

In the course of the ISIMIP2b simulation phase there have been some improvements of the protocol that do not directly refer to the reviewers' comments but have led to associated adjustments of the manuscript:

1. Instead of the originally suggested linear interpolation from historical land use patterns from HYDE3.2 to future projections generated by the LU model MAgPIE we have decided to apply a harmonization method that has recently been developed in the context of the CMIP6 process (Hurtt et al., in preparation). While the underlying MAgPIE simulations have not changed the main text and the SI have been adjusted to describe the new harmonization approach. Figure 3 of the main text now shows the areas of crop land from the historical reconstruction and the original MAgPIE simulations without interpolations. The SI contains a comparison of the harmonized crop land areas and the original data for the IPSL-CM5A-LR climate model. The patterns for the other models are currently generated. George Hurtt, Louise Chini, Ritvik Sahapal, Benjamin Bodirsky, Jan Volkholz, and Steve Frothingham have been added to the list of authors as they were involved in the generation of the new harmonized LUH2-ISIMIP2b land use data set.
2. We were able to integrate a section on the simulation of climate-change effects on lakes using coupled lake-hydrodynamic and water-quality models into the ISIMIP2b protocol. Rafael Marcé, Don Pierson and Jonas Jägermeyr have led the development of the section and have been added to the list of co-authors.
3. Similarly, a “terrestrial biodiversity sector” has been added to the ISIMIP2b protocol. Christian Hof and Matthias Biber have worked on the development of the associated section of the protocol document (<https://www.isimip.org/protocol/#isimip2b>) together with Thomas Hickler and they have thus been added to the list of co-authors.
4. We now also provide spatially explicit GDP distributions as input for the ISIMIP2b simulations or to e.g. estimate damages in post-processing of bio-physical impact simulations. The new data set covers the period from 1860 to 2100 and is consistent with reported national GDP data for the historical period and future projections on national level following SSP2 (see section 6 of the main text). The development has been done by Daisuke Murakami, Yoshiki Yamagata, and Tobias Geiger who have been added to the list of co-authors.
5. We now propose a method to account for the effect of changes in Terrestrial Water Storage (TWS) e.g. due to projected changes in ground water abstraction according to SSP2 on sea level rise. The approach is designed to be consistent with projected changes in land use and irrigation patterns as provided within ISIMIP2b and will be applied to generate spatially explicit patterns of sea level change for the Group 3 simulations within the coastal infrastructure sector. A description of the associated addition to the Group 2 sea level projections has been added to the paper. Riccardo Riva has been involved in the development of the approach and will contribute the sea level fingerprints associated with the projected changes in TWS. He has been added to the list of co-authors.
6. The hurricane simulations are no longer considered as an additional impact sector within ISIMIP2b but as a complement to the climate input data sets provided to force the impact models. Therefore the associated description has become part of Section 3 on climate input data.

### Detailed answers to the review by A. J. Dolman:

This is a difficult paper to review. There is no doubt that it should be published, as it contains the deliberations that go in to developing scenarios to quantify the impacts of warming, socio economic trends and land use in an attempt to remain below the Paris goal of 1.5 C. The paper as such provides a very useful and needed reference for the impact community. The paper is also clear, contains no mistakes or errors.

Answer:

We thank the reviewer for this generally positive judgement of our paper!

That being said, the paper is very hard to read. My suggestion would be to keep the paper as it is up to section 8. In section 8, the level of detail, repeating of similar tables is such that anyone would loose direction. I appreciate that the sector specific implementation is important, but I would give only one example, and put the other tables in the supplementary material.

Answer:

We fully agree with the reviewer that the details listed in section 8 are more relevant for modelers who want to join ISIMIP2b than for general readers of the paper. We therefore generated a separate protocol document published on the ISIMIP website (<https://www.isimip.org/protocol/#isimip2b>) including all technical details required to generate the impact models runs within the divers sectors, e.g. data formats and naming conventions. The document serves as the most-up to date reference for the modelers and now also includes the tables of scenarios and output data previously listed in section 8 and the SI. In this way 1) the paper becomes more readable and 2) we avoid confusion regarding the latest reference for technical details of the implementation that might have to be adjusted in the process of the project if they turned out to be impractical or confusing. We decided to only keep one table of scenarios in the main paper for illustration.

On page 5, line 15-20 the item number 3 is missing.

Answer:

Thank you very much for the hint. We have adjusted the numbering.

## Detailed answers to the review by D. Jacob:

Dear All,

I suggest to publish the manuscript almost as it is. It is a good paper, well written. The method explained is solid and fits to the purpose.

Answer:

Thank you very much for this positive evaluation of the paper!

There are a few minor issues: the paper is very detailed. There is a lot of repetition of the simulations design. It is listed in many sections.

Answer:

To avoid repetition and increase the readability of the paper we have moved the largest part of the sector specific scenario lists from section 8 to the new ISIMIP2b protocol document including all technical details required to set-up the model simulations within the individual sectors. We also tried to avoid repetition of the scenario design across the other sections. In particular, the introduction has been re-structured and shortened.

on page 4 in the middle paragraph it says that the data from ISIMIP2a will eventually be publicly available. In order to help the community in this kind of studies and for trust building - they should be made publicly available. Otherwise it is not possible for outsiders to judge on the quality of all follow up and proposed simulation results.

Answer:

Yes, it is the clear purpose of ISIMIP to make the impacts simulations of each individual simulations round publically available. The quality checks of the ISIMIP2a data are nearly finished and a first package of the data is already listed on the ESGF server (<https://esg.pik-potsdam.de>) and will be released and freely available very soon. The others will follow soon after finalizing the doi assignment. For ISIMIP2b we even agreed with the modelers to forgo the usual "embargo period" of the archive and release the data as soon as possible to provide the opportunity to other researchers to work on the data and potentially provide additional input for the IPCC Special Report. Publication rules for the ISIMIP data in general and the ISIMIP2b output in particular are described in the "How to join ISIMIP" document (<https://www.isimip.org/protocol/terms-of-use/>) underlining the clear intention of providing open access to the simulation data comparable to e.g. the CMIP data. The associated reference is now included in the paper.

At the end, the paper is too detailed and hard to read.

Answer:

We hope that we could solve this issue by moving large parts of the sector specific more technical information to the protocol document.

In chapter 3 it is unclear if the chosen GCMs are representative for a spread on possibilities. How do they compare to the full set of CMPI5 simulations.

Answer:

To illustrate to what extent the 4 selected GCMs cover the range of projections provided by CMIP5 the SI now includes two additional plots. They show regional changes in annual temperatures and precipitation plotted against global mean temperature change for the considered 4 GCMs and the range of other models from CMIP5. As the bias-adjustment only preserves relative changes in precipitation on the grid level changes in the bias-adjusted input data cannot be directly compared to the non-bias-adjusted CMIP5 projections. Due to this problem, the comparison is based on the raw CMIP5 data. The selected regions cover the ISIMIP focus regions (river basins + oceanic regions) and global land and ocean temperatures. Regional changes are plotted against global mean temperature changes as ISIMIP2b is intended to quantify impacts at different levels of global warming, in particular the difference between impacts at 1.5°C and 2°C of global mean temperature change. In order to measure how well the ISIMIP2b set covers the ranges of regional climate change projections, we have added an analysis of the Fractional Range Coverage (FRC) as proposed by (McSweeney and Jones, 2016) to the SI. In sum the 4 GCMs (originally chosen on the basis of climate input data requirements) provide an FRC close to the mean FRC across randomly chosen four-member sets of CMIP5 GCMs.

What is the role of the bias correction (which by the way should be named bias- adjustment, since the bias will only be reduced but not corrected!!!) on the final results?

Answer:

We have adjusted the naming throughout the manuscript. The bias-adjustment is critical for the impact simulations as the represented processes may show a non-linear response to changes in temperatures or other variables. So e.g. US crop yields have been shown to drop strongly as soon as temperature exceed a critical threshold of about 30°C, dams provide flood protections as long as water levels do not exceed a certain threshold, or mortality non-linearly depends on temperatures showing a strong increase beyond site-specific threshold. In many cases these temperature dependencies are implemented in absolute terms and biases in the input data could lead to a quite different historical distribution in impacts variables than the observed ones and changes in terms of global mean temperature are expected to depend on these starting conditions. To this end we decided in favor a bias-adjustment although it comes at the cost of losing full physical consistency of the climate variables.

Since all impact models are so different and the input sets are also very different, I did not understand, how comparable the final results will be.

Answer:

ISIMIP is designed to allow for model intercomparisons within sectors but also for an aggregation or integration of impacts across sectors. To this end climate and socio-economic inputs are harmonized and all modeling groups within a given sector are asked to provide the same list of output variables. Nevertheless, different decisions about processes to implement (e.g. inclusion of direct human interferences or not), different ways of representing these processes, different parameter settings etc. may lead to strong differences between models. This is partly accounted for by considering different scenarios within the sectors (e.g. naturalized simulation (nosoc), simulations with constant present day management (pressoc) and simulations accounting for changes in management (varsoc)). So even models not accounting for the influences of direct (human) disturbances could be compared to others in a basic naturalized setting. In general ISIMIP is an ongoing process improving the mutual understanding of the models that may lead to improvements of the protocols and models in further rounds. In general, it has turned out that it is extremely helpful to start from a very basic intercomparison only building on a common climate input and identical socio-economic storylines avoiding too much harmonization.



# Assessing the impacts of 1.5°C global warming – simulation protocol of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP2b)

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14 **Abstract.** In Paris, France, December 2015, the Conference of the Parties (COP) to the United Nations  
15 Framework Convention on Climate Change (UNFCCC) invited the Intergovernmental Panel on Climate Change  
16 (IPCC) to provide a “special report in 2018 on the impacts of global warming of 1.5°C above pre-industrial levels  
17 and related global greenhouse gas emission pathways”. In Nairobi, Kenya, April 2016, the IPCC panel accepted  
18 the invitation. Here we describe the response devised within the Inter-Sectoral Impact Model Intercomparison  
19 Project (ISIMIP) to provide tailored, cross-sectorally consistent impacts projections **to broaden the scientific**  
20 **basis for the report.** The simulation protocol is designed to allow for 1) separation of the impacts of historical  
21 warming starting from pre-industrial conditions from **impacts of** other drivers such as historical land-use  
22 changes (based on pre-industrial and historical impact model simulations); 2) quantification of the **impacts** of  
23 additional warming up to 1.5°C, including a potential overshoot and long-term **impacts** up to 2299, **and**  
24 **comparison to higher levels of global mean temperature change** (based on the low-emissions Representative  
25 Concentration Pathway RCP2.6 and a no-mitigation pathway RCP6.0) with socio-economic conditions fixed at  
26 2005 levels; and 3) assessment of the climate effects based on the same climate scenarios **while** accounting for  
27 simultaneous changes in socio-economic conditions following the middle-of-the-road Shared Socioeconomic  
28 Pathway (SSP2, Fricko et al., 2016) and **in particular** differential bio-energy requirements associated with the  
29 transformation of the energy system to comply with RCP2.6 compared to RCP6.0. With the aim of providing the  
30 scientific basis for an aggregation of impacts across sectors and analysis of cross-sectoral interactions that may  
31 dampen or amplify sectoral impacts, the protocol is designed to facilitate consistent impacts projections from a  
32 range of impact models across different sectors (global and regional hydrology, **lakes**, global crops, global  
33 vegetation, regional forests, global and regional marine ecosystems and fisheries, global and regional coastal  
34 infrastructure, energy supply and demand, **temperature-related mortality, and global terrestrial biodiversity**).

## 35 **1 Introduction**

36 Societies are strongly influenced by weather and climate conditions. **It is generally understood that** persistent  
37 weather patterns influence lifestyle, infrastructures, and agricultural practices across climatic zones. **In**  
38 **addition**, individual weather events **can cause immediate economic damages and displacement.** However, the

1 precise translation of projected changes in weather and climate into societal impacts is complex and not yet  
2 fully understood or captured by predictive models (Warren, 2011). Empirical approaches have linked pure  
3 climate indicators like temperature or precipitation to highly-aggregated socio-economic indicators such as  
4 national Gross Domestic Product (GDP) (Burke et al., 2015; Dell et al., 2012), but do not resolve the underlying  
5 mechanisms. At the same time a growing array of detailed (process-based) models have been developed to  
6 translate projected changes in climate and weather into specific impacts on individual systems or processes,  
7 including: vegetation cover, crop yields, marine ecosystems and fishing potentials, frequency and intensity of  
8 river floods, coastal flooding due to sea level rise, water scarcity, distribution of vector-borne diseases, changes  
9 in biodiversity and ecosystem services, heat and cold-related mortality, labour productivity, and energy supply  
10 (e.g. hydropower potentials) or demand. These models provide a basis for a more process-based quantification  
11 of societal risks.

12 Traditionally, sector-specific impact models are constructed independently and do not interact (except for a  
13 few multi-sector models). However, by considering the behaviour of multiple sector specific models within a  
14 single simulation framework, it is possible to begin to assess the integrated impacts of climate change. Current  
15 damages from weather related natural disasters amount to about \$US95 billion per year on average over 1980-  
16 2014 (Munich Re, 2015) and, from 2008 to 2015, an estimated 21.5 million people per year were displaced by  
17 weather events (Internal Displacement Monitoring Centre and Norwegian Refugee Council, 2015) where the  
18 underlying causes are diverse: storms accounted for 51% of the economic damages of weather events, flood  
19 and mass movements induced 32%, and extreme temperatures, droughts and wildfire inflicted 17% of the  
20 overall losses. Displacement was mainly driven by floods (64%) and storms (35%), with minor contributions  
21 from extreme temperatures (0.6%), wet mass movement (0.4%), and wildfires (0.2%) (the more indirect effects  
22 of rainfall deficits and agricultural droughts on displacement are not even captured in these global statistics of  
23 displacement). Thus, projections of fluctuations and long-term trends in the most basic proxies of immediate  
24 disaster induced economic losses and displacements such as “exposed assets” or “number of people affected”  
25 require a range of different types of climate impacts models (e.g. hydrological models for flood risks, biomes  
26 models for risks of wildfires, crop models for heat or drought-induced crop failure), which have to be forced by  
27 the same climate input to allow for an aggregation of the respective impacts.

28 ISIMIP is designed to address this challenge by forcing a wide range of climate-impact models with the same  
29 climate and socio-economic input (Schellhuber et al., 2013, [www.isimip.org](http://www.isimip.org)) and by making the data publicly  
30 available (<https://www.isimip.org/protocol/terms-of-use/>), similarly to the climate simulations generated  
31 within the Coupled Model Intercomparison Project (CMIP, Taylor et al., 2012). In its first phase, the ISIMIP Fast  
32 Track provided the first set of cross-sectorally consistent, multi-model impact projections (Warszawski et al.,  
33 2014). The data are publicly available through <https://esg.pik-potsdam.de>. Now in its second phase, the first  
34 simulation round (ISIMIP2a) was dedicated to historical simulations with a view to detailed model evaluation,  
35 in particular with respect to the impacts of extreme events. So far, over 65 international modelling groups have

1 submitted data to the ISIMIP2a repository, which will be made publicly available in 2017. First sectoral  
2 packages of ISIMIP2a data are already available through <https://esg.pik-potsdam.de>. Here, we describe the  
3 simulation protocol and scientific rationale for the next round of simulations (ISIMIP2b). The protocol was  
4 developed in response to the planned IPCC Special Report on the 1.5°C target, reflecting the responsibility of  
5 the impacts-modelling community to provide the best scientific basis for political discussions about mitigation  
6 and adaptation measures. Importantly, the simulations also offer a broad basis for climate impacts research  
7 beyond the scope and time frame of the Special Report. Given the tight timeline the ISIMIP2b data will be  
8 made publicly available according to adjusted terms of use, superseding the usual embargo period  
9 (<https://www.isimip.org/protocol/terms-of-use/>). In this way the ISIMIP2b simulation data can be used by a  
10 wider community to extend the scientific evidence base for the Special Report..

11 In Paris, parties agreed on “...holding the increase in the global average temperature to well below 2 °C above  
12 pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels,  
13 recognizing that this would significantly reduce the risks and impacts of climate change.” (UNFCCC, 2015).  
14 While the statement “holding below 2°C” implies keeping global warming below the 2°C limit over the full  
15 course of the century and afterwards, “efforts to limit the temperature increase to 1.5°C” is often interpreted  
16 as allowing for a potential overshoot before returning to below 1.5°C (Rogelj et al., 2015). Given the remaining  
17 degrees of freedom regarding the timing of maximum warming and the length of an overshoot, the translation  
18 of emissions into global mean temperature change, and, even more importantly, the uncertainty in associated  
19 regional climate changes, a wide range of climate change scenarios, all consistent with these political targets,  
20 should be considered and multiple ways to reach a given target. However, the computational expense of  
21 climate and climate-impact projections limits the set of scenarios that can be feasibly computed. These should  
22 therefore be carefully selected to serve as the basis for efficient extrapolations of impacts to a wider range of  
23 relevant climate-change scenarios. In the ISIMIP2b protocol, the Representative Concentration Pathway (RCP)  
24 RCP2.6 was chosen, being the lowest emission scenario considered within CMIP5 and in line with a 1.5°C or 2°C  
25 limit of global warming depending on the definition and the considered Global Circulation Model (GCM). While  
26 there are plans within the next phase of CMIP to generate climate projections for a lower emission scenario  
27 (RCP2.0), these data will not be available in time to do the associated impacts projections for the Special  
28 Report.

29 The ISIMIP protocol covers a core set of scenarios that can be run by all participating impact-modelling groups,  
30 ensuring a minimal set of multi-model impact simulations consistent across sectors, and therefore allowing for  
31 cross-sectoral aggregation and integration of impacts. In Section 2 of the paper we outline the basic set of  
32 scenarios and the rationale for their selection. Sections 3-8 provide a more detailed description of the input  
33 data, i.e. climate input data, land use (LU) and irrigation patterns accounting for mitigation-related expansion  
34 of managed land (e.g. for bioenergy production), population and GDP data, and associated harmonized input  
35 representing other drivers on impact indicators. Section 9 provides exemplary information about the sector-

1 specific implementation of the different scenarios while **comprehensive up-to-date** lists of **sector-specific**  
2 **requested output variables, precise scenario descriptions, and detailed information about data formats etc. is**  
3 **included in a separate ISIMIP2b modelling protocol on the ISIMIP website ([www.isimip.org/protocol/#isimip2b](http://www.isimip.org/protocol/#isimip2b))**  
4 **that should be used as up-to-date reference by participating modelling groups when setting up and performing**  
5 **simulations.**

## 6 **2 The rationale of the basic scenario design**

7 Core **ISIMIP2b** simulations will focus on 1) quantification of impacts of the historical warming compared to pre-  
8 industrial reference levels (see Section 2.1, **Figure 1a**, Group 1), 2) quantification of the climate change effects  
9 based on **a strong mitigation pathway** and **a Business-As-Usual (BAU) pathway** assuming fixed, present-day  
10 management, land-use and irrigation patterns and societal conditions (see Section 2.2, **Figure 1a**, Group 2)  
11 including a quantification of the long-term effects of low-level global warming following a potential overshoot  
12 based on an **extension of the strong mitigation pathway** to 2299, and 3) quantification of the impacts of “low-  
13 level” (~1.5°C) global warming based on **the strong mitigation and BAU pathway**, while accounting for  
14 additional (human) influences such as changes in management and LU patterns in response to population  
15 growth and bioenergy demand (see Section 2.3, **Figure 1b**, Group 3).

