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A framework for ensemble modelling of climate change impacts on lakes worldwide: the ISIMIP Lake Sector

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Supplementary Information

S1. Supplementary tables

Table S1. Summary of lake characteristics of 62 lakes participating in the local spatial domains of ISIMIP2a simulation runs. For site type, "L" refers to lakes and "R" refers to reservoirs.

Site Name	Country	Site type	Coordinates (lat; lon)	Climatic Zone	Surface area	Mean/Max Depth	Water transparency	Data time span	Sampling frequency / tempora aggregation
[--]	[--]	[--]	[decimal degrees]	[--]	km2	[m]	Average Seechi depth [m]; Diffuse attenuation coefficient [1/m]	[year]	[--]
Allequash	US	L	46.04, -89.62	Dfb	1.64	2.90, 8.00	3.2; NA	1981-2014	monthly / daily
Alqueva [(a)]	PT	R	38.20, -7.49	Csa	250	16.60, 92.00	2.9; 0.69	2017-2018	sub-daily / hourly
Annecy	FR	L	45.87, 6.17	Cfb	27	41.00, 65.00	5.2; NA	2001-2015	monthly / daily
Annie	US	L	27.21, -81.35	Csc	0.36	4.30, 68.00	NA; NA	2008-2018	sub-daily / 15-min
Argyle	AU	R	-16.31, 128.68	Bsh	980	10.10, 51.00	NA; 0.89	2011-2012	sub-daily / 15-min
Biel	CH	L	47.08, 7.16	Cfb	39.3	30.00, 74.00	NA; 0.51	1973-2015	monthly / daily
Big Muskellunge	US	L	46.02, -89.612	Dfb	3.63	7.50, 21.30	6.6; NA	1981-2014	monthly / daily
Black Oak	US	L	46.16, -89.32	Dfb	2.28	10.36, 25.91	32.1; NA	2004-2015	monthly / daily
Bourget	FR	L	45.76, 5.86	Cfb	44	80.00, 145.00	NA; NA	2010-2014	Sub-monthly/ daily
Burley Griffin	AU	R	-35.30, 149.07	Cfb	6.64	5.00, 17.00	1.4; NA	1981-2011	monthly / daily
Crystal	US	L	46.003, -89.61	Dfb	0.38	10.40, 20.40	7.5; NA	1981-2014	monthly / daily
Crystal Bog	US	L	46.008, -89.61	Dfb	0.01	1.70, 2.50	1.5; NA	1981-2014	monthly / daily
Delavan	US	L	42.61, -88.60	Dfa	6.96	7.61, 16.46	3.5; NA	1997-2018	monthly / daily
Dickie	CA	L	45.15, -79.09	Dfb	0.94	5.00, 12.00	3.1; NA	2004-2014	monthly / daily
Eagle	CA	L	44.68, -76.70	Dfb	6.65	10.10, 31.10	4.6; NA	2011-2013	daily / daily
Ekoln	SE	L	59.75, 17.62	Cfb	20.18	11.50, 50.00	NA; 1.09	1998-2005	daily / 30-min;
Erken	SE	L	59.84, 18.63	Cfb	24	9.00, 21.00	3.8; NA	1961-2017 (daily); 1989-2016 (sub-daily)	monthly / daily; daily / 30-min
Esthwaite Water	UK	L	54.37, -2.99	Cfb	0.96	6.90, 16.00	NA, 0.82	2008-2010	sub-daily / hourly

