ISIMIP2b Simulation Protocol

Published on 28 February 2019

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.

Contents

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 according to SSP2 (Group 3).

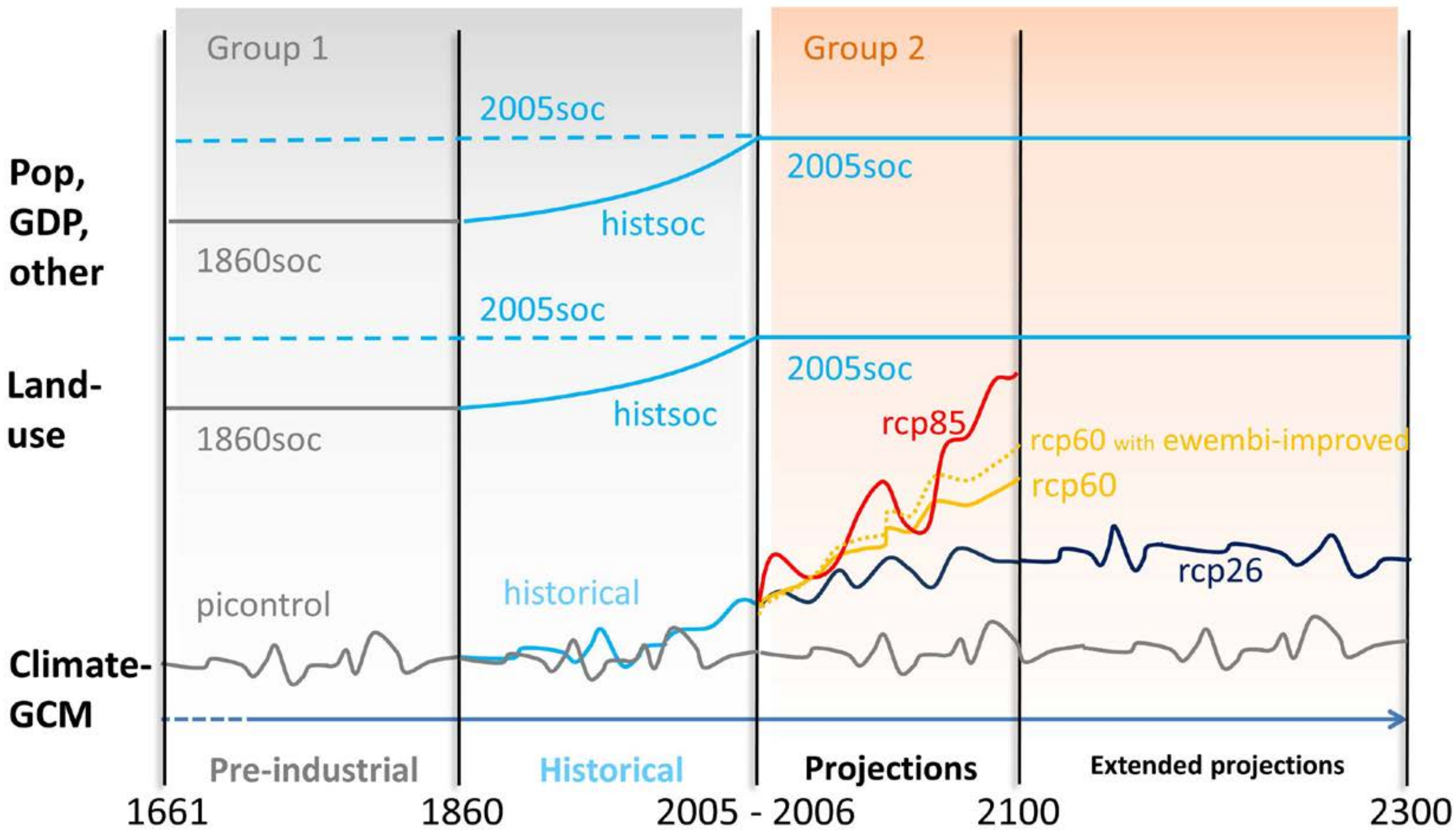

Figure 1 Schematic representation of the scenario design for ISIMIP2b **Group 1** and **Group 2** runs. "Other" includes other non-climatic anthropogenic forcing factors and management, such as irrigation, fertilizer input, selection of crop varieties, flood protection levels, dams and reservoirs, water abstraction for human use, fishing effort, atmospheric nitrogen deposition, etc. **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). The yellow dashed line represents an optional

sensitivity run with RCP6.0 climate forcing using statistical downscaling and improved bias-correction (ewembi-isimip3basd). This run, as well as the RCP8.5 run (red line) were introduced in February 2019.

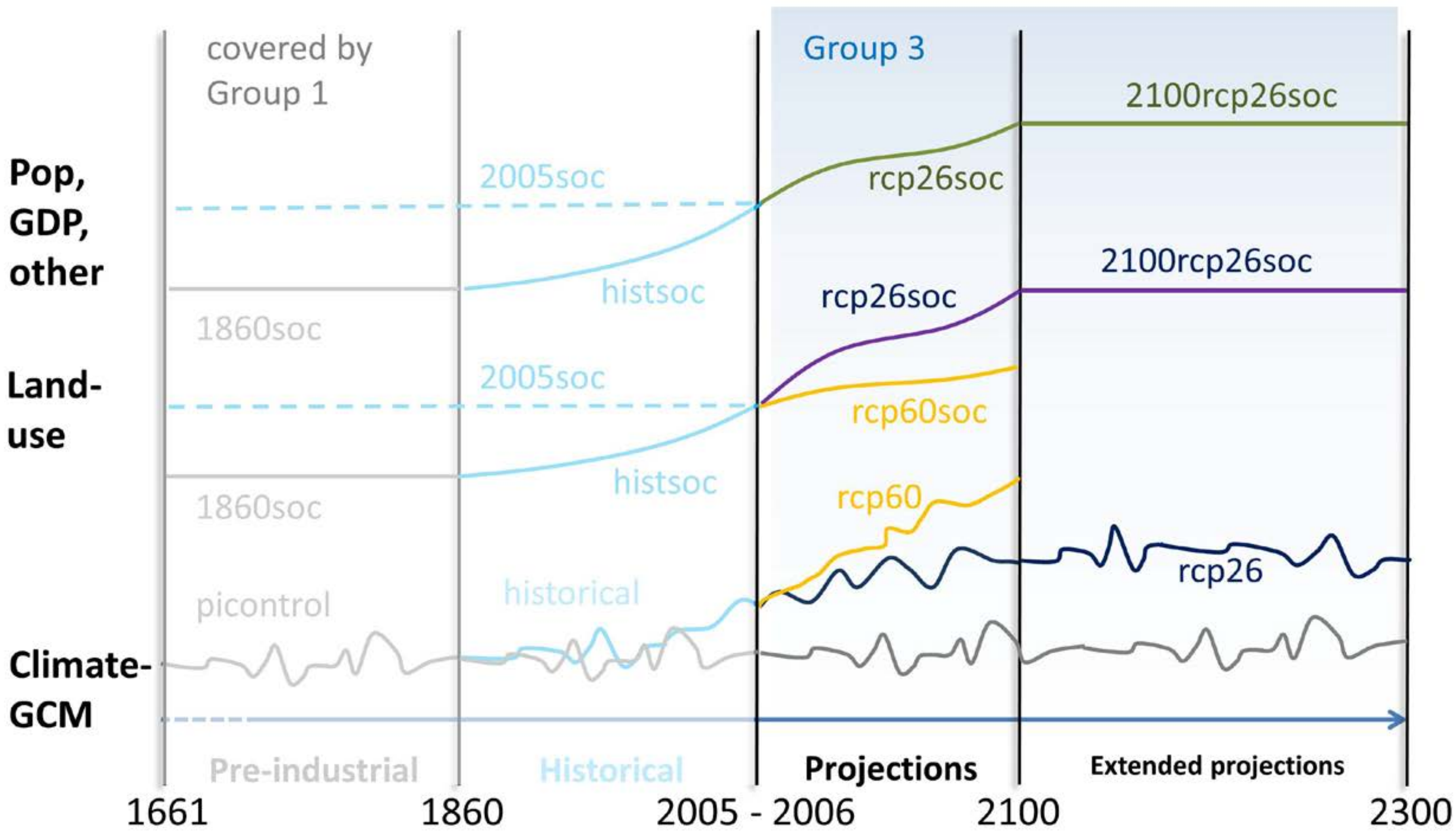

Figure 2 Schematic representation of the scenario design for **Group 3** runs. Group 3 consists of model runs to quantify the effects of the land use changes, and changes in population, GDP, and management from 2005 onwards associated with RCP6.0 (no mitigation scenario under SSP2) and RCP2.6 (strong 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 two updated versions of Fast-Track methods. The first of these two methods was used to bias-correct the bulk of the climate input data and is applied to climate model output data that was first spatially interpolated to 0.5° spatial resolution. This method is described in Frieler et al. (2017, doi:10.5194/gmd-10-4321-2017, section 3) and Lange (2018, doi:10.5194/esd-9-627-2018). The second method was only applied to RCP6.0 climate projections. It comes with many new features compared to the first method including trend preservation in all quantiles, the robust adjustment of extremes, and the explicit statistical downscaling from the spatial resolution of the climate model to that of the observation. This method is described in Lange (2018, doi:tba) and is deemed to be used for all bias corrections in ISIMIP3. (For some locations, additional climate input data is available where climate model data was bias-corrected to local weather station data; see sector-specific chapters.)
- 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/).
- For some GCMs, it was necessary to recycle pre-industrial control climate data in order to fill the entire 1661-2299 period (for more information see, Frieler et al. 2017).
- Priorization of climate models (from highest to lowest):
  1. IPSL-CM5A-LR
  2. GFDL-ESM2M
  3. MIROC5
  4. HadGEM2-ES

Table 1 Bias-corrected climate 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 et al., 2017) (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.