16 To ensure wide sectoral coverage by a large number of impact models, the set of scenarios is restricted to 1)  
17 **the SSP2 socio-economic storyline** representing middle-of-the-road socio-economic development concerning  
18 population and mitigation and adaptation challenges (O’Neill et al., 2014) (see Section 5); 2) climate input from  
19 four global climate models (GCMs) (see Section 3), 3) simulations of the historical period, and future  
20 projections for **a no-mitigation baseline scenario (SSP2 + RCP6.0)** (Fricko et al., 2016) and the strong mitigation  
21 scenario (SSP2 + RCP2.6) closest to the global warming limits agreed on in Paris (see Section 3); and 4)  
22 representation of potential **changes in LU, irrigation and fertilizer input** associated with SSP2 + RCP6.0  
23 (**LU\_ISIMIP2b\_ssp2\_rcp60**) and SSP2 + RCP2.6 (**LU\_ISIMIP2b\_ssp2\_rcp26**) as generated by the global LU model  
24 MAgPIE (Model of Agricultural Production and its Impact on the Environment, Lotze-Campen et al., 2008; Popp  
25 et al., 2014a; Stevanović et al., 2016) **and adjusted to ensure a smooth transition from historical patterns.**  
26 **MAgPIE simulations** account for climate-induced changes in crop production, water availability and terrestrial  
27 carbon content and differential bio-energy application (see Section 4).

### 28 **2.1 Quantification of pure climate-change effects of the historical warming compared to pre-industrial** 29 **reference levels (Figure 1a, Group 1)**

30 The Paris Agreement explicitly asks for an assessment of “the impacts of global warming of 1.5°C above pre-  
31 industrial levels”, **particularly including a quantification of impacts of the historical warming to about ~1°C.**  
32 Usually, impact projections (such as those generated within the ISIMIP Fast Track, Warszawski et al., 2013) only  
33 allow for a quantification of projected impacts (of say 1.5°C warming) compared to “present day” or “recent

1 past” reference levels, because the impacts model simulations rarely cover the pre-industrial period. This  
2 severely restricts the opportunities to gain a better understanding of climate-change impacts already unfolding  
3 and the options to address questions associated with the “detection and attribution” of historical impacts in  
4 the context of the “loss and damage” debate (James et al., 2014). In the Fifth Assessment Report of the  
5 Intergovernmental Panel on Climate Change (IPCC AR5), an entire chapter is dedicated to the detection and  
6 attribution of observed climate-change impacts (Cramer et al., 2014). However, the conclusions that can be  
7 drawn are limited by: 1) the lack of long-term and homogeneous observational data, and 2) the confounding  
8 influence of other drivers such as population growth and management changes (e.g. expansion of agriculture in  
9 response to growing food demand, changes in irrigation water withdrawal, building of dams and reservoirs,  
10 changes in fertilizer input, and switching to other crop varieties) on climate impact indicators such as river  
11 discharge, crop yields and energy demand etc.. For the historical period these other influences may also  
12 comprise known natural disturbances such as wild fires, outbreaks of diseases and pests etc. that could be  
13 considered as external drivers in part of the models. However, for simplicity we refer to the entire group of  
14 external drivers as “socio-economic conditions” throughout the paper. Over the historical period, these  
15 influences have evolved simultaneously with climate, rendering the quantification of the pure climate-change  
16 signal difficult. Model simulations could help to fill these gaps and could become essential tools to separate the  
17 effects of climate change from other historical drivers. To address these challenges the ISIMIP2b protocol  
18 includes: 1) a multi-centennial pre-industrial reference simulation (picontrol + fixed pre-industrial socio-  
19 economic conditions (1860soc), 1660-1860); 2) historical simulations accounting for varying socio-economic  
20 conditions but assuming pre-industrial climate (picontrol + histsoc, 1861-2005); 3) historical impact simulations  
21 accounting for varying socio-economic conditions and climate change (historical + histsoc, 1861-2005). These  
22 scenarios facilitate the separation of the effects of historical warming (as simulated by GCMs) from the other  
23 drivers by taking the difference between the two model runs covering the historical period. The full period of  
24 historical simulation results also allows for cross-sectorial assessments of when the climate signal becomes  
25 significant. In addition, the control simulations will provide a large sample of pre-industrial reference conditions  
26 allowing for robust determination of extreme-value statistics (e.g. the water levels of one hundred year flood  
27 events) and e.g. the typical spatial distribution of impacts associated with certain large-scale circulation  
28 patterns such as El Nino (Iizumi et al., 2014; Ward et al., 2014) or other circulation regimes capable of  
29 synchronising the occurrence of extreme events across sectors and regions (Coumou et al., 2014; Francis and  
30 Vavrus, 2012). In addition, the pre-industrial reference represents more realistic starting (and spin-up)  
31 conditions for e.g. the vegetation models or marine ecosystem models compared to artificial “equilibrium  
32 present day” conditions as used in the ISIMIP fast track.

33 For models that are not designed to represent temporal changes in LU patterns or socio-economic conditions  
34 simulations should be based on constant present day (year 2005) societal conditions (“2005soc”, dashed line in  
35 Figure 1a). Modelling teams whose models do not account for any human influences are also invited to  
36 contribute simulations for Group 1 and Group 2 based on naturalized settings (to be labelled “nosoc”). A

1 detailed documentation of the individual model-specific settings implemented by the different modelling  
2 groups will be made accessible on the ISIMIP website (see [www.isimip.org/impactmodels](http://www.isimip.org/impactmodels)).

### 3 **2.2 Future impact projections accounting for low and high Greenhouse gas emissions assuming present day** 4 **socio-economic conditions (Figure 1a, Group 2)**

5 To quantify the pure effect of additional warming to 1.5°C or higher above pre-industrial levels, the scenario  
6 choice includes a group of future projections assuming socio-economic conditions fixed at present day (chosen  
7 to be 2005) conditions (2005soc, see Figure 1a, Group 2). The Group 2 simulations start from the Group 1  
8 simulations and assume: 1) fixed, year 2005 socio-economic conditions but pre-industrial climate (picontrol +  
9 2005soc, 2006-2099), 2) fixed year 2005 socio-economic conditions and climate change under the strong-  
10 mitigation scenario RCP2.6 (rcp26 + 2005soc, 2006-2099), 3) fixed year 2005 socio-economic conditions and  
11 climate change under the no-mitigation scenario RCP6.0 (rcp60 + 2005soc, 2006-2099), and 4) extension of the  
12 RCP2.6 simulations to 2299 assuming socio-economic conditions fixed at year 2005 levels (rcp26 + 2005soc,  
13 2101-2299). In this way, the distribution of impact indicators within certain time windows, in which global  
14 warming is around e.g. 1.5°C or 2°C, can be compared without the confounding effects of other drivers that  
15 vary with time (e.g. Fischer and Knutti, 2015; Schleussner et al., 2015). In particular, the impacts at these future  
16 levels of warming can be compared to the pre-industrial reference climate, assuming a representation of pre-  
17 industrial levels of socio-economic conditions (picontrol + 1860soc, Group 1) and pre-industrial reference  
18 climate but present-day levels of socio-economic conditions (picontrol + 2005soc, Group 2).

19 The extension of the RCP2.6 projections to 2299 is important because: 1) global mean temperature may only  
20 return to warming levels below 2°C after 2100 (see HadGEM2-ES and IPSL-CM5A-LR, Figure 2), and 2) impacts  
21 of global warming will not necessarily emerge in parallel with global mean temperature change, because, for  
22 example, climate models show a hysteresis in the response of the hydrological cycle due to ocean inertia (Wu  
23 et al., 2010). Similarly, sea-level rise associated with a certain level of global warming will only fully manifest  
24 over millennia. In addition to the lagged responses of climate to Greenhouse gas emissions, there is additional  
25 inertia in the affected systems (such as vegetation changes and permafrost thawing) that will delay responses.  
26 Thus, an assessment of the risks associated with 1.5°C global warming requires simulations of impacts when  
27 1.5°C global warming is reached, as well as of the impacts when global warming returns to 1.5°C and stabilizes.  
28 The characteristic peak and decline in global mean temperature associated with RCP2.6 (depending on the  
29 climate model) will help to get a better understanding of the associated impacts dynamics. This could be used  
30 to derive reduced-form approximations of the complex-model simulations, allowing for a scaling of the impacts  
31 to other global-mean-temperature and CO<sub>2</sub> pathways by e.g. identifying the functional relationships between  
32 global mean temperature change and the considered impact in case of instantaneous responses (Hirabayashi et  
33 al., 2013) or using approaches that allow for delayed responses of the system under consideration (Mengel et  
34 al., 2016; Winkelmann and Levermann, 2013). In each case simplified models trained in RCP2.6 could be tested

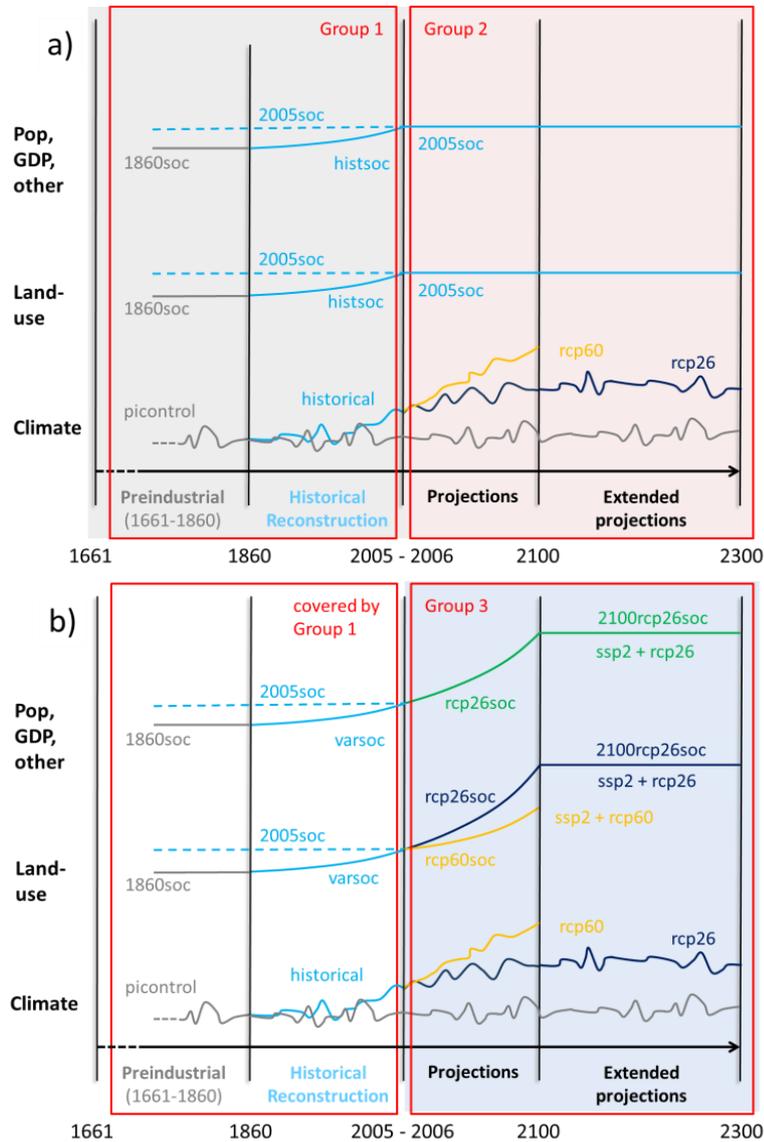
1 on RCP6.0. Providing the basis for the development of these tools is critical given the range of scenarios  
2 consistent with the temperature goals as described in the Paris agreement.

3 Depending on the time scale of stabilization of the climate and the lag in the response of the impacts to climate  
4 change the extension of the simulations to 2299 could provide a sample of a relatively stable distribution of  
5 impacts associated with RCP2.6 levels of emissions. Similar to the 200-year pre-industrial reference  
6 simulations, this sample could provide a basis for the estimation of extreme-value distributions that can be  
7 compared to the associated pre-industrial reference distributions (picontrol + 1860soc (Group 1) or picontrol +  
8 2005soc (Group 2)).

### 9 **2.3 Future impact projections accounting for low and high levels of climate change accounting for** 10 **socioeconomic changes (Figure 1b, Group 3)**

11 Future projections of the impacts of climate change also depend on future socio-economic development. For  
12 example many impact indicators such as “number of people affected by flood events” (Hirabayashi et al., 2013)  
13 or “number of people affected by long-term changes going beyond a certain range of the reference  
14 distribution” (Piontek et al., 2014) directly depend on population projections (exposure) or socio-economic  
15 conditions e.g. reflected in flood protection levels (vulnerability). While socio-economic drivers can partly be  
16 accounted for in post-processing (e.g. for the number of people affected by tropical cyclones) others are  
17 directly represented in the models such as dams and reservoirs or LU changes. To capture the associated  
18 effects on the impact indicators, the ISIMIP2b protocol contains a set of future projections accounting for  
19 potential changes in socio-economic conditions (e.g. rcp26soc), building on the SSP2 story line (see Figure 1b,  
20 Group 3). The relevance and representation of specific socio-economic drivers strongly differs from sector to  
21 sector or impact model to impact model. Here, we focus on changes 1) in population patterns and national GDP  
22 (see Section 6), 2) land-use, irrigation patterns and fertilizer input (see Section 4), and 3) nitrogen deposition  
23 (see Section 7). However, even beyond these indicators, models that represent other individual drivers should  
24 account for associated changes according to their own implementation of the SSP2 storyline. The simulations  
25 start from the Group 1 simulations and assume 1) future changes in human influences but pre-industrial  
26 climate (picontrol + rpc26soc or rcp60soc, 2006-2099), 2) future changes in human influences and climate  
27 change under the strong mitigation scenario RCP2.6 (rcp26 + rcp26soc, 2006-2099), 3) future changes in human  
28 influences and climate change under the no-mitigation scenario RCP6.0 (rcp60 + rcp60soc, 2006-2099), and 4)  
29 and extension of the RCP2.6 simulations to 2299 assuming human influences fixed at 2100 levels (rcp26 +  
30 2100rcp26soc, 2101-2299).

31 The representation of changes in LU, irrigation, and fertilizer input is particularly challenging as it should be  
32 consistent with historical records, and future changes are affected by multiple factors including 1) population  
33 growth, 2) changing diets under economic development, 3) climate-change effects on crop yields, and 4)  
34 bioenergy demand associated with the level of climate change mitigation. The ISIMIP2b protocol is designed to  
35 account for all these aspects (see Section 4). Using associated LU patterns in the impact models participating in



1 ISIMIP2b will allow for the assessment of potential side-effects of certain transformations of the energy system  
 2 associated with a 1.5°C global-mean-temperature limit, such as the allocation of land areas to bioenergy  
 3 production. The scenario design will facilitate estimation of the consequences of the suggested LU changes in  
 4 comparison to the avoided impacts of climate change.

5

6

7

8 **Figure 1** Schematic representation of the scenario design for ISIMIP2b. “Other” includes other non-climatic forcing factors  
 9 such as fertilizer input, irrigation, selection of crop varieties, flood protection levels, dams and reservoirs, water abstraction  
 10 for human use, fishing effort, atmospheric nitrogen deposition, etc. Panel a) shows the Group 1 and Group 2 runs. Group 1  
 11 consists of model runs to separate the pure effect of the historical climate change from other (human) influences. Models  
 12 that cannot account for changes in a particular forcing factor are asked to hold that forcing factor at 2005 levels (2005soc,  
 13 dashed lines). Group 2 consists of model runs to estimate the pure effect of the future climate change assuming fixed year  
 14 2005 levels of population, economic development, LU and management (2005soc). Panel b) shows Group 3 runs. Group 3

1 consists of model runs to quantify the effects of the LU changes, and changes in population, GDP, and management from  
2 2005 onwards associated with RCP6.0 (no mitigation scenario under SSP2) and RCP2.6 (strong mitigation scenario under  
3 SSP2). Forcing factors for which no future scenarios exist (e.g. dams/reservoirs) are held constant after 2005.

### 4 **3 Climate input data**

5 **Bias-adjusted** climate input data at daily temporal and 0.5° horizontal resolution representing pre-industrial,  
6 historical and future (RCP2.6 and RCP6.0) conditions will be provided based on CMIP5 output of GFDL-ESM2M,  
7 HadGEM2-ES, IPSL-CM5A-LR and MIROC5. Output from the first three of these four GCMs was already used in  
8 the ISIMIP fast track. In contrast to the ISIMIP fast track we will also provide **bias-adjusted** atmospheric data  
9 over the ocean, which is, for example, relevant for the impacts on offshore **wind** energy generation or the  
10 physical representation of coastal flooding. Output from two of the GCMs (GFDL-ESM2M and IPSL-CM5A-LR)  
11 includes the physical and biogeochemical ocean data required by the marine ecosystem sector of ISIMIP (see  
12 FISH-MIP, [www.isimip.org/gettingstarted/marine-ecosystems-fisheries/](http://www.isimip.org/gettingstarted/marine-ecosystems-fisheries/)). The fast-track model NorESM1-M was  
13 taken out of the selection due to the unavailability of near-surface wind data, and MIROC-ESM-CHEM was  
14 replaced by MIROC5, which in comparison features twice the horizontal atmospheric resolution (Watanabe et  
15 al., 2010, 2011), a lower equilibrium climate sensitivity (Flato et al., 2013), a smaller temperature drift in the  
16 pre-industrial control run (0.36°C/ka compared to 0.93°C/ka), and more realistic representations of ENSO  
17 (Bellenger et al., 2014), the Asian summer monsoon (Sperber et al., 2013) and North Atlantic extratropical  
18 cyclones (Zappa et al., 2013) during the historical period.

