

ISIMIP2b Simulation Protocol

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- 5 The simulation protocol describes the simulation scenarios, input data sets and output variables necessary to participate in the ISIMIP2b simulation round. The scientific rationale and more detailed information about the pre-processing of input data can be found in the accompanying description paper Frieler et al. 2017 *Assessing the impacts of 1.5 °C global warming – simulation protocol of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP2b)*, Geoscientific Model Development. 10, 4321–4345 doi.org/10.5194/gmd-10-4321-2017.

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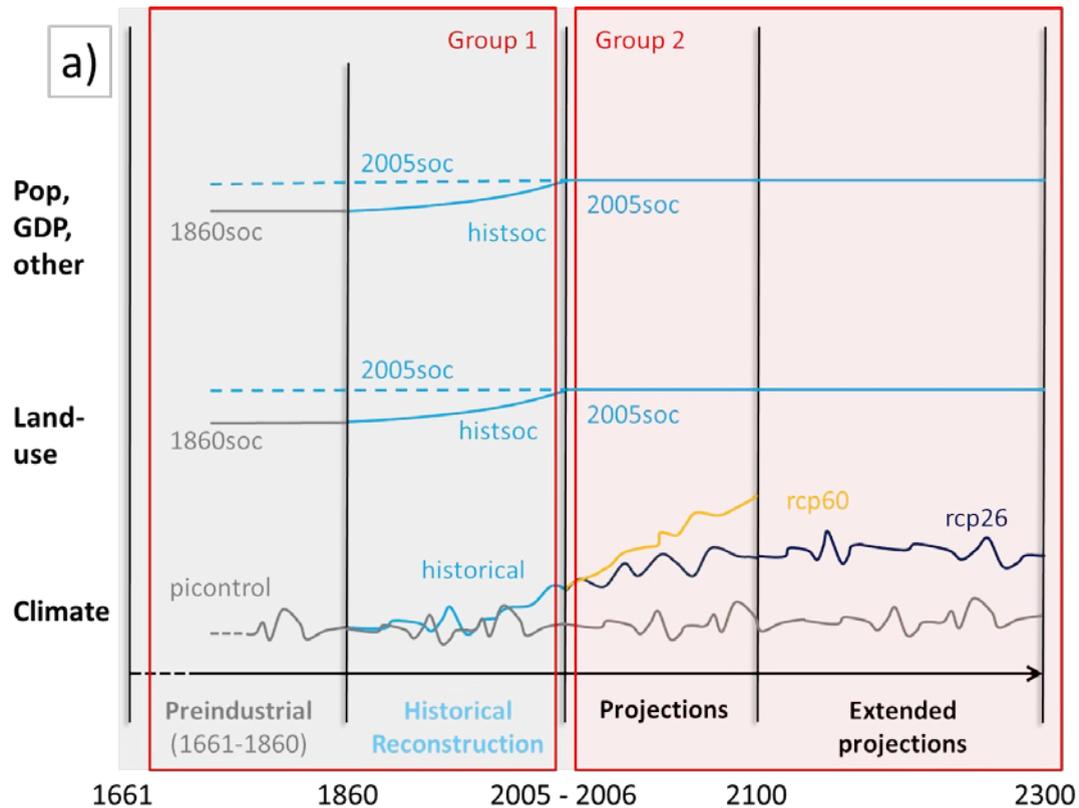
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1 Scenario design

The simulation scenarios are divided into three groups, depicted in **Figure 1** and **Figure 2**, directed at addressing distinct scientific questions:

- Quantification of pure climate-change effects of the historical warming compared to pre-industrial reference levels (Group 1).
- Future impact projections accounting for low (RCP2.6) and high (RCP6.0) greenhouse gas emissions assuming present day socio-economic conditions (Group 2).
- Future impact projections accounting for low (RCP2.6) and high (RCP6.0) greenhouse gas emissions assuming dynamic future socio-economic conditions (Group 3).



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

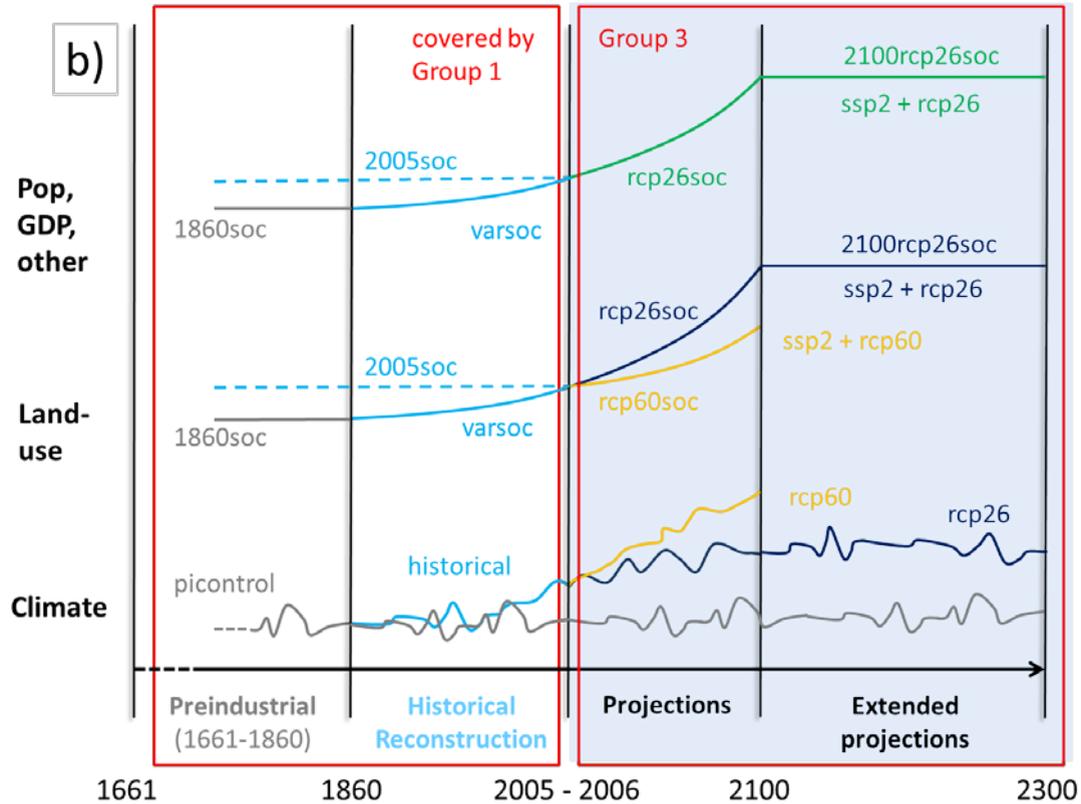


Figure 2 Schematic representation of the scenario design for **Group 3** runs. Group 3 consists of model runs to quantify the effects of the land use changes, and changes in population, GDP, and management from 2005 onwards associated with RCP6.0 (no mitigation scenario under SSP2) and RCP2.6 (strong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

2 Input data

- Information about how to access ISIMIP Input Data can be found here: www.isimip.org/gettingstarted/downloading-input-data
- A full list of ISIMIP input-data sets can be found here: www.isimip.org/gettingstarted/#input-data-bias-correction

2.1 Climate input data

- Bias-corrected to the EWEMBI data set at daily temporal and 0.5° horizontal resolution using updated versions of Fast-Track methods (see bias-correction Fact Sheet at www.isimip.org for methods description and further references).
- Daily time step, 0.5° horizontal resolution
- Pre-industrial (1661-1860), historical (1861-2005) and future (RCP2.6 and RCP6.0) conditions provided based on CMIP5 output of GFDL-ESM2M, HadGEM2-ES, IPSL-CM5A-LR and MIROC5. Output from two GCMs (GFDL-ESM2M and IPSL-CM5A-LR) includes the physical and biogeochemical ocean data required by the marine ecosystem sector of ISIMIP (see FISH-MIP, www.isimip.org/gettingstarted/marine-ecosystems-fisheries/).
- Priorities:
 - IPSL-CM5A-LR
 - GFDL-ESM2M
 - MIROC5
 - HadGEM2-ES

Table 1 Bias-corrected climate variables, including data sources of individual EWEMBI variables.

Variable	Short name	Unit
Near-Surface Relative Humidity	hurs	%
Near-Surface Specific Humidity	huss	kg kg ⁻¹
Precipitation (rainfall + snowfall)	pr	kg m ⁻² s ⁻¹
Snowfall Flux	prsn	kg m ⁻² s ⁻¹
Sea-level Air Pressure	ps	Pa

Surface Air Pressure	psl	Pa
Surface Downwelling Longwave Radiation	rlds	W m ⁻²
Surface Downwelling Shortwave Radiation	rsds	W m ⁻²
Near-Surface Wind Speed	sfcWind	m s ⁻¹
Near-Surface Air Temperature	tas	K
Daily Maximum Near-Surface Air Temperature	tasmax	K
Daily Minimum Near-Surface Air Temperature	tasmin	K

Table 2 Variables provided without bias correction.

Variable	Short name	Unit	Temporal resolution
Ocean variables (for marine ecosystems & fisheries sector)			
Sea Water X Velocity	uo	m s ⁻¹	monthly
Sea Water Y Velocity	vo	m s ⁻¹	monthly
Sea Water Z Velocity	wo	m s ⁻¹	monthly
Sea Water Temperature	to	K	monthly
Dissolved Oxygen Concentration	o2	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	mol C m ⁻² s ⁻¹	monthly
Small Phytoplankton Productivity	spp	mol C m ⁻³ s ⁻¹	monthly
Large Phytoplankton Productivity	lpp	mol C m ⁻³ s ⁻¹	monthly
Diazotroph Primary Productivity	dpp	mol C m ⁻³ s ⁻¹	monthly
Total Phytoplankton Carbon Concentration [sum of lphy + sphy (IPSL) or lphy + sphy + dphy (GFDL)]	phy	mol C m ⁻³	monthly
Small Phytoplankton Carbon Concentration	sphy	mol C m ⁻³	monthly

Large Phytoplankton Carbon Concentration	lphy	mol C m ⁻³	monthly
Diazotroph Carbon Concentration	dphy [diaz]	mol C m ⁻³	monthly
Total Zooplankton Carbon Concentration [sum of lzoo + szoo]	zooc	mol C m ⁻³	monthly
Small Zooplankton Carbon Concentration	szoo	mol C m ⁻³	monthly
Large Zooplankton Carbon Concentration	lzoo	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	mmol C m ⁻³	monthly
Photosynthetically-active radiation	Par	Einstein m ⁻² day ⁻¹	monthly
Ocean variables (for tropical cyclones)			
Depth-resolved monthly mean Sea Water Potential Temperature	thetao	K	monthly
Sea Surface Temperature	tos	K	monthly
Atmospheric variables (for tropical cyclones)			
Air Temperature at all atmospheric model levels	ta	K	monthly
Specific Humidity at all atmospheric model levels	hus	kg kg ⁻¹	monthly
Eastward Wind at 250 and 850 hPa levels	ua	m s ⁻¹	daily
Northward Wind at 250 and 850 hPa levels	va	m s ⁻¹	daily
Atmospheric variables (for coastal infrastructure)			
Sea Level Pressure	psl	Pa	3-hourly
Eastward Near-Surface Wind	uas	m s ⁻¹	3-hourly
Northward Near-Surface Wind	vas	m s ⁻¹	3-hourly

2.2 Land-use patterns

The following land-use data are provided and described in detail in **Table 4**:

- Historical land-use (LU) changes from the HYDE3.2 data (Klein Goldewijk, 2016b) (see **Figure 3**). Three, consistently generated disaggregation levels are provided:
 - Rainfed crop land, irrigated crop land, pastures and total crop land (the sum of rainfed and irrigated) – filename includes “landuse-totals”;

- As above, with crop land divided into 5 functional crop types (LUH2) – filename includes “landuse-5crops”;
- As above, with crop land divided into 15 individual crops or crop groups (based on (Monfreda et al., 2008)) – filename includes “landuse-15crops”;
- Transient, future LU patterns generated by the LU model MAGPIE (Popp et al., 2014; Stevanović et al., 2016), assuming population growth and economic development as described in SSP2, for climate-change scenarios using RCP2.6 and RCP6.0 (see **Figure 3**). These scenarios should be referred to as “landuse_ISIMIP2b_ssp2_rcp26” and “landuse_ISIMIP2b_ssp2_rcp60” respectively. Note that while these data sets cover the period 2006-2100, the period 2006-2014 are taken from historical data.

5

The transition from historical to future LU patterns requires a harmonisation between the land-use classes and areas between the different data sets. A full description of how this will be done will appear here shortly.

Table 3 Agricultural land-use categories

Land-use type	Historical reconstruction	Future projections	Disaggregation into functional crop types (LUH2)	Individual crops or crop groups
Irrigated crops	HYDE	MAGPIE	Total cropland disaggregated into: C ₃ annual, C ₃ nitrogen-fixing, C ₃ perennial, C ₄ annual, C ₄ perennial (contains only sugarcane)	C ₃ annual disaggregated into: rapeseed, rice, temperate cereals, temperate roots, tropical roots, sunflower, others C ₃ annual C ₃ perennial: (no further disaggregation) C ₃ nitrogen-fixing disaggregated into: groundnut, pulses, soybean, others C ₃ nitrogen-fixing C ₄ annual disaggregated into: maize, tropical cereals C ₄ perennial: sugarcane
Rainfed crops	HYDE	MAGPIE	Total cropland disaggregated into: C ₃ annual, C ₃ nitrogen-fixing, C ₃ perennial, C ₄ annual, C ₄ perennial (contains only sugarcane)	C ₃ annual disaggregated into: rapeseed, rice, temperate cereals, temperate roots, tropical roots, sunflower, others C ₃ annual C ₃ perennial: (no further disaggregation) C ₃ nitrogen-fixing disaggregated into: groundnut, pulses, soybean, others C ₃ nitrogen-fixing C ₄ annual disaggregated into: maize, tropical cereals C ₄ perennial: sugarcane
Pastures	HYDE	MAGPIE	Total pastures are provided.	In addition, pastures are split into managed pastures and (natural) rangelands

bioenergy production (rainfed grass)	-	MAGPIE		
bioenergy production (rainfed trees)	-	MAGPIE		
Urban	HYDE	constant (HYDE)		
Other (natural vegetation etc.)	1 - everything else	1 - everything else	The LUH2 data set includes additional natural land classes, which are consistent with the historical LU data provided here, and could be provided upon request.	(to be specified)

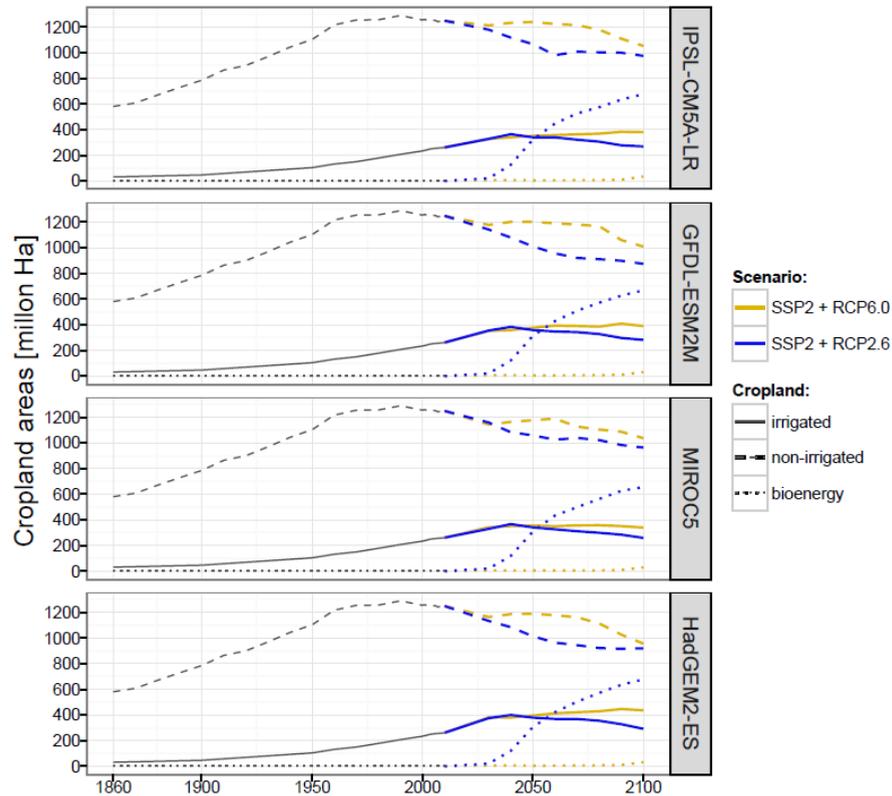
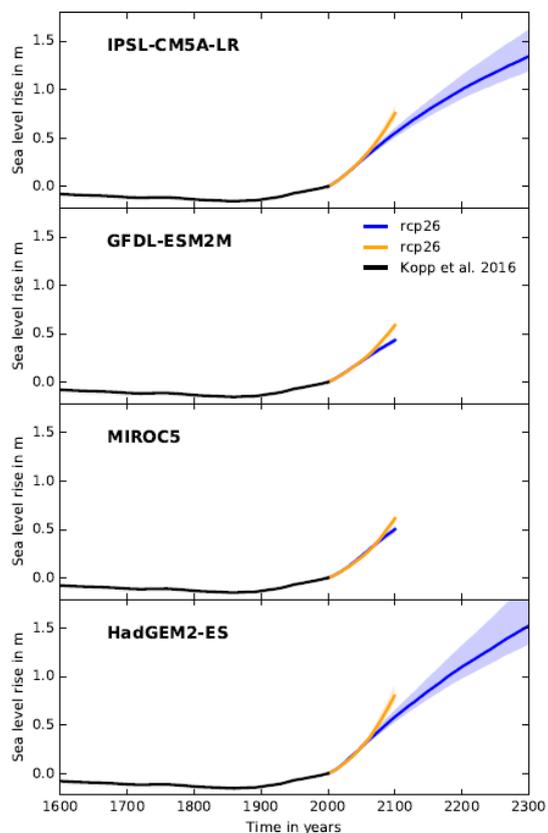


Figure 3 Time series of total crop land (irrigated (solid lines) and non-irrigated (dashed lines)) as reconstructed for the historical period (1860 - 2015) based on HYDE3.2 (Klein Goldewijk, 2016b) and projected under SSP2 (2016-2100) assuming no explicit mitigation of greenhouse gas emissions (RCP6.0, yellow line) and strong mitigation (RCP2.6, dark blue line) as suggested by MAgPIE. Future projections also include land areas for second generation bioenergy production (not included in “total crop land”) for the demand generated from the Integrated Assessment Modelling Framework REMIND/MAgPIE, as implemented in the SSP exercise (dotted lines). Global data were linearly interpolated between the historical data set and the projections.

