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Supporting Information for

Rapid and highly variable warming of lake surface waters around the globe

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Introduction

The supporting information presented here provides details associated with the dataset and more comprehensive details that complement the analyses presented in the text, allowing a more complete assessment of our findings. This includes information about the suite of lakes extracted from the *Sharma et al.* [2015] database, both locations and a summary of geomorphic characteristics. We provide summary results from the multiple regression and the regression tree analysis, as well as the trends from each lake. All papers cited in this Supporting Information document are listed at the end in the references.

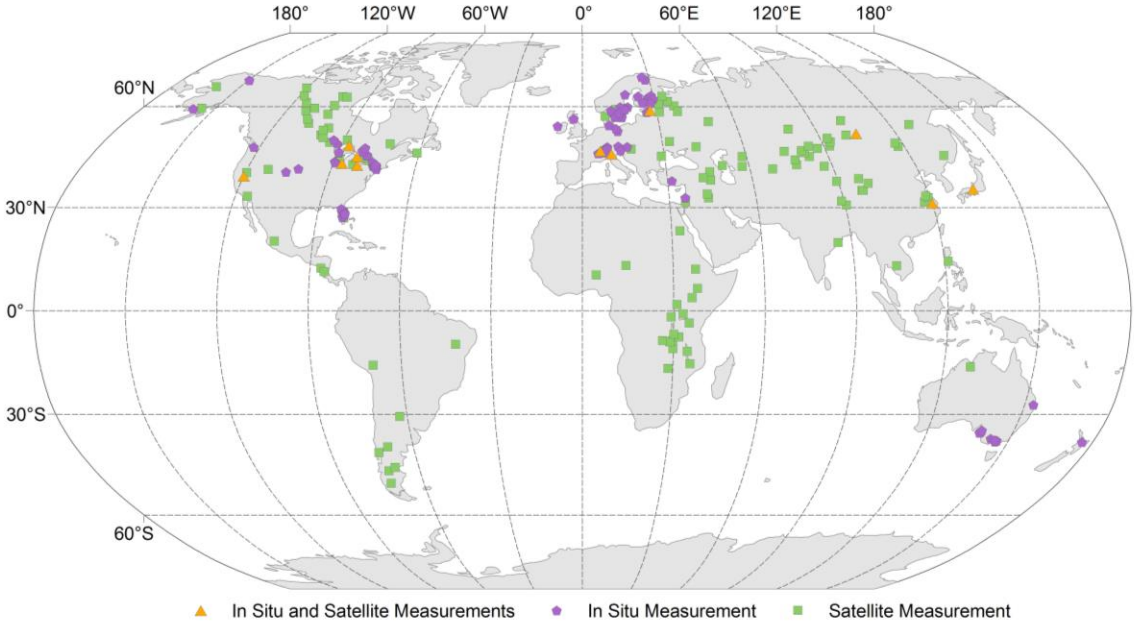

Figure S1. Lake locations. Map of lakes sampled using in situ and satellite measurements that were used in this study. For eleven lakes, we had both in situ and satellite data.