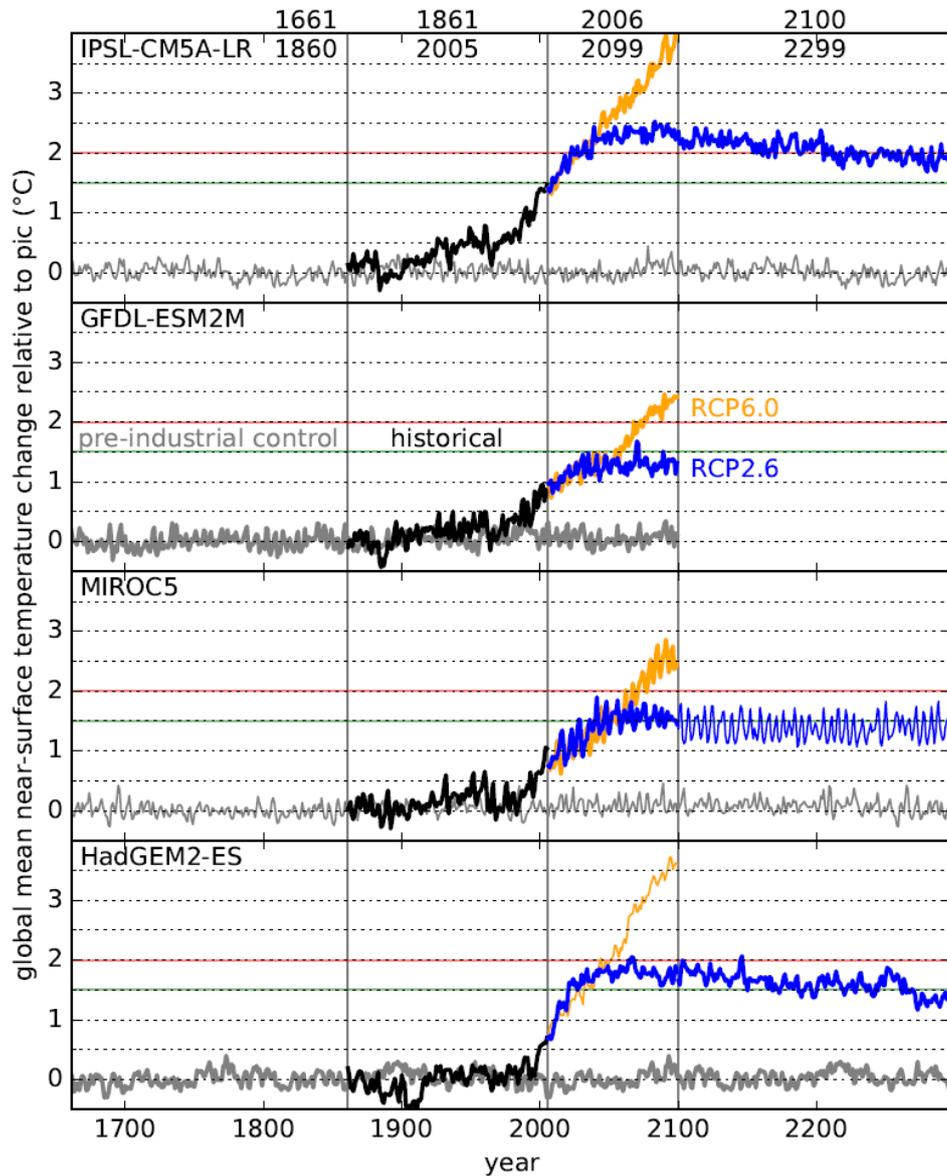
19 GCM selection was heavily constrained by CMIP5 data availability since we employed a strict climate input data  
20 policy to facilitate unrestricted cross-sectoral impact assessments. In order to be included in the selection, daily  
21 CMIP5 GCM output had to be available for the atmospheric variables listed in Table 1 covering at least **200** pre-  
22 industrial control years, the whole historical period from 1861 to 2005, and RCP2.6 and RCP6.0 from 2006 to  
23 2099 each. **Originally**, these requirements **were** completely met for GFDL-ESM2M, IPSL-CM5A-LR and MIROC5.  
24 **Gaps** in HadGEM2-ES data (see Figure 2) **were** filled by re-running the model accordingly.

25 **The small number of only four GCMs is not sufficient to span the range of regional climate changes projected**  
26 **by the entire CMIP5 ensemble. Figure S7 and S8 of the SI allow for a comparison of the regional temperature**  
27 **and precipitation changes as projected by the selected GCMs to the projections of the entire CMIP5 ensemble**  
28 **of GCMs. The comparison is provided for all ISIMIP2b focus regions (see Figure 6) that will be covered by**  
29 **regional hydrological simulations (selected river basins) and simulations of changes in marine ecosystems and**  
30 **fisheries (selected ocean Sections). Figure S9 provides an additional analysis of the Fractional Range Coverage**  
31 **(FRC; McSweeney and Jones, 2016) of these regional climate change signals by the ISIMIP2b set of GCMs. While**  
32 **originally chosen on the basis of climate input data requirements, the four selected GCMs provide an FRC close**  
33 **to the mean FRC across randomly chosen four-member sets of CMIP5 GCMs.**

1 Data from IPSL-CM5A-LR and GFDL-ESM2M are the first and second priority climate input data sets  
2 respectively, since these GCMs provide all the monthly ocean data required by FISH-MIP and since IPSL-CM5A-  
3 LR additionally offers an extended RCP2.6 projection. That means impacts modelling groups that do not have  
4 the capacities to do all simulations described in the ISIMIP2b protocol should start to force their model by the  
5 IPSL-CM5A-LR data and then continue with the GFDL-ESM2M runs if possible. Usage of MIROC5 data is of third  
6 priority. Since the HadGEM2-ES climate input data only became available at a later stage in the project, it is the  
7 fourth priority.

8 Global-mean-temperature projections from IPSL-CM5A-LR and HadGEM2-ES under RCP2.6 exceed 1.5°C  
9 relative to pre-industrial levels in the second half of the 21<sup>st</sup> century (see Figure 2). While global-mean-  
10 temperature change returns to 1.5°C or even slightly lower by 2299 in HadGEM2-ES, it only reaches about 2°C  
11 in IPSL-CM5A-LR by 2299. For GFDL-ESM2M, global-mean-temperature change stays below 1.5°C until 2100.  
12 For MIROC5, it stabilizes at about 1.5°C during the second half of the 21<sup>st</sup> century.

13 For HadGEM2-ES, IPSL-CM5A-LR and MIROC5, it was necessary to recycle pre-industrial control climate data in  
14 order to fill the entire 1661–2299 period. Based on available data, the recycled time series start after the first  
15 320 (HadGEM2-ES), 440 (IPSL-CM5A-LR) and 570 (MIROC5) pre-industrial control years, which means that pre-  
16 industrial control climate data from 1981, 2101 and 2231 onwards are identical to those from 1661 onwards,  
17 respectively. For GFDL-ESM2M, no such recycling was necessary. For all four GCMs, temperature drifts in the  
18 pre-industrial control run are considered sufficiently small relative to inter-annual variability and temperature  
19 changes in the historical and future periods, so that de-trending pre-industrial control climate data was  
20 deemed unnecessary.



1

2 **Figure 2** Time series of annual global mean near-surface temperature change relative to pre-industrial levels (1361-1860) as  
 3 simulated with IPSL-CM5A-LR, GFDL-ESM2M, MIROC5 and HadGEM2-ES (from top to bottom). Colour coding indicates the  
 4 underlying CMIP5 experiments (grey: pre-industrial control, black: historical, blue: RCP2.6, yellow: RCP6.0) with  
 5 corresponding time periods given at the top. Thick lines indicate model-experiment combinations for which 3-hourly  
 6 climate input data are available (cf. Table 2).

7

### 8 **3.1 Bias adjusted atmospheric GCM data**

9 For most variables, the provided atmospheric GCM data have been bias-adjusted using slightly modified  
 10 versions of the ISIMIP fast-track methods, which adjusts multi-year monthly mean values, such that trends are  
 11 preserved in absolute and relative terms for temperature and non-negative variables respectively, and derive  
 12 transfer functions to adjust the distributions of daily anomalies from monthly mean values (Hempel et al.,

1 2013). Known issues of the **Fast-Track** methods are: 1) humidity was not **adjusted** since the methods were not  
 2 designed for variables with both lower and upper bounds, such as relative humidity, and since their application  
 3 to specific humidity yields relative humidity statistics that compare poorly with those observed; 2) **bias-**  
 4 **adjusted** daily mean shortwave radiation values too frequently exceed  $500 \text{ W m}^{-2}$  over Antarctica and high-  
 5 elevation sites; 3) **for pressure, wind speed, longwave and shortwave radiation they produce noticeable**  
 6 **discontinuities in daily climatologies at each turn of the month, similar to those found by** (Rust et al., 2015); 4)  
 7 they occasionally generate spuriously high precipitation events in semi-arid regions, and 5) they do not adjust  
 8 the inter-annual variability of monthly mean values, which would be an important improvement for the  
 9 purpose of impact projections (Sippel et al., 2016). While 5) and 4) are items of future work, problems 3), 2)  
 10 and 1) were solved through modifications of the **methods of adjustment** for pressure, wind speed and  
 11 longwave radiation (see below), and by using newly developed, approximately trend-preserving **bias**  
 12 **adjustment** methods for relative humidity and shortwave radiation (Lange et al., 2017a). **The known issues and**  
 13 **their solutions are described in more detail in an associated Fact Sheet**  
 14 **(<https://www.isimip.org/gettingstarted/isimip2b-bias-correction/>).**

15 In addition to these adjustments, we **adjust** to a new reference data set. While in the fast track, WATCH forcing  
 16 data (Weedon et al., 2011) were employed for **bias adjustment**, the ISIMIP2b forcing data are **adjusted** to the  
 17 newly compiled reference dataset EWEMBI (E2OBS, WFDEI and ERAI data Merged and Bias-corrected for  
 18 ISIMIP; Lange, 2016), which covers the entire globe at  $0.5^\circ$  horizontal and daily temporal resolution from 1979  
 19 to 2013. Data sources of EWEMBI are ERA-Interim reanalysis data (ERA-I; Dee et al., 2011), WATCH forcing data  
 20 methodology applied to ERA-Interim reanalysis data (WFDEI; Weedon et al., 2014), earth2Observe forcing data  
 21 (E2OBS; Dutra, 2015) and NASA/GEWEX Surface Radiation Budget data (SRB; Stackhouse Jr. et al., 2011). The  
 22 SRB data were used to bias-adjust E2OBS shortwave and longwave radiation using a new method that has been  
 23 developed particularly for this purpose (Lange et al., 2017b) in order to reduce known deviations of E2OBS  
 24 radiation statistics from the respective SRB estimates over tropical land (Dutra, 2015). Data sources of  
 25 individual EWEMBI variables are given in **Table 1**.

26 **Table 1** Data sources of individual variables of the EWEMBI dataset (Lange, 2016). Note that E2OBS data are identical to  
 27 WFDEI over land and ERAI over the ocean, except for precipitation over the ocean, which was bias-adjusted using GPCPv2.1  
 28 monthly precipitation totals (Balsamo et al., 2015; Dutra, 2015). WFDEI-GPCC means WFDEI with GPCCv5/v6 monthly  
 29 precipitation totals used for bias adjustment (Weedon et al., 2014; note that the WFDEI precipitation products included in  
 30 E2OBS were those that were bias-adjusted with CRU TS3.101/TS3.21 monthly precipitation totals). E2OBS-SRB means  
 31 E2OBS with SRB daily mean radiation used for bias adjustment (Lange et al., 2017b). E2OBS-ERAI means E2OBS everywhere  
 32 except over Greenland and Iceland (cf. Weedon et al., 2010, p. 9), where monthly mean diurnal temperature ranges were  
 33 restored to those of ERAI using the Sheffield et al. (2006) method. Note that precipitation here means total precipitation,  
 34 i.e., rainfall plus snowfall.

Variable	Short name	Unit	Source dataset over land	Source dataset over the ocean
Near-Surface Relative Humidity	hurs	%	E2OBS	E2OBS
Near-Surface Specific Humidity	huss	$\text{kg kg}^{-1}$	E2OBS	E2OBS

Precipitation	pr	$\text{kg m}^{-2} \text{s}^{-1}$	WFDEI-GPCC	E2OBS
Snowfall Flux	prsn	$\text{kg m}^{-2} \text{s}^{-1}$	WFDEI-GPCC	E2OBS
Surface Pressure	ps	Pa	E2OBS	E2OBS
Sea Level Pressure	psl	Pa	E2OBS	E2OBS
Surface Downwelling Longwave Radiation	rlds	$\text{W m}^{-2}$	E2OBS-SRB	E2OBS-SRB
Surface Downwelling Shortwave Radiation	rsds	$\text{W m}^{-2}$	E2OBS-SRB	E2OBS-SRB
Near-Surface Wind Speed	sfcWind	$\text{m s}^{-1}$	E2OBS	E2OBS
Near-Surface Air Temperature	tas	K	E2OBS	E2OBS
Daily Maximum Near-Surface Air Temperature	tasmax	K	E2OBS-ERA1	E2OBS
Daily Minimum Near-Surface Air Temperature	tasmin	K	E2OBS-ERA1	E2OBS

1 The bias **adjustment** was performed on the regular  $0.5^\circ$  EWEMBI grid, to which raw CMIP5 GCM data were  
2 interpolated with a first-order conservative remapping scheme (Jones, 1999). GCM-to-EWEMBI transfer-  
3 function coefficients were calculated based on GCM data from the historical and RCP8.5 CMIP5 experiments  
4 representing the periods 1979–2005 and 2006–2013, respectively.

5 The variables pr, prsn, rlds, sfcWind, tas, tasmax and tasmin were **bias adjusted** as described by Hempel et al.  
6 (2013), except that we defined dry days using a modified threshold value of 0.1 mm/day, since this value was  
7 used to **adjust** WFDEI dry-day frequencies (Harris et al., 2013; Weedon et al., 2014). Also, in order to prevent  
8 the bias **adjustment** from creating unrealistically extreme temperatures, we introduced a maximum value of 3  
9 for the **adjustment** factors of  $\text{tas} - \text{tasmin}$  and  $\text{tasmax} - \text{tas}$  (cf. Hempel et al., 2013, Eq. (25)) and limited **tas**,  
10 **tasmin** and **tasmax** to the range  $[-90^\circ\text{C}, 60^\circ\text{C}]$ . These limits are in line with  $-89.2^\circ\text{C}$  and  $54.0^\circ\text{C}$ , the lowest and  
11 highest near-surface temperatures ever recorded on Earth if the 1913 Death Valley reading of  $56.7^\circ\text{C}$  and other  
12 similarly controversial observations beyond  $54.0^\circ\text{C}$  are taken out of consideration  
13 (<https://wmo.asu.edu/content/global-weather-climate-extremes>,  
14 [https://www.wunderground.com/blog/weatherhistorian/hottest-reliably-measured-air-temperatures-on-](https://www.wunderground.com/blog/weatherhistorian/hottest-reliably-measured-air-temperatures-on-earth.html)  
15 [earth.html](https://www.wunderground.com/blog/weatherhistorian/hottest-reliably-measured-air-temperatures-on-earth.html)). Lastly, in order to avoid discontinuities in daily climatologies of bias-adjusted rlds and sfcWind at  
16 the end of each month, a slightly adjusted version of the approach used to interpolate between monthly  
17 transfer function coefficients in the adjustment methods for tas, tasmax and tasmin (Hempel et al., 2013, Eqs.  
18 (16–20)) is now also applied to the adjustment factor of multi-year monthly mean rlds and sfcWind (Hempel et  
19 al., 2013, Eq. (4)) in the adjustment methods for these variables.

1 Bias-adjusted surface pressure was obtained from CMIP5 output of sea level pressure (psl) in three steps. First,  
2 EWEMBI ps was reduced to EWEMBI psl using EWEMBI tas, WFDEI surface elevation over land except  
3 Antarctica and ERAI surface elevation for Antarctica, and

$$psl = ps * \exp\left[\frac{g * z}{R * tas}\right], (1)$$

4 where z is surface elevation, g is gravity and R is the specific gas constant of dry air. Simulated psl was then  
5 adjusted using EWEMBI psl and the tas adjustment method described by Hempel et al. (2013). Finally, the bias-  
6 adjusted psl was transformed to a bias-adjusted ps using (1) with WFDEI and ERAI surface elevation and bias-  
7 adjusted tas. As alluded to above, hurs and rsds were bias adjusted using newly developed methods which  
8 respect the lower and upper limits that these variables are exposed to (Lange et al., 2017a). A bias- adjusted  
9 huss consistent with bias- adjusted hurs, ps and tas was calculated using the equations of Buck (1981) as  
10 described in Weedon et al. (2010). In contrast to the ISIMIP fast track we decided against adjusting the wind  
11 components uas and vas to match the adjusted total daily mean velocity as the calculation of the total velocity  
12 from wind components is non-linear, i.e. the total velocity calculated from daily means of the wind  
13 components is not equal to the daily mean of total wind velocities. A suitable solution was not found at the  
14 time of the study. Therefore, the inconsistency has to be kept in mind when comparing models using adjusted  
15 total wind velocity to others using non-adjusted wind components. Information about the considered input  
16 data will be documented on the ISIMIP website (<https://www.isimip.org/impactmodels/>). We provide  
17 unadjusted 3-hourly sea level pressure and near-surface eastward and northward wind data as e.g. relevant for  
18 the costal infrastructure and energy sector (see Table 2).

### 19 **3.2 Tropical cyclones**

20 The input data set comprises projections of tropical cyclones based on the dynamical downscaling technique  
21 described in detail by (Emanuel et al., 2008). To generate a large sample of potential cyclone tracks and wind  
22 speeds the underlying model is provided with unadjusted depth-resolved sea water potential temperature, sea  
23 surface temperature, air temperature and specific humidity at all atmospheric model levels, and eastward and  
24 northward wind at 250 and 850 hPa levels.