2.3 Sea-level rise patterns

Table 4 Information on sea-level-rise data.

Driver	Historical reconstruction	Future projections	Long-term projections
Sea-level rise	Observed time series up to 2000	From 2000 onwards, spatial patterns derived from GCMs. Regional variation of sea-level rise from glaciers and the large ice sheets are scaled from their respective gravitational patterns.	Constrained extrapolations have been extended to 2299.



5 **Figure 4** Time series of global total sea-level rise based on observations (Kopp et al., 2016, black line) until year 2000 and global-mean-temperature change from IPSL-CM5A-LR (panel 1), GFDL-ESM2M (panel 2), MIROC5 (panel 3) and HadGEM2-ES (panel 4) after year 2000: solid lines: Median projections, shaded areas: uncertainty range between the 5th and 95th percentile of the uncertainty distribution associated with the ice components. Blue: RCP2.6, yellow: RCP6.0. All time series relative to year 2000. Non-climate-driven contribution from glaciers and land water storage are added to the projections.

2.4 Population patterns and economic output (Gross Domestic Product, GDP)

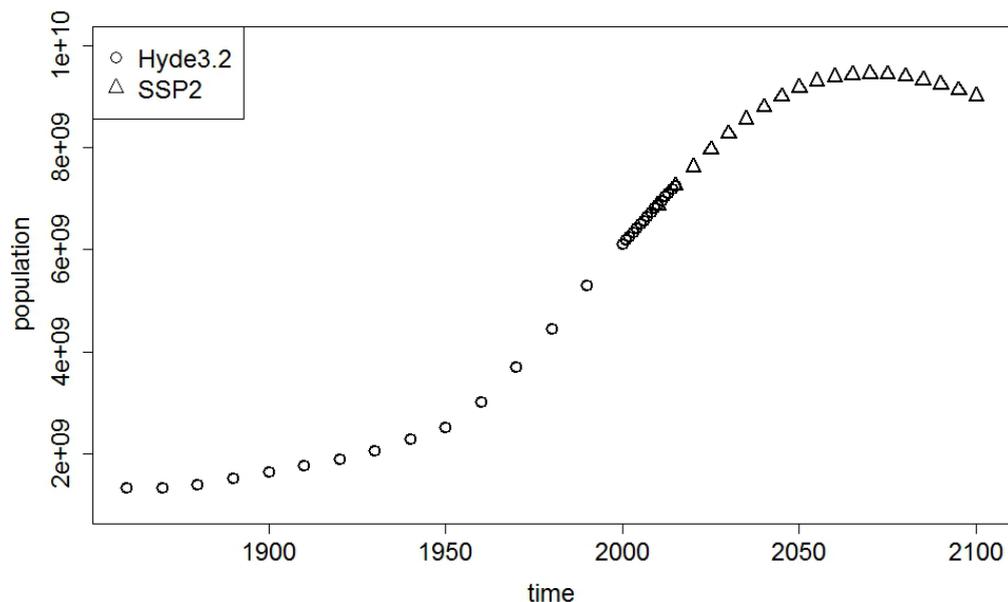


Figure 5 Time series of global population for the historical period (dots) and future projections following the SSP2 storyline (triangles).

5 **Table 5** Socio-economic input data corresponding to SSP2.

Driver	Historical reconstruction	Future projections
GDP	<ul style="list-style-type: none"> Annual country-level data derived from the Maddison project (Bolt and van Zanden, 2014, www.ggdc.net/maddison/maddison-project/home.htm) and extended by Penn World Tables 9.0 and World Development Indicators. Annual data on 0.5° grid corresponding to SSP2. 	<ul style="list-style-type: none"> Annual country-level data based on OECD projections from the SSP database (Dellink et al., 2015, https://secure.iiasa.ac.at/web-apps/ene/SspDb/) corresponding to SSP2. Annual data on 0.5° grid based on downscaling of country-level data (Murakami and Yamagata, 2016).
Population	<ul style="list-style-type: none"> Annual data on a 0.5° and 5' grid based on the HYDE3.2 database (Klein Goldewijk, 2016a). Annual country-level, age-specific population data based on the HYDE3.2 database (Klein Goldewijk, 2016a). 	<ul style="list-style-type: none"> Annual data on a 0.5° grid based on the national SSP2 population projections as described in Samir and Lutz, (2014). Annual country-level, age-specific data in 5-year age groups and all-age mortality rates in 5-year time. Also includes

	rural/urban division.
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2.5 Other human influences

For all of these input variables, we describe reconstructions to be used for the historical **histsoc** simulations (see **Table 6**). For models that do not allow for time-varying human influences across the historical period, human influences should be fixed at present-day (**2005soc**) levels (see dashed line in **Figure 1**, Group 1). Beyond 2005 all human influences should be held constant (Group 2) or varied according to SSP2 if associated projections are available (**Figure 2**, Group 3). As ISIMIP2b Group 3 only considers SSP2 and no other socio-economic storylines, the SSP scenario is not explicitly mentioned in the file names, although the changes in land-use patterns, etc. certainly not only depend on the RCP (due to the accounting for associated climate impacts of, e.g., crop yields), but also on the SSP. Within ISIMIP2b projections are provided for future irrigation-water extraction, fertilizer application rates and nitrogen deposition (see **Table 6**).

Table 6 Data sets representing “other human influences” for the historical simulations (**histsoc**, Group 1) and the future projections accounting for changes in socio-economic drivers (**rcp26soc/rcp60soc**, Group 3).

Driver	Historical reconstruction	Future projections
Reservoirs & dams <ul style="list-style-type: none">• location• upstream area• capacity• construction/commissioning year	<p>Global data on 0.5° grid based on GranD database and the DDm30 routing network.</p> <p>Documentation: http://www.gwsp.org/products/grand-database.html</p> <p>Note: Simple interpolation can result in inconsistencies between the GranD database and the DDM30 routing network (wrong upstream area due to misaligned dam/reservoir location). A file is provided with locations of all larger dams/reservoirs adapted to DDM30 so as to best match reported upstream areas.</p>	<p>No future data sets are provided.</p> <p>Held fixed at year 2005 levels in all simulations.</p>

<p>Water abstraction for domestic and industrial uses</p>	<p>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 until 2005.</p>	<p>Generated by each modelling group individually.</p> <p>For modelling groups that do not have their own representation, we provide files containing the multi-model mean (from the global water models WaterGAP, PCRGLOBWB, and H08) domestic and industrial water withdrawal and consumption under SSP2 from the Water Futures and Solutions (WFaS) (Wada et al., 2016) project.</p> <p>This data is available from 2006 until 2050. The values should be kept constant from 2050 onwards.</p> <p>The data provided for rcp26soc and rcp60soc are identical and both are 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>Irrigation water extraction (km³)</p>	<p>Individually derived from the land-use and irrigation patterns provided. Water directly used for livestock (e.g. animal husbandry and drinking), except for indirect uses by irrigation of feed crops, is expected to be very low (Müller Schmied et al., 2016) and could be set to zero if not directly represented in the individual models.</p>	<p>Derived from future land-use and irrigation patterns provided based on output from the MAgPIE model (see section 0). Land-use projections are provided for:</p> <ul style="list-style-type: none"> • SSP2+RCP6.0 • SSP2+RCP2.6; <p>Direct water use for livestock should be ignored (i.e. can be set to zero).</p>

<p>N fertilizer use (kg per ha of cropland)</p>	<p>Annual crop-specific input per ha of crop land for C₃ and C₄ annual, C₃ and C₄ perennial and C₃ Nitrogen fixing. This data set is part of the LUH2 dataset developed for CMIP6 (Hurtt et al.) based on HYDE3.2.</p>	<p>Crop group-specific inorganic N fertilizer use per area of cropland provided by the LUH2-ISIMIP2b dataset, which differs for SSP2CRCP2.6 and SSP2CRCP6.0. To allow for the allcrops model set-up this information is extrapolated to all land cells using a nearest neighbor algorithm.</p>
<p>Nitrogen (NH_x and NO_y) deposition</p>	<p>Annual and monthly, 0.5° gridded data for 1850-2005 derived by taking the average of three atmospheric chemistry models (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>GISS-E2-R provided monthly data; CCSM-CAM3.5 provided monthly data in each decade from 1850s to the 2000s; and GFDL-AM3 provided monthly data for 1850-1860, 1871-1950, 1961-1980, 1991-2000 and 2001-2010.</p> <p>Annual deposition rates calculated by aggregating the monthly data, and 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>	<p>As per historical reconstruction for 2006-2099 following RCP2.6 and RCP6.0.</p>
<p>Fishing intensity</p>	<p>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 technology increase and SAUP economic reconstructions.</p> <p>Given that the SAUP historical reconstruction starts in 1950, fishing effort should be held at a constant 1950 value from 1860-1950.</p>	<p>Held constant after 2005 (2005soc)</p>

Forest management	Based on observed stem numbers (see Table 17-Table 18)	Based generic future management practices (see Table 16-Table 18)
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2.6 Focus Regions

Simulation data are welcome for all world regions. Even single model simulations for specific sites will help to generate a more comprehensive picture of climate change impacts and potentially allow for constraining global models. However, to allow for model intercomparisons simulations should also be provided for the sector specific focus regions shown in **Figure 6** and defined in **Table 7**, if feasible with your model. For regions not defined in the protocol, please contact the ISIMIP Team to agree on appropriate naming and define the location of the region in the metadata of your output files.

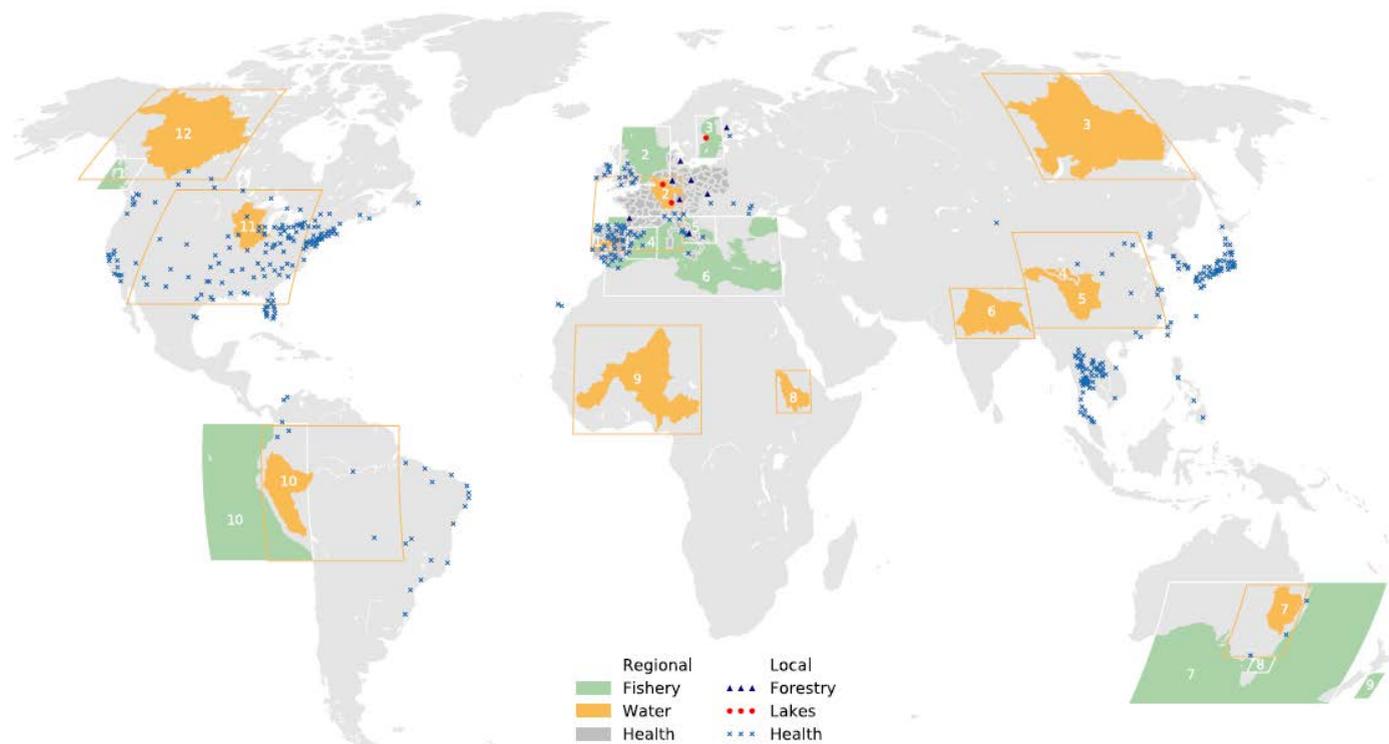


Figure 6 ISIMIP focus regions. See **Table 7** for region definitions.

2.7 Lake specifications

Grid-scale lake fraction is provided based on the Global Lake and Wetland Database (GLWD; Lehner and Döll, 2004) and available on the DKRZ input data repository (/work/bb0820/ISIMIP/ISIMIP2b/InputData/lakes/pctlake.nc4; Subin et al., 2012).

5 Since a 0.5°x0.5° pixel potentially contains multiple lakes with different characteristics (e.g. in terms of bathymetry, transparency, fetch), it is not possible to fully represent this subgrid-scale heterogeneity. Instead, the global-scale lake simulations should represent a ‘representative lake’ for a given pixel. Consequently, no stringent requirement is imposed with respect to lake depth, light extinction coefficient or initial conditions. However, lake depth, modellers are encouraged to use the data from the Global Lake Data Base (GLDB). A regridded lake-depth field based on GLDBv1 (Kourzeneva, 2010) is available at 0.5°x0.5° resolution on the DKRZ input data repository (/work/bb0820/ISIMIP/ISIMIP2b/InputData/lakes/lakedepth.nc4); this field was aggregated from 30 arc sec to 1.9°x2.5° and then interpolated again
 10 to 0.5°x0.5°; Subin et al., 2012). Alternatively, modellers may choose to use the more recent GLDBv2 available at 30 arc sec (<http://www.flake.igb-berlin.de/ep-data.shtml>, Choulga et al., 2014).

Table 7 List of ISIMIP focus regions as shown in **Figure 6**.

