To the Editors of GMD,

Attached is our point-by-point response to the reviewer reports of our article, *Reduced complexity model intercomparison project phase 1: Protocol, results and initial observations (gmd-2019-375)*. The latexdiff is included at the end of this document. We would like to thank the reviewer for the time taken to review our paper.

We are glad that you and the reviewer recognise the importance and benefit of a model intercomparison for reduced complexity models. We also appreciate that the manuscript in its submitted form was too wide in scope and difficult to follow. We have addressed this in this revision: narrowing the scope of the manuscript considerably, clarifying the research questions we attempt to address and delineating the research questions from possible extensions more clearly. This has resulted in the manuscript's length being reduced from 16 pages to 12. As documented in detail below, we hope that we have thereby addressed the reviewer comments.

In the responses below, the original reviewer reports are in black, while all our comments are in blue. We have also numbered all the reviewer comments and our replies for clarity. We have *quoted text from the manuscript in grey italics*.

We thank you and the reviewers for the time invested into our manuscript and hope that it now reaches the high standards of *Geoscientific Model Development*.

Best regards,

Zebedee Nicholls and Robert Gieseke (corresponding authors)

Reviewer comments and replies

Reviewer 1 Comment 1

The experiment description paper Reduced Complexity Model Intercomparison Project (Phase 1) has changed in a fundamental way. Thank you for your effort. My point of view is external and I have to assess the present manuscript. Having a model RCM intercomparison is a great idea but the present manuscript does not meet the quality standards of GMD. I suggest a major revision. Otherwise, the authors should cancel the GMD publication process. In general, the authors should elaborate on the scientific goals and research questions that are associated with their intercomparison project. Next, the authors should elaborate on a consistent and unified experimental strategy. Finally, the authors should improve the format of the paper. To date, the present manuscript is a collection of interesting thoughts rather than a coherent text to describe a scientific idea.

Thank you for recognising the considerable effort we put into our revised manuscript. We have put a similar level of effort into this revision and hope that the present manuscript now meets the quality standards of GMD.

We have restructured the paper to make clear the scientific goals of RCMIP and this Phase 1. We feel that there are two major components to the work we have presented here. The first is captured by our first research question, namely, "Is the reduced complexity modelling community ready to run an intercomparison and how long would such an intercomparison take to run?" We have now made explicit that, before this paper, this question was not yet answered and it was unclear how quickly the RCM community could actually perform such an intercomparison (see new Research Question 1 in Section 2). This information is vital for future planning. For example, if the modelling groups all take 12 months or more to do their runs (like most ESMs), then the possibilities are very different from the case where modelling groups can complete runs within 3 months.

The second major component is scientific. This component comprises the remaining research questions, which focus on the models' global-mean temperature response. The key question is whether the various simple structures can replicate the temperature evolution of Earth System Models. To the extent they can, various interesting research questions can then be answered, for example a comparison of SSP and RCP scenarios and to what extent temperature differences can be expected.

Our revised "Experimental design" section now makes our experimental strategy explicitly clear, and removes all references to experiments which are not used for the results of this paper. We hope that this removal of extraneous details improves the clarity of the text and the format of the paper.

Finally, the manuscript now focuses on the research questions and uses these research questions to tie the entire work together. We hope that this makes clear which scientific questions we are answering, improving the coherency of the text and the scientific ideas we have addressed.

Reviewer 1 Comment 2

The referees have given a variety of advices during the first phase of the review process. These advices are general comments on how to elaborate on the scientific goals or research questions that are associated with the model intercomparison project as well as specific comments on the wording in single sentences. Concerning the maturity of the present manuscript, I do not provide comments on single sentences or the wording which must improve, because I think the authors should rewrite or delete entire sections. At the same time, I am convinced of the scientific idea and think that a RCM intercomparison project is very valuable. In that respect, I would like to provide comments on every section.

We thank the reviewer for their comments on each of our sections and for supporting the principle of our RCM intercomparison efforts. We have considerably re-written many sections and deleted many others too (as suggested). We hope that these changes are suitable responses to your suggestions, we certainly feel that they have significantly improved the manuscript, particularly in terms of clarity and cohesiveness.

Reviewer 1 Comment 3
The title of the paper is unspecific and I do not know what Phase 1 actually means. The authors should introduce the experimental design and strategy of their RCM intercomparison project, and the title should be somehow related to this stage of development. The abstract is imprecise in the sense that the content of the abstract does not put forward the main messages of the main body of the manuscript. It is not about the experimental design and strategy. The content of the introduction should be related to intercomparison projects such as CMIP or scenario-MIP in order to establish common ground and explain why it is necessary to have a RCM intercomparison.

We agree that the title was unspecific. We have provided an updated suggestion ("Reduced Complexity Model Intercomparison Project Phase 1: introduction and evaluation of global-mean temperature response") which we hope better expresses the current stage of the project, but we are happy to take other suggestions too. We feel that the Phase 1 idea is important, as we intend for RCMIP to go through multiple phases and be used in multiple contexts, much like CMIP has extended over multiple generations of AOGCMs and ESMs. In fact, a new second phase is already well underway, focussing on probabilistic results.

We have updated the abstract so that it relates directly to the manuscript's research questions, experiments and key results.

Relevant new text in abstract

> *In Phase 1, we focus on the RCMs' global-mean temperature responses, comparing them to observations, exploring the extent to which they emulate more complex models and considering how the relationship between temperature and cumulative emissions of \chem{CO_2} varies across the RCMs. Our work uses experiments which mirror those found in the Coupled Model Intercomparison Project (CMIP), which focuses on complex earth system and atmosphere-ocean general circulation models. Using both scenario-based and idealised experiments, we examine RCMs global-mean temperature response under a range of forcings. We find that the RCMs can all reproduce the approximately 1\degree C of warming since pre-industrial times, with varying representations of natural variability, volcanic eruptions and aerosols. We also find that RCMs can emulate the global-mean temperature response of CMIP models to within a root-mean square error of 0.2\degree C over a range of experiments. Furthermore, we find that for the RCP and SSP-based scenario pairs that share the same AR5-consistent stratospheric-adjusted radiative forcing, the RCMs indicate higher effective radiative*

> *forcings for the SSP-based scenarios and correspondingly higher temperatures when run with the same climate settings. In our idealised setup of RCMs with a climate sensitivity of 3\degree C, the difference for the ssp585 versus rcp85 pair by 2100 is around $0.23\unit{\degree C}\ (\pm 0.12$\unit{\degree C}) due to a difference in effective radiative forcings between the two scenarios. Phase 1 demonstrates the utility of RCMIP's open-source infrastructure, paving the way for further phases of RCMIP to build on the research presented here and deepen our understanding of RCMs.*

In addition, we have updated the introduction so it includes specific comparisons with CMIP. We hope this clarifies the need for RCMIP.

Reviewer 1 Comment 4
Section 2 is crucial and about the scientific focus of the RCM intercomparison project. However, it is unspecific and the authors should use common language such as scientific goals or associated research questions. I suggest that the authors spend some effort into specifying the research questions in order to highlight the actual variables or quantities that are evaluated. The RCM intercomparison should be consistent in the sense that the specific research questions and variables apply to the full range of RCMs considered here.

Thank you for highlighting the importance of Section 2. We have overhauled this section so it now uses the common language of 'research questions'. We have also clarified the research questions so they can be used as the focal point of the paper, upon which everything else (experiments, requested output, results, extensions and conclusions) builds.

All of the research questions and variables now included apply to the full range of RCMs. Unfortunately, given the tight timeline on which modelling teams were asked to submit results, not all modelling teams have submitted results for all variables and experiments - which is an inevitable part of large, multi-research group efforts. We hope the reviewer understands that we have chosen to present results even where only a limited number of groups could submit results because these results nonetheless present valuable insight and encourage other groups to consider submitting such results in further phases of RCMIP.

Reviewer 1 Comment 5
Section 3 is a mix of the organization of the RCM intercomparison project and the experimental strategy. In this connection, I do not think that the section title simulation design is appropriate. The authors should elaborate on section 3.1 model configuration and say in a direct way how the different RCMs compare and how the different RCMs are fitted to complex model output. I think having the equilibrium climate sensitivity tuned to 3°C is a good start. I would propose to focus on additional constrains such as changes in the energy budget if possible.

We thank the reviewer for pointing out the slightly odd mix we had presented. We have now addressed this, clearly separating the discussion of participating models (new Section 3) from our experimental design (new Section 4). The model configuration section is now more comprehensive and provides an overview of the model complexity spectrum and the model configurations we have used. For reasons of brevity, we have pointed interested readers to relevant literature. A complete discussion of the details of how every model relates and their individual configurations would take multiple papers, as illustrated by the literature highlighted by each modelling team in the updated Table 1. In this stage of RCMIP, we have not specified any constraints on the models beyond the ECS of 3C (and have clarified this in the updated text in the new Section 3.1). We hope to perform experiments where we specify additional constraints on the models, in a more systematic way, in future work. Such experiments are beyond the scope of the initial comparison we present here.

Reviewer 1 Comment 6

Section 3.2 is about the forcing that drives the temperature evolution of the different RCMs. It is a collection of different RCM drivers that can be associated with CMIP projects. I think a RCM intercomparison should be as simple as possible because of the great variety of RCMs. In that respect, the authors should establish common ground or common language and introduce the radiative forcing concept. I would propose to focus on CO2 concentrations and emissions in the first place or select specific emission scenarios in order to make the RCM intercomparison tangible. Irrespective of the latter advice, the authors should explain why they use the different setups. The setups presented in this section should apply to the full range of RCMs considered here.

Thank you for these suggestions. In response to this and other comments, we have created a new stand-alone Experimental design section. In this section we introduce the different ways of forcing RCMs, introduce the effective radiative forcing concept and clarify the experiments we have performed. As suggested, we now focus on specific scenarios and idealised, CO2-only experiments and explain these choices. We hope it is now clear that the limited set of experiments we use in this section can be applied to the full range of RCMs considered (although not all groups have submitted results for all experiments due to differing resources (mainly human resources) as discussed previously).

Reviewer 1 Comment 7

Section 3.3 and 4 is about the experimental design or organization. I think that sections on the input format, output specifications and data sources do not belong to the main body of the manuscript. They should be briefly described in the appendix. Moreover, the first RCM intercomparison should be limited to a small set of variables or quantities, and these variables should be common to the full range of RCMs. The authors should focus on the experimental strategy, and explain specifically why it is necessary to consider the idealized experiments and scenarios presented in this section. The experiments presented in this section should apply to the full range of RCMs. I would propose to focus on a set of experiments that are most important to the authors and generate the most important insights. Please also elaborate on the section on probabilistic outputs in case you still wish to include this section. It is unclear to me how these probabilistic ensembles are generated.

Thank you for this comment. We have now moved the technical details to the supplementary material. In addition, we have now focussed both our experimental strategy and requested variables, discussing only those experiments and variables which are used in the results section. We have also highlighted how each experiment relates to our research questions. The additional experiments and data are available for others to examine (given everything is openly available under creative commons licenses).

We have removed the section on probabilistic outputs for reasons of scope. We will leave such a discussion for future research, namely Phase 2.

Reviewer 1 Comment 8

Section 5 presents illustrative results. A paper should be based on solid findings that emerge from a consistent and unified procedure. There are great figures. The experiment description paper should focus on the scientific goals, research questions and experimental strategy. In that respect, the results should be based on the definition of specific research questions and the associated experimental strategy. I would propose to elaborate on the experimental strategy and present the most important results based on that experimental strategy. Furthermore, the results should be presented in an explicit way with respect to the research questions, and the results should be related to the full range of RCMs considered in the RCM intercomparison project. In this connection, section 6 raises different issues and does not relate the future research questions to the current experimental strategy or stage of development. Finally, the figures and tables of the appendix should be somehow related to the main body of the manuscript. A table which describes the different models and their structural differences is crucial.

Thank you for highlighting these improvements. We have now updated our results section so that it directly relates to our research questions, via our updated experimental design and output request.

As highlighted in Comment 6, we have now elaborated on our experiment strategy.

Following this, we now only present the most important results based on that strategy. Specifically: (1) global-mean temperature responses, (2) their comparison to observations, (3) the comparison to more complex models and (4) the relationship between temperature and cumulative emissions of CO_2 across the RCMs.

We have attempted to make the connection between our results and the research questions explicit. Once again, we relate them to all the RCMs considered, but can only present results that have been submitted. We feel that a practical reality of large model intercomparisons is that modelling groups have different capacities to participate.

We have re-written Section 6, the Extensions section, so it relates to the research questions presented in this paper and provides a natural extension to the work performed to date.

We have updated the supplementary material, retaining only those components with a direct connection to the main body of the paper.

We have re-introduced the overview of the different models and their structural differences (having taken it out in the previous revision in response to the reviewers, largely due to issues of scope). This provides the opportunity for the reader to trace the relevant literature in regards to the origins and details of each model (see updated Table 1). As noted in Comment 5 and our response to the previous round of reviews, a complete, thorough in-depth description of all the RCMs is a paper in itself hence we do not attempt to include such an analysis here for reasons of scope.

Reduced Complexity Model Intercomparison Project ~~(~~Phase 1~~)~~: introduction and evaluation of global-mean temperature response

Zebedee R. J. Nicholls[1,2], Malte Meinshausen[1,2,3], Jared Lewis[1], Robert Gieseke[4], Dietmar Dommenget[5], Kalyn Dorheim[6], Chen-Shuo Fan[5], Jan S. Fuglestvedt[7], Thomas Gasser[8], Ulrich Golüke[9], Philip Goodwin[10], Corinne Hartin[6], Austin P. Hope[11], Elmar Kriegler[3], Nicholas J. Leach[12], Davide Marchegiani[5], Laura A. McBride[13], Yann Quilcaille[8], Joeri Rogelj[8,14], Ross J. Salawitch[11,13,15], Bjørn H. Samset[7], Marit Sandstad[7], Alexey N. Shiklomanov[6], Ragnhild B. Skeie[7], Christopher J. Smith[8,16], Steve Smith[6], Katsumasa Tanaka[17,18], Junichi Tsutsui[19], and Zhiang Xie[5]

[1]Australian–German Climate and Energy College, The University of Melbourne, Parkville, Victoria, Australia
[2]School of Earth Sciences, The University of Melbourne, Parkville, Victoria, Australia
[3]Potsdam Institute for Climate Impact Research (PIK), Member of the Leibniz Association, Potsdam, Germany
[4]Unaffiliated
[5]Monash University, School of Earth, Atmosphere and Environment, Clayton, Victoria 3800, Australia
[6]Joint Global Change Research Institute, Pacific Northwest National Laboratory, College Park, MD, USA
[7]CICERO Center for International Climate Research, Oslo, Norway
[8]International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria
[9]BI Norwegian Business School, Nydalsveien 37, 0484 Oslo, Norway
[10]School of Ocean and Earth Science, University of Southampton, Southampton, UK
[11]Department of Atmospheric and Oceanic Sciences, University of Maryland-College Park, College Park, 20740, USA
[12]Department of Physics, Atmospheric Oceanic and Planetary Physics, University of Oxford, United Kingdom
[13]Department of Chemistry and Biochemistry, University of Maryland-College Park, College Park, 20740, USA
[14]Grantham Institute for Climate Change and the Environment, Imperial College London, UK
[15]Earth System Science Interdisciplinary Center, University of Maryland-College Park, College Park, 20740, USA
[16]Priestley International Centre for Climate, University of Leeds, UK
[17]National Institute for Environmental Studies (NIES), Tsukuba, Japan
[18]Laboratoire des Sciences du Climat et de l'Environnement (LSCE), Commissariat à l'énergie atomique et aux énergies alternatives (CEA), Gif sur Yvette, France
[19]Central Research Institute of Electric Power Industry, Abiko, Japan

Correspondence: Zebedee Nicholls (zebedee.nicholls@climate-energy-college.org)

Abstract.

Reduced complexity climate models (RCMs) are critical in the policy and decision making space, and are directly used within multiple Intergovernmental Panel on Climate Change (IPCC) reports to complement the results of more comprehensive Earth System Models. To date, evaluation of RCMs has been limited to a few independent studies. Here we ~~propose~~ introduce a systematic evaluation of RCMs in the form of the Reduced Complexity Model Intercomparison Project (RCMIP). We ~~have performed Phase~~ expect RCMIP will extend over multiple phases, with this Phase 1 ~~of RCMIP with two scientific themes: examining how RCMscompare to observationsand how RCMs compare to results from more complex climate models such as those participating in the Sixth~~ being the first. In Phase 1, we focus on the RCMs' global-mean temperature responses, comparing them to observations, exploring the extent to which they emulate more complex models and considering how the relationship between temperature and cumulative emissions of CO_2 varies across the RCMs. Our work uses experiments which mirror those found in the Coupled Model Intercomparison Project (CMIP6). We also present our standardised data formats, experiment protocols and output specifications. So far 15 modelshave participated and submitted results for over 50 experiments. We present illustrative figures comparing model output with historic global surface air temperature (GSAT) observations, showing probabilistic projections, demonstrating different calibrations with CMIP model output as well as temperature change against cumulative emissions, and exploring differences between CMIP5CMIP), which focuses on complex earth system and atmosphere-ocean general circulation models. Using both scenario-based and idealised experiments, we examine RCMs global-mean temperature response under a range of forcings. We find that the RCMs can all reproduce the approximately 1°C of warming since pre-industrial times, with varying representations of natural variability, volcanic eruptions and aerosols. We also find that RCMs can emulate the global-mean temperature response of CMIP models to within a root-mean square error of 0.2°C over a range of experiments. Furthermore, we find that for the RCP and SSP-based scenario pairs that share the same AR5-consistent stratospheric-adjusted radiative forcing, the RCMs indicate higher effective radiative forcings for the SSP-based scenarios and correspondingly higher temperatures when run with the same climate settings. In our idealised setup of RCMs with a climate sensitivity of 3°C, the difference for the ssp585 versus rcp85 pair by 2100 is around 0.23°C ($\pm$0.12°C) due to a difference in effective radiative forcings between the two scenarios. Phase 1 demonstrates the utility of RCMIP's Representative Concentration Pathways (RCPs) and CMIP6's SSP-based (Shared Socioeconomic Pathways based) scenarios. Further research on these and other questions can open-source infrastructure, paving the way for further phases of RCMIP to build on the open data and open source processing code provided with this paperresearch presented here and deepen our understanding of RCMs.

1 Introduction

Sufficient computing power to enable running our most comprehensive, physically complete climate models for every application of interest is not available. Thus, for many applications, less computationally demanding approaches are used. One common approach is the use of reduced complexity climate models (RCMs), also known as simple climate models (SCMs).

RCMs are designed to be computationally efficient tools, allowing for exploratory research and have smaller spatial, if any, and temporal resolution than complex models. Typically, they describe highly parameterised macro properties of the climate system. Usually this means that they simulate the climate system on a global-mean, annual-mean scale although some RCMs have slightly higher spatial and/or temporal resolutionseven use coarse resolution spatial grids and monthly time-steps. As a result of their highly parameterised approach, RCMs can be on the order of a million or more times faster than more complex models (in terms of simulated model years per unit CPU time).

The computational efficiency of RCMs means that they can be used where computational constraints would otherwise be limiting. For example, some applications of in the hierarchy of climate models - RCMs, the Earth System Models of intermediate complexity (EMICs) and Earth System Models (ESMs) - it is only RCMs that are sufficiently efficient for large probabilistic ensembles for hundreds of scenarios. In addition, some Integrated Assessment Models (IAMs) require iterative climate simulations. As a result, In such cases, only RCMs are computationally feasible because hundreds to thousands of climate realisations must be integrated by the IAM for a single scenario to be produced. RCMs also enable the exploration of interacting uncertainties from multiple parts of the climate system or the constraining of unknown parameters by combining multiple lines of evidence in an internally consistent setup. In the context of the assessment reports Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC), a prominent example is the climate assessment of socioeconomic emission scenarios by IPCC Working Group 3 (WGIII). Hundreds of emission scenarios were assessed in the IPCC's Fifth Assessment Report (AR5, see Clarke et al. (2014)) as well as its more recent Special Report on Global Warming of 1.5°C (SR1.5, see Rogelj et al. (2018); Huppmann et al. (2018)). (Scenario data is available at https://secure.iiasa.ac.at/web-apps/ene/AR5DB and https://data.ene.iiasa.ac.at/iamc-1.5c-explorer/ for AR5 and SR1.5 respectively, both databases are hosted by the IIASA Energy Program). For the IPCC's forthcoming Sixth Assessment Report (AR6), it is anticipated that the number of scenarios will be in the several hundreds to a thousand (for example, see the full set of scenarios based on the SSPs at https://tntcat.iiasa.ac.at/SspDb). Both the number of scenarios and the tight timelines of the IPCC assessments render it infeasible to use the world's most comprehensive models to estimate the climate implications of these IAM scenarios.

There are two key modes of use which are relevant for the assessment of a large number of IAM scenarios. The first is 'emulation' mode, where the RCMs are run in a setup which has been calibrated to reproduce the behaviour of a Coupled Model Intercomparison Project (CMIP) (Eyring et al., 2016; **?**) model as closely as possible over a range of scenarios. The second is 'probabilistic' mode, where the RCMs are run with a parameter ensemble which captures the uncertainty in estimates of specific Earth system quantities, be it observations of historical global mean temperature increase, radiative forcing, ocean heat uptake, or cumulative land or ocean carbon uptake. Probabilistic climate projections are derived by running parametric ensembles of RCM simulations which capture the range of responses consistent with our understanding of the climate system (Meinshausen et al., 2009; Smith et al., 2018a; Goodwin, 2016). The resulting ensemble is designed to capture the likelihood that different warming levels are reached under a specific emissions scenario (e.g. 50% and 66%) based on the combined available evidence hence is quite different from an ensemble emulating multiple model outputs, which have been produced independently with no relative relationship or probabilities in mind. The two approaches, emulation of complex models and historically constrained probabilistic mode, can also be combined, e.g. where historical constraints are very weak. For example, the MAGICC6 probabilistic setup used in AR5 (Clarke et al., 2014) used randomly drawn emulations for the carbon cycle response whilst using a probabilistic parameter ensemble for the climate response to radiative forcing (Meinshausen et al., 2009) .

RCMs also play the role of 'integrators of knowledge', examining the combined response of multiple interacting components of the climate system. The most comprehensive RCMs will include (highly parameterised) representations of the carbon cycle, permafrost, non-gas cycles, aerosol chemistry, temperature response to radiative forcing, ocean heat uptake, sea-level rise and all their interactions and feedbacks. More complex models cannot include as many interactive components without the computational cost quickly becoming prohibitive for running multiple century-long simulations. As a result, RCMs are able to examine the implications of the Earth System's feedbacks and interactions in a way which cannot be done with other techniques.

1.1 Evaluation of reduced complexity climate models

The validity of the RCM approach rests on the premise that RCMs are able to replicate the behaviour of the Earth system and response characteristics of our most complete models. Over time, multiple independent efforts have been made to evaluate this ability. In 1997, an IPCC Technical Paper (Houghton et al., 1997), investigated the simple climate models used in the IPCC Second Assessment Report and compared their performance with idealised Atmosphere-Ocean General Circulation Model (AOGCM) results. Later, van Vuuren et al. (2011b) compared the climate components used in IAMs, such as DICE (Nordhaus, 2014) , FUND (Waldhoff et al., 2011)and and FUND (Waldhoff et al., 2011). Van Vuuren et al. (2011b) also included the RCM MAGICC (version 4 at the time (Wigley and Raper, 2001)), which is (version 4 at the time, Wigley and Raper, 2001), which was used in several IAMs. They focused on five CO_2-only experiments to quantify the differences in the behaviour of the RCMs used by each IAM. Harmsen et al. (2015) Harmsen et al. (2015) extended the work of van Vuuren et al. (2011b) to consider the impact of non-CO_2 climate drivers in the RCPs. Recently, Schwarber et al. (2019) proposed a series of impulse tests for simple climate models in order to isolate differences in model behaviour under idealised conditions.

Building on Despite these efforts, an the RCM community does not yet have a systematic, regular intercomparison effort. This led to the following statement in SR1.5 (Forster et al., 2018), 'The veracity of these reduced complexity climate models is a substantial knowledge gap in the overall assessment of pathways and their temperature thresholds.' This study provides a first step to fill this gap via a systematic intercomparison. A systematic intercomparison is also likely to provide other benefits, similar to those that the AOGCM and ESM modelling communities have gained over multiple iterations of CMIP (Carlson and Eyring, 2017). Developing a systematic comparison for RCMs will provide similar benefits to the RCM community including building a community of reduced complexity modellers, facilitating comparison of model behaviour, improving understanding of RCMs' strengths and limitations, and ultimately improving RCMs.

An ongoing comprehensive evaluation and assessment of RCMs requires an established protocol. The Reduced Complexity Model Intercomparison Project (RCMIP) proposed here provides such a protocol (also see rcmip.org). In the RCMIP community call (available at rcmip.org) RCMs were broadly defined as follows: "[...] RCMIP is aimed at reduced complexity, simple climate models and small emulators that are not part of the intermediate complexity EMIC or complex GCM/ESM categories." In practice, we encouraged any group in the scientific community who identifies with the label of RCM to participate in RCMIP, see Table 1 for an overview of the models which participated in RCMIP Phase 1.

We aim for RCMIP to provide a focal point for further development and an experimental design which allows models to be readily compared and contrasted. We believe that a comprehensive, systematic effort will result in a number of benefits seen in other MIPs (Carlson and Eyring, 2017) including building a community of reduced complexity modellers, facilitating comparison of model behaviour, improving understanding of their strengths and limitations, and ultimately also improving ., mirroring the regular comparisons which are performed for AOGCMs and ESMs in each of CMIP's iterations. We intend for RCMIP to faciliate more regular and targeted assessment of RCMs.

~~RCMIP~~ Thus, while RCMIP mirrors many of the experimental setups developed within CMIP6, RCMIP focuses on RCMs and is hence not one of the official CMIP6 (Eyring et al., 2016) endorsed intercomparison projects ~~that are designed for Earth System Models. However, RCMIP does replicate~~ (that are instead targeted at ESMs). Nonetheless, RCMs are part of the climate model hierarchy so we aim to make comparing the RCMIP results with results from other modelling communities, specifically CMIP, as simple as possible. Accordingly, RCMIP replicates selected experimental designs of many of the CMIP-endorsed MIPs, particularly the DECK ~~simulations (Eyring et al., 2016) , ScenarioMIP (O'Neill et al., 2016) , AerChemMIP (?), C4MIP (?), ZECMIP (?), DAMIP (?) and PMIP4 (?). Hence whilst RCMIP is not a CMIP6 endorsed intercomparison, its design is closely related in the hope that its results may be useful beyond the RCM community.~~ (Eyring et al., 2016) and ScenarioMIP (O'Neill et al., 2016) simulations.

In what follows, we describe RCMIP Phase 1. In section 2, we detail the domain of RCMIP Phase 1 and its ~~scientific objectives. In sections 4 and ??, we described the simulations performed and outputs requested from each model~~research questions. In section 3, we provide an overview of the participating models and their configuration. In section 4, we describe the experimental setup. In section 6 we present ~~sample~~ results from RCMIP Phase 1, before presenting possible extensions ~~to RCMIP Phase 1 and conclusions in sections 6 and~~ in section 6 and conclusions in section 7.

2 ~~Science themes~~Research questions

~~In the RCMIP community call (available at rcmip.org) RCMs were broadly defined as follows: "...RCMIP is aimed at reduced complexity, simple climate models and small emulators that are not part of the intermediate complexity EMIC or complex GCM/ESM categories." In practice, we encouraged and encourage any group in the scientific community who identifies with the label of RCM to participate in RCMIP, see Table 1 for an overview of the models which participated in RCMIPPhase 1.~~ The key point of this paper is to introduce RCMIP, its goals and its setup. As a proof of concept, we also include key initial research questions, the implemented experimental setup and associated results from RCMIP's first phase.

~~RCMIP Phase 1 focuses on evaluation of RCMs. Specifically, comparing them against observations of the Earth System and the output of more complex models from CMIP5 and CMIP6 within two scientific themes.~~ **Research question 1: Is the reduced complexity modelling community ready to run an intercomparison and how long would such an intercomparison take to run?**

~~**Theme 1: To what extent can reduced complexity models reproduce observed ranges of key climate change indicators (e.g. surface warming, ocean heat uptake, land carbon uptake)?**~~

~~The first theme focuses on evaluating models against observations. Before using any model, one important question to ask is whether it can reproduce observations of the climate's recent evolution. For RCMs, the key observation is changes in air and ocean temperatures (??). Beyond this, RCMs should also be evaluated against observed changes in ocean heat uptake (??) and estimates of carbon content in the air, land and oceans (?).~~ Model intercomparisons require significant effort on the part of the organising community and each of the modelling teams involved. The reduced complexity modelling community has not undertaken such an effort previously, hence the first question is whether the community is ready to perform an intercomparison.

These comparisons evaluate the extent to which the model's approximations cause its response to deviate from observational data. However, most RCMs can be calibrated, i. e. have their parameters adjusted, such that they reproduce our best-estimate (typically median) observations. Hence, where available, we also evaluate the extent to which RCMs can be configured to reproduce the range of available observational estimates too. The handling of such observational estimates, particularly their uncertainties, is a complex topic in and of itself. In RCMIP we rely on published estimates and make basic assumptions about how their uncertainty estimates should be compared to model output ranges, each of which we detail when the comparison is performedIn addition to whether an intercomparison is possible, the second question is how long and how much effort is required to perform the intercomparison. The most successful intercomparisons are built on standardised protocols for experiment design, model setup and data handling. To date, no such standards exist for the reduced complexity modelling community.

Here we investigate how easily the benefits of systematic intercomparison can be brought to the reduced complexity modelling community by performing the first of many envisaged rounds of intercomparison. In the process, we gain vital insights into the effort, timelines and scope which can reasonably be managed by the participating modelling teams. Such knowledge is vital for planning future efforts.

Given the **Research question 2: Can reduced complexity climate models capture observed historical global-mean surface air temperature (GSAT) trends?**

The second research question focuses on a key metric for evaluating RCMs against observations. This research question evaluates the extent to which each RCM's approximations and parameterisations cause its response to deviate from observational data.

However, given the limited amount of observations availableand the ease of calibration of RCMs, comparing only with observations leaves us with little understanding of how RCMs perform in scenarios apart from a historic historical one in which anthropogenic emissions are heating the climate. Recognising that there are a range of possible futures, it is vital to also assess RCMs in other scenarios. Prominent examples include stabilising or falling anthropogenic emissions, strong mitigation of non-CO_2 climate forcers and scenarios with CO_2 removal. The limited observational set motivates RCMIP's second themethird research question: evaluation against more complex models.

Theme 2Research question 3: To what extent can reduced complexity models emulate the global-mean temperature response of more complex models?

Whilst the response of more comprehensive models may not represent the behaviour of the actual Earth System, they are the best available representation of our understanding of the Earth System's physical processes. By evaluating RCMs against more complex models, we can quantify the extent to which the simplifications made in RCMs limit their ability to capture physically-based model responses. For example, the extent to which the approximation of a constant climate feedback limits an in some RCMs limits the RCM's ability to replicate ESMs' longer-term response under either higher forcing or lower overshoot scenarios (Rohrschneider et al., 2019).