The transition from historical to future LU patterns requires a harmonisation between the land-use classes and areas between the different data sets.

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) C3 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)

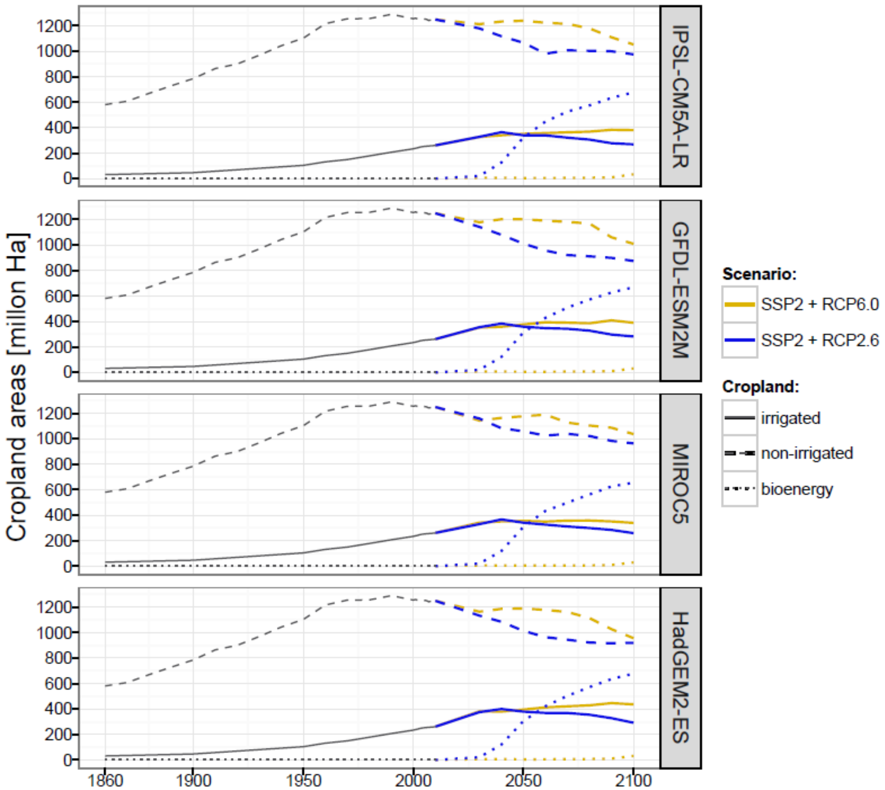

Figure 3 Time series of total crop land (irrigated (solid lines) and non-irrigated (dashed lines)) as reconstructed for the historical period (1860 - 2015) based on HYDE3.2 (Klein Goldewijk et al., 2017) and projected under SSP2 (2016-2100) assuming no explicit mitigation of greenhouse gas emissions (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.

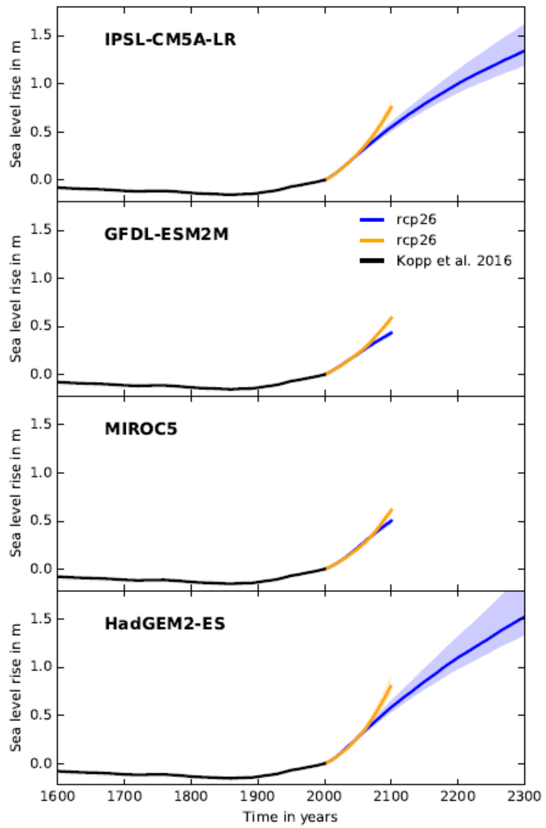

Figure 4 Time series of global total sea-level rise based on observations (Kopp et al., 2016, black line) until year 2000 and global-mean-temperature change from IPSL-CM5A-LR (panel 1), GFDL-ESM2M (panel 2), MIROC5 (panel 3) and HadGEM2-ES (panel 4) after year 2000: solid lines: Median projections, shaded 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)

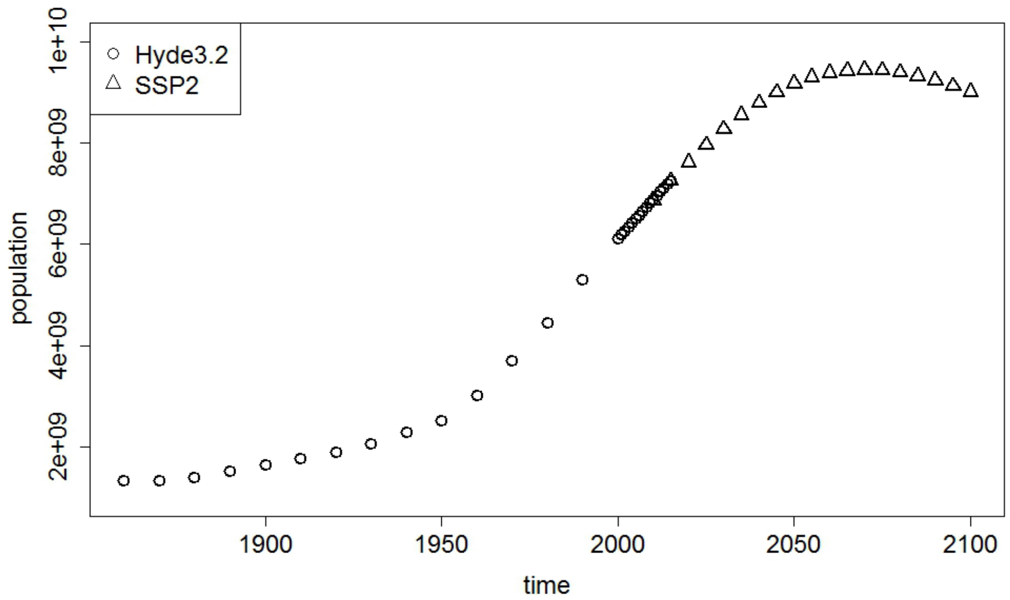

Figure 5 Time series of global population for the historical period (dots) and future projections following the SSP2 storyline (triangles).

Table 5 Socio-economic input data corresponding to SSP2.

Driver	Historical reconstruction	Future projections
GDP	• 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 (1861-2005). • Annual data on 0.5° grid corresponding to SSP2 (1861-2005).	• 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 (2006-2299). • Annual data on 0.5° grid based on downscaling of country-level data (Murakami and Yamagata, 2016) (2006-2299).

Population	• Annual data on a 0.5° and 5'grid based on the HYDE3.2 database (Klein Goldewijk et al., 2017) (1861-2005). • Annual country-level, age-specific population data based on the HYDE3.2 database (Klein Goldewijk et al., 2017) (1861-2005).	• Annual data on a 0.5° grid based on the national SSP2 population projections as described in Samir and Lutz, (2014) (2006-2299). • Annual country-level, age-specific data in 5-year age groups and all-age mortality rates in 5-year time (2006-2299). Also includes rural/urban division.

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 • **location** • **upstream area** • **capacity** • **construction/commissioning year**	Global data on 0.5° grid based on GranD database and the DDm30 routing network. Documentation: http://www.gwsp.org/products/grand-database.html **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.	No future data sets are provided. Held fixed at year 2005 levels in all simulations.

Water abstraction for domestic and industrial uses	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.	Generated by each modelling group individually. For modelling groups that do not have their own representation, we provide files containing the multi-model mean (from the global water models WaterGAP, PCRGLOBWB, and H08) domestic and industrial water withdrawal and consumption under SSP2 from the Water Futures and Solutions (WFaS) (Wada et al., 2016) project. This data is available from 2006 until 2050. The values should be kept constant from 2050 onwards. 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.

Irrigation water abtraction	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.	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: • SSP2+RCP6.0 • SSP2+RCP2.6; Direct water use for livestock should be ignored (i.e. can be set to zero).
N fertilizer use (kg per ha of cropland)	Annual crop-specific input per ha of crop land for C_3 and C_4 annual, C_3 and C_4 perennial and C_3 Nitrogen fixing. This data set is part of the LUH2 dataset developed for CMIP6 (Hurtt et al.) based on HYDE3.2.	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.
Nitrogen (NH_X and NO_Y) deposition	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). 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. 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.	As per historical reconstruction for 2006-2099 following RCP2.6 and RCP6.0.

Fishing intensity	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. Given that the SAUP historical reconstruction starts in 1950, fishing effort should be held at a constant 1950 value from 1860-1950.	Held constant after 2005 (**2005soc**)
Forest management	Based on observed stem numbers (see Table 17-Table 18)	Based on generic future management practices (see **Table 16**-**Table 18**)

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.

