Technical Note 3 – methods for producing warming level projections

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Introduction and context

International agreements on climate change (e.g. the Paris Agreement, 2015) are framed around keeping the global average surface temperature change below specific levels (1.5 °C or 2 °C), relative to pre-industrial conditions. This global warming framing is now of strong interest (e.g. Harrington et al., 2018). In this technical note we describe the methods and choices used to produce regional projections for Australia at specific global warming levels of relevance to decision-makers and next-users.

Data and methods

Change is estimated relative to the 'early industrial' baseline of 1850–1900 that is now widely used (Hawkins et al., 2017; Schurer et al., 2017). Four global warming levels are considered here: 1.5, 2, 3, and 4 °C above to this early industrial baseline. Hereafter these will be referred to as +1.5, +2, +3 and +4 °C worlds.

There are various methods available to estimate projected regional climate change at warming levels. Some information can be deduced from historical change, including the ratio of global to regional warming, and this is done for temperature change for the 1.5 °C warming levels presented in the ***'Years at +1.5 °C level'*** page. All other methods use climate models in some capacity.

It would be useful to run experiments with a future climate carefully equilibrated for each warming level, and this has been attempted under the Benefits of Reduced Anthropogenic Climate Change (BRACE) project of Sanderson et al. (2018) and the Half a degree of warming, Prognosis and Projected Impacts (HAPPI) project of Mitchell et al. (2017). However, it was not feasible within this project. Most other techniques use the transient simulations from the World Climate Research Program's (WCRP) Coupled Model Inter-comparison Project Phase 5 (CMIP5) models (Taylor et al. 2012), run for the Representative Concentration Pathways (RCPs) of Van Vuuren et al. (2011). These highly sophisticated global climate models simulate many aspects of the global climate as well as their complex interactions. By running these models with future greenhouse gas emissions pathways, we can project what the future climate may look like.

There are various methods that can be used with CMIP models to generate warming level projections using the transient simulations available, see James et al. (2017) for a review of many of them, including: pattern scaling, which is a reasonable approximation for Australia (Tebaldi and Knutti 2018; King et al. 2018) but is not considered here, or sub-selecting models that happen to produce the warming level at the desired timeframe, also not used here.

We primarily use the method of time sampling climate models, sampling the transient model simulations in time as they move through each warming level (see James et al. 2017 for a description). The specific choices for producing the projections are laid out in order.

1. Model only

Changes are calculated relative to each model's own baseline and we don't use observed change from the early baseline to the recent baseline to calibrate the results. This has the advantage of keeping internal consistency within a model and avoiding a short calibration period that ignores each model's internal climate variability.

2. *Representative Concentration Pathway 8.5 (RCP8.5)*

Warming level projections can be generated using any and all RCPs. For example, projections for +1.5 °C global warming can be produced from RCP2.6, RCP4.5, RCP6.0, and RCP8.5 simulations, or any combination of any or all of these. Some higher warming levels are only reached by higher RCPs, and then not by all models. Choice of RCP/s to use is a balance of sampling model diversity and achieving a large enough sample size (warming levels can be passed through quickly under RCP8.5).

For these projections we focus on the CMIP5 high emissions scenario, representative concentration pathway 8.5 (RCP8.5) simulations; we don't combine all RCPs together. This allows us to study the full range of global warming levels for a consistent large sample of climate models. We note that the choice of emissions pathways does slightly impact the projections by warming level at the regional scale, however these differences are likely due in part to sampling biases since lower emissions scenarios will have fewer models at the highest warming levels (see example in **Figure 1**). By using the RCP8.5 scenario, we are able to sample projected changes from at least 28 CMIP5 models for all the global warming levels of interest here.