In combination, these two research themes examine how well the reduced complexity approach can a) reproduce historical observations of the climate and b) respond to scenarios other than the recent past in a way which is consistent with our best understanding of the Earth system's physical and biogeochemical processes. **Research question 4: What can a multi-model ensemble of RCMs tell us about the difference between the SSP-based and RCP scenarios?**

The SSP-based scenarios (O'Neill et al., 2016; Riahi et al., 2017) are the cornerstone of CMIP6's ScenarioMIP and are an update of CMIP5's RCP scenarios (van Vuuren et al., 2011a). One of the key intents behind some of the SSP-based scenarios is that they share the same nameplate 2100 radiative forcing level as the RCPs (e.g. ssp126 and rcp26, ssp245 and rcp45), the idea being that they would have similar climatic outcomes despite their different atmospheric concentration inputs. However, the nameplate radiative forcing comparisons between RCPs and SSPs were undertaken on the basis of IPCC AR5-consistent stratospheric-adjusted radiative forcings (Myhre et al., 2013). Taking into account new insights into respective CO_2 and CH_4 forcings, as well as effective radiative forcings, different climate responses can be expected. In fact, Wyser et al. (2020) suggest that the difference in atmospheric concentrations results in non-trivial differences in climate projections.

Unfortunately, evaluating the scenario differences between RCPs and SSP-based scenarios with a large, identical set of CMIP models is difficult because of the computational cost (many CMIP6 modelling groups will not perform all CMIP6 ScenarioMIP experiments, let alone performing extra CMIP5 experiments). With an ensemble of RCMs, we can provide further insight into how much the change in emissions pathways affects climate projections using identical models, building on the insights from the CMIP groups which can afford to run the required experiments. In addition, RCMs also offer one other benefit: they can diagnose effective radiative forcing directly. As a result, RCMs can provide more detailed insights into the reasons for differences because they provide a more detailed breakdown of the emissions-climate change cause-effect chain. In contrast, diagnosing effective radiative forcing from CMIP models is a difficult task which requires a number of extra experiments, all of which come at additional computational cost (Smith et al., 2020).

Research question 5: How does the relationship between cumulative CO_2 emissions and global-mean temperature vary both between RCMs and within a parameter ensemble of an RCM?

The relationship between cumulative CO_2 emissions and global-mean temperature is key to deriving the transient climate response to emissions (Matthews, 2018), a key metric in the calculation of our remaining carbon budget (Rogelj et al., 2019). Here we investigate how this relationship varies between RCMs and within a parameter ensemble from a given RCM. While a multi-model ensemble demonstrates variance due to model structure, the parameter ensemble demonstrates variance that arises solely as a result of changes in the strength of the response of individual components. These insights build on results from experiments with more complex models (see e.g. Arora et al., 2020), which cannot perform such large perturbed parameter ensembles because of computational cost.

3 Simulation designParticipating models and their configuration

15 models have participated in RCMIP Phase 1 ~~includes over~~ (see Table 1 for an overview and links to key description papers). We encourage any other interested groups to join further phases of the project.

Even within the reduced complexity category, there is considerable variation in both model complexity and the number of climate components (Table 1). At the simplest end, we have the radiative forcing-driven (see Section 4) impulse response models, represented by the AR5IR model variants. These models project global-mean temperature only and, in the setup submitted here, provide only annual-mean values (although they can be run at higher temporal resolution if desired). At the other end of the spectrum, we have MAGICC, which includes representations of 43 greenhouse gas cycles, includes parameterisations of the relationship between aerosol emissions and aerosol effective radiative forcing, distinguishes between different hemispheres and land/ocean regions of the globe, has 50 ~~experiments. To help modelling groups prioritise model runs and ensure comparibility of core experiments three tiers of model runs and output variables were defined. Ideally at least all Tier 1 scenarios andvariables for a default model version should be submitted~~ ocean layers in each hemisphere, and runs on a monthly time step internally (although all output is annual-mean only). Some models take a more hybrid approach, increasing complexity in only a single component whilst retaining simplicity elsewhere. Examples of increased complexity in specific domains include OSCAR's regionalised land carbon cycle and EMGC's representation of natural variability. ~~The following describes the simulation design, model runs as well as data sources and format of RCMIP.~~

An in-depth description of these models and their differences is beyond the scope of this paper (but is planned for future research). For readers interested in the details of all the participating models, we refer to the references provided in Table 1.

3.1 Model configuration

RCMs are usually highly flexible. Their response to anthropogenic and natural drivers strongly depends on the configuration in which they are run (i.e. their parameter values). ~~To mitigate this as a cause of difference between models in~~ In RCMIP Phase 1, we have requested that all models provide one set of simulations in which their equilibrium climate sensitivity is equal to 3°C. While this does not define the entirety of a model's behaviour, it removes a major cause of difference between model output which is not related to model structure. Within Phase 1 of RCMIP, we have given modelling groups the freedom to choose whether they apply any additional constraints or not.

On top of ~~these~~ the 3°C climate sensitivity ~~simulations~~configuration, we have also invited groups to submit ~~other~~ two other configuration categories. The first is any other best-guess or default configurations, where each participating modelling group is free to choose their own ~~defaults. In practice, these defaults are typically a group's most likely parameter values given their own expert judgement. Finally, where available, we have also requested probabilistic output i.e. output which quantifies the probable range of a number of output variables rather than a single timeseries for each output variable (see section 1).~~

3.2 ~~RCM drivers~~

~~Depending on the experiment in RCMIP, the drivers of the RCMs will vary e.g. the RCMs might run with prescribed concentrations and calculate consistent emissions or the opposite i.e. run with prescribed emissions and calculate consistent concentrations.~~

Below we describe each of the different setups used in RCMIP. However, a model did not need to be able to run in all of these ways to participate in RCMIP Phase 1.

3.1.1 Concentration driven

The concentration driven setup can strictly better be described as 'well-mixed greenhouse gas concentration' driven. Here, 'well-mixed greenhouse gases' refers to , , , hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and hydrochlorofluorocarbons (HCFCs). Depending on the experiment, these simulations are also supplemented by aerosol emissions and natural effective radiative forcing (specifically solar and volcanic forcings). For models which do not include the aerosol emissions to effective radiative forcing step, prescribed aerosol effective radiative forcing can instead be used.

This setup mirrors the majority of experiments performed in best-guess (the details of which can be found in the references provided in Table 1). The second is configurations deliberately designed to emulate specific ESMs from CMIP5 and CMIP6such as the historical, RCP/SSP-based scenario and one percent per year rise in atmospheric concentration (1pctCO2)experiments. The key difference between the RCMIP experiments and the CMIP experiments is that some RCMs include more anthropogenic drivers than CMIP models. Specifically, CMIP models do not include the full range of HFC, PFC and HCFC species, instead using equivalent concentrations (Meinshausen et al., 2017, 2020). In addition, some CMIP models will not include the effect of aerosol precursors such as nitrates, ammonia and organic carbon (McCoy et al., 2017).

3.1.1 emissions driven

In the emissions driven setup emissions are amended with concentrations of non-well-mixed greenhouse gases. Like the concentration-driven setup, these simulations are also supplemented by aerosol emissions (or aerosol effective radiative forcing) and natural effective radiative forcings.

This setup mirrors the emissions driven experiments performed in CMIP5 and CMIP6 such as the esm-hist, esm-ssp/rcp and esm-1pctCO2 experiments. As above, a cause of difference between CMIP and RCMIP simulations is the number of climate drivers that are explicitly modelled.

3.1.1 Emissions driven

The emissions driven or rather 'well-mixed greenhouse gas emissions' driven setup is, like the concentration-driven and emissions driven setups, supplemented by aerosol emissions (or aerosol effective radiative forcing) and natural effective radiative forcings.

These experiments have no obvious equivalent within the CMIP protocol. . Given the complexities involved in calibration (see e.g. Meinshausen et al., 2011a; Tsutsui, 2020), not all modelling groups submitted such CMIP5- and CMIP6-specific configurations. However, for many climate policy applications they are the most relevant set of experiments, given that anthropogenic emissions and reduction targets are what climate policy is directly concerned with (rather than atmospheric concentrations of GHGs). In addition, these experiments are of particular interest to the Integrated Assessment Modelling

Consortium (IAMC) community and their contribution in IPCC WGIII because they require climate assessment of socioeconomic scenarios that are described in terms of their corresponding emissions, not concentrations. those groups that do, these emulation setups provide valuable insight into the extent to which the model's structure limits its ability to reproduce the behaviour of more complex models. Given the complexity of the topic, we leave decisions about how to calibrate their model up to the individual modelling teams (details of each group's approach can be found in the references provided in Table 1). A more top-down approach will be undertaken in a future phase of RCMIP (see Section 6).

3.2 Experimental design

4 Experimental design

RCMIP's experimental design focuses on a limited set of the CMIP6 experiment protocol (Eyring et al., 2016) plus some CMIP5 experiments (**?**). We then complement this CMIP-based set with other experiments of interest to RCMs generally model multiple steps in the RCM and IAMC communities.

Systematic intercomparison projects such as RCMIP require the definition of a clear input and output data handling framework (see Section **??** for output specifications). Historically, comparing RCMs required learning how to set up , configure and run multiple RCMs in order to produce results. This required significant time and hence, as previously discussed, has only been attempted in standalone cases with a limited number of models (Houghton et al., 1997; van Vuuren et al., 2011b; Harmsen et al., 2015; Sch . With a common framework, once a model has participated in RCMIP, it is simpler to run it again in different experiments and provide output in a common, standardised format. This allows researchers to design, run and analyse experiments with far less effort than was previously required. As a result, it becomes feasible to do more regular and targeted assessment of RCMs. This capacity improves our knowledge of RCMs, our understanding of the implications of their quantitative results and our ability to develop and improve them.

Our input protocol is designed to be easy to use and hence easily able to be extended within future RCMIP phases or in separate research. The full set of RCMIP experiments is described in Supplementary Table **??** and available at emissions-climate change cause-effect chain including gas cycles (emissions to concentration step), radiative forcing parameterisations (concentrations to radiative forcing step) and temperature response (radiative forcing to warming step). Here, effective radiative forcing and radiative forcing are defined following Myhre et al. (2013). In contrast to radiative forcing, effective radiative forcing includes rapid adjustments beyond stratospheric temperature adjustments thus is a better indicator of long-term climate change.

4.0.1 Input format

All input data is provided in a text-based format based on the specifications used by the IAMC community (Gidden and Huppmann, 2019) . The computational simplicity of RCMs means that their input specifications are relatively lightweight and hence using an uncompressed, text-based input format is possible. Further, the format is explicit about associated metadata and ensures metadata remains attached to the timeseries. As the IAMC community is a major user of RCMs, as well as being the source of input data for many experiments run with RCMs, using their data format ensures that data can be shared easily and assessment of IAM emissions scenarios can be performed with minimal data handling overhead.

The inputs are formatted as text files with comma separated values (CSV) , with each row of the CSV file being a timeseries (see). This format is also often referred to as 'wide' although this term is imprecise (Wickham, 2014). The columns provide metadata about the timeseries, specifically the timeseries' variable, units, region, model and scenario. Other columns provide the values for each timestep within the timeseries.

Being simplified models, RCMs typically do not take gridded input. Hence we use a selection of highly aggregated socio-economic regions, which once again follow IAMC conventions (Gidden and Huppmann, 2019). RCMIP's variables and units are described in Section 4.2. The regions used in RCMIP are described in Table **??**. Scenarios are discussed in section **??** and summarised in Table **??**.

One complication of using the IAMC format is that the 'model' column is reserved for the name of the integrated assessment model which produced the scenario. To enhance compatibility with the IAMC format, we don't use the 'model' column. Instead, as described in Section **??**, we use the separate 'climate _model' column to store metadata about the climate model which provided the timeseriesEach point in the chain can be used as the starting point for simulations i.e.

In general, we follow the naming conventions provided by the CMIP6 protocol (Eyring et al., 2016). These typically specify -emissions driven runs by prefixing the scenario name with 'esm-', with all other scenarios being concentration-driven. Where it is not possible to follow CMIP6 naming schemes, we use our own custom conventions. For example, full greenhouse gas emissions driven runs are typically not performed in CMIP6 because of computational cost. RCMIP's convention is to denote all greenhouse gas emissions driven by prefixing the scenario name with 'esm-' as well as suffixing the name with '-allGHG' (e.g. 'esm-ssp245-allGHG'). In addition, RCMIP includes a number of CMIP5 experiments, which sometimes have the same name as their CMIP6 counterpart (e. g. 'historical'). Where such a clash exists, we append the CMIP5 experiment with '-cmip5' to distinguish the two (e.g. 'historical-cmip5'). Finally, if an experiment is not a CMIP6-style experiment then we cannot use a CMIP6 name for it. In such cases, we choose our own name and describe it within Table **??**.

4.0.1 Idealised experiments

The first group of experiments in RCMIPis idealised experiments. They focus on examining model response in highly idealised experiments . These experiments provide an easy point of comparison with output from other models, particularly CMIP output, as well as information about basic model behaviour and dynamics which can be useful for understanding the differences between models.

RCMIP's Tier 1 idealised experimentsare: piControl, esm-piControlthe simulation might be defined in terms of prescribed concentrations, emissions or radiative forcing. In Phase 1 of RCMIP, we focus on experiments which are defined in terms of concentrations to facilitate a direct comparison with CMIP experiments, 1pctCO2, 1pctCO2-4xext, abrupt-4xCO2, abrupt-2xCO2 and abrupt-0p5xCO2 (Table **??**). The piControl and esm-piControl control experiments serve as a useful check of model type. Most RCMs are perturbation models and hence do not include any internal variability, so will simply return constant values in their control experiments. Deviations from constant values in the control experiments quickly reveals those models with more complexity. Apart from esm-piControl, all of the Tier 1 experiments are concentration drivenmost of which are also defined in terms of concentrations.

After the control experiments, the other Tier RCMIP Phase 1 experiments examine the models' responses to idealised, -only concentration changes. They reveal differences in model response to forcing, particularly whether the RCM response to forcing includes non-linearities. In addition, these experiments also provide a direct comparison with CMIP experiments (i.e. more complex model behaviour) and are a key benchmark when examining an RCM's ability to emulate more complex models.

The idealised Tier 2 experiments add idealised removal experiments, which complement the typically rising/abruptly changing Tier 1 experiments. Idealised Tier 3 experiments examine the carbon cycle response in more detail with idealised emissions driven experiments as well as experiments in which the carbon cycle is only coupled to the climate system radiatively or biogeochemically (the '1pctCO2-rad' and '1pctCO2-bgc' experiments (?)). In concentration-driven experiments, RCMs report emissions (often referred to as 'inverse emissions')and carbon cycle behaviour consistent with the prescribed pathway. For brevity, we do not go through all Tier 2 and 3 experiments in detail here, further information can be found in Table **??**focuses on 19 experiments, which can be broken down into two categories: scenario-based and idealised. We provided all inputs following, and requested all outputs follow, a standard format to facilitate ease of data analysis and re-use (Supplementary Section S1). This common data format was developed for RCMIP and combines elements of the integrated assessment community standard (Gidden and Huppmann, 2019) and the CMIP6 definitions of variables and scenarios.

4.0.1 Scenario experiments

4.1 Scenario based experiments

In addition to the idealised experiments, RCMIP also includes a number of scenario based experiments . These Scenario based experiments examine model responses to historical transient forcing as well as a range of future scenarios. The historical experiments provide a way to compare RCM output against observational data records (Research Question 2), and are complementary to the idealised experiments (Section 4.1) which provide a cleaner assessment of model response to forcing. The future scenarios probe RCM responses to a range of possible climate futures, both continued warming as well as stabilisation or overshoots in forcing. The variety of scenarios is a key test of model behaviour, evaluating them over a range of conditions rather than only over the historical period. Direct comparison with CMIP output then provides information about the extent to which the simplifications involved in RCM modelling are able to reproduce the response of our the most advanced, physically-based modelsESMs (Research Question 3).

RCMIP 's Tier 1 Phase 1's scenario experiments are: historical, ssp119, ssp585, esm-hist, esm-ssp119, esm-ssp585, esm-hist-allGHG, esm-ssp119-allGHG and esm-ssp585-allGHGssp126, ssp245, ssp370, ssp434, ssp460, ssp534-over, ssp585, rcp26, rcp45, rcp60 and rcp85. We focus on simulations (historical plus future) which cover the highest forcing (ssp585) and lowest forcing (ssp119) range in forcing scenarios from the CMIP6 ScenarioMIP exercise (O'Neill et al., 2016)(O'Neill et al., 2016; Riahi et al., 2017) and CMIP5 RCP scenarios (van Vuuren et al., 2011a). These quickly reveal differences in model projections over the widest available scenario range which can also be compared to CMIP6 output.

The Tier 2 experiments expand the CMIP6 scenario set to include the full range of ScenarioMIP concentration-driven experiments (O'Neill et al., 2016), which examine scenarios between the two extremes of ssp585 and ssp119, as well as the The CMIP5 historical experiments . The CMIP5 experiments are particularly useful as they provide a direct comparison between CMIP5 and CMIP6 scenarios (Research Question 4), something which has only been done to a limited extent with more complex models (Wyser et al., 2019). Finally, the Tier 3 experiments add the remaining emissions-driven ScenarioMIP experiments, the rest of the CMIP5 scenario experiments (the so-called 'RCPs') and detection and attribution experiments (?) designed to examine the response to specific climate forcers over both the historical period and under a middle of the road emissions scenario (ssp245).

4.1.1 Data sources

CMIP6 emissions projections follow Gidden et al. (2019) and are available at (hosted by IIASA). Where All of these experiments are defined in terms of concentrations of well-mixed greenhouse gases. Here, 'well-mixed greenhouse gases' refers to CO_2, CH_4, N_2O, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and hydrochlorofluorocarbons (HCFCs). However, scenario experiments include more than just well-mixed greenhouse gas emissions are missing, we use inverse emissionsbased on the CMIP6 concentrations from MAGICC7.0.0 (Meinshausen et al., 2020). Where regional emissions information is missing, we use the downscaling procedure described in Meinshausen et al. (2020). The emissions extensions also follow the convention described in Meinshausen et al. (2020).

For CMIP6 historical emissions (year 1850-2014), we have used data sources which match the harmonisation used for the CMIP6 emissionsprojections. This ensures consistency with CMIP6, although it means that we do not always use the latest data sources. CMIP6 historical anthropogenic emissions for , , BC, CO, , NOx, OC, and gases so these concentrations are supplemented by aerosol precursor species emissions, ozone-relevant emissions and natural effective radiative forcing variations. Here, 'aerosol precursor species emissions' refers to emissions of sulfur, nitrates, black carbon, organic carbon and ammonia. 'Ozone-relevant emissions' refers to emissions of carbon monoxide and non-methane volatile organic compounds (NMVOCs)come from CEDS (Hoesly et al., 2018). Biomass burning emissions data for , BC, CO, , NOx, OC, and NMVOCs come from UVA (van Marle et al., 2017). The biomass burning emissions are a blend of both anthropogenic and natural emissions, which could lead to some inconsistency between RCMs as they make different assumptions about the particular anthropogenic/natural emissions split. global land-use emissions are taken from the Global Carbon Budget 2016 (Quéré et al., 2016). Emissions of and the regional breakdown of land-use emissions come from PRIMAP-hist Version 1.0 (Gütschow et al., 2016, see https://doi.org/10.5880/PIK.2016.003). Where required, historical emissions were extended back to 1750 by assuming a constant relative rate of decline based on the period 1850-1860 (noting that historical emissions are somewhat uncertain, we require consistent emissions inputs in Phase 1, uncertainty in historical emissions will be explored in future research). . For models which do not include the aerosol emissions to effective radiative forcing or ozone-relevant emissions to ozone effective radiative forcing steps, prescribed effective radiative forcings can instead be used. Here 'natural effective radiative forcing variations' refers to effective radiative forcing due to natural volcanic eruptions and changes in solar irradiance. All data sources are described in Supplementary Section S2.

CMIP6 concentrations follow Meinshausen et al. (2020). CMIP6 radiative forcings follow the data provided at The key difference between the RCMIP experiments and the CMIP experiments is that some RCMs include more anthropogenic drivers than CMIP models. Specifically, CMIP models do not include the full range of HFC, PFC and HCFC species, instead using equivalent concentrations (Meinshausen et al., 2017, 2020). In addition, some CMIP models will not include the effect of aerosol precursors such as nitrates, ammonia and organic carbon (McCoy et al., 2017). CMIP5 emissions, concentrations and radiative forcings follow Meinshausen et al. (2011b) and are taken from .

5 Output specifications

4.1 Idealised experiments

In addition to the scenario-based experiments, RCMIP Phase 1 's submission template (see or) is composed of two parts. The first part is the data submission and is identical to the input format (see Section ??). This allows for simplified analysis with the same tools we used to develop the input protocols and exchange with the IAMC community as they can analyse the data using existing tools such as pyam (Gidden and Huppmann, 2019). The second part is model metadata. This includes the model's name, version number, brief description, literature reference and other diagnostics (see Section ??). We also request a configuration label, which uniquely identifies the configuration in which the model was run to produce the given results. also includes a number of idealised experiments. All of these experiments are defined in terms of CO_2 concentrations alone. These experiments provide an easy point of comparison with output from other models, particularly CMIP output, as well as information about basic model behaviour and dynamics which can be useful for understanding the differences between models.

Given the typical temporal resolution of RCMs, we request all output be reported with an annual timestep. In addition, to facilitate use of the output, participating modelling groups agree to have their submitted data made available under a Creative Commons Attribution-ShareAlike 4.0 International (CC BY-SA 4.0)license. All input and output data, as well as all code required to produce this paper, is available at and archived at .

4.2 Variables

RCMIP has a large variable request (26 Tier RCMIP Phase 1variables, 344 Tier 2 variables and 13 Tier 3 variables) , reflecting the large number of climate components included in RCMs. Here we discuss the Tier 1 variables. Tier 2 and 3 variables, which go into more detail for various parts of the climate system, are described in Supplementary Table S2.

The Tier 1 variables focus on key steps in the cause-effect chain from emissions to warming. We request emissions of black carbon, , carbon monoxide, 's idealised experiments are: 1pctCO2, 1pctCO2-4xext, abrupt-4xCO2, abrupt-2xCO2 and abrupt-0p5xCO2. These examine the RCMs' response to a one percent per year increase in atmospheric CO_2 concentrations

(1pctCO2), ~~, , nitrous oxides, organic carbon, sulphates and non-methane volatile organic compounds. These cover the major greenhouse gases plus aerosol pre-cursor emissions. In the case of emissions driven runs, these emissions are prescribed hence we only request that these variables are reported as outputs where the modelling groups have had to alter them (e.g. their model includes internal land-use calculations which cannot be exogenously overridden) . In the case of~~ 1pctCO2 followed by constant CO_2 concentrations once atmospheric CO_2 concentrations quadruple (1pctCO2-4xext) and abrupt changes in atmospheric CO_2 to four times pre-industrial levels (abrupt-4xCO2), double pre-industrial levels (abrupt-2xCO2) and half pre-industrial levels (abrupt-0p5xCO2) - mirroring the respective CMIP experiments (Eyring et al., 2016).

The experiments reveal differences in model response to forcing, particularly whether the RCM response to forcing includes non-linearities. In addition, these experiments also provide a direct comparison with CMIP experiments (i.e. more complex model behaviour) and are a key benchmark when examining an RCM's ability to emulate more complex models (Research Question 3). In these concentration-driven ~~runs, we request emissions compatible~~ experiments, RCMs report emissions (often referred to as 'inverse emissions') and carbon cycle behaviour consistent with the prescribed ~~concentration pathway(where these can be derived). We also request~~ CO_2 pathway. These inverse emissions are key to exploring the variation in the relationship between surface air temperature change and cumulative emissions of CO_2 ~~given their strong relationship with peak warming (Allen et al., 2009; Matthews et al., 2009; Meinshausen et al., 2009; Zickfeld et al., 2009)~~ (Allen et al., 2009; Matthews et al., 20 over a range of models and parameter values (Research Question 5).

~~In Tier~~

4.2 Output Variables

Phase 1 ~~, we only request atmospheric concentrations of and . Many models are capable of reporting much more detail than this, and we encourage them to report this detail, however some models only~~ of RCMIP focuses on five key output variables. The focus on a limited set ~~of concentrations hence we restrict our Tier 1 variables.~~ allows us to discern major differences between RCMs and provides insights into the reasons for such differences. The first variable of interest is surface air temperature change. We choose this variable because it is comparable to available observations and CMIP output and is also policy-relevant.

In addition to ~~concentrations~~surface air temperature change, we request total, anthropogenic, CO_2 and aerosol effective radiative forcing~~and radiative forcing~~. These forcing variables are key indicators of the long-term drivers of climate change within each model as well as being ~~a key metric~~ key metrics for the IAMC community. ~~Effective radiative forcing and radiative forcing are defined following Myhre et al. (2013). In contrast to radiative forcing,~~ In particular, aerosol effective radiative forcing ~~includes rapid adjustments beyond stratospheric temperature adjustments thus is a better indicator of long-term climate change~~is highly uncertain and a key source of difference between RCMs.

~~Finally in Tier 1, we request output of total climate system heat uptake, ocean heat uptake, surface air temperature change and surface ocean temperature change. These variables are most directly comparable to available observations and CMIP output, with surface temperature also being highly policy-relevant. Focusing on these key variables allows us to discern major differences between RCMs, with Tier 2 and 3 variables then providing further points of comparison at a finer level of detail.~~

4.2.1 ~~Probabilistic outputs~~

~~To reduce the total data volume~~The final variable we request is CO_2 emissions. Given that all our experiments are defined in terms of concentrations, we request ~~that groups provide only a limited set of percentiles from reporting probabilistic outputs, rather than every run which makes up the probabilistic ensemble. The 10th, 50th (median) and 90th percentiles are Tier 1, with the 5th, 17th, 33rd, 67th, 83rd and 95th percentiles being Tier 2. When calculating these percentiles, groups must take care to calculate derived quantities (e. g. Effective Climate Sensitivity) from each run in the probabilistic ensemble first and then calculate the percentiles in a second step. Doing the reverse (calculating percentiles first, then derived quantities from percentiles) will not necessarily lead to the same answer.~~ CO_2 emissions compatible with the prescribed CO_2 pathways.

4.3 ~~Diagnostics~~

5 Results

~~On top of the variable request, we ask for one other diagnostic. This is the equilibrium climate sensitivity, defined as 'the equilibrium warming following an instantaneous doubling of atmospheric concentrations'. Unlike more complex models, RCMs typically have analytically tractable equilibrium climate sensitivities. This means we do not need to include ten thousand year long simulations, which would allow the models to reach true equilibrium. In contrast to the equilibrium climate sensitivity, the more commonly used effective climate sensitivity, derived using the Gregory method (**?**), underestimates warming at true equilibrium in many models (Rohrschneider et al., 2019).~~

6 ~~Illustrative results~~

Within three months of beginning RCMIP and publishing the protocols, 15 ~~models have participated in RCMIP Phase 1 (see Table 1 for an overview and links to key description papers). This is a promising start, demonstrating that the protocol~~ different RCMs submitted data. Given that this is the first phase of RCMIP, we expect even shorter turnarounds in future. The submitted results demonstrate that the RCM community, via RCMIP, now has the capacity to run multi-model studies, and to run them comparatively quickly. In addition, the number of participating modelling groups demonstrates that the RCMIP infrastructure is accessible to a wide range of modelling teams. ~~We encourage any other interested groups to join further phases of the project.~~

~~The groups which have participated have submitted a number of results. We provide a brief overview of these here to give an initial assessment of the diversity of models which have submitted results to date. However, this is not intended as a comprehensive comparison or evaluation.~~

~~Firstly, we present a comparison of model best-estimates against observational best estimates (Figure 1). Such comparisons are a natural starting point for evaluation of all RCMs . We see that all the RCMs~~ All the RCMs are able to capture the approximately 1°C of warming seen in the historical observations (Figure 1), compared to a pre-industrial reference period (Richardson et al., 2016; Rogelj et al., 2019). ~~We also see that all the RCMs~~ However, the RCMs vary in the detail which they represent. Most of the RCMs include some representation of the impact of volcanic eruptions, most notably the drop in global-mean temperatures after the eruption of Mount Agung in 1963. ~~The exception is the~~ In addition, most of the RCMs do not capture natural variability driven by processes such as the El Niño Southern Oscillation (Wolter and Timlin, 2011), the Pacific Decadal Oscillation (Zhang et al., 1997) and the Indian Ocean Dipole (Saji et al., 1999). The exception to this is the EMGC model, which includes representations of the impact of all of these processes. At the other end of the complexity spectrum, we have the CO_2-only model, GREB~~, which~~. Unlike the other RCMs, GREB lacks the volcanic and aerosol induced cooling signals of the 19th and 20th Centuries.

~~Another way to evaluate RCMs is to compare their probabilistic results to observational best estimates as well as uncertainties (Figure ??). Such comparisons are vital to understanding the limits of projected probabilistic ranges and their dependence on model structure. Here we see large differences in probabilistic projections despite the similarities in the models' historical simulations. Determining the underlying causes of such differences requires investigation into and understanding of how the probabilistic distributions are created.~~

RCMIP also facilitates a comparison of model calibrations and CMIP output (Figure 2). ~~Each RCM is calibrated to a different number of CMIP models (some RCMs provide no calibrations at all) because there is no common resource of calibration data. Instead, the CMIP models to which each RCM is calibrated depends on each RCM development team's capability and the time at which they last accessed the CMIP archives.~~

Examining multiple emulation setups~~(Figures S1 - S24),~~ , we see that RCMs can reproduce the temperature response of CMIP models to ~~idealised~~ forcing changes to within a root-mean square error of 0.2°C (Table 2). A detailed comparison of RCMs with 24 CMIP6 ESM ensemble members is available in the Supplementary (Table S1 and Supplementary Figures S1 to S24). In scenario-based experiments, it appears to be harder for RCMs to emulate CMIP output than in idealised experiments. We suggest two key explanations. The first is that effective radiative forcing cannot be easily diagnosed in ~~SSP~~ SSP-based scenarios hence it is hard to know how best to force the RCM during calibration. The second is that the forcing in these scenarios includes periods of increase, sudden decrease due to volcanoes as well as longer term stabilisation rather than the simpler changes seen in the idealised experiments. Fitting all three of these regimes is a more difficult challenge than fitting the ~~the~~ idealised experiments alone.

~~We also present plots of the relationship between surface air temperature change and cumulative emissions from the 1pctCO2 and 1pctCO2-4xext experiments (Figure 4) . These can be used to derive the transient climate response to emissions (Matthews, 2018), a key metric in the calculation of our remaining carbon budget (Rogelj et al., 2019). The illustrative results here demonstrate a range of relationships between these two key variables, from weakly sub-linear to weakly super-linear (see further discussion in Nicholls et al. (2020a)).~~ Only 6 models (Table 2) have been able to submit emulation configurations. Furthermore, each RCM is calibrated to a different number of CMIP models, with some modeling teams unable to provide any calibrations at all. The reason is that there is to-date no common resource of calibration data from the CMIP6 repositories. The technical challenge of diagnosing, stitching together, creating area-weighted averages and de-drifting a large amount of CMIP6 output data within a short time period has turned out to be a hurdle for many modelling teams. As an off-spring from RCMIP, we attempt to address this challenge for the future by providing a unifying data portal (see cmip6.science.unimelb.edu.au, Nicholls et al., 2020b .