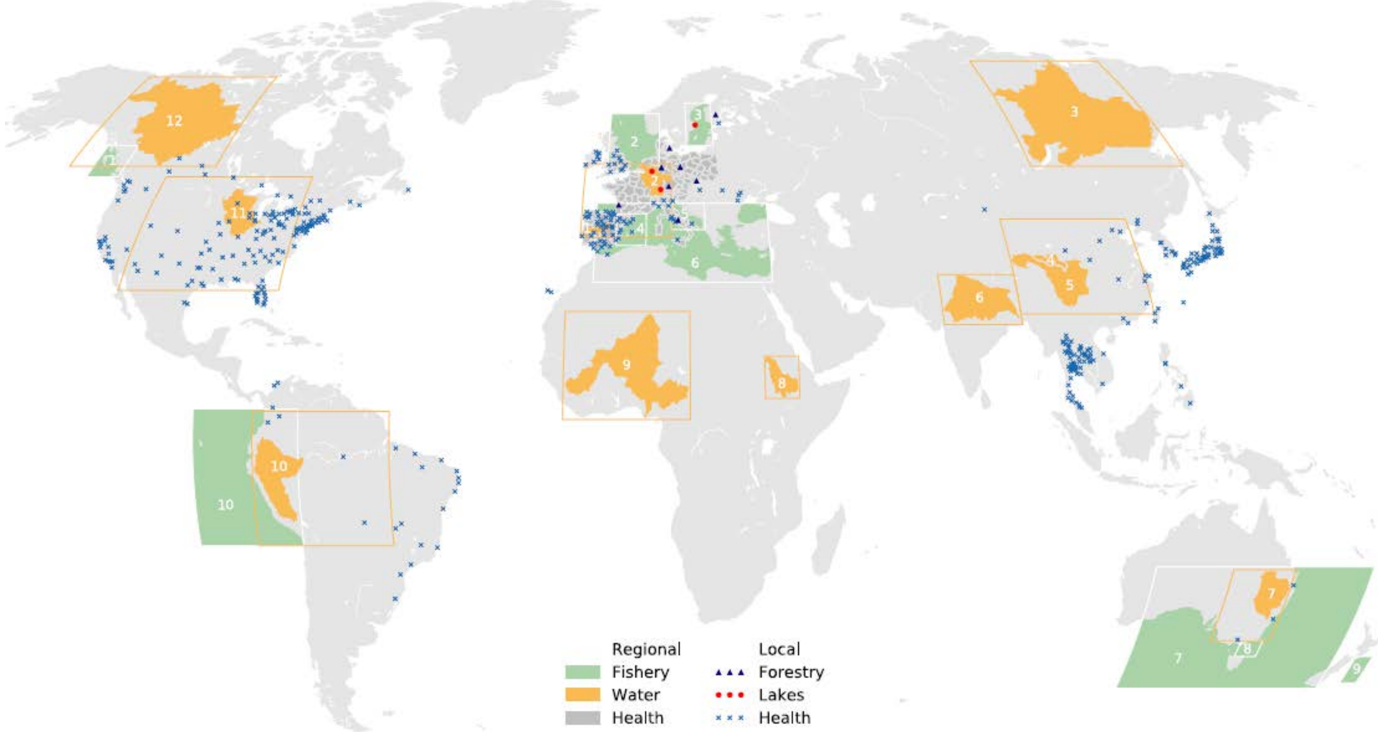

Figure 6 ISIMIP focus regions. See **Table 7** for region definitions.

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).

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 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).

An up-to-date list of lakes that are analysed in the ISIMIP Lake sector can be found under https://docs.google.com/spreadsheets/d/1UY_KSR02o7LtmNoOs6jOgOxdcFEKrf7MmhR2BYDlm-Q/edit#gid=555498854.

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

Focus region (shortname) Number refers to **Figure 6**	Zonal extent (longitude)	Meridional extent (latitude)	River basin(s) or Region (shortname).
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 forest 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 Time slices for individual files

For time slices holding global daily data, files should cover 10 years starting in the second year of a decade and end in the first year of the next decade (e.g. 1991-2000). If the time period starts after the second year of the decade, or ends before the first year of the new decade, the start or end year of the time period should be used as the start or end year of the file respectively. Data on a lower than daily temporal resolution or non-global data should be submitted for the entire simulation period in single files per variable.

Examples of time slices for individual files with global daily data:

Pre-industrial: 1661_1670, 1671_1680, ..., 1851_1860
Historical: 1861_1870, 1871_1880, ..., 2001_2005
Future: 2006_2010, 2011_2020, ..., 2081_2090, 2091_2099
Extended future: 2100_2100, 2101_2110, ..., 2281_2290, 2291_2299

Time slices for individual files with non-global or non-daily data:

Pre-industrial: 1661_1860
Historical: 1861_2005
Future: 2006_2099
Extended future: 2100_2299

3.1.2 File names

File names consist of a series of identifiers, separated by underscores; see examples below. Things to note:

- Report **one** variable per file
- In filenames, use **lowercase** letters only
- Use underscore (“_”) to separate identifiers
- Variable names consist of a single word without hyphens or underscores
- Use hyphens (”-“) to separate strings within an identifier, e.g. in a 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 8**. Identifiers 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 identifiers	Description
<modelname>		Model name
<gcm>	hadgem2-es, ipsl-cm5a-lr, miroc5, gfdl-esm2m	Name of the General Circulation Model (global climate model) from which climate-forcing data was used.

<bias-correction>	nobc, localbc, ewembi, ewembi-isimip3basd	The target observed climate data used for the bias correction. nobc Indicates that no bias correction was performed on the climate data (e.g. ocean data). 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° grid. ewembi-isimip3basd refers to EWEMBI data used for the bias-correction globally on a 0.5° grid, using improved bias-correction methods (Lange 2018, doi: 10.5194/esd-9-627-2018), and with statistical downscaling (instead of interpolation) of GCM data to the 0.5° grid prior to bias-correction.
<climate-scenario>	picontrol, historical, rcp26, rcp60, rcp85	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.

For further instructions on file naming and formatting, please also refer to our website: https://www.isimip.org/protocol/isimip2b-files/#file-formats-and-meta-data

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.
rcp85	Future climate and CO_2 concentration from RCP8.5.
Human influence and land use	
1860soc	Pre-industrial 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. Please indicate in the metadata of the file and the model description on the ISIMIP website which option you used.
histsoc	Varying historical land use and other human influences.
2005soc	Fixed year-2005 land use and other human influences.
nosoc	No direct human influences on the water cycle. This is only for models that do not represent any water abstraction. Such model simulations should be labeled "nosoc" even if human land-use is represented.
rcp26soc	Varying water abstraction and land use 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 water abstraction and land use 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	Human influences and land use 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 the purpose of the global water sector, "**human influences**" is defined as human interference directly with the hydrological fluxes of the water cycle for the purposes of any one or several of: water management (e.g. dams/reservoirs), irrigation, domestic water use, manufacturing and livestock production. I.e. human land use alone does not represent a human influence.

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 any human influences *at all* (as defined above) 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 (even if human land use is included).

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) should 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. Option 3 only if neither option 1 nor option 2 are possible. Simulations must follow a single row for each experiment; mixing of different options is not possible! **If you can only run simulations with 2005soc, then it is sufficient to provide only 200 years worth of picontrol climate (1661-1860).

	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	Option 1: **1860soc**	Option 1: **histsoc**	Option 1: **2005soc**	Option 1: **2005soc**
			Option 2*: **2005soc**	Option 2*: **2005soc****	Option 2*: **2005soc****	Option 2*: **2005soc****
			Option 3*: **nosoc**	Option 3*: **nosoc**	Option 3*: **nosoc**	Option 3*: **nosoc**
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 1/2*: **2005soc**	Option 1/2*: **2005soc**
				Option 2*: **2005soc**		
				Option 3*: **nosoc**	Option 3*: **nosoc**	Option 3*: **nosoc**
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			Option 1/2*: **2005soc**	
					Option 3*: **nosoc**	
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**	
VIII	RCP8.5 climate & CO_2	Climate & CO_2	Experiment I	Experiment II	**rcp85**	not simulated
	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU			Option 1/2*: **2005soc**	
					Option 3*: **nosoc**	
IX	Optional: RCP6.0 climate & CO_2 with **improved bias-correction and statistical downscaling** of climate variables (ewembi-improved)	Climate & CO_2	**picontrol**	**historical**	**rcp60**	not simulated
	LU & human influences fixed at 2005 levels	Human & LU	Option 1: **1860soc**	Option 1: **histsoc**	Option 1/2*: **2005soc**	
			Option 2*: **2005soc**	Option 2*: **2005soc**		
			Option 3*: **nosoc**	Option 3*: **nosoc**	Option 3*: **nosoc**	