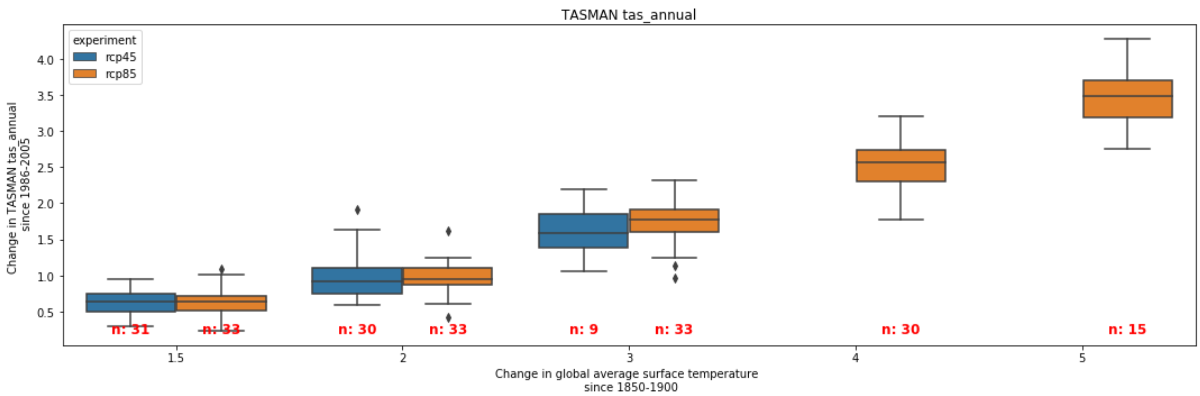

Figure 1 Projections of average annual temperature for Tasmania from CMIP5 models under two RCPs. The number of models is shown in red. Note the different range of results between RCP4.5 and RCP8.5 caused in large part by a different number of models considered – particularly for +3 °C.

3. *Identifying epochs for each global warming level with ±0.2 °C tolerance*

The epochs (time periods) for each global warming level are identified individually for each CMIP5 model. We begin by calculating the global area weighted average monthly timeseries of surface temperature. A smoothed global average temperature timeseries is calculated by applying a ten-year running mean. We can then calculate an anomalous global average temperature timeseries by subtracting the 1850-1900 mean.

Clearly the exact warming levels would be too strict a criterion for sampling, since the transient simulations are unlikely to remain at that exact level of global warming for very long, if at all. Even in an equilibrium experiment, year-to-year variability would also contribute to variations from a particular warming level. To account for this, we provide a tolerance in the definition of each warming level. We then select years where global temperatures were within the range for each warming level, as well as the five years on either side of each selected year. This allows for a sufficient sample size for each warming level. We tested two different tolerances: ±0.1 °C (**Figure 2**) and ±0.2 °C (**Figure 3**). Based on the size of the sampled years at each warming level, we concluded that the ±0.2 °C tolerance was more useful – especially given that we are using RCP8.5 which can move into and out of the ±0.1 °C tolerance window quickly.

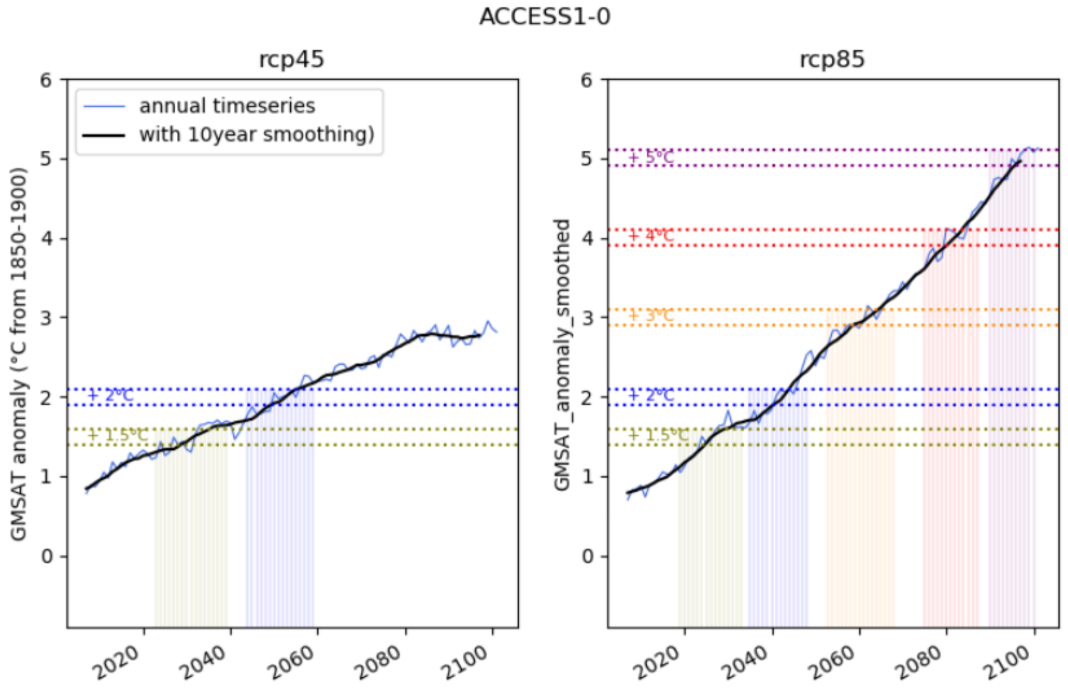

Figure 2 The global mean surface temperature (GMST) relative to 1850–1900 from Run1 of ACCESS-1.0 model for RCP4.5 and 8.5, with the years indicated that meet the conditions for a +1.5 °C and +2 °C world (with ±0.1C tolerance).

