1 and the caption in Fig. 1 suggest that the terrestrial regions are only defined over land (as was the case in AR5). This brings up 2 questions:

- Clearly the new terrestrial regions avoid the open ocean by definition, but this still means that the coastal grid boxes are not included in any region. How much of the Earth's surface is not included in any region at all?
- Some of the old regions were defined as both land and sea regions (for example the aptly named SEA), with the Caribbean region combining both. The manuscript needs to both explicitly state, and justify why, you eschewed such an option in these updated regions?

Response: The land regions are defined including both land (grey) and ocean regions (in white) for simplicity (in order to have simple polygonal definitions, avoid the complex coastal regions); however, the ocean regions are not considered in the calculation of model values, using the land/sea mask of the models (or the reference grids) for this purpose (i.e. only land model gridboxes are used to compute land values). We agree this was not clear enough in the original manuscript, so we will clarify this in the revised manuscript. The two specific questions are answered below:

- As mentioned by the referee, the coastal regions are not included in the land regions nor in open ocean (in blue) regions used to represent atmospheric variables. Coastal ocean regions for representing oceanic variables require specific reference regions focusing on e.g. upwelling key areas and should treated differently. Several options for this have been proposed in the literature. In the revised manuscript we will include a description on this issue and provide references for additional reference regions (e.g. ocean biomes).
- Regarding the use of some regions as both land and ocean ones (e.g. the Caribbean), we agree with the referee and would include those dual land/ocean regions at least for the Caribbean and the Mediterranean.

Comment: Your discussion around Fig. 3 (P4, L20) suggests that 20 gridboxes is sufficient, but less than that should be treated with caution. What is the impact of the variations in resolution of the CMIP6 models on the fidelity the 4 small regions highlighted? I note that for example the GISS-E2-1-G model has a resolution of 2°x2.5° - so clearly falls into the 'treat with caution' category. Perhaps you could advise readers on an approach to acknowledge this uncertainty.

Response: A comment on this will be included together with the new calculation of the number of gridboxes for individual models; see comment (a).

Comment: I was surprised by your choice of which regions to illustrate in Fig. 6. You may want to consider highlighting some of the new regions that you've defined in this manuscript – perhaps even in comparison to an old one.

Response: The code provided allows to automatically calculate the same figures for any other reference region (just by changing the region "code" in the script). We have use three regions where a clear gradient is shown in climate change signal for precipitation (increasing/neutral/decreasing in the north/center/south).

Comment: I appreciate that you've provided scripts to use these regions in both python and R. Would you be able to comment on the scripts' performance? For example, does the region extraction take a long time? Is the R approach faster than the Python?

Response: The calculation of the regional aggregated values is time consuming (but computed offline and provided in the GitHub repository). Accessing the values and plotting the results is straightforward and the scripts provided are almost instantaneous. We will include some comments on this in the revised manuscript.

2 Comments about the actual regions

Comment: I can see a lot merit in the criticisms from both Jason Evans and Michael Grose about the new Central Australian region. I have little preference as to which version you pick – but their comments highlight the issues inherent in writing a manuscript that argues against the old regions - rather than arguing for the new ones.

Response: We also see the need of the change requested (the reasons given are very convincing). Therefore we will include a new region (Eastern Australia, EAU) following the comments of both reviewers.

Comment: I found your new sub-divisions for South America puzzling.

(a) You provide little justification for division between NSA and SAM. The only differences visible in the variables shown in figure 2 occur in the Koppen- Geiger classification. Yet other regions, most notably CAF, happily combine these classes. **Response:** We appreciate the reviewer's comment. Although several studies on South America have analyzed regional climate variability at the scale of the Amazon entire, most of them have documented that Amazon has a heterogeneous climate, particularly a strong temporal and spatial rainfall variability (e.g., Espinoza et al., 2019). In our study, the NSA and SAM regions were proposed because they present different climate regimes. They exhibit a well-identified seasonal cycle of precipitation (Figure 4), represent sub-continental areas of greater climatic coherency (Figure 2c), and consistent with climate change projections signal over the Amazon region (NWS, NSA, and SAM) (Christensen et al., 2013). For instance, the precipitation for SAM shows the rainy season from October to March, while for NSA, there are no clear wet and dry seasons. These new areas then provide further insight into sub-continental observed climate variability and projected changes in South America. Using it as an opportunity, we have now edited the text to improve clarity and added literature references. The newly added text states, "In South America, the old northwestern Amazonia region is divided into three subregions to separate the Northern South America (NSA) region from the western region including the northern Andes Mountains range (NWS), and the South America Monsoon (SAM) region. The NSA and SAM regions exhibit a well-identified seasonal cycle of precipitation (Figure 4), represent sub-continental areas of greater climatic coherency (Figure 2c), and consistent with climate change projections signal over the Amazon region (NWS, NSA, and SAM) (Christensen et al., 2013). For instance, the precipitation for SAM shows the rainy season from October to March, while for NSA, there are no clear wet and dry seasons (Figure 4). The Northeastern region is maintained, but the name is changed to Northeastern South America (NES). A new region has been also defined in the South (SSA) to encompass the subpolar climates exhibited in this region (see Figure 2c)."