Falling Creek [a]	US	R	37.31, -79.84	Csc	119	4.00, 9.30	NA; 0.87	2013-2015	weekly / hourly
Feeagh	IE	L	53.94, -9.58	Cfa	3.9	14.50, 44.00	1.7; 0.98	2004-2016	daily / hourly
Fish [a]	US	L	43.29, -89.65	Dfb	0.8	6.60, 18.90	2.4; NA	1996-2014	monthly / daily
Geneva	FR/CH	L	46.45, 6.59	Cfa	580.1	152.70, 309.70	6.0; NA	2010-2015	monthly / daily
Great Pond	US	L	44.53, -69.89	Dfb	32.55	6.40, 21.00	6.7; NA	2014-2016	daily / hourly
Green	US	L	43.81, -89.00	Dfb	29.48	33.55, 72.00	4.8; NA	2004-2018	sub-monthly / daily
Harp	CA	L	45.38, -79.13	Dfb	0.71	13.32, 37.50	4.08; NA	2004-2014 (daily); 2013-2014 (sub-daily)	sub-monthly / daily; sub-daily hourly
Kilpisjarvi	FI	L	69.03, 20.77	Dfc	37.3	20.00, 57.00	NA; 0.3	2014-2017	daily / daily
Kinneret	IL	L	32.83, 35.583	Bsh	168	24.00, 45.00	2.95; 0.51	2011-2015	daily / daily
Kivu	RW/CD	L	-1.73, 29.24	Aw	2700	240.00, 485.00	5.21; 0.27	2002-2014	monthly /daily
Kuivajarvi	FI	L	61.85, 24.28	Dfc	0.62	6.30, 13.20	NA; 0.6	2013-2017	sub-daily / hourly
Langtjern	NO	L	60.37, 9.73	Dfc	0.23	2.00, 12.00	1.4; 2.25	2010-2014	daily / daily
Laramie [a]	US	L	40.62, -105.84	Dfc	0.14	NA, 6.40	0.6; NA	2015-2017	monthly / daily
Lower Lake Zurich	CH	L	47.28, 8.58	Cfb	67	49.00, 136.00	NA; 0.39	1902-2013	monthly / daily
Mendota	US	L	43.10, -89.41	Dfb	39.61	12.80, 25.30	3; NA	1996-2014	monthly / daily
Monona	US	L	43.06, -89.36	Dfb	13.6	8.20, 22.50	2.4; NA	1996-2014	monthly / daily
Mozhaysk [a]	RU	R	55.59, 35.82	Dfb	30.7	7.00, 23.00	1; NA	2016 (daily); 2015-2016 (sub-daily)	daily / daily; sub-daily / hourly;
Mt Bold [a]	AU	R	-35.12, 138.71	Csb	3.08	13.00, 45.40	1.24; 1.16	2006-2015	daily / hourly
Muggelsee	DE	L	52.43, 13.65	Cfb	7.4	4.90, 7.70	2; 1.48	2008-2018	daily / hourly
Neuchatel	CH	L	46.91, 6.89	Cfb	217	64.00, 152.00	NA; 0.25	1963-2013	monthly / daily
Ngoring	CN	L	34.90, 97.7	ET	611	17.60, 30.70	NA; 0.3	2015-2016	daily / daily
Nohipalo Mustjarv	EE	L	57.93, 27.34	Dfb	0.22	3.90, 8.90	0.46; NA	2015-2017	sub-daily / 10-min
Nohipalo Valgejarv	EE	L	57.94, 27.35	Dfb	0.07	6.20, 12.50	4.52; NA	2015-2017	sub-daily / 10-min
Okauchee	US	L	43.13, -88.43	Dfa	4.9	7.62, 28.65	6.94; NA	1988-2014	monthly / daily
Paajarvi	FI	L	61.07, 25.13	Dfb	13.44	15.00, 85.00	2.2; 1.15	2012-2016	monthly / daily
Rappbode	DE	R	51.74, 10.89	Cfb	3.95	28.60, 89.00	4.8; 0.25	2015-2017	sub-monthly / hourly
Rimov [a]	CZ	R	48.85, 14.49	Cfb	2.11	16.00, 44.00	2.9; NA	2007-2012	sub-daily / hourly
Rotorua	NZ	L	-38.08, 176.28	Cfb	425	10.80, 52.90	2.63; 0.61	1999-2016	monthly / daily
Sammamish	US	L	47.59, -122.10	Csb	19.8	17.70, 32.00	5; NA	1993-2017	sub-monthly / hourly
Sau	ES	R	41.97, 2.39	Cfa	5.8	29.00, 65.00	2.57; 0.84	1963-2017	monthly / daily
Sparkling	US	L	46.01, -89.70	Dfb	0.64	10.90, 20.00	6.2; NA	1981-2014	monthly /daily
Stechlin	DE	L	53.17, 13.03	Cfb	2.23	23.20, 69.50	8.6; 0.29	1996-2017	monthly / daily
Sunapee	US	L	43.39, -72.05	Dfb	16.55	11.40, 34.00	8.5; NA	1986-2013 (daily);	daily / daily; sub-daily / hourly