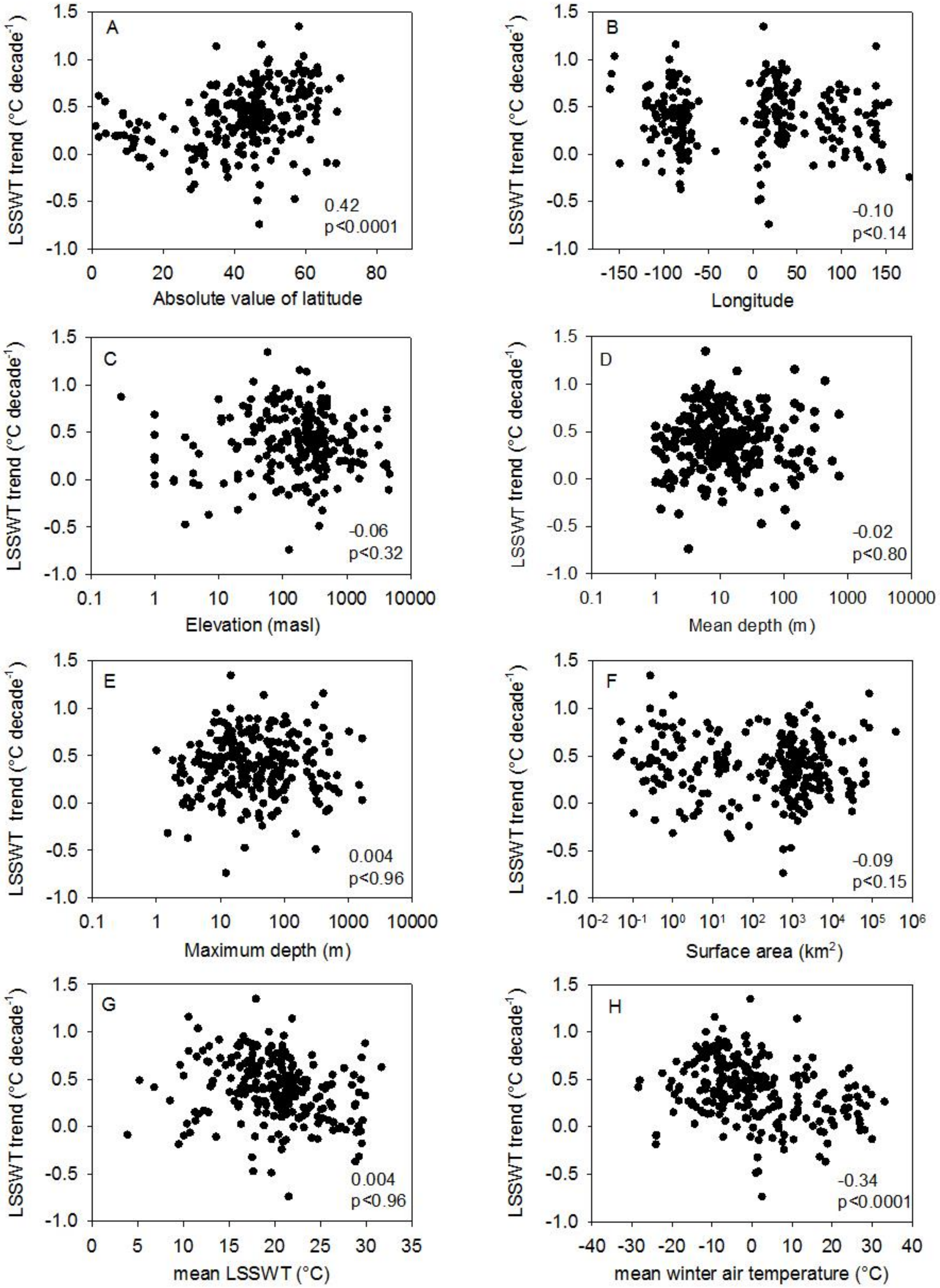

Figure S2. Lake summer surface water temperature trends (LSSWT) relative to geomorphic factors and basic conditions. a-b, location, **c-f**, morphometric characteristics, **g**, mean lake summer surface water temperature, and **h**, mean winter air temperature. Spearman correlation coefficients and significance values are shown in the lower right of each graph. Even when significant, the correlations were only weak (<0.2) to moderate (<0.4).

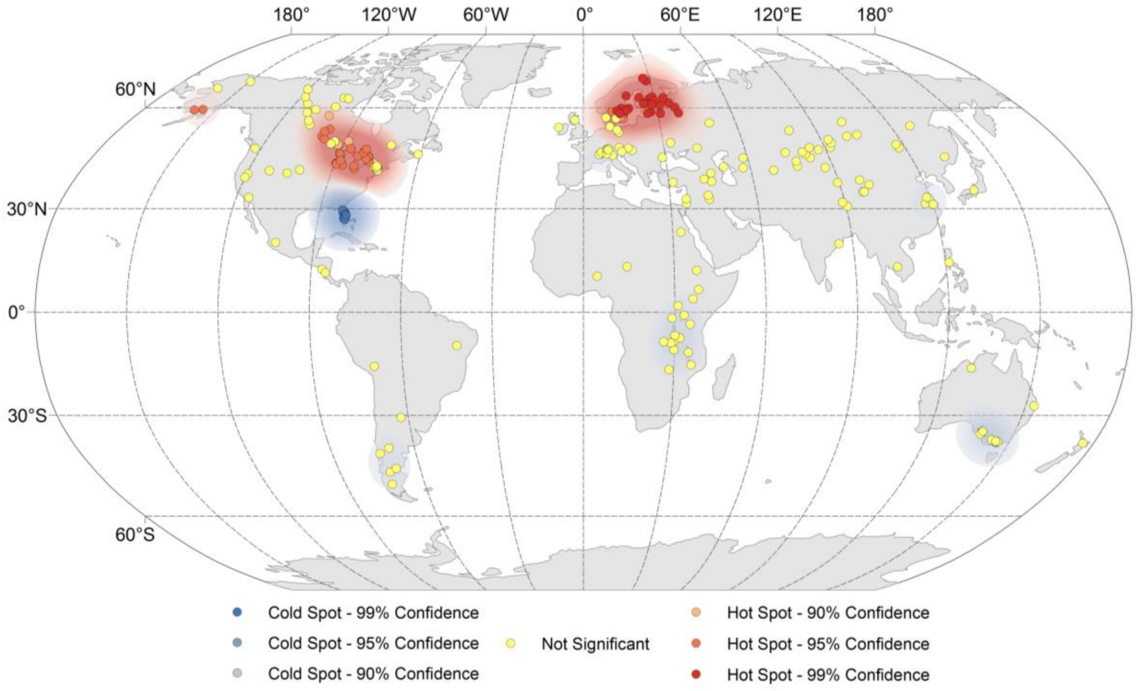

Figure S3. Proximal similarity map of lake summer surface water temperature trends. Proximal similarity (also called ‘hotspot’ analysis) was determined using Getis-Ord Gi* z-scores for all lakes. The map shows the significance of the z-score for each lake. The color gradient overlay is a kernel density map based on standard deviations of the Getis-Ord Gi* z-score for each lake. The darker the gradient color, the higher the densities of statistically significant clusters of warming or cooling lakes; the color lightens as the densities of such clusters decrease.