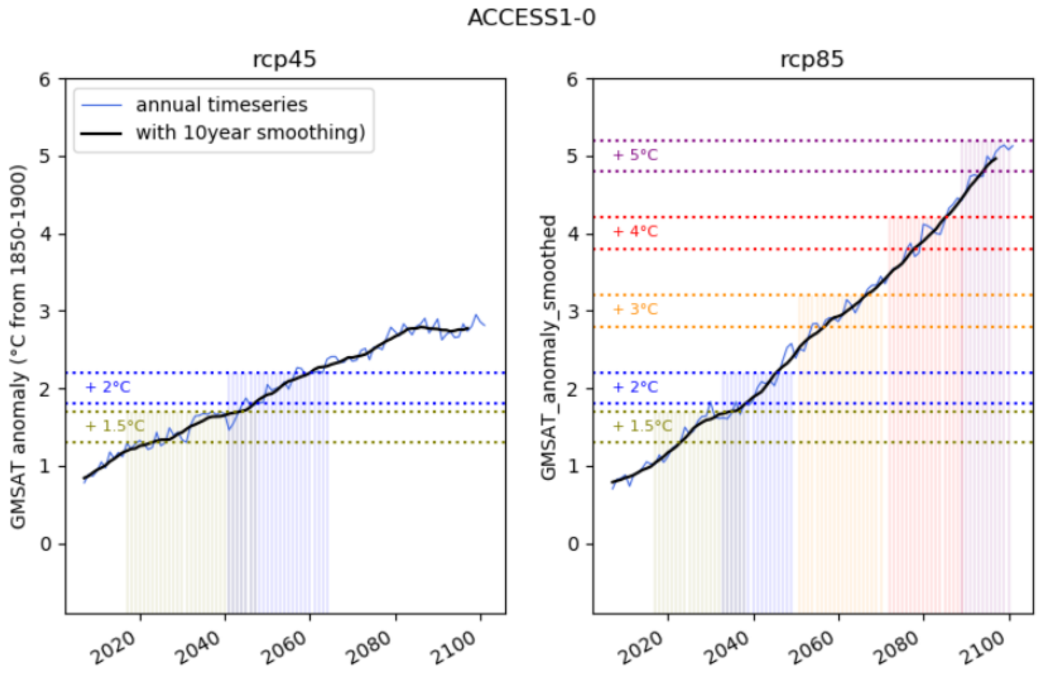

Figure 3 AS for Figure 2 but using a ±0.2 °C tolerance

One important caveat here is that each epoch in each model is potentially of a different size. For example, depending on its individual response to the greenhouse gas forcing, a model may spend more time in a +1.5 °C world than in a +3 °C world. While not ideal, this is a consequence of using transient simulations to estimate changes for each global warming level.

All years for a given warming level for a model are then pooled into a combined sample and statistics are calculated. In this project we only consider annual and seasonal averages, but extremes statistics can also be calculated.

Calculating multi-model mean changes for each global warming level epoch

To generate spatial maps and calculate model agreement for stippling, each model result is first re-gridded to a common 120 x 240 grid (1.5 x 1.5 °Lat/Lon). Model agreement on the sign of change is shown, using a threshold of 80% of model agreement – showing a stipple where this level of agreement is *not* reached; doesn't appear for any temperature plot (**Figure 4**), but is widespread in rainfall results (**Figure 5**).