25 Broadly, the technique begins by randomly seeding with weak proto-cyclones the large-scale, time-evolving  
26 state given by the GCM climate model data. These seed disturbances are assumed to move with the GCM-  
27 provided large-scale flow in which they are embedded, plus a westward and poleward component owing to  
28 planetary curvature and rotation. Their intensity is calculated using the Coupled Hurricane Intensity Prediction  
29 System (CHIPS; Emanuel et al., 2004), a simple axisymmetric hurricane model coupled to a reduced upper  
30 ocean model to account for the effects of upper ocean mixing of cold water to the surface. Applied to the  
31 synthetically generated tracks, this model predicts that a large majority of the disturbances dissipate owing to  
32 unfavorable environments. Only the 'fittest' storms survive; thus the technique relies on a kind of natural

1 selection. Extensive comparisons to historical events by Emanuel et al. (2008) and subsequent papers provide  
 2 confidence that the statistical properties of the simulated events are in line with those of historical tropical  
 3 cyclones. Seeding is adjusted to provide a sample of 300 potential realizations of tropical cyclones globally each  
 4 year and for each of the selected GCMs, for the historical period (1950-2005), and RCP2.6 and RCP6.0 based  
 5 future projections (2006-2099), yielding a total of 16,800 simulated tropical cyclones for each model in the  
 6 historical period, and 28,500 simulated cyclones per model and future scenario. In addition, we derive the  
 7 expected global number of tropical cyclones for each year. The response to global warming of both the  
 8 frequency and intensity of the synthetic events compares favorably to that of more standard downscaling  
 9 methods applied to the Coupled Model Intercomparison Project 3 (CMIP3) generation of climate models  
 10 (Christensen et al., 2013).

11 **Table 2** 3-hourly data GCM data (not bias adjusted) and tropical cyclone information provided within ISIMIP2

Variable	Short name	Unit	Temporal resolution
<b>Atmospheric variables (e.g. for coastal infrastructure or energy sector)</b>			
Sea Level Pressure	psl	Pa	3-hourly
Eastward Near-Surface Wind	uas	m s <sup>-1</sup>	3-hourly
Northward Near-Surface Wind	vas	m s <sup>-1</sup>	3-hourly
<b>Tropical cyclones (e.g. for coastal infrastructure sector)</b>			
latitude of cyclone center	latstore	degrees	2-hourly
longitude of cyclone center	longstore	degrees	2-hourly
minimum central pressure	pstore	hPa	2-hourly
1-min maximum sustained wind speed	vstore	m s <sup>-1</sup>	2-hourly
radius of maximum winds	rmstore	km	2-hourly
expected number of cyclones per year	freqyear		annual

12

### 13 3.3 Oceanic data

14 In order to cover the special data needs of FISH-MIP, we additionally provide unadjusted depth-resolved,  
 15 depth-integrated, surface and bottom oceanic data at monthly temporal resolution (see Table 3).

16 **Table 3** Oceanic data provided without bias-adjustment.

Variable	Short name	Unit	Temporal resolution
<b>Ocean variables (for marine ecosystems &amp; fisheries sector)</b>			
Depth-resolved monthly mean Sea Water Potential Temperature	thetao	K	monthly
Sea Surface Temperature	tos	K	monthly

Sea Water X Velocity	uo	$\text{m s}^{-1}$	monthly
Sea Water Y Velocity	vo	$\text{m s}^{-1}$	monthly
Sea Water Z Velocity	wo	$\text{m s}^{-1}$	monthly
Sea Water Temperature	to	K	monthly
Dissolved Oxygen Concentration	o2	$\text{mol m}^{-3}$	monthly
Total Primary Organic Carbon Production (by all types of phytoplankton) [calculated as sum of lpp + spp (IPSL) or sum of lpp + spp + dpp (GFDL)]	intpp	$\text{mol C m}^{-2} \text{s}^{-1}$	monthly
Small Phytoplankton Productivity	spp	$\text{mol C m}^{-3} \text{s}^{-1}$	monthly
Large Phytoplankton Productivity	lpp	$\text{mol C m}^{-3} \text{s}^{-1}$	monthly
Diazotroph Primary Productivity	dpp	$\text{mol C m}^{-3} \text{s}^{-1}$	monthly
Total Phytoplankton Carbon Concentration [sum of lphy + sphy (IPSL) or lphy + sphy + dphy (GFDL)]	phy	$\text{mol C m}^{-3}$	monthly
Small Phytoplankton Carbon Concentration	sphy	$\text{mol C m}^{-3}$	monthly
Large Phytoplankton Carbon Concentration	lphy	$\text{mol C m}^{-3}$	monthly
Diazotroph Carbon Concentration	dphy [diaz]	$\text{mol C m}^{-3}$	monthly
Total Zooplankton Carbon Concentration [sum of lzoo + szoo]	zoo	$\text{mol C m}^{-3}$	monthly
Small Zooplankton Carbon Concentration	szoo	$\text{mol C m}^{-3}$	monthly
Large Zooplankton Carbon Concentration	lzoo	$\text{mol C m}^{-3}$	monthly
pH	ph	1	monthly
Sea Water Salinity	so	psu	monthly
Sea Ice Fraction	sic	%	monthly
Large size-class particulate organic carbon pool	goc	$\text{mmol C m}^{-3}$	monthly
Photosynthetically-active radiation	Par	$\text{Einstein m}^{-2} \text{day}^{-1}$	monthly

1

## 2 **4 Land-use Patterns**

3 The second component of the request for the 1.5°C special report refers to an assessment of “related global  
4 greenhouse gas emission pathways”. ISIMIP2b will address this issue by assessing the impacts of the socio-  
5 economic changes associated with the considered RCPs insofar as they are reflected in LU and agricultural  
6 management changes (irrigation and fertilizer input).

7 Future projections of LU, irrigation fractions and fertilizer input are based on the LU model MAgPIE (Popp et al.,  
8 2014a; Stevanović et al., 2016) where bioenergy demand and greenhouse gas prices were provided by the  
9 MAgPIE-REMIND assessment, assuming population growth and economic development according to the SSP2  
10 storyline (Popp et al., 2017). LU patterns derived by MAgPIE are designed to ensure demand-fulfilling food  
11 production where demand is externally prescribed based on an extrapolation of historical relationships

1 between population and GDP on national levels (Bodirsky et al., 2015). In contrast to the standard SSP  
2 scenarios generated within an Integrated Assessment Model scenario process (Riahi et al., 2017), LU changes  
3 assessed for ISIMIP2b additionally account for climate and atmospheric CO<sub>2</sub> fertilization effects on the  
4 underlying patterns of potential crop yields, water availability and terrestrial carbon content. To this end the  
5 underlying crop, water, and biomes simulations by the LPJmL model are forced by atmospheric CO<sub>2</sub>  
6 concentrations and patterns of climate change associated with RCP6.0 or RCP2.6, respectively. Potential crop  
7 production under rain-fed conditions as well as full irrigation were generated by the global gridded crop  
8 component of LPJmL within the ISIMIP fast track (Rosenzweig et al., 2014) and used by MAgPIE to derive LU  
9 patterns under cost optimization (see time series of total crop land (irrigated vs. non-irrigated) in Figure 3).  
10 Projections of climate change are taken from the four GCMs also used to force the other impacts projections  
11 within ISIMIP2b to ensure maximum consistency. As the MIROC5 climate input data were not part of the ISIMIP  
12 Fast Track, the associated crop yield projections by LPJmL were generated from MIROC5 climate analogously to  
13 the Fast Track simulations to calculate the associated LU patterns. Under an SSP2 storyline and based on the  
14 REMIND-MAgPIE Integrated Assessment Modelling Framework, RCP6.0 represents a BAU greenhouse gas  
15 concentration pathway without explicit mitigation measures for the reduction of greenhouse gas emissions  
16 (Riahi et al., 2016). Given lower emission targets, REMIND-MAgPIE is designed to derive an optimal mitigation  
17 mix under climate-policy settings, maximizing aggregate social consumption across the 21<sup>st</sup> century. To reach  
18 the low emissions RCP2.6 scenario from an RCP6.0 reference pathway, land-based mitigation measures are of  
19 great importance (Popp et al., 2014b, 2017). The REMIND-MAgPIE framework accounts for reduced emissions  
20 from LU change via avoided deforestation, reduction of non-CO<sub>2</sub> emissions from agricultural production, and a  
21 strong expansion of bioenergy production partly combined with carbon capture and storage (BECCS, see total  
22 land area used for second-generation bioenergy production in Figure 3).

23 Historical LU patterns to be used for the group 1 simulations were taken from the new LUH2 land-use history  
24 reconstruction based on agricultural land area from HYDE3.2 (Klein Goldewijk, 2016), the Food and Agriculture  
25 Organization of the United Nations (Food and Agriculture Organization of the United Nations, 2016), Monfreda  
26 et al., 2008, and other sources. The MAgPIE projections do not transition continuously from the LUH2 historical  
27 dataset. To ensure a smooth transition from historical LU patterns used for the historical ISIMIP2b group 1  
28 simulations to the future LU patterns used for the ISIMIP2b group 3 impact projections we applied the  
29 harmonization method developed within the context of CMIP6 (LUH2, Hurtt et al., 2017). To highlight the  
30 difference in underlying LU projections and additional adjustments described below, the LU, irrigations and  
31 fertilizer data set provided within ISIMIP2b should be referred to as LUH2-ISIMIP2b compared to the LUH2 data  
32 generated for CMIP6. The RCP specific patterns should be referred to as “landuse\_ISIMIP2b\_ssp2\_rcp26” and  
33 “landuse\_ISIMIP2b\_ssp2\_rcp60”, respectively.

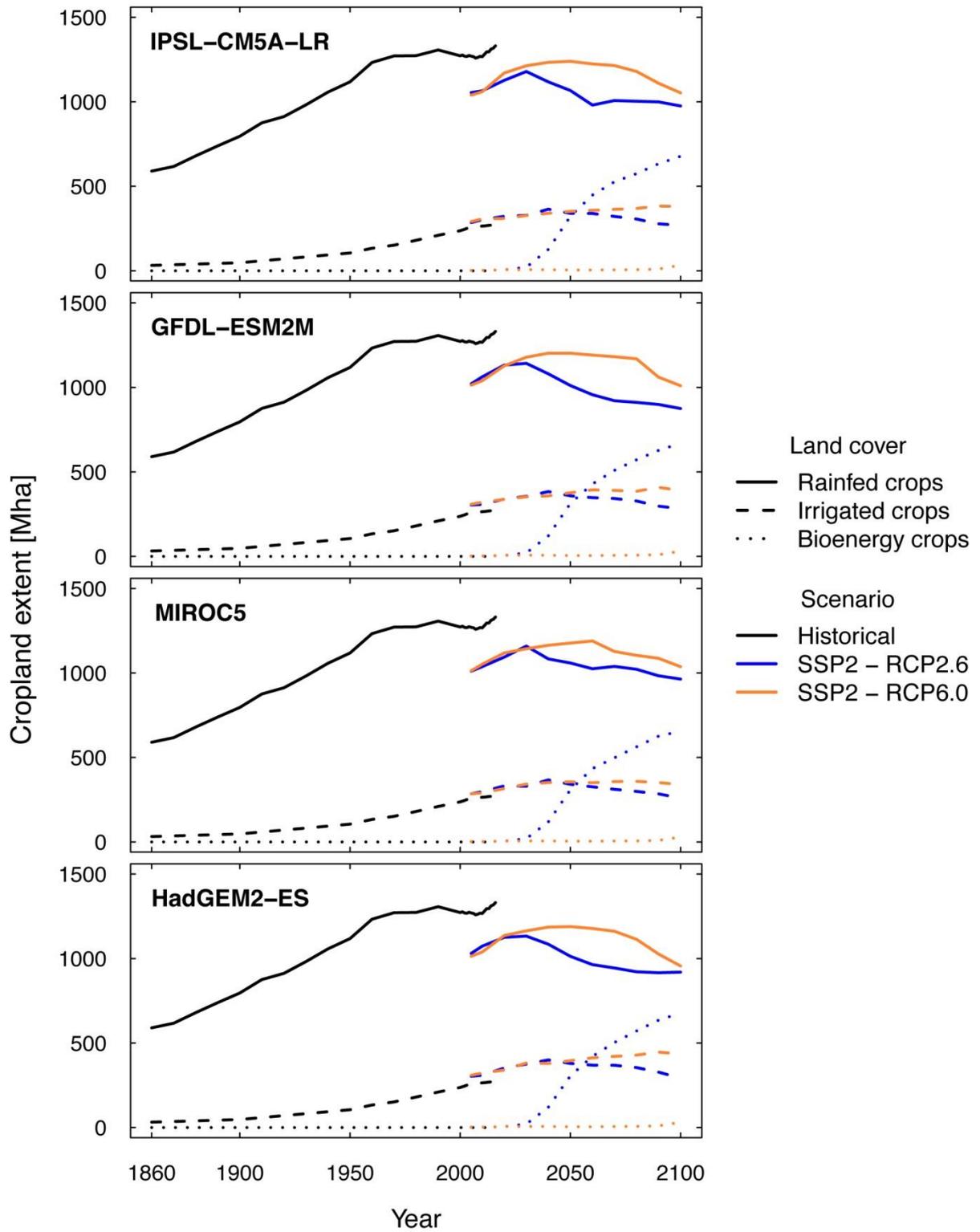
34 The harmonization method ensures that future projections start from the end of the historical reconstruction  
35 and attempts to preserve absolute changes at various spatial scales, depending on the variable being

1 harmonized projected by MAgPIE for key variables including areas of crop-land, pastures, urban land, and area  
2 used for bioenergy, irrigated areas, and relative changes in fertilizer rates (per crop type and ha). For IPSL-  
3 CM5A-LR the generation of the harmonized LU patterns is finalized. The changes in total irrigated and rain-fed  
4 crop land and the total area for bioenergy generation in the harmonized dataset are quite similar to the  
5 associated changes in total areas derived from the original MAgPIE simulations (see SI) even though the  
6 harmonization method is not designed to generate convergence from historical patterns to the original  
7 patterns provided by MAgPIE.

8

9 The harmonization method provides a large number of LU related information. Only part of the information is  
10 provided within ISIMIP2b and therefore added to the LUH2-ISIMIP2b data set. It comprises LU, irrigation and  
11 fertilization information on two different levels of aggregation. On the first level we provide the fraction of  
12 each grid cell covered by the following types of land use and management: 1) pastures (pastures), 2) urban land  
13 (urbanareas), 3) C3 annual crops (c3ann), 4) C3 perennial crops (c3per), 5) C4 annual crops (c4ann), 6) C4  
14 perennial crops (c4per), 7) C3 nitrogen-fixing crops (c3nfx), 8) bioenergy grass (bioenergy\_grass) and 9)  
15 bioenergy trees (bioenergy\_trees). The c3per, c4per, c3ann, c4ann, c3nfx, bioenergy\_grass and  
16 bioenergy\_trees classes are additionally split up into irrigated and rainfed fractions. For each crop type there is  
17 additional information about nitrogen fertilizer input per ha. The original harmonization method only provides  
18 the fractions of each grid cell covered by c3per, c4per, c3ann, c4ann, and c3nfx and additional information  
19 about the fraction of overall crop land used for 2<sup>nd</sup> generation biofuel plantations. However, the latter fraction  
20 is not explicitly attributed to these classes. To allow for an implementation of bioenergy crops in the impact  
21 simulations implementation we explicitly separate land areas covered by bioenergy\_grass and bioenergy\_trees  
22 from the other classes of crop land where 1) the total area of irrigated cropland is preserved and 2) the sum of  
23 total cropland, land for bioenergy plantations and pastures equals the sum of total cropland and pastures as  
24 provided by the harmonization method (see SI for details of the separation). As needed by many impact  
25 models, LUH2-ISIMIP2b also contains a further level of disaggregation of the agricultural land classes c3per,  
26 c4per, c3ann, c4ann, and c3nfx into major individual food-crops (maize, groundnut, rapeseed, soybeans,  
27 sunflower, rice, sugarcane, pulses, temperate cereals (incl. wheat), temperate roots, tropical cereals, tropical  
28 roots, others annual, others perennial, and others N-fixing) following Monfreda et al. (2008). For all classes we  
29 also separate between rainfed and irrigated areas based on the irrigation fraction of total crop land described  
30 within HYDE3.2 or projected by MAgPIE (see SI).

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3 **Figure 3** Time series of total crop land (**non-irrigated** (solid lines) and irrigated (dashed lines)) as reconstructed for the  
4 historical period (1860 - 2010) based on HYDE3.2 (Klein Goldewijk, 2016) and projected under SSP2 (2030-2099) assuming  
5 no explicit mitigation of greenhouse gas emissions (RCP6.0, yellow line) and strong mitigation **including land-based**  
6 **mitigation** (RCP2.6, dark blue line) as suggested by MAgPIE. Future projections also include land areas for second  
7 generation bioenergy production (not included in “total crop land”) for the demand generated from the Integrated  
8 Assessment Modelling Framework REMIND-MAgPIE, as implemented in the SSP exercise (dotted lines).

## 9 **5 Patterns of sea-level rise**

10 Sea-level rise is an important factor for climate-change-related impacts on coastal **infrastructure and**  
11 **ecosystems**. For ISIMIP2b we utilize knowledge on the individual components of sea-level rise to provide time-  
12 **dependent and spatially-resolved patterns of sea-level rise**. Thermal expansion, mountain glaciers and ice caps,  
13 **and the large ice sheets on Greenland and Antarctica are the major climate-dependent contributors to sea level**  
14 **rise**. In contrast, land water storage depends predominantly on human activities of groundwater extraction and  
15 **dam building, with no clear direct relation to climate change on multi-decadal timescales**. We construct the  
16 **pattern of total sea level rise by the sum of these components, using the pattern of oceanic changes directly**  
17 **from the four GCMs and utilizing fingerprints (Bamber and Riva, 2010) to scale the global glacier and ice sheet**  
18 **contributions**. Group 2 and Group 3 experiments differ by the additional land water storage term considered in  
19 **the sea level patterns provided for the Group 3 simulations**. The associated spatial patterns are also  
20 **constructed through fingerprinting**. While glacier and ice sheet fingerprints are constant in time, the **spatially-**  
21 **resolved changes in land water storage are incorporated in its fingerprint**.

22 **We derive the global future sea-level contribution** from mountain glaciers and the Greenland and the Antarctic  
23 ice sheets with the “constrained extrapolation” approach (Mengel et al., 2016), driven by the global-mean-  
24 temperature evolution of the four ISIMIP GCMs. The approach combines information about long-term sea-level  
25 change with observed short-term responses and allows the projection of the different contributions to climate-  
26 driven sea-level rise from global-mean-temperature change (see SI Figure S1 – S5). **We add the contribution**  
27 **from glaciers that is not driven by current climate change (Marzeion et al., 2014)**. The linear trend of the  
28 **natural-glacier contribution (Marzeion and Levermann, 2014, Fig. 1c) suggests** that the natural contribution  
29 reaches zero around year 2056. We therefore approximate this contribution by a parabola with a maximum in  
30 2056, extended with zero trend beyond that year (see SI, black line in Fig. S5). **Future total global sea level rise**  
31 **as the combination of thermal expansion and the glaciers and ice sheets contribution is shown in Figure 4 (blue**  
32 **and yellow line for RCP2.6 and RCP6.0, respectively)**.