~~Finally, we present initial results from running both~~ The ensemble of RCMs also provides insights into the differences between CMIP5 and CMIP6 generation scenarios ('RCP' and 'SSP-based' scenarios respectively) ~~with the same~~ when these scenarios are run with identical models (Figure 3). In the ~~small~~ selection of models which have submitted all RCP, SSP-based scenario pairs, the SSP-based scenarios are ~~0.21~~0.20°C (standard deviation 0.10°C across the ~~models' default setups~~available models) warmer than their corresponding RCPs (Figure 3(b)). This difference is driven by the ~~0.42 ±0.26~~ 0.39 ±0.24 $\mathrm{W m^{-2}}$ larger effective radiative forcing in the SSP-based scenarios (Figure 3(d)), which itself is driven by the 0.53 ±0.44 $\mathrm{W m^{-2}}$ larger CO_2 effective radiative forcing in the SSP-based scenarios (Figure 3(f)). ~~As noted previously, these are only initial results , not a comprehensive evaluation and should be treated as such. Nonetheless, they agree with other work (Wyser et al., 2020)~~ These results add to the work of Wyser et al. (2020) which suggests that even when run with the same model (in a concentration-driven setup), the SSP-based scenarios result in ~~(non-trivially)~~ warmer projections than the RCPs. When we run one of the RCMs (MAGICC) with an AR5-consistent stratospheric-adjusted radiative forcing definition (Myhre et al., 2013), the SSP-based and RCP scenarios are within 6% of each other in 2100 (albeit their AR5-consistent stratospheric-adjusted radiative forcing trajectories can differ by up to 15% at different times over the 21st Century). Thus, we find that the update to effective radiative forcing (Forster et al., 2016), mainly using the formulations presented in Etminan et al. (2016) plus any rapid adjustment terms (Smith et al., 2018b), increases the total forcing in the SSP-based scenarios, because their generally higher CO_2 concentrations are partially, but not fully, offset by lower CH_4 concentrations (see e.g. Fig. 11 in Meinshausen et al., 2020). There is a clear need for further, more comprehensive exploration of the differences between the RCP and SSP-based scenarios.

Finally, we present variations in the relationship between surface air temperature change and cumulative CO_2 emissions from the 1pctCO2 and 1pctCO2-4xext experiments (Figure 4). To date, only three models (GIR, MCE and OSCAR) have been able to provide the required outputs (in particular deriving inverse emissions from these concentration-defined experiments). From the available results, it is clear that the relationship between these two key variables varies over MCE's parameter ensemble, from weakly sub-linear to weakly super-linear. Such variation can have notable implications for the remaining carbon budget (Nicholls et al., 2020a). We also see that the MCE model's parameter ensemble covers a large range, dwarfing the differences between it and the GIR and OSCAR models, which are shown here in their 3°C climate sensitivity configurations. This suggests that, at least for RCMs, the response of individual components and their configuration is more important than model structure, although this conclusion is tempered by the paucity of available results.

6 ~~Extensions~~Options for future RCMIP Phases

RCMIP Phase 1 provides proof of concept of the RCMIP approach to RCM evaluation, comparison and examination. ~~The RCMIP~~ However, Phase 1 ~~protocol focuses on model evaluation hence is limited to experiments which are directly comparable to observations and CMIP output~~has been limited to a very specific set of questions and there is wide scope to use RCMs to examine other scientific questions of interest. In this section we present a number of ways in which further research and phases of RCMIP could build on the work presented in this paper.

The first is a deeper evaluation of the results submitted to RCMIP Phase 1. Here we have only presented illustrative results, however these can be evaluated and investigated in far more detail.For example, quantifying the degree to which different RCMs agree with observations, carefully considering how to handle observational uncertainties, natural variability (which many RCMs cannot capture) and model tuningan exploration of probabilistic outputs. Most RCMs can be calibrated, i.e. have their parameters adjusted, such that they reproduce our best-estimate (typically median) observations. However, RCMs are also used in a probabilistic mode. In this mode a parametric ensemble is run for a given RCM and set of climate forcers. The results are then used to capture the likelihood that different climate changes will unfold, particularly the likelihood of reaching different warming levels. Given the widespread use of probabilistic distributions, particularly for quantifying likely ranges of climate sensitivity and climate projections (see e.g. Meinshausen et al., 2009; Skeie et al., 2018; Vega-Westhoff et al., 2019), examining the differences between existing probabilistic model setups is an obvious next step.

Secondly, there is a wide range of RCMs available in the literature. This variety can be confusing, especially to those who are not intimately involved in developing the models. An overview of the different models, their structure and relationship to one another (in the form of a genealogy) would help reduce the confusion and provide clarity about the implications of using one model over another.

The third suggested extension is an investigation into how different RCMs reach equilibrium in response to a step change in forcing. In RCMIP Phase 1, we only specified the equilibrium climate sensitivity value but temperature response is potentially further defined by linear and nonlinear feedbacks on different timescales. Further phases could investigate whether model structure is a driver of difference between model output or whether these differences are largely controlled by differences in parameter values.

Fourthly, Thirdly, emulation results have generally only been submitted for a limited set of experiments(see Supplementary Table S1 and Supplementary Figures S1 - S24). Hence it is still not clear whether the emulation performance seen in idealised experiments also carries over to scenarios, particularly the SSP-based scenarios. As the number of available CMIP6 results continues to grow, this area is ripe for investigation and will lead to improved understanding of the limits of the reduced complexity approach. A common resource The development of a common resource (see cmip6.science.unimelb.edu.au, Nicholls et al., 2020b) for RCM calibration would will greatly aid this effort because CMIP6 datahandling requires specialist big data handling skillsby ensuring that each group has access to the same set of calibration data.

Fifthly, while RCMIP Phase 1 allows us to evaluate the differences between RCMs Finally, while evaluating RCMs is a useful exercise, the root causes of these differences may not be clear. This can be addressed by extending RCMIP to include performing experiments which specifically diagnose the reasons for differences between models e.g. simple pulse emissions of different species or prescribed step changes in atmospheric greenhouse gas concentrations. Such experiments could build on existing research (van Vuuren et al., 2011b; Schwarber et al., 2019) and would allow even more comprehensive examination and understanding of RCM behaviour.

Following this, there is clearly some variation in probabilistic projections. However, what is not yet known is the extent to which variations in model structure, calibration data and calibration technique drive such differences. Investigating these questions would help understand the limits of probabilistic projections and their uncertainties. Experiments could involve constraining two different models with the same constraining technique and data, constraining a single model with two different techniques but the same data or constraining a single model with a single technique but two different datasets.

Next, the current experiments can be extended to examine the behaviour of models' gas cycles, particularly their interactions and feedbacks with other components of the climate system. This will This would require custom experimentsbut is important for understanding the behaviour of these emissions driven runs. Such experiments are particularly important , particularly for the carbon cycle, which is strongly coupled to other parts of the climate system. It should be noted that, for ESMs, the suggestion of extra experiments is limited by human and computational constraints. This constraint does not apply to RCMs because of their computational efficiency: However, unlike ESMs, adding extra RCM experiments adds relatively little technical burden. or human burden, because RCMs are computationally cheap and because RCMIP's standardised formats facilitate highly automated experiment pipelines.

One final suggestion for future research is the importance of the choice of reference period. Within the reference period, all model results and observations will be artificially brought together, narrowing uncertainty and disagreement within this period (**?**). This can alter conclusions as the reference period will become less important for any fitting algorithm (because of the artificial agreement), placing more weight on other periods. Developing a method to rebase both the mean and variance of model and observational results onto other reference periods would allow the impact of the reference period choice to be explored in a more systematic fashion.

7 Conclusions

RCMs are used in many applications, particularly where computational constraints prevent other techniques from being used. Due to their importance in climate policy assessments, in carbon budget calculations, as well as applicability to a wide range of scientific questions, understanding the behaviour and output from RCMs is highly relevant and requires continuous updating with the latest science. Here we have presented the Reduced Complexity Model Intercomparison Project (RCMIP), an effort to facilitate the evaluation and understanding of RCMs in a systematic, standardised and detailed way. We hope this can greatly improve ease of use of, and familiarity with, RCMs.

We have performed RCMIP Phase 1, which provides an initial database of experiments conducted with 15 participating models from the RCM community. RCMIP Phase 1 focused on basic evaluation and benchmarking of RCMs , providing some key starting points for all users of RCMs to examine when considering their model of choice. Here we have only presented illustrative results and further analysis is warranted to quantify the differences in behaviour (and associated uncertainty) between the different RCMs. comparisons of RCMs with observed global-mean temperature changes, comparisons of RCMs with the global-mean temperature response of more complex models, the difference between the SSP-based and RCP scenarios and an exploration of the relationship between cumulative CO_2 emissions and surface air temperature change in the RCMs.

These initial comparisons demonstrate that RCMIP's infrastructure is a useful tool for such intercomparisons and that the RCM community is able to perform such intercomparisons on timescales of the order of months. Further work will examine the ~~results from Phase 1 and RCMsin more detail, improving evaluation, comparison and understanding of the implications~~ relationship between different RCMs, RCMs' probabilistic projections and the cause of differences between ~~models~~RCMs.

RCMIP ~~aims to fill~~ fills a gap in our understanding of RCM behaviour, in particular, ~~in~~ how different RCMs perform relative to each other as well as ~~in absolute terms~~how they compare with observations. This gap is particularly important to fill given the widespread use of RCMs throughout the integrated assessment modelling community and in large-scale climate science assessments. We welcome requests, suggestions and further involvement from throughout the climate modelling research community. With our efforts, we ~~hope~~ aim to increase understanding of and confidence in RCMs, particularly for their many users at the science-policy interface.

Code and data availability. RCMIP input timeseries and results data along with processing scripts as used in this submission are available from the RCMIP GitLab repository at https://gitlab.com/rcmip/rcmip and archived by Zenodo (https://doi.org/10.5281/zenodo.3593569).

The ACC2 model code is available upon request.

The implementation of the AR5IR model used in this study is available in the OpenSCM repository: https://github.com/openscm/openscm/blob/ar5ir-notebooks/notebooks/ar5ir_rcmip.ipynb

The model version of ESCIMO used to produce the RCMIP runs can be downloaded from http://www.2052.info/wp-content/uploads/2019/12/mo191107%202%20ESCIMO-rcimpfrom%20mo160911%202100%20ESCIMO.vpm. The vpm extension allows you to view, examine and run the model, but not save it. The original model with full documentation is available from http://www.2052.info/escimo/.

FaIR is developed on GitHub at https://github.com/OMS-NetZero/FAIR and v1.5 used in this study is archived at Zenodo (Smith et al., 2019).

The GREB model source code used is available, upon request, on Bitbucket: https://bitbucket.org/rcmipgreb/greb-official/src/official-rcmip/. The last stable versions are available on GitHub at https://github.com/christianstassen/greb-official/releases.

The Held two layer model implementation used in this study is available in the OpenSCM repository: https://github.com/openscm/openscm/blob/ar5ir-notebooks/notebooks/held_two_layer_rcmip.ipynb

Hector is developed on GitHub at https://github.com/JGCRI/hector. The exact version of Hector used for these simulations can be found at https://github.com/ashiklom/hector/releases/tag/rcmip-phase-1. The scripts for the RCMIP runs are available at https://github.com/ashiklom/hector-rcmip.

MAGICC's Python wrapper is archived at Zenodo (https://doi.org/10.5281/zenodo.1111815) and developed on GitHub at https://github.com/openclimatedata/pymagicc/.

OSCAR v3 is available on GitHub at https://github.com/tgasser/OSCAR.

WASP's code for the version used in this study is available from the supplementary material of Goodwin (2018): https://doi.org/10.1029/2018EF000889. See also the WASP website at http://www.waspclimatemodel.info/download-wasp.

The other participating models are not yet available publicly for download or as open source. Please also refer to their respective model description papers for notes and code availability.

Author contributions. ZN and RG conceived the idea for RCMIP. ZN, MM and JL setup the RCMIP website (rcmip.org), produced the first draft of the protocol and derived the data format. All authors contributed to updating and improving the protocol. ACC2 results were provided by KT and EK. AR5IR and Held et al. two layer model were provided by ZN. CICERO-SCM results were provided by JF, BS, MS and RS. ESCIMO results were provided by UG. FaIR results were provided by CS. GIR results were provided by NL. GREB results were provided by DD, CF, DM and ZX. Hector results were provided by AS and KD. MAGICC results were provided by MM, JL and ZN. MCE results were provided by JT. OSCAR results were provided by TG and YQ. WASP results were provided by PG. ZN wrote, except for the model descriptions, the first manuscript draft, produced all the figures and led the manuscript writing process with support from RG. All authors contributed to writing and revising the manuscript.

Competing interests. The authors declare that they have no conflict of interest.

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Table 1. Models participating in RCMIP Phase 1.

Model (acronym used in figures)	Spatial resolution	Climate response to radiative forcing	Key references
ACC2 (ACC2-v4-2)	Global land/ocean	1D ocean heat diffusion (DOECLIM)	Tanaka and O'Neill (2018); Tanaka et al. (2007) (also Hooss et al. (2001); Bruckner et al. (2003); Kriegler (200)
AR5IR (ar5ir-2box, ar5ir-3box)	Global	Impulse response	Myhre et al. (2013)
CICERO-SCM (CICERO-SCM)	Hemispheric	Energy balance/upwelling diffusion ocean	Skeie et al. (2017) (also Schlesinger et al. (1992); Joos et al. (1996); Etminan et al. (20)
EMGC (EMGC)	Global	Multiple linear regression model (temperature regressed against radiative forcing and natural variability indices)	Canty et al. (2013); Hope et al. (2017)
ESCIMO (ESCIMO)	Global	Conserved flows of carbon, heat, albedo, permafrost, biome and biomass change. Driven by GHG emissions, the rest is endogenous.	Randers et al. (2016)
FaIR (FaIR-v1-5)	Global	Modified impulse response	Smith et al. (2018a); Etminan et al. (2016)
GIR (GIR)	Global	Modified impulse response	Leach et al. (2020)
GREB (GREB-v1-0-1)	96 x 48 grid	Energy balance model with atmospheric transport of heat and moisture, surface and subsurface ocean layers	Dommenget et al. (2019)
Hector (hector)	Global	1D ocean heat diffusion (DOECLIM)	Hartin et al. (2015); Dorheim et al. (Under Review at Earth an (see also Kriegler (2005); Tanaka et al. (2007))

Table 1. Continued.

Model (acronym used in figures)	**Spatial resolution**	**Climate response to radiative forcing**	**Key references**
Held et. al two layer model (held-two-layer-uom)	Global	Energy balance with two-layer ocean and state-dependent climate feedback factor	Rohrschneider et al. (2019); Held et al. (2010)
MAGICC (MAGICC-v7-1-0-beta)	Hemispheric land/ocean	Atmospheric energy balance model with 50-layer upwelling-diffusion-entrainment ocean	Meinshausen et al. (2011a, 2020) (see also von Deimling et al. (2012); Nauels et al. (2017))
MCE (MCE-v1-1)	Global	Impulse response	Tsutsui (2017, 2020) (see also Joos et al. (1996); Hooss et al. (2001))
OSCAR (OSCAR-v3-0)	Global, with regionalized land carbon cycle	Impulse response	Gasser et al. (2017)
WASP (WASP-v2)	Global	Energy balance using time evolving climate feedback, with conservation of heat	Goodwin (2018); Goodwin et al. (2019) (see also Goodwin et al. (2014); Goodwin (2016))

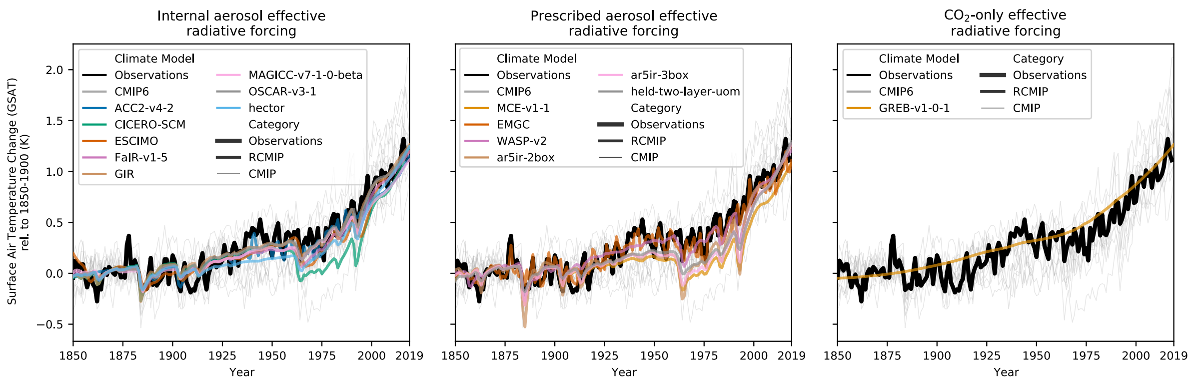

Figure 1. Historical global-mean annual mean surface air temperature (GSAT) simulations. Thick black line is observed GSAT (Richardson et al., 2016; Rogelj et al., 2019). Medium thickness lines are default configurations for RCMIP models. Thin grey solid lines are CMIP6 models. In order to provide timeseries up until 2019, we have used data from the combination of historical and ssp585 simulations.

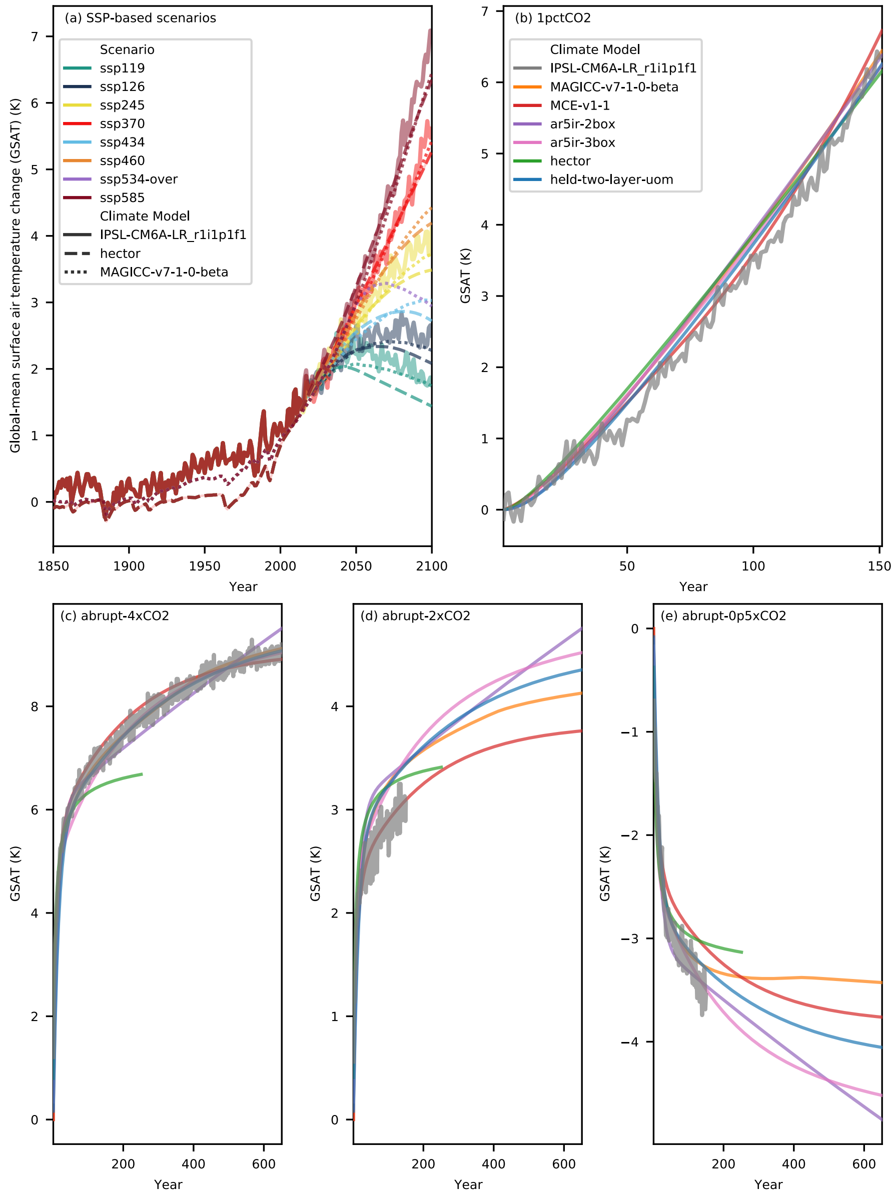

Figure 2. Emulation of CMIP6 models by RCMs. The thick transparent lines are the target CMIP6 model output (here from IPSL-CM6A-LR r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend). See the Supplementary Information for other target CMIP6 models.

Table 2. Model emulation scores over all emulated models and scenarios. Here we provide root-mean square errors over the SSPs plus four idealised CO_2-only experiments (abrupt-2xCO2, abrupt-4xCO2, abrupt-0p5xCO2, 1pctCO2). As the models have not all provided emulations for the same set of target models and scenarios, the model emulation scores are indicative only and are not a true, fair test of skill. For target model by target model emulation scores, see Table S1.

Model (number of emulated scenarios)	**Surface Air Temperature Change (GSAT aka tas) root-mean square error (indicative only)**
MAGICC-v7-1-0-beta (131)	0.21 K
MCE-v1-1 (44)	0.19 K
ar5ir-2box (36)	0.24 K
ar5ir-3box (36)	0.28 K
hector (64)	0.28 K
held-two-layer-uom (34)	0.18 K

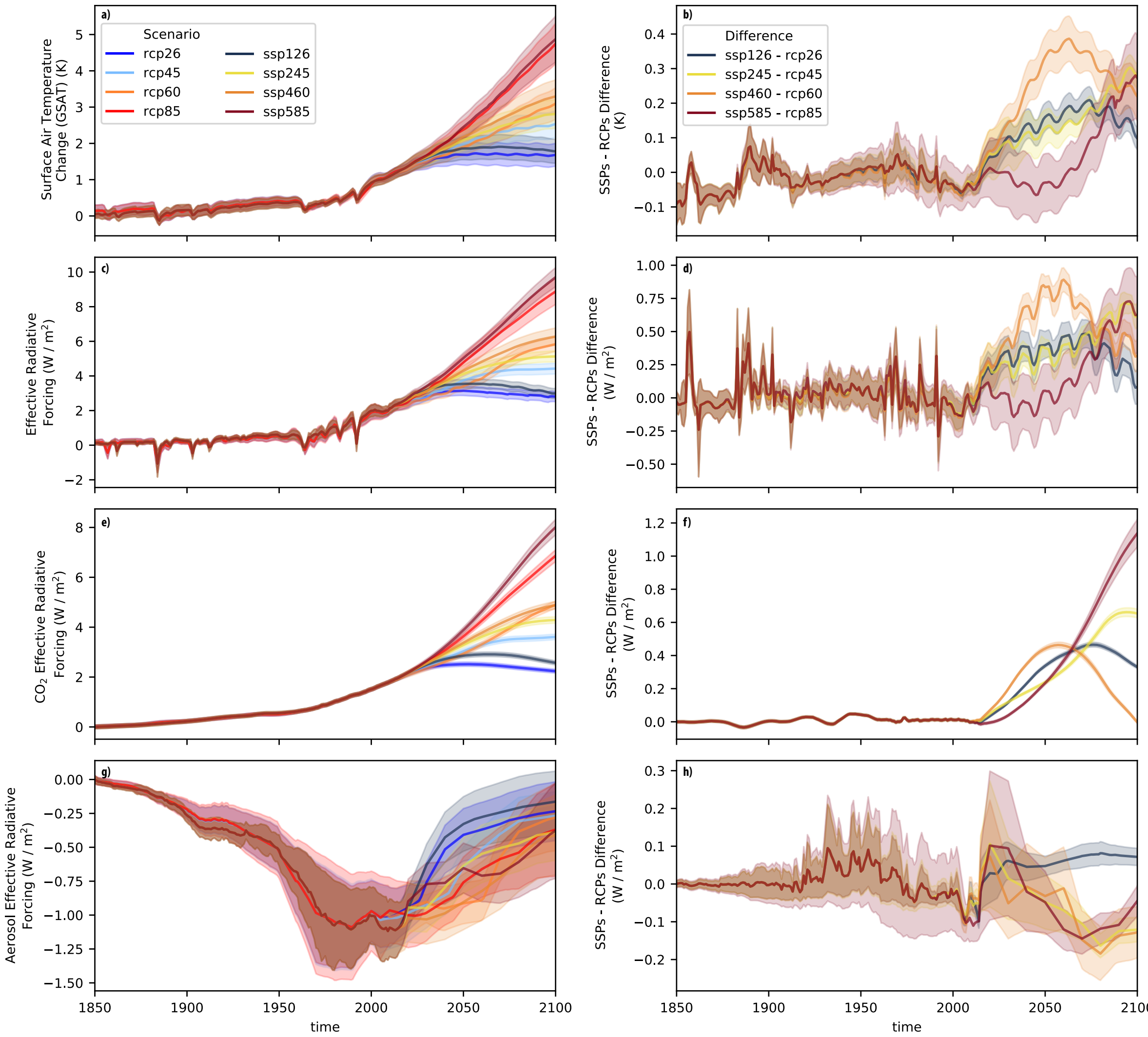

Figure 3. Output from the RCPs and SSP-based scenarios up until 2100. The left-hand column shows raw model output. The right-hand column shows the difference between RCP SSP-based scenario pairs for a given model's output. The shaded range shows one standard deviation about the median (solid lines). Output is shown for surface air temperature change (GSAT, (a) and (b)), effective radiative forcing ((c) and (d)), CO_2 effective radiative forcing ((e) and (f)) and aerosol effective radiative forcing ((g) and (h)). The results here are based on a limited set of models: CICERO-SCM, MAGICC, OSCAR, GIR and FaIR. Only these models have performed the required RCP, SSP-based scenario pair experiments.

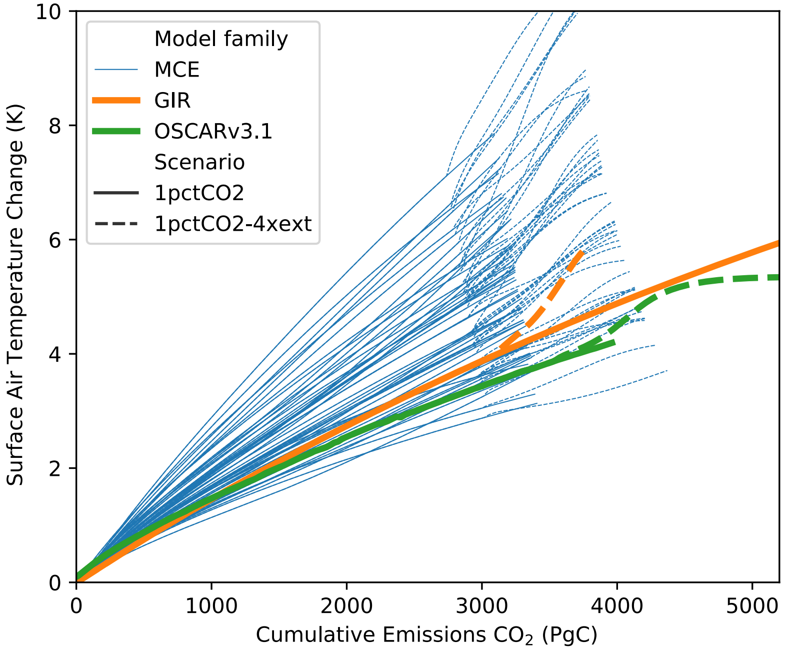

Figure 4. Surface air temperature change against cumulative CO_2 emissions in the 1pctCO2 and 1pctCO2-4xext experiments. Thin lines are used for the MCE model's family of emulation setups. Thick lines are used for the GIR and OSCAR 3°C climate sensitivity setups.

S1 Data formats

Systematic intercomparison projects such as RCMIP require the definition of a clear input and output data handling framework. Historically, comparing RCMs required learning how to set up, configure and run multiple RCMs in order to produce results. This required significant time and hence, as previously discussed, has only been attempted in standalone cases with a limited number of models (Houghton et al., 1997; van Vuuren et al., 2011b; Harmsen et al., 2015; Schwarber et al., 2019). With a common framework, once a model has participated in RCMIP, it is simpler to run it again in different experiments and provide output in a common, standardised format. This allows researchers to design, run and analyse experiments with far less effort than was previously required. As a result, it becomes feasible to do more regular and targeted assessment of RCMs. This capacity improves our knowledge of RCMs, our understanding of the implications of their quantitative results and our ability to develop and improve them. Our data format is designed to be easy to use and hence easily able to be extended within future RCMIP phases or in separate research.

S1.1 Inputs

All input data is provided in a text-based format based on the specifications used by the IAMC community (Gidden and Huppmann, 2019) . The computational simplicity of RCMs means that their input specifications are relatively lightweight and hence using an uncompressed, text-based input format is possible. Further, the format is explicit about associated metadata and ensures metadata remains attached to the timeseries. As the IAMC community is a major user of RCMs, as well as being the source of input data for many experiments run with RCMs, using their data format ensures that data can be shared easily and assessment of IAM emissions scenarios can be performed with minimal data handling overhead.

The inputs are formatted as text files with comma separated values (CSV), with each row of the CSV file being a timeseries (see rcmip.org). This format is also often referred to as 'wide' although this term is imprecise (Wickham, 2014). The columns provide metadata about the timeseries, specifically the timeseries' variable, units, region, model and scenario. Other columns provide the values for each timestep within the timeseries.

Being simplified models, RCMs typically do not take gridded input. Hence we use a selection of highly aggregated socio-economic regions, which once again follow IAMC conventions (Gidden and Huppmann, 2019).

S1.2 Outputs

RCMIP Phase 1's submission template (see rcmip.org or https://doi.org/10.5281/zenodo.3593570) is composed of two parts. The first part is the data submission and is identical to the input format. Using a consistent data format allows for simplified analysis with the same tools we used to develop the input protocols and exchange with the IAMC community as they can analyse the data using existing tools such as pyam (Gidden and Huppmann, 2019). However, one complication of using the IAMC format is that the 'model' column is reserved for the name of the integrated assessment model which produced the scenario. To enhance compatibility with the IAMC format, we don't use the 'model' column. Instead, we use the separate 'climate_model' column to store metadata about the climate model which provided the timeseries.

The second part of submissions is model metadata. This includes the model's name, version number, brief description and literature reference. We also request a configuration label, which uniquely identifies the configuration in which the model was run to produce the given results.

Given the typical temporal resolution of RCMs, we request all output be reported with an annual timestep. In addition, to facilitate use of the output, participating modelling groups agree to have their submitted data made available under a Creative Commons Attribution-ShareAlike 4.0 International (CC BY-SA 4.0) license. All input and output data, as well as all code required to produce this paper, is available at gitlab.com/rcmip/rcmip and archived at https://doi.org/10.5281/zenodo.3593569.

S2 Scenario-based experiments data sources

CMIP6 emissions projections follow Gidden et al. (2019) and are available at https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=60 (hosted by IIASA). Where regional emissions information is missing, we use the downscaling procedure described in Meinshausen et al. (2020). The emissions extensions also follow the convention described in Meinshausen et al. (2020).

For CMIP6 historical emissions (year 1850-2014), we have used data sources which match the harmonisation used for the CMIP6 emissions projections. This ensures consistency with CMIP6, although it means that we do not always use the latest data sources. CMIP6 historical anthropogenic emissions for CO_2, CH_4, BC, CO, NH_3, NOx, OC, SO_2 and non-methane volatile organic compounds (NMVOCs) come from CEDS (Hoesly et al., 2018). Biomass burning emissions data for CH_4, BC, CO, NH_3, NOx, OC, SO_2 and NMVOCs come from UVA (van Marle et al., 2017). The biomass burning emissions are a blend of both anthropogenic and natural emissions, which could lead to some inconsistency between RCMs as they make different assumptions about the particular anthropogenic/natural emissions split. CO_2 global land-use emissions are taken from the Global Carbon Budget 2016 (Quéré et al., 2016). Emissions of N_2O and the regional breakdown of CO_2 land-use emissions come from PRIMAP-hist Version 1.0 (Gütschow et al., 2016, see https://doi.org/10.5880/PIK.2016.003). Where well-mixed greenhouse gas emissions are missing, we use inverse emissions based on the CMIP6 concentrations from MAGICC7.0.0 (Meinshausen et al., 2020). Where required, historical emissions were extended back to 1750 by assuming a constant relative rate of decline based on the period 1850-1860 (noting that historical emissions are somewhat uncertain, we require consistent emissions inputs in Phase 1, uncertainty in historical emissions will be explored in future research).