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 (i.e. not shaded) 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	Unit (NetCDF format)	Resolution	Comments
Hydrological Variables				
*Runoff	**qtot**	kg m-2 s-1	daily (0.5°x0.5°)	total (surface + subsurface) runoff (qtot = qs + qsb). If daily resolution not possible, please provide monthly.
Surface runoff	**qs**	kg m-2 s-1	monthly (0.5°x0.5°)	Water that leaves the surface layer (top soil layer) e.g. as overland flow / fast runoff
Subsurface runoff	**qsb**	kg m-2 s-1	monthly (0.5°x0.5°)	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**	kg m-2 s-1	monthly (0.5°x0.5°)	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**	kg m-2 s-1	monthly (0.5°x0.5°)	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**	m3 s-1	daily (0.5°x0.5°)	If daily resolution not possible, please provide monthly
Discharge (gauge level)	**dis**	m3 s-1	daily (see website for gauge locations)	If daily resolution not possible, please provide monthly
Monthly maximum of daily discharge	**maxdis**	m3 s-1	monthly (0.5°x0.5°)	Reporting this variable is not mandatory, but desirable particularly if daily discharge data is unfeasible
Monthly minimum of daily discharge	**mindis**	m3 s-1	monthly (0.5°x0.5°)	Reporting this variable is not mandatory, but desirable particularly if daily discharge data is unfeasible
Evapotranspiration	**evap**	kg m-2 s-1	monthly (0.5°x0.5°)	Sum of transpiration, evaporation, interception losses, and sublimation.
Evapotranspiration	**evap**	kg m-2 s-1	monthly (average for basin until gauge location)	Sum of transpiration, evaporation, interception losses, and sublimation.
Potential Evapotranspiration	**potevap**	kg m-2 s-1	monthly (0.5°x0.5°)	as for *evap*, but with all resistances set to zero, except the aerodynamic resistance.
*Soil moisture (= soil water storage)	**soilmoist**	kg m-2	monthly (0.5°x0.5°)	provide soil moisture for all depth layers (i.e. 3D-field), and indicate depth in m.
Soil moisture, root zone	**rootmoist**	kg m-2	monthly (0.5°x0.5°)	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**	kg m-2	monthly (0.5°x0.5°)	water content of frozen soil
**Temperature of Soil	**tsl**	K	daily (0.5°x0.5°)	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**	m	monthly (0.5°x0.5°)	Grid cell mean depth of snowpack.
*Snow water equivalent (= snow water storage)	**swe**	kg m-2	monthly (0.5°x0.5°)	Total water mass of the snowpack (liquid or frozen), averaged over a grid cell.
Total water storage	**tws**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in all compartments. Please indicate in the netcdf metadata which storage compartments are considered.
Canopy water storage	**canopystor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in the canopy.
Glacier storage	**glacierstor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in glaciers.
Groundwater storage	**groundwstor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in groundwater layer.
Lake storage	**lakestor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in lakes (except reservoirs).
Wetland storage	**wetlandstor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in wetlands.
Reservoir storage	**reservoirstor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in reservoirs.
River storage	**riverstor**	kg m-2	monthly (0.5°x0.5°)	Mean monthly water storage in rivers.

*Annual maximum daily thaw depth	**thawdepth**	m	annual (0.5°x0.5°)	calculated from daily thaw depths, which do not need to be submitted themselves.
Rainfall	**rainf**	kg m-2 s-1	monthly (0.5°x0.5°)	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**	kg m-2 s-1	monthly (0.5°x0.5°)	
Water management variables (for models that consider water management/human impacts)				
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 **i**rrigation and **l**ivestock sectors would be "pilww"; combined actual water consumption in the **i**rrigation, **d**omestic, **m**anufacturing, **e**lectricity, and **l**ivestock sectors would be "aidmeluse" (see section 2.6 for the latest naming convention regarding file names).				
Irrigation water demand (=potential irrigation water Withdrawal)	**pirrww**	kg m-2 s-1	monthly (0.5°x0.5°)	Irrigation water withdrawal, assuming unlimited water supply
Actual irrigation water withdrawal	**airrww**	kg m-2 s-1	monthly (0.5°x0.5°)	Irrigation water withdrawal, taking water availability into account; please provide if computed
Potential irrigation water consumption	**pirruse**	kg m-2 s-1	monthly (0.5°x0.5°)	portion of withdrawal that is evapo-transpired, assuming unlimited water supply
Actual irrigation water consumption	**airruse**	kg m-2 s-1	monthly (0.5°x0.5°)	portion of withdrawal that is evapotranspired, taking water availability into account; if computed

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

Actual livestock water withdrawal	**aliveww**	kg m-2 s-1	monthly (0.5°x0.5°)	if computed
Actual livestock water consumption	**aliveuse**	kg m-2 s-1	monthly (0.5°x0.5°)	if computed
Total (all sectors) actual water consumption	**Atotuse**	kg m-2 s-1	monthly (0.5°x0.5°)	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**	kg m-2 s-1	monthly (0.5°x0.5°)	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**	1	static (0.5°x0.5°) or monthly (0.5°x0.5°) where appropriate	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>**	dry matter (t ha-1 per growing season)	per growing season (0.5°x0.5°)	irrigation setting = "cirr" for "constraint irrigation" or "noirr" for rainfed

Actual planting dates	**plantday-<crop>-<irrigation setting>**	Day of year	per growing season (0.5°x0.5°)	Julian dates
Actual planting year	**plantyear-<crop>-<irrigation setting>**	Year of planting	per growing season (0.5°x0.5°)	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>**	Day of year of anthesis	per growing season (0.5°x0.5°)	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>**	year of anthesis	per growing season (0.5°x0.5°)	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>**	Day of year of maturity	per growing season (0.5°x0.5°)	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>**	year of maturity	per growing season (0.5°x0.5°)	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>**	kg ha-1 per growing season	per growing season (0.5°x0.5°)	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>**	Dry matter (t ha-1 per growing season)	per growing season (0.5°x0.5°)	
Soil carbon emissions	**sco2-<crop>-<irrigation setting>**	kg C ha-1	per growing season (0.5°x0.5°)	Ideally should be modeled with realistic land-use history and initial carbon pools. Subject to extra study.
Nitrous oxide emissions	**sn2o-<crop>-<irrigation setting>**	kg N2O-N ha-1	per growing season (0.5°x0.5°)	Ideally should be modeled with realistic land-use history and initial carbon pools. Subject to extra study.
Nitrogen application rate	**initr-<crop>-<irrigation setting>**	kg ha-1 per growing season	per growing season (0.5°x0.5°)	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

Simulations should be provided for the four major crops (wheat, maize, soy, and rice) but output for other crops and also bioenergy 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.

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 GGCMI convention (Elliott et al. 2015: The Global Gridded Crop Model intercomparison: data and modelling protocols for Phase 1) and part of this agricultural protocol (section 10).

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

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). Bias-corrected meteorological forcing is available at the global scale (that is, do not use the land-only forcing models). 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). In case the lake model has no built-in calculation of the light extinction coefficient, modellers may consider using the parameterisation proposed by Shatwell (unpubl.): extcoeff = 5.681 * max(depth,1) ^(-0.795), derived from a collection of 1258 lakes, or the parameterisation proposed by Hakanson (1995, Aquatic sciences): extcoeff = 1.1925 * max(lakedepth,1)^(-0.424), derived from 88 Swedish glacial lakes. Yet it should be noted that modellers are free to decide how to represent extinction coefficient.

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 hyolimnion concentration is set to a missing value.

Diagnostic for lake stratification

As density is a non-linear function of temperature and a global analysis requires examination of a wide range of lake temperatures it is preferable to use a density-derived definition of stratification to a purely temperature-related definition, as follows:

Calculate density (ρ) from temperature using the formula (Millero & Poisson, 1981):

ρ = 999.842594 + (6.793952 x 10-2 t) – (9.095290 x 10-3 t2) + (1.001685 x 10-4 t3) – (1.120083 x 10-6 t4) + (6.536336 x 10-9 t5),

where t is water temperature of the lake layer in °C.

Define the lake to be stratified whenever the density difference between the surface and the bottom of the lake is greater than 0.1 kg m-3. Note this definition does not distinguish between 'normal' and 'reverse' stratification, that is, stratification when surface water density is less than the maximum density of water, found particularly under ice. While a separate step can be used to distinguish these events by assessing whether the surface temperature is greater than or less than 3.98 °C, this separation is not requested by the protocol.

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.
rcp85	Future climate and CO_2 concentration from RCP8.5.
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.
nosoc	No direct human influences on the water cycle. This is only for models that do not represent any water abstraction. Such model simulations should be labeled "nosoc" even if human land-use is represented.
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.

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.

Table 11 ISIMIP2b scenarios for lakes simulations**.** *Option 2 only if option 1 not possible. **If you can only run simulations with 2005soc, then it is sufficient to provide 200 years worth of picontrol climate (1661-1860).

<table>
<tr><th></th><th>Experiment</th><th>Input</th><th>pre-industrial
1661-1860</th><th>historical
1861-2005</th><th>future
2006-2099</th><th>extended future
2100-2299</th></tr>
<tr><td rowspan="4">I</td><td>no climate change, pre-industrial CO_2</td><td>Climate & CO_2</td><td>picontrol</td><td>picontrol</td><td>picontrol</td><td>picontrol</td></tr>
<tr><td rowspan="3">varying LU and other human influences according to RCP2.6 + SSP2 up to 2100, then fixed at 2100 levels thereafter</td><td rowspan="3">Human & LU</td><td>Option 1: 1860soc</td><td>Option 1: histsoc</td><td>Option 1*: 2005soc</td><td>Option 1*: 2005soc</td></tr>
<tr><td>Option 2*: 2005soc</td><td>Option 2*: 2005soc**</td><td>Option 2*: 2005soc**</td><td>Option 2*: 2005soc**</td></tr>
<tr><td>Option 3*: nosoc</td><td>Option 3*: nosoc</td><td>Option 3*: nosoc</td><td>Option 3*: nosoc</td></tr>
<tr><td rowspan="3">II</td><td>RCP2.6 climate & CO_2</td><td>Climate & CO_2</td><td rowspan="3">Experiment I</td><td>historical</td><td>rcp26</td><td>rcp26</td></tr>
<tr><td rowspan="2">varying LU and other human influences according to RCP2.6 + SSP2 up to 2100, then fixed at 2100 levels thereafter</td><td rowspan="2">Human & LU</td><td>Option 1: histsoc</td><td rowspan="2">2005soc</td><td rowspan="2">2005soc</td></tr>
<tr><td>Option 2*: 2005soc</td></tr>
<tr><td rowspan="2">IIa</td><td>RCP2.6 climate, CO_2 after 2005 fixed at 2005 levels</td><td>Climate & CO_2</td><td rowspan="2">Experiment I</td><td rowspan="2">Experiment II</td><td>rcp26, 2005co2</td><td>rcp26, 2005co2</td></tr>
<tr><td>LU & human influences fixed at 2005 levels after 2005</td><td>Human & LU</td><td>2005soc</td><td>2005soc</td></tr>
<tr><td rowspan="2">III</td><td>RCP6.0 climate & CO_2</td><td>Climate & CO_2</td><td rowspan="2">Experiment I</td><td rowspan="2">Experiment II</td><td>rcp60</td><td rowspan="2">not simulated</td></tr>
<tr><td>varying LU & human influences up to 2005, then fixed at 2005 levels thereafter</td><td>Human & LU</td><td>2005soc</td></tr>
</table>