								2007-2013 (sub-daily)	
Tahoe	US	R	39.09, -120.03	Csb	490	304.80, 501.00	19.9; NA	2012-2018	monthly / daily
Tarawera	NZ	L	-38.21, 176.43	Cfb	41.3	50.00, 87.50	8.3; 0.18	1996-2016	monthly / daily
Toolik	US	L	68.63, -149.60	Dfc	1.49	7.00, 26.00	4.6; NA	1983-2014	sub-monthly / daily
Trout	US	L	46.03, -89.67	Dfb	15.65	14.60, 35.70	4.7; NA	1981-2014	monthly /daily
Trout Bog	US	L	46.04, -89.69	Dfb	0.011	5.60, 7.90	1.1; NA	1981-2014	monthly /daily
Two Sisters	US	L	45.77, -89.53	Dfb	2.91	9.14, 19.20	17.8; NA	1999-2015	monthly /daily
Vendyurskoe	RU	L	62.10, 33.10	Dfc	10.4	5.30, 13.40	3.5; 1.5	2007-2015	daily / daily
Vortsjarv [(a)]	EE	L	58.31, 26.01	Dfb	270	2.80, 6.00	0.9; 2.76	2013-2018	sub-daily / 10-min
Washington	US	L	47.64, -122.27	Csb	87.6	33.00, 65.20	5.3; NA	1993-2017	sub-daily / 30-min
Windermere	UK	L	54.31, -2.95	Cfb	14.76	21.30, 64.00	NA; 0.46	2008-2010	sub-daily / hourly
Wingra	US	L	43.05, -89.46	Dfb	1.36	2.70, 6.70	0.7; NA	1996-2014	monthly / daily

[(a)] Waterbodies experiencing significant water level fluctuations

Table S2 Simulation information for models used in the local domain

Model Information								
	Model name	FLake[1]	ALBM[2]	air2water[3]	MyLake[4]	Simstrat[5]	GLM[6]	GOTM[7]
	Model version	1.0	2.0	2.0.0 parm.	1.12	2.1.2	3.0.0	5.3
	Temporal Resolution Input Data	3-hourly	daily	daily	daily	daily	daily	daily
Calibration								
	Was The Model Calibrated	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Forcing data for Calibration?	EWEMBI	EWEMBI	EWEMBI	EWEMBI	EWEMBI	EWEMBI	EWEMBI
	Calibration performance metrics	rmse, centred rmse, bias	rmse, r2 and correlation	rmse, nse	TSS, rmse, r2, rsr	rmse	Pearson_r, MAE, RMSE, NSE	Pearson_r, RMSE, NSE
Spin Up								
	Was a scenario spin-up used?	Yes	Yes	Yes	Yes	No	Yes	Yes
	Spin-Up Design	First year of each simulation period	For the majority lakes, a 2-year spin-up was used. For some deep lakes 10 years or more.	First year of each simulation period was run starting from LSWT at 4°C.	First two years of each simulation period	Only when calibration data started less than 1 yr after EWEMBI forcing	Only when calibration data started less than 1 yr after EWEMBI forcing	
Initialization method								
		uniform 4°C or minimum monthly air temp, whichever is greatest	uniform 4°C. or uniform mean temp at the start of the spin-up.	4°C on January 1st	4°C on January 1st	Initial measured temperature profile	Initial measured temperature profile	Initial me temperature p
Output resolution								
	Temporal Resolution	Daily	Daily	Daily	Daily	Daily	Daily	Daily
	Vertical Structure	Parametrized temperature profile	multi-layer variable	single, time-varying surface layer	multi-layer variable	multi-layer	multi-layer variable	multi-layer fix
	Runtime Layer Thickness	Time varying	Irregular	Time varying depending on an empirical law	0.5 m	0.5m(<50m) 1m(>50m)	0.5 m	0.5 m
	Number of Layers reported	20	50	surface only	0.5-Max Depth	0.5-Max Depth	0.5-Max Depth	0.5-Max Dept