CMIP6 concentrations follow Meinshausen et al. (2020). CMIP6 radiative forcings follow the data provided at https://doi.org/10.5281/zenodo.3515339). CMIP5 emissions, concentrations and radiative forcings follow Meinshausen et al. (2011b) and are taken from http://www.pik-potsdam.de/~mmalte/rcps/.

Table S1. Emulation scores and equilbrium climate sensitivities (ECSs) for RCMIP model calibrations. In parentheses we show the number of simulations available for each model variant.

Target CMIP6 model	RCMIP model	RMSE (K)
AWI-CM-1-1-MR_r1i1p1f1 (5)	MAGICC-v7-1-0-beta (5)	0.16
BCC-CSM2-MR_r1i1p1f1 (6)	MCE-v1-1 (2)	0.21
	MAGICC-v7-1-0-beta (6)	0.16
	ar5ir-2box (2)	0.13
	ar5ir-3box (2)	0.13
	held-two-layer-uom (2)	0.13
BCC-ESM1_r1i1p1f1 (4)	MCE-v1-1 (2)	0.12
	MAGICC-v7-1-0-beta (3)	0.13
	ar5ir-2box (2)	0.18
	ar5ir-3box (2)	0.15
	held-two-layer-uom (2)	0.12
CanESM5_r1i1p1f1 (10)	MCE-v1-1 (2)	0.13
	hector (9)	0.18
	MAGICC-v7-1-0-beta (10)	0.30
	ar5ir-2box (2)	0.19
	ar5ir-3box (2)	0.21
	held-two-layer-uom (2)	0.30
CanESM5_r1i1p2f1 (7)	MCE-v1-1 (2)	0.13
	hector (7)	0.18
	MAGICC-v7-1-0-beta (7)	0.27
CanESM5_r10i1p1f1 (5)	hector (5)	0.22
	MAGICC-v7-1-0-beta (5)	0.18
CESM2-WACCM_r1i1p1f1 (6)	MCE-v1-1 (2)	0.15
	hector (6)	0.22
	MAGICC-v7-1-0-beta (6)	0.21
	ar5ir-2box (2)	0.45
	ar5ir-3box (2)	0.21
	held-two-layer-uom (2)	0.13

Table S1. Continued.

Target CMIP6 model	RCMIP model	RMSE (K)
CESM2_r1i1p1f1 (6)	MCE-v1-1 (2)	0.17
	hector (6)	0.32
	MAGICC-v7-1-0-beta (6)	0.27
	ar5ir-2box (2)	0.24
	ar5ir-3box (2)	0.24
	held-two-layer-uom (2)	0.20
CNRM-CM6-1_r1i1p1f2 (8)	MCE-v1-1 (4)	0.24
	hector (8)	0.34
	MAGICC-v7-1-0-beta (8)	0.18
	ar5ir-2box (4)	0.43
	ar5ir-3box (4)	0.43
	held-two-layer-uom (4)	0.16
CNRM-ESM2-1_r1i1p1f2 (10)	MCE-v1-1 (2)	0.20
	hector (9)	0.24
	MAGICC-v7-1-0-beta (9)	0.18
	ar5ir-3box (2)	0.27
	ar5ir-2box (2)	0.27
	held-two-layer-uom (2)	0.17
E3SM-1-0_r1i1p1f1 (2)	MCE-v1-1 (2)	0.17
	MAGICC-v7-1-0-beta (2)	0.22
EC-Earth3-Veg_r1i1p1f1 (7)	MCE-v1-1 (2)	0.19
	MAGICC-v7-1-0-beta (7)	0.25
	ar5ir-3box (2)	0.22
	ar5ir-2box (2)	0.27
	held-two-layer-uom (2)	0.19

Table S1. Continued.

Target CMIP6 model	RCMIP model	RMSE (K)
FGOALS-g3_r1i1p1f1 (4)	MAGICC-v7-1-0-beta (4)	0.15
GISS-E2-1-G_r1i1p1f1 (4)	MCE-v1-1 (4)	0.16
	MAGICC-v7-1-0-beta (4)	0.19
	ar5ir-2box (4)	0.15
	ar5ir-3box (4)	0.58
	held-two-layer-uom (4)	0.15
GISS-E2-1-H_r1i1p1f1 (3)	MCE-v1-1 (3)	0.15
	MAGICC-v7-1-0-beta (3)	0.16
	ar5ir-3box (3)	0.15
	ar5ir-2box (3)	0.16
	held-two-layer-uom (3)	0.14
GISS-E2-2-G_r1i1p1f1 (3)	MAGICC-v7-1-0-beta (3)	0.19
	ar5ir-3box (3)	0.66
	ar5ir-2box (3)	0.16
	held-two-layer-uom (3)	0.14
IPSL-CM6A-LR_r1i1p1f1 (20)	MCE-v1-1 (4)	0.25
	hector (9)	0.40
	MAGICC-v7-1-0-beta (9)	0.25
	ar5ir-2box (4)	0.34
	ar5ir-3box (4)	0.26
	held-two-layer-uom (4)	0.29
IPSL-CM6A-LR_r1i1p1f2 (2)	hector (2)	0.34
	MAGICC-v7-1-0-beta (2)	0.21
IPSL-CM6A-LR_r10i1p1f1 (3)	MCE-v1-1 (1)	0.21
	hector (3)	0.34
	MAGICC-v7-1-0-beta (3)	0.32
MCM-UA-1-0_r1i1p1f2 (4)	MAGICC-v7-1-0-beta (4)	0.16

Table S1. Continued.

Target CMIP6 model	**RCMIP model**	**RMSE (K)**
MIROC6_r1i1p1f1 (14)	MCE-v1-1 (4)	0.28
	MAGICC-v7-1-0-beta (12)	0.19
NorESM2-LM_r1i1p1f1 (3)	MCE-v1-1 (2)	0.32
	MAGICC-v7-1-0-beta (2)	0.22
	ar5ir-3box (2)	0.19
	ar5ir-2box (2)	0.19
SAM0-UNICON_r1i1p1f1 (2)	MCE-v1-1 (2)	0.15
	MAGICC-v7-1-0-beta (2)	0.24
UKESM1-0-LL_r1i1p1f2 (9)	MCE-v1-1 (2)	0.16
	MAGICC-v7-1-0-beta (9)	0.30
	ar5ir-3box (2)	0.19
	ar5ir-2box (2)	0.26
	held-two-layer-uom (2)	0.19

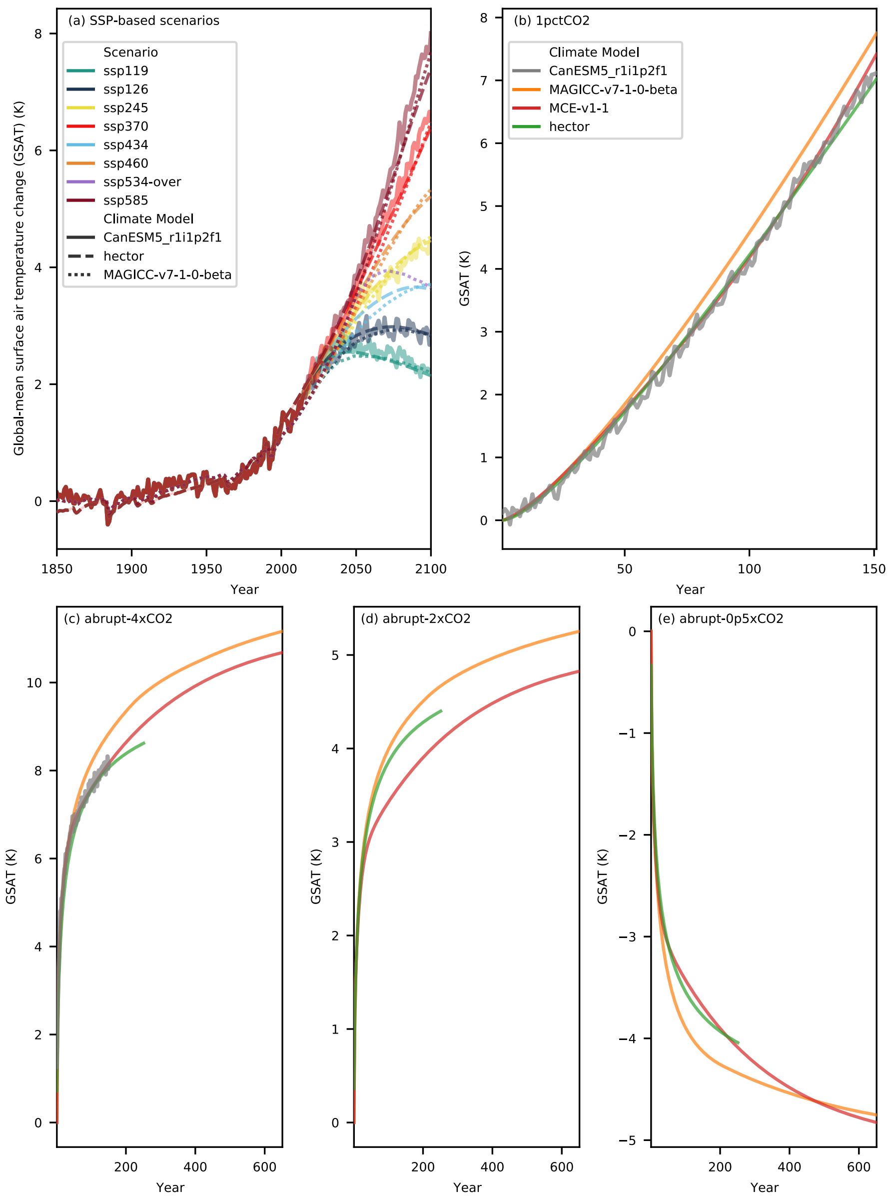

Figure S1. Emulation of CanESM5_r1i1p2f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from CanESM5_r1i1p2f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

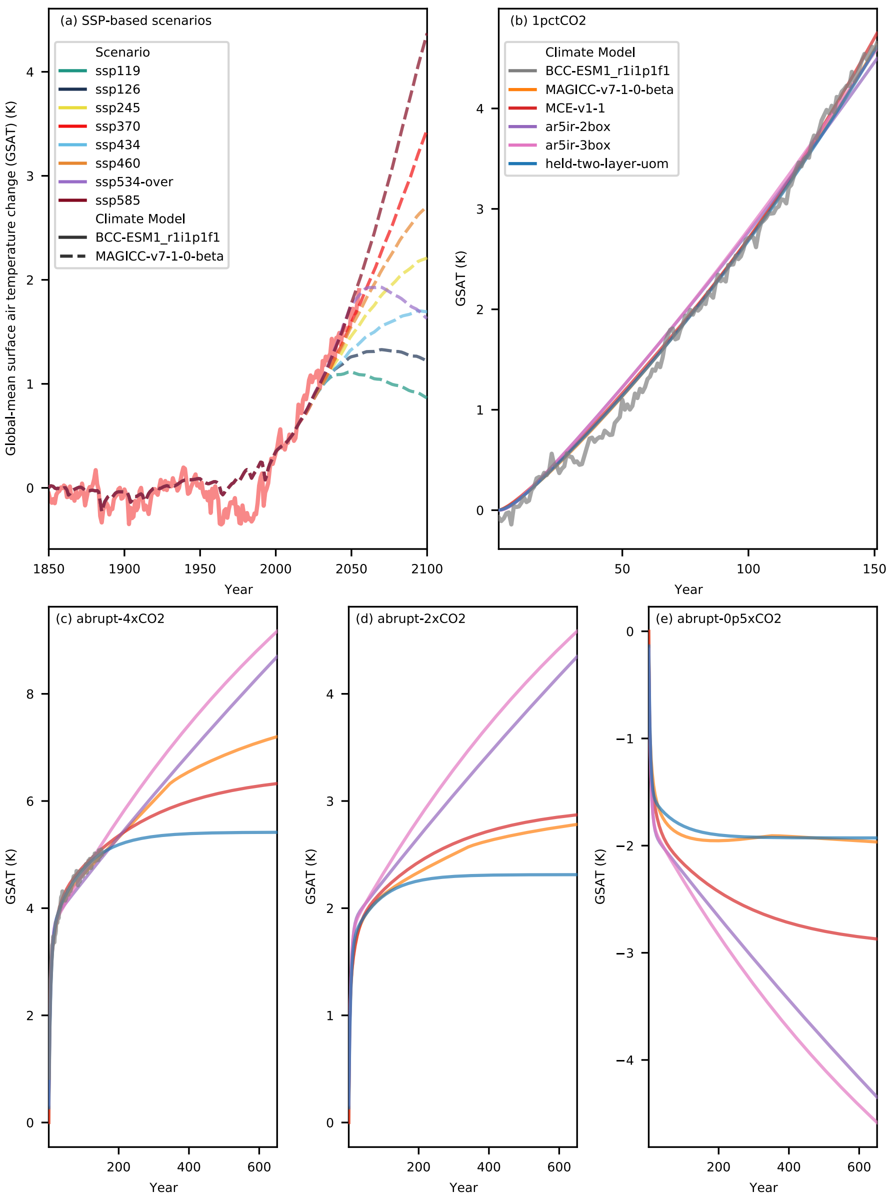

Figure S2. Emulation of BCC-ESM1_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from BCC-ESM1_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

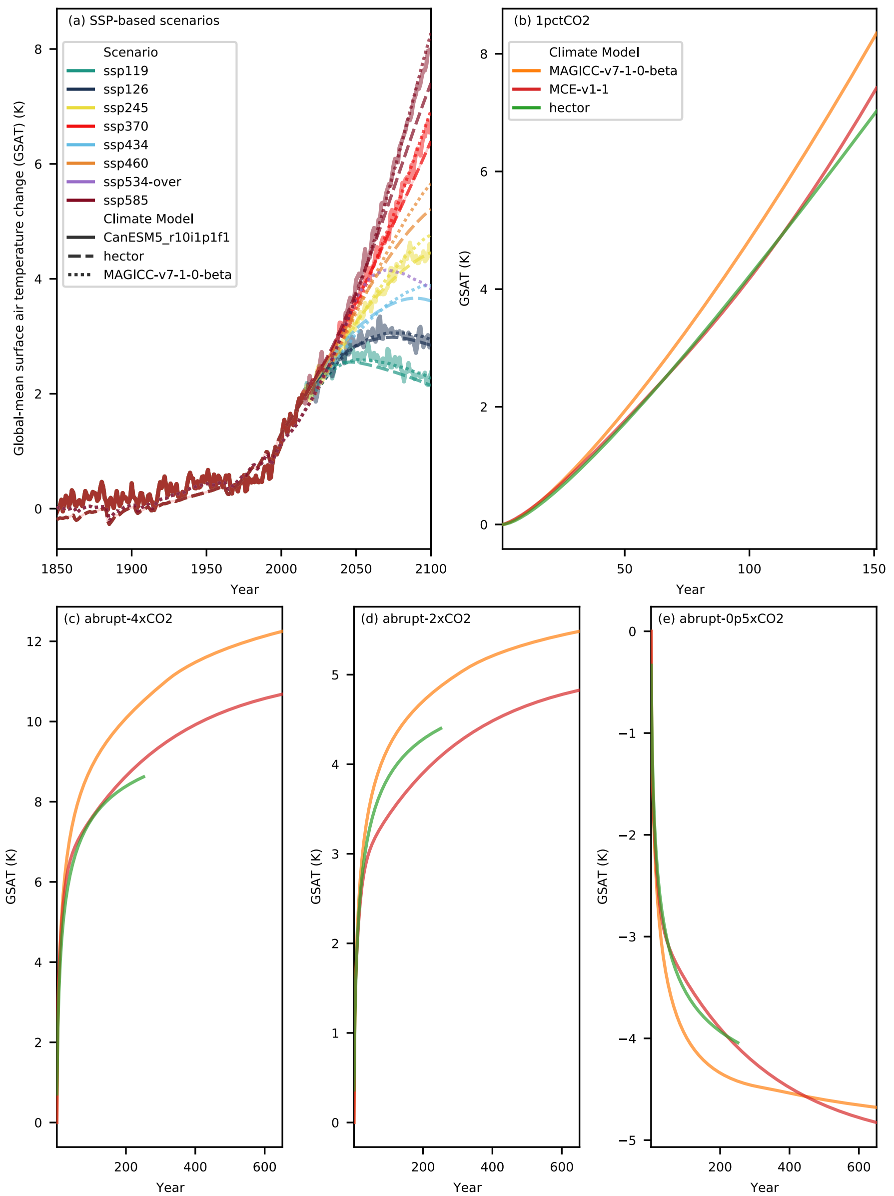

Figure S3. Emulation of CanESM5_r10i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from CanESM5_r10i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

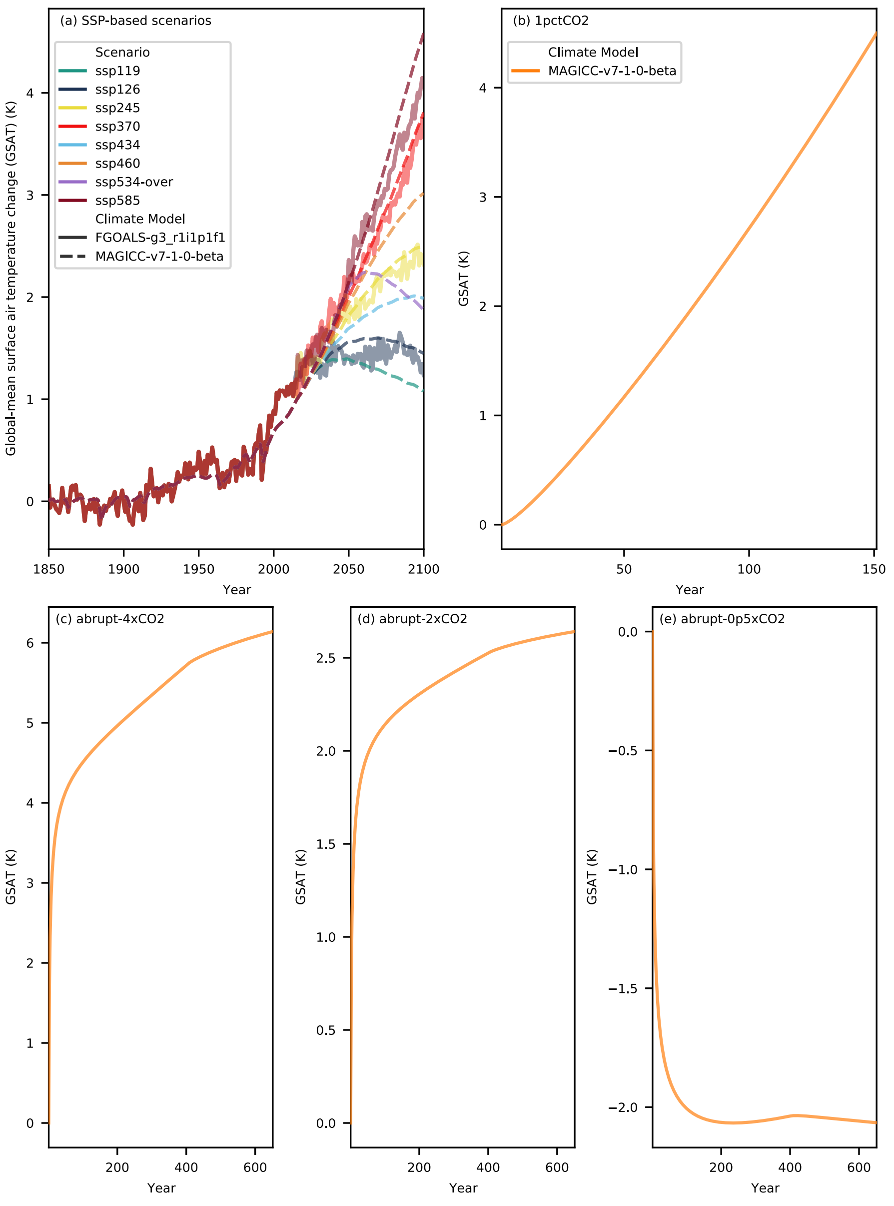

Figure S4. Emulation of FGOALS-g3_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from FGOALS-g3_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

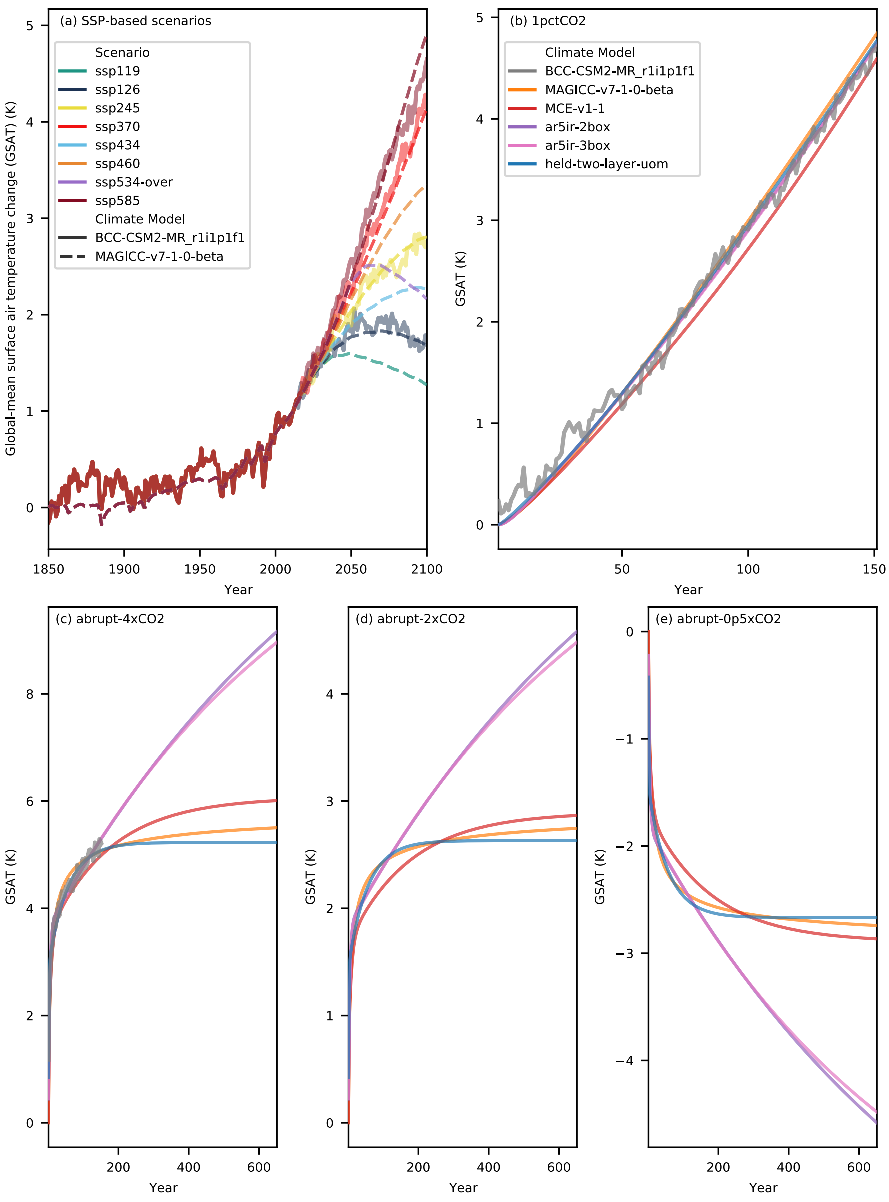

Figure S5. Emulation of BCC-CSM2-MR_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from BCC-CSM2-MR_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

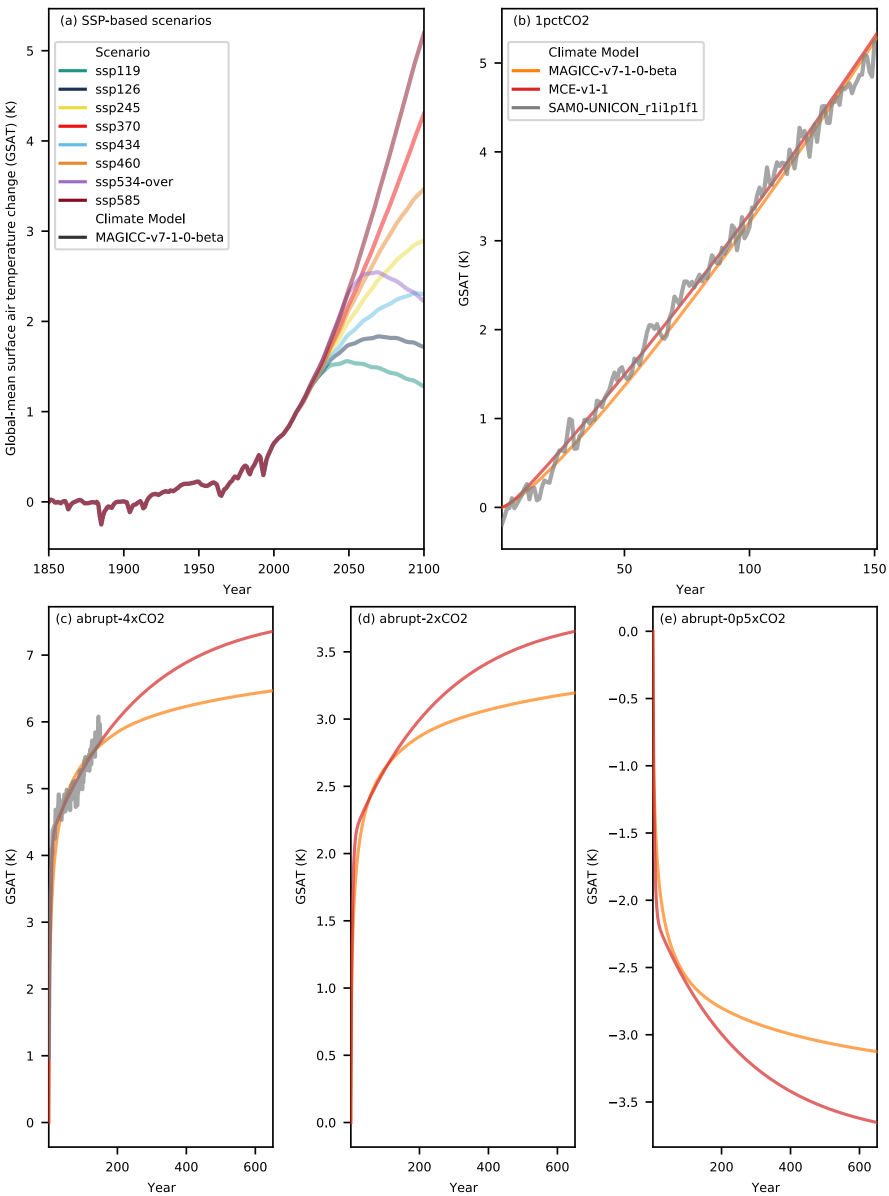

Figure S6. Emulation of SAM0-UNICON_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from SAM0-UNICON_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

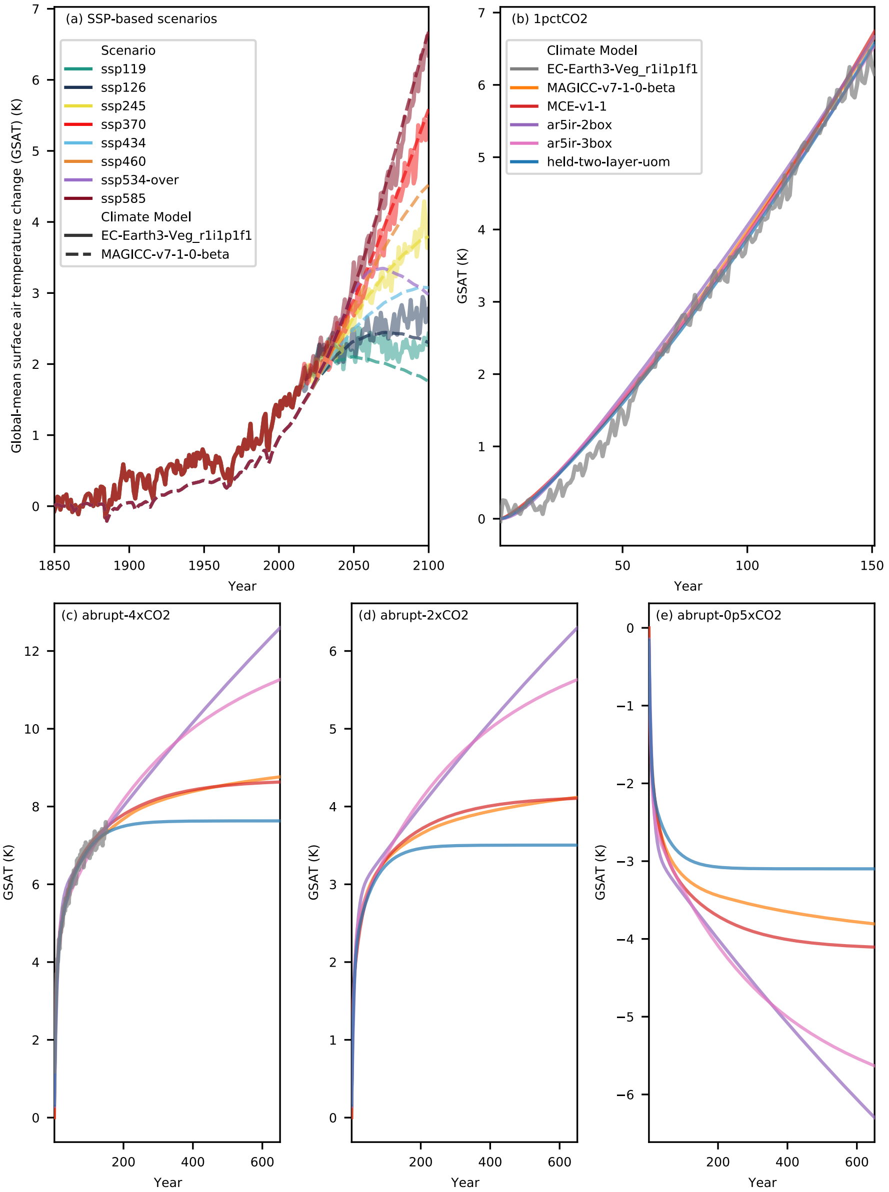

Figure S7. Emulation of EC-Earth3-Veg_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from EC-Earth3-Veg_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