Focus region (shortname)	Zonal extent (longitude)	Meridional extent (latitude)	River basin(s) or Region (shortname).
Number refers to Figure 6			
Regional water simulations			
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)
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)	140°0′W– 103°0′W	52°0′N–69°0′N	Mackenzie (mackenzie)
Regional lake simulations			

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	
Lake in northern Spain			TBC, depending on funding of WATExR, Rafael
Regional forestry simulations			
bily-kriz	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-beech	9.570	51.770	
solling-spruce	9.570	51.770	
peitz	14.350	51.917	
le-bray	-0.769	44.717	
Ocean regions			
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 Meditteranean (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
Meditteranean 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
(10) (psp)	90°30'W–30°30'E		48°30'N–70°30'N

(11) (mat)	90°30'W–30°30'E	35°30'N–49°30'N
(12) (med-atl)	90°30'W–30°30'E	17°30'N–36°30'N
(13) (tst)	90°30'W–30°30'E	0°30'S–18°30'N
North Humboldt Sea (14) (Humboldt-n)	93°30'W–69°30'W	20°30'S–6°30'N

3 Conventions for File Names and Formats

3.1 General Notes

It is important that you comply precisely with the formatting specified below, in order to facilitate the analysis of your simulation results in the ISIMIP framework. Incorrect formatting can seriously delay the analysis. The ISIMIP Team will be glad to assist with the preparation of these files if necessary.

For questions or clarifications, please contact info@isimip.org or the data manager directly (buechner@pik-potsdam.de) before submitting files.

3.1.1 File names

Things to note:

- Report **one** variable per file
- Use **lowercase** letters in file names only
- Separate only specifiers with underscore “_”
- Use hyphens for specifier internal string separation, e.g. in model name
- NetCDF file extension is .nc4

The file name format is:

```
<modelname>_<gcm>_<bias-correction>_<climate-scenario>_<soc-scenario>_<co2sens-scenarios>_<variable>_<region>_<timestep>_<start-year>_<end-year>.nc4
```

The identifiers in brackets should be replaced with the appropriate identifiers from **Table 9**. Specifiers may be dependent on the sector. The identifiers <variable> might also contain information about the plant functional type (in the biomes and permafrost sectors). The pft naming is model-specific and hence has to be reported in the impact-model database entries for each model (www.isimip.org/impactmodels). In the forest sector the identifier <variable> might contain information about the tree species. The species names codes are listed in **Table 20**.

Examples:

```
lpjml_ipsl-cm5a-lr_ewembi_historical_histsoc_co2_qtot_global_annual_1861_1870.nc4
```

```
lpjml_ipsl-cm5a-lr_ewembi_rcp26_rcp26soc_2005co2_yield-mai-noirr_global_annual_2006_2010.nc4
```

Table 8 Identifiers for file naming convention.

Item	Possible specifiers	Description
<modelname>		Model name

<gcm>	hadgem2-es, ipsl-cm5a-lr, miroc5, gfdl-esm2m	Name of the General Circulation Model from which climate-forcing data was used.
<bias_correction>	nobc, localbc, ewembi	The target observed climate data used for the bias correction. localbc refers to local data from weather stations used for the bias-correction in e.g. the forest sector. ewembi refers to EWEMBI data used for the bias-correction globally on a 0.5°C grid nobc Indicates that no bias correction was performed on the climate data (e.g. ocean data)
<climate_scenario>	picontrol, historical, rcp26, rcp60	Climate & CO2 concentration scenario (RCP). Note: even though “picontrol” uses fixed co2-levels, it should come with the <co2sens-scenario> qualifier “co2” (see below)
<soc -scenario>	nosoc, 1860soc, histsoc, 2005soc, rcp26soc, rcp60soc, 2100rcp26soc	Scenario describing other human influences, such as land use and land management.
<co2sens-scenario>	co2, 2005co2	‘co2’ for all experiments other than the sensitivity experiments for which 2005co2 is explicitly written. Note: even models in which CO2 has no effect should use the co2 identifier relevant to the experiment.
<variable>		Output variable names – see sector-specific tables.
<region>	global, [region/basin/sites]	Region, basin or site names given in Section 2.6. Where simulations are provided for a single station within a river basin, the tag should have the format [basin]-[station].
<timestep>	3hr, daily, monthly, annual	The temporal resolution of your output data files.
<start-year>_<end-year>	e.g. 1861_1870	Files should be uploaded in 10-year pieces. For the transition from the historical to the future period (2005-2006), files should be separated, i.e. the identifiers would be 2001_2005 and 2006_2010.

		For the forest simulations, no time slices are needed and the full simulation period can be covered in one file.
--	--	--

4 Sector-specific implementation of scenario design

Here we provide a more detailed description of the sector-specific simulations. The grey, red, and blue background colours of the different entries in the tables indicate Group 1, 2, 3 runs, respectively. Runs marked in violet represent additional sector-specific sensitivity experiments. Each simulation run has a name (Experiment I to VII) that is consistent across sectors, i.e. runs from the individual experiments could be combined for a consistent cross-sectoral analysis. Since human influences represented in individual sectors may depend on the RCPs (such as land-use changes), while human influences relevant for other sectors may only depend on the SSP, the number of experiments differs from sector to sector.

5 Water (hydrological models)

5.1 Scenarios

Climate & CO ₂ concentration scenarios	
picontrol	Pre-industrial climate and 286ppm CO ₂ concentration. The climate data for the entire period (1661-2299) are unique – no (or little) recycling of data has taken place.
historical	Historical climate and CO ₂ concentration.
rcp26	Future climate and CO ₂ concentration from RCP2.6
rcp60	Future climate and CO ₂ concentration from RCP6.0
Human influence and land-use scenarios	
1860soc	Pre-industrial land use and other human influences. Given the small effect of dams & reservoirs before 1900, modellers may apply the 1901 dam/reservoir configuration during the pre-industrial period and the 1861-1900 part of the historical period if that is significantly easier than applying the 1861 configuration.
histsoc	Varying historical land use and other human influences.
2005soc	Fixed year-2005 land use and other human influences.
rcp26soc	Varying land use, water abstraction and other human influences according to SSP2 and RCP2.6; fixed year-2005 dams and reservoirs. For models using fixed LU types, varying irrigation areas can also be considered as varying land use.
rcp60soc	Varying land use, water abstraction and other human influences according to SSP2 and RCP6.0, fixed year-2005 dams and reservoirs. For models using fixed LU types, varying irrigation areas can also be considered as varying land use.
2100rcp26soc	Land use and other human influences fixed at year 2100 levels according to RCP2.6.

For the historical period, groups that have limited computational capacities may choose to report only part of the full period, but including at least 1961-2005. All other periods should be reported completely. For those models that do not represent *changes* in human influences, those influences should be held fixed at 2005 levels throughout all Group 1 (cf. **2005soc** marked as dashed blue lines in Fig. 1) and Group 2 simulations. Group 3 will be identical to Group 2 for these models and thus does not require additional simulations. Models that do not include human influences *at all* should

nevertheless run the Group 1 and Group 2 simulation, since these simulations will still allow for an exploration of the effects of climate change compare to pre-industrial climate, and will also allow for a better assessment of the relative importance of human impacts versus climate impacts. These runs should be named as **nosoc** simulations.

5 The regional-scale simulations are performed for 12 large river basins. In six river basins (Tagus, Niger, Blue Nile, Ganges, Upper Yangtze and Darling) water management (dams/reservoirs, water abstraction) will be implemented. In the other six river basins, human influences such as LU changes, dams and reservoirs, and water abstraction is not relevant (Upper Yellow, Upper Amazon) or negligible (Rhine, Lena, Upper Mississippi), and can be ignored. Apart from this, regional water simulations should follow the global water simulations to allow for a cross-scale comparison of the simulations. The focus lakes for the local lake models are located within the focus river basins and listed in section 5.2.

Table 9 ISIMIP2b scenarios for global and regional water simulations. Option 2* only if option 1 not possible.

Experiment	Input	pre-industrial	historical	future	extended future	
		1661-1860	1861-2005	2006-2099	2100-2299	
I	no climate change, pre-industrial CO ₂	Climate & CO ₂	picontrol	picontrol	picontrol	picontrol
	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU	Option 1: 1860soc Option 2*: 2005soc	Option 1: histsoc Option 2*: 2005soc	2005soc	2005soc
II	RCP2.6 climate & CO ₂	Climate & CO ₂	Experiment I	historical	rcp26	rcp26
	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU		Option 1: histsoc Option 2*: 2005soc	2005soc	2005soc
III	RCP6.0 climate & CO ₂	Climate & CO ₂	Experiment I	Experiment II	rcp60	not simulated
	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU			2005soc	
IV	no climate change, pre-industrial CO ₂	Climate & CO ₂	Experiment I	Experiment I	picontrol	picontrol

	varying human influences & LU up to 2100 (RCP2.6), then fixed at 2100 levels thereafter	Human & LU			rcp26soc	2100rcp26soc
V	no climate change, pre-industrial CO ₂	Climate & CO ₂	Experiment I	Experiment I	picontrol	not simulated
	varying human influences & LU (RCP6.0)	Human & LU			rcp60soc	
VI	RCP2.6 climate & CO ₂	Climate & CO ₂	Experiment I	Experiment II	rcp26	rcp26
	varying human influences & LU up to 2100 (RCP2.6), then fixed at 2100 levels thereafter	Human & LU			rcp26soc	2100rcp26soc
VII	RCP6.0 climate & CO ₂	Climate & CO ₂	Experiment I	Experiment II	rcp60	not simulated
	varying human influences & LU (RCP6.0)	Human & LU			rcp60soc	

5.2 Global and regional hydrological models

Variable names are chosen to comply, where feasible, with the ALMA convention (www.lmd.jussieu.fr/~polcher/ALMA/convention_output_3.html) and the names used in WATCH/WaterMIP. All variables are to be reported as time-averages with the indicated resolution; do not report instantaneous values ('snapshots'). Exceptions are **maxdis** and **mindis**, which are the maximum and minimum daily-average discharge in a given month, respectively, to be reported on a monthly basis (see below).

5.2.1 Output data

Table 10 Output variables to be reported by water sector models. Variables highlighted in orange are requested from both global and regional models; discharge at gauge level (highlighted in purple) is requested only from regional models; other variables are requested only from global models. Variables marked by * are also relevant for the permafrost sector and also listed there. Variables marked by ** are **only** relevant for the permafrost sector.

Variable (long name)	Variable name	Resolution	Unit (NetCDF format)	Comments
----------------------	---------------	------------	----------------------------	----------

Hydrological Variables				
*Runoff	qtot	daily (0.5°x0.5°)	kg m ⁻² s ⁻¹	total (surface + subsurface) runoff (qtot = qs + qsb). If daily resolution not possible, please provide monthly.
Surface runoff	qs	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	Water that leaves the surface layer (top soil layer) e.g. as overland flow / fast runoff
Subsurface runoff	qsb	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	Sum of water that flows out from subsurface layer(s) including the groundwater layer (if present). Equals qg in case of a groundwater layer below only one soil layer
Groundwater recharge	qr	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	Water that percolates through the soil layer(s) into the groundwater layer. In case seepage is simulated but no groundwater layer is present, report seepage as qr and qg.
Groundwater runoff	qg	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	Water that leaves the groundwater layer. In case seepage is simulated but no groundwater layer is present, report seepage as qr and qg.
Discharge (gridded)	dis	daily (0.5°x0.5°)	m ³ s ⁻¹	If daily resolution not possible, please provide monthly
Discharge (gauge level)	dis	daily (see website for gauge locations)	m ³ s ⁻¹	If daily resolution not possible, please provide monthly
Monthly maximum of daily discharge	maxdis	monthly (0.5°x0.5°)	m ³ s ⁻¹	Reporting this variable is not mandatory, but desirable particularly if daily discharge data is unfeasible
Monthly minimum of daily discharge	mindis	monthly (0.5°x0.5°)	m ³ s ⁻¹	Reporting this variable is not mandatory, but desirable particularly if daily discharge data is unfeasible
Evapotranspiration	evap	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	Sum of transpiration, evaporation, interception losses, and sublimation.

Potential Evapotranspiration	potevap	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	as for <i>evap</i> , but with all resistances set to zero, except the aerodynamic resistance.
*Soil moisture (= soil water storage)	soilmoist	monthly (0.5°x0.5°)	kg m ⁻²	provide soil moisture for all depth layers (i.e. 3D-field), and indicate depth in m.
Soil moisture, root zone	rootmoist	monthly (0.5°x0.5°)	kg m ⁻²	Total simulated soil moisture available for evapotranspiration. If simulated by the model. Please indicate the depth of the root zone for each vegetation type in your model
**Frozen soil moisture for each layer	soilmoistfroz	monthly (0.5°x0.5°)	kg m ⁻²	water content of frozen soil
**Temperature of Soil	tsl	daily (0.5°x0.5°)	K	Temperature of each soil layer. Reported as "missing" for grid cells occupied entirely by "sea". Also need depths in meters. Daily would be great, but otherwise monthly would work. **if daily resolution not possible, please provide monthly
**Snow depth	snd	monthly (0.5°x0.5°)	m	Grid cell mean depth of snowpack.
*Snow water equivalent (= snow water storage)	swe	monthly (0.5°x0.5°)	kg m ⁻²	Total water mass of the snowpack (liquid or frozen), averaged over a grid cell.
Total water storage	tws	monthly (0.5°x0.5°)	kg m ⁻²	Mean monthly water storage in all compartments. Please indicate in the netcdf metadata which storage compartments are considered.
Canopy water storage	canopystor	monthly (0.5°x0.5°)	kg m ⁻²	Mean monthly water storage in the canopy.
Glacier storage	glacierstor	monthly (0.5°x0.5°)	kg m ⁻²	Mean monthly water storage in glaciers.
Groundwater storage	groundwstor	monthly (0.5°x0.5°)	kg m ⁻²	Mean monthly water storage in groundwater layer.
Lake storage	lakestor	monthly (0.5°x0.5°)	kg m ⁻²	Mean monthly water storage in lakes (except reservoirs).

Wetland storage	wetlandstor	monthly (0.5°x0.5°)	kg m ⁻²	Mean monthly water storage in wetlands.
Reservoir storage	reservoirstor	monthly (0.5°x0.5°)	kg m ⁻²	Mean monthly water storage in reservoirs.
River storage	riverstor	monthly (0.5°x0.5°)	kg m ⁻²	Mean monthly water storage in rivers.
*Annual maximum daily thaw depth	thawdepth	annual (0.5°x0.5°)	m	calculated from daily thaw depths, which do not need to be submitted themselves.
Rainfall	rainf	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	These variables are required for test purposes only. If you need to reduce output data volumes, please provide these variables only once, with the first (test) data set you submit, e.g. for the first decade of each experiment. NOTE: rainf + snowf = total precipitation
Snowfall	snowf	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	
Water management variables (for models that consider water management/human impacts)				
<p>NOTE: Models that cannot differentiate between water-use sectors may report the respective totals and include the first letter of each sector included in the filenames. E.g. combined potential water withdrawal in the irrigation and livestock sectors would be “p_il_ww”; combined actual water consumption in the irrigation, domestic, manufacturing, electricity, and livestock sectors would be “a_id_me_luse” (see section 2.6 for the latest naming convention regarding file names).</p>				
Irrigation water demand (=potential irrigation water Withdrawal)	p _i r _w w	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	Irrigation water withdrawal, assuming unlimited water supply
Actual irrigation water withdrawal	a _i r _w w	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	Irrigation water withdrawal, taking water availability into account; please provide if computed
Potential irrigation water consumption	p _i r _r use	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	portion of withdrawal that is evapo-transpired, assuming unlimited water supply
Actual irrigation water consumption	a _i r _r use	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	portion of withdrawal that is evapotranspired, taking water availability into account; if computed

Actual green water consumption on irrigated cropland	airrusegreen	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	actual evapotranspiration from rain water over irrigated cropland; if computed
Potential green water consumption on irrigated cropland	prrusegreen	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	potential evapotranspiration from rain water over irrigated cropland; if computed and different from airrusegreen
Actual green water consumption on rainfed cropland	arainfusegreen	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	actual evapotranspiration from rain water over rainfed cropland; if computed
Actual domestic water withdrawal	adomww	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	if computed
Actual domestic water consumption	adomuse	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	if computed
Actual manufacturing water withdrawal	amanww	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	if computed
Actual Manufacturing water consumption	amanuse	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	if computed
Actual electricity water withdrawal	aelecww	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	if computed
Actual electricity water consumption	aelecuse	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	if computed
Actual livestock water withdrawal	aliveww	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	if computed
Actual livestock water consumption	aliveuse	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	if computed

Total (all sectors) actual water consumption	Atotuse	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	Sum of actual water consumption from all sectors in case it is not possible to provide this information sector-specific.
Total (all sectors) actual water withdrawal	Atotww	monthly (0.5°x0.5°)	kg m ⁻² s ⁻¹	Sum of actual water withdrawal from all sectors in case it is not possible to provide this information sector-specific
Static output				
Soil types	Soil	static (0.5°x0.5°)		Soil types or texture classes as used by your model. Please include a description of each type or class, especially if these are different from the standard HSWD and GSWP3 soil types. Please also include a description of the parameters and values associated with these soil types (parameter values could be submitted as spatial fields where appropriate).
Leaf Area Index	lai	static (0.5°x0.5°) or monthly (0.5°x0.5°) where appropriate	1	if used by, or computed by the model
Agricultural variables (optional output for all water models that also simulate crop yields)				
Crop yields	yield-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	dry matter (t ha ⁻¹ per growing season)	irrigation setting = "cirr" for "constraint irrigation" or "noirr" for rainfed
Actual planting dates	plantday-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	Day of year	Julian dates

Actual planting year	plantyear-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	Year of planting	Attention: This is an additional output compared to the ISIMIP2a reporting. It allows for clear identification of planting that is also easy to follow for potential users from outside the project.
Anthesis dates	anthday<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	Day of year of anthesis	Attention: This has changed compared to the ISIMIP2a reporting where we asked for the “day from planting date”. Together with the year of anthesis added to the list of outputs (see below) it allows for clear identification of anthesis that is also easy to follow for potential users from outside the project.
Year of anthesis	anthyear-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	year of anthesis	Attention: This is an additional output compared to the ISIMIP2a reporting. It allows for clear identification of anthesis that is also easy to follow for potential users from outside the project.
Maturity dates	matyday-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	Day of year of maturity	Attention: This has changed compared to the ISIMIP2a reporting where we asked for the “day from planting date”. Together with the year of maturity added to the list of outputs (see below) it allows for clear identification of maturity that is also easy to follow for potential users from outside the project.
Year of maturity	matyyear-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	year of maturity	Attention: This is an additional output compared to the ISIMIP2a reporting. It allows for clear identification of maturity that is also easy to follow for potential users from outside the project.
Nitrogen application rate	initr-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	kg ha ⁻¹ per growing season	Total nitrogen application rate. If organic and inorganic amendments are applied, rate should be reported as inorganic nitrogen equivalent (ignoring residues).