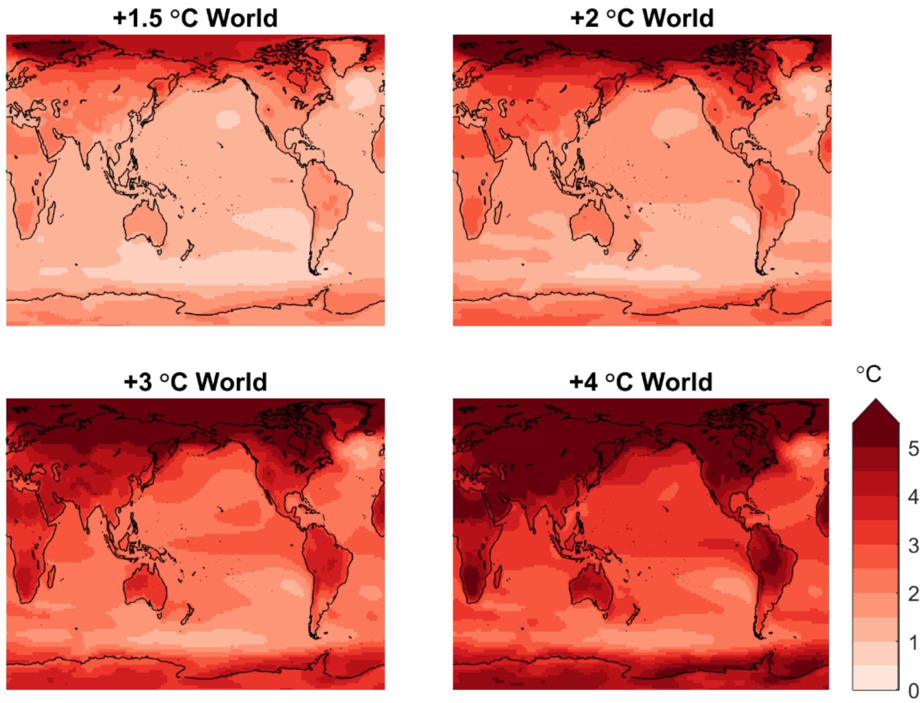

Figure 4 Multi-model mean of mean annual surface temperature change from 1850–1900 for global warming levels using the time sampling method of CMIP5 models

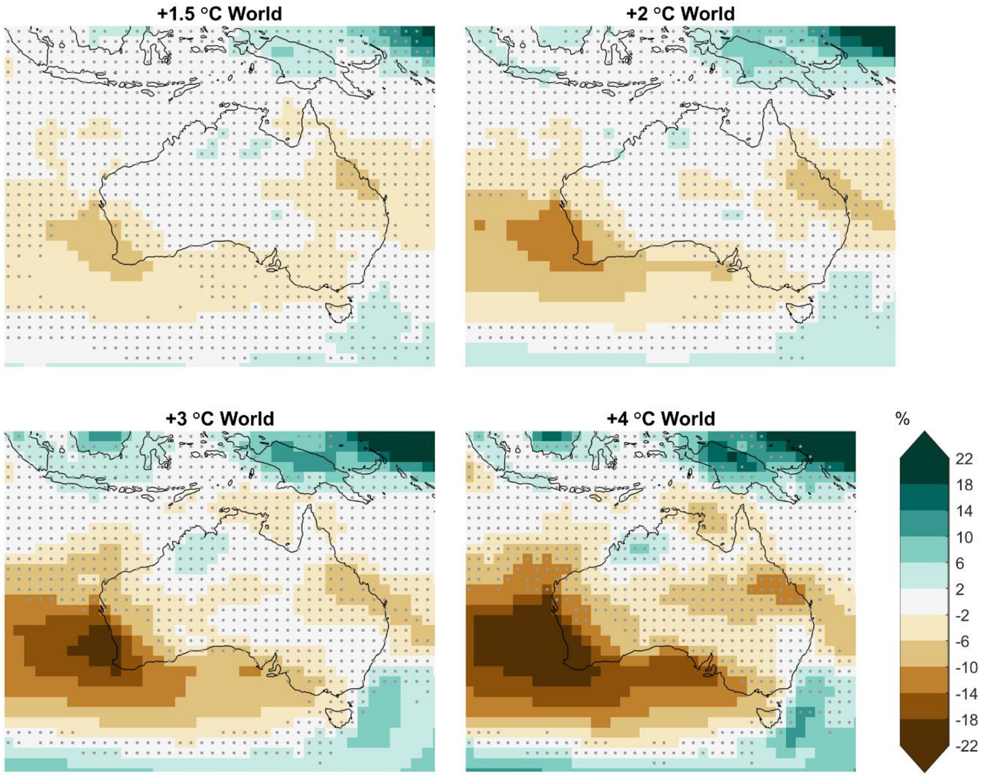

Figure 5 Multi-model mean change in mean annual rainfall from 1986–2005 for global warming levels using the time sampling method of CMIP5 models.