Dark red regions indicate areas with clusters of lakes that shared SSWT trends significantly higher than the global trend. The dark red Northern European cluster has many lakes with Getis-Ord Gi* z-scores significant at the 99% confidence interval and a handful significant at a 95% confidence interval. The Eastern North America dark red cluster contains several lakes with Getis-Ord Gi* z-scores significant at the 95% confidence level and a number of others at the 90% level.

Dark blue regions indicate areas with clusters of lakes that shared SSWT trends significantly lower than the global trend. Nearly all of the lakes in Southeastern North America had Getis-Ord Gi* z-scores significant at the 99% level, whereas the Southern Europe only had a handful of lakes with Getis-Ord Gi* z-scores that were statistically significant (at the 90% confidence interval), thus a fainter blue shading in the color gradient map overlay there. A slight blue shade is observable in East Africa and southern Australia indicating regional LSSWT trend values are lower than the global trend. Although the Getis-Ord Gi* z-scores were not statistically significant and the data are sparse in these regions, there is enough similarity in lakes within the 1300 km search distance to indicate the possibility of a regional trend in LSSWTs.

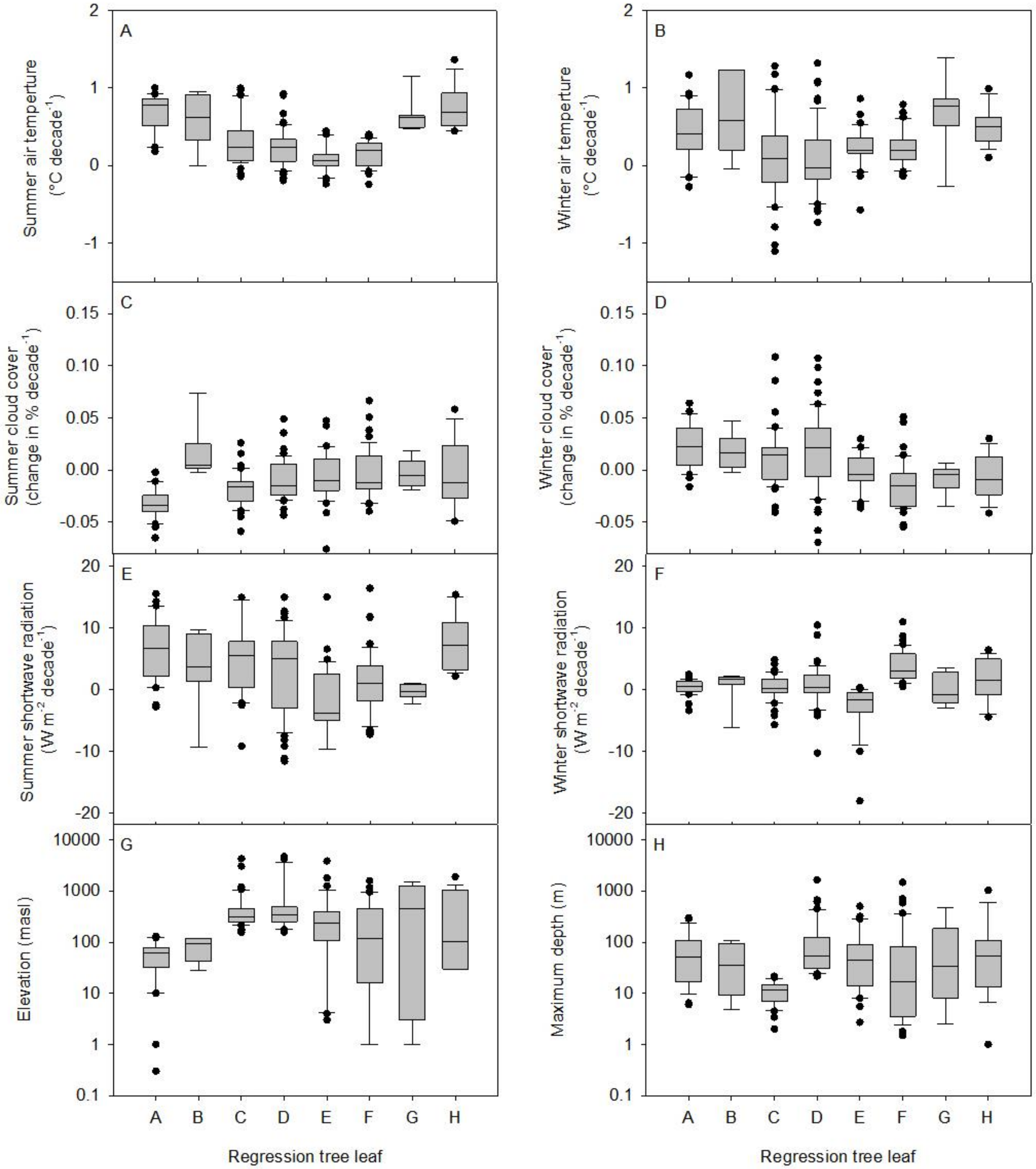

Figure S4. Box and Whiskers plots for summer and winter for characteristics identified using regression tree analysis. a-b, air temperature trends, **c-d**, cloud cover trends, **e-f**, shortwave radiation trends, **g**, elevation and **h**, maximum depth for each of the regression tree leaves. The fastest warming lake trends were found for leaves A-D and H.