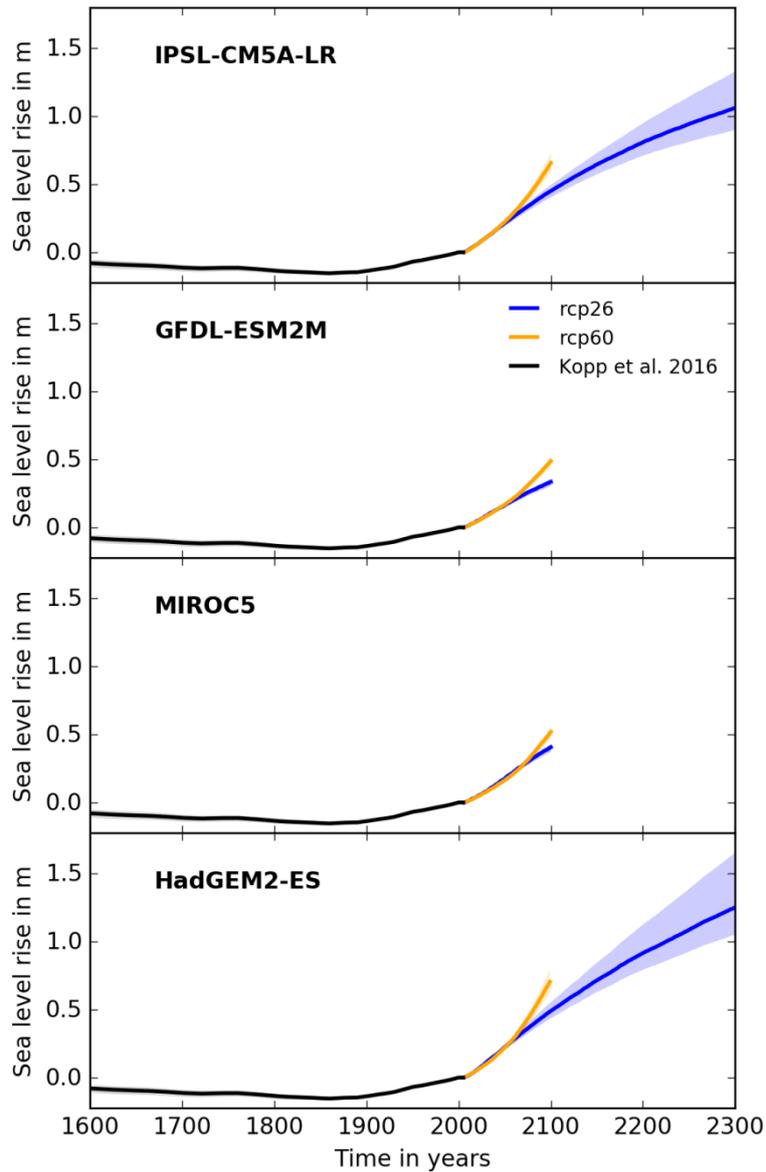
33 **Global water models can provide projections of future terrestrial water storage (TWS)**. Reductions in terrestrial  
34 **water storage influence sea level through adding mass to the ocean and through its gravitational and rotational**  
35 **fingerprint**. Within ISIMIP2b we will use TWS projections from the Group 3 simulations by the global water  
36 **model PCR-GLOBWB accounting for ground water depletion (Wada et al., 2012)**. Projections will be combined

1 with fingerprinting (Bamber and Riva, 2010) to provide the pattern of sea level rise from TWS changes for each  
2 ISIMIP2b GCM. As Group 3 PCR-GLOBWB experiments are not yet available, TWS changes are not reflected in  
3 Figure 4.

4  
5

6 Past global sea-level rise is available through a meta-analysis of proxy relative sea-level reconstructions (Kopp  
7 et al., 2016). We match past observed and future projected total sea level rise by providing both time series  
8 relative to the year 2005. We use the observed time series before the year 2005 (Figure 4, black line) and the  
9 projections after that year (Figure 4, blue (RCP2.6) and yellow (RCP6.0) line). We here do not provide patterns  
10 of regional sea level rise for the past. Modellers should use the global mean sea level rise for simulations of the  
11 past (Group 1 historical experiment).

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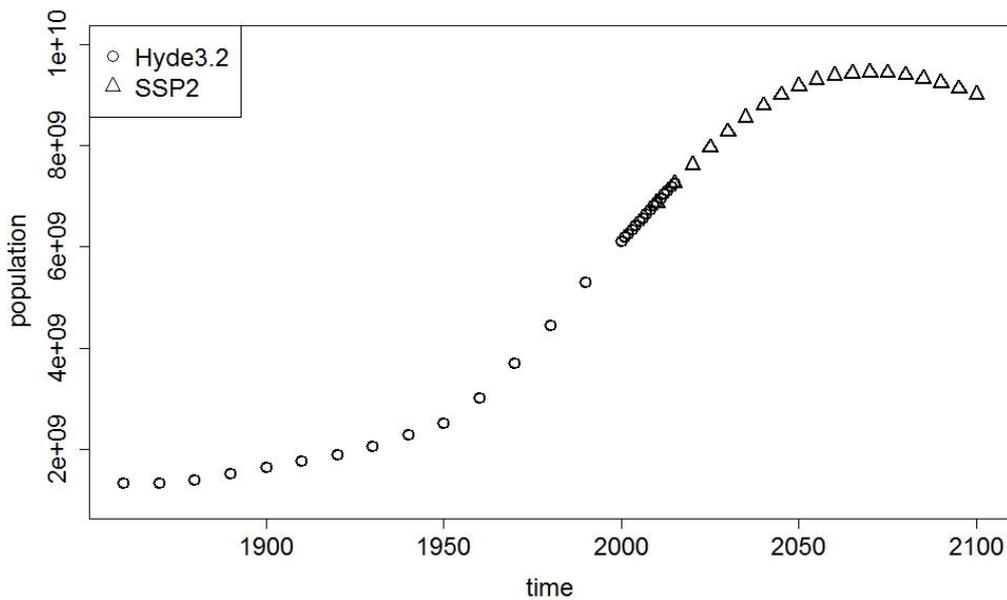
2 **Figure 4** Time series of global total sea-level rise based on observations (Kopp et al., 2016, black line) until year 2005 and  
 3 global-mean-temperature change from IPSL-CM5A-LR (top panel), GFDL-ESM2M (second top panel), MIROC5 (third top  
 4 panel) and HadGEM2-ES (bottom panel) after year 2005: solid lines: Median projections, shaded areas: uncertainty range  
 5 between the 5<sup>th</sup> and 95<sup>th</sup> percentile of the uncertainty distribution associated with the ice components. Blue: RCP2.6,  
 6 yellow: RCP6.0. All time series relative to year 2005. Non-climate-driven contribution from glaciers and land water storage  
 7 are added to the projections.

1 **6 Information about population patterns and economic output (Gross**  
2 **Domestic Product, GDP)**

3 We provide **annual** population data on a 0.5° grid covering the whole period from 1860 to 2100. The historic  
4 data are taken from the HYDE3.2 database (Klein Goldewijk, 2011; Klein Goldewijk et al., 2010), which covers  
5 the period 1860 to 2000 in 10-year time steps plus yearly data between 2001 and 2015 with a default  
6 resolution of 5'.

7 For the future period, gridded data based on the national SSP2 population projections as described in Samir  
8 and Lutz, (2014) are available (Jones and O'Neill, 2016) covering the period 2010-2100 in 10-year time steps,  
9 with a 7.5' resolution. **For ISIMIP2b both data sets are remapped to the ISIMIP 0.5° grid and interpolated to**  
10 **yearly time steps using a simple linear algorithm. From 2005 onwards, historical population data is linearly**  
11 **interpolated to match with 2010 SSP2 population projections.** In addition, we provide age-specific population  
12 data (in 5-year age groups: 0-4, 5-9, etc.) and all-age mortality rates in 5-year time steps on a country level for  
13 2010-2100, corresponding to the same SSP2 projections by Samir and Lutz (2014). **Figure 5** shows total global  
14 population over time. Both datasets take into account urbanisation trends.

15



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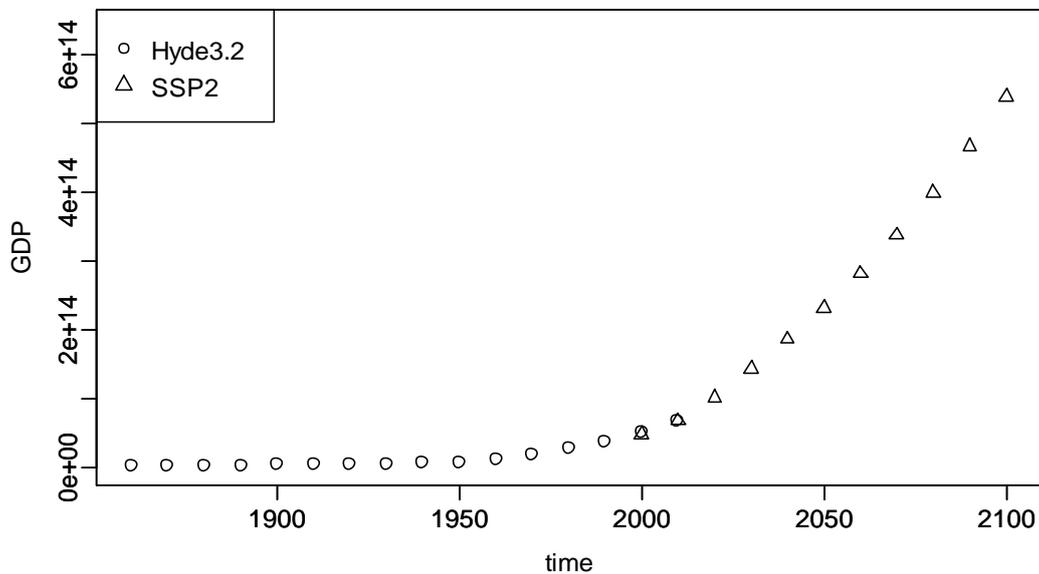
17 **Figure 5** Time series of global population for the historical period (dots) and future projections following the SSP2 storyline  
18 (triangles).

19 Furthermore, annual country-level GDP data (in 2005 PPP \$) are provided (Geiger and Frieler, 2017, see Figure  
20 6). The historical data (1860-2010) are derived by extrapolating national income (GDP/capita) and GDP time

1 series (2005 PPP \$) between 1960-2009 from Penn World Tables 8.1 (Feenstra et al., 2015, [www.ggd.net/pwt](http://www.ggd.net/pwt))  
2 with per capita growth rates from the Maddison project (Bolt and van Zanden, 2014,  
3 [www.ggd.net/maddison/maddison-project/home.htm](http://www.ggd.net/maddison/maddison-project/home.htm)). Missing country data is filled using data first from  
4 Penn World Tables 9.0 (Feenstra et al., 2015) and then World Development Indicators  
5 (<http://data.worldbank.org/>) upon required transformation from 2011 PPP \$ to 2005 PPP \$ (Geiger, 2017).

6 Future projections of national GDP are taken from the SSP database (Dellink et al., 2015,  
7 <https://secure.iiasa.ac.at/web-apps/ene/SspDb/>). The database includes country-level GDP projections from  
8 2010-2100 in 10-year time steps that are linearly interpolated to provide annual coverage. From 2005 onwards,  
9 historical national GDP data are linearly interpolated to match with OECD SSP2 GDP projections in 2010.

10 In addition, consistent gridded (0.5°x0.5°) GDP data are also provided for the period 1860-2100. For the  
11 historical period, the above-mentioned national GDP time series in 10 year increments are downscaled to  
12 0.125° grid resolution based on the methodology described in Murakami and Yamagata (2017) and  
13 corresponding gridded population data from the HYDE3.2 database (Klein Goldewijk, 2011; Klein Goldewijk et  
14 al., 2010). Using linear interpolation routines, the data are upscaled to the ISIMIP 0.5° grid and interpolated to  
15 yearly time steps. For the future period, gridded GDP data were generated similarly, using OECD SSP2 national  
16 GDP and SSP2 gridded population projections (Jones and O'Neill, 2016) as input for the downscaling. The GDP  
17 data will be additionally available from "Global dataset of gridded population and GDP scenarios," which is  
18 provided by the Global Carbon Project, National Institute for Environmental Studies  
19 (<http://www.cger.nies.go.jp/gcp/population-and-gdp.html>).



20  
21 **Figure 6** Time series of global GDP for the historical period (dots) and future projections following the SSP2 storyline  
22 (triangles).

## 7 Representation of other external drivers

There are other drivers that are well documented and partly represented in climate-impact models and also refer to representation of “socio-economic conditions” here. Available indicators apart from climate change, population changes, changes in national GDP, and LU patterns are primarily: 1) construction of dams and reservoirs; 2) irrigation-water extraction; 3) patterns of inorganic fertilizer application rates; 4) nitrogen deposition; 5) information about fishing intensities; 6) forest management; and 7) initial conditions for the forestry simulations. For all of these input variables, we describe reconstructions to be used for the historical “histsoc” simulations (see Table 4). For models that do not allow for time-varying socio-economic conditions across the historical period, the conditions should be fixed at present-day (year 2005) levels (see dashed line in Figure 1, Group 1). Beyond 2005 socio-economic conditions should be held constant (Group 2) or varied according to SSP2 if associated projections are available (Group 3). Within ISIMIP2b we provide projections of future domestic and industrial water withdrawal and consumption, fertilizer application rates and nitrogen deposition (see Table 4)

**Table 4** Representations of socio-economic drivers for the historical simulations (histsoc, Group 1) and the future projections accounting for changes in socio-economic drivers (rcp26soc or rcp60soc, Group 3). Grey color means that it is mandatory to use the data set(s) provided (if applicable), for reasons of harmonization across models. In other cases, data sets are provided only in support of modelling groups who may need them, but groups are free to use other data or generate the data based on their own simulations following the rules described below.

<b>Reservoirs &amp; dams</b>	Includes location, upstream area, capacity, and construction/commissioning year, on a global 0.5° grid. Documentation: <a href="http://www.gwsp.org/products/grand-database.html">http://www.gwsp.org/products/grand-database.html</a> (Döll and Lehner, 2002; Lehner et al., 2011) <b>Note:</b> Simple interpolation can result in inconsistencies between the GranD database and the DDM30 routing network (wrong upstream area due to misaligned dam/reservoir location). We provide a file with locations of all larger dams/reservoirs adapted to DDM30 such as to best match reported upstream areas.	No future data sets are provided. Assumed to be fixed at year 2005 levels.
<b>Water withdrawal and consumption for domestic &amp; industrial purposes</b>	Generated by each modelling group individually (e.g. following the varsoc scenario in ISIMIP2a). For modelling groups that do not have their own representation, we provide files containing the multi-model mean domestic and industrial water withdrawal and consumption generated from the ISIMIP2a varsoc runs of WaterGAP, PCR-GLOBWB and H08. This data is available from 1901.	Generated by each modelling group individually. For modelling groups that do not have their own representation, we provide files containing the multi-model mean (from the global water models WaterGAP, PCR-GLOBWB and H08) domestic and industrial water withdrawal and consumption under SSP2 from the Water Futures and Solutions (WFaS) (Wada et al., 2016) project. Since this data is only available until 2050, the values should be kept

		<p>constant from 2050 onwards.</p> <p>Also, the data provided for rcp26soc and rcp60soc are identical and both taken from simulations based on RCP6.0. The combination SSP2-RCP2.6 was not considered in WFaS; the difference is expected to be small since the choice of RCP only affects cooling water demand in one of the three models.</p> <p>Generated by each modelling group individually.</p> <p>Modelling groups that do not have their own representation should use the mean (of three models) scenarios for domestic and industrial uses from the Water Futures and Solutions (WFaS; Wada et al., 2016) project consistent with SSP2 and RCP2.6/6.0.</p>
<b>Water withdrawal (or consumption) for irrigation</b>	Individually derived by each modelling group from the provided land use and irrigation patterns (see Section 4)	<p>Individually derived by each modelling group from future land-use and irrigation patterns provided by MAgPIE (see Section 4). Land-use projections are provided for</p> <ul style="list-style-type: none"> <li>• SSP2+RCP6.0,</li> <li>• SSP2+RCP2.6.</li> </ul>
<b>Water withdrawal (or consumption) for livestock production</b>	Water directly used for livestock (e.g. animal husbandry and drinking) is expected to be very low (Müller Schmied et al., 2016) and may be set to zero if not directly represented in the individual models.	
<b>Fertilizer (kg per ha of cropland)</b>	Annual crop-specific input per ha of crop land for C <sub>3</sub> and C <sub>4</sub> annual, C <sub>3</sub> and C <sub>4</sub> perennial and C <sub>3</sub> Nitrogen fixing. This data set is part of the LUH2 dataset based on HYDE3.2.	Inorganic N fertilizer use per area of crop land provided by the LUH2-ISIMIP2b dataset, which differs for SSP2+RCP2.6 and SSP2+RCP6.0.
<b>Nitrogen deposition (NH<sub>x</sub> and NO<sub>y</sub>)</b>	<p>Annual, gridded NH<sub>x</sub> and NO<sub>y</sub> deposition during 1850-2005 derived by averaging three atmospheric chemistry models (i.e., GISS-E2-R, CCSM-CAM3.5, and GFDL-AM3) in the Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP) (0.5° x 0.5°) (Lamarque et al., 2013a, 2013b).</p> <p>The GISS-E2-R provided monthly nitrogen deposition output; CCSM-CAM3.5 provided monthly nitrogen deposition in each decade from 1850s to the 2000s; and GFDL-AM3 provided monthly nitrogen deposition in five periods (1850-1860, 1871-1950, 1961-1980, 1991-2000, 2001-2010).</p> <p>Annual deposition rates were calculated by aggregating the monthly data, and nitrogen deposition rates in years without model output were calculated according to spline interpolation (CCSM-CAM3.5) or linear interpolation (for GFDL). The original deposition data was downscaled to spatial resolution of half degree (90° N to 90° S, 180° W to 180° E) by applying the nearest interpolation.</p>	As per historical reconstruction for 2006-2099 following RCP2.6 and RCP6.0.

