5 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.

Reporting

All variables are to be reported as time-averages with the indicated resolution.

For depth-varying variables, data should be provided either as fully-resolved vertical profiles, or, if that is not possible, as a mean of the epilimnion or mixed layer ("mean epi"), and mean of the hypolimnion ("mean hypo"). 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):

$$\rho = 999.842594 + (6.793952 \text{ x } 10\text{-}2\ t) – (9.095290 \text{ x } 10\text{-}3\ t2) + (1.001685 \text{ x } 10\text{-}4\ t3) – (1.120083 \text{ x } 10\text{-}6\ t4) + (6.536336 \text{ x } 10\text{-}9\ t5),$$

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. Reverse stratification means that the surface is colder than the bottom, but the 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.

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 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).

Experiment		**Input**	**pre-industrial** **1661-1860**	**historical** **1861-2005**	**future** **2006-2099**	**extended future** **2100-2299**
I	no climate change, pre-industrial CO_2	Climate & CO_2	**picontrol**	**picontrol**	**picontrol**	**picontrol**
	varying LU and other human influences according to RCP2.6 + SSP2 up to 2100, then fixed at 2100 levels thereafter	Human & LU	Option 1: **1860soc**	Option 1: **histsoc**	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 and other human influences according to RCP2.6 + SSP2 up to 2100, then fixed at 2100 levels thereafter	Human & LU		Option 1: **histsoc**	**2005soc**	**2005soc**
				Option 2*: **2005soc**		
IIa	RCP2.6 climate, CO_2 after 2005 fixed at 2005 levels	Climate & CO_2	Experiment I	Experiment II	**rcp26, 2005co2**	**rcp26, 2005co2**
	LU & human influences fixed at 2005 levels after 2005	Human & LU			**2005soc**	**2005soc**
III	RCP6.0 climate & CO_2	Climate & CO_2	Experiment I	Experiment II	**rcp60**	not simulated
	varying LU & human influences up to 2005, then fixed at 2005 levels thereafter	Human & LU			**2005soc**	
IV	no climate change, pre-industrial CO_2	Climate & CO_2	Experiment I	Experiment I	**picontrol**	**picontrol**
	varying LU and other human influences according to RCP2.6 + SSP2 up to 2100, then fixed at 2100 levels thereafter	Human & LU			**rcp26soc**	**2100rcp26soc**
V	no climate change, pre-industrial CO_2	Climate & CO_2	Experiment I	Experiment I	**picontrol**	not simulated
	varying human influences & LU (RCP6.0)	Human & LU			**rcp60soc**	
VI	RCP2.6 climate & CO_2	Climate & CO_2	Experiment I	Experiment II	**rcp26**	**rcp26**
	varying human influences & LU up to 2100 (RCP2.6), then fixed at 2100 levels thereafter	Human & LU			**rcp26soc**	**2100rcp26soc**

VII	RCP6.0 climate & CO_2	Climate & CO_2	Experiment I	Experiment II	**rcp60**	not simulated
	varying human influences & LU (RCP6.0)	Human & LU			**rcp60soc**	
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**	

5.1.1 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						
Thermal stratification	**strat**	*unitless*	Representative lake associated with grid cell	Daily	None	1 if lake grid cell is thermally stratified 0 if lake grid cell is not thermally stratified
Depth of Thermocline	**thermodepth**	m	Representative lake associated with grid cell	Daily	None	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)	None	Average of the upper layer in case not simulated directly.
Bottom temperature	**bottemp**	K	Representative lake associated with grid cell	Daily (monthly)	None	Average of the lowest layer in case not simulated directly.
Lake ice cover	**ice**	*unitless*	Representative lake associated with grid cell	Daily	None	1 if ice cover is present in lake grid cell 0 if no ice cover is present in lake grid cell
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)	None	
Snow thickness	**snowthick**	m	Representative lake associated with grid cell	Daily (monthly)	None	
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**	kg m-1 s-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)	Either full profile, or mean epi and mean hypo	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)	Either full profile, or mean epi and mean hypo	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)	Either full profile, or mean epi and mean hypo	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)	Either full profile, or mean epi and mean hypo	Total simulated Zooplankton biomass
Total Phosphorus	**tp**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and mean hypo	
Particulate Phosphorus	**pp**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and mean hypo	
Total Dissolved Phosphorus	**tpd**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and mean hypo	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)	Either full profile, or mean epi and mean hypo	
Particulate Nitrogen	**pn**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and mean hypo	
Total Dissolved Nitrogen	**tdn**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and mean hypo	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)	Either full profile, or mean epi and mean hypo	
Dissolved Organic Carbon	**doc**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and mean hypo	Not always available
Dissolved Silica	**si**	mole m-3	Representative lake associated with grid cell	Daily (monthly)	Either full profile, or mean epi and mean hypo	Not always available