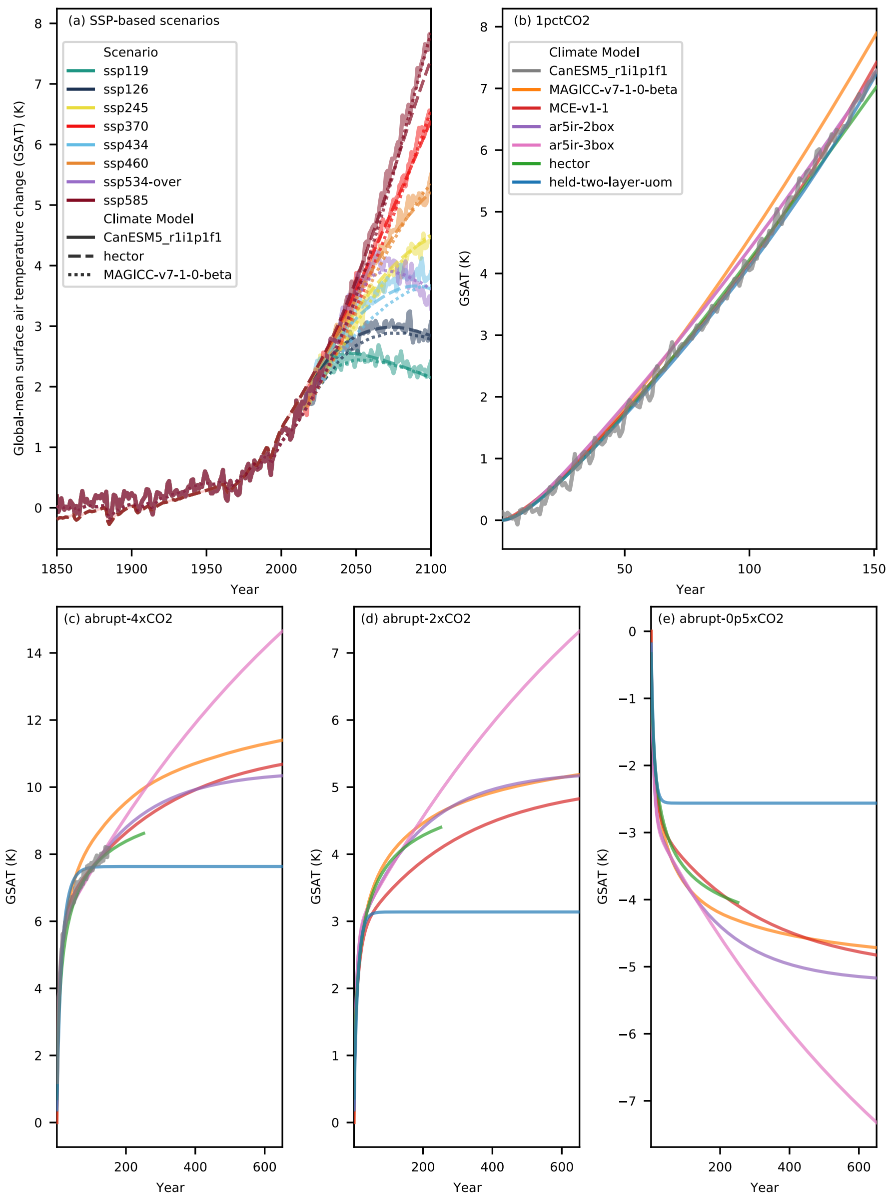

Figure S8. Emulation of CanESM5_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from CanESM5_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

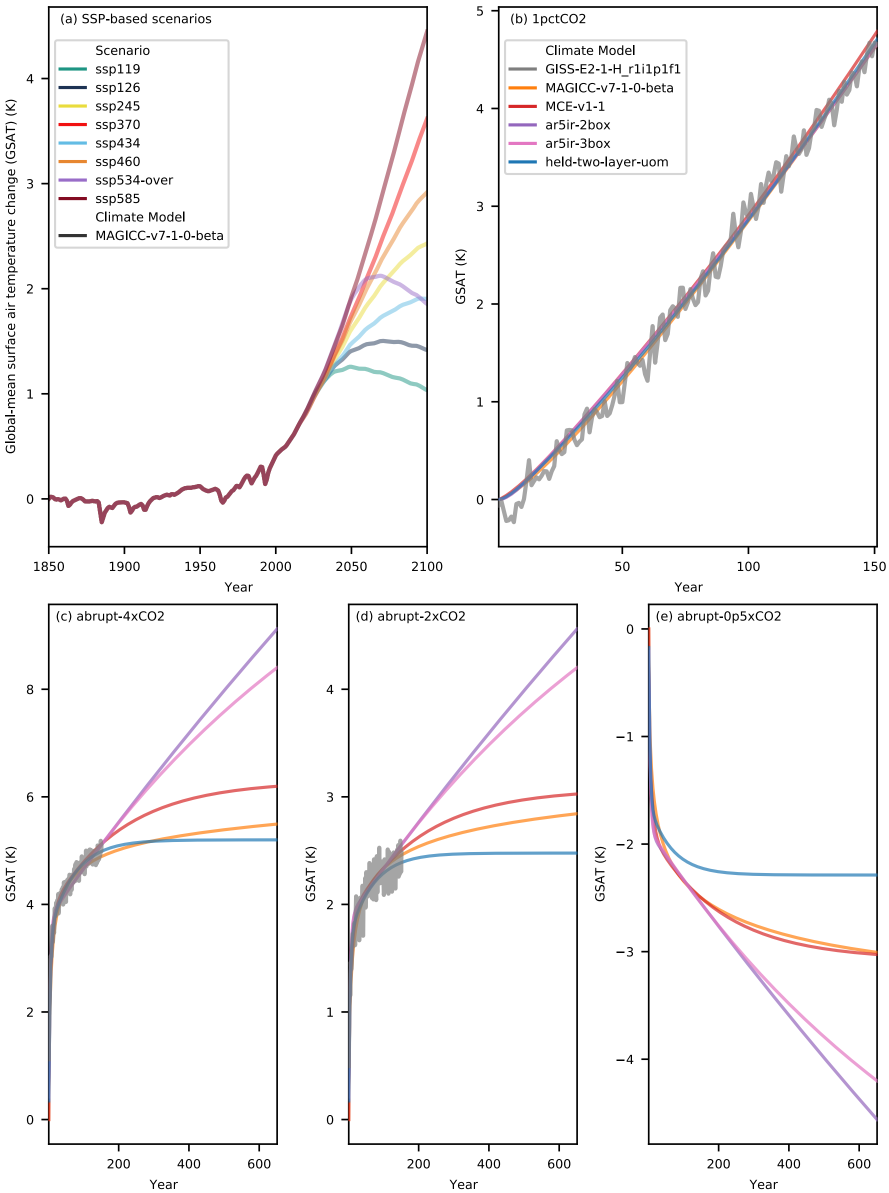

Figure S9. Emulation of GISS-E2-1-H_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from GISS-E2-1-H_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

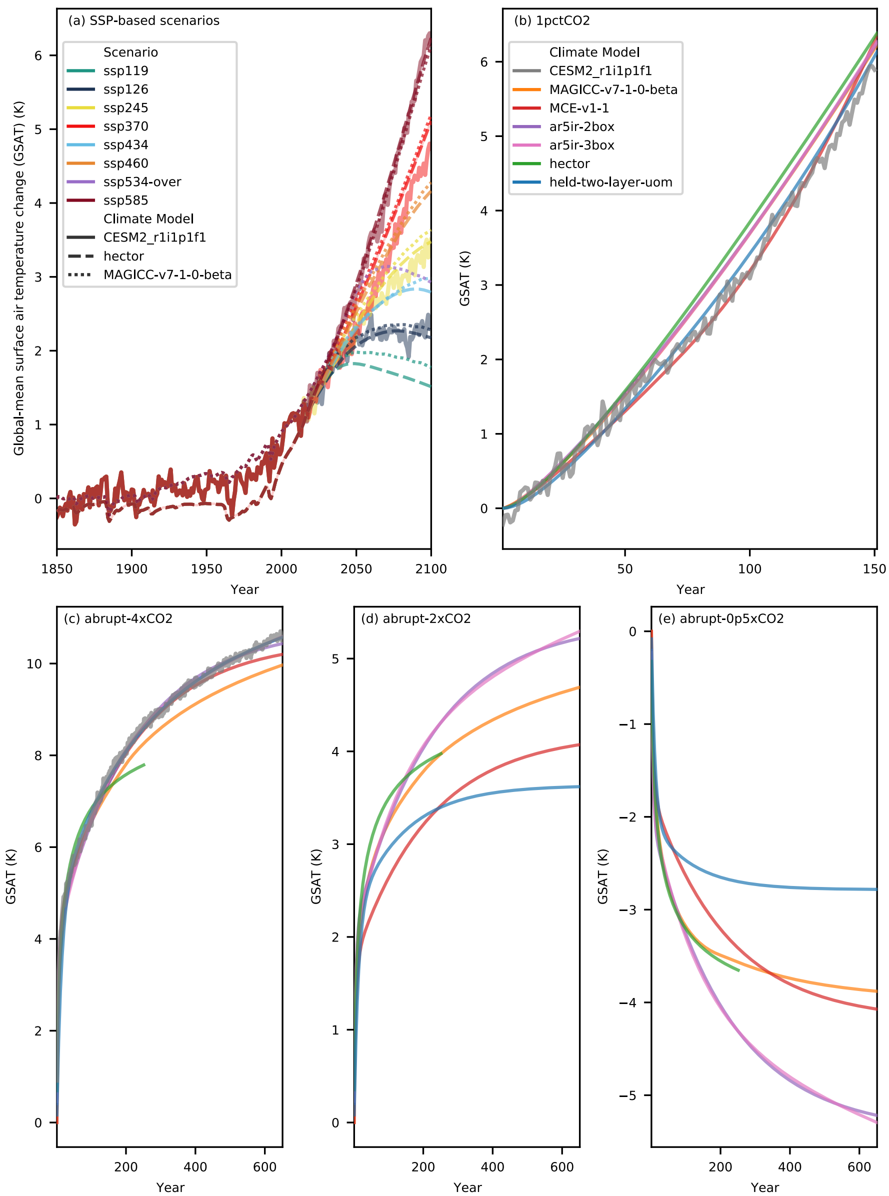

Figure S10. Emulation of CESM2_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from CESM2_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

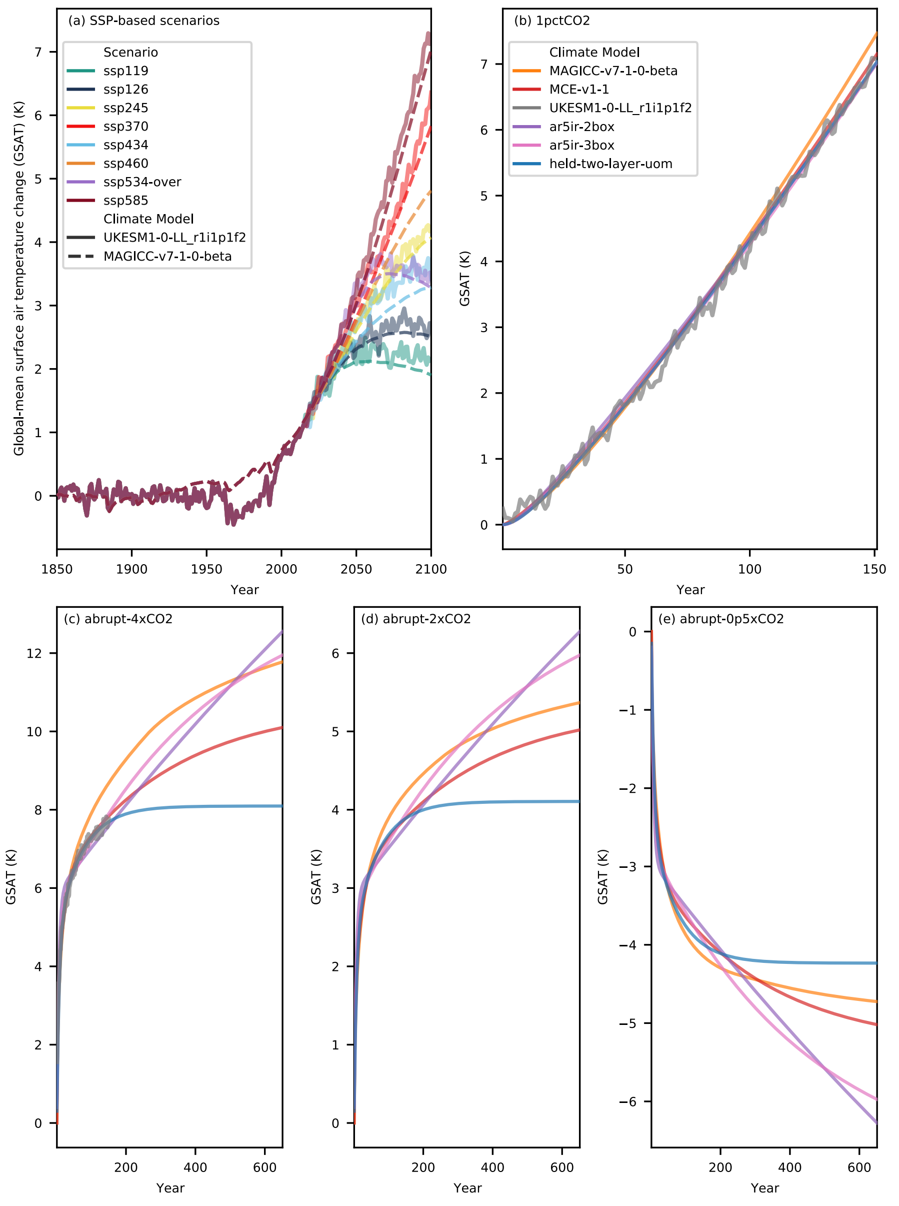

Figure S11. Emulation of UKESM1-0-LL_r1i1p1f2 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from UKESM1-0-LL_r1i1p1f2). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

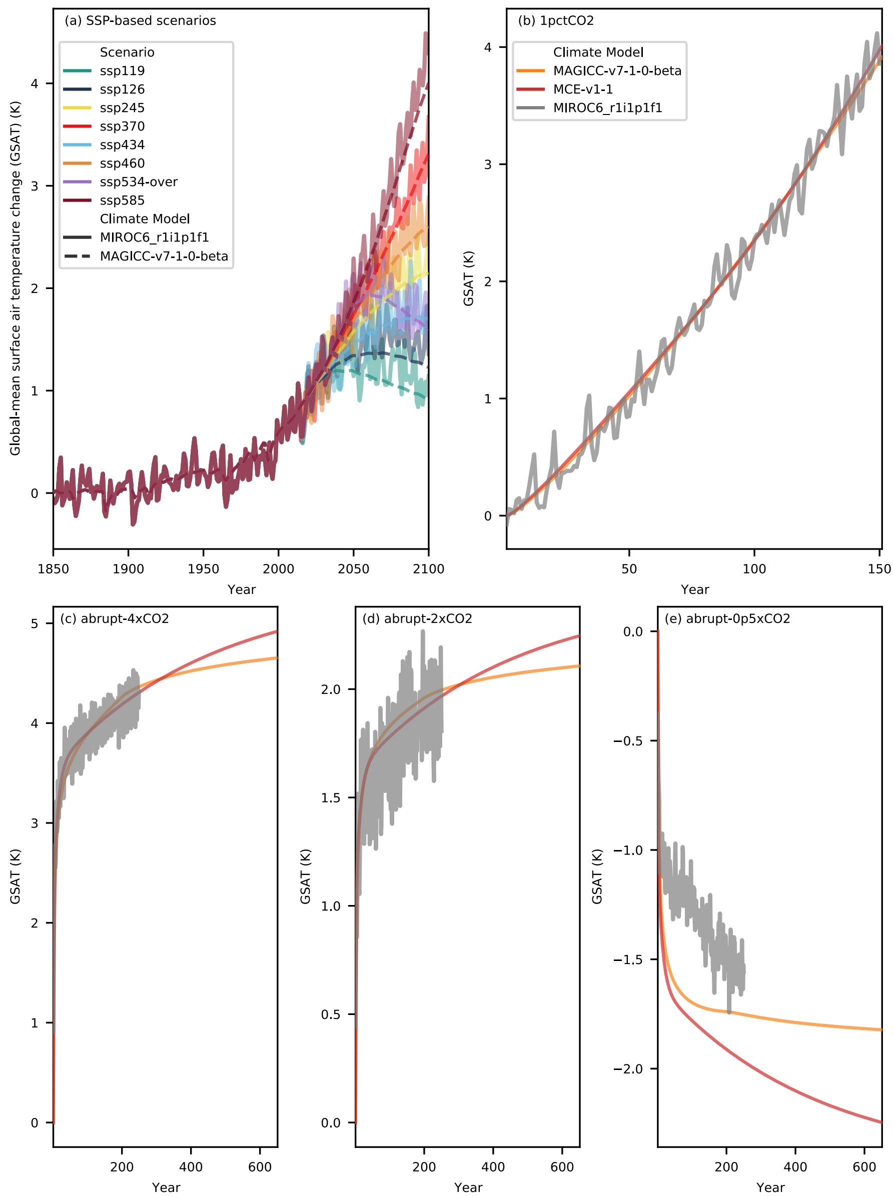

Figure S12. Emulation of MIROC6_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from MIROC6_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

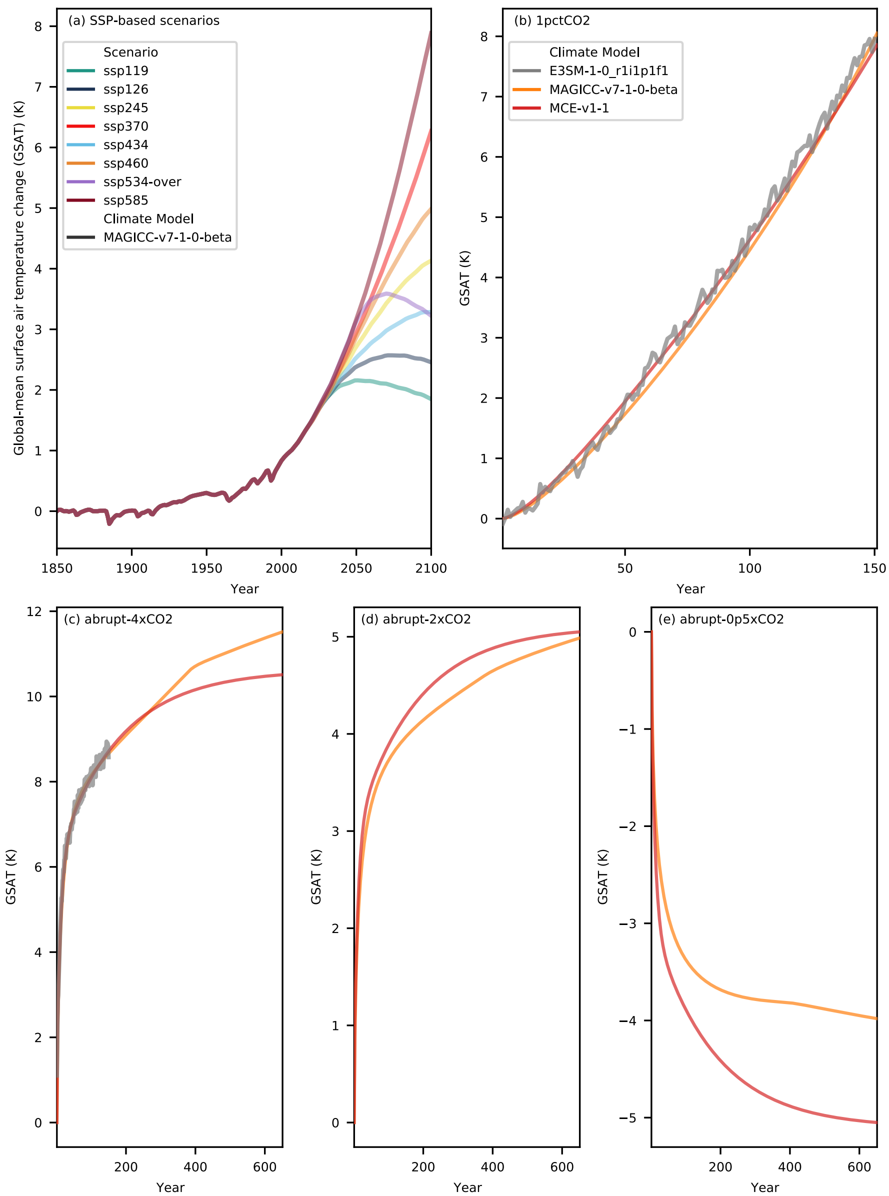

Figure S13. Emulation of E3SM-1-0_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from E3SM-1-0_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

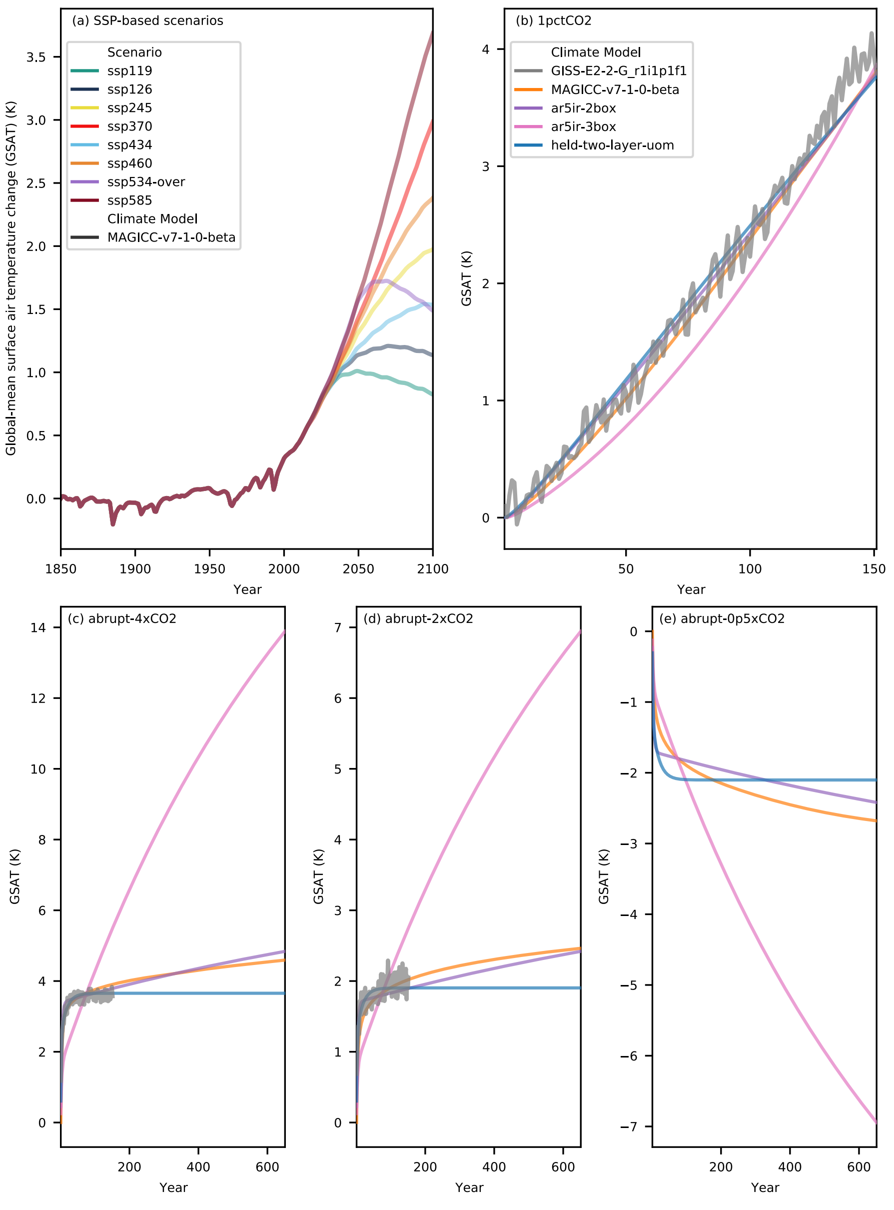

Figure S14. Emulation of GISS-E2-2-G_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from GISS-E2-2-G_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

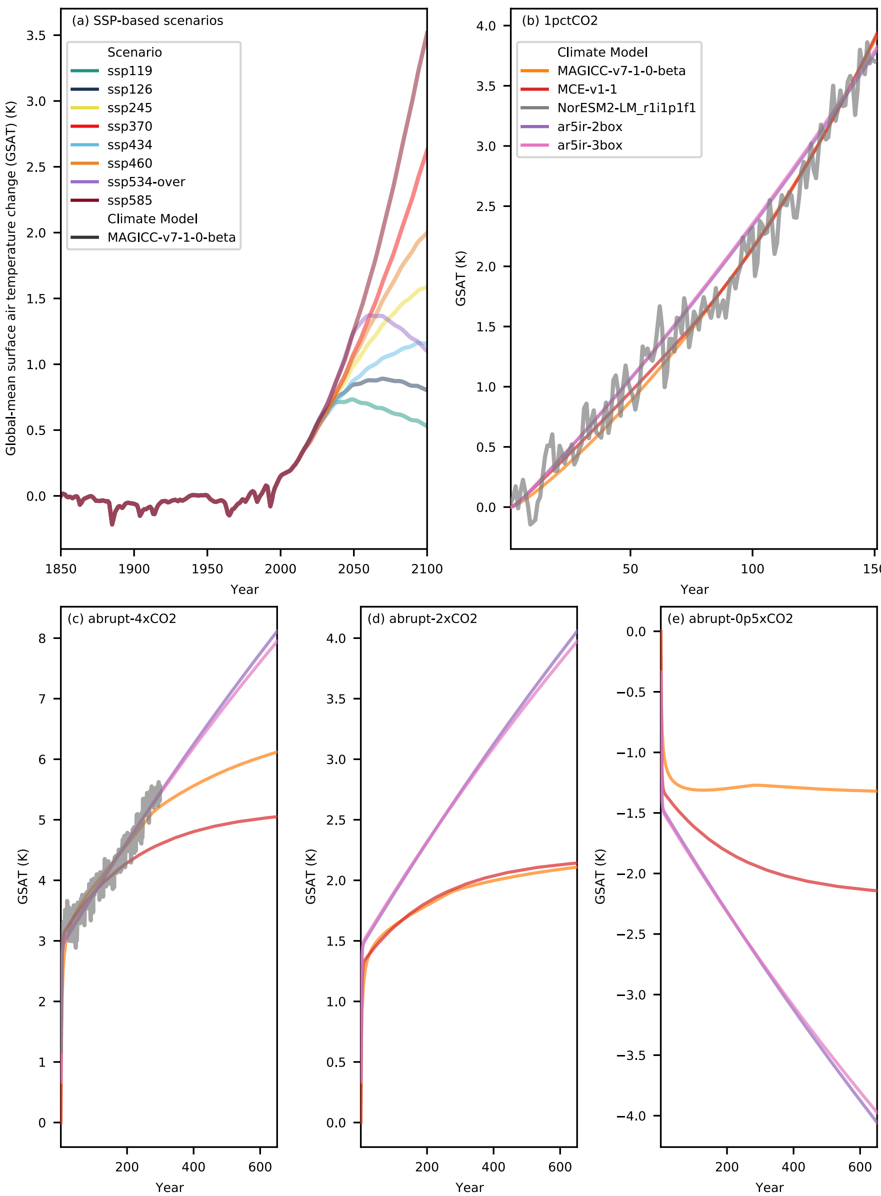

Figure S15. Emulation of NorESM2-LM_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from NorESM2-LM_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

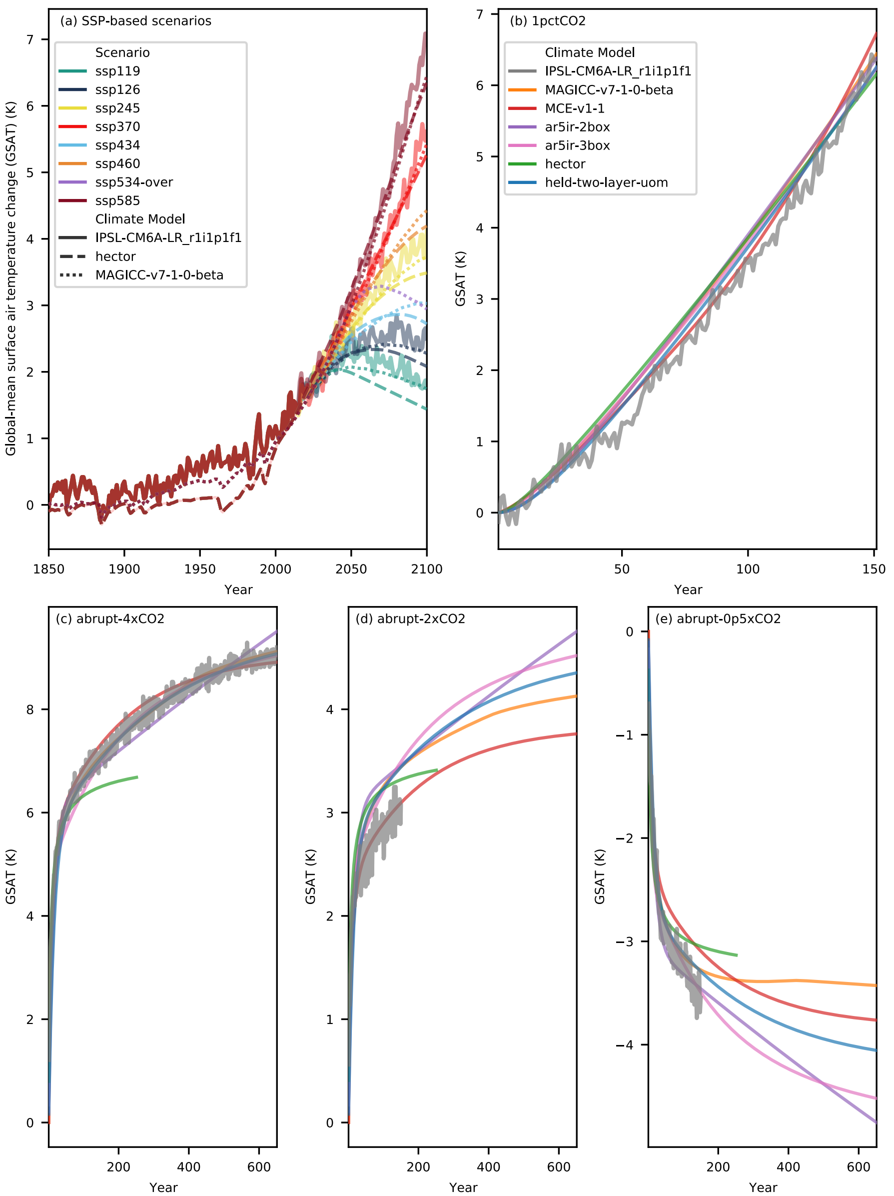

Figure S16. Emulation of IPSL-CM6A-LR_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from IPSL-CM6A-LR_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

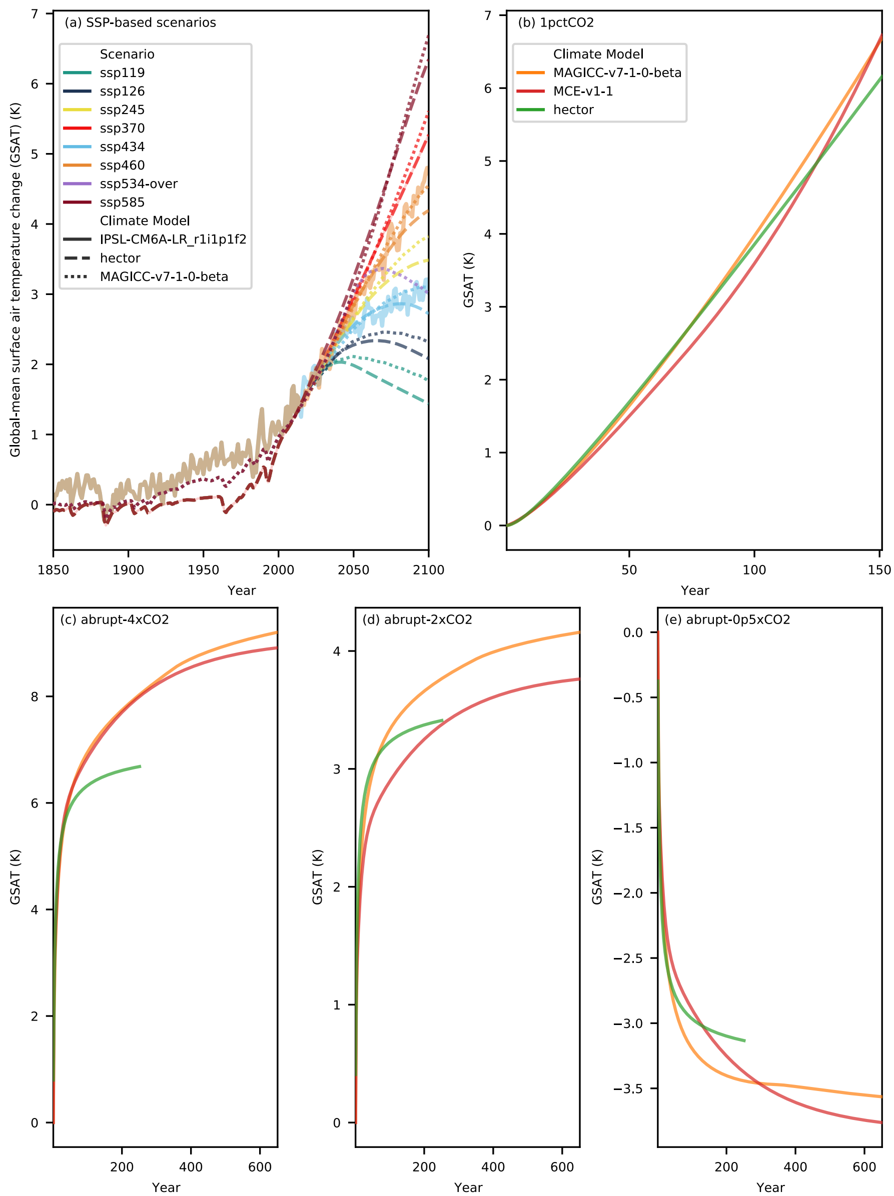

Figure S17. Emulation of IPSL-CM6A-LR_r1i1p1f2 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from IPSL-CM6A-LR_r1i1p1f2). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