			Elevation (m)			Mean Depth (m)			Max Depth (m)			Surface Area (km^2)			Volume (km^3)		
Region		n	Md	Min	Max	Md	Min	Max	Md	Min	Max	Md	Min	Max	Md	Min	Max
Africa	S	19	773	96	1786	9	1	572	15	1	1471	3035	573	67075	30	0.9	18880
Asia	I	3	69	2	450	41	1.9	730	104	2.6	1637	2399	659	31925	28	4	23000
Asia	S	35	450	1	4704	9	1	730	15	2.4	1637	1363	534	31925	24	0.9	23000
ENA	I	42	330	109	495	10	2.8	148	23	5.8	406	0.8	0.05	81936	0.006	0.0002	12221
ENA	S	16	200	35	326	15	3.4	148	64	7	406	4634	526	81936	32	3.4	12221
Europe	I	40	100	0	481	10	1.2	176	43	1.8	370	23	0.04	4400	0.5	0.0001	89
Europe	S	17	56	1	372	8	3.3	153	38	2.5	350	1890	368	17539	49	1.9	837
Middle East	I	1	-209	-209	-209	26	26	26	43	43	43	170	170	170	4	4	4
Middle East	S	10	45	-404	1876	40	5	182	67	9	1025	1965	660	378119	59	0.003	78200
Oceania	I	16	228	40	396	13	4.6	42	41	8.4	81	3	0.6	80	0.03	0.0045	0.9
Oceania	S	2	46	40	79	7	2.8	11	35	7.3	63	932	884	980	7	3.2	11
SENA	I	10	13	12	34	2	1.2	6	3	1.5	21	23	0.4	186	0.06	0.001	0.5
SENA	S	1	4	4	4	3	2.7	3	5	4.5	4.5	1437	1437	1437	5	5.2	5.2
S. America	S	10	238	31	3827	18	2	182	86	5.5	586	1625	812	8779	20	1.6	893
WNA	I	6	858	5	3048	24	1.5	305	54	4.7	501	85	0.05	495	2.5	0.00006	151
WNA	S	18	262	-74	1897	15	1.2	442	65	2	614	1330	448	30530	23	13	2236

Table S1. Summary of geomorphic characteristics of the lakes by region. Median (Md), minimum (Min) and maximum values (Max). I = in situ, S = satellite, ENA = Eastern North America, SENA = Southeastern North America, WNA = Western North America.

Lake name	Latitude	Longitude	Dataset (S=satellite, I=in situ)	# of years	P value	Lake SSWT trend (°C decade^{-1})
Abaya	6.48	37.90	S	15	>0.1	0.19
Ai pi/Ebiner	44.86	83.02	S	19	0.01	0.62
Alakol	46.00	81.79	S	25	0.01	0.46
Albert	1.81	31.11	S	15	0.01	0.62
Aleknagik	59.35	-158.83	I	21	0.03	0.85
Allequash	46.04	-89.63	I	25	0.003	0.85
Allgjuttern	57.95	16.10	I	21	>0.1	0.22
Annecy	45.86	6.17	I	14	>0.1	-0.14
Annie	27.21	-81.35	I	15	>0.1	-0.18
Apopka	28.62	-81.62	I	23	>0.1	0.05
Aral Sea	44.80	58.44	S	24	>0.1	0.22
Argentina	-50.24	-72.36	S	14	>0.1	-0.07
Argyle	-16.29	128.83	S	18	>0.1	-0.13
Ashokan-East	41.98	-74.15	I	24	>0.1	0.36
Ashokan-West	41.97	-74.26	I	24	>0.1	0.40
Athabasca	59.47	-109.39	S	21	>0.1	0.42
Ayakkum	37.55	89.46	S	16	>0.1	0.17
Bahral Milh/Razazzza	32.74	43.54	S	24	0.01	0.50
Baikal-South	51.65	104.72	I	25	>0.1	0.03
Baikal-South	51.65	104.72	S	22	>0.1	0.68
Balaton	46.98	18.07	S	15	0.07	-0.74
Balkhash	46.31	74.51	S	24	0.04	0.35
Bangweulu	-11.00	29.90	S	24	0.06	0.17
Barossa Reservoir	-34.65	138.84	I	24	0.003	0.54
Bay	14.42	121.14	S	21	>0.1	-0.04
Beauclair	28.77	-81.66	I	20	>0.1	0.33
Beloye	60.18	37.65	S	22	0.01	0.88
Beysehir	37.70	31.57	S	20	>0.1	0.10
Big Muskellunge	46.02	-89.61	I	25	0.01	0.73
Biwa	35.33	136.17	I	25	0.07	0.43
Biwa	35.33	136.17	S	15	>0.1	0.18
Blue Chalk	45.20	-78.94	I	23	>0.1	0.38
Blue Cypress	27.73	-80.75	I	13	>0.1	-0.37
BoengTonleChhma/ Tonle Sap	13.04	103.92	S	22	>0.1	-0.03
Bosten	41.99	86.98	S	21	0.003	0.57
Bourget	45.73	5.87	I	22	0.01	0.42
Bras D´Or	45.84	-60.80	S	15	0.04	0.56