Biomass yields	biom-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	Dry matter (t ha ⁻¹ per growing season)	
Soil carbon emissions	sco2-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	kg C ha ⁻¹	Ideally should be modeled with realistic land-use history and initial carbon pools. Subject to extra study.
Nitrous oxide emissions	sn2o-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	kg N ₂ O-N ha ⁻¹	Ideally should be modeled with realistic land-use history and initial carbon pools. Subject to extra study.
Nitrogen application rate	initr-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	kg ha ⁻¹ per growing season	Total nitrogen application rate. If organic and inorganic amendments are applied, rate should be reported as inorganic nitrogen equivalent (ignoring residues).

Comments related to the optional agricultural outputs

5 Simulations should be provided for the four major crops (wheat, maize, soy, and rice) but output for other crops is highly welcome, too. For each crop, yields should be reported separately for irrigated land (cirr for “constraint irrigation”) and rainfed conditions (noirr). This complements the full irrigation (firr) pure crop runs requested in the agriculture part of the protocol (section 10). Yields simulations provided in the water sector should account for irrigation water constraints and have to be labeled by the “cirr” to highlight the difference.

10 The reporting of the crop yield-related outputs differs from the reporting of other variables in the water sector, as it is not done according to time but according to growing seasons to resolve potential multiple harvests. The unit of the time dimension of the NetCDF v4 output file is thus “growing seasons since YYYY-01-01 00:00:00”. The first season in the file (with value time=1) is then the first complete growing season of the time period provided by the input data without any assumed spin-up data, which equates to the growing season with the first planting after this date. To ensure that data can be matched to individual years in post-processing, it is essential to also provide the actual planting dates (as day of the year), actual planting years (year), anthesis dates (as day of the year), year of anthesis (year), maturity dates (day of the year), and year of maturity (year). This

procedure is identical to the GGCM convention (Elliott et al. 2015: The Global Gridded Crop Model intercomparison: data and modeling protocols for Phase 1) and part of this agricultural protocol (section 10).

5 Those models that cannot simulate time varying management/human impacts/fertilizer input should keep these fixed at year 2005 levels throughout the simulations (“2005soc” scenario in Group 1 (dashed line in **Figure 1**) and “2005soc” scenario in Group 2). They only need to run the first preindustrial period of Experiment I (1661-1860). Group 3 runs refer to models that are able to represent future changes in human management (varying crop varieties or fertilizer input). Assumptions about historical (Group 1) and future (Group 3) fertilizer inputs are harmonized and centrally provided within ISIMIP2b (Frieler et al., GMD, 2017).

6 Lakes

Simulations of climate-change effects on lakes will be made using coupled lake-hydrodynamic and water-quality models. Models can operate on the global scale (uncalibrated) or on a number of case-study lakes (calibrated). Both global and local models will conduct the same set of scenarios.

Global lake models

- 5 Global-scale simulations should be performed either assuming a lake present in every pixel or using grid-scale lake fraction based on the Global Lake and Wetland Database (GLWD; Lehner and Döll, 2004) and available on the DKRZ input data repository (/work/bb0820/ISIMIP/ISIMIP2b/InputData/lakes/pctlake.nc4; Subin et al., 2012). Since a 0.5°x0.5° pixel potentially contains multiple lakes with different characteristics (e.g. in terms of bathymetry, transparency, fetch), it is not possible to fully represent this subgrid-scale heterogeneity. Instead, the global-scale lake simulations should represent a 'representative lake' for a given pixel. Consequently, no stringent requirement is imposed with respect to lake depth, light extinction coefficient or initial conditions.

- For lake depth, modellers are encouraged to use the data from the Global Lake Data Base (GLDB). A regridded lake depth field based on GLDBv1 (Kourzeneva, 2010) is available at 0.5°x0.5° resolution on the DKRZ input data repository (/work/bb0820/ISIMIP/ISIMIP2b/InputData/lakes/lakedepth.nc4; this field was aggregated from 30 arc sec to 1.9°x2.5° and then interpolated again to 0.5°x0.5°; Subin et al., 2012), but modellers may choose to use the more recent GLDBv2 available at 30 arc sec (<http://www.flake.igb-berlin.de/ep-data.shtml>, Choulga et al., 2014). Modellers are requested to document their approach regarding lake depth, light extinction coefficient and initial conditions in the ISIMIP Impact Model Database (www.isimip.org/impactmodels).

Local lake models

- Simulations will be made for case-study lakes selected based on the availability of high-quality meteorological and limnological observations, thereby aiming for a good spread across climates and lake types. Model inputs consist of the meteorological variables given in **Table 1**, water inputs from hydrological model simulations, and nutrient loads estimated using simple loading function (Haith and Shoemaker., 1987; Schneiderman et al., 2002) or statistical estimation procedures. In addition site-specific data will be needed such as lake bathymetry data. Climate-change effects on lakes will be proportioned according to the ISIMP2b experiments (**Table 10**). Direct climate effects on lakes that influence factors such as water temperature stratification period, mixing depth etc. will be simulated using climate scenarios shown in **Table 11** and water inflows from hydrologic model simulations based on the **Table 9** experiments. Lake water quality simulations, which affect factors such as phytoplankton and nutrient levels, will also need to include simple nutrient loading inputs linked to the hydrologic model simulations.

All variables are to be reported as time-averages with the indicated resolution. It is expected that most models will output data at daily resolution.

- Model outputs that indicate the timing or duration of seasonal changes and do not vary with depth (i.e. onset of thermal stratification) are shaded light blue. The remaining outputs vary with both time and depth (i.e. Chlorophyll Concentration). In the case of time and depth-varying, data should be provided as a mean of the epilimnion or mixed layer, and mean of the hypolimnion, and as fully-resolved vertical profiles. When the lake is simulated as completely mixed or isothermal, the mean of the entire water column is assigned to the epilimnion, and the hypolimnion concentration is set to a missing value.

Note that the range of model outputs will vary from model to model. Below are generic outputs that capture the basic information provided by most lake-eutrophication models. Modelling groups whose models do not provide all information listed here are invited to report on the reduced set of variables implemented in their models.

6.1 Scenarios

Climate & CO ₂ concentration scenarios	
picontrol	Pre-industrial climate and 286ppm CO ₂ concentration. The climate data for the entire period (1661-2299) are unique – no (or little) recycling of data has taken place.
historical	Historical climate and CO ₂ concentration.
rcp26	Future climate and CO ₂ concentration from RCP2.6
rcp60	Future climate and CO ₂ concentration from RCP6.0
Human influence and land-use scenarios	
1860soc	Pre-industrial land use and other human influences. Given the small effect of dams & reservoirs before 1900, modellers may apply the 1901 dam/reservoir configuration during the pre-industrial period and the 1861-1900 part of the historical period if that is significantly easier than applying the 1861 configuration.
histsoc	Varying historical land use and other human influences.
2005soc	Fixed year-2005 land use and other human influences.
rcp26soc	Varying land use ((e.g. point source inputs of nutrients and operational changes of reservoirs), water abstraction and other human influences according to SSP2 and RCP2.6; fixed year-2005 dams and reservoirs. For models using fixed LU types, varying irrigation areas can also be considered as varying land use.
rcp60soc	Varying land use, water abstraction and other human influences according to SSP2 and RCP6.0, fixed year-2005 dams and reservoirs. For models using fixed LU types, varying irrigation areas can also be considered as varying land use.
2100rcp26soc	Land use and other human influences fixed at year 2100 levels according to RCP2.6.

5

For the historical period, groups that have limited computational capacities may choose to report only part of the full period, but including at least 1961-2005. All other periods should be reported completely. For those models that do not represent *changes* in human influences, those influences

should be held fixed at 2005 levels throughout all Group 1 (cf. **2005soc** marked as dashed blue lines in Fig. 1) and Group 2 simulations. Group 3 will be identical to Group 2 for these models and thus does not require additional simulations. Models that do not include human influences *at all* should nevertheless run the Group 1 and Group 2 simulation, since these simulations will still allow for an exploration of the effects of climate change compare to pre-industrial climate, and will also allow for a better assessment of the relative importance of human impacts versus climate impacts.

5 These runs should be named as **nosoc** simulations.

Table 11 ISIMIP2b scenarios for lakes simulations. Option 2* only if option 1 not possible.

Experiment		Input	pre-industrial 1661-1860	historical 1861-2005	future 2006-2099	extended future 2100-2299
I	no climate change, pre-industrial CO ₂	Climate & CO ₂	picontrol	picontrol	picontrol	picontrol
	varying LU and other human influences according to RCP2.6 + SSP2 up to 2100, then fixed at 2100 levels thereafter	Human & LU	Option 1: 1860soc	Option 1: histsoc	2005soc	2005soc
		Option 2*: 2005soc	Option 2*: 2005soc			
II	RCP2.6 climate & CO ₂	Climate & CO ₂	Experiment I	historical	rcp26	rcp26
	varying LU and other human influences according to RCP2.6 + SSP2 up to 2100, then fixed at 2100 levels thereafter	Human & LU		Option 1: histsoc	2005soc	2005soc
		Option 2*: 2005soc				
Ila	RCP2.6 climate, CO ₂ after 2005 fixed at 2005 levels	Climate & CO ₂	Experiment I	Experiment II	rcp26, 2005co2	rcp26, 2005co2
	LU & human influences fixed at 2005 levels after 2005	Human & LU			2005soc	2005soc
III	RCP6.0 climate & CO ₂	Climate & CO ₂	Experiment I	Experiment II	rcp60	not simulated
	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU			2005soc	

IV	no climate change, pre-industrial CO ₂	Climate & CO ₂	Experiment I	Experiment I	picontrol	picontrol
	varying LU and other human influences according to RCP2.6 + SSP2 up to 2100, then fixed at 2100 levels thereafter	Human & LU			rcp26soc	2100rcp26soc
V	no climate change, pre-industrial CO ₂	Climate & CO ₂	Experiment I	Experiment I	picontrol	not simulated
	varying human influences & LU (RCP6.0)	Human & LU			rcp60soc	
VI	RCP2.6 climate & CO ₂	Climate & CO ₂	Experiment I	Experiment II	rcp26	rcp26
	varying human influences & LU up to 2100 (RCP2.6), then fixed at 2100 levels thereafter	Human & LU			rcp26soc	2100rcp26soc
VII	RCP6.0 climate & CO ₂	Climate & CO ₂	Experiment I	Experiment II	rcp60	not simulated
	varying human influences & LU (RCP6.0)	Human & LU			rcp60soc	

6.1.1 Output data

Table 12 Output variables to be reported by lake models.

Variable (long name)	Variable name	Spatial Resolution	Temporal Resolution	Depth Resolution	Unit (NetCDF format)	Comments
Hydrothermal Variables						
Onset of thermal stratification	stratstart	Representative lake associated with grid cell)	Seasonal	None	Day of year when stratification started (1-365)	Day of year associated with the onset of thermal stratification

Loss of Stratification	stratend	(Representative lake associated with grid cell)	Seasonal	None	Day of year when stratification ended (1-365)	Day of year associated with the loss of thermal stratification
Duration of stratification	stratdur	Representative lake associated with grid cell)	Seasonal	None	d	Total days of thermal stratification
Onset of lake Ice cover	icestart	Representative lake associated with grid cell)	Seasonal	None	Day of year when ice cover started (1-365)	Day of year associated with the onset of permanent ice cover
Loss of lake Ice cover	iceend	Representative lake associated with grid cell)	Seasonal	None	Day of year when ice cover ended (1-365)	Day of year associated with the loss of permanent ice cover
Duration of Lake Ice Cover.	icedur	Representative lake associated with grid cell)	Seasonal	None	d	Total days of continuous ice cover
Depth of Thermocline	thermodepth	Representative lake associated with grid cell)	Daily	Single depth	m	Depth corresponding the maximum water density gradient
Water temperature	watertemp	Representative lake associated with grid cell)	Daily	Mean Epi Mean Hypo Full Profile	K	Simulated water temperature. Layer averages and full profiles
Lake layer ice mass fraction	lakeicefrac	Representative lake associated with grid cell)	Monthly (Daily)	Mean Epi	unitless	Fraction of mass of a given layer taken up by ice

ice thickness	icethick	Representative lake associated with grid cell)	Monthly	Single thickness	m	
snow thickness	snowthick	Representative lake associated with grid cell)	Monthly	Single thickness	m	
temperature at the ice upper surface	icetemp	Representative lake associated with grid cell)	Monthly	None	K	
temperature at the snow upper surface	snowtemp	Representative lake associated with grid cell)	Monthly	None	K	
sensible heat flux at the lake-atmosphere interface	sensheatf	Representative lake associated with grid cell)	Monthly	None	W/m ²	At the surface of snow, ice or water depending on the layer in contact with the atmosphere. positive if upwards.
latent heat flux at the lake-atmosphere interface	latentheatf	Representative lake associated with grid cell)	Monthly	None	W/m ²	See sensible heat flux
momentum flux at the lake-atmosphere interface	momf	Representative lake associated with grid cell)	Monthly	None	W/m ²	See sensible heat flux

upward long-wave radiation flux at the lake-atmosphere interface	lwup	Representative lake associated with grid cell)	Monthly	None	W/m ²	See sensible heat flux. Not to be confused with net longwave radiation
downward heat flux at the lake-atmosphere interface	lakeheatf	Representative lake associated with grid cell)	Monthly	None	W/m ²	See sensible heat flux
surface albedo	albedo	Representative lake associated with grid cell)	Monthly	None	unitless	Albedo of the surface interacting with the atmosphere (water, ice or snow)
Water Quality Variables						
Chlorophyll Concentration	chl	Representative lake associated with grid cell)	Daily	Mean Epi Mean Hypo Full Profile	g ⁻³ m ⁻³	Total water chlorophyll concentration – indicator of phytoplankton
Phytoplankton Functional group biomass	phytobio	Representative lake associated with grid cell)	Daily	Mean Epi Mean Hypo Full Profile	mole m ⁻³ as carbon	Different models will have different numbers of functional groups so that the reporting of these will vary by model
Zoo plankton biomass	zoobio	Representative lake associated with grid cell)	Daily	Mean Epi Mean Hypo Full Profile	mole m ⁻³ as carbon	Total simulated Zooplankton biomass

Total Phosphorus	tp	Representative lake associated with grid cell)	Daily	Mean Epi Mean Hypo Full Profile	mole m ⁻³	
Particulate Phosphorus	pp	Representative lake associated with grid cell)	Daily	Mean Epi Mean Hypo Full Profile	mole m ⁻³	
Total Dissolved Phosphorus	tpd	Representative lake associated with grid cell)	Daily	Mean Epi Mean Hypo Full Profile	mole m ⁻³	Some models may also output data for soluble reactive phosphorus (SRP)
Total Nitrogen	tn	Representative lake associated with grid cell)	Daily	Mean Epi Mean Hypo Full Profile	mole m ⁻³	
Particulate Nitrogen	pn	Representative lake associated with grid cell)	Daily	Mean Epi Mean Hypo Full Profile	mole m ⁻³	
Total Dissolved Nitrogen	tdn	Representative lake associated with grid cell)	Daily	Mean Epi Mean Hypo Full Profile	mole m ⁻³	Some models may also output data for Nitrate (NO ₂) nitrite (NO ₃) and ammonium (NH ₄)
Dissolved Oxygen	do	Representative lake associated with grid cell)	Daily	Mean Epi Mean Hypo Full Profile	mole m ⁻³	

Dissolved Organic Carbon	doc	Representative lake associated with grid cell)	Daily	Mean Epi Mean Hypo Full Profile	mole m ⁻³	Not always available
Dissolved Silica	si	Representative lake associated with grid cell)	Daily	Mean Epi Mean Hypo Full Profile	mole m ⁻³	Not always available

7 Biomes

7.1 Scenarios

- 5 Since the pre-industrial simulations are an important part of the experiments, the spin-up has to finish before the pre-industrial simulations start. The spin-up should be using pre-industrial climate (**picontrol**) and year 1860 levels of “other human influences”. For this reason, the pre-industrial climate data should be replicated as often as required. The precise implementation of the spin up will be model specific, the description of which will be part of the reporting process.