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**	
VIII	RCP8.5 climate & CO_2	Climate & CO_2	Experiment I	Experiment II	**rcp85**	not simulated
	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU			**2005soc**	
IX	Optional: RCP6.0 climate & CO_2 with **improved bias-correction and statistical downscaling** of climate variables (ewembi-improved)	Climate & CO_2	**picontrol**	**historical**	**rcp60**	not simulated
	LU & human influences fixed at 2005 levels	Human & LU	Option 1: **1860soc**	Option 1: **histsoc**	Option 1/2*: **2005soc**	
			Option 2*:	Option 2*: **2005soc**		

			2005soc			
			Option 3*: **nosoc**	Option 3*: **nosoc**	Option 3*: **nosoc**	

6.1.1 Output data

Table 12 Output variables to be reported by lake models.

Variable (long name)	Variable name	Unit (NetCDF format)	Spatial Resolution	Temporal Resolution	Depth Resolution	Comments
Hydrothermal Variables						
Onset of thermal stratification	**stratstart**	Day of year when stratification started (1-365)	Representative lake associated with grid cell	Seasonal	None	Day of year associated with the onset of thermal stratification. See protocol for stratification computation.
Loss of thermal stratification	**stratend**	Day of year when stratification ended (1-365)	Representative lake associated with grid cell	Seasonal	None	Day of year associated with the loss of thermal stratification. See protocol for stratification computation.
Duration of stratification	**stratdur**	d	Representative lake associated with grid cell	Seasonal	None	Longest continuous period of lake stratification in any given season, reported in year in which stratification is lost. See protocol for stratification computation.
Onset of lake Ice cover	**icestart**	Day of year when ice cover started (1-365)	Representative lake associated with grid cell	Seasonal	None	Day of year associated with the onset of permanent ice cover

Loss of lake Ice cover	**iceend**	Day of year when ice cover ended (1-365)	Representative lake associated with grid cell	Seasonal	None	Day of year associated with the loss of permanent ice cover
Duration of Lake Ice Cover.	**icedur**	d	Representative lake associated with grid cell	Seasonal	None	Longest continuous period of lake ice in any given season, reported in the year in which lake ice is lost.
Depth of Thermocline	**thermodepth**	m	Representative lake associated with grid cell	Daily	Single depth	Depth corresponding the maximum water density gradient
Water temperature	**watertemp**	K	Representative lake associated with grid cell	Daily	Full Profile	Simulated water temperature. Layer averages and full profiles
Surface temperature	**surftemp**	K	Representative lake associated with grid cell	Daily (monthly)	Single depth	Average of the upper layer in case not simulated directly.
Bottom temperature	**bottemp**	K	Representative lake associated with grid cell	Daily (monthly)	Single depth	Average of the lowest layer in case not simulated directly.
Lake layer ice mass fraction	**lakeicefrac**	unitless	Representative lake associated with grid cell	Daily (monthly)	Mean Epi	Fraction of mass of a given layer taken up by ice

Ice thickness	**icethick**	m	Representative lake associated with grid cell	Daily (monthly)	Single thickness	
Snow thickness	**snowthick**	m	Representative lake associated with grid cell	Daily (monthly)	Single thickness	
Temperature at the ice upper surface	**icetemp**	K	Representative lake associated with grid cell	Monthly	None	
Temperature at the snow upper surface	**snowtemp**	K	Representative lake associated with grid cell	Monthly	None	
Sensible heat flux at the lake-atmosphere interface	**sensheatf**	W m-2	Representative lake associated with grid cell	Daily (monthly)	None	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**	W m-2	Representative lake associated with grid cell	Daily (monthly)	None	See sensible heat flux

Momentum flux at the lake-atmosphere interface	**momf**	W m-2	Representative lake associated with grid cell	Daily (monthly)	None	See sensible heat flux
Upward shortwave radiation flux at the lake-atmosphere interface	**swup**	W m-2	Representative lake associated with grid cell	Daily (monthly)	None	See sensible heat flux. Not to be confused with net shortwave radiation
Upward longwave radiation flux at the lake-atmosphere interface	**lwup**	W m-2	Representative lake associated with grid cell	Daily (monthly)	None	See sensible heat flux. Not to be confused with net longwave radiation
Downward heat flux at the lake-atmosphere interface	**lakeheatf**	W m-2	Representative lake associated with grid cell	Daily (monthly)	None	See sensible heat flux the residual term of the surface energy balance, i.e. the net amount of energy that enters the lake on daily time scale: lakeheatf = swdown - swup + lwdown - lwup - sensheatf - latenheatf (terms defined positive when directed upwards)
Turbulent diffusivity of heat	**turbdiffheat**	m2 s-1	Representative lake associated with grid cell	Daily (monthly)	Mean Epi Mean Hypo Full Profile	only if computed by the model

Surface albedo	**albedo**	unitless	Representative lake associated with grid cell	Daily (monthly)	None	Albedo of the surface interacting with the atmosphere (water, ice or snow)
Light extinction coefficient	**extcoeff**	m-1	Representative lake associated with grid cell	Constant	None	only to be reported for global models, local models should use extcoeff as input
Sediment upward heat flux at the lake-sediment interface	**sedheatf**	W m-2	Representative lake associated with grid cell	Daily (monthly)	None	Positive if upwards. Only if computed by the model.
Water Quality Variables						
Chlorophyll Concentration	**chl**	g-3 m-3	Representative lake associated with grid cell	Daily (monthly)	Mean Epi Mean Hypo Full Profile	Total water chlorophyll concentration – indicator of phytoplankton
Phytoplankton Functional group biomass	**phytobio**	mole m-3 as carbon	Representative lake associated with grid cell	Daily (monthly)	Mean Epi Mean Hypo Full Profile	Different models will have different numbers of functional groups so that the reporting of these will vary by model

Zoo plankton biomass	**zoobio**	mole m-3 as carbon	Representative lake associated with grid cell	Daily (monthly)	Mean Epi Mean Hypo Full Profile	Total simulated Zooplankton biomass
Total Phosphorus	**tp**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Mean Epi Mean Hypo Full Profile	
Particulate Phosphorus	**pp**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Mean Epi Mean Hypo Full Profile	
Total Dissolved Phosphorus	**tpd**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Mean Epi Mean Hypo Full Profile	Some models may also output data for soluable reactive phosphorus (SRP)
Total Nitrogen	**tn**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Mean Epi Mean Hypo Full Profile	
Particulate Nitrogen	**pn**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Mean Epi Mean Hypo Full Profile	

Total Dissolved Nitrogen	**tdn**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Mean Epi Mean Hypo Full Profile	Some models may also output data for Nitrate (N02) nitrite (NO3) and ammonium (NH4)
Dissolved Oxygen	**do**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Mean Epi Mean Hypo Full Profile	
Dissolved Organic Carbon	**doc**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Mean Epi Mean Hypo Full Profile	Not always available
Dissolved Silica	**si**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Mean Epi Mean Hypo Full Profile	Not always available

7 Biomes

7.1 Scenarios

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.
rcp85	Future climate and CO_2 concentration from RCP8.5.
2005co2	CO2 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**
IIa	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**	
VIII	RCP8.5 climate & CO_2	Climate & CO_2	Experiment I	Experiment II	**rcp85**	not simulated
	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU			**2005soc**	
IX	Optional: RCP6.0 climate & CO_2 with **improved bias-correction and statistical downscaling** of climate variables (ewembi-improved)	Climate & CO_2	**picontrol**	**historical**	**rcp60**	not simulated
	LU & human influences fixed at 2005 levels	Human & LU	**1860soc**	**histsoc**	**2005soc**	

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

	Experiment	Input	Pre-industrial 1661-1860	Historical 1861-2005	Future 2006-2099	Extended future 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**	
IIIc	RCP8.5 climate, CO_2 after 2005 fixed at 2005 levels	Climate & CO_2	Experiment I	Experiment II	**rcp85, 2005co2**	not simulated
	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU			**2005soc**	

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.

Variable (long name)	Variable name	Unit (NetCDF name)		Resolution	Comment
Essential outputs					
Pools					
*Carbon Mass in Vegetation biomass	**cveg-<pft>**	kg m-2	per pft and gridcell total	annual	Gridcell total cveg is essential. Per PFT information is desirable.
*Carbon Mass in aboveground vegetation biomass	**cvegag-<pft>**	kg m-2	per pft and gridcell total	annual	Gridcell total cvegag is essential. Per PFT information is desirable.
*Carbon Mass in belowground vegetation biomass	**cvegbg-<pft>**	kg m-2	per pft and gridcell total	annual	Gridcell total cvegbg is essential. Per PFT information is desirable.
*Carbon Mass in Litter Pool	**clitter**	kg m-2	per gridcell total	annual	Info for each individual pool.
*Carbon Mass in Soil Pool	**csoil**	kg m-2	per gridcell total	annual	Info for each individual pool.