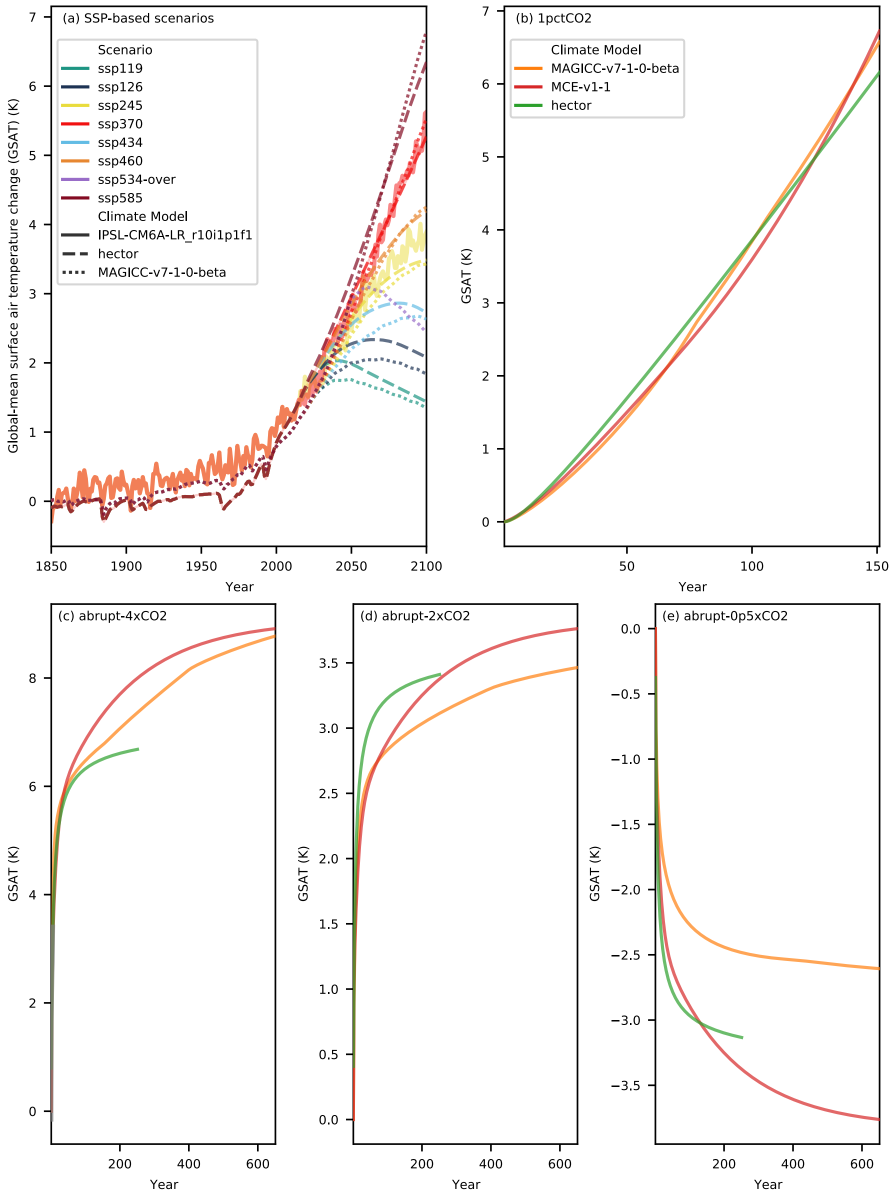

Figure S18. Emulation of IPSL-CM6A-LR_r10i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from IPSL-CM6A-LR_r10i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

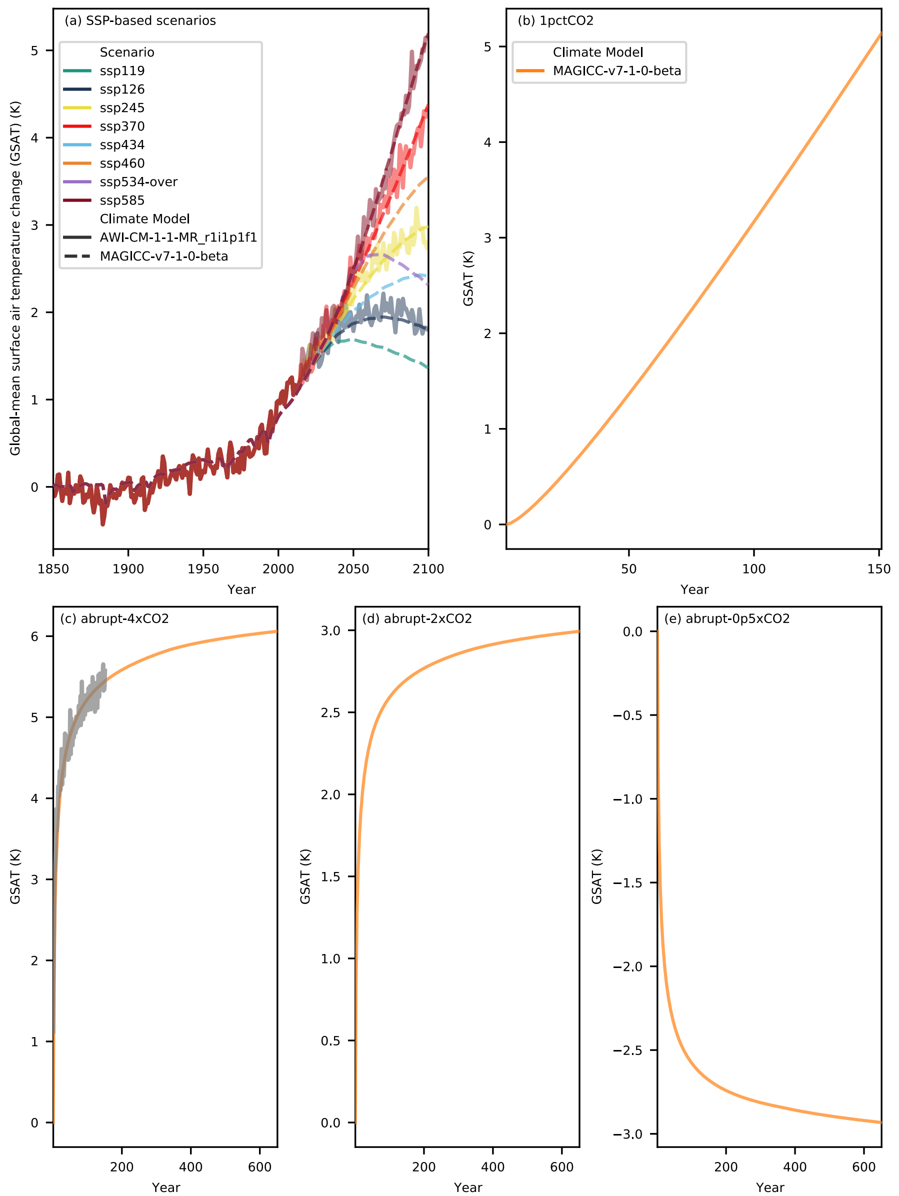

Figure S19. Emulation of AWI-CM-1-1-MR_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from AWI-CM-1-1-MR_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

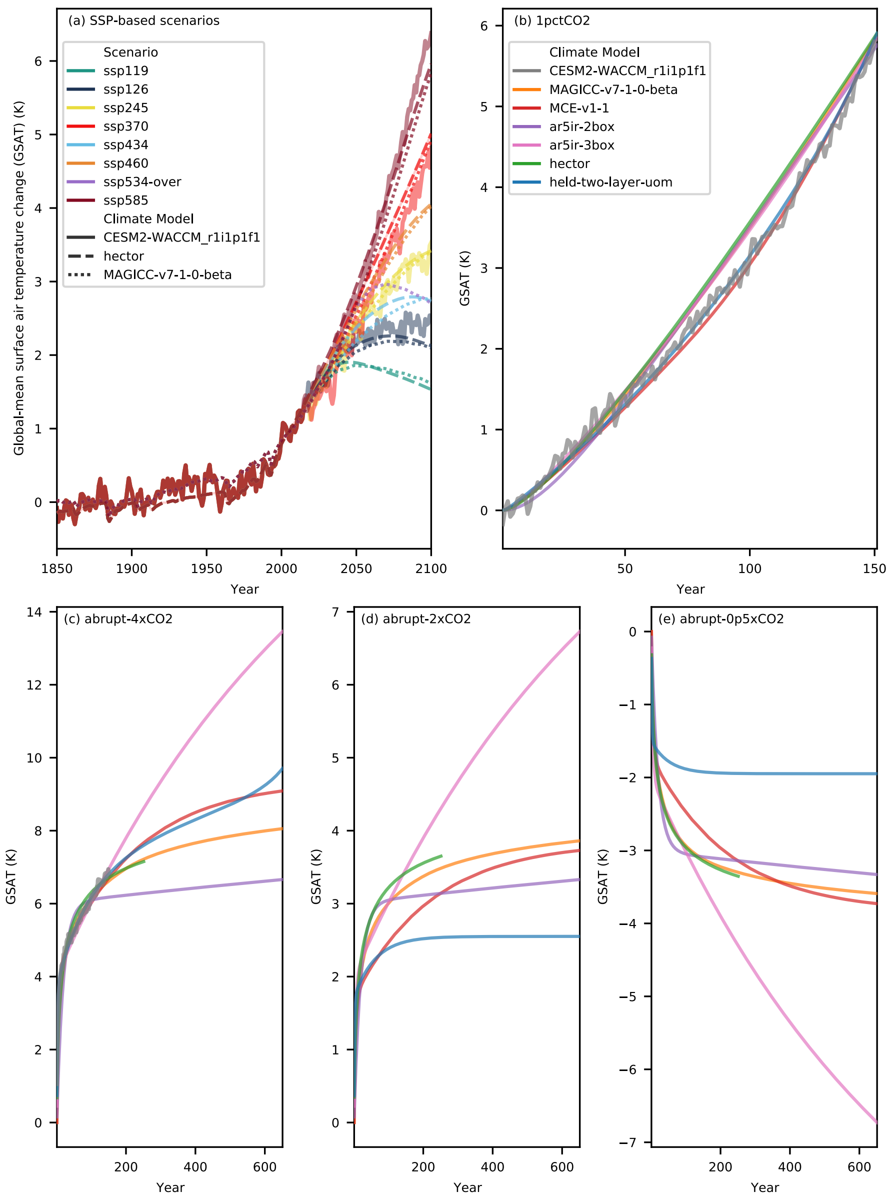

Figure S20. Emulation of CESM2-WACCM_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from CESM2-WACCM_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

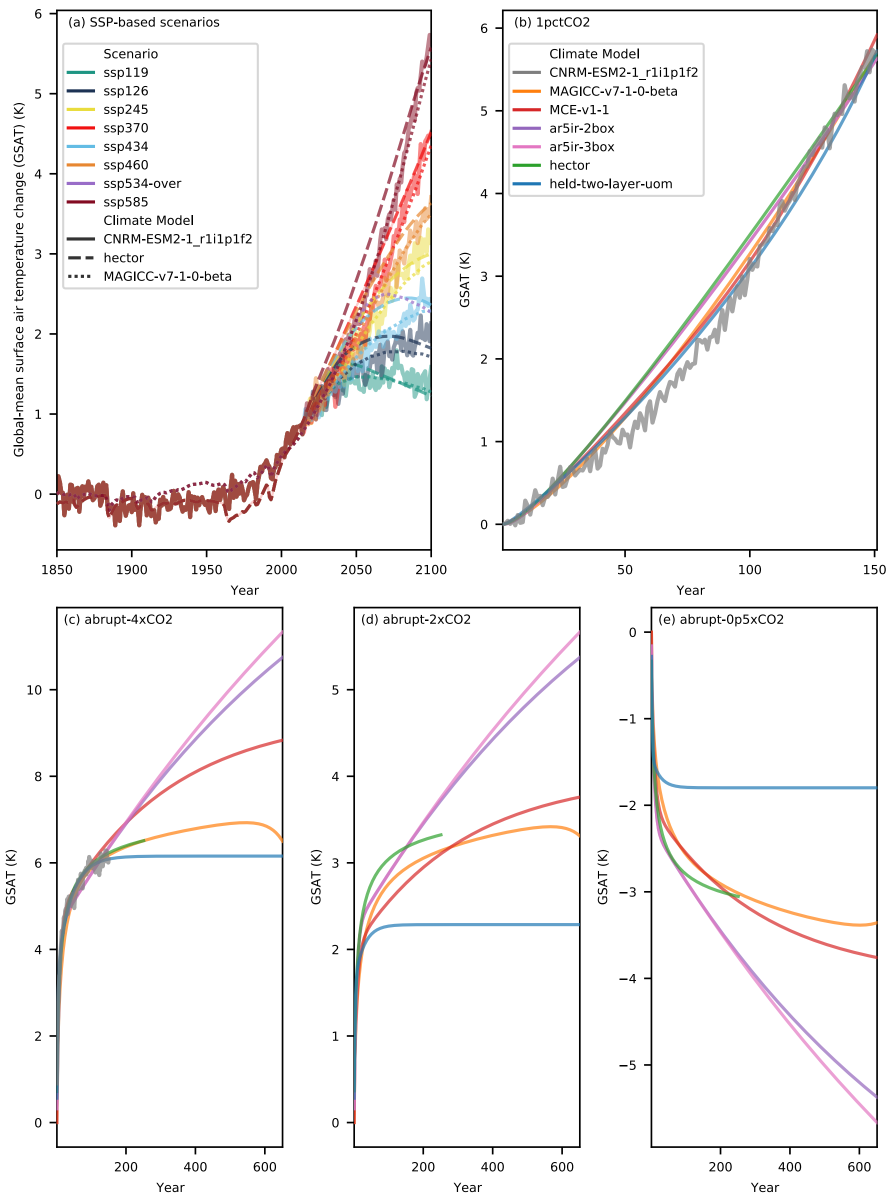

Figure S21. Emulation of CNRM-ESM2-1_r1i1p1f2 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from CNRM-ESM2-1_r1i1p1f2). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

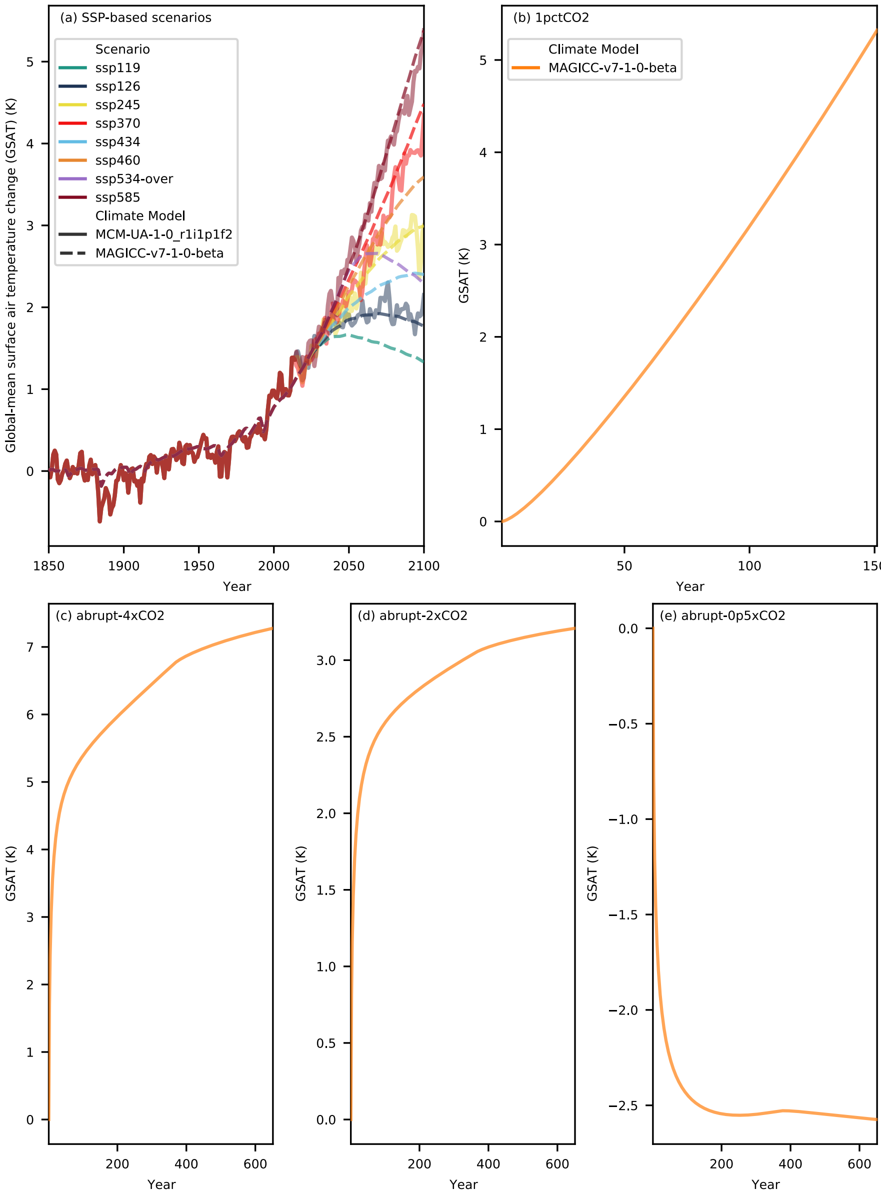

Figure S22. Emulation of MCM-UA-1-0_r1i1p1f2 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from MCM-UA-1-0_r1i1p1f2). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

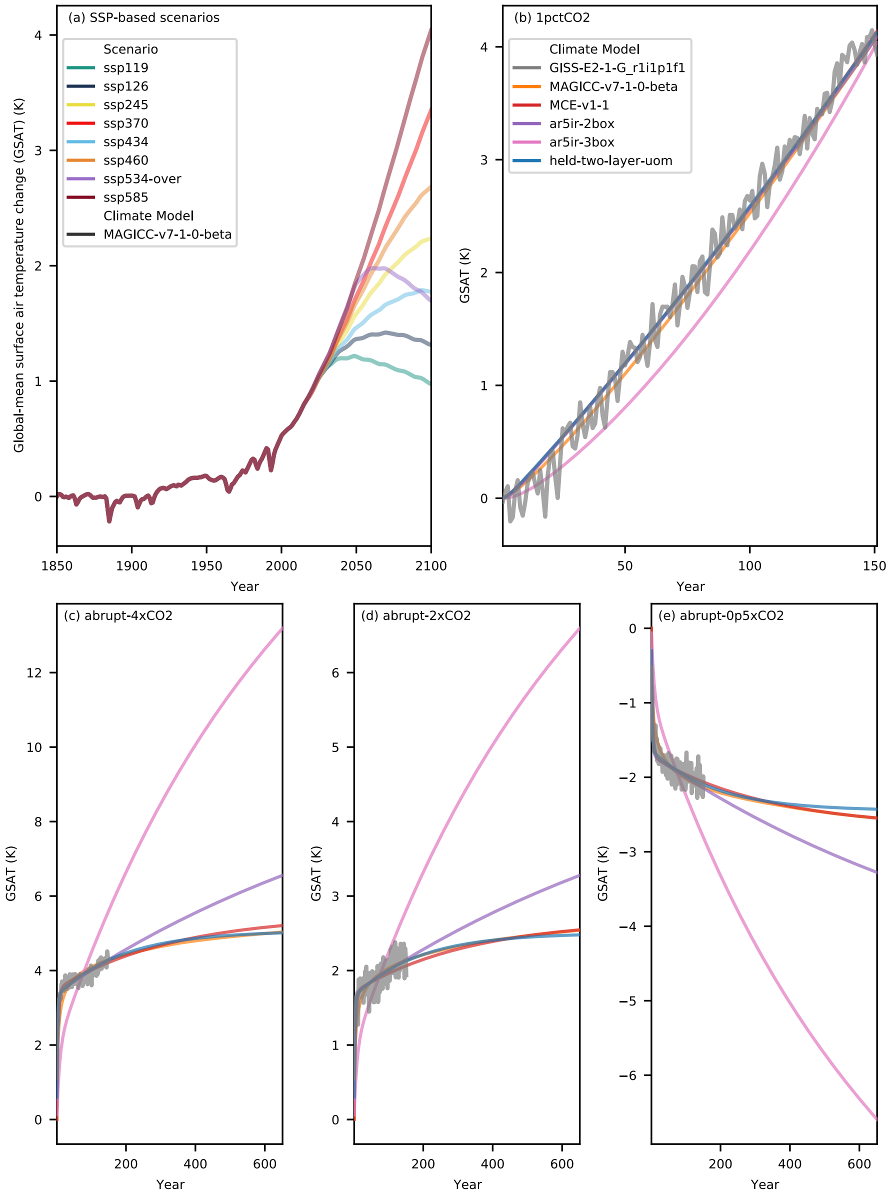

Figure S23. Emulation of GISS-E2-1-G_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from GISS-E2-1-G_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

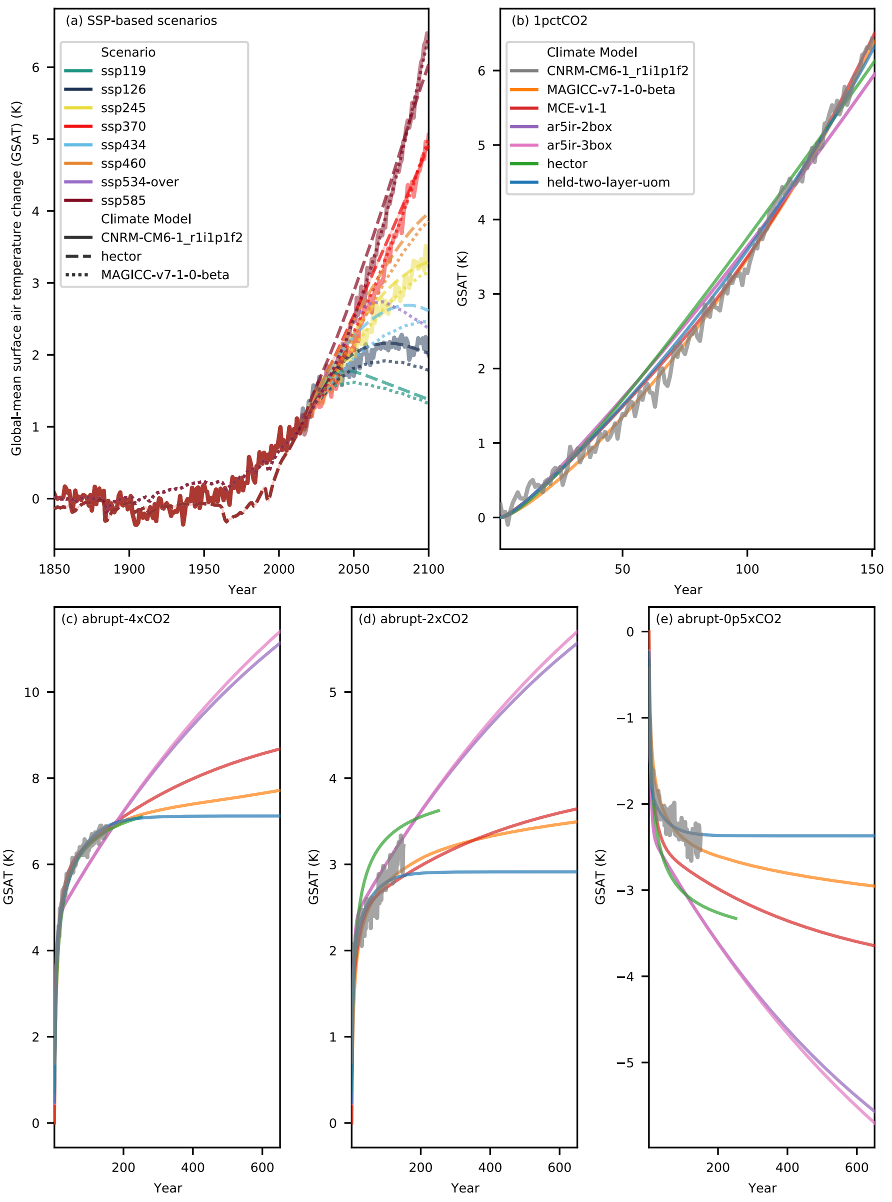

Figure S24. Emulation of CNRM-CM6-1_r1i1p1f2 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from CNRM-CM6-1_r1i1p1f2). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO_2-only experiments (note that panels (b) - (e) share the same legend).

Table S2. RCMIP Phase 1 variable overview (also available at rcmip.org).

Variable	**Unit**	**Definition**
Surface Air Temperature Change	K	Change in surface air tempertaure (i.e. 2m air temperature or best proxy thereof)
Effective Radiative Forcing	$W\,m^{-2}$	Effective radiative forcing from all anthropogenic and natural sources (after stratospheric temperature adjustments and rapid adjustments)
Effective Radiative Forcing|Anthropogenic|Aerosols	$W\,m^{-2}$	Effective radiative forcing from aerosols (after stratospheric temperature adjustments and rapid adjustments)
Effective Radiative Forcing|Anthropogenic|CO2	$W\,m^{-2}$	Effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of CO_2
Emissions|CO2	$MtCO_2\,yr^{-1}$	Total carbon dioxide emissions

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Overview of the physical components of the models participating in RCMIP Phase 1. **Model (acronym used in figures) Spatial resolution Key references**

ACC2 (ACC2-v4-2) Global land/ocean Tanaka and O'Neill (2018); Tanaka et al. (2007) (also Hooss et al. (2001); Bruckner et al. (2003)) AR5IR (ar5ir-2box, ar5ir-3box) Global Myhre et al. (2013) CICERO-SCM (CICERO-SCM) Hemispheric Skeie et al. (2017)

(also Schlesinger et al. (1992); Joos et al. (1996); Etminan et al. (2016); Skeie et al. (2018)) EMGC (EMGC) Global Canty et al. (2013); H ESCIMO (ESCIMO) Global Randers et al. (2016) FaIR (FaIR-v1-5) Global Smith et al. (2018a); Etminan et al. (2016) GIR (GIR) Global Leach et al. (2020) GREB (GREB-v1-0-1) 96 x 48 grid Dommenget et al. (2019) Hector (hectorl62381e71) Global Hartin et al. (2015); Dorheim et al. (Under Review at Earth and Space Science); Vega-Westhoff et al. (2019) (see also Kriegler (2005); Tar) Held et. al two layer model (held-two-layer-uom) Global Rohrschneider et al. (2019); Held et al. (2010) MAGICC (MAGICC-v7-1-0-beta Hemispheric land/ocean Meinshausen et al. (2011a, 2020) (see also von Deimling et al. (2012); Nauels et al. (2017)) MCE (MCE-v1-1) Global Tsutsui (2017, 2020) (see also Joos et al. (1996); Hooss et al. (2001)) OSCAR (OSCAR-v3-0) Global, with regionalized land carbon cycle Gasser et al. (2017) WASP (WASP-v2) Global Goodwin (2018); Goodwin et al. (2019) (see also Goodwin et al. (2014);)

Historical global-mean annual mean surface air temperature (GSAT) simulations. Thick black line is observed GSAT (Richardson et al., 2016; Rogelj et al., 2019). Medium thickness lines are illustrative configurations for RCMIP models. Thin grey solid lines are CMIP6 models. In order to provide timeseries up until 2019, we have used data from the combination of historical and ssp585 simulations for RCMIP and CMIP6 models and rcp85 data for CMIP5 models.

Probabilistic projections. Black line is observed GSAT (Richardson et al., 2016; Rogelj et al., 2019). Coloured lines are results for different RCMs for the SSP-based scenarios (ranges are 66% ranges). Note that not all groups have been able to perform all simulations.

Emulation of CMIP6 models by RCMs. The thick transparent lines are the target CMIP6 model output (here from IPSL-CM6A-LR r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend). See the Supplementary Information for other target CMIP6 models.

Model emulation scores over all emulated models and scenarios. Here we provide root-mean square errors over the SSPs plus four idealised CO2-only experiments (abrupt-2xCO2, abrupt-4xCO2, abrupt-0p5xCO2, 1pctCO2). As the models have not all provided emulations for the same set of models and scenarios, the model emulation scores are indicative only and are not a true, fair test of skill. For target model by target model emulation scores, see Table S1. **Model (number of emulated scenarios) Surface Air Temperature Change (GSAT aka tas) root-mean square error (indicative only)** MAGICC-v7-1-0-beta (131) 0.21 K MCE-v1-1 (44) 0.19 K ar5ir-2box (36) 0.24 K ar5ir-3box (36) 0.28 K hectorl1d51f (64) 0.28 K held-two-layer-uom (34) 0.18 K

Surface air temperature change against cumulative emissions in the 1pctCO2 and 1pctCO2-4xext experiments. Thin lines are used for the MCE model's family of emulation setups. Thick lines are used for the GIR (3 box) and OSCARv3.1 default setups (OSCARv3.1's probabilistic output is available but not shown).

Output from the RCPs and SSP-based scenarios up until 2100. The left-hand column shows raw model output. The right-hand column shows the difference between scenarios for a given model's output. The shaded range shows one standard deviation about the median (solid lines). Output is shown for surface air temperature change (GSAT, (a) and (b)), effective radiative forcing ((c) and (d)), effective radiative forcing ((e) and (f)) and aerosol effective radiative forcing ((g) and (h)). The results here are illustrative and provided only for those models which have done RCP, SSP-based scenario pairs.

Emulation scores and equilibrium climate sensitivities (ECSs) for RCMIP model calibrations. In parentheses we show the number of simulations available for each model variant.