Climate & CO ₂ scenarios	
picontrol	Pre-industrial climate and 286ppm CO ₂ concentration. The climate data for the entire period (1661-2299) are unique – no (or little) recycling of data has taken place.
historical	Historical climate and CO ₂ concentration.
rcp26	Future climate and CO ₂ concentration from RCP2.6
rcp60	Future climate and CO ₂ concentration from RCP6.0
2005co2	CO ₂ concentration fixed at 2005 levels at 378.81ppm.
Human influence and land-use scenarios	
1860soc	Constant pre-industrial (1860) land use, nitrogen deposition, and fertilizer input.
histsoc	Varying historical land use, nitrogen deposition and fertilizer input.
2005soc	Fixed year-2005 land use, nitrogen deposition and fertilizer input.
rcp26soc	Varying land use, water abstraction, nitrogen deposition and fertilizer input according to SSP2 and RCP2.6.
rcp60soc	Varying land use, water abstraction, nitrogen deposition and fertilizer input according to SSP2 and RCP6.0.
2100rcp26soc	Land use, nitrogen deposition and fertilizer input fixed at year 2100 levels according to RCP2.6 in 2100.

Table 13 ISIMIP2b scenarios for the global biomes simulations.

Experiment		Input	Pre-industrial 1661-1860	Historical 1861-2005	Future 2006-2099	Extended future 2100-2299
I	no climate change, pre-industrial CO ₂	Climate & CO ₂	picontrol	picontrol	picontrol	picontrol
	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU	1860soc	histsoc	2005soc	2005soc
II	RCP2.6 climate & CO ₂	Climate & CO ₂	Experiment I	historical	rcp26	rcp26
	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU		histsoc	2005soc	2005soc
Ila	RCP2.6 climate, CO ₂ after 2005 fixed at 2005 levels	Climate & CO ₂	Experiment I	Experiment II	rcp26, 2005co2	rcp26, 2005co2
	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU			2005soc	2005soc
III	RCP6.0 climate & CO ₂	Climate & CO ₂	Experiment I	Experiment II	rcp60	not simulated
	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU			2005soc	
IV	no climate change, pre-industrial CO ₂	Climate & CO ₂	Experiment I	Experiment I	picontrol	picontrol
	varying human influences & LU up to 2100 (RCP2.6), then fixed at 2100 levels thereafter	Human & LU			rcp26soc	2100rcp26soc
V	no climate change, pre-industrial CO ₂	Climate & CO ₂	Experiment I	Experiment I	picontrol	not simulated
	varying human influences & LU (RCP6.0)	Human & LU			rcp60soc	

VI	RCP2.6 climate & CO ₂	Climate & CO ₂	Experiment I	Experiment II	rcp26	rcp26
	varying human influences & LU up to 2100 (RCP2.6), then fixed at 2100 levels thereafter	Human & LU			rcp26soc	2100rcp26soc
VII	RCP6.0 climate & CO ₂	Climate & CO ₂	Experiment I	Experiment II	rcp60	not simulated
	varying human influences & LU (RCP6.0)	Human & LU			rcp60soc	

Table 14 Additional sector-specific simulations for the biome sector.

	Experiment	Input	Pre-industrial	Historical	Future	Extended future
			1661-1860	1861-2005	2006-2099	2100-2299
Ia	no climate change, pre-industrial CO ₂	Climate & CO ₂	picontrol	picontrol	picontrol	picontrol
	LU & human influences fixed at 1860 levels	Human & LU	1860soc	1860soc	1860soc	1860soc
Iib	RCP2.6 climate & CO ₂	Climate & CO ₂	Experiment I	historical	rcp26	rcp26
	LU & human influences fixed at 1860 levels	Human & LU		1860soc	1860soc	1860soc
IIIa	RCP6.0 climate, CO ₂ after 2005 fixed at 2005 levels	Climate & CO ₂	Experiment I	Experiment II	rcp60, 2005co2	not simulated
	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU			2005soc	
IIIb	RCP6.0 climate & CO ₂	Climate & CO ₂	Experiment I	Experiment II	rcp60	not simulated

	LU & human influences fixed at 1860 levels	Human & LU			1860soc	
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5 7.2 Output data

Table 15 Variables to be reported by biomes models. Variables marked by * are also relevant for the permafrost sector and also listed in **Table 21**.
Note: If you cannot provide the data at the temporal or spatial resolution specified, please provide it the highest possible resolution of your model.

long name	units		output variable name	resolution	comment
Essential outputs					
Pools					
*Carbon Mass in Vegetation biomass	kg m ⁻²	per pft and gridcell total	cveg-<pft>	annual	Gridcell total cveg is essential. Per PFT information is desirable.
*Carbon Mass in aboveground vegetation biomass	kg m ⁻²	per pft and gridcell total	cvegag-<pft>	annual	Gridcell total cvegag is essential. Per PFT information is desirable.
*Carbon Mass in belowground vegetation biomass	kg m ⁻²	per pft and gridcell total	cvegbg-<pft>	annual	Gridcell total cvegbg is essential. Per PFT information is desirable.
*Carbon Mass in Litter Pool	kg m ⁻²	per gridcell total	clitter	annual	Info for each individual pool.
*Carbon Mass in Soil Pool	kg m ⁻²	per gridcell total	csoil	annual	Info for each individual pool.

Fluxes					
*Carbon Mass Flux out of atmosphere due to Gross Primary Production on Land	kg m ⁻² s ⁻¹	gridcell total	gpp	monthly (daily)	
*Carbon Mass Flux out of atmosphere due to Gross Primary Production on Land	kg m ⁻² s ⁻¹	per pft	gpp-<pft>	annual	
*Carbon Mass Flux into atmosphere due to Autotrophic (Plant) Respiration on Land	kg m ⁻² s ⁻¹	gridcell total	ra	monthly (daily)	
*Carbon Mass Flux out of atmosphere due to Net Primary Production on Land	kg m ⁻² s ⁻¹	gridcell total	npp	monthly(daily)	
*Carbon Mass Flux out of atmosphere due to Net Primary Production on Land	kg m ⁻² s ⁻¹	per pft	npp-<pft>	annual	
*Carbon Mass Flux into atmosphere due to Heterotrophic Respiration on Land	kg m ⁻² s ⁻¹	gridcell total	rh	monthly(daily)	
*Carbon Mass Flux into atmosphere due to total Carbon emissions from Fire	kg m ⁻² s ⁻¹	gridcell total	fireint	monthly(daily)	

*Carbon Mass Flux out of Atmosphere due to Net biome Production on Land (NBP)	kg m ⁻² s ⁻¹	gridcell total	ecoatmflux	monthly(daily)	This is the net mass flux of carbon between land and atmosphere calculated as photosynthesis MINUS the sum of plant and soil respiration, carbon fluxes from fire, harvest, grazing and land use change. Positive flux is into the land.
Structure					
*Leaf Area Index	1	per pft	lai-<pft>	annual	
*Leaf Area Index	1	gridcell average	lai	monthly (daily)	
*Plant Functional Type Grid Fraction	%	per gridcell	pft-<pft>	annual (or once if static)	The categories may differ from model to model, depending on their PFT definitions. This may include natural PFTs, anthropogenic PFTs, bare soil, lakes, urban areas, etc. Sum of all should equal the fraction of the grid-cell that is land. Value between 0 and 100.
Hydrological variables					
Total Evapo-Transpiration	kg m ⁻² s ⁻¹	gridcell total	evap	monthly (daily)	
Evaporation from Canopy (interception)	kg m ⁻² s ⁻¹	gridcell total	intercep	monthly (daily)	the canopy evaporation+sublimation (if present in model).
Water Evaporation from Soil	kg m ⁻² s ⁻¹	per gridcell	esoil	monthly (daily)	includes sublimation.
Transpiration	kg m ⁻² s ⁻¹	per gridcell	trans	monthly (daily)	

*Runoff	kg m ⁻² s ⁻¹	per gridcell	qtot	monthly (daily**)	total (surface + subsurface) runoff (qtot = qs + qsb). **for models also participating in the water sector If daily resolution not possible, please provide monthly. If storage issues keep you from reporting daily data, please contact the ISIMIP team to discuss potential solutions.
*Soil Moisture	kg m ⁻²	per gridcell	soilmoist	monthly (daily)	If possible, please provide soil moisture for all depth layers (i.e. 3D-field), and indicate depth in m. Otherwise, provide soil moisture of entire column.
Surface Runoff	kg m ⁻² s ⁻¹	per gridcell	qs	monthly (daily)	Total surface runoff leaving the land portion of the grid cell.
*Frozen soil moisture for each layer	kg m ⁻²	per gridcell	soilmoistfroz	monthly	Please provide soil moisture for all depth levels and indicate depth in m.
*Snow depth	m	per gridcell	snd	monthly	Grid cell mean depth of snowpack.
*Snow water equivalent	kg m ⁻²	per gridcell	swe	monthly	Total water mass of the snowpack (liquid or frozen), averaged over a grid cell.
*Annual maximum thaw depth	m	per gridcell	thawdepth	annual	calculated from daily thaw depths Please provide for purposes of permafrost sector.
Other outputs					

*Temperature of Soil	K	per gridcell	tsl	daily (mon)	Temperature of each soil layer. Reported as "missing" for grid cells occupied entirely by "sea". Also needs depths in meters. Daily would be great, but otherwise monthly would work.
Burnt Area Fraction	%	per gridcell	burntarea	monthly (daily)	Area percentage of grid cell that has burned at any time of the given day/month/year (for daily/monthly/annual resolution)
Albedo	1	per gridcell	albedo	monthly	average of pfts, snow cover, bare ground and water surfaces, range between 0-1
*N ₂ O emissions into atmosphere	kg m ⁻² s ⁻¹	gridcell total	n2o	monthly	From land, not from industrial fossil fuel emissions and transport
*CH ₄ emissions into atmosphere	kg m ⁻² s ⁻¹	gridcell total	ch4	monthly	From land, not from industrial fossil fuel emissions and transport

8 Regional forests

A number of sites has been selected in the COST Action PROFOUND for which a wide range of forest models can be rather easily initialized. To get access to this PROFOUND Database, please contact reyer@pik-potsdam.de.

- 5 1) **Management:** The modeling experiments mostly encompass managed forests. The standard management (“histsoc”) during the historical period is the observed management as defined by the data available for each site (e.g. reduction in stem numbers) and, after the observations end, missing management information is to be substituted with generic future management guidelines from Table 16-Table 18. This future management (2005soc) corresponds best to “intensive even-aged forestry” as defined by Duncker et al. 2012. After harvesting the stands (c.f. Table 16 and Table 17), please proceed after harvest as your model usually does, e.g. plant the same tree species again or allow for regeneration of the same species according to the regeneration guidelines outlined in Table 18. A “natural reference run (nosoc)” without any management will help assessing the influence of forest management.
10
- 2) **Calibration:** Some of the models may require some kind of calibration or model development before they can contribute to ISIMIP. Such alterations of the model can influence the results of a model comparison and “model calibration” is understood differently by different modelers. All alterations to the model in the framework of this exercise should be reported in the model experiment documentation provided together with the upload of the simulations. Whenever the model calibration or development is driven by an improvement of the model after a comparison to data that were originally made available in ISIMIP for model evaluation, a part of those data should be kept
15 aside for model evaluation and not used for calibration.
 - a. Model development needed to run a model at specific sites is welcomed and needs to be transparent/ properly documented (e.g. adjustment of phenology model to include chilling effects). This is also applicable for more general calibration (i.e. fixing parameters once but not changing afterwards) for example to include a new tree species in a model.
 - 20 b. Manual or automatic site-specific “tuning” of species-specific and process-specific parameters should be avoided. The same “model” (i.e. also with the same parameter values) should be used in all simulations. If needed, any tuning needs to be documented in a transparent way and should be backed up by existing data (e.g. from TRY-database). If your model contains genetic processes where the change in parameters is part of the model processes, this is naturally part of “your model approach” and should be clearly spelled out as part of the documentation of your model. In this specific case, please contact the sectoral coordinators to
25 discuss if it makes sense to include a “genetic adaptation” and a “parameter-fixed, control” run.
- 3) **Reporting Period:** Each phase of ISIMIP has its own reporting period but you should always start your reporting period for the first time step for which stand data is available (e.g. 1948 for the Peitz stand) and run your model until the last point in time where climate data is available.

8.1 Scenarios

Climate scenarios	
picontrol	Pre-industrial climate and 286ppm CO ₂ concentration. The climate data for the entire period (1661-2299) are unique – no (or little) recycling of data has taken place. The regional forest simulation should start at the first point in time for which initialisation data is available (Table 17).
historical	Historical climate and CO ₂ concentration.
rcp26	Future climate and CO ₂ concentration from RCP2.6.
rcp60	Future climate and CO ₂ concentration from RCP6.0.
2005co2	CO ₂ concentration fixed at 2005 levels at 378.81ppm.
Human influences scenarios	
histsoc	Manage forests according to historical management guidelines without species change and keeping the same rotation length and thinning types. (see Table 17)
2005soc	Manage future forests according to present-day generic management guidelines without species change and keeping the same rotation length and thinning types (see Table 18-Table 20).
rcp26soc	Future forests are assumed to be managed by changing the tree species and the forest management towards maximizing mitigation benefits. Depending on the region and forest stand, this could mean focusing on species and management measures to maximize (1) the production of wood for bioenergy (highly productive species, short rotations), (2) in situ carbon stocks, or (3) production of harvested wood products with a long lifetime.
rcp60soc	Future forest are assumed to require adaptive management such as “assisted migration” where present-day forests are managed according to current practices until final harvest and then replaced by tree species that would be the natural vegetation under the projected climate change according to Hanewinkel et al. (2012).
2100rcp26soc	This scenario means managing future forests according to rcp26soc guidelines.
nosoc	No forest management (but nitrogen deposition should be included). If your model includes natural regeneration, please only regeneration those species previously present on the plot.

Table 16: ISIMIP2b scenarios for the regional forest simulations.

Experiment		Input	Pre-industrial 1661-1860	Historical 1861-2005	Future 2006-2100	Extended future 2101-2299
I	no climate change, pre-industrial CO ₂	Climate & CO ₂	not simulated	picontrol	picontrol	picontrol
	varying LU & human influences up to 2005, fixed present-day management afterwards	Human & LU		histsoc	2005soc	2005soc
II	RCP2.6 climate & CO ₂	Climate & CO ₂	not simulated	historical	rcp26	rcp26
	varying LU & human influences up to 2005, fixed present-day management afterwards	Human & LU		histsoc	2005soc	2005soc
Ila	RCP2.6 climate, CO ₂ fixed after 2005	Climate & CO ₂	not simulated	Experiment II	rcp26, 2005co2	rcp26, 2005co2
	fixed present-day management after 2005	Human & LU			2005soc	2005soc
III	RCP6.0 climate & CO ₂	Climate & CO ₂	not simulated	Experiment II	rcp60	not simulated
	fixed present-day management after 2005	Human & LU			2005soc	
IV	no climate change, pre-industrial CO ₂	Climate & CO ₂	not simulated	Experiment I	picontrol	picontrol
	varying management (forest management for mitigation)	Human & LU			rcp26soc	2100rcp26soc
V	no climate change, pre-industrial CO ₂	Climate & CO ₂	not simulated	Experiment I	picontrol	
	varying management (forest management for adaptation)	Human & LU			rcp60soc	

VI	RCP2.6 climate & CO ₂	Climate & CO ₂	not simulated	Experiment II	rcp26	rcp26
	varying management (forest management for mitigation)	Human & LU			rcp26soc	2100rcp26soc
VII	RCP6.0 climate & CO ₂	Climate & CO ₂	not simulated	Experiment II	rcp60	
	varying management (forest management for adaptation)	Human & LU			rcp60soc	

The regional forest simulations as described above are carried out once using the ISIMIP2b climate of the grid cell in which the forest sites are located and once using locally bias-adjusted data based on locally observed meteorological data.