Fluxes					
*Carbon Mass Flux out of atmosphere due to Gross Primary Production on Land	**gpp**	kg m-2 s-1	gridcell total	daily (monthly)	
*Carbon Mass Flux out of atmosphere due to Gross Primary Production on Land	**gpp-<pft>**	kg m-2 s-1	per pft	annual	
*Carbon Mass Flux into atmosphere due to Autotrophic (Plant) Respiration on Land	**ra**	kg m-2 s-1	gridcell total	daily (monthly)	
*Carbon Mass Flux out of atmosphere due to Net Primary Production on Land	**npp**	kg m-2 s-1	gridcell total	daily (monthly)	
*Carbon Mass Flux out of atmosphere due to Net Primary Production on Land	**npp-<pft>**	kg m-2 s-1	per pft	annual	
*Carbon Mass Flux into atmosphere due to Heterotrophic Respiration on Land	**rh**	kg m-2 s-1	gridcell total	daily (monthly)	
*Carbon Mass Flux into atmosphere due to total Carbon emissions from Fire	**fireint**	kg m-2 s-1	gridcell total	daily (monthly)	
*Carbon Mass Flux out of Atmosphere due to Net biome Production on Land (NBP)	**ecoatmflux**	kg m-2 s-1	gridcell total	daily (monthly)	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	**lai-<pft>**	1	per pft	annual	
*Leaf Area Index	**lai**	1	gridcell average	daily (monthly)	
*Plant Functional Type Grid Fraction	**pft-<pft>**	%	per gridcell	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	**evap**	kg m-2 s-1	gridcell total	daily (monthly)	
Evaporation from Canopy (interception)	**intercep**	kg m-2 s-1	gridcell total	daily (monthly)	the canopy evaporation+sublimation (if present in model).
Water Evaporation from Soil	**esoil**	kg m-2 s-1	per gridcell	daily (monthly)	includes sublimation.
Transpiration	**trans**	kg m-2 s-1	per gridcell	daily (monthly)	

*Runoff	**qtot**	kg m-2 s-1	per gridcell	daily** (monthly)	total (surface + subsurface) runoff (qtot = qs + qsb). ** especially 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	**soilmoist**	kg m-2	per gridcell	daily (monthly)	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	**qs**	kg m-2 s-1	per gridcell	daily (monthly)	Total surface runoff leaving the land portion of the grid cell.
*Frozen soil moisture for each layer	**soilmoistfroz**	kg m-2	per gridcell	monthly	Please provide soil moisture for all depth levels and indicate depth in m.
*Snow depth	**snd**	m	per gridcell	monthly	Grid cell mean depth of snowpack.
*Snow water equivalent	**swe**	kg m-2	per gridcell	monthly	Total water mass of the snowpack (liquid or frozen), averaged over a grid cell.
*Annual maximum thaw depth	**thawdepth**	m	per gridcell	annual	calculated from daily thaw depths Please provide for purposes of permafrost sector.
Other outputs					

*Temperature of Soil	**tsl**	K	per gridcell	daily (monthly)	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	**burntarea**	%	per gridcell	daily (monthly)	Area percentage of grid cell that has burned at any time of the given day/month/year (for daily/monthly/annual resolution)
Albedo	**albedo**	1	per gridcell	monthly	average of pfts, snow cover, bare ground and water surfaces, range between 0-1
*N_2O emissions into atmosphere	**n2o**	kg m-2 s-1	gridcell total	monthly	From land, not from industrial fossil fuel emissions and transport
*CH4 emissions into atmosphere	**ch4**	kg m-2 s-1	gridcell total	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.

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. Additionally, site-specific, future management guidelines are presented in **Table 19**.

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 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.
    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 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.
rcp85	Future climate and CO_2 concentration from RCP8.5.
2005co2	CO2 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 towards maximizing mitigation benefits (e.g. by changing the tree species or the silvicultural regime). 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) high in situ carbon stocks, or (3) production of harvested wood products with a long lifetime (sawntimber, veneer…). Specific scenarios to be defined in the FORMASAM project.
rcp60soc	Future forest are assumed to require adaptive management (such as “assisted migration” or reduction of disturbance damage) where present-day forests are managed according to current practices until final harvest and then new, more adapted forests are established (e.g. with management focusing on increasing the stability of the stand or on replacing tree species that would be the natural vegetation under the projected climate change according to

	Hanewinkel et al. (2012)). Specific scenarios to be defined in the FORMASAM project.
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**
IIa	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**	
VIII	RCP8.5 climate & CO_2	Climate & CO_2	Experiment I	Experiment II	**rcp85**	not simulated
	varying management (forest management for adaptation)	Human & LU			**2005soc**	
IX	Optional: RCP6.0 climate & CO_2 with **improved bias-correction and statistical downscaling** of climate variables (ewembi-	Climate & CO_2	**picontrol**	**historical**	**rcp60**	not simulated

	improved)					
	fixed present-day management	Human & LU	1860soc	histsoc	2005soc	

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 1661-1860	Historical 1861-2005	Future 2006-2099	Extended future 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**
IIIa	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**	
IIIb	RCP6.0 climate & CO_2	Climate & CO_2	not simulated	Experiment II	**rcp60**	not simulated
	No forest management	Human & LU			**nosoc**	
IIIc	RCP8.5 climate, CO_2 after 2005 fixed at 2005 levels	Climate & CO_2	Experiment I	Experiment II	**rcp85, 2005co2**	not simulated
	LU & human influences fixed at 1860 levels	Human & LU			**2005soc**	
IVa	no climate change, pre-industrial CO_2	Climate & CO_2	not simulated	Experiment I	**picontrol**	**picontrol**
	varying management (forest management for mitigation)	Human & LU			**nosoc**	**nosoc**

Table 18 Generic future management scenarios for the different tree species. For past simulations and depending on the model, modellers should use the observed stem numbers from the time series of stand and tree level data to mimick stand management. Future management should then be added according to the generic management guidelines outlined below. E.g., The last management for the Peitz site can be infered from the tree data is taking place in 2011, hence the next management would then happen in 2026 according to **Table 17**.

Species	Thinning regime	Intensity [% of basal area]	Interval [yr]	Stand age for final harvest	Remarks
pisy	below	20	15	140	Pukkala et al. 1998; Fuerstenau et al. 2007; Gonzales et al-2005; Lasch et al. 2005
piab	below	30	15	120	Pape 2008; Pukkala et al. 1998; Hanewinkel and Pretzsch-2000; Sterba 1986; Laehde et al. 2010
fasy	above	30	15	140	Schuetz 2006; Mund et al. 2004; Hein and Dhote 2006; Cescatti and Piutti 1998
quro/qupe	above	15	15	200	Hein and Dhote 2006; Fuerstenau et al. 2007; Štefančík 2012; Kerr 1996; Gutsch et al. 2011

pipi	below	20	10	45	Management after Loustau et al. 2005 & Thivolle-Cazat et al. 2013

Table 19 Management schedules for the sites included in the simulation experiments. The first available data point is used for model initialization (Ini). Following data points are used to mimick historic management (HM). When no more observed data is available, the generic management rules from **Table 16** are being used (FM). harvest and planting are marked in bold. Note that depending on how models represent the planting/regeneration information in Table 20, the overall stand- age maybe slightly higher than in Table 18 (e.g. seedlings planted with an age of 2 in 2033 will be harvested at an age of 142 after 140 years of rotation in 2173).

Name	Ini	HM	FM1	FM2	FM3	FM4	FM5	FM6	FM7	FM8	FMX	FMX	FMX	FMX	FMX	Remarks
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. ****= 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 brackest 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.

Variable (long name)	Variable name	Unit (NetCDF format)		Resolution	Comment
Essential outputs					
Mean DBH	**dbh-<species/total>**	cm	per species and stand total	annual	
Mean DBH of 100 highest trees	**dbhdomhei**	cm	stand total	annual	100 highest trees per hectare.
Stand Height	**hei-<species/total>**	m	per species and stand total	annual	For models including natural regeneration this variable may not make sense, please report dom_height
Dominant Height	**domhei**	m	stand total	annual	Mean height of the 100 highest trees per hectare.
Stand Density	**density-<species/total>**	ha-1	per species and stand total	annual	As trees per hectare
Basal Area	**ba-<species/total>**	m2 ha-1	per species and stand total	annual	
Volume of Dead Trees	**mort-<species/total>**	m3 ha-1	per species and stand total	annual	
Harvest by dbh-class	**harv-<species/total>-<dbhclass/total>**	m3 ha-1	per species and stand total and dbh-class	annual	

Remaining stem number after disturbance and management by dbh class	**stemno-<species/total>-<dbhclass/total>**	ha-1	per species and stand total	annual	As trees per hectare, dbhclass_name as specific in **Table 20**.
Stand Volume	**vol-<species/total>**	m3 ha-1	per species and stand total	annual	
Carbon Mass in Vegetation biomass	**cveg-<species/total>**	kg m-2	per species and stand total	annual	As kg carbon*m^{-2}
*Carbon Mass in aboveground vegetation biomass	**cvegag-<species/total>**	kg m-2	per species and stand total	annual	As kg carbon*m^{-2}
*Carbon Mass in belowground vegetation biomass	**cvegbg-<species/total>**	kg m-2	per species and stand total	annual	As kg carbon*m^{-2}
Carbon Mass in Litter Pool	**clitter-<species/total>**	kg m-2	per species and stand total	annual	As kg carbon*m^{-2}, Info for each individual pool.
Carbon Mass in Soil Pool	**csoil-<species/total>**	kg m-2	per species and stand total	annual	As kg carbon*m^{-2}, Info for each individual soil layer
Tree age by dbh class	**age-<species/total>-<dbhclass/total>**	yr	per species and stand total	annual	dbhclass_name as specified in **Table 20**.
Gross Primary Production	**gpp-<species/total>**	kg m-2 s-1	per species and stand total	daily	As kg carbon*m^{-2}*s^{-1}
Net Primary Production	**npp-<species/total>**	kg m-2 s-1	per species and stand total	daily	As kg carbon*m^{-2}*s^{-1}
Autotrophic (Plant) Respiration	**ra-<species/total>**	kg m-2 s-1	per species and stand total	daily	As kg carbon*m^{-2}*s^{-1}