RMSE (K) Target CMIP6 model RCMIP model

AWI-CM-1-1-MR_r1i1p1f1 (5) MAGICC-v7-1-0-beta (5) 0.16 BCC-CSM2-MR_r1i1p1f1 (6) MCE-v1-1 (2) 0.21 MAGICC-v7-1-0-bet (6) 0.16 ar5ir-2box (2) 0.13 ar5ir-3box (2) 0.13 held-two-layer-uom (2) 0.13 BCC-ESM1_r1i1p1f1 (4) MCE-v1-1 (2) 0.12 MAGICC-v7-1-0-beta (3) 0.13 ar5ir-2box (2) 0.18 ar5ir-3box (2) 0.15 held-two-layer-uom (2) 0.12 CanESM5_r1i1p1f1 (10) MCE-v1-1 (2) 0.13 hector|1d51f (9) 0.18 MAGICC-v7-1-0-beta (10) 0.30 ar5ir-2box (2) 0.19 ar5ir-3box (2) 0.21 held-two-layer-uom (2) 0.30 CanESM5_r1i1p2f1 (7) MCE-v1-1 (2) 0.13 hector|1d51f (7) 0.18 MAGICC-v7-1-0-beta (7) 0.27 CanESM5_r10i1p1f1 (5) hector|1d51f (5) 0.22 MAGICC-v7-1-0-beta (5) 0.18 CESM2-WACCM_r1i1p1f1 (6) MCE-v1-1 (2) 0.15 hector|1d51f (6) 0.22 MAGICC-v7-1-0-beta (6) 0.21 ar5ir-2box (2) 0.45 ar5ir-3box (2) 0.21 held-two-layer-uom (2) 0.13

Continued.

RMSE (K) Target CMIP6 model RCMIP model

CESM2_r1i1p1f1 (6) MCE-v1-1 (2) 0.17 hector|1d51f (6) 0.32 MAGICC-v7-1-0-beta (6) 0.27 ar5ir-2box (2) 0.24 ar5ir-3box (2) 0.24 held-two-layer-uom (2) 0.20 CNRM-CM6-1_r1i1p1f2 (8) MCE-v1-1 (4) 0.24 hector|1d51f (8) 0.34 MAGICC-v7-1-0-beta (8) 0.18 ar5ir-2box (4) 0.43 ar5ir-3box (4) 0.43 held-two-layer-uom (4) 0.16 CNRM-ESM2-1_r1i1p1f2 (10) MCE-v1-1 (2) 0.20 hector|1d51f (9) 0.24 MAGICC-v7-1-0-beta (9) 0.18 ar5ir-3box (2) 0.27 ar5ir-2box (2) 0.27 held-two-layer-uom (2) 0.17 E3SM-1-0_r1i1p1f1 (2) MCE-v1-1 (2) 0.17 MAGICC-v7-1-0-beta (2) 0.22 EC-Earth3-Veg_r1i1p1f1 (7) MCE-v1-1 (2) 0.19 MAGICC-v7-1-0-beta (7) 0.25 ar5ir-3box (2) 0.22 ar5ir-2box (2) 0.27 held-two-layer-uom (2) 0.19

Continued.

RMSE (K) Target CMIP6 model RCMIP model

FGOALS-g3_r1i1p1f1 (4) MAGICC-v7-1-0-beta (4) 0.15 GISS-E2-1-G_r1i1p1f1 (4) MCE-v1-1 (4) 0.16 MAGICC-v7-1-0-beta (4) 0.19 ar5ir-2box (4) 0.15 ar5ir-3box (4) 0.58 held-two-layer-uom (4) 0.15 GISS-E2-1-H_r1i1p1f1 (3) MCE-v1-1 (3) 0.15 MAGICC-v7-1-0-beta (3) 0.16 ar5ir-3box (3) 0.15 ar5ir-2box (3) 0.16 held-two-layer-uom (3) 0.14 GISS-E2-2-G_r1i1p1f1 (3) MAGICC-v7-1-0-beta (3) 0.19 ar5ir-3box (3) 0.66 ar5ir-2box (3) 0.16 held-two-layer-uom (3) 0.14 IPSL-CM6A-LR_r1i1p1f1 (20) MCE-v1-1 (4) 0.25 hector|1d51f (9) 0.40 MAGICC-v7-1-0-beta (9) 0.25 ar5ir-2box (4) 0.34 ar5ir-3box (4) 0.26 held-two-layer-uom (4) 0.29 IPSL-CM6A-LR_r1i1p1f2 (2) hector|1d51f (2) 0.34 MAGICC-v7-1-0-beta (2) 0.21 IPSL-CM6A-LR_r10i1p1f1 (3) MCE-v1-1 (1) 0.21 hector|1d51f (3) 0.34 MAGICC-v7-1-0-beta (3) 0.32 MCM-UA-1-0_r1i1p1f2 (4) MAGICC-v7-1-0-beta (4) 0.16

Continued.

RMSE (K) Target CMIP6 model RCMIP model

MIROC6_r1i1p1f1 (14) MCE-v1-1 (4) 0.28 MAGICC-v7-1-0-beta (12) 0.19 NorESM2-LM_r1i1p1f1 (3) MCE-v1-1 (2) 0.32 MAGICC-v7-1-0-beta (2) 0.22 ar5ir-3box (2) 0.19 ar5ir-2box (2) 0.19 SAM0-UNICON_r1i1p1f1 (2) MCE-v1-1 (2) 0.15 MAGICC-v7-1-0-beta (2) 0.24 UKESM1-0-LL_r1i1p1f2 (9) MCE-v1-1 (2) 0.16 MAGICC-v7-1-0-beta (9) 0.30 ar5ir-3box (2) 0.19 ar5ir-2box (2) 0.26 held-two-layer-uom (2) 0.19

~~Emulation of CanESM5_r1i1p2f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from CanESM5_r1i1p2f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).~~

~~Emulation of BCC-ESM1_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from BCC-ESM1_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).~~

~~Emulation of CanESM5_r10i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from CanESM5_r10i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).~~

~~Emulation of FGOALS-g3_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from FGOALS-g3_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).~~

~~Emulation of BCC-CSM2-MR_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from BCC-CSM2-MR_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).~~

~~Emulation of SAM0-UNICON_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from SAM0-UNICON_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).~~

~~Emulation of EC-Earth3-Veg_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from EC-Earth3-Veg_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).~~

~~Emulation of CanESM5_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from CanESM5_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).~~

~~Emulation of GISS-E2-1-H_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from GISS-E2-1-H_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for~~

scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).

Emulation of CESM2_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from CESM2_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).

Emulation of UKESM1-0-LL_r1i1p1f2 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from UKESM1-0-LL_r1i1p1f2). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).

Emulation of MIROC6_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from MIROC6_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).

Emulation of E3SM-1-0_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from E3SM-1-0_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).

Emulation of GISS-E2-2-G_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from GISS-E2-2-G_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).

Emulation of NorESM2-LM_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from NorESM2-LM_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).

Emulation of IPSL-CM6A-LR_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from IPSL-CM6A-LR_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).

Emulation of IPSL-CM6A-LR_r1i1p1f2 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from IPSL-CM6A-LR_r1i1p1f2). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).

Emulation of IPSL-CM6A-LR_r10i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from IPSL-CM6A-LR_r10i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).

Emulation of AWI-CM-1-1-MR_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from AWI-CM-1-1-MR_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).

Emulation of CESM2-WACCM_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from CESM2-WACCM_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).

Emulation of CNRM-ESM2-1_r1i1p1f2 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from CNRM-ESM2-1_r1i1p1f2). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).

Emulation of MCM-UA-1-0_r1i1p1f2 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from MCM-UA-1-0_r1i1p1f2). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).

Emulation of GISS-E2-1-G_r1i1p1f1 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from GISS-E2-1-G_r1i1p1f1). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).

Emulation of CNRM-CM6-1_r1i1p1f2 by RCMs in RCMIP Phase 1. The thick transparent lines are the target CMIP6 model output (here from CNRM-CM6-1_r1i1p1f2). The thin lines are emulations from different RCMs. Panel (a) shows results for scenario based experiments while panels (b) - (e) show results for idealised CO2-only experiments (note that panels (b) - (e) share the same legend).

RCMIP Phase 1 region overview (also available at). The 'Category' column provides a name for different regional splits. 'Region' is the name used throughout RCMIP. 'Definition' describes the components of that region, with precise country by country definitions available from .

Category Region Definition All World Global coverage R5.2 World|R5.2ASIA Most Asian countries with the exception of the Middle East, Japan and Former Soviet Union States R5.2 World|R5.2LAM Latin America and the Caribbean R5.2 World|R5.2MAF Middle East and Africa R5.2 World|R5.2REF Reforming economies of Eastern Europe and the Former Soviet

Union R5.2 World|R5.2OECD OECD90 and EU member states and candidates Hemispheric World|Northern Hemisphere Northern hemisphere Hemispheric World|Southern Hemisphere Southern hemisphere

RCMIP Phase 1 experiment overview (also available at). In the ‘drivers’ column, the acronyms show the inputs which are provided to the models in order to perform the run. CC: concentrations; CO: non-WMGHG concentrations; EC: emissions; EO: non-WMGHG emissions; A: aerosol emissions; S: solar effective radiative forcing; V: volcanic effective radiative forcing. ESDOC refers to the Earth System Documentation service (). **ID Drivers Summary Further information Tier** piControl CC, CO, A, S, V Pre-industrial control simulation. ESDOC 1 esm-piControl EC, CO, A, S, V Pre-industrial control simulation with zero anthropogenic perturbation to CO2 emissions. ESDOC 1 esm-piControl-allGHG EC, EO, A, S, V Pre-industrial control simulation with zero anthropogenic perturbation to GHG emissions. RCMIP specific experiment 2 1pctCO2 CC 1 % per year increase in atmospheric CO2 concentrations. ESDOC 1 1pctCO2-4xext CC 1 % per year increase in atmospheric CO2 concentrations until atmospheric CO2 concentrations quadruple, constant CO2 concentrations thereafter. ESDOC 1 1pctCO2-cdr CC 1 % per year increase in atmospheric CO2 concentrations until atmospheric CO2 concentrations quadruple and then 1% per year decrease in atmospheric CO2 concentrations until CO2 returns to pre-industrial levels, constant thereafter. ESDOC 2 abrupt-4xCO2 CC Abrupt quadrupling of atmospheric CO2 concentrations. ESDOC 1 abrupt-2xCO2 CC Abrupt doubling of atmospheric CO2 concentrations. ESDOC 1 abrupt-0p5xCO2 CC Abrupt halving of atmospheric CO2 concentrations. ESDOC 1 esm-pi-cdr-pulse EC Removal of 100 GtC in a single year from pre-industrial atmosphere, zero CO2 emissions thereafter. ESDOC 2

Continued. **ID Drivers Summary Further information Tier** esm-pi-CO2pulse EC Addition of 100 GtC in a single year from pre-industrial atmosphere, zero CO2 emissions thereafter. ESDOC 2 esm-bell-1000PgC EC Cumulative addition of 1000 PgC following a bell-curved shaped emissions timeseries. ESDOC 3 esm-bell-2000PgC EC Cumulative addition of 2000 PgC following a bell-curved shaped emissions timeseries. ESDOC 3 esm-bell-750PgC EC Cumulative addition of 750 PgC following a bell-curved shaped emissions timeseries. ESDOC 3 historical CC, CO, A, S, V Simulation of 1850-2014. ESDOC 1 historical-cmip5 CC, CO, A, S, V Simulation of 1850-2004, matching forcings as estimated in CMIP5. 2 hist-aer A Simulation of 1850-2014 with aerosol emissions only. ESDOC 3 hist-CO2 CC Simulation of 1850-2014 with changing CO2 concentrations only. ESDOC 3 hist-GHG CC, CO Simulation of 1850-2014 with changing GHG concentrations only. ESDOC 3 hist-nat S, V Simulation of 1850-2014 with changing natural forcings only. ESDOC 3 hist-sol S Simulation of 1850-2014 with changing solar forcing only. ESDOC 3 hist-volc V Simulation of 1850-2014 with changing volcanic forcing only. ESDOC 3 ssp119 CC, CO, A, S, V Low-end scenario reaching radiative forcing ∼1.9 in 2100 (using the SSP1 socioeconomic storyline). ESDOC 1 esm-ssp119 EC, CO, A, S, V As above except CO2 emissions driven. ESDOC 1 esm-ssp119-allGHG EC, EO, A, S, V As above except all GHG emissions driven. ESDOC 2

Continued. **ID Drivers Summary Further information Tier** ssp126 CC, CO, A, S, V Update of RCP2.6 based on the SSP1 socioeconomic storyline. ESDOC 2 esm-ssp126 EC, CO, A, S, V As above except CO2 emissions driven. ESDOC 3 esm-ssp126-allGHG EC, EO, A, S, V As above except all GHG emissions driven. ESDOC 3 ssp245 CC, CO, A, S, V Update of RCP4.5 based on the SSP2 socioeconomic storyline. ESDOC 2 esm-ssp245 EC, CO, A, S, V As above except CO2 emissions driven. ESDOC 3 esm-ssp245-allGHG EC, EO, A, S, V As above except all GHG emissions driven. ESDOC 3 ssp370 CC, CO, A, S, V Gap-filling scenario reaching radiative forcing ~7.0 in 2100 (using the SSP3 socioeconomic storyline). ESDOC 2 esm-ssp370 EC, CO, A, S, V As above except CO2 emissions driven. ESDOC 3 esm-ssp370-allGHG EC, EO, A, S, V As above except all GHG emissions driven. ESDOC 3 ssp370-lowNTCF CC, CO, A, S, V Gap-filling scenario reaching radiative forcing ~7.0 in 2100 with low near-term climate forcers (using the SSP3 socioeconomic storyline). ESDOC 2 esm-ssp370-lowNTCF EC, CO, A, S, V As above except CO2 emissions driven. ESDOC 3 esm-ssp370-lowNTCF-allGHG EC, EO, A, S, V As above except all GHG emissions driven. ESDOC 3 ssp370-lowNTCF-gidden CC, CO, A, S, V Comparison scenario, follows the ssp370-lowNTCF quantification presented in Gidden et al. (2019). RCMIP specific 3

Continued. **ID Drivers Summary Further information Tier** esm-ssp370-lowNTCF-gidden EC, CO, A, S, V As above except CO2 emissions driven. RCMIP specific 3 esm-ssp370-lowNTCF-gidden-allGHG EC, EO, A, S, V As above except all GHG emissions driven. RCMIP specific 3 ssp434 CC, CO, A, S, V Gap-filling scenario reaching radiative forcing ~3.4 in 2100 with low near-term climate forcers (using the SSP4 socioeconomic storyline). ESDOC 2 esm-ssp434 EC, CO, A, S, V As above except CO2 emissions driven. ESDOC 3 esm-ssp434-allGHG EC, EO, A, S, V As above except all GHG emissions driven. ESDOC 3 ssp460 CC, CO, A, S, V Update of RCP6.0 based on the SSP4 socioeconomic storyline. ESDOC 2 esm-ssp460 EC, CO, A, S, V As above except CO2 emissions driven. ESDOC 3 esm-ssp460-allGHG EC, EO, A, S, V As above except all GHG emissions driven. ESDOC 3 ssp534-over CC, CO, A, S, V Overshoot scenario reaching radiative forcing ~3.4 in 2100 having followed the ssp585 pathway until 2030 (using the SSP5 socioeconomic storyline). ESDOC 2 esm-ssp534-over EC, CO, A, S, V As above except CO2 emissions driven. ESDOC 3 esm-ssp534-over-allGHG EC, EO, A, S, V As above except all GHG emissions driven. ESDOC 3 ssp585 CC, CO, A, S, V Update of RCP8.5 based on the SSP5 socioeconomic storyline. ESDOC 1 esm-ssp585 EC, CO, A, S, V As above except CO2 emissions driven. ESDOC 1

Continued. **ID Drivers Summary Further information Tier** esm-ssp585-allGHG EC, EO, A, S, V As above except all GHG emissions driven. ESDOC 2 rcp26 CC, CO, A, S, V RCP2.6 (from CMIP5). 3 esm-rcp26 EC, CO, A, S, V As above except CO2 emissions driven. 3 esm-rcp26-allGHG EC, EO, A, S, V As above except all GHG emissions driven. 3 rcp45 CC, CO, A, S, V RCP4.5 (from CMIP5). 3 esm-rcp45 EC, CO, A, S, V As above except CO2 emissions driven. 3 esm-rcp45-allGHG EC, EO, A, S, V As above except all GHG emissions driven. 3 rcp60 CC, CO, A, S, V RCP6.0 (from CMIP5). 3 esm-rcp60 EC, CO, A, S, V As above except CO2 emissions driven. 3 esm-rcp60-allGHG EC, EO, A, S, V As above except all GHG emissions driven. 3 rcp85 CC, CO, A, S, V RCP8.5 (from CMIP5). 3 esm-rcp85 EC, CO, A, S, V As above except CO2 emissions driven. 3 esm-rcp85-allGHG EC, EO, A, S, V As above except all GHG emissions driven. 3

RCMIP Phase 1 variable overview (also available at). **Category Variable Unit Definition Tier** Atmospheric Concentrations Atmospheric Concentrations|CH4 atmospheric concentrations of 1 Atmospheric Concentrations Atmospheric Concentrations|CO2 atmospheric concentrations of 1 Atmospheric Concentrations Atmospheric Concentrations|F-Gases equivalent species atmospheric concentrations of F-gases, expressed as -equivalent 3 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|HFC equivalent species atmospheric concentrations of hydrofluorocarbons (HFCs and HCFCs), provided as aggregate -equivalent 3 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|HFC|HFC125 atmospheric concentrations of HFC125 2 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|HFC|HFC134a atmospheric concentrations of HFC134a 2 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|HFC|HFC143a atmospheric concentrations of HFC143a 2

Atmospheric Concentrations Atmospheric Concentrations|F-Gases|HFC|HFC152a atmospheric concentrations of HFC152a 2 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|HFC|HFC227ea atmospheric concentrations of HFC227ea 2 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|HFC|HFC23 atmospheric concentrations of HFC23 2 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|HFC|HFC236fa atmospheric concentrations of HFC236fa 2

Continued. **Category Variable Unit Definition Tier** Atmospheric Concentrations Atmospheric Concentrations|F-Gases|HFC|HFC245fa atmospheric concentrations of HFC245fa 2 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|HFC|HFC32 atmospheric concentrations of HFC32 2 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|HFC|HFC365mfc atmospheric concentrations of HFC365mfc 2 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|HFC|HFC4310mee atmospheric concentrations of HFC43-10mee 2 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|NF3 atmospheric concentrations of nitrogen trifluoride () 2 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|PFC equivalent species atmospheric concentrations of perfluorocarbons (PFCs, as defined by Table 8.A.1 of AR5), provided as aggregate -equivalents 3 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|PFC|C2F6 atmospheric concentrations of 2 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|PFC|C3F8 atmospheric concentrations of 2 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|PFC|C4F10 atmospheric concentrations of 2 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|PFC|C5F12 atmospheric concentrations of 2 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|PFC|C6F14 atmospheric concentrations of 2

Continued. **Category Variable Unit Definition Tier** Atmospheric Concentrations Atmospheric Concentrations|F-Gases|PFC|C7F16 atmospheric concentrations of 2 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|PFC|C8F18 atmospheric concentrations of 2 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|PFC|cC4F8 atmospheric concentrations of 2 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|PFC|CF4 atmospheric concentrations of 2 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|SF6 atmospheric concentrations of sulfur hexafluoride () 2 Atmospheric Concentrations Atmospheric Concentrations|F-Gases|SO2F2 atmospheric concentrations of sulfuryl fluoride () 2 Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases equivalent species atmospheric concentrations of Montreal gases, expressed as equivalent 3 Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases|CCl4 atmospheric concentrations of 2 Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases|CFC atmospheric concentrations of CFC gases, expressed as equivalent 3 Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases|CFC|CFC11 atmospheric concentrations of CFC11 2 Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases|CFC|CFC113 atmospheric concentrations of CFC113 2

Continued. **Category Variable Unit Definition Tier** Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases|CFC|CFC114 atmospheric concentrations of CFC114 2 Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases|CFC|CFC115 atmospheric concentrations of CFC115 2 Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases|CFC|CFC12 atmospheric concentrations of CFC12 2 Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases|CH2Cl2 atmospheric concentrations of 2 Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases|CH3Br atmospheric concentrations of 2 Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases|CH3CCl3 atmospheric concentrations of 2 Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases|CH3Cl atmospheric concentrations of 2 Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases|CHCl3 atmospheric concentrations of 2 Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases|Halon1202 atmospheric concentrations of Halon-1202 2 Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases|Halon1211 atmospheric concentrations of Halon-1211 2

Continued. **Category Variable Unit Definition Tier** Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases|Halon1301 atmospheric concentrations of Halon-1301 2 Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases|Halon2402 atmospheric concentrations of Halon-2402 2 Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases|HCFC141b atmospheric concentrations of HCFC141b 2 Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases|HCFC142b atmospheric concentrations of HCFC22 2 Atmospheric Concentrations Atmospheric Concentrations|Montreal Gases|HCFC22 atmospheric concentrations of HCFC22 2 Atmospheric Concentrations Atmospheric Concentrations|N2O atmospheric concentrations of 2 Carbon Cycle Net Land to Atmosphere Flux|CH4 net flux of from the land to the atmosphere (not including AFOLU and other anthropogenic emissions). A positive value indicates release of from the land, a negative value indicates a net land uptake. 2 Carbon Cycle Net Land to Atmosphere Flux|CH4|Earth System Feedbacks net flux of from the land to the atmosphere (not including AFOLU and other anthropogenic emissions) due to Earth System Feedbacks. A positive value indicates release of from the land, a negative value indicates a net land uptake. 2 Carbon Cycle Net Land to Atmosphere Flux|CH4|Earth System Feedbacks|Other net flux of from the land to the atmosphere (not including AFOLU and other anthropogenic emissions) due to non-permafrost feedbacks. A positive value indicates release of from the land, a negative value indicates a net land uptake. 2

Continued. **Category Variable Unit Definition Tier** Carbon Cycle Net Land to Atmosphere Flux|CH4|Earth System Feedbacks|Permafro net flux of from the land to the atmosphere (not including AFOLU and other anthropogenic emissions) due to the permafrost feedback. A positive value indicates release of from the land, a negative value indicates a net land uptake. 2 Carbon Cycle Net Land to Atmosphere Flux|CO2 net flux of from the land to the atmosphere (not including AFOLU and other anthropogenic emissions). A positive value indicates release of from the land, a negative value indicates a net land uptake. 2 Carbon Cycle Net Land to Atmosphere Flux|CO2|Earth System Feedbacks net flux of from the land to the atmosphere (not including AFOLU and other anthropogenic emissions) due to Earth System Feedbacks. A positive value indicates release of from the land, a negative value indicates a net land uptake. 2 Carbon Cycle Net Land to Atmosphere Flux|CO2|Earth System Feedbacks|Other net flux of from the land to the atmosphere (not including AFOLU and other anthropogenic emissions) due to non-permafrost feedbacks. A positive value indicates release of from the land, a negative value indicates a net land uptake. 2

Continued. **Category Variable Unit Definition Tier** Carbon Cycle Net Land to Atmosphere Flux|CO2|Earth System Feedbacks|Permafro net flux of from the land to the atmosphere (not including AFOLU and other anthropogenic emissions) due to the permafrost feedback. A positive value indicates release of from the land, a negative value indicates a net land uptake. 2 Carbon Cycle Net Ocean to Atmosphere Flux|CH4 net flux of from the ocean to the atmosphere (not including anthropogenic emissions). A positive value indicates release of from the ocean, a negative value indicates a net ocean uptake. 2 Carbon Cycle Net Ocean to Atmosphere Flux|CO2 cumulative net flux of from the ocean to the atmosphere (not including anthropogenic emissions). A positive value indicates release of from the ocean, a negative value indicates a net ocean uptake. 2 Carbon Cycle Cumulative

Net Land to Atmosphere Flux|CH4 cumulative net flux of from the land to the atmosphere (not including AFOLU and other anthropogenic emissions). A positive value indicates release of from the land, a negative value indicates a net land uptake. 2 Carbon Cycle Cumulative Net Land to Atmosphere Flux|CH4|Earth System Feedbacks cumulative net flux of from the land to the atmosphere (not including AFOLU and other anthropogenic emissions) due to Earth System Feedbacks. A positive value indicates release of from the land, a negative value indicates a net land uptake. 2

Continued. **Category Variable Unit Definition Tier** Carbon Cycle Cumulative Net Land to Atmosphere Flux|CH4|Earth System Feedbacks|Other cumulative net flux of from the land to the atmosphere (not including AFOLU and other anthropogenic emissions) due to non-permafrost feedbacks. A positive value indicates release of from the land, a negative value indicates a net land uptake. 2 Carbon Cycle Cumulative Net Land to Atmosphere Flux|CH4|Earth System Feedbacks|Permafrost cumulative net flux of from the land to the atmosphere (not including AFOLU and other anthropogenic emissions) due to the permafrost feedback. A positive value indicates release of from the land, a negative value indicates a net land uptake. 2 Carbon Cycle Cumulative Net Land to Atmosphere Flux|CO2 cumulative net flux of from the land to the atmosphere (not including AFOLU and other anthropogenic emissions). A positive value indicates release of from the land, a negative value indicates a net land uptake. 2 Carbon Cycle Cumulative Net Land to Atmosphere Flux|CO2|Earth System Feedbacks cumulative net flux of from the land to the atmosphere (not including AFOLU and other anthropogenic emissions) due to Earth System Feedbacks. A positive value indicates release of from the land, a negative value indicates a net land uptake. 2

Continued. **Category Variable Unit Definition Tier** Carbon Cycle Cumulative Net Land to Atmosphere Flux|CO2|Earth System Feedbacks|Other cumulative net flux of from the land to the atmosphere (not including AFOLU and other anthropogenic emissions) due to non-permafrost feedbacks. A positive value indicates release of from the land, a negative value indicates a net land uptake. 2 Carbon Cycle Cumulative Net Land to Atmosphere Flux|CO2|Earth System Feedbacks|Permafrost cumulative net flux of from the land to the atmosphere (not including AFOLU and other anthropogenic emissions) due to the permafrost feedback. A positive value indicates release of from the land, a negative value indicates a net land uptake. 2 Carbon Cycle Cumulative Net Ocean to Atmosphere Flux|CH4 cumulative net flux of from the ocean to the atmosphere (not including anthropogenic emissions). A positive value indicates release of from the ocean, a negative value indicates a net ocean uptake. 2 Carbon Cycle Cumulative Net Ocean to Atmosphere Flux|CO2 cumulative net flux of from the ocean to the atmosphere (not including anthropogenic emissions). A positive value indicates release of from the ocean, a negative value indicates a net ocean uptake. 2

Continued. **Category Variable Unit Definition Tier** Carbon Cycle Carbon Pool|Atmosphere total amount of in the atmospheric carbon pool 2 Carbon Cycle Carbon Pool|Soil total amount of in the soil carbon pool 2 Carbon Cycle Carbon Pool|Detritus total amount of in the detritus carbon pool 2 Carbon Cycle Carbon Pool|Plant total amount of in the plant carbon pool 2 Carbon Cycle Net Primary Productivity global total net primary productivity 2 CCS Carbon Sequestration total carbon dioxide emissions captured and stored 1 CCS Carbon Sequestration|CCS total carbon dioxide emissions captured and stored in geological deposits (e.g. in depleted oil and gas fields, unmined coal seams, saline aquifers) and the deep ocean, stored amounts should be reported as positive numbers 2 CCS Carbon Sequestration|CCS|Biomass total carbon dioxide emissions captured from bioenergy use and stored in geological deposits (e.g. in depleted oil and gas fields, unmined coal seams, saline aquifers) and the deep ocean,

~~stored amounts should be reported as positive numbers 2 CCS Carbon Sequestration|CCS|Fossil total carbon dioxide emissions captured from fossil fuel use and stored in geological deposits (e.g. in depleted oil and gas fields, unmined coal seams, saline aquifers) and the deep ocean, stored amounts should be reported as positive numbers 2~~

~~Continued. **Category Variable Unit Definition Tier** CCS Carbon Sequestration|Direct Air Capture total carbon dioxide sequestered through direct air capture 2 CCS Carbon Sequestration|Enhanced Weathering total carbon dioxide sequestered through enhanced weathering 2 CCS Carbon Sequestration|Feedstocks total carbon dioxide sequestered in feedstocks (e.g., lubricants, asphalt, plastics) 2 CCS Carbon Sequestration|Land Use total carbon dioxide sequestered through land-based sinks (e.g., afforestation, soil carbon enhancement, biochar) 2 CCS Carbon Sequestration|Land Use|Afforestation total carbon dioxide sequestered through afforestation 2 CCS Carbon Sequestration|Land Use|Biochar total carbon dioxide sequestered through biochar 2 CCS Carbon Sequestration|Land Use|Other total carbon dioxide sequestered through other land-based mitigation techniques 2 CCS Carbon Sequestration|Land Use|Soil Carbon Management total carbon dioxide sequestered through soil carbon management techniques 2 CCS Carbon Sequestration|Other total carbon dioxide sequestered through other techniques 2 Climate Airborne Fraction|CO2 fraction of (cumulative) emitted which is still in the atmosphere 2 Climate Effective Climate Sensitivity effective climate sensitivity over time, here defined as ECS_eff(t) = Delta T(t) * RF2x / (RF(t) - dH/dt) where ECS_eff is effective climate sensitivity, Delta T(t) is Surface Air Temperature Change, RF2x is radiative forcing due to a doubling of atmospheric concentrations, RF(t) is radiative forcing and dH/dt is the energy imbalance at the top of the atmosphere (likely equal to ocean heat uptake in most of our reduced complexity models) 2~~

~~Continued. **Category Variable Unit Definition Tier** Climate Effective Climate Feedback effective climate feedback over time, here defined as lambda_eff(t) = (RF(t) - dH/dt) / Delta T(t) where lambda_eff is effective climate feedback, Delta T(t) is Surface Air Temperature Change, RF(t) is radiative forcing and dH/dt is the energy imbalance at the top of the atmosphere (likely equal to ocean heat uptake in most of our reduced complexity models) 2 Climate Heat Uptake total Heat Uptake of the Earth System (ZJ is zetta joules i.e.), equivalent to the the energy imbalance at the top of the atmosphere. 1 Climate Heat Uptake|Ice ice Heat Uptake (ZJ is zetta joules i.e.) 2 Climate Heat Uptake|Land land Heat Uptake (ZJ is zetta joules i.e.) 2 Climate Heat Uptake|Ocean ocean Heat Uptake through surface layer of the ocean (ZJ is zetta joules i.e.) 1 Climate Heat Uptake|Other other Heat Uptake (ZJ is zetta joules i.e.). 2 Climate Heat Content|Ocean total ocean heat content 2 Climate Heat Content|Ocean|0-700m ocean heat content between 0 and 700m 2 Climate Heat Content|Ocean|700-2000m ocean heat content between 700 and 2000m 2~~

~~Continued. **Category Variable Unit Definition Tier** Climate Instantaneous TCRE warming per unit cumulative (this should simply be your 'Surface Air Temperature Change' divided by 'Cumulative Emissions|') 2 Climate Surface Air Ocean Blended Temperature Change change in blended surface air/ocean tempertaure (i.e. quantity which is directly comparable with observational datasets e.g. HadCRUT4 or best proxy thereof). 2 Climate Surface Air Temperature Change change in surface air tempertaure (i.e. 2m air temperature or best proxy thereof). 1 Climate Surface Ocean Temperature Change change in surface layer ocean tempertaure. 1 Cumulative Emissions Cumulative Emissions|CO2 cumulative carbon dioxide emissions 1 Cumulative Emissions Cumulative Emissions|CO2|MAGICC AFOLU cumulative carbon dioxide emissions from agriculture, forestry and other land use (IPCC category 3), excluding any fossil-fuel based emissions in the Agricultural sector (hence not~~

identical to WG3 AFOLU) 2 Cumulative Emissions Cumulative Emissions|CO2|MAGICC Fossil and Industrial cumulative carbon dioxide emissions from energy use on supply and demand side (IPCC category 1A, 1B), industrial processes (IPCC category 2), waste (IPCC category 4) and other (IPCC category 5) 2 Cumulative Emissions Cumulative Emissions|CO2|Other cumulative carbon dioxide emissions from other sources 2