Table 17: Additional sector-specific simulations for the regional forest sector.

	Experiment	Input	Pre-industrial	Historical	Future	Extended future
			1661-1860	1861-2005	2006-2099	2100-2299
Ia	no climate change, pre-industrial CO ₂	Climate & CO ₂	not simulated	picontrol	picontrol	picontrol
	No forest management	Human & LU		nosoc	nosoc	nosoc
Iib	RCP2.6 climate & CO ₂	Climate & CO ₂	not simulated	historical	rcp26	rcp26
	No forest management	Human & LU		nosoc	nosoc	nosoc
Iic	RCP2.6 climate, CO ₂ fixed after 2005	Climate & CO ₂	not simulated	Experiment II	rcp26, 2005co2	rcp26, 2005co2
	No forest management	Human & LU			nosoc	nosoc
Illa	RCP6.0 climate, CO ₂ after 2005 fixed at 2005 levels	Climate & CO ₂	Experiment I	Experiment II	rcp60, 2005co2	not simulated
	LU & human influences fixed at 1860 levels	Human & LU			2005soc	

bily-kriz	1997	1998-2015 ^T	2030 ^T	2045 ^T	2060 ^T	2075 ^T	2090 ^T	2101^H	2102^P	2117 ^T	...	2222^H	2223^P	2238 ^T	...
collelongo	1992	1997-2012 ^T	2027 ^T	2032^H	2033^P	2048 ^T	2063 ^T	2078 ^T	2093 ^T	...	2173^H	2174^P	2189 ^T
hyytiala*	1995	1996-2011 ^T	2026 ^T	2041 ^T	2056 ^T	2071 ^T	2086 ^T	2101^H	2102^P	2117 ^T	...	2242^H	2243^P	2258 ^T	... ***
kroof*	1997	1999-2010 ^T	2025 ^T	2040 ^T	2055 ^T	2070 ^T	2085 ^T	2100 ^T	2101^H	2102^P	2117 ^T	...	2222^H	2223^P	... ****
le-bray	1986	1987-2009 ^T	2015^H	2016^P	2026 ^T	2036 ^T	2046 ^T	2056 ^T	2061^H	2062^P	2072 ^T	...	2107^H	2108^P	2118 ^T
peitz	1948**	1952-2011 ^T	2026 ^T	2040^H	2041^P	2056 ^T	2071 ^T	2086 ^T	2101 ^T	...	2181^H	2182^P	2197 ^T
solling-beech*	1967	1968-2014 ^T	2015^H	2016^P	2031 ^T	2046 ^T	2061 ^T	2076 ^T	2091 ^T	...	2156^H	2157^P	2172 ^T	...	2297^H
solling-spruce*	1967	1968-2014 ^T	2024^H	2025^P	2040 ^T	2055 ^T	2070 ^T	2085 ^T	2100 ^T	...	2145^H	2146^P	2161 ^T	...	2266^H
soro	1944**	1945-2005 ^T	2020 ^T	2035 ^T	2050 ^T	2061^H	2062^P	2077 ^T	2092 ^T	...	2202^H	2203^P	2218 ^T

Ini = Initialization data, HM = Historic Management, FM = Future Management, T=Thinning, H= Harvest, P=Planting, *=maximum age extended a bit to match local management during observed period or avoid harvesting just before the end of the simulation, **= the GCM data only starts in 1950, hence for future runs (Experiment 2a), you have to initialize these forests at the first time step after 1949 (i.e. 1952 for Peitz and 1950 for Soro). For the historical validation runs (Experiment 1a) you can start with the first available stand initialization. ***= Only simulate pine and spruce (no hard-woods) **and regenerate as pure pine stand.**

5 ******= Harvest all species at the same time (i.e. 120 years).**

Table 20 Planting information for the sites included in the simulation experiments. DBH is defined as diameter at breast height of 1.30m. The numbers in bracket indicate plausible ranges.

Name	Density ha ⁻¹	Age years	Height m	DBH cm	age when DBH is reached years	Remarks
bily-kriz	4500	4	0.5	na	9	Historical planting density was 5000/ha but current practices are 4500/ha only
collelongo	10000	4	1.3	0.1	4	Only a rough approximation, usually natural regeneration is the regeneration method.
hyytiala	2250 (2000-2500)	2	0.25 (0.2-0.3)	na	6 (5-7)	Regenerate as pure pine stand
kroof (beech)	6000 (5000-7000)	2	0.6 (0.5-0.7)	0.5	5	The planting density is for single-species stands, hence when regenerating the 2-species-stand KROOF, the planting density of each species should be halved
kroof (spruce)	2250 (2000-2500)	2	0.35 (0.3-0.4)	0.5	7	See above
le-bray	1250 (1000-14000)	1	0.2 (0.1-0.25)	na	3 (2-5)	These are the current practices (De Lary, 2015) and should be used for future regeneration. Historically, the site was seeded with 3000-5000 seedlings per ha and then cleared once or twice to reach a density of 1250/ha at 7-year old when seedlings reach the size for DBH recruitment. → modelers could mimic this by "planting" trees with DBH of 7.5cm and 6m height in 1978 with a density of 1250 trees/ha
peitz	9000 (8000-10000)	2	0.175 (0.1-0.25)	0.1	5	The "age when DBH is reached = 5" is an estimate
solling-beech	8500 (7000-10000)	2	0.3 (0.2-0.4)	0.5	4	The actual stand was established in 1847 from natural regeneration. Until begin of measurements in 1966, the stand was regularly thinned. All figures in table are estimates. Natural regeneration is the recommended regeneration method of stand establishment; stem count in 2014: 130
solling-spruce	3000 (2500-3500)	2	0.35 (0.25-0.5)	0.5	3	The actual stand was planted in 1891 on a former meadow. Until begin of measurements in 1966, the stand was regularly thinned. All figures in table are estimates.; stem count in 2014: 290
soro	6000	4	0.82	na	6	Planted in 1921, stem count in 288 ha-1 in 2010, (Wu et al. 2013)

8.2 Output data

Table 21 Variables to be reported by forest models.

Long name	units		output variable name	resolution	comment
Essential outputs					
Mean DBH	cm	per species and stand total	dbh-<species/total>	annual	
Mean DBH of 100 highest trees	cm	stand total	dbhdomhei	annual	100 highest trees per hectare.
Stand Height	m	per species and stand total	hei-<species/total>	annual	For models including natural regeneration this variable may not make sense, please report dom_height
Dominant Height	m	stand total	domhei	annual	Mean height of the 100 highest trees per hectare.
Stand Density	ha ⁻¹	per species and stand total	density-<species/total>	annual	As trees per hectare
Basal Area	m ² ha ⁻¹	per species and stand total	ba-<species/total>	annual	
Volume of Dead Trees	m ³ ha ⁻¹	per species and stand total	mort-<species/total>	annual	
Harvest by dbh-class	m ³ ha ⁻¹	per species and stand total and dbh-class	harv-<species/total>-<dbhclass/total>	annual	

Remaining stem number after disturbance and management by dbh class	ha ⁻¹	per species and stand total	stemno-<species/total>-<dbhclass/total>	annual	As trees per hectare, dbhclass_name as specific in Table 20 .
Stand Volume	m ³ ha ⁻¹	per species and stand total	vol-<species/total>	annual	
Carbon Mass in Vegetation biomass	kg m ⁻²	per species and stand total	cveg-<species/total>	annual	As kg carbon*m ⁻²
*Carbon Mass in aboveground vegetation biomass	kg m ⁻²	per species and stand total	cvegag-<species/total>	annual	As kg carbon*m ⁻²
*Carbon Mass in belowground vegetation biomass	kg m ⁻²	per species and stand total	cvegbg-<species/total>	annual	As kg carbon*m ⁻²
Carbon Mass in Litter Pool	kg m ⁻²	per species and stand total	clitter-<species/total>	annual	As kg carbon*m ⁻² , Info for each individual pool.
Carbon Mass in Soil Pool	kg m ⁻²	per species and stand total	csoil-<species/total>	annual	As kg carbon*m ⁻² , Info for each individual soil layer
Tree age by dbh class	yr	per species and stand total	age-<species/total>-<dbhclass/total>	annual	dbhclass_name as specified in Table 20 .
Gross Primary Production	kg m ⁻² s ⁻¹	per species and stand total	gpp-<species/total>	daily	As kg carbon*m ⁻² *s ⁻¹
Net Primary Production	kg m ⁻² s ⁻¹	per species and stand total	npp-<species/total>	daily	As kg carbon*m ⁻² *s ⁻¹
Autotrophic (Plant) Respiration	kg m ⁻² s ⁻¹	per species and stand total	ra-<species/total>	daily	As kg carbon*m ⁻² *s ⁻¹

Heterotrophic Respiration	$\text{kg m}^{-2} \text{ s}^{-1}$	stand total	rh-<total>	daily	As $\text{kg carbon} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$
Net Ecosystem Exchange	$\text{kg m}^{-2} \text{ s}^{-1}$	per stand	nee-<total>	daily	As $\text{kg carbon} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$
Mean Annual Increment	$\text{m}^3 \text{ ha}^{-1}$	per species and stand total	mai-<species/total>	annual	
Fraction of absorbed photosynthetically active radiation	%	per species and stand total	fapar-<species/total>	daily	Value between 0 and 100.
Leaf Area Index	$\text{m}^2 \text{ m}^{-2}$	per species and stand total	lai-<species/total>	monthly	
Species composition	%	per ha	species-<species>	annual (or once if static)	As % of basal area; the categories may differ from model to model, depending on their species and stand definitions.
Total Evapotranspiration	$\text{kg m}^{-2} \text{ s}^{-1}$	stand total	evap	daily	sum of transpiration, evaporation, interception and sublimation. (=intercept + esoil + trans)
Evaporation from Canopy (interception)	$\text{kg m}^{-2} \text{ s}^{-1}$	per species and stand total	intercept-<species/total>	daily	the canopy evaporation+ sublimation (if present in model).
Water Evaporation from Soil	$\text{kg m}^{-2} \text{ s}^{-1}$	per stand	esoil	daily	includes sublimation.
Transpiration	$\text{kg m}^{-2} \text{ s}^{-1}$	per species and stand total	trans-<species/total>	daily	

Soil Moisture	kg m ⁻²	per stand	soilmoist	daily	If possible, please provide soil moisture for all depth layers (i.e. 3D-field), and indicate depth in m. Otherwise, provide soil moisture of entire column.
Optional outputs					
Removed stem numbers by size class by natural mortality	ha ⁻¹	per species and stand total	mortstemno-<species/total>-<dbhclass/total>	annual	As trees per hectare, dbhclass_name as specific in Table 20 .
Removed stem numbers by size class by management	ha ⁻¹	per species and stand total	harvstemno-<species/total>-<dbhclass/total>	annual	As trees per hectare, dbhclass_name as specific in Table 20 .
Volume of disturbance damage	m ³ ha ⁻¹	per species and stand total	dist-<dist-name>	annual	dist_name as specific in Table 20 .
Nitrogen of annual Litter	g m ⁻² a ⁻¹	per species and stand total	nlit-<species/total>	annual	As g Nitrogen m ⁻² a ⁻¹
Nitrogen in Soil	g m ⁻² a ⁻¹	stand total	nsoil-<total>	annual	As g Nitrogen m ⁻² a ⁻¹
Net Primary Production allocated to leaf biomass	kg m ⁻² s ⁻¹	per species and stand total	nppleaf-<species>	daily	As kg carbon*m ⁻² *s ⁻¹
Net Primary Production allocated to fine root biomass	kg m ⁻² s ⁻¹	per species and stand total	npproot-<species>	daily	As kg carbon*m ⁻² *s ⁻¹
Net Primary Production allocated to above ground wood biomass	kg m ⁻² s ⁻¹	per species and stand total	nppagwood-<species>	daily	As kg carbon*m ⁻² *s ⁻¹

Net Primary Production allocated to below ground wood biomass	kg m ⁻² s ⁻¹	per species and stand total	nppbgwood- <species>	daily	As kg carbon*m ⁻² *s ⁻¹
Root autotrophic respiration	kg m ⁻² s ⁻¹	per species and stand total	rr-<species/total>	daily	As kg carbon*m ⁻² *s ⁻¹
Carbon Mass in Leaves	kg m ⁻²	per species and stand total	cleaf-<species>	annual	
Carbon Mass in Wood	kg m ⁻²	per species and stand total	cwood-<species>	annual	including sapwood and hardwood
Carbon Mass in Roots	kg m ⁻²	per species and stand total	croot-<species>	annual	including fine and coarse roots
Temperature of Soil	K	per stand	tsl	daily	Temperature of each soil layer

Table 22 Codes for species, disturbance names and dbh classes as used in protocol (species, dist-name, dbhclass).

Long name	Short name
Fagus sylvatica	fasy
Quercus robur	quro
Quercus petraea	qupe
Pinus sylvestris	pisy
Picea abies	piab
Pinus pinaster	pipi
Larix decidua	lade
Acer platanoides	acpl
Eucalyptus globulus	eugl
Betula pendula	bepe
Betula pubescens	bepu
Robinia pseudoacacia	rops
Fraxinus excelsior	frex
Populus nigra	poni

Sorbus aucuparia	soau
C3 grass	c3gr
hard woods	hawo
fire	fi
wind	wi
insects	ins
drought	dr
grazing	graz
diseases	dis
DBH-class_<X>-<X+5>*	dbh-c<X>
DBH-class_>140*	dbh-c140

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*the boundaries of the dbh classes should interpreted as follows: dbh-class-0-5 = 0 to<5 cm; dbh-class-5-10 =5 to<10 cm, etc....
the dbh class dbh-c140 includes all trees of 140cm dbh and larger.

9 Permafrost

9.1 Scenarios

5 The simulation scenarios for models only participating as permafrost models are described below. Assuming that for the relevant regions “other human influences” only play a minor role, i.e. the regional simulations can be done as “naturalized” runs (nosoc). Results from permafrost modules embedded in global biomes models should be reported for the biomes model simulations specified in Section 6 and the extension beyond 2299 described below.

IMPORTANT: Please contact the permafrost sector coordinators (see <https://www.isimip.org/about/#contact>) before starting permafrost simulations. The list of requested output variables may be added to.

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

Table 23 ISIMIP2b scenario specification for the permafrost simulations.

Experiment		Input	Pre-industrial 1661-1860	Historical 1861-2005	Future 2006-2099	Extended future 2100-2299	Beyond 2299
I	no climate change, pre-industrial CO ₂	Climate & CO ₂	picontrol	not simulated	not simulated	not simulated	not simulated
	no other human influences	Human & LU	nosoc				
II	RCP2.6 climate & CO ₂	Climate & CO ₂	Experiment I	historical	rcp26	rcp26	2299rcp26
	no other human influences	Human & LU		nosoc	nosoc	nosoc	nosoc
Ila	RCP6.0 climate, CO ₂ varying until 2005, then fixed at 2005 levels thereafter	Climate & CO ₂	Experiment I	Experiment II	rcp26, 2005co2	rcp26, 2005co2	2299rcp26, 2005co2
	no other human influences	Human & LU			nosoc	nosoc	nosoc
III	RCP2.6 climate & CO ₂	Climate & CO ₂	Experiment I	Experiment II	rcp60	not simulated	not simulated
	no other human influences	Human & LU			nosoc		

9.2 Output data

Table 24 Variables to be reported by permafrost models.