<b>Fishing intensity</b>	Depending on model construction, one of: Fishing effort from the Sea Around Us Project (SAUP); catch data from the Regional Fisheries Management Organizations (RFMOs) local fisheries agencies; exponential fishing technological increase and SAUP economic reconstructions. Given that the SAUP historical reconstruction starts in 1950, fishing effort should be held at a constant 1950 value from 1860-1950.	Held constant after 2005 ( <b>2005soc</b> )
<b>Forest management</b>	Based on observed stem numbers and common management practices (see Forest Chapter of ISIMIP2b protocol)	Based on species-specific future management practices and site specific regeneration guidelines (see Forest Chapter of ISIMIP2b protocol)
<b>Forest site, soil and stand description</b>	Initial site, soil, and stand description of forest stands based on observed site (elevation, aspect, slope), soil (physical and chemical soil properties) and stand descriptions (including individual tree data for diameter at breast height, tree height and species and stand data for basal area, age, biomasses of tree compartments etc.) following (Reyer and et al., n.d.) (see Forest Chapter of ISIMIP2b protocol for details)	Unless dynamically simulated initial values from site and soil description should be held constant

## 1 **8 Focus regions**

- 2 Simulation data are welcome for all world regions. Even single model simulations for specific sites will help to
- 3 generate a more comprehensive picture of climate change impacts and potentially allow for constraining global
- 4 models. However, to allow for model intercomparisons simulations should primarily be provided for the sector
- 5 specific focus regions shown in Figure 7 and defined in Table 5, if feasible with your model.

1 **Table 5** List of ISIMIP focus regions as shown in Figure 7.

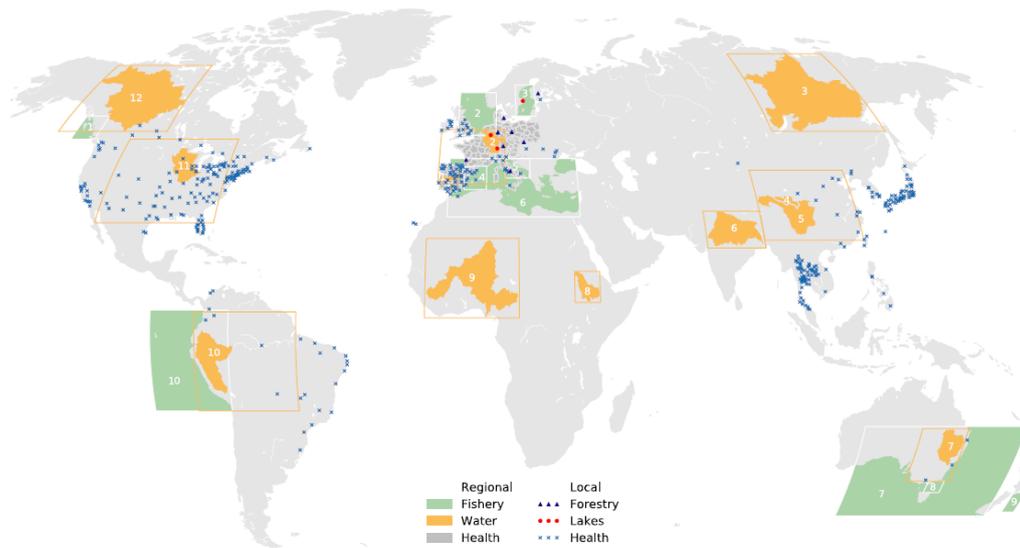
Focus region (shortname)	Zonal extent (longitude)	Meridional extent (latitude)	River basin(s) or Region (shortname).
Numbers refer to 7.			
<b>Regional water simulations</b>			
North America (11) (nam)	114°0'W– 77°30'W	28°30'N–50°0'N	Mississippi (mississippi)
Western Europe (1, 2) (weu)	9°30'W–12°0'E	38°30'N–52°30'N	Tagus und Rhine (rhine)
West Africa (9) (waf)	12°0'W–16°0'E	4°0'N–24°30'N	Niger (niger)
South Asia (6) (sas)	73°0'E–90°30'E	22°0'N–31°30'N	Ganges (ganges)
China (4, 5) (chi)	90°30'E–120°30'E	24°0'N–42°0'N	Yellow (yellow), Yangtze (yangtze) (yellow,gtze)
Australia (7) (aus)	138°30'E–152°30'E	38°0'S –24°30'S	Murray Darling (murrydarling)
Amazon (10) (ama)	80°0'W–50°0'W	20°0'S–5°30'N	Amazon (amazon)
Blue Nile (8) (blu)	32°30'E–40°0'E	8°0'N–16°0'N	Blue Nile (bluenile)
Lena (3) (len)	103°0'E–141°30'E	52°0'N–72°0'N	Lena (lena)
Canada (12) (can)	140°0'W– 103°0'W	52°0'N–69°0'N	Mackenzie (mackenzie)
<b>Regional lake simulations</b>			
Große Dhünn (reservoir)	7°12'E	51°04'N	
Lake Constance (Bodensee)	9°24'E	47°37'N	
Lake Erken	18°35'E	59°51'N	
<b>Regional forestry simulations</b>			
BilyKriz	18.32	49.300	-
Collelongo	13.588	41.849	
Soro	11.645	55.486	
Hyytiala	24.295	61.848	
Kroof	11.400	48.250	

Solling 304	9.570	51.770	
Solling 305	9.570	51.770	
Peitz	14.350	51.917	
LeBray	-0.769	44.717	
<b>Ocean regions</b>			
North-West Pacific (1) (pacific-nw)	134°30'W–125°30'W	49°30'N–56°30'N	
North Sea (2) (north-sea)	4°30'W–9°30'E	50°30'N–62°30'N	
Baltic Sea (3)	15°30'E–23°30'E	55°30'N–64°30'N	
North-West Mediterranean (4) (med-nw)	1°30'W–6°30'E	36°30'N–43°30'N	
Adriatic Sea (5) (adriatic-sea)	11°30'E–20°30'E	39°30'N–45°30'N	
Mediterranean Sea (6) (med- glob)	6°30'W–35°30'E	29°30'N–45°30'N	
Australia (7) (australia)	120°30'E–170°30'E	47°30'S–23°30'S	
Eastern Bass Strait (8) (eastern-bass-strait)	145°30'E–151°30'E	41°30'S–37°30'S	
Cook Strait (9) (cook-strait)	174°30'E–179°30'E	46°30'S–40°30'S	
North Humboldt Sea (14) (humboldt-n)	93°30'W–69°30'W	20°30'S–6°30'N	

1

2

1



2

3 **Figure 7** ISIMIP focus regions. The coordinates of the numbered regions are listed in Table 5.

### 4 **9 Sector-specific implementation of scenario design**

5

6 The detailed description of the sector-specific simulations can be found at [www.isimip.org/protocol/#isimip2b](http://www.isimip.org/protocol/#isimip2b).  
 7 Here we provide an example of the chosen simulation scenarios consistent with those depicted in Figure 1. The  
 8 grey, red, and blue background colours of the different entries in the tables indicate Group 1, 2, 3 runs,  
 9 respectively. Runs marked in violet represent additional sector-specific sensitivity experiments. Each simulation  
 10 run has a name (Experiment I to VII) that is consistent across sectors, i.e. runs from the individual experiments  
 11 could be combined for a consistent cross-sectoral analysis. Since socio-economic conditions represented in  
 12 individual sectors may depend on the RCPs (such as land-use changes), while socio-economic conditions  
 13 relevant for other sectors may only depend on the SSP, the number of experiments differs from sector to  
 14 sector.

15

16 **Table 6:** Scenario description

Climate & CO <sub>2</sub> concentration scenarios	
<b>picontrol</b>	Pre-industrial climate and 286ppm CO <sub>2</sub> concentration. The climate data for the entire period (1661-2299) are unique – no (or little) recycling of data has taken place.
<b>historical</b>	Historical climate and CO <sub>2</sub> concentration.
<b>rcp26</b>	Future climate and CO <sub>2</sub> concentration from RCP2.6
<b>rcp60</b>	Future climate and CO <sub>2</sub> concentration from RCP6.0
<b>2005co2</b>	CO <sub>2</sub> concentration fixed at 2005 levels (378.81 ppm).
<b>2299rcp26</b>	Repeating climate between 2270 and 2299 for additional 200 years up to 2500 (or equilibrium if possible), CO <sub>2</sub> fixed at year 2299 levels

<b>Representation of socio-economic conditions</b>	
Refers to land use and <b>other (human)</b> influences including nitrogen deposition, fertilizer input, irrigation, water abstraction, dams and reservoirs, forest management, mortality baselines, exposure-response functions (temperature-related mortality), population and GDP data, coastal protection, fishing catch data.	
<b>1860soc</b>	Pre-industrial land use and <b>socio-economic conditions</b> .
<b>histsoc</b>	Varying historical land use and <b>socio-economic conditions</b> .
<b>2005soc</b>	Fixed year-2005 land use and <b>socio-economic conditions</b> .
<b>UMsoc</b>	No forest management (forests simulations).
<b>rcp26soc</b>	Varying land use <b>and socio-economic conditions</b> according to SSP2 and RCP2.6.
<b>rcp60soc</b>	Varying land use and <b>socio-economic conditions</b> according to SSP2 and RCP6.0.
<b>2100rcp26soc</b>	Land use and <b>socio-economic conditions</b> fixed at year 2100 levels according to the final year of RCP2.6.
<b>ssp2soc_adapt</b>	Varying society according to SSP2 – with adaptation (temperature-related mortality simulations).
<b>nosoc</b>	No human influences (permafrost and fisheries simulations).

1

2 **Table 7:** ISIMIP2b scenario specification **example** for the global water model simulations. Option 2\* only if  
 3 option 1 not possible.

Experiment	Input	pre-industrial 1661-1860	historical 1861-2005	future 2006-2099	extended future 2100-2299
<b>I</b>	No climate change, pre-industrial CO <sub>2</sub>	picontrol	picontrol	picontrol	picontrol
	Varying LU & <b>socio-economic conditions</b> up to 2005, then fixed at 2005 levels thereafter	<b>socio-economy</b>	Option 1: 1860soc	2005soc	2005soc
	Option 2*: 2005soc				
<b>II</b>	RCP2.6 climate & CO <sub>2</sub>	Experiment I	historical	rcp26	rcp26
	Varying LU <b>socio-economic conditions</b> up to 2005, then fixed at 2005 levels thereafter		Option 1: histsoc	2005soc	2005soc
	Option 2*: 2005soc				
<b>III</b>	RCP6.0 climate & CO <sub>2</sub>	Experiment I	Experiment II	rcp60	not simulated
	Varying LU <b>socio-economic conditions</b> up to 2005, then fixed at 2005 levels thereafter			2005soc	
<b>IV</b>	No climate change, pre-industrial CO <sub>2</sub>	Experiment I	Experiment I	picontrol	picontrol
	Varying LU and <b>socio-economic conditions</b> up to 2100 (RCP2.6), then fixed at 2100 levels thereafter			rcp26soc	2100rcp26soc

<b>V</b>	No climate change, pre-industrial CO <sub>2</sub>	Climate & CO <sub>2</sub>	Experiment I	Experiment I	picontrol	not simulated
	Varying LU and socio-economic conditions (RCP6.0)	socio-economy			rcp60soc	
<b>VI</b>	RCP2.6 climate & CO <sub>2</sub>	Climate & CO <sub>2</sub>	Experiment I	Experiment II	rcp26	rcp26
	Varying LU and socio-economic conditions up to 2100 (RCP2.6), then fixed at 2100 levels thereafter	socio-economy			rcp26soc	2100rcp26soc
<b>VII</b>	RCP6.0 climate & CO <sub>2</sub>	Climate & CO <sub>2</sub>	Experiment I	Experiment II	rcp60	not simulated
	Varying LU and socio-economic conditions (RCP6.0)	socio-economy			rcp60soc	

1 For the historical period, groups that have limited computational capacities may choose to report only part of  
2 the full period, but including at least 1961-2005. All other periods should be reported completely. For those  
3 models that do not represent *changes* in socio-economic conditions, those impacts should be held fixed at  
4 2005 levels throughout all Group 1 (cf. “2005soc” marked as dashed blue lines in **Figure 1**) and Group 2  
5 simulations. Group 3 will be identical to Group 2 for these models and thus does not require additional  
6 simulations. Models that do not include human impacts *at all* are asked to run the Group 1 and Group 2  
7 simulations nonetheless, since these simulations will still allow for an exploration of the effects of climate  
8 change compare to pre-industrial climate, and will also allow for a better assessment of the relative importance  
9 of human impacts versus climate impacts. These runs should be named as “nosoc” simulations.

10

## 11 **9.1 Model spin-up**

12

13 Since the pre-industrial simulations are an important part of the experiments, the spin-up has to be finished  
14 before the pre-industrial simulations start. The spin-up should be for the pre-industrial climate (picontrol) and  
15 year 1860 socio-economic conditions. For this reason, the pre-industrial climate data should be replicated by  
16 each modelling group as often as required. The precise implementation of the spin up will be model specific,  
17 the description of which will be part of the reporting process.

## 10 Intended time line of simulations

The time line of ISIMIP2b has been chosen to meet the critical deadlines of the drafting process of the IPCC Special Report, with the submission deadline for papers to be considered in the Special Report being in October 2017 and the associated acceptance deadline being in April 2018. ISIMIP2b simulations are therefore envisaged to be completed well before October 2017. Except for the oceanic all input data for the group 1 and 2 simulations is available. The processing of the LU patterns will soon be finalized to allow for starting the group 3 simulations. The ISIMIP2b repository will stay open for impacts simulations submitted beyond October 2017, since the described simulations provide a basis for further research beyond the direct demands of the Special Report, including for the IPCC Sixth Assessment Report.

## 11 Discussion

Our protocol addresses a timely and important research gap that we have identified for developing a framework for assessing the impacts of 1.5°C and 2°C global warming on a multitude of different impact sectors. Whilst a number of studies have investigated the impacts of 1.5°C and 2°C on individual impact sectors (Arnell et al., 2014; Gosling et al., 2016; Roudier et al., 2015), our approach provides a novel extension to these by: 1) incorporating multiple GCMs, impact models and sectors; 2) inclusion of a pre-industrial reference and full coverage of the historical period, 3) providing a consistent and documented framework for the assessment of impacts at the global scale; and 4) seeking to achieve multi-model integration between sectors in order to better represent the links and feedbacks that occur in the observed Earth system.

The last novelty above, in particular, is a significant step-change in how climate-change-impact modelling is conducted, since up until now the assessment of global-scale climate-sensitive impacts for different sectors have typically been conducted in isolation of one another, e.g. the water-sector models do not use LU changes from the biomes-sector models, and in turn the crop-sector models do not use runoff from the water-sector models etc. Running impact models in isolation of one another can ignore complex interdependencies which in turn can be detrimental to the representation of spatial patterns in climate change impacts, as well as their sign and magnitude of change (Harrison et al., 2016). Enhancing cross-sectoral integration has been one of the driving forces behind the development of the ISIMIP2b protocol, so we anticipate that the simulations which arise from it will yield some of the most cutting-edge projections of climate change impacts to date.

As well as facilitating an understanding of the impacts of 1.5°C and 2°C warming, the ISIMIP2b scenario design also enables an assessment of the impacts of the 1°C of global warming that has occurred between pre-industrial times and the present-day. There are surprisingly few studies that have investigated this, in part due to the significant resources needed to conduct the lengthy climate and impact simulations that are required. To understand what effect anthropogenic climate change has had since pre-industrial times requires an understanding of the climate-change conditions that would prevail in the present-day in the absence of

1 anthropogenic greenhouse gas emissions as well as an estimate of how climate-sensitive impacts have  
2 responded to human-induced LU change and land-management since pre-industrial times.

3 To disentangle the magnitude of climate-sensitive impacts from changes in these impacts that have occurred  
4 due to other human activities, the scenario design compares a simulations, where human influences on  
5 climate-sensitive impacts occur under a pre-industrial climate, driven by stable greenhouse gas concentrations,  
6 with another simulation for the same time period, where the climate responds to increases in greenhouse gas  
7 emissions, and where there are **direct (human)** influences on climate-sensitive **indicators**. It seems intuitive  
8 that the difference between these two simulations will yield the pure effect of climate change, whilst  
9 controlling for **the other drivers**. However, we acknowledge that in practical terms, the effects of human  
10 activity on the climate, and climate-sensitive impacts respectively, are intrinsically linked and cannot be  
11 separated precisely. For example, whilst we are able to use historical estimates of water abstractions and dam  
12 construction as one of the human influences in both of the above simulations, a proportion of the abstractions  
13 and construction of dams will have occurred at the time in response to climate variability and based on  
14 decisions related to planning for future climate change. Such a caveat has to be accepted within the context of  
15 a numerical modelling framework such as ours.

16 However, the explicit representation **of socio-economic drivers** on impact indicators means an important step  
17 forward compared to the ISIMIP fast track simulations. In particular, the assessment of potential trade-offs of  
18 specific mitigation measures such expansion of bioenergy production will become critical when implementing  
19 the Paris agreement of limiting global warming to “well below 2°C”.

## 20 **12 Code and data availability**

21 All input data described in Section 3 to Section 7 will be made publicly available. Availability **is documented on**  
22 [www.isimip.org](http://www.isimip.org) where the way of accessing the data will also be described. Model output [https://esg.pik-](https://esg.pik-potsdam.de)  
23 [potsdam.de](https://esg.pik-potsdam.de). Access to the hurricane projections can be gained by request via [info@windrisktech.com](mailto:info@windrisktech.com).