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Contact responsible for simulations: Tadhg Moore (tadhgm@vt.edu)

Table S3 Simulation information for models used in the global domain

Model Information							
Impact model name:	VIC-LAKE[1]	ALBM[2]	LAKE[3]	FLake[4]	Simstrat-UoG[5]	GOTM[6]	CLM4.5[7]
Model version	1.0	2.0	2.0	1.0	1.4 modified	5.3	4.5
Spin-Up							
Was A Spin-Up Performed?	Yes	Yes	Yes	Yes	Yes	No	No
Spin-Up Design	Historical 10 years of spin-up from the piControl. Future simulations started from historical simulations no spin-up needed	A 2-Year spin-up was conducted. Forcing data from 2006 used for future runs and 1979 used for historical runs.	30 years of spinup using 1661-1670 picontrol data	2-year spin-up to 'set' initial conditions (first two years of met data used)	30-year spin-up (year 1661 repeated 30 times) were used with the picontrol simulations. Historical simulations started from the picontrol	1-year spin-up using the first year of each simulation	Initialized from spu picontrol simulation
Initialization method							
	lake temperature based on mean soil temperature	uniform 4°C. or uniform mean temp at the start of the spin-up.	linear profile 4°C at bottom to surface temp equal to air temp.	uniform 4°C.	uniform 10°C.		
Input Resolution							
Spatial Aggregation:	regular grid	regular grid	regular grid	regular grid	regular grid	regular grid	regular grid
Spatial Resolution	0.5 degree	0.5 degree	0.5 degree	0.5 degree	0.5 degree	0.5 degree	0.5 degree
Temporal Resolution Input Data	6-hourly	daily	daily	daily	3-hourly	daily	daily
Output resolution							
Temporal Resolution	daily	daily	daily	daily	daily	daily	daily
Vertical Structure	multi-layer	multi-layer	multi-layer	surface only	multi-layer	multi-layer	multi-layer
Layer Thickness	irregular	grid variable	irregular		irregular	irregular	variable
Number of Layers	1000	50	20		13	10	10

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Table S4. List of output variables from lake models to be reported in the Lake Sector of ISIMIP2a/b. See simulation protocol (https://www.isimip.org/protocol) for more details and an up-to-date list.

Variable Abbreviation [unit]	Variable full name [text]
Albedo [0-1]	Surface albedo
Bottemp [K]	Bottom temperature (i.e., Integrated over hypolimnion)
Extcoeff [m^{-1}]	Diffuse attenuation coefficient
Ice [0-1]	Lake ice cover
Icetemp [K]	Temperature at the ice upper surface
Icethick [m]	Ice thickness
Lakeheatf [W m^{-2}]	Downward heat flux at the lake atmosphere interface (i.e., net heat flux)
Lakeicefrac [0-1]	Lake layer ice mass fraction
Latentheatf [W m^{-2}]	Latent heat flux at the lake-atmosphere interface
Lwup [W m^{-2}]	Upward longwave radiation flux at the lake-atmosphere interface
Momf [kg m^{-1} s^{-2}]	Momentum flux at the lake-atmosphere interface
Sedheatf [W m^{-2}]	Sediment upward heat flux at the lake sediment interface
Sensheatf [W m^{-2}]	Sensible heat flux at the lake-atmosphere interface
Snowtemp [K]	Temperature at the snow upper surface
Snowthick [m]	Snow thickness
Strat [0-1]	Thermal stratification
Surftemp [K]	Surface temperature (i.e., Integrated over epilimnion)
Swup [W m^{-2}]	Upward shortwave radiation flux at the lake-atmosphere interface
Thermodepth [m]	Depth of thermocline
Turbdiffheat [m^2 s^{-1}]	Turbulent diffusivity of heat
Watertemp [K]	Water temperature (i.e., full profile)

Figure S1. Global mean annual surface temperature of lakes by end of the 21st century (2070-2099) under three greenhouse gas emission scenarios (RCP2.6, RCP6.0, RCP8.5) simulated with GOTM global (**Panels A, C, E**); End-of-century temperature anomaly (2070-2099) under three greenhouse gas emission scenarios (RCP2.6, RCP6.0, RCP8.5) compared to pre-industrial control levels (**Panels B, D, F**).