Heterotrophic Respiration	**rh-< total>**	kg m-2 s-1	stand total	daily	As kg carbon*m^{-2}*s^{-1}
Net Ecosystem Exchange	**nee-<total>**	kg m-2 s-1	per stand	daily	As kg carbon*m^{-2}*s^{-1}
Mean Annual Increment	**mai-<species/total>**	m^3 ha-1	per species and stand total	annual	
Fraction of absorbed photosynthetically active radiation	**fapar-<species/total>**	%	per species and stand total	daily	Value between 0 and 100.
Leaf Area Index	**lai-<species/total>**	m2 m-2	per species and stand total	monthly	
Species composition	**species-<species>**	%	per ha	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	**evap**	kg m-2 s-1	stand total	daily	sum of transpiration, evaporation, interception and sublimation. (=intercept + esoil + trans)
Evaporation from Canopy (interception)	**intercept-<species/total>**	kg m-2 s-1	per species and stand total	daily	the canopy evaporation+ sublimation (if present in model).
Water Evaporation from Soil	**esoil**	kg m-2 s-1	per stand	daily	includes sublimation.
Transpiration	**trans-<species/total>**	kg m-2 s-1	per species and stand total	daily	

Soil Moisture	**soilmoist**	kg m-2	per stand	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	**mortstemno-<species/total>-<dbhclass/total>**	ha-1	per species and stand total	annual	As trees per hectare, dbhclass_name as specific in **Table 20**.
Removed stem numbers by size class by management	**harvstemno-<species/total>-<dbhclass/total>**	ha-1	per species and stand total	annual	As trees per hectare, dbhclass_name as specific in **Table 20**.
Volume of disturbance damage	**dist-<dist-name>**	m3 ha-1	per species and stand total	annual	dist_name as specific in **Table 20**.
Nitrogen of annual Litter	**nlit-<species/total>**	g m-2 a-1	per species and stand total	annual	As g Nitrogen m^{-2} a^{-1}
Nitrogen in Soil	**nsoil-<total>**	g m-2 a-1	stand total	annual	As g Nitrogen m^{-2} a^{-1}
Net Primary Production allocated to leaf biomass	**nppleaf-<species>**	kg m-2 s-1	per species and stand total	daily	As kg carbon*m^{-2}*s^{-1}
Net Primary Production allocated to fine root biomass	**npproot-<species>**	kg m-2 s-1	per species and stand total	daily	As kg carbon*m^{-2}*s^{-1}

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

*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

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.

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.

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.
rcp85	Future climate and CO_2 concentration from RCP8.5.
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**
IIa	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**		

IV-VII	Not simulated						
VIII	RCP8.5 climate & CO_2	Climate & CO_2	Experiment I	Experiment II	**rcp85**	not simulated	not simulated
	no other human influences	Human & LU			**nosoc**		
IX	Optional: RCP2.6 climate & CO_2 with **improved bias-correction and statistical downscaling** of climate variables (ewembi-improved)	Climate & CO_2	**picontrol**	**historical**	**rcp60**	not simulated	not simulated
	no other human influences	Human & LU	**1860soc**	**histsoc**	**nosoc**		

9.2 Output data

Table 24 Variables to be reported by permafrost models.

Variable name (long name)	Variable name	Unit (NetCDF format)		Resolution	Comment
Essential outputs					
Temperature of Soil	**tsl**	K	per gridcell	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	**cveg-<pft>**	kg m-2	per pft and gridcell total	annual	Gridcell total cveg is essential. Per PFT information is desirable.
Carbon Mass in aboveground vegetation biomass	**cvegag-<pft>**	kg m-2	per pft and gridcell total	annual	Gridcell total cvegag is essential. Per PFT information is desirable.
Carbon Mass in belowground vegetation biomass	**cvegbg-<pft>**	kg m-2	per pft and gridcell total	annual	Gridcell total cvegbg is essential. Per PFT information is desirable.
Carbon Mass in Litter Pool	**clitter**	kg m-2	per gridcell total	annual	Info for each individual pool.
Carbon Mass in Soil Pool	**csoil**	kg m-2	per gridcell total	annual	Info for each individual pool.
Fluxes (as Biomes output Table)					
Carbon Mass Flux out of atmosphere due to Gross Primary Production on Land	**gpp**	kg m-2 s-1	gridcell total	daily (monthly)	
Carbon Mass Flux out of atmosphere due to Gross Primary Production on Land	**gpp-<pft>**	kg m-2 s-1	per pft	annual	
Carbon Mass Flux into atmosphere due to Autotrophic (Plant) Respiration on Land	**ra**	kg m-2 s-1	gridcell total	daily (monthly)	
Carbon Mass Flux out of atmosphere due to	**npp**	kg m-2 s-1	gridcell total	daily (monthly)	

Net Primary Production on Land					
Carbon Mass Flux out of atmosphere due to Net Primary Production on Land	**npp-<pft>**	kg m-2 s-1	per pft	annual	
Carbon Mass Flux into atmosphere due to Heterotrophic Respiration on Land	**rh**	kg m-2 s-1	gridcell total	daily (monthly)	
Carbon Mass Flux into atmosphere due to total Carbon emissions from Fire	**fireint**	kg m-2 s-1	gridcell total	daily (monthly)	
Carbon Mass Flux out of Atmosphere due to Net biome Production on Land (NBP)	**ecoatmflux**	kg m-2 s-1	gridcell total	daily (monthly)	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	**lai-<pft>**	1	per pft	annual	
Leaf Area Index	**lai-<pft>**	1	gridcell average	daily (monthly)	
Plant Functional Type Grid Fraction	**pft-<pft>**	%	per gridcell	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	**qtot**	kg m-2 s-1	per gridcell	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	**soilmoist**	kg m-2	per grid cell	monthly	Please provide soil moisture for all depth layers (i.e. 3D-field), and indicate depth in m.
Frozen soil moisture for each layer	**soilmoistfroz**	kg m-2	per gridcell	monthly	Please provide frozen soil moisture for all depth levels and indicate depth in m.
Snow depth	**snd**	m	per gridcell	daily (monthly)	Grid cell mean depth of snowpack.
Snow water equivalent	**swe**	kg m-2	per gridcell	daily (monthly)	Total water mass of the snowpack (liquid or frozen), averaged over a grid cell.
Annual maximum thaw depth	**thawdepth**	m	per gridcell	annual	calculated from daily thaw depths
Other outputs					
Burnt Area Fraction	**burntarea**	%	per gridcell	daily (monthly)	fraction of entire grid cell that is covered by burnt vegetation
N_2O emissions into atmosphere	**n2o**	kg m-2 s-1	gridcell total	monthly	From land, not from industrial fossil fuel emissions and transport
CH4 emissions into atmosphere	**ch4**	kg m-2 s-1	gridcell total	monthly	From land, not from industrial fossil fuel emissions and transport

10 Agriculture (crop modelling)

10.1 Scenarios

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).

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 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.
rcp85	Future climate and CO_2 concentration from RCP8.5.
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. **If you can only run simulations with 2005soc, then it is sufficient 200 years worth of picontrol climate (1661-1860).

	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****	**2005soc****	**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		
IIa	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**	
VIII	RCP8.5 climate & CO_2	Climate & CO_2	Experiment I	Experiment II	**rcp85**	not simulated

	management fixed at 2005 levels	Human & LU			**2005soc**	
IX	Optional: RCP6.0 climate & CO_2 with **improved bias-correction and statistical downscaling** of climate variables (ewembi-improved)	Climate & CO_2	**picontrol**	**historical**	**rcp60**	not simulated
	management fixed at 2005 levels	Human & LU	**1860soc**	**histsoc**	**2005soc**	

10.2 Output data

Table 26 Variables to be reported by crop models

Variable (long name)	Variable name	Unit (NetCDF format)	Resolution	Comments
Key model outputs				
Crop yields	yield-<crop>-<irrigation setting>	dry matter (t ha-1 per growing season)	per growing season (0.5°x0.5°)	
Irrigation water withdrawal (assuming unlimited water supply)	pirrw-<crop>-<irrigation setting>	mm per growing season	per growing season (0.5°x0.5°)	*Irrigation water withdrawn in case of optimal irrigation (in addition to rainfall), assuming no losses in conveyance and application.*
Key diagnostic variables				
Actual evapotranspiration	aet-<crop>-<irrigation setting>	mm per growing season	per growing season (0.5°x0.5°)	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>	kg ha-1 per growing season	per growing season (0.5°x0.5°)	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>	Day of year	per growing season (0.5°x0.5°)	Julian dates
Actual planting year	plantyear-<crop>-<irrigation setting>	Year of planting	per growing season (0.5°x0.5°)	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>	Day of year of anthesis	per growing season (0.5°x0.5°)	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>	year of anthesis	per growing season (0.5°x0.5°)	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>	Day of year of maturity	per growing season (0.5°x0.5°)	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>	year of maturity	per growing season (0.5°x0.5°)	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>	Dry matter (t ha-1 per growing season)	per growing season (0.5°x0.5°)	
Soil carbon emissions	sco2-<crop>-<irrigation setting>	kg C ha-1	per growing season (0.5°x0.5°)	Ideally should be modeled with realistic land-use history and initial carbon pools. Subject to extra study.
Nitrous oxide emissions	sn2o-<crop>-<irrigation setting>	kg N2O-N ha-1	per growing season (0.5°x0.5°)	Ideally should be modeled with realistic land-use history and initial carbon pools. Subject to extra study.
Total N uptake (total growing season sum)	tnup-<crop>-<irrigation setting>	kg ha -1 yr -1	monthly (0.5°x0.5°)	Nitrogen balance: uptake