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1 Supporting Online Material for:

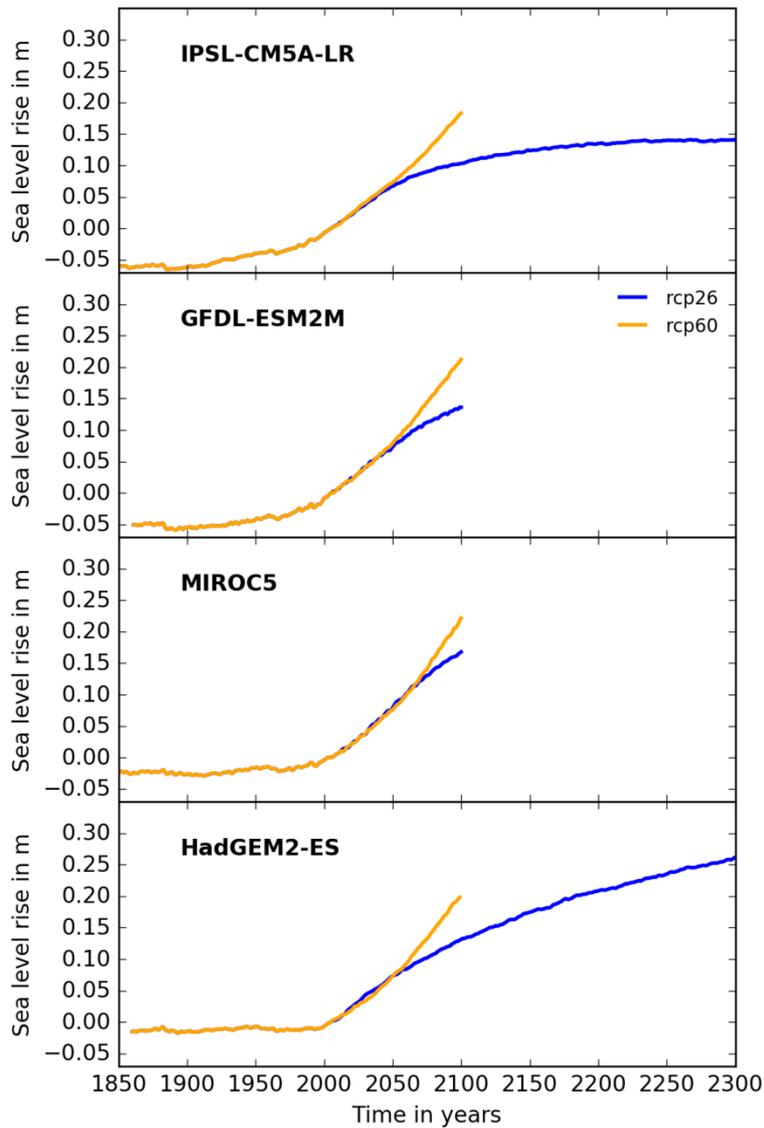
2 **Assessing the impacts of 1.5°C global warming –**  
3 **simulation protocol of the Inter-Sectoral Impact Model**  
4 **Intercomparison Project (ISIMIP2b)**

5 *Katja Frieler, Stefan Lange, Franziska Piontek, Christopher P.O. Reyer, Jacob Schewe, Lila Warszawski, Fang Zhao,*  
6 *Louise Chini, Sebastien Denvil, Kerry Emanuel, Tobias Geiger, Kate Halladay, George Hurtt, Matthias Mengel,*  
7 *Daisuke Murakami, Sebastian Ostberg, Alexander Popp, Riccardo Riva, Miodrag Stevanovic, Tatsuo Suzuki, Jan*  
8 *Volkholz, Eleanor Burke, Philippe Ciais, Kristie Ebi, Tyler D. Eddy, Joshua Elliott, Eric Galbraith, Simon N. Gosling,*  
9 *Fred Hattermann, Thomas Hickler, Jochen Hinkel, Christian Hof, Veronika Huber, Jonas Jägermeyr, Valentina*  
10 *Krysanova, Rafael Marcé, Hannes Müller Schmied, Ioanna Mouratiadou, Don Pierson, Derek P. Tittensor, Robert*  
11 *Vautard, Michelle van Vliet, Matthias F. Biber, Richard A. Betts, Benjamin Bodirsky, Delphine Deryng, Steve*  
12 *Frolking, Chris D. Jones, Heike K. Lotze, Hermann Lotze-Campen, Ritvik Sahpal, Kirsten Thonicke, Hanqin Tian,*  
13 *Yoshiki Yamagata*

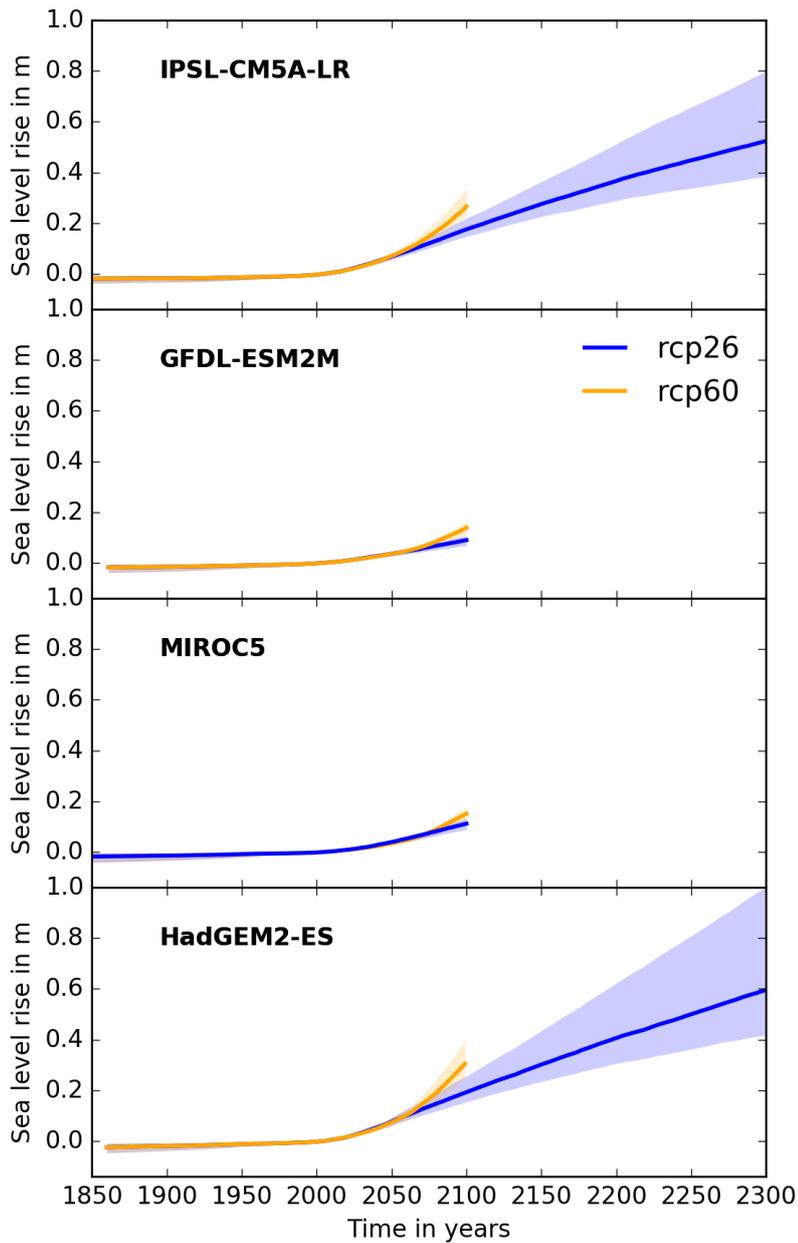
14

15

# 1 Individual contributions to sea level rise

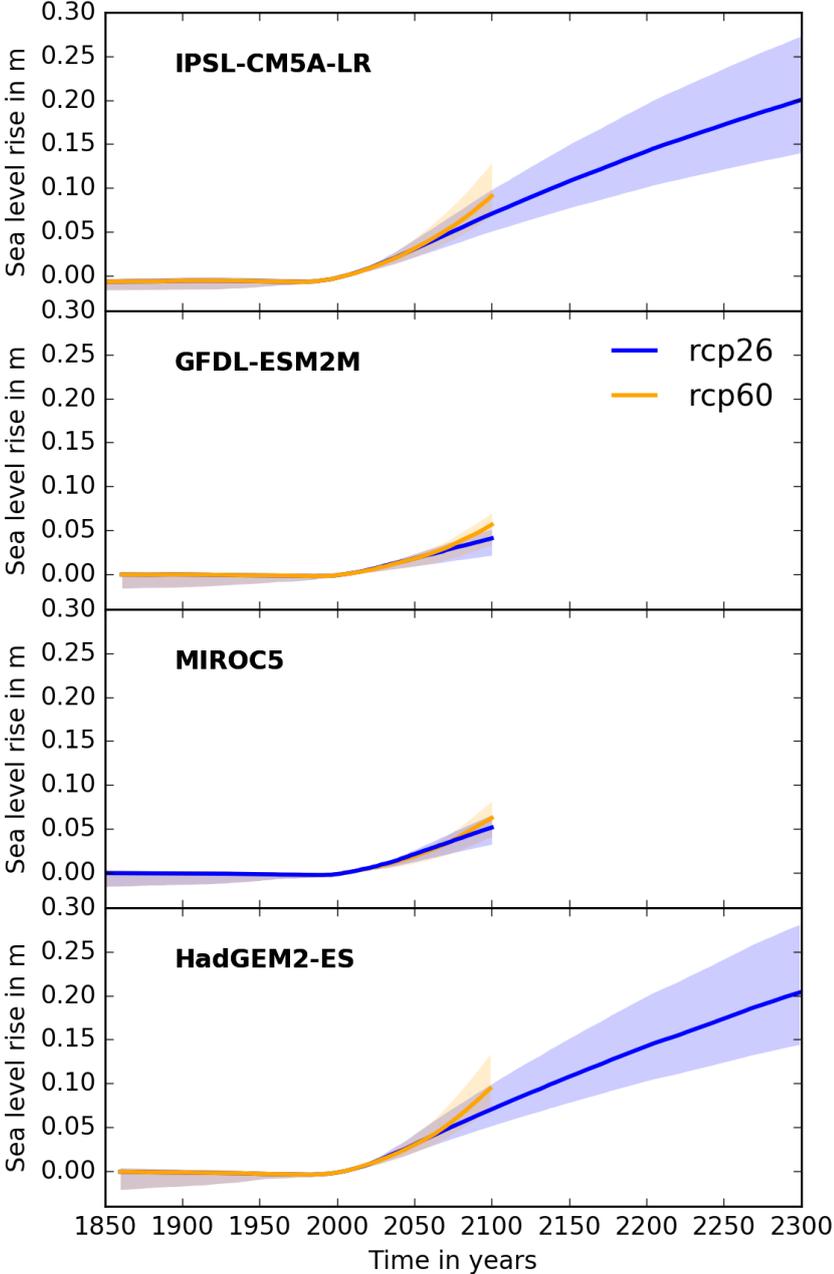


**Figure S1** Time series of sea level rise due to thermal expansion as projected by GFDL-ESM2M (panel 1), HadGEM2-ES (panel 2), IPSL-CM5A-LR (panel 3) and MIROC5 (panel 4) for the historical simulations and RCP2.6 (blue) and RCP6.0 (yellow). All timeseries relative to year 2005.

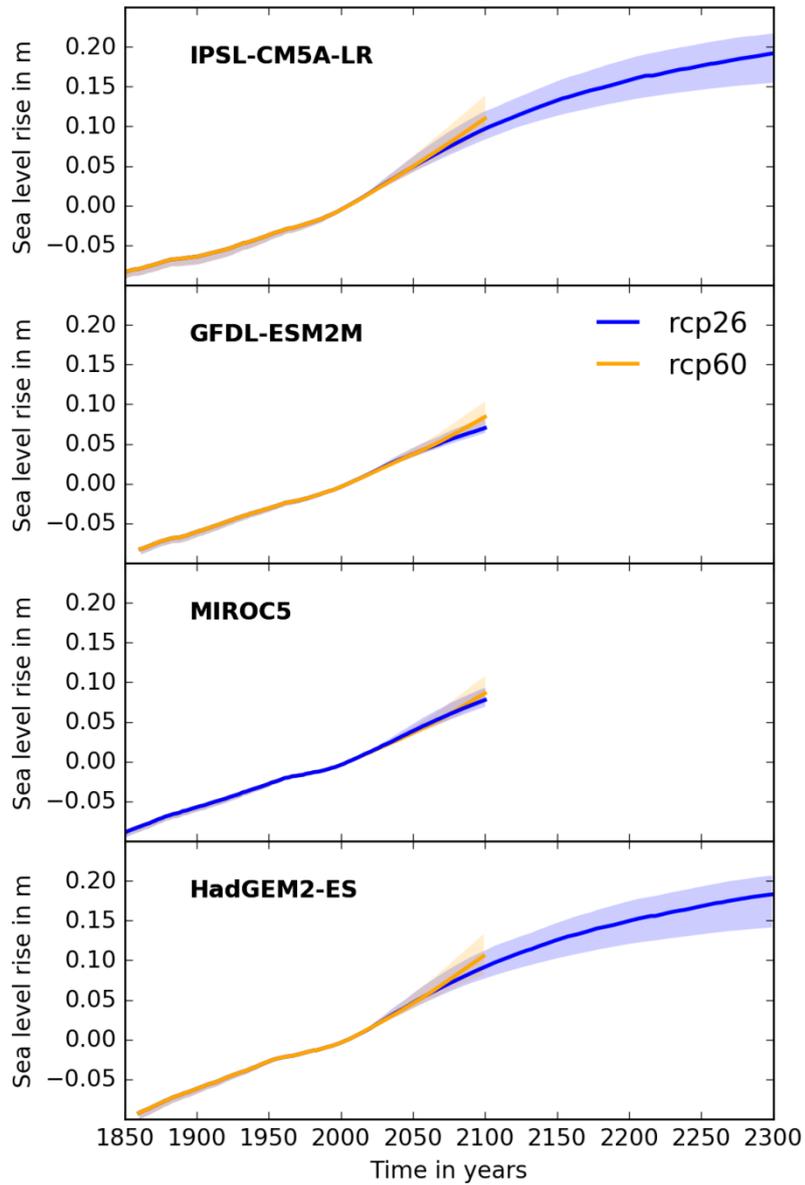


**Figure S2** Time series of Greenland's combined contribution from solid ice discharge and surface mass balance changes to sea level rise based on global mean temperature change from GFDL-ESM2M (panel 1), HadGEM2-ES (panel 2), IPSL-CM5A-LR (panel 3) and MIROC5 (panel 4). Solid lines: Median projections, shaded areas:

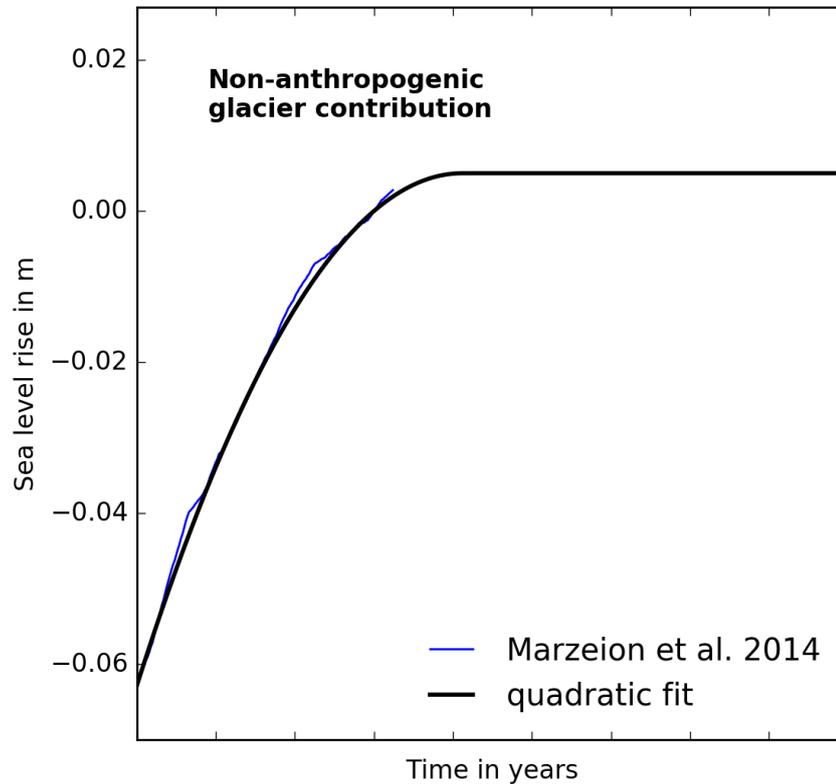
uncertainty range between the 5<sup>th</sup> and 95<sup>th</sup> percentile of the distribution. Blue: RCP2.6, yellow: RCP6.0. All timeseries relative to year 2005.



**Figure S3** Time series of Antarctica's combined contribution from solid ice discharge and surface mass balance changes to sea level rise based on global mean temperature change from GFDL-ESM2M (panel 1), HadGEM2-ES (panel 2), IPSL-CM5A-LR (panel 3) and MIROC5 (panel 4). Solid lines: Median projections, shaded areas: uncertainty range between the 5<sup>th</sup> and 95<sup>th</sup> percentile of the distribution. Blue: RCP2.6, yellow: RCP6.0. All timeseries relative to year 2005.