Lake name	Latitude	Longitude	Dataset (S=satellite, I=in situ)	# of years	P value	Lake SSWT trend (°C decade^{-1})
Bratskoye	55.63	102.00	S	16	>0.1	0.58
Brunnsjön	56.60	15.73	I	22	>0.1	-0.11
Buenos Aires	-46.50	-71.45	S	21	>0.1	0.15
BuhayratAthTharthar	33.89	43.31	S	25	0.01	0.54
Buyr/Bei´er	47.82	117.71	S	24	0.01	0.66
Cannonsville	42.06	-75.37	I	19	>0.1	0.42
Cardinia	-37.96	145.41	I	15	>0.1	0.51
Caspian Sea	42.20	50.49	S	25	0.02	0.75
Chad	13.13	14.45	S	19	>0.1	0.34
Chao	31.51	117.57	S	23	>0.1	0.04
Chapala	20.24	-102.90	S	18	>0.1	0.01
Chardarinskoye/ Shardara	41.14	68.20	S	13	>0.1	-0.12
Chilka	19.77	85.40	S	20	0.03	0.39
Chilwa	-15.36	35.73	S	25	0.0001	0.31
Chiquita	-30.65	-62.49	S	24	>0.1	0.09
Chishi/Cheshi	-8.66	29.73	S	24	0.01	0.41
Chocon	-39.52	-69.07	S	18	>0.1	0.22
Chub	48.74	-91.92	I	23	>0.1	0.26
Claire	58.60	-112.08	S	22	>0.1	0.27
Clearwater	46.37	-81.05	I	23	0.10	0.33
Colhue Huapi	-45.54	-68.73	S	13	>0.1	0.51
Constance (Upper)	47.65	9.30	I	25	0.0001	0.53
Crosson	45.08	-79.03	I	23	>0.1	0.19
Crystal	46.00	-89.61	I	25	0.02	0.59
Dauphin	51.19	-99.71	S	19	0.04	0.61
Dead Sea	31.46	35.48	S	25	0.0001	0.63
Denham	28.77	-81.91	I	16	>0.1	-0.32
Dickie	45.15	-79.09	I	24	0.05	0.48
Dore	54.77	-107.29	S	21	>0.1	0.38
Dubawnt	63.17	-101.47	S	16	>0.1	0.49
Erie	41.68	-82.40	I	23	>0.1	0.08
Erie	42.25	-81.15	S	24	>0.1	0.09
Erken	59.84	18.59	I	14	0.07	0.61
Eyasi	-3.59	35.13	S	20	0.08	0.56
Feeagh	53.92	-9.57	I	25	>0.1	0.35
Fiolen	57.09	14.53	I	20	>0.1	0.58
Fish	43.29	-89.65	I	13	>0.1	0.49
Fracksjön	58.15	12.18	I	22	0.0001	1.35
Gaoyou	32.84	119.35	S	21	>0.1	0.21

Lake name	Latitude	Longitude	Dataset (S=satellite, I=in situ)	# of years	P value	Lake SSWT trend (°C $decade^{-1}$)
Garda	45.54	10.64	I	19	>0.1	0.15
Garda	45.54	10.64	S	16	>0.1	-0.01
Geneva	46.46	6.59	I	24	>0.1	0.11
Geneva	46.46	6.59	S	13	>0.1	-0.49
George	29.28	-81.58	I	15	>0.1	0.24
Great Bear	66.00	-120.32	S	22	>0.1	-0.09
Great Salt Lake	41.02	-112.43	S	21	0.01	0.49
Great Slave	61.36	-114.79	S	24	>0.1	0.15
Gyaring/ Zhaling	34.92	97.29	S	16	0.07	0.74
Hannah	46.44	-81.04	I	23	0.003	0.44
Happy Valley Reservoir	-35.07	138.57	I	24	>0.1	0.19
Har/Hala	38.30	97.56	S	21	0.0001	0.65
Harp	45.38	-79.14	I	24	>0.1	0.28
Harus	47.95	92.16	S	22	0.03	0.47
Heney	45.13	-79.10	I	24	>0.1	0.24
Hongze/ Hung-tse	33.30	118.73	S	21	>0.1	0.45
HovsGol/ Kovsgol	51.22	100.53	S	16	>0.1	0.27
Hulun	48.83	117.26	S	24	>0.1	0.26
Huron	45.35	-82.84	I	25	0.08	0.85
Huron	44.76	-82.33	S	24	>0.1	0.44
Hyargas	49.20	93.25	S	18	>0.1	0.34
Iliamna Lake	59.47	-155.60	S	14	0.05	1.03
IlMen	58.25	31.21	S	23	0.003	0.65
Inari	68.85	28.28	I	25	0.06	0.45
Issyk kul	42.42	77.32	S	24	0.04	0.29
Itaparica	-9.72	-41.73	S	23	>0.1	0.03
Jesup	28.70	-81.23	I	14	>0.1	-0.05
Kainji	10.41	4.57	S	18	>0.1	0.32
Kallavesi	62.90	27.73	I	25	>0.1	0.34
Kangaroo Creek Reservoir	-34.86	138.79	I	13	0.02	1.14
KapchagayskoyeVodo/ Kapshagay	43.84	77.42	S	23	0.04	0.51
Kariba	-16.69	28.45	S	22	0.01	0.13
Kasba	60.33	-102.11	S	16	>0.1	-0.19
Kensico	41.09	-73.76	I	21	0.01	0.65
Kevojärvi	69.75	27.00	I	21	0.04	0.80
Khanka	45.09	132.43	S	23	>0.1	0.33
Kinneret	32.83	35.58	I	25	0.003	0.44
Kivu	-1.80	29.14	S	14	>0.1	0.18
Kremenshugskoye	49.23	32.79	S	23	0.0001	0.96