Calculating regional changes for each global warming level

For each Australian state and territory, as well as the four Natural Resource Management (NRM) superclusters (CSIRO and Bureau of Meteorology 2015) we calculate the area average monthly timeseries of surface temperature and rainfall. This is done using a fractional mask for each region, on each models' native grid.

Using the epochs for each global warming level, the years in the regional average surface temperature and rainfall are selected and averaged. From this we obtain a regional average change for each model for each global warming level.

For surface temperatures we present only the annual mean changes, however we present these relative to two different baseline periods: 1850–1900, and 1986–2005. We do this in order to provide information relevant to a recent baseline, but also to benchmark what the projected range of regional change is relative to the global change.

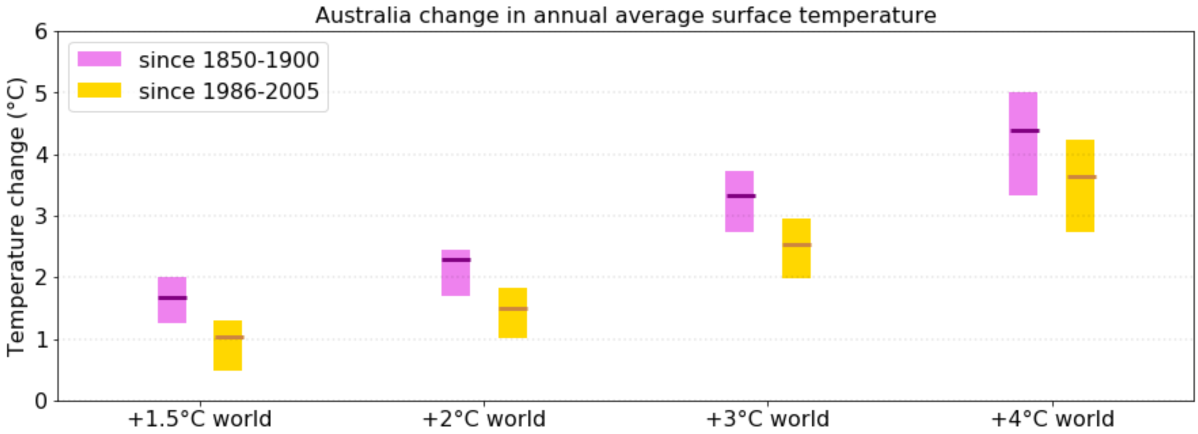

Figure 6 Area-average mean annual temperature for Australia from the baselines indicated from CMIP5: dark line shows model median, bar shows the 10-90 percentile of the model range

Table 1 Change in mean annual temperature for Australia to global warming levels from the baselines listed, the multi-model median is given then the 10-90 percentile range in brackets

Global warming level (^{o}C)	Australian warming from 1850–1900 (^{o}C)	Australian warming from 1986–2005 (^{o}C)
+1.5 ^{o}C	1.7 (1.2 to 2.0)	1.0 (1.0 to 1.7)
+2 ^{o}C	2.3 (1.7 to 2.4)	1.5 (1.0 to 1.8)
+3 ^{o}C	3.3 (2.7 to 3.7)	2.5 (2.0 to 3.0)
+4 ^{o}C	4.4 (3.3 to 5.0)	3.6 (2.7 to 4.2)

Rainfall changes are presented for the annual mean as well as the seasonal means (December to February, March to May, June to August, September to November), and are only shown as anomalies from a more recent baseline (1986 to 2005). We note that this is a different baseline from that used to calculate the global warming levels. While this may seem confusing at first, this choice allows next-users and decision-makers to consider the changes relative to a recently experienced and therefore more relevant period.