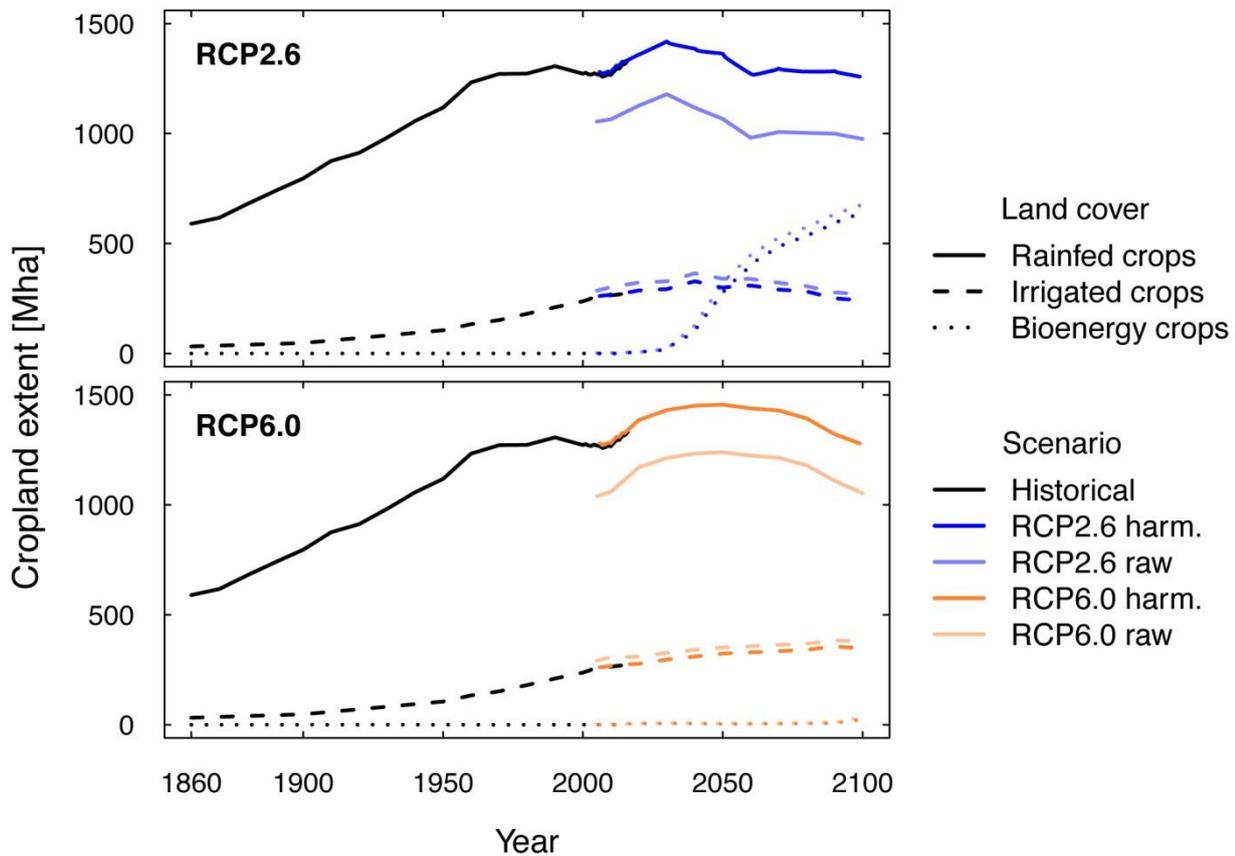


**Figure S4** Time series of the contribution of mountain glaciers to sea level rise based on global mean temperature change from GFDL-ESM2M (panel 1), HadGEM2-ES (panel 2), IPSL-CM5A-LR (panel 3) and MIROC5 (panel 4). Solid lines: Median projections, shaded areas: uncertainty range between the 5<sup>th</sup> and 95<sup>th</sup> percentile of the distribution. Blue: RCP2.6, yellow: RCP6.0. We here show the combined non-anthropogenic and anthropogenic glacier response. All timeseries relative to year 2005.



**Figure S5** Parametrized natural contribution from global glaciers: Blue line as in Marzeion et al., 2014; black line: quadratic fit).

## 2 Comparison of MAgPIE crop land areas to the associated areas after harmonization



5

**Figure S6: Comparison of areas of crop land from the original MAgPIE simulations and the harmonized version as derived for the IPSL-CM5A-LR climate projections.** Upper panel: Historical reconstruction (black lines) + crop land areas associated with RCP2.6 (blue lines); lower panel: Historical reconstruction (black lines) + crop land areas associated with RCP6.0 (orange lines). Solid lines: Rainfed crop land; dashed lines: irrigated crop land;

7

dotted lines: areas used for bioenergy production. Darkblue: Areas of crop land after harmonization; lightblue: Areas of crop land from the original MAgPIE simulations; dark orange: Areas of crop land after harmonization; light orange: Areas of crop land from the original MAgPIE simulations.

### 3 Separation of bioenergy areas (first level of disaggregation)

The original harmonization method provides the fraction of total crop land ( $c_{3per} + c_{4per} + c_{3ann} + c_{4ann} + c_{3nfx}$ ) that is used for bioenergy production but does not designate bioenergy areas within the 5 five crop classes. In the original MAgPIE setting bioenergy grass and bioenergy trees are distinguished and the associated areas of bioenergy production are considered purely rainfed. To reflect these features we used the following procedure to

10 separate bioenergy areas from the 5 crop classes:

1. Areas for biofuel plantations are taken from rainfed  $c_{4per}$  and designated as "bioenergy grass, rainfed" if the grid cell contains bioenergy grass in the original MAgPIE simulations. Analogously the bioenergy area is taken from rainfed  $c_{3per}$  and designated "bioenergy trees, rainfed" if the grid cell contains bioenergy trees in the original MAgPIE simulations.
- 15 2. If the matching rainfed crop area is too small an attempt is made to extend into the matching irrigated crop type, i.e. irrigated  $c_{4per}$  in case of bioenergy grass or irrigated  $c_{3per}$  in case of bioenergy trees. The whole bioenergy area is considered to be rainfed. To conserve total irrigated area, irrigation shares of the other crop types are increased accordingly.
3. If the sum of matching rainfed and irrigated crop area is too small the sum of both  $c_{3per}$  and  $c_{4per}$  is used starting from the crop type corresponding to the bioenergy type in the original MAgPIE simulation.
- 20 4. If still insufficient to allocate bioenergy plantations,  $c_{3ann}$ ,  $c_{4ann}$ , and  $c_{3nfx}$  areas are reduced starting from the rainfed fractions. Only if the total area of rainfed crops is insufficient irrigated  $c_{3ann}$ ,  $c_{4ann}$ , and  $c_{3nfx}$  are reduced and assumed to be covered by irrigated bioenergy plantations according to the MAgPIE category.

## 4 Derivation of crop-specific land-use and irrigation patterns (second level of disaggregation)

The **historical reconstruction and the harmonized MAgPIE future projections** only provides information on land use at a highly aggregated level while many of the hydrological or biomes models that account for land use changes offer a more specific representation of different crops and therefore also require a more detailed representation of land use patterns as input for their simulations. While LUH2 offers a disaggregation of the historical HYDE3.2 patterns into 5 crop classes ( $C_3$  annual,  $C_3$  nitrogen-fixing,  $C_3$  perennial,  $C_4$  annual,  $C_4$  perennial) many models even need further disaggregation. To allow for an efficient use of the land use information for the historical and future period we provide a further disaggregation of the historical and future agricultural land use categories into the following individual crops

1) maize, 2) groundnut, 3) rapeseed, 4) soybeans, 5) sunflower, 6) rice, 7) sugarcane

and crop classes

1) pulses, 2) temperate cereals (incl. wheat), 3) temperate roots, 4) tropical cereals, 5) tropical roots, 6) others annual, 7) others perennial, and 8) others N-fixing.

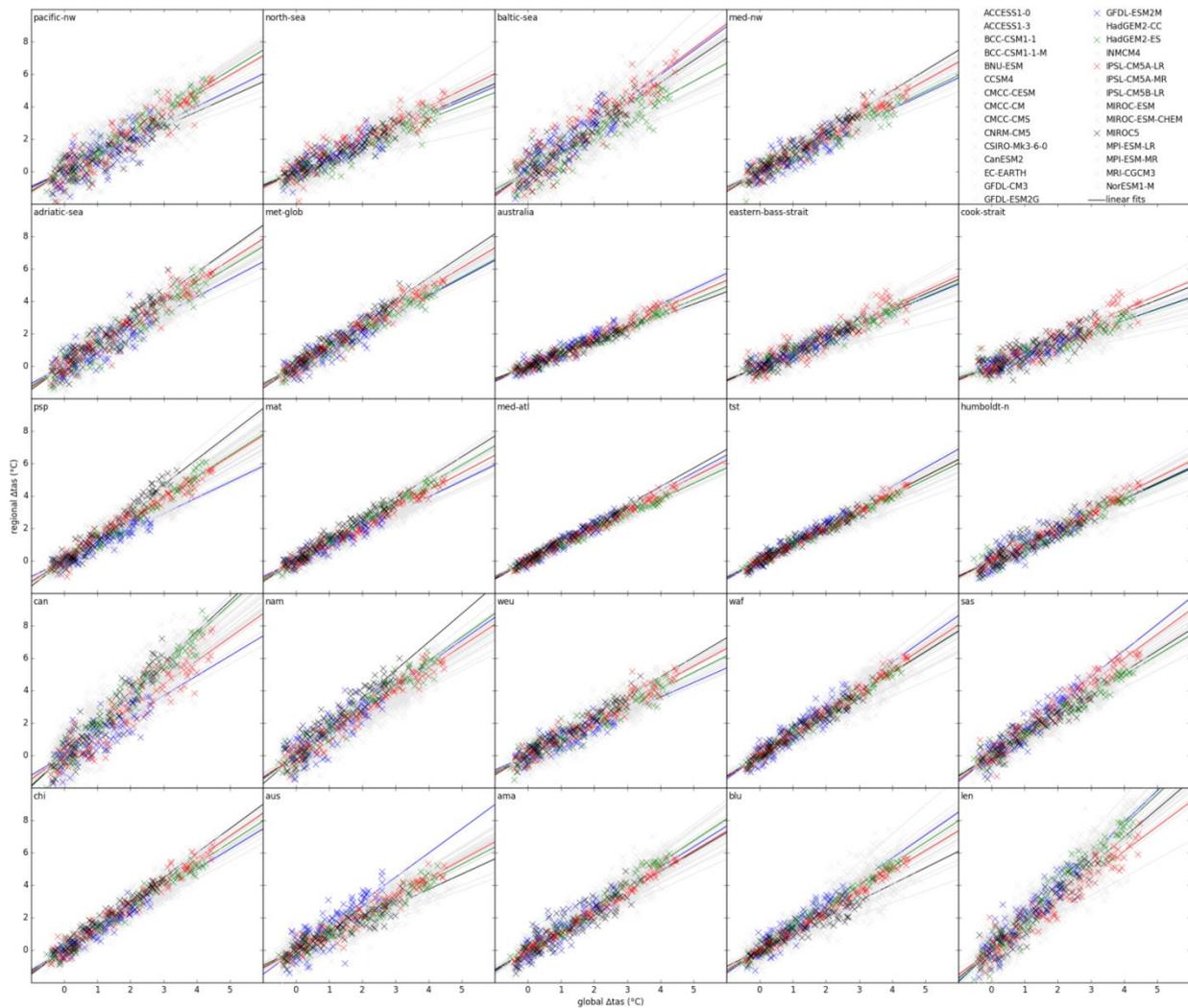
For all classes we also separate between rainfed and irrigated areas **based on the irrigation fractions provided by the LUH2-ISIMIP2b dataset**. The disaggregation **from the LUH2 categories to the finer classes** is based on the harvested areas of 175 crops provided by Monfreda et al. (2008) for the year 2000. The share

$$x_{i,j} = \frac{C_{i,j}}{C_i}$$

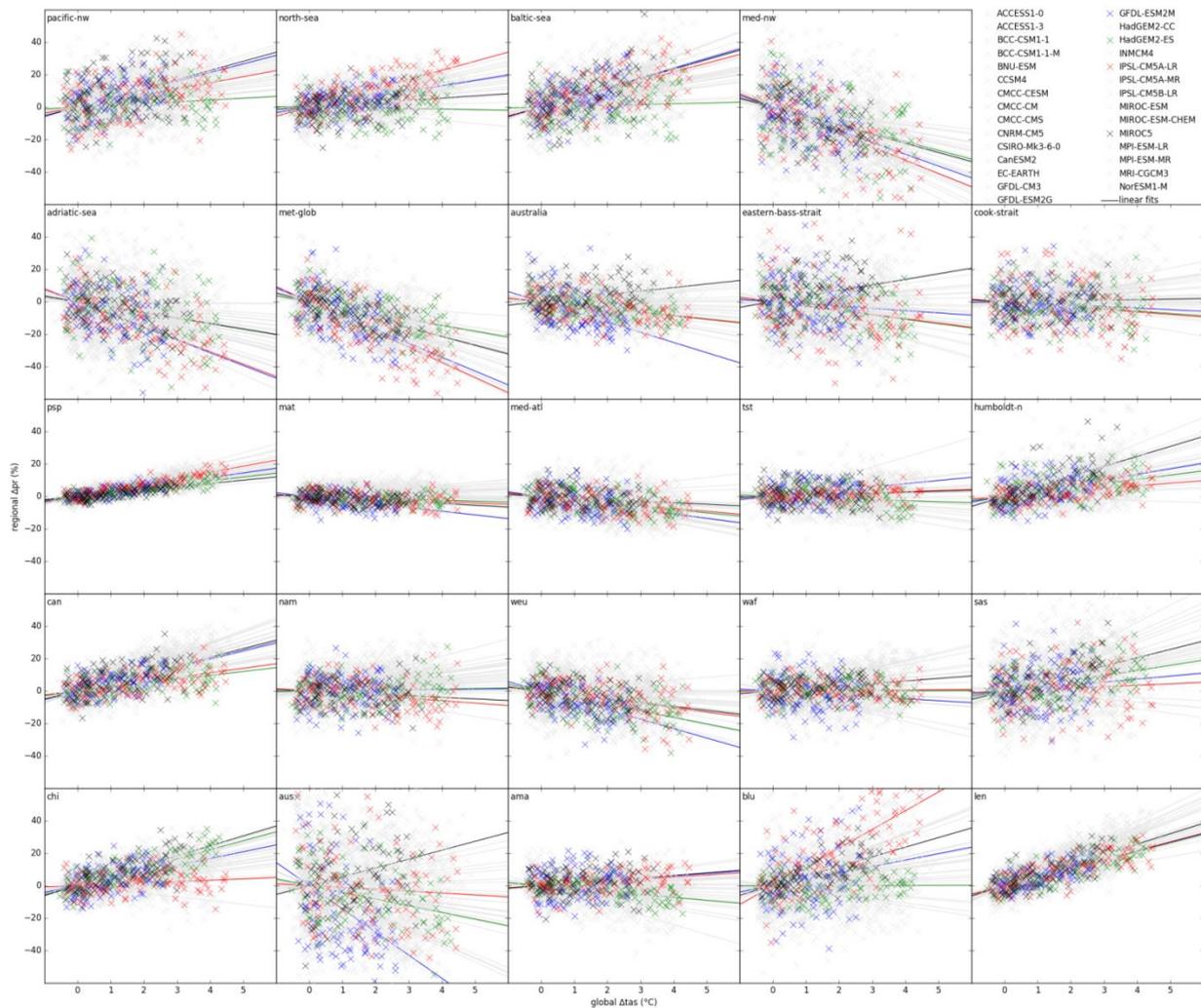
of a specific class  $C_{i,j}$  (e.g. “maize”) in the broader class  $C_i$  (e.g. “ $C_4$  annual”) is assumed to stay constant. For grid cells that contain crop land in the LUH2-ISIMIP2b data while they are not covered by crop land in Monfreda data set we apply a fraction  $x_{i,j}$  that is representative of the country average crop mix the grid cell belongs to.

## 5 Regional climate change projections of ISIMIP2b GCMs compared to CMIP5 GCMs

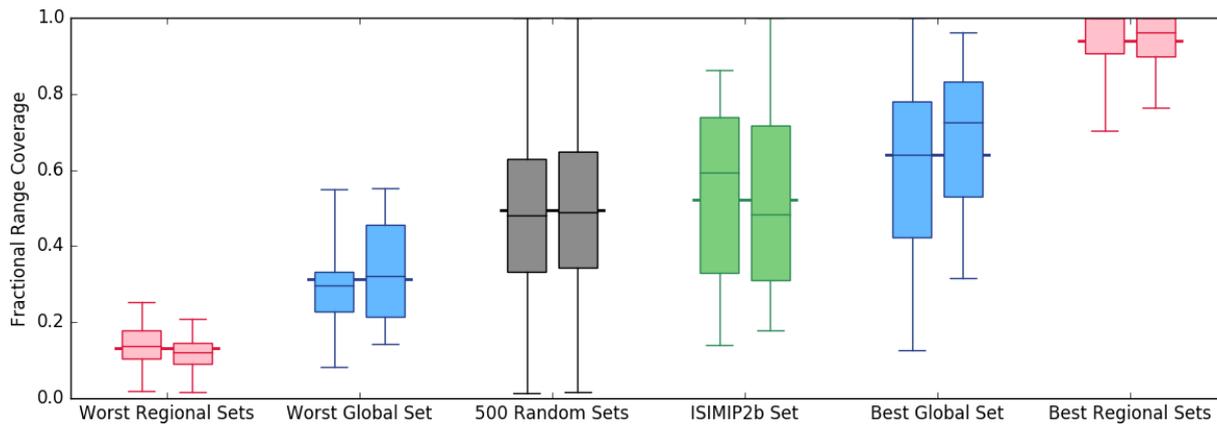
Regional mean temperature and precipitation changes versus global mean temperature change as projected by a range of CMIP5 GCMs including those selected for ISIMIP2b are shown in Figures S6 and S7. To allow for a direct comparison it is based on the raw data of the ISIMIP2b GCMs before the bias-adjustment. In order to assess how well the ISIMIP2b set covers these ranges of regional climate change projections, an analysis of the Fractional Range Coverage (FRC) as proposed by (McSweeney and Jones, 2016) is presented in Figure S8. Here, the FRC is calculated for the slopes of the linear fit lines depicted in Figures S6 and S7. We generated 500 random four-member subsets of the GCMs included in Figures S6 and S7. For each of these subsets and for the ISIMIP2b subset we then calculated all regional temperature and precipitation change FRCs. Then we determined the subset that yields the greatest/least mean value of these FRCs. Following the McSweeney and Jones (2016) terminology, this subset is called the Best/Worst Global Set. For the sake of completeness, we also determined the Best/Worst Regional Sets, which are a collection of the subsets that yield the greatest/least intra-regional mean FRCs.



**Figure S7** Regional versus global annual mean temperature change under RCP8.5 as simulated by the four ISIMIP2b GCMs (colored) and other CMIP5 GCMs (grey, see legend) for the 2006-2099 time period and all ISIMIP2b focus regions (see Figure 6 and Table 8). Temperature change is defined relative to the respective 2006-2028 mean value. Straight lines represent least-square zero-intercept linear fits to the annual data depicted as crosses.



**Figure S8** Regional annual mean precipitation change versus global annual mean temperature change under RCP8.5 as simulated by the four ISIMIP2b GCMs (colored) and other CMIP5 GCMs (grey, see legend) for the 2006-2099 time period and all ISIMIP2b focus regions (see Figure 6 and Table 8). All precipitation and temperature changes are defined relative to the corresponding 2006-2028 mean value. Straight lines represent least-square zero-intercept linear fits to the annual data depicted as crosses.



**Figure S9** Distribution of the Fractional Range Coverage (FRC) of the regional temperature and precipitation change signals depicted as straight lines in Figures S6 and S7 for various (collections of) four-member subsets of the CMIP5 GCMs listed in Figures S6 and S7. Please see the text for a definition of the different subsets. For each subset or collection of subsets, left and right box-whisker plots represent distributions of regional temperature and precipitation change FRCs, respectively. The upper and lower whiskers are the maximum and minimum FRC, respectively. The thin horizontal lines represent the three quartiles. The thick line in the background represents the mean FRC of all regional temperature and precipitation change signals.

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