Long name	Units		Output variable name	Resolution	Comment
Essential outputs					
Temperature of Soil	K	per gridcell	tsl	daily (monthly)	Temperature of each soil layer. Reported as "missing" for grid cells occupied entirely by "sea". THIS IS THE MOST IMPORTANT VARIABLE. Also need depths in meters. Daily would be great, but otherwise monthly would work.
Pools (as Biomes output Table)					
Carbon Mass in Vegetation biomass	kg m ⁻²	per pft and gridcell total	cveg-<pft>	annual	Gridcell total cveg is essential. Per PFT information is desirable.
Carbon Mass in aboveground vegetation biomass	kg m ⁻²	per pft and gridcell total	cvegag-<pft>	annual	Gridcell total cvegag is essential. Per PFT information is desirable.
Carbon Mass in belowground vegetation biomass	kg m ⁻²	per pft and gridcell total	cvegbg-<pft>	annual	Gridcell total cvegbg is essential. Per PFT information is desirable.
Carbon Mass in Litter Pool	kg m ⁻²	per gridcell total	clitter	annual	Info for each individual pool.
Carbon Mass in Soil Pool	kg m ⁻²	per gridcell total	csoil	annual	Info for each individual pool.
Fluxes (as Biomes output Table)					
Carbon Mass Flux out of atmosphere due to Gross Primary Production	kg m ⁻² s ⁻¹	gridcell total	gpp	monthly (daily)	

on Land					
Carbon Mass Flux out of atmosphere due to Gross Primary Production on Land	kg m ⁻² s ⁻¹	per pft	gpp <pft>	annual	
Carbon Mass Flux into atmosphere due to Autotrophic (Plant) Respiration on Land	kg m ⁻² s ⁻¹	gridcell total	ra	monthly (daily)	
Carbon Mass Flux out of atmosphere due to Net Primary Production on Land	kg m ⁻² s ⁻¹	gridcell total	npp	monthly (daily)	
Carbon Mass Flux out of atmosphere due to Net Primary Production on Land	kg m ⁻² s ⁻¹	per pft	npp <pft>	annual	
Carbon Mass Flux into atmosphere due to Heterotrophic Respiration on Land	kg m ⁻² s ⁻¹	gridcell total	rh	monthly (daily)	
Carbon Mass Flux into atmosphere due to total Carbon emissions from Fire	kg m ⁻² s ⁻¹	gridcell total	fireint	monthly (daily)	
Carbon Mass Flux out of Atmosphere due to Net biome Production on Land (NBP)	kg m ⁻² s ⁻¹	gridcell total	ecoatmflux	monthly (daily)	This is the net mass flux of carbon between land and atmosphere calculated as photosynthesis MINUS the sum of plant and soil respiration, carbon fluxes from fire, harvest, grazing and land-use change. Positive flux is into the land.
Structure [as Biomes output Table]					
Leaf Area Index	1	per pft	lai <pft>	annual	
Leaf Area Index	1	gridcell average	lai <pft>	monthly (daily)	

Plant Functional Type Grid Fraction	%	per gridcell	pft-<pft>	annual (or once if static)	The categories may differ from model to model, depending on their PFT definitions. This may include natural PFTs, anthropogenic PFTs, bare soil, lakes, urban areas, etc.. Sum of all should equal the fraction of the grid-cell that is land.
Hydrological variables [as per Biomes output Table]					
Runoff	kg m ⁻² s ⁻¹	per gridcell	qtot	daily** (monthly)	total (surface + subsurface) runoff (qtot = qs + qsb). If daily resolution not possible, please provide monthly. If storage issues keep you from reporting daily data, please contact the ISI-MIP team to discuss potential solutions. **For those models also participating in the water simulations
Soil moisture	kg m ⁻²	per grid cell	soilmoist	monthly	please provide soil moisture for all depth layers (i.e. 3D-field), and indicate depth in m.
Frozen soil moisture for each layer	kg m ⁻²	per gridcell	soilmoistfroz	monthly	Please provide frozen soil moisture for all depth levels and indicate depth in m.
Snow depth	m	per gridcell	snd	monthly	Grid cell mean depth of snowpack.
Snow water equivalent	kg m ⁻²	per gridcell	swe	monthly	Total water mass of the snowpack (liquid or frozen), averaged over a grid cell.
Annual maximum thaw depth	m	per gridcell	thawdepth	annual	calculated from daily thaw depths
Other outputs					
Burnt Area Fraction	%	per gridcell	burntarea	monthly (daily)	fraction of entire grid cell that is covered by burnt vegetation
N ₂ O emissions into atmosphere	kg m ⁻² s ⁻¹	gridcell total	n2o	monthly	From land, not from industrial fossil fuel emissions and transport
CH ₄ emissions into atmosphere	kg m ⁻² s ⁻¹	gridcell total	ch4	monthly	From land, not from industrial fossil fuel emissions and transport

10 Global crop simulations

10.1 Scenarios

5 Crop-model simulations should be provided as pure crop runs (i.e. assuming that each crop grows everywhere), so that future LU patterns can be applied in post-processing ensuring maximum flexibility. Simulations should be provided for the four major crops (wheat, maize, soy, and rice). For each crop there should be a full irrigation run (firr) and a no-irrigation run (noirr).

Those models that cannot simulate time varying management/human impacts/fertilizer input should keep these fixed at year 2005 levels throughout the simulations (“2005soc” scenario in Group 1 (dashed line in **Figure 1**) and “2005soc” scenario in Group 2). They only need to run the first preindustrial period of Experiment I (1661-1860). Group 3 runs only refer to models that are able to represent future changes in human management (varying crop varieties or fertilizer input).

10 To resolve potential double harvests within one year, crop yields should be reported per growing and not per calendar year. The unit of the time dimension of the NetCDF v4 output file is thus “growing seasons since YYYY-01-01 00:00:00”. Cumulative growing season variables as, e.g., actual evapotranspiration or precipitation are to be accumulated over the growing season. The first season in the file (with value time=1) is then the first complete growing season of the time period provided by the input data without any assumed spin-up data, which equates to the growing season with the first planting after this date. To ensure
 15 that data can be matched to individual years in post-processing, it is essential to also provide the actual planting dates (as day of the year), actual planting years (year), anthesis dates (as day of the year), year of anthesis (year), maturity dates (day of the year), and year of maturity (year). This procedure is identical to the GGCMi convention (Elliott et al. 2015: The Global Gridded Crop Model intercomparison: data and modeling protocols for Phase 1).

Climate & CO ₂ scenarios	
picontrol	Pre-industrial climate and 286ppm CO ₂ concentration. The climate data for the entire period (1661-2299) are unique – no (or little) recycling of data has taken place.
historical	Historical climate and CO ₂ concentration.
rcp26	Future climate and CO ₂ concentration from RCP2.6
rcp60	Future climate and CO ₂ concentration from RCP6.0
2005co2	Fixed year 2005 levels of CO ₂ at 378.81ppm.
Human influence & land-use scenarios	
1860soc	Pre-industrial levels of fertilizer input.
histsoc	Varying historical fertilizer input.
2005soc	Fixed year 2005 management
rcp26soc	Varying level of fertilizer input and varying varieties of the same crop associated with SSP2 and RCP2.6

rcp60soc	Varying level of fertilizer input and varying varieties of the same crop associated with SSP2 and RCP6.0
2100rcp26soc	Fertilizer input and varieties of the same crop fixed at year 2100.

Table 25 ISIMIP2b scenarios for global crop simulations. *Option 2 only if option 1 not possible.

Experiment		Input	Pre-industrial 1661-1860	Historical 1861-2005	Future 2006-2099	Extended future 2100-2299
I	no climate change, pre-industrial CO ₂	Climate & CO ₂	picontrol	picontrol	picontrol	picontrol
	varying management until 2005, then fixed at 2005 levels thereafter	Human & LU	Option 1*: 1860soc	Option 1*: histsoc	2005soc	2005soc
			Option 2*: 2005soc	Option 2*: 2005soc		
II	RCP2.6 climate & CO ₂	Climate & CO ₂	Experiment I	historical	rcp26	rcp26
	varying management until 2005, then fixed at 2005 levels thereafter	Human & LU		Option 1*: histsoc	2005soc	2005soc
			Option 2*: 2005soc			
Ila	RCP2.6 climate, CO ₂ after 2005 fixed at 2005 levels	Climate	Experiment I	Experiment II	rcp26, 2005co2	rcp26, 2005co2
	varying management until 2005, then fixed at 2005 levels thereafter	Human & LU			2005soc	2005soc
III	RCP6.0 climate & CO ₂	Climate & CO ₂	Experiment I	Experiment II	rcp60	not simulated
	varying management until 2005, then fixed at 2005 levels thereafter	Human & LU			2005soc	
IV	no climate change, pre-industrial CO ₂	Climate & CO ₂	Experiment I	Experiment I	picontrol	picontrol
	varying management up to 2100 (RCP2.6), then fixed at 2100 levels thereafter	Human & LU			rcp26soc	2100rcp26soc

V	no climate change, pre-industrial CO ₂	Climate & CO ₂	Experiment I	Experiment I	picontrol	not simulated
	varying management (RCP6.0)	Human & LU			rcp60soc	
VI	RCP2.6 climate & CO ₂	Climate & CO ₂	Experiment I	Experiment II	rcp26	rcp26
	varying management up to 2100 (RCP2.6), then fixed at 2100 levels thereafter	Human & LU			rcp26soc	2100rcp26soc
VII	RCP6.0 climate & CO ₂	Climate & CO ₂	Experiment I	Experiment II	rcp60	
	varying management (RCP6.0)	Human & LU			rcp60soc	

10.2 Output data

Table 26 Variables to be reported by crop models

Variable	Variable name	Resolution	Unit	Comments
Key model outputs				
Crop yields	yield<crop> <irrigation setting>	per growing season (0.5°x0.5°)	dry matter (t ha ⁻¹ per growing season)	
Irrigation water withdrawal (assuming unlimited water supply)	pirrw<crop> <irrigation setting>	per growing season (0.5°x0.5°)	mm per growing season	<i>Irrigation water withdrawn in case of optimal irrigation (in addition to rainfall), assuming no losses in conveyance and application.</i>
Key diagnostic variables				
Actual evapotranspiration	aet<crop> <irrigation setting>	per growing season (0.5°x0.5°)	mm per growing season	portion of all water (including rain) that is evapo-transpired, the water amount should be accumulated over the entire growing period (not the calendar year)

Nitrogen application rate	initr-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	kg ha ⁻¹ per growing season	Total nitrogen application rate. If organic and inorganic amendments are applied, rate should be reported as inorganic nitrogen equivalent (ignoring residues).
Actual planting dates	plantday-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	Day of year	Julian dates
Actual planting year	plantyear-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	Year of planting	Attention: This is an additional output compared to the ISIMIP2a reporting. It allows for clear identification of planting that is also easy to follow for potential users from outside the project.
Anthesis dates	anthday-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	Day of year of anthesis	Attention: This has changed compared to the ISIMIP2a reporting where we asked for the “day from planting date”. Together with the year of anthesis added to the list of outputs (see below) it allows for clear identification of anthesis that is also easy to follow for potential users from outside the project.
Year of anthesis	anthyear-<crop>-<irrigation setting>	per growing season (0.5°x0.5°)	year of anthesis	Attention: This is an additional output compared to the ISIMIP2a reporting. It allows for clear identification of anthesis that is also easy to follow for potential users from outside the project.

Maturity dates	matyday- <crop>- <irrigation setting>	per growing season (0.5°x0.5°)	Day of year of maturity	Attention: This has changed compared to the ISIMIP2a reporting where we asked for the “day from planting date”. Together with the year of maturity added to the list of outputs (see below) it allows for clear identification of maturity that is also easy to follow for potential users from outside the project.
Year of maturity	matyyear- <crop>- <irrigation setting>	per growing season (0.5°x0.5°)	year of maturity	Attention: This is an additional output compared to the ISIMIP2a reporting. It allows for clear identification of maturity that is also easy to follow for potential users from outside the project.
Additional output variables (optional)				
Biomass yields	biom<crop>- <irrigation setting>	per growing season (0.5°x0.5°)	Dry matter (t ha ⁻¹ per growing season)	
Soil carbon emissions	sco2<crop>- <irrigation setting>	per growing season (0.5°x0.5°)	kg C ha ⁻¹	Ideally should be modeled with realistic land-use history and initial carbon pools. Subject to extra study.
Nitrous oxide emissions	sn2o<crop>- <irrigation setting>	per growing season (0.5°x0.5°)	kg N ₂ O-N ha ⁻¹	Ideally should be modeled with realistic land-use history and initial carbon pools. Subject to extra study.

11 Energy

The Energy protocol has been removed temporarily, since it was outdated. It will be replaced by an updated version shortly.

12 Health (Temperature-related mortality)

12.1 11.1 Scenarios

5 The following protocol has been designed for contributions on temperature-related mortality (TRM). There are no restrictions regarding the type of empirical models (GAMs, DLNMs, log-linear, simple exponential etc.) to be used as long as the methodology has been documented in previous peer-reviewed publications. It also does not matter at which spatial scale the model operates (city-scale, regional, national, global), with the possible restrictions stemming from the input data provided.

Group 3 runs (experiments IV to VII, blue cells in Table 23) only refer to models that are able to represent future changes in societal conditions (demographic changes, shifts in mortality baselines, adaptation/acclimatization).

Climate	
picontrol	Pre-industrial climate (year specific for the entire period 1661-2299)
historical	Historical climate
rcp26	Future climate from RCP2.6
rcp60	Future climate from RCP6.0
Human influence	
2005soc	Representation of fixed year 2005 society: <ul style="list-style-type: none"> • Present-day exposure-response functions • Present-day mortality baselines (average from observational records, or from grid based 2005 mortality data (SSP2)) • 2005 population data from your observational records, or from ISIMIP grid based population data (SSP2)
ssp2soc	Varying society according to SSP2 – no adaptation <ul style="list-style-type: none"> • Present-day exposure-response functions • Mortality baselines according to SSP2^a • Population data according to SSP2^b
2100ssp2soc	Society in 2100 according to SSP2 – no adaptation <ul style="list-style-type: none"> • As ssp2soc but mortality and population data fixed at 2100 levels
ssp2soc-adapt	Varying society according to SSP2 – with adaptation <ul style="list-style-type: none"> • changing exposure-response relationships according to default adaptation assumptions^c • mortality baselines and population according to SSP2

^a It is also possible to neglect shifts in mortality baselines and only consider population shifts in this experiment; if changes in mortality baselines are accounted for, scaling from SSP2 national projections to city-scale/regional scale should be done as for population data (see ^b)

^b Use grid-based or national population data for 2005-2100 in 5-year intervals for 5-year age groups (0-4,5-9,...,100+), split
5 between urban and rural population from SSP database. For mortality models working on city scale, projected national urban population growth rates should be applied to 2005 city populations (assuming that city-scale projections scale directly to nation-scale projections)

^c Uncertainty on acclimatization/adaptation is large. Based on your available data choose the most plausible approach to incorporate acclimatization into your exposure-response functions (e.g., shift MMT, shift slope); this approach will have to be
10 documented in detail

Additional Notes:

Definition of attributable mortality: Where applicable attributable mortality should be defined as e.g., in Gasparrini & Leone (2014); Here attributable refers to mortality attributable to excursion of ambient temperature from MMT.

Definition of climate change impacts: Additional deaths due to climate change will be derived as the difference between attributable mortality estimates based on the pre-industrial control (picontrol) and climate change scenario runs (rcp26, rcp60)
15 or as difference between present-day reference (2010-2019) and future decades.

Local bias-correction of climate time-series: For TRM models working on a point scale (e.g., city scale) or small regional scale, a downscaling and bias correction to the local observational climate time-series will be undertaken (using ISIMIP2b bias-correction method). Other support regarding preparation of climate input data (aggregation to specific regions, conversion from netcdf to
20 txt etc.) might be provided on demand.

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Table 27 ISIMIP2b scenarios for temperature-related mortality simulations. Option 2* only if option 1 not possible.