Table 2. Change in mean annual and seasonal rainfall for Australia to global warming levels from the baselines listed, the multi-model median is given then the 10-90 percentile range in brackets

Global warming level (°C)	Season	Change Value (%)
1.5	Annual	-1 (-11 to 5)
	Dec to Feb	2 (-7 to 11)
	Mar to May	-3 (-13 to 13)
	Jun to Aug	-8 (-16 to 8)
	Sep to Nov	-1 (-16 to 13)
2	Annual	-1 (-11 to 4)
	Dec to Feb	0 (-11 to 17)
	Mar to May	2 (-12 to 17)
	Jun to Aug	-7 (-22 to 12)
	Sep to Nov	-4 (-19 to 11)
3	Annual	-3 (-14 to 8)
	Dec to Feb	1 (-12 to 13)
	Mar to May	0 (-18 to 22)
	Jun to Aug	1 (-33 to 34)
	Sep to Nov	-3 (-33 to 16)
4	Annual	-5 (-23 to 15)
	Dec to Feb	-3 (-20 to 15)
	Mar to May	2 (-23 to 25)
	Jun to Aug	-16 (-45 to 20)
	Sep to Nov	-16 (-43 to 31)

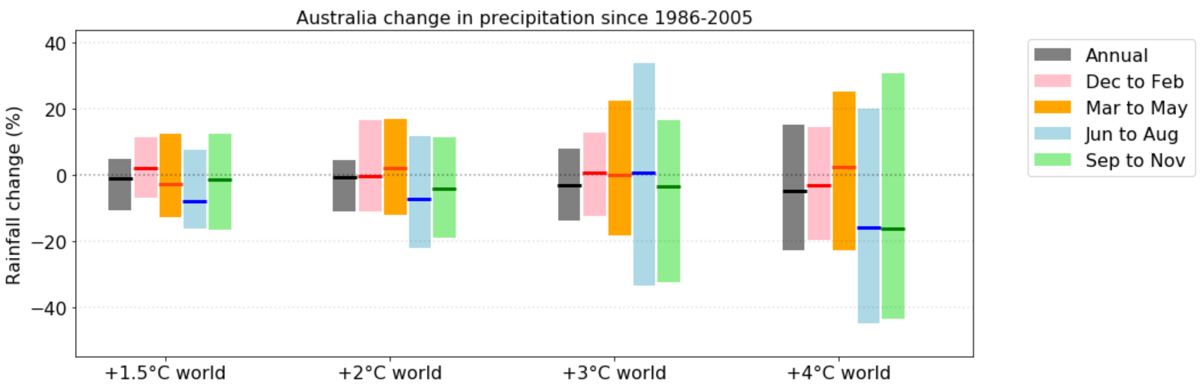

Figure 7 Area-average mean annual temperature for Australia from the baselines indicated from CMIP5: dark line shows model median, bar shows the 10-90 percentile of the model range

References

CSIRO and Bureau of Meteorology (2015). Climate Change in Australia, Technical Report. Melbourne Australia. www.climatechangeinaustralia.gov.au.

Harrington, L.J., Frame, D., King, A.D., & Otto, F.E.L. (2018). How Uneven Are Changes to Impact-Relevant Climate Hazards in a 1.5 °C World and Beyond? *Geophysical Research Letters*. https://doi.org/10.1029/2018GL078888

Hawkins, E., Ortega, P., Suckling, E., Schurer, A., Hegerl, G., Jones, P., et al. (2017). Estimating changes in global temperature since the pre-industrial period. *Bulletin of the American Meteorological Society*, BAMS-D-16-0007.1. https://doi.org/10.1175/BAMS-D-16-0007.1

James, R., Washington, R., Schleussner, C.-F., Rogelj, J. and Conway, D. (2017). Characterizing half-a-degree difference: a review of methods for identifying regional climate responses to global warming targets. *Wiley Interdisciplinary Reviews: Climate Change.* 8: e457.

Mitchell, D. and co-authors (2017). Half a degree additional warming, prognosis and projected impacts (HAPPI): background and experimental design. Geosci. Model Dev. 10: 571-583.

Sanderson, B.M., Oleson, K.W., Strand, W.G., Lehner, F. and O'Neill, B.C. (2018). A new ensemble of GCM simulations to assess avoided impacts in a climate mitigation scenario. Climatic Change 146: 303-318.

Schurer, A.P., Mann, M.E., Hawkins, E., Tett, S.F.B., & Hegerl, G.C. (2017). Importance of the pre-industrial baseline for likelihood of exceeding Paris goals. *Nature Climate Change*, *7*(8), 563–567. https://doi.org/10.1038/nclimate3345

Taylor, K.E., Stouffer, R.J. and Meehl, G.A. (2012). An Overview of CMIP5 and the Experiment Design. *Bulletin of the American Meteorological Society* 93: 485-498.

van Vuuren, D., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K. et al. (2011). The representative concentration pathways: an overview. Climatic Change 109: 5-31.

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