Lake name	**Latitude**	**Longitude**	**Dataset (S=satellite, I=in situ)**	**# of years**	**P value**	**Lake SSWT trend (°C decade^{-1})**
Kulundinskoye	53.02	79.53	S	24	>0.1	0.15
Kuybyshevskoye	55.29	49.61	S	24	0.0001	0.69
L223	49.75	-93.75	I	14	>0.1	1.00
L224	49.75	-93.75	I	25	>0.1	0.42
L227	49.75	-93.75	I	25	0.02	0.86
L239	49.75	-93.75	I	25	0.02	0.72
L240	49.75	-93.75	I	22	0.02	0.81
L302s	49.75	-93.75	I	23	>0.1	0.44
Ladoga	60.78	31.65	S	23	0.01	0.65
Lake of the Woods	49.06	-94.89	S	22	>0.1	0.14
Lappajärvi	63.27	23.63	I	25	0.04	0.89
Lianquihui	-41.13	-72.79	S	22	>0.1	0.02
Limfjorden	56.95	9.06	S	15	>0.1	-0.47
Little Para Reservoir	-34.75	138.72	I	17	0.04	0.72
Loch Leven	56.20	-3.38	I	22	0.10	0.75
Lohi	46.39	-81.04	I	24	0.07	0.45
Lower Zurich	47.30	8.58	I	25	0.01	0.75
Maggiore	45.95	8.63	I	16	>0.1	0.31
Malären	59.50	17.20	I	25	0.0001	0.87
Malawi	-11.74	34.62	S	24	0.06	0.11
Managua	12.38	-86.36	S	24	0.09	0.25
Manitoba	50.42	-98.29	S	22	0.04	0.39
Maroondah	-37.63	145.56	I	13	>0.1	-0.16
Martre	63.45	-118.19	S	22	>0.1	0.56
McConaughy	41.23	-101.72	I	15	>0.1	0.31
Mendota	43.10	-89.41	I	25	>0.1	0.38
Michigan	42.67	-87.03	I	25	>0.1	0.42
Michigan	42.85	-86.95	S	24	>0.1	0.20
Middle	46.44	-81.02	I	23	0.05	0.48
Millbrook Reservoir	-34.83	138.81	I	24	>0.1	0.32
Mondsee	47.83	13.38	I	25	0.10	0.31
Monona	43.06	-89.36	I	15	>0.1	0.47
Mount Bold Reservoir	-35.12	138.71	I	16	>0.1	0.15
Müggelsee	52.43	13.65	I	24	0.01	0.85
Mweru	-9.01	28.74	S	24	0.09	0.20
Myponga Reservoir	-35.40	138.44	I	23	>0.1	0 25
Na Mu/ Nam Co	30.70	90.45	S	15	>0.1	0.06
Nasser	23.19	32.79	S	21	>0.1	0.26
Neusiedler See/ Ferto	47.75	16.75	I	25	0.08	0.45

Lake name	Latitude	Longitude	Dataset (S=satellite, I=in situ)	# of years	P value	Lake SSWT trend (°C decade^{-1})
Neversink	41.83	-74.64	I	18	>0.1	0.45
Newnans	29.65	-82.22	I	14	>0.1	0.01
Ngoring/ Eling	34.90	97.71	S	16	>0.1	0.14
Nicaragua	11.37	-85.21	S	24	>0.1	0.07
Nipigon	49.73	-88.64	S	22	>0.1	0.72
Okeechobee	26.93	-80.80	S	12	>0.1	0.07
Onegh/ Onega	61.65	35.54	S	19	>0.1	0.72
Oneida	43.18	-75.93	I	25	0.0001	0.48
Ontario	43.63	-77.62	S	23	>0.1	0.33
Övre Skärsjön	59.84	15.55	I	21	0.09	0.66
Päijänne/ Murtoselka	61.52	25.50	I	20	0.05	0.83
Peipsi	58.80	27.44	I	25	0.01	0.69
Peipsi	58.80	27.44	S	24	0.003	0.76
Pepacton	42.08	-74.97	I	19	>0.1	0.54
PeterPond	56.03	-108.92	S	21	>0.1	0.21
Pielinen	63.53	29.13	I	25	0.06	0.85
Plastic	45.18	-78.82	I	24	>0.1	0.13
Plusssee	54.15	10.38	I	24	0.05	0.78
Poinsett	28.34	-80.83	I	13	>0.1	0.36
Pyhäselkä	62.47	29.77	I	19	0.10	0.86
Pyramid Lake	40.10	-119.59	S	20	0.0001	0.51
Qinghai	36.96	100.28	S	24	0.05	0.36
Razelm/ Razim	44.92	28.95	S	19	0.03	0.47
Red Chalk	45.19	-78.95	I	23	>0.1	0.21
Reindeer	57.57	-102.15	S	22	>0.1	0.48
Remmarsjön	63.86	18.27	I	18	0.10	0.67
Rondout	41.80	-74.43	I	18	0.01	0.79
Rotehogstjärnen	58.82	11.61	I	21	>0.1	0.40
Rotorua	-38.08	176.27	I	14	>0.1	-0.24
Rukwa	-7.59	31.79	S	24	0.05	0.20
Rybinkskoye	58.41	38.51	S	24	0.0001	0.89
Saimaa	61.08	28.27	I	23	0.0001	0.64
Saint Clair	42.43	-82.71	S	24	0.03	0.49
Salton Sea	33.25	-115.73	S	21	0.003	0.73
Samsonvale/North Pine Dam	-27.26	152.94	I	16	>0.1	0.54
Sans Chambre	46.72	-81.13	I	19	>0.1	0.38
Sarykamyshskoye	41.87	57.51	S	24	0.01	0.42
Sasykkol	46.57	80.89	S	22	0.03	0.62
Schoharie	42.39	-74.45	I	19	>0.1	0.00