Continued. **Category Variable Unit Definition Tier** Effective Radiative Forcing Effective Radiative Forcing effective radiative forcing from all anthropogenic and natural sources (after stratospheric temperature adjustments and rapid adjustments) 1 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic effective radiative forcing from all anthropogenic sources (after stratospheric temperature adjustments and rapid adjustments) 1 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols effective radiative forcing from aerosols (after stratospheric temperature adjustments and rapid adjustments) 1 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-cloud Interactions effective radiative forcing from indirect effects of aerosols on clouds (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions effective radiative forcing from aerosol-radiative effects (after stratospheric temperature adjustments and rapid adjustments), note that the breakdown of this variable can come in multiple different forms 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|BC and OC|BC effective radiative forcing from aerosol-radiative effects from black carbon emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|BC and OC|BC|Biomass Burning effective radiative forcing from aerosol-radiative effects from black carbon biomass burning emissions (after stratospheric temperature adjustments and rapid adjustments) 2

Continued. **Category Variable Unit Definition Tier** Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Ae Interactions|BC and OC|BC|Fossil and Industrial effective radiative forcing from aerosol-radiative effects from black carbon fossil and industrial emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|BC and OC|OC effective radiative forcing from aerosol-radiative effects from organic carbon emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|BC and OC|OC|Biomass Burning effective radiative forcing from aerosol-radiative effects from organic carbon biomass burning emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|BC and OC|OC|Fossil and Industrial effective radiative forcing from aerosol-radiative effects from organic carbon fossil and industrial emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Biomass Burning effective radiative forcing from aerosol-radiative effects from biomass burning emissions (after stratospheric temperature adjustments and rapid adjustments) 2

Continued. **Category Variable Unit Definition Tier** Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Ae Interactions|Biomass Burning|BC and OC effective radiative forcing from aerosol-radiative effects from black and organic carbon biomass burning emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative

Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Biomass Burning|BC and OC|BC effective radiative forcing from aerosol-radiative effects from black carbon biomass burning emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosol Interactions|Biomass Burning|BC and OC|OC effective radiative forcing from aerosol-radiative effects from organic carbon biomass burning emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Biomass Burning|NH3 effective radiative forcing from aerosol-radiative effects from ammonia biomass burning emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Biomass Burning|Nitrate effective radiative forcing from aerosol-radiative effects from nitrate precursor biomass burning emissions (after stratospheric temperature adjustments and rapid adjustments) 2

Continued. **Category Variable Unit Definition Tier** Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Ae Interactions|Biomass Burning|Sulfate effective radiative forcing from aerosol-radiative effects from sulfate precursor biomass burning emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Fossil and Industrial effective radiative forcing from aerosol-radiative effects from fossil and industrial emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Fossil and Industrial|BC and OC effective radiative forcing from aerosol-radiative effects from black and organic carbon fossil and industrial emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Fossil and Industrial|BC and OC|BC effective radiative forcing from aerosol-radiative effects from black carbon fossil and industrial emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Fossil and Industrial|BC and OC|OC effective radiative forcing from aerosol-radiative effects from organic carbon fossil and industrial emissions (after stratospheric temperature adjustments and rapid adjustments) 2

Continued. **Category Variable Unit Definition Tier** Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Ae Interactions|Fossil and Industrial|NH3 effective radiative forcing from aerosol-radiative effects from ammonia fossil and industrial emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Fossil and Industrial|Nitrate effective radiative forcing from aerosol-radiative effects from nitrate precursor fossil and industrial emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Fossil and Industrial|Sulfate effective radiative forcing from aerosol-radiative effects from sulfate precursor fossil and industrial emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Mineral Dust effective radiative forcing from aerosol-radiative effects from mineral dust emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|NH3 effective radiative forcing from aerosol-radiative effects from ammonia emissions (after stratospheric temperature adjustments and rapid adjustments) 2

Continued. **Category Variable Unit Definition Tier** Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Ae Interactions|NH3|Biomass Burning effective radiative forcing from aerosol-radiative effects from ammonia biomass burning emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|NH3|Fossil and Industrial effective radiative forcing from aerosol-radiative effects from ammonia fossil and industrial emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Nitrate effective radiative forcing from aerosol-radiative effects from nitrate precursor emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Nitrate|Biomass Burning effective radiative forcing from aerosol-radiative effects from nitrate precursor biomass burning emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Nitrate|Fossil and Industrial effective radiative forcing from aerosol-radiative effects from nitrate fossil and industrial emissions (after stratospheric temperature adjustments and rapid adjustments) 2

Continued. **Category Variable Unit Definition Tier** Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Ae Interactions|Other effective radiative forcing from aerosol-radiative effects not covered in the other categories (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosol Interactions|Sulfate effective radiative forcing from aerosol-radiative effects from sulfate precursor emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosol Interactions|Sulfate|Biomass Burning effective radiative forcing from aerosol-radiative effects from sulfate precursor biomass burning emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Sulfate|Fossil and Industrial effective radiative forcing from aerosol-radiative effects from sulfate precursor fossil and industrial emissions (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Albedo Change effective radiative forcing from albedo change (after stratospheric temperature adjustments and rapid adjustments) 2

Continued. **Category Variable Unit Definition Tier** Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|CH4 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|CO2 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of 1 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of F-gases 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|HFC effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of hydrofluorocarbons (HFCs, as defined by Table 8.A.1 of AR5) not controlled under the Montreal protocol 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|HFC|HFC125 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of HFC125 2 Effective Radiative Forcing Effective

Radiative Forcing|Anthropogenic|F-Gases|HFC|HFC134a effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of HFC134a 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|HFC|HFC143a effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of HFC143a 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|HFC|HFC152a effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of HFC152a 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|HFC|HF effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of HFC227ea 2

Continued. **Category Variable Unit Definition Tier** Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|HF effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of HFC23 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|HFC|HFC236fa effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of HFC236fa 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-G effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of HFC245fa 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|HFC|HFC32 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of HFC32 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|HFC|HFC3 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of HFC365mfc 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|HFC|HFC4310mee effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of HFC43-10mee 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|NF3 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of nitrogen trifluoride () 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|PFC effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of perfluorocarbons (PFCs, as defined by Table 8.A.1 of AR5) 2

Continued. **Category Variable Unit Definition Tier** Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|PF effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|PFC|C3F8 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|PFC|C4F10 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|PFC|C5F12 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|PFC|C6F14 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|PFC|C7F16 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|PFC|C8F18 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|PFC|cC4F8 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of 2

Continued. **Category Variable Unit Definition Tier** Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|PF effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of 2 Effective Radiative Forcing

Effective Radiative Forcing|Anthropogenic|F-Gases|SF6 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of sulfur hexafluoride () 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|F-Gases|SO2F2 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of sulfuryl fluoride () 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Montreal Gases effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of Montreal gases 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic Gases|CCl4 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Montreal Gases|CFC effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of CFC gases (as defined by Table 8.A.1 of AR5) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Montreal Gases|CFC|CFC11 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of CFC11 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Montre Gases|CFC|CFC113 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of CFC113 2

Continued. **Category Variable Unit Definition Tier** Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Montreal Gases|CFC|CFC114 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of CFC114 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Montreal Gases|CFC|CFC115 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of CFC115 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Montreal Gases|CFC|CFC12 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of CFC12 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Montreal Gases|CH2Cl2 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Montreal Gases|CH3Br effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Montreal Gases|CH3CCl3 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Montreal Gases|CH3Cl effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of 2

Continued. **Category Variable Unit Definition Tier** Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Montreal Gases|CHCl3 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Montreal Gases|Halon1202 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of Halon-1202 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Montreal Gases|Halon1211 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of Halon-1211 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Montreal Gases|Halon1301 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of Halon-1301 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Montreal Gases|Halon2402 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of Halon-2402 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Montreal Gases|HCFC141b effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of HCFC141b 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Montreal

Gases|HCFC142b effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of HCFC22 2

Continued. **Category Variable Unit Definition Tier** Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Montreal Gases|HCFC22 effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of HCFC22 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|N2O effective radiative forcing (after stratospheric temperature adjustments and rapid adjustments) of 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Other effective radiative forcing from factors not covered in other categories (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Other|BC on Snow effective radiative forcing from black carbon on snow (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Other|Contrails and Contrail-induced Cirrus effective radiative forcing from contrails and contrail-induced cirrus (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Other|CH4 Oxidation Stratospheric H2O effective radiative forcing from methane oxidation of stratospheric H2O (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Other|Other WMGHGs effective radiative forcing from WMGHG not covered in other categories (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Stratospheric Ozone effective radiative forcing from stratospheric ozone (after stratospheric temperature adjustments and rapid adjustments) 2

Continued. **Category Variable Unit Definition Tier** Effective Radiative Forcing Effective Radiative Forcing|Anthropogenic|Tropospheric Ozone effective radiative forcing from tropospheric ozone (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Natural effective radiative forcing from all natural drivers, i.e. solar and volcanic forcing (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Natural|Solar effective radiative forcing from variations in solar irradience (after stratospheric temperature adjustments and rapid adjustments) 2 Effective Radiative Forcing Effective Radiative Forcing|Natural|Volcanic effective radiative forcing due to volcanic eruptions (after stratospheric temperature adjustments and rapid adjustments) 2 Emissions Emissions|BC total black carbon emissions 1 Emissions Emissions|BC|MAGICC AFOLU black carbon emissions from agriculture, forestry and other land use (IPCC category 3), excluding any fossil-fuel based emissions in the Agricultural sector (hence not identical to WG3 AFOLU) 2 Emissions Emissions|BC|MAGICC Fossil and Industrial black carbon emissions from energy use on supply and demand side (IPCC category 1A, 1B), industrial processes (IPCC category 2), waste (IPCC category 4) and other (IPCC category 5) 2 Emissions Emissions|BC|Other black carbon emissions from other sources 2 Emissions Emissions|CH4 total methane emissions 1 Emissions Emissions|CH4|MAGICC AFOLU methane emissions from agriculture, forestry and other land use (IPCC category 3), excluding any fossil-fuel based emissions in the Agricultural sector (hence not identical to WG3 AFOLU) 2

Continued. **Category Variable Unit Definition Tier** Emissions Emissions|CH4|MAGICC Fossil and Industrial methane emissions from energy use on supply and demand side (IPCC category 1A, 1B), industrial processes (IPCC category 2), waste (IPCC category 4) and other (IPCC category 5) 2 Emissions Emissions|CH4|Other methane emissions from other sources 2

Emissions Emissions|CO total carbon monoxide emissions 1 Emissions Emissions|CO|MAGICC AFOLU carbon monoxide emissions from agriculture, forestry and other land use (IPCC category 3), excluding any fossil-fuel based emissions in the Agricultural sector (hence not identical to WG3 AFOLU) 2 Emissions Emissions|CO|MAGICC Fossil and Industrial carbon monoxide emissions from energy use on supply and demand side (IPCC category 1A, 1B), industrial processes (IPCC category 2), waste (IPCC category 4) and other (IPCC category 5) 2 Emissions Emissions|CO|Other carbon monoxide emissions from other sources 2 Emissions Emissions|CO2 total carbon dioxide emissions 1 Emissions Emissions|CO2|MAGICC AFOLU carbon dioxide emissions from agriculture, forestry and other land use (IPCC category 3), excluding any fossil-fuel based emissions in the Agricultural sector (hence not identical to WG3 AFOLU) 2

Continued. **Category Variable Unit Definition Tier** Emissions Emissions|CO2|MAGICC Fossil and Industrial carbon dioxide emissions from energy use on supply and demand side (IPCC category 1A, 1B), industrial processes (IPCC category 2), waste (IPCC category 4) and other (IPCC category 5) 2 Emissions Emissions|CO2|Other carbon dioxide emissions from other sources 2 Emissions Emissions|F-Gases total F-gas emissions, including sulfur hexafluoride (), nitrogen trifluoride (), sulfuryl fluoride (), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) 3 Emissions Emissions|F-Gases|HFC equivalent species total emissions of hydrofluorocarbons (HFCs and HCFCs), provided as aggregate -equivalents 3 Emissions Emissions|F-Gases|HFC|HFC125 total emissions of HFC125 2 Emissions Emissions|F-Gases|HFC|HFC134a total emissions of HFC134a 2 Emissions Emissions|F-Gases|HF total emissions of HFC143a 2 Emissions Emissions|F-Gases|HFC|HFC152a total emissions of HFC152a 2 Emissions Emissions|F-Gases|H total emissions of HFC227ea 2 Emissions Emissions|F-Gases|HFC|HFC23 total emissions of HFC23 2 Emissions Emissions|F-Gases|HFC| total emissions of HFC236fa 2 Emissions Emissions|F-Gases|HFC|HFC245fa total emissions of HFC245fa 2 Emissions Emissions|F-Gases| total emissions of HFC32 2 Emissions Emissions|F-Gases|HFC|HFC365mfc total emissions of HFC365mfc 2 Emissions Emissions|F-Gases|HFC|HFC4310mee total emissions of HFC43-10mee 2 Emissions Emissions|F-Gases|NF3 total emissions of nitrogen trifluoride () 2 Emissions Emissions|F-Gases|PFC equivalent species total emissions of perfluorocarbons (PFCs, as defined by Table 8.A.1 of AR5), provided as aggregate -equivalents 3

Continued. **Category Variable Unit Definition Tier** Emissions Emissions|F-Gases|PFC|C2F6 total emissions of 2 Emissions Emissions|F-Gases|PFC|C3F8 total emissions of 2 Emissions Emissions|F-Gases|PFC|C4F10 total emissions of 2 Emissions Emissions|F-Gases|PFC|C5F12 total emissions of 2 Emissions Emissions|F-Gases|PFC|C6F14 total emissions of 2 Emissions Emissions|F-Gases|PFC|C7F16 total emissions of 2 Emissions Emissions|F-Gases|PFC|C8F18 total emissions of 2 Emissions Emissions|F-Gases|PFC|cC4F8 total emissions of 2 Emissions Emissions|F-Gases|PFC|CF4 total emissions of 2 Emissions Emissions|F-Gases|SF6 total emissions of sulfur hexafluoride () 2 Emissions Emissions|F-Gases|SO2F2 total emissions of sulfuryl fluoride () 2 Emissions Emissions|Montreal Gases equivalent species total Montreal gas emissions, provided as CFC-11 equivalents 3 Emissions Emissions|Montreal Gases|CCl4 total emissions of 2 Emissions Emissions|Montreal Gases|CFC equivalent species total CFC emissions, provided as CFC-11 equivalents 3 Emissions Emissions|Montreal Gases|CFC|CFC11 total emissions of CFC11 2 Emissions Emissions|Montreal Gases|CFC|CFC113 total emissions of CFC113 2 Emissions Emissions|Montreal Gases|CFC|CFC114 total emissions of CFC114 2

Continued. **Category Variable Unit Definition Tier** Emissions Emissions|Montreal Gases|CFC|CFC115 total emissions of CFC115 2 Emissions Emissions|Montreal Gases|CFC|CFC12 total emissions of CFC12 2 Emissions Emissions|Montreal

Gases|CH2Cl2 total emissions of 2 Emissions Emissions|Montreal Gases|CH3Br total emissions of 2 Emissions Emissions|Montreal Gases|CH3CCl3 total emissions of 2 Emissions Emissions|Montreal Gases|CH3Cl total emissions of 2 Emissions Emissions|Montreal Gases|CHCl3 total emissions of 2 Emissions Emissions|Montreal Gases|Halon1202 total emissions of Halon-1202 2 Emissions Emissions|Montreal Gases|Halon1211 total emissions of Halon-1211 2 Emissions Emissions|Montreal Gases|Halon1301 total emissions of Halon-1301 2 Emissions Emissions|Montreal Gases|Halon2402 total emissions of Halon-2402 2 Emissions Emissions|Montreal Gases|HCFC141b total emissions of HCFC141b 2 Emissions Emissions|Montreal Gases|HCFC142b total emissions of HCFC22 2 Emissions Emissions|Montreal Gases|HCFC22 total emissions of HCFC22 2

Continued. **Category Variable Unit Definition Tier** Emissions Emissions|N2O total nitrogen emissions 1 Emissions Emissions|N2O|MA AFOLU nitrogen emissions from agriculture, forestry and other land use (IPCC category 3), excluding any fossil-fuel based emissions in the Agricultural sector (hence not identical to WG3 AFOLU) 2 Emissions Emissions|N2O|MAGICC Fossil and Industrial nitrogen emissions from energy use on supply and demand side (IPCC category 1A, 1B), industrial processes (IPCC category 2), waste (IPCC category 4) and other (IPCC category 5) 2 Emissions Emissions|N2O|Other nitrogen emissions from other sources 2 Emissions Emissions|NH3 total ammonia emissions 1 Emissions Emissions|NH3|MAGICC AFOLU ammonia emissions from agriculture, forestry and other land use (IPCC category 3), excluding any fossil-fuel based emissions in the Agricultural sector (hence not identical to WG3 AFOLU) 2 Emissions Emissions|NH3|MAGICC Fossil and Industrial ammonia emissions from energy use on supply and demand side (IPCC category 1A, 1B), industrial processes (IPCC category 2), waste (IPCC category 4) and other (IPCC category 5) 2 Emissions Emissions|NH3|Other ammonia emissions from other sources 2

Continued. **Category Variable Unit Definition Tier** Emissions Emissions|NOx total nitrous oxide emissions 1 Emissions Emissions|NOx|MAGICC AFOLU nitrous oxide emissions from agriculture, forestry and other land use (IPCC category 3), excluding any fossil-fuel based emissions in the Agricultural sector (hence not identical to WG3 AFOLU) 2 Emissions Emissions|NOx|MAGICC Fossil and Industrial nitrous oxide emissions from energy use on supply and demand side (IPCC category 1A, 1B), industrial processes (IPCC category 2), waste (IPCC category 4) and other (IPCC category 5) 2 Emissions Emissions|NOx|Other nitrous oxide emissions from other sources 2 Emissions Emissions|OC total organic carbon emissions 1 Emissions Emissions|OC|MAGICC AFOLU organic carbon emissions from agriculture, forestry and other land use (IPCC category 3), excluding any fossil-fuel based emissions in the Agricultural sector (hence not identical to WG3 AFOLU) 2 Emissions Emissions|OC|MAGICC Fossil and Industrial organic carbon emissions from energy use on supply and demand side (IPCC category 1A, 1B), industrial processes (IPCC category 2), waste (IPCC category 4) and other (IPCC category 5) 2 Emissions Emissions|OC|Other organic carbon emissions from other sources 2

Continued. **Category Variable Unit Definition Tier** Emissions Emissions|Sulfur total sulfur (as a precursor for sulfates) emissions 1 Emissions Emissions|Sulfur|MAGICC AFOLU sulfur (as a precursor for sulfates) emissions from agriculture, forestry and other land use (IPCC category 3), excluding any fossil-fuel based emissions in the Agricultural sector (hence not identical to WG3 AFOLU) 2 Emissions Emissions|Sulfur|MAGICC Fossil and Industrial sulfur (as a precursor for sulfates) emissions from energy use on supply and demand side (IPCC category 1A, 1B), industrial processes (IPCC category 2), waste (IPCC category 4) and other (IPCC category 5) 2 Emissions Emissions|Sulfur|Other sulfur (as a precursor for sulfates) emissions from other sources 2 Emissions Emissions|VOC total (non-methane) volatile organic compounds emissions 1 Emissions

Emissions|VOC|MAGICC AFOLU (non-methane) volatile organic compounds emissions from agriculture, forestry and other land use (IPCC category 3), excluding any fossil-fuel based emissions in the Agricultural sector (hence not identical to WG3 AFOLU) 2 Emissions Emissions|VOC|MAGICC Fossil and Industrial (non-methane) volatile organic compounds emissions from energy use on supply and demand side (IPCC category 1A, 1B), industrial processes (IPCC category 2), waste (IPCC category 4) and other (IPCC category 5) 2

Continued. **Category Variable Unit Definition Tier** Emissions Emissions|VOC|Other (non-methane) volatile organic compounds emissions from other sources 2 Methane Cycle Atmospheric Lifetime|CH4 total atmospheric lifetime of methane 3 Nitrogen Cycle Atmospheric Lifetime|N2O total atmospheric lifetime of nitrogen 3 Ocean Ocean pH pH of the ocean's surface layer 3 Radiative Forcing Radiative Forcing radiative forcing from all anthropogenic and natural sources (after stratospheric temperature adjustments) 1 Radiative Forcing Radiative Forcing|Anthropogenic radiative forcing from all anthropogenic sources (after stratospheric temperature adjustments) 1 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols radiative forcing from aerosols (after stratospheric temperature adjustments) 1 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-cloud Interactions radiative forcing from indirect effects of aerosols on clouds (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions radiative forcing from aerosol-radiative effects (after stratospheric temperature adjustments), note that the breakdown of this variable can come in multiple different forms 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|BC and OC|BC radiative forcing from aerosol-radiative effects from black carbon emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|BC and OC|BC|Biomass Burning radiative forcing from aerosol-radiative effects from black carbon biomass burning emissions (after stratospheric temperature adjustments) 2

Continued. **Category Variable Unit Definition Tier** Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|BC and OC|BC|Fossil and Industrial radiative forcing from aerosol-radiative effects from black carbon fossil and industrial emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols- Interactions|BC and OC|OC radiative forcing from aerosol-radiative effects from organic carbon emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|BC and OC|OC|Biomass Burning radiative forcing from aerosol-radiative effects from organic carbon biomass burning emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|BC and OC|OC|Fossil and Industrial radiative forcing from aerosol-radiative effects from organic carbon fossil and industrial emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols- Interactions|Biomass Burning radiative forcing from aerosol-radiative effects from biomass burning emissions (after stratospheric temperature adjustments) 2

Continued. **Category Variable Unit Definition Tier** Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Biomass Burning|BC and OC radiative forcing from aerosol-radiative effects from black and organic carbon biomass burning emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Ae Interactions|Biomass Burning|BC and OC|BC radiative forcing from aerosol-radiative effects from black carbon biomass burning emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-ra

Interactions|Biomass Burning|BC and OC|OC radiative forcing from aerosol-radiative effects from organic carbon biomass burning emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-ra Interactions|Biomass Burning|NH3 radiative forcing from aerosol-radiative effects from ammonia biomass burning emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Biomass Burning|Nitrate radiative forcing from aerosol-radiative effects from nitrate biomass burning emissions (after stratospheric temperature adjustments) 2

Continued. **Category Variable Unit Definition Tier** Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Biomass Burning|Sulfate radiative forcing from aerosol-radiative effects from sulfate biomass burning emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Fossil and Industrial radiative forcing from aerosol-radiative effects from fossil and industrial emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Foss and Industrial|BC and OC radiative forcing from aerosol-radiative effects from black and organic carbon fossil and industrial emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Fossil and Industrial|BC and OC|BC radiative forcing from aerosol-radiative effects from black carbon fossil and industrial emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols- Interactions|Fossil and Industrial|BC and OC|OC radiative forcing from aerosol-radiative effects from organic carbon fossil and industrial emissions (after stratospheric temperature adjustments) 2

Continued. **Category Variable Unit Definition Tier** Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Fossil and Industrial|NH3 radiative forcing from aerosol-radiative effects from ammonia fossil and industrial emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Fossil and Industrial|Nitrate radiative forcing from aerosol-radiative effects from nitrate fossil and industrial emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Fossil and Industrial|Sulfate radiative forcing from aerosol-radiative effects from sulfate fossil and industrial emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Mineral Dust radiative forcing from aerosol-radiative effects from mineral dust emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|NH3 radiative forcing from aerosol-radiative effects from ammonia emissions (after stratospheric temperature adjustments) 2

Continued. **Category Variable Unit Definition Tier** Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|NH3|Biomass Burning radiative forcing from aerosol-radiative effects from ammonia biomass burning emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|NH3|Fossil and Industrial radiative forcing from aerosol-radiative effects from ammonia fossil and industrial emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Nitrate radiative forcing from aerosol-radiative effects from nitrate emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Nitrate|Biomass Burning radiative forcing from aerosol-radiative effects from nitrate biomass burning emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Nitrate|Fossil and Industrial radiative forcing from aerosol-radiative effects from nitrate fossil and industrial emissions (after stratospheric temperature adjustments) 2

Continued. **Category Variable Unit Definition Tier** Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Other radiative forcing from aerosol-radiative effects not covered in the other categories (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Sulfate radiative forcing from aerosol-radiative effects from sulfate emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Sulfate|Biomass Burning radiative forcing from aerosol-radiative effects from sulfate biomass burning emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Aerosols|Aerosols-radiation Interactions|Sulfate|Fossil and Industrial radiative forcing from aerosol-radiative effects from sulfate fossil and industrial emissions (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Albedo Change radiative forcing from albedo change (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogenic|CH4 radiative forcing (after stratospheric temperature adjustments) of 2 Radiative Forcing Radiative Forcing|Anthropogenic|CO2 radiative forcing (after stratospheric temperature adjustments) of 1

Continued. **Category Variable Unit Definition Tier** Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases radiative forcing (after stratospheric temperature adjustments) of F-gases 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|HFC radiative forcing (after stratospheric temperature adjustments) of hydrofluorocarbons (HFCs, as defined by Table 8.A.1 of AR5) not controlled under the Montreal protocol 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|HFC|HFC125 radiative forcing (after stratospheric temperature adjustments) of HFC125 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|HF
radiative forcing (after stratospheric temperature adjustments) of HFC134a 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|H
radiative forcing (after stratospheric temperature adjustments) of HFC143a 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|H
radiative forcing (after stratospheric temperature adjustments) of HFC152a 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|H
radiative forcing (after stratospheric temperature adjustments) of HFC227ea 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|
radiative forcing (after stratospheric temperature adjustments) of HFC23 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|HF
radiative forcing (after stratospheric temperature adjustments) of HFC236fa 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|
radiative forcing (after stratospheric temperature adjustments) of HFC245fa 2

Continued. **Category Variable Unit Definition Tier** Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|HFC|HFC32 radiative forcing (after stratospheric temperature adjustments) of HFC32 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|HF
radiative forcing (after stratospheric temperature adjustments) of HFC365mfc 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gase
radiative forcing (after stratospheric temperature adjustments) of HFC43-10mee 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Ga
radiative forcing (after stratospheric temperature adjustments) of nitrogen trifluoride () 2 Radiative Forcing Radiative Forcing|Anthropogeni
radiative forcing (after stratospheric temperature adjustments) of perfluorocarbons (PFCs, as defined by Table 8.A.1 of AR5) 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|PFC|C2F6 radiative forcing (after stratospheric temperature adjustments) of 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|PFC|C3F8 radiative forcing (after stratospheric temperature adjustments) of 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|PFC|C4F10 radiative forcing (after

stratospheric temperature adjustments) of 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|PFC|C5F12 radiative forcing (after stratospheric temperature adjustments) of 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|PFC|C6F14 radiative forcing (after stratospheric temperature adjustments) of 2

Continued. **Category Variable Unit Definition Tier** Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|PFC|C7F16 radiative forcing (after stratospheric temperature adjustments) of 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|PFC|C8F18 radiative forcing (after stratospheric temperature adjustments) of 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|PFC|cC4F8 radiative forcing (after stratospheric temperature adjustments) of 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|PFC|CF4 radiative forcing (after stratospheric temperature adjustments) of 2 Radiative Forcing Radiative Forcing|Anthropogenic|F-Gases|SF6 radiative forcing (after stratospheric temperature adjustments) of sulfur hexafluoride () 2 Radiative Forcing Radiative Forcing|Anthropogenic radiative forcing (after stratospheric temperature adjustments) of sulfuryl fluoride () 2 Radiative Forcing Radiative Forcing|Anthropogenic|M Gases radiative forcing (after stratospheric temperature adjustments) of Montreal gases 2 Radiative Forcing Radiative Forcing|Anthropogeni Gases|CCl4 radiative forcing (after stratospheric temperature adjustments) of 2 Radiative Forcing Radiative Forcing|Anthropogenic|Montrea Gases|CFC radiative forcing (after stratospheric temperature adjustments) of CFC gases (as defined by Table 8.A.1 of AR5) 2 Radiative Forcing Radiative Forcing|Anthropogenic|Montreal Gases|CFC|CFC11 radiative forcing (after stratospheric temperature adjustments) of CFC11 2

Continued. **Category Variable Unit Definition Tier** Radiative Forcing Radiative Forcing|Anthropogenic|Montreal Gases|CFC|CFC113 radiative forcing (after stratospheric temperature adjustments) of CFC113 2 Radiative Forcing Radiative Forcing|Anthropogenic|Montreal Gases|CFC|CFC114 radiative forcing (after stratospheric temperature adjustments) of CFC114 2 Radiative Forcing Radiative Forcing|Anthropogenic|Montreal Gases|CFC|CFC115 radiative forcing (after stratospheric temperature adjustments) of CFC115 2 Radiative Forcing Radiative Forcing|Anthropogenic|Montreal Gases|CFC|CFC12 radiative forcing (after stratospheric temperature adjustments) of CFC12 2 Radiative Forcing Radiative Forcing|Anthropogenic|Montreal Gases|CH2Cl2 radiative forcing (after stratospheric temperature adjustments) of 2 Radiative Forcing Radiative Forcing|Anthropogenic|Montreal Gases|CH3Br radiative forcing (after stratospheric temperature adjustments) of 2 Radiative Forcing Radiative Forcing|Anthropogenic|Montreal Gases|CH3CCl3 radiative forcing (after stratospheric temperature adjustments) of 2 Radiative Forcing Radiative Forcing|Anthropogenic|Montreal Gases|CH3Cl radiative forcing (after stratospheric temperature adjustments) of 2 Radiative Forcing Radiative Forcing|Anthropogenic|Montr Gases|CHCl3 radiative forcing (after stratospheric temperature adjustments) of 2

Continued. **Category Variable Unit Definition Tier** Radiative Forcing Radiative Forcing|Anthropogenic|Montreal Gases|Halon1202 radiative forcing (after stratospheric temperature adjustments) of Halon-1202 2 Radiative Forcing Radiative Forcing|Anthropogenic|Montrea Gases|Halon1211 radiative forcing (after stratospheric temperature adjustments) of Halon-1211 2 Radiative Forcing Radiative Forcing|Anthropogenic|Montreal Gases|Halon1301 radiative forcing (after stratospheric temperature adjustments) of Halon-1301 2 Radiative Forcing Radiative Forcing|Anthropogenic|Montreal Gases|Halon2402 radiative forcing (after stratospheric temperature adjustments) of Halon-2402 2 Radiative Forcing Radiative Forcing|Anthropogenic|Montreal Gases|HCFC141b radiative forcing (after stratospheric temperature adjustments) of HCFC141b 2 Radiative Forcing Radiative Forcing|Anthropogenic|Montreal Gases|HCFC142b radiative forcing (after stratospheric temperature adjustments) of HCFC22 2 Radiative Forcing Radiative Forcing|Anthropogenic|Montreal Gases|HCFC22 radiative forcing (after stratospheric temperature adjustments) of HCFC22 2

Radiative Forcing Radiative Forcing|Anthropogenic|N2O radiative forcing (after stratospheric temperature adjustments) of 2 Radiative Forcing Radiative Forcing|Anthropogenic|Other radiative forcing from factors not covered in other categories (after stratospheric temperature adjustments) 2

Continued. **Category Variable Unit Definition Tier** Radiative Forcing Radiative Forcing|Anthropogenic|Stratospheric Ozone radiative forcing from stratospheric ozone (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Anthropogen Ozone radiative forcing from tropospheric ozone (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Natural radiative forcing from all natural drivers, i.e. solar and volcanic forcing (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Natural|Solar radiative forcing from variations in solar irradience (after stratospheric temperature adjustments) 2 Radiative Forcing Radiative Forcing|Natural|Volcanic radiative forcing due to volcanic eruptions (after stratospheric temperature adjustments) 2