Experiment		Input	Pre-industrial 1661-1860	Historical 1861-2005	Future 2006-2099	Extended future 2100-2299
I	no climate change	Climate	picontrol	picontrol	picontrol	picontrol
	varying society up to 2005, then fixed at 2005 levels thereafter, no adaptation	Human	Option 1: 1860soc	Option 1: histsoc	2005soc	2005soc
	society fixed at 2005 levels, no adaptation		Option 2*: 2005soc	Option 2*: 2005soc		
II	RCP2.6 climate	Climate	Experiment I	historical	rcp26	rcp26
	varying society up to 2005, then fixed at 2005 levels thereafter, no adaptation	Human		Option 1*: histsoc	2005soc	2005soc
	society fixed at 2005 levels, no adaptation			Option 2*: 2005soc		
III	RCP6.0 climate	Climate	Experiment I	Experiment II	rcp60	not simulated
	society fixed at 2005 levels, no adaptation	Human			2005soc	
IV	no climate change	Climate	Experiment I	Experiment II	picontrol	picontrol
	varying society (SSP2) up to 2100, then fixed at 2100 levels thereafter, no adaptation	Human			ssp2soc	2100ssp2soc
V	Not simulated					
VI	RCP2.6 climate	Climate	Experiment I	Experiment II	rcp26	rcp26
	varying society (SSP2) up to 2100, then fixed at 2100 levels thereafter, no adaptation	Human			ssp2soc	2100ssp2soc

Vla	RCP2.6 climate	Climate	Experiment I	Experiment II	rcp26	not simulated
	varying society (SSP2) with adaptation	Human			ssp2soc-adapt	
VII	RCP6.0 climate	Climate	Experiment I	Experiment II	rcp60	not simulated
	varying society (SSP2), no adaptation	Human			ssp2soc	
VIIa	RCP6.0 climate	Climate	Experiment I	Experiment II	rcp60	not simulated
	varying society (SSP2), with adaptation	Human			ssp2soc-adapt	

12.2 Output data

Table 28 Variables to be reported by TRM models

Note: The variable name should specify the age group x for which mortality estimates are supplied:

x = -all, -65minus, -65plus, etc.

Long name	Units	Variable name	Spatial resolution	Temporal resolution	Comments
Number of deaths attributable to cold in age group x	Total number of deaths	an-tot-cold-x	Per city/region /grid cell	daily	Temperature below minimum mortality temperature (MMT)
Number of deaths attributable to heat in age group x	Total number of deaths	an-tot-heat-x	Per city/region /grid cell	daily	Temperature above MMT
Death rate attributable to cold in age group x	Deaths per 100 000 population	an-rate-cold-x	Per city/region /grid cell	daily	Temperature below MMT
Death rate attributable to heat in age group x	Deaths per 100 000 population	an-rate-heat-x	Per city/region /grid cell	daily	Temperature above MMT
Attributable fraction (cold) in age group x	%	af-cold-x	Per city/region /grid cell	daily	Temperature below MMT
Attributable fraction (heat) in age group x	%	af-heat-x	Per city/region /grid cell	daily	Temperature above MMT

13 Coastal Infrastructure

13.1 Scenarios

Climate change affects coastal infrastructure through rising mean and extreme sea levels, causing damages through temporary flooding and losses due to permanent submergence of land. To assess these impacts, climate scenarios have to be complemented by sea-level-rise projections. While the information about thermal expansion and dynamical changes of sea level is provided by the four GCMs considered, contributions from mountain glaciers and ice sheets have to be added from other sources, which introduces a further dimension of uncertainty (see section 5). The uncertainty range introduced is substantial and a least on equal footing with the climate model and scenario uncertainty (e.g. Kopp et al. 2014). To reflect this aspect we include an additional scenario dimension in the scenario design for this sector and sample this by providing projections for the median and 5th and 95th percentiles of the contributions from ice sheets and mountain glaciers to sea-level rise. One aspect specific to the coastal-infrastructure sector is that impacts are extremely non-linear in and sensitive to adaptation. Impacts without adaptation are 2-3 orders of magnitudes higher than those with adaptation (Hinkel et al. 2014). This leads to the circumstance that the regions with the highest infrastructure damages under the scenarios without adaptation are actually the regions least vulnerable to sea-level rise, because it is highly cost-efficient and standard practise to protect those regions against sea-level rise. Scenarios including adaptation are therefore added to the protocol to provide projections of climate change risks including adaptation potentials.

Those models that do not account for varying societal conditions (population, GDP, protection levels etc.) should keep these fixed at year 2005 levels throughout the simulations (**2005soc** scenario in Group 1 (dashed line in Figure 1 a) + **rcp26soc** or **rcp60soc** scenario in Group 2). They only need to run the first pre-industrial period of Experiment I (1661-1860). Group 3 runs only refer to models that are able to represent future changes in societal conditions.

Climate & CO ₂ scenarios	
picontrol	Pre-industrial climate (year specific for the entire period 1661-2299)
historical	Historical climate and CO ₂ concentration.
rcp26	Future climate and CO ₂ concentration from RCP2.6
rcp60	Future climate and CO ₂ concentration from RCP6.0
Human influence & land-use scenarios	
1860soc	Pre-industrial society and protection
2005soc	Representation of fixed year 2005 society and protection
ssp2soc	Varying society and protection according to SSP2
2100ssp2soc	Representation of fixed year 2100 society and protection according to SSP2

Table 29 ISIMIP2b scenario specification for the simulations of impacts on coastal infrastructure.

Experiment		Input	Pre-industrial 1661-1860	Historical 1861-2005	Future 2006-2099	Extended future 2100-2299
I	no climate change, pre-industrial CO ₂	Climate & CO ₂	picontrol	picontrol	picontrol	picontrol
	varying society & protection up to 2005, then fixed at 2005 levels thereafter	Human & LU	Option 1: 1860soc	Option 1: histsoc	2005soc	2005soc
			Option 2*: 2005soc	Option 2*: 2005soc		
II	RCP2.6 climate & CO ₂	Climate & CO ₂	Experiment I	historical	rcp26	rcp26
	varying society & protection up to 2005, then fixed at 2005 levels thereafter	Human & LU		Option 1*: histsoc	2005soc	2005soc
			Option 2*: 2005soc			
III	RCP6.0 climate & CO ₂	Climate & CO ₂	Experiment I	Experiment II	rcp60	not simulated
	varying society & protection up to 2005, then fixed at 2005 levels thereafter	Human & LU			2005soc	
IV	no climate change, pre-industrial CO ₂	Climate & CO ₂	Experiment I	Experiment I	picontrol	picontrol
	varying society & protection up to 2100 (SSP2), then fixed at 2100 levels thereafter	Human & LU			ssp2soc	2100ssp2soc
VI	RCP2.6 climate & CO ₂	Climate & CO ₂	Experiment I	Experiment II	rcp26	rcp26
	varying society & protection up to 2100 (SSP2), then fixed at 2100 levels thereafter	Human & LU			ssp2soc	2100ssp2soc
VII	RCP6.0 climate & CO ₂	Climate & CO ₂	Experiment I	Experiment II	rcp60	not simulated
	varying society & protection (SSP2)	Human & LU			ssp2soc	

13.2 Output data

Table 30 Variables to be reported by coastal infrastructure models.

Variable	Variable name	Resolution	Unit	Comments
Expected number of people flooded annually	par	Time resolved grid	thousands/yr (1000 yr ⁻¹)	Par = People at risk.
Expected seafood costs	seafloodcost		million dollars/yr (mio 2005US\$ yr ⁻¹)	Expected annual damage caused by seafoods
Adaptation costs of building and upgrading dikes	seadikecost		million dollars/yr (mio 2005US\$ yr ⁻¹)	Cost for building/upgrading dikes
Adaptation costs of maintaining dikes	seadikemain		million dollars/yr (mio 2005US\$ yr ⁻¹)	Cost for maintenance of dikes build since the initial year (2000), but not cost for dikes “build” in the initialization of the model.

14 Fisheries and Marine Ecosystems

14.1 Scenarios

5 The fisheries and marine ecosystem models are quite diverse. Most include climate-impact models via ESM-simulated primary-production changes, and many also include impacts of changes in water temperature on ectotherm metabolic rates. A very small subset of the models includes ocean-acidification effects. Most models include fishing, either as an imposed process based on observed historical fishing effort (which start in 1950), or as an endogenous process based on simple economic factors.

10 Fishing effort should be held at constant 1950 levels from 1861-1950. It should then follow the standard historical reconstruction from 1950-2006 typically used by the model, using reconstructed effort or economic forcings as appropriate. Effective effort should be held constant following 2005 in all simulations. For models that include acidification effects, all simulations should include ocean acidification in accordance with the respective climate scenario.

Climate scenarios	
picontrol	Pre-industrial climate and 286ppm CO ₂ concentration. The climate data for the entire period (1661-2299) are unique – no (or little) recycling of data has taken place.
historical	Historical climate and CO ₂ concentration.
rcp26	Future climate and CO ₂ concentration from RCP2.6
rcp60	Future climate and CO ₂ concentration from RCP6.0
Human influences scenarios	
nosoc	No fishing
histsoc	Historical reconstruction of fishing starting in 1950
2005soc	Fishing fixed at year 2005 levels

Table 31 ISIMIP2b scenarios for simulations of the impacts on marine ecosystems and fisheries.

	Experiment	Input	Pre-industrial	Historical	Future	Extended future
			1661-1860	1861-2005	2006-2099	2100-2299
I	no climate change, pre-industrial CO ₂	Climate & CO ₂	picontrol	picontrol	picontrol	picontrol
	varying fishing up to 2005, then fixed at 2005 levels thereafter	Human & LU	nosoc	histsoc	2005soc	2005soc
II	RCP2.6 climate & CO ₂	Climate & CO ₂	Experiment I	historical	rcp26	rcp26
	varying fishing up to 2005, then fixed at 2005 levels thereafter	Human & LU		histsoc	2005soc	2005soc
III	RCP6.0 climate & CO ₂	Climate & CO ₂	Experiment I	Experiment II	rcp60	not simulated
	varying fishing up to 2005, then fixed at 2005 levels thereafter	Human & LU			2005soc	

14.1.1 Output data

Table 32 Common output variables to be provided by global and regional marine fisheries models.

Output variable	Variable name	Resolution	Unit (NetCDF format)	Comments
Essential outputs from global and regional models (provide as many as possible)				
TOTAL system biomass density	tsb	monthly	g C m ⁻²	all primary producers and consumers
TOTAL consumer biomass density	tcb	monthly	g C m ⁻²	all consumers (trophic level >1, vertebrates and invertebrates)
Biomass density of consumers >10cm	b10cm	monthly	g C m ⁻²	if L infinity is >10 cm, include in >10 cm class

Biomass density of consumers >30cm	b30cm	monthly	g C m ⁻²	if L infinity is >30 cm, include in >30 cm class
TOTAL Catch (all commercial functional groups / size classes) where fishing included in model	tc	monthly	g wet biomass / m ² , g m ⁻²	catch at sea (commercial landings plus discards, fish and invertebrates)
TOTAL Landings (all commercial functional groups / size classes) where fishing included in model	tla	monthly	g wet biomass / m ² , g m ⁻²	commercial landings (catch without discards, fish and invertebrates)
Optional output from global and regional models				
Biomass density of commercial species where fishing included in model	bcom	monthly	g C m ⁻²	Discarded species not included (Fish and invertebrates)
Biomass density (by functional group / size class) where fishing included in model	b-<class>-<group>	monthly	g C m ⁻²	Provide name of each size class (<class>) and functional group (<group>) used, and provide a definition of each class/group
Catch (by functional group / size class) where fishing included in model	c-<class>-<group>	monthly	g wet biomass / m ² , g m ⁻²	Provide name of each size class (<class>) and functional group (<group>) used, and provide a definition of each class/group

15 Terrestrial biodiversity

The following protocol describes the contribution of global terrestrial biodiversity models to ISIMIP2b. Biodiversity is influenced by both climate and land-use change, as well as the biome changes resulting from these drivers. All of these drivers will be considered in biodiversity simulations.

- 5 Different model types may be used to simulate biodiversity, such as correlative species distribution models, macroecological species richness models, process-based biodiversity models, and others. There are no restrictions regarding the model type, as long as the methodology has been documented in previous peer-reviewed publications.

In its initial stage, this protocol focuses on correlative species distribution models; it will be amended with the needs and requirements of other model types as required.

- 10 Species distribution models (SDMs) are used to identify the potential climatic niche of a species and so allow to predict a species' probability of occurrence under present and future climatic conditions. Running these models for multiple species, one can aggregate the individual occurrence probabilities to a summed probability of occurrence (a proxy of species richness).

Species distribution data, in combination with the observed climate dataset "EWEMBI" provided by ISIMIP, are used for the initial model construction (i.e., model calibration). Biodiversity projections are then calculated using the ISIMIP2b bias-corrected

- 15 GCM data.

The effects of biome and land-use changes on biodiversity are currently not considered. In the future, biome and land-use changes may be directly used as predictor variables during model construction.

15.1 Scenarios

Climate scenarios	
picontrol	Pre-industrial climate (year specific for the entire period 1661-2299)
historical	Historical climate.
rcp26	Future climate from RCP2.6
rcp60	Future climate from RCP6.0
Human influences scenarios	
nosoc	No human influences considered. Land-use scenarios (see other Sectors) are currently not considered, but will be possibly included in future model runs.

Table 33* ISIMIP2b scenarios for global (and potentially regional) biodiversity simulations.

Experiment		Input	Pre-industrial 1660-1860	Historical 1861-2005 ¹	Future 2006-2099 ²	Extended future 2101-2299 ²
I	pre-industrial climate	Climate	picontrol	picontrol	picontrol	picontrol
	no other human influences	Human & LU	nosoc	nosoc	nosoc	nosoc
II	RCP2.6 climate	Climate	Experiment I	historical	rcp26	rcp26
	no other human influences	Human & LU		nosoc	nosoc	nosoc
III	RCP6.0 climate	Climate	Experiment I	Experiment II	rcp60	not simulated
	no other human influences	Human & LU			nosoc	

*for now, only correlative species distribution models are considered. Additional scenario combinations will be contributed from other model types in due time.

¹for the Terrestrial biodiversity sector, “historical” refers to a 30-year period of current conditions (i.e., 1976-2005).

5 ²within these long-term time periods, biodiversity models will be run for average conditions of selected 30-year periods (2006-2035, 2036-2065, 2066-2095, 2086-2115, 2136-2165, 2186-2215, 2236-2265) and the 30-year periods centered around the 1.5°C GCM-specific Global Mean Temperature (GMT) thresholds (1996-2025, 2012-2041, 2018-2047, 2034-2063, 2038-2067, 2042-2071) provided by ISIMIP (<https://www.isimip.org/protocol/temperature-thresholds-and-time-slices/>) are considered.

10 15.2 Output data

Table 34 Output variables to be reported by biodiversity sector models.

Variable (long name)	Variable name	Resolution	Unit	Comments
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(NetCDF format)

Amphibian species probability of occurrence	amphibianprob²	30-year averages of selected time periods ¹ (0.5°x0.5°)	Probability of occurrence per cell	Results from individual SDMs assuming full dispersal³
Terrestrial bird species probability of occurrence	birdprob²			
Terrestrial mammal species probability of occurrence	mammalprob²			
Amphibian summed probability of occurrence	amphibiansumprob²	30-year averages of selected time periods ¹ (0.5°x0.5°)	Summed probability of occurrence per cell ²	Aggregated results from individual SDMs with different dispersal scenarios⁴
Terrestrial bird summed probability of occurrence	birdsumprob²			
Terrestrial mammal summed probability of occurrence	mammalsumprob²			
Summed probability of endemic amphibian species ⁵	endamphibiansumprob²			
Summed probability of endemic terrestrial bird species ⁵	endbirdsumprob²			
Summed probability of endemic terrestrial mammal species ⁵	endmammalsumprob²			
Summed probability of threatened amphibian species ⁶	thramphibiansumprob²			
Summed probability of threatened terrestrial bird species ⁶	thrbirdsumprob²			

Summed probability of threatened terrestrial mammal species ⁶	thrmammalsumprob ²			
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¹ Currently the following 30-year periods (2006-2035, 2036-2065, 2066-2095, 2086-2115, 2136-2165) and the 30-year periods centered around the 1.5°C GCM-specific Global Mean Temperature (GMT) thresholds (1996-2025, 2012-2041, 2018-2047, 2034-2063, 2038-2067, 2042-2071) provided by ISIMIP (<https://www.isimip.org/protocol/temperature-thresholds-and-time-slices/>) are considered.

5 ² For the Maximum Entropy (MaxEnt) model algorithm the output is not probability, but habitat suitability/relative occurrence probability. Values also range between 0 and 1.

³ Probability of occurrence is projected to the currently present and all neighbouring realms of a species and so sort of represents the unlimited dispersal of a species into the future.

⁴ Summed probability of occurrence is calculated for different dispersal scenarios (no dispersal, 0.5*d, 1*d, 2*d, full dispersal).

10 Full dispersal represents the sum of the probability of occurrence output files. No dispersal assumes that species can only be present where they are actually present according to the IUCN and BirdLife range maps. The other three dispersal scenarios consider species-specific dispersal buffers added to the present range, where **d** is the largest diameter of the original range of the species.

⁵ Endemic (range-restricted) species are the smallest ranging 15% of all species.

15 ⁶ Threatened species are all species that are (i) either critically endangered, (ii) endangered or (iii) vulnerable according to their IUCN red list status.

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