Lake name	**Latitude**	**Longitude**	**Dataset (S=satellite, I=in situ)**	**# of years**	**P value**	**Lake SSWT trend (°C decade^{-1})**
Se lin/ Siling Go	31.79	89.09	S	21	>0.1	-0.11
Segozero	63.27	33.71	S	20	0.08	0.92
Selawik Lake	66.47	-160.52	S	15	0.01	0.69
Sevan	40.30	45.40	S	24	>0.1	>0.1
Silvan	-37.83	145.42	I	13	>0.1	-0.13
Simcoe	44.44	-79.35	S	22	>0.1	0.29
Sparkling	46.01	-89.70	I	25	0.01	0.81
St. Jean	48.56	-71.97	S	23	0.06	0.40
St. Skarsjon	56.67	13.07	I	22	0.09	0.85
Stechlinsee	53.17	13.03	I	25	>0.1	0.40
Stensjön	58.10	14.83	I	21	0.06	0.95
Stora Envättern	59.11	17.35	I	22	0.06	0.63
Sugarloaf	-37.11	143.40	I	19	>0.1	-0.08
Superior	47.58	-86.59	I	25	0.07	1.16
Superior	48.05	-87.10	S	21	>0.1	0.80
Swan	46.37	-81.11	I	24	0.0001	0.66
Tahoe	39.11	-120.03	I	24	0.01	0.54
Tahoe	39.11	-120.03	S	25	0.0001	0.71
Taihu	31.24	120.12	I	18	>0.1	0.00
Taihu	31.24	120.12	S	22	>0.1	-0.02
Tana	12.07	37.39	S	24	>0.1	0.16
Tanganyika	-6.79	30.07	S	24	0.06	0.19
The Loch	40.29	-105.65	I	21	>0.1	0.53
Titicaca	-15.78	-69.40	S	23	0.01	0.15
Toolik (JJA)	68.63	-149.60	I	24	>0.1	-0.10
Trout Lake	46.03	-89.67	I	25	0.02	0.77
Tsimlyanskoye	47.71	42.38	S	23	0.01	0.40
Tulemalu	62.96	-99.35	S	15	>0.1	0.41
Turkana	3.78	36.05	S	24	0.04	0.22
U Yarra	-37.68	145.92	I	17	>0.1	0.10
Ulungar/ Wu Lun Gu Hu	47.24	87.21	S	22	0.01	0.68
Upemba	-8.62	26.40	S	24	0.0001	0.43
Upper Zurich	47.21	8.84	I	22	>0.1	0.41
Urmia	37.92	45.25	S	23	0.003	0.65
Uvs	50.30	92.70	S	23	0.04	0.39
Valkea Kotinen	61.24	25.06	I	20	>0.1	0.50
Van	38.63	42.70	S	24	0.09	0.28
Vänern	59.07	13.60	S	24	>0.1	0.62
Vattern	58.33	14.56	S	23	0.04	0.63

Lake name	Latitude	Longitude	Dataset (S=satellite, I=in situ)	# of years	P value	Lake SSWT trend (°C $decade^{-1}$)
Victoria	-0.96	33.04	S	19	0.09	0.30
Võrtsjärv	58.27	26.03	I	24	0.09	0.40
Walenstadt	47.12	9.22	I	21	>0.1	-0.33
Warren Reservoir	-34.71	138.93	I	23	0.04	0.51
Washington (Washington)	47.63	-122.26	I	25	0.01	0.27
Washington (Florida)	28.15	-80.75	I	13	>0.1	-0.06
Whitepine	47.38	-80.62	I	16	>0.1	0.27
Winnebago	44.03	-88.41	S	23	0.06	0.74
Winnipeg	53.40	-98.40	S	23	>0.1	0.23
Winnipegosis	52.67	-99.87	S	22	0.04	0.55
Woerther See	46.63	14.15	I	24	0.01	0.47
Yan Yean	-37.55	145.14	I	15	>0.1	0.10
Zaysan	47.88	84.26	S	23	>0.1	0.25
Zeyskoye	54.44	127.71	S	20	0.06	0.41