Total N inputs (total growing season sum)	tnin-<crop>-<irrigation setting>	kg ha -1 yr -1	monthly (0.5°x0.5°)	Nitrogen balance: inputs
Total N losses (total growing season sum)	tnloss-<crop>-<irrigation setting>	kg ha -1 yr -1	monthly (0.5°x0.5°)	Nitrogen balance: losses

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 Scenarios

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.
rcp85	Future climate from RCP8.5.
Human influence	
2005soc	Representation of fixed year 2005 society: • 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 • 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 • As ssp2soc but mortality and population data fixed at 2100 levels
ssp2soc-adapt	Varying society according to SSP2 – with adaptation • 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 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 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) 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 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**
VIa	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**	
VIII	RCP8.5 climate	Climate	Experiment I	Experiment II	**rcp85**	not simulated
	society fixed at 2005 levels, no adaptation	Human			**2005soc**	
IX	Optional: RCP6.0 climate with **improved bias-correction and statistical downscaling** of climate variables (ewembi-improved)	Climate	**picontrol**	**historical**	**rcp60**	not simulated

	society fixed at 2005 levels, no adaptation	Human	**1860soc**	**histsoc**	**2005soc**	

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.

Variable (long name)	Variable name	Unit (NetCDF format)	Spatial resolution	Temporal resolution	Comments
Number of deaths attributable to cold in age group x	**an-tot-cold-x**	Total number of deaths	Per city/region/grid cell	daily	Temperature below minimum mortality temperature (MMT)
Number of deaths attributable to heat in age group x	**an-tot-heat-x**	Total number of deaths	Per city/region/grid cell	daily	Temperature above MMT
Death rate attributable to cold in age group x	**an-rate-cold-x**	Deaths per 100 000 population	Per city/region/grid cell	daily	Temperature below MMT
Death rate attributable to heat in age group x	**an-rate-heat-x**	Deaths per 100 000 population	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.
rcp85	Future climate and CO_2 concentration from RCP8.5.
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 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 society & protection 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 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**	
VIII	RCP8.5 climate & CO_2	Climate & CO_2	Experiment I	Experiment II	**rcp85**	not simulated
	varying society & protection up to 2005, then fixed at 2005 levels thereafter	Human & LU			**2005soc**	
IX	Optional: RCP6.0 climate & CO_2 with **improved bias-correction and statistical downscaling** of climate variables (ewembi-improved)	Climate & CO_2	**picontrol**	**historical**	**rcp60**	not simulated
	society & protection fixed at 2005 levels	Human & LU	**1860soc**	**histsoc**	**2005soc**	

13.2 Output data

Table 30 Variables to be reported by coastal infrastructure models.

Variable (long name)	Variable name	Unit (NetCDF format)	Resolution	Comments
Expected number of people flooded annually	**par**	thousands/yr (1000 yr-1)	Time resolved grid	Par = People at risk.
Expected seaflood costs	**seafloodcost**	million dollars/yr (mio 2005US$ yr-1)		Expected annual damage caused by seafloods
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

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.

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.
rcp85	Future climate and CO_2 concentration from RCP8.5.
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.

<table>
<tr><th></th><th>Experiment</th><th>Input</th><th>Pre-industrial
1661-1860</th><th>Historical
1861-2005</th><th>Future
2006-2099</th><th>Extended future
2100-2299</th></tr>
<tr><td rowspan="2">I</td><td>no climate change, pre-industrial CO_2</td><td>Climate & CO_2</td><td>picontrol</td><td>picontrol</td><td>picontrol</td><td>picontrol</td></tr>
<tr><td>varying fishing up to 2005, then fixed at 2005 levels thereafter</td><td>Human & LU</td><td>nosoc</td><td>histsoc</td><td>2005soc</td><td>2005soc</td></tr>
<tr><td rowspan="2">II</td><td>RCP2.6 climate & CO_2</td><td>Climate & CO_2</td><td rowspan="2">Experiment I</td><td>historical</td><td>rcp26</td><td>rcp26</td></tr>
<tr><td>varying fishing up to 2005, then fixed at 2005 levels thereafter</td><td>Human & LU</td><td>histsoc</td><td>2005soc</td><td>2005soc</td></tr>
<tr><td rowspan="2">III</td><td>RCP6.0 climate & CO_2</td><td>Climate & CO_2</td><td rowspan="2">Experiment I</td><td rowspan="2">Experiment II</td><td>rcp60</td><td rowspan="2">not simulated</td></tr>
<tr><td>varying fishing up to 2005, then fixed at 2005 levels thereafter</td><td>Human & LU</td><td>2005soc</td></tr>
<tr><td>IV-VII</td><td colspan="6">not simulated</td></tr>
<tr><td rowspan="2">VIII</td><td>RCP8.5 climate & CO_2</td><td>Climate & CO_2</td><td rowspan="2">Experiment I</td><td rowspan="2">Experiment II</td><td>rcp85</td><td rowspan="2">not simulated</td></tr>
<tr><td>varying fishing up to 2005, then fixed at 2005 levels thereafter</td><td>Human & LU</td><td>2005soc</td></tr>
</table>

IX	<u>Optional</u>: RCP6.0 climate & CO_2 with **improved bias-correction and statistical downscaling** of climate variables (ewembi-improved)	Climate & CO_2	**picontrol**	**historical**	**rcp60**	not simulated
	fishing fixed at 2005 levels	Human & LU	**1860soc**	**histsoc**	**2005soc**	

14.1.1 Output data

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

Variable name (long name)	Variable name	Unit (NetCDF format)	Resolution	Comments
Essential outputs from global and regional models (provide as many as possible)				
TOTAL system biomass density	**tsb**	g C m-2	monthly	all primary producers and consumers
TOTAL consumer biomass density	**tcb**	g C m-2	monthly	all consumers (trophic level >1, vertebrates and invertebrates)
Biomass density of consumers >10cm	**b10cm**	g C m-2	monthly	if L infinity is >10 cm, include in >10 cm class
Biomass density of consumers >30cm	**b30cm**	g C m-2	Monthly	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**	g wet biomass / m2, g m-2	monthly	catch at sea (commercial landings plus discards, fish and invertebrates)
TOTAL Landings (all commercial functional groups / size classes) where fishing included	**tla**	g wet biomass /	monthly	commercial landings (catch without discards, fish and invertebrates)

in model		m2, g m-2		
Optional output from global and regional models				
Biomass density of commercial species where fishing included in model	**bcom**	g C m-2	monthly	Discarded species not included (Fish and invertebrates)
Biomass density (by functional group / size class) where fishing included in model	**b-<class>-<group>**	g C m-2	monthly	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>**	g wet biomass / m2,g m-2	monthly	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 terrestrial biodiversity simulations.

Different model types may be used to simulate terrestrial 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.

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 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.
rcp85	Future climate from RCP8.5.

Human influences scenarios	
nosoc	No human influences considered.

Table 33* ISIMIP2b scenarios for global (and potentially regional) terrestrial 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**	
IV-VII	not simulated					
VIII	RCP8.5 climate	Climate	Experiment I	Experiment II	**rcp85**	not simulated

	no other human influences	Human & LU			nosoc	
IX	Optional: RCP6.0 climate with **improved bias-correction and statistical downscaling** of climate variables (ewembi-improved)	Climate	**picontrol**	**historical**	**rcp60**	not simulated
	no other human influences	Human & LU	**1860soc**	**histsoc**	**nosoc**	

* For now, only correlative species distribution models are considered.

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

[2] Within 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.

15.2 Output data

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

Variable (long name)	Variable name	Unit (NetCDF format)	Resolution	Comments
Amphibian species probability of occurrence	**amphibianprob[2]**	Probability of occurrence per cell	30-year averages of selected time	Results from individual SDMs

Terrestrial bird species probability of occurrence	**birdprob[2]**		periods[1] (0.5°x0.5°)	assuming full dispersal[3]
Terrestrial mammal species probability of occurrence	**mammalprob[2]**			
Amphibian summed probability of occurrence	**amphibiansumprob[2]**	Summed probability of occurrence per cell[2]	30-year averages of selected time periods[1] (0.5°x0.5°)	Aggregated results from individual SDMs with different dispersal scenarios[4]
Terrestrial bird summed probability of occurrence	**birdsumprob[2]**			
Terrestrial mammal summed probability of occurrence	**mammalsumprob[2]**			
Summed probability of endemic amphibian species[5]	**endamphibiansumprob[2]**			
Summed probability of endemic terrestrial bird species[5]	**endbirdsumprob[2]**			
Summed probability of endemic terrestrial mammal species[5]	**endmammalsumprob[2]**			
Summed probability of threatened amphibian species[6]	**thramphibiansumprob[2]**			

Summed probability of threatened terrestrial bird species[6]	**thrbirdsumprob[2]**			
Summed probability of threatened terrestrial mammal species[6]	**thrmammalsumprob[2]**			

[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.

[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). 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.

[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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