References:

Espinoza, J.C., Ronchail, J., Marengo, J.A. et al. Contrasting North–South changes in Amazon wet-day and dry-day frequency and related atmospheric features (1981–2017). Clim Dyn 52, 5413–5430 (2019). https://doi.org/10.1007/s00382-018-4462-2

Christensen, J.H., K. Krishna Kumar, E. Aldrian, S.-I. An, I.F.A. Cavalcanti, M. de Castro, W. Dong, P. Goswami, A. Hall, J.K. Kanyanga, A. Kitoh, J. Kossin, N.-C. Lau, J. Renwick, D.B. Stephenson, S.-P. Xie and T. Zhou, 2013: Climate Phenomena and their Relevance for Future Regional Climate Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Comment: (b) I was unsure that the subdivision of Southern South America provides an improvement. The new SWS region mashes together both the Atacama desert and the Mediterranean climate – a distinction which is made in N. Africa Europe, Australia and North America.

Response: The reviewer is right that SWS combined areas with desertic and Mediterranean climates and even cool rain forest in the south tip. We have now included the southern part of the region into the modified SSA region (see response to your next comment). However further separating this region would lead to regions that are way too small (e.g., the Atacama Desert occupies a relatively small area). It should be noted that the new SSW constitutes a clear improvement compared to the AR5 WSA version that, in addition to desertic and Mediterranean climates, also included tropical rainforest and monsoonal areas (see Figures 1-2 in the main text).

Comment: (c) The creation of SSA – a region focussed on Patagonia – seems reasonable. But it was unclear why 47âŮęS was taken as a dividing boundary. Given the small size of the region (as you warn readers about in Fig. 3), why did you pick that latitude as

its boundary? Politically, the Argentinian Province of Chubut provides two convenient alternate latitudes, given that it strad- dles 42-46âŮęS. I would leave it to the authors to assess whether Chubut is sufficiently Patagonian for inclusion into the region or not.

Response: The reviewer makes a good point. Based on the Koppen-Geiger classification and the CMIP5 projected future changes in precipitation, it would be reasonable to include the Argentinian province of Chubut as part of the novel SSA. Consequently, we have moved the northern boundary of SSA and SSW regions from -47 to -40 degrees. This change has the additional benefit of substantially increasing the size of the currently relatively small SSA region. The new SSA region corresponds pretty well with the region that is generally refer as Patagonia and, thus, we will consider changing its name from SSA to Patagonia (PAT).

Comment: What about Madagascar? Inspecting the variables shown in Fig 2a-c and the fact that it's not contiguous, I wonder if it should really be considered as part of the South East Africa. It is certainly a larger landmass that New Zealand.

Response: We agree with the referee and will split Madagascar from South East Africa, including a new region.

Comment: Will ensemble-wide relationships between the North Atlantic Ocean warming and the AMOC be confounded because both the Labrador and Norwegian Seas are not incorporated into the region?

Response: The open ocean regions are used for representing atmospheric variables (see a comment above). We will move the northern boundary of the North Atlantic region as much as possible.

Comment: Is the New Zealand region adequately resolved as a land-only region across all CMIP6 model resolutions?

Response: New Zealand and the Caribbean are the smallest regions (with 26 and 20 land gridboxes for the reference 1° region, respectively). This is considered adequate

for representing the region. We will discuss this in more detail in the revised manuscript taking into account the results for the individual models.

Comment: Why do the Russian Arctic and Far East regions stop at 180âŮę? Why does NWA exclude the Alaskan Peninsula (defining a latitude lower that 60âŮęN may not be unsuitable)? The peninsula and Russian area around the Bering Strait are the only examples of continental land masses that is incorporated into ocean regions.

Response: The referee is right. There is no reason for stopping at 180° (apart from convenience for representing the region) and therefore, the regions will be extended accordingly in the revised versión. Similarly, NWN will be extended to include the Alaskan península and other land regions excluded from the orginal definition.

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