Table S2. Summer surface water temperature trends for each lake. Lake names and alternative names, geographic location, satellite or in situ data, number of years in the record (all ≥13 years), significance of the trend, and the lake summer surface water temperature (LSSWT) trend. Trends were calculated using Sen slopes. The Sen slope estimator is a nonparametric analysis in which the slope is estimated by the median of all pairwise slopes in the data set. This analysis was chosen as the appropriate temporal estimator of slope because it can be used to test for linear trends over time in non-normally distributed data. Because sampling effort was not always equal across lakes, it is possible that trends are underestimated for some lakes with longer data gaps. Specific geomorphic and climate data for lake are available in *Sharma et al.* [2015].

The observed trends can be subject to artifacts that may make their true uncertainty greater than is apparent just from the statistics shown here. For example, the satellite-based trends can be affected by long-term changes in atmospheric parameters such as aerosol loading, cloud occurrence, or inter-instrument biases. While previous studies have shown using a comparison with in-situ reference data that these effects are minimal and that the satellite-derived trends are able to well replicate trends in ground-based observations [*Schneider and Hook*, 2010], it should be noted that the trend confidence intervals provided here do not account for such potential sources of uncertainty. However, overall, given that our approach is to compare trends across lakes, noise is more likely to obscure patterns rather than to create them.

Even though the majority of lakes are warming, 10% of the lakes in our survey had cooling trends, although only one of these was significant at $p<0.1$. If actually occurring, potential underlying reasons for cooling were apparently site-specific. On the Tibetan Plateau, cooling of some lakes reflected increased glacial meltwater inputs due to rising air temperatures [*Zhang et al.*, 2014]. In southeastern North America, lakes experienced increases in summer air temperature, increases in summer and winter shortwave radiation, and decreases in summer and winter cloud cover, yet paradoxically had cooling LSSWT (all were classified into leaf F, which had the lowest average LSSWT trend). Each of these lakes has undergone decreases in transparency that may have contributed to cooler late-summer temperatures [*Persson and Jones*, 2008] - in this region, decreased water transparency over this time period has been associated with increased precipitation during the warm phase of the Atlantic Multidecadal Oscillation (AMO) in Florida [*Gaiser et al.*, 2009].

Model	Intercept	Elevation	Maximum Depth	Surface Area	Short-wave Summer	Short-wave Winter	% Cloud Summer	% Cloud Winter	Air Temp Summer	Air Temp Winter	Rsqrd	RMSE
Interannual multiple regression (years as pseudoreplicates)												
Beta	2.195	-9.24E-05	-0.002	-6.51E-06	0.008	0.002	2.697	0.91	0.773	0.018	0.82	1.97
Std. Err.	0.505	6.69E-05	1.74E-04	1.24E-06	0.002	0.001	0.308	0.245	0.012	0.004		
t value	4.344	-1.381	-12.866	-5.248	4.025	1.727	8.757	3.708	64.817	4.151		
p value	1.43E-05	0.168	2.00E-16	1.62E-07	5.81E-05	0.084	2.00E-16	2.12E-04	2.00E-16	3.38E-05		
Std. Beta	-6.56E-16	-0.015	-0.099	-0.041	0.06	0.025	0.095	0.026	0.846	0.051		
% Explained Variance		8.758	2.481	0.329	8.845	9.905	3.047	0.167	51.057	15.411		
Interannual random effects model (accounting for lake identity)												
Beta	5.56E+00	-3.42E-04	-2.66E-03	-6.44E-06	9.14E-03	1.04E-03	-4.84E-01	2.47E-01	7.05E-01	2.00E-02	0.98	0.66
Std. Err.	4.36E-01	1.75E-04	7.43E-04	5.37E-06	1.25E-03	1.51E-03	2.13E-01	1.54E-01	1.35E-02	5.80E-03		
t value	12.75	-1.95	-3.58	-1.2	7.3	0.69	-2.27	1.61	52.36	3.45		
Annual multiple regression (no pseudoreplication)												
β-1986	5.732	2.54E-04	-1.94E-03	-8.10E-06	-0.014	0.003	1.468	1.790	0.812	0.055	0.81	2.17
β-1987	4.178	4.24E-05	-2.01E-03	-4.67E-06	-0.007	0.002	1.314	1.703	0.827	0.019	0.82	1.93
β-1988	0.839	-6.57E-05	-1.73E-03	-6.70E-06	0.015	0.006	2.734	0.865	0.731	0.014	0.76	2.15
β-1989	1.421	-4.50E-04	-1.54E-03	-1.01E-05	0.019	0.001	3.042	0.808	0.678	0.028	0.81	1.89
β-1990	3.324	-1.09E-04	-2.15E-03	-8.97E-06	-0.002	0.001	-0.910	3.720	0.816	-0.003	0.83	1.75
β-1991	0.037	-4.96E-04	-3.98E-03	-4.40E-06	0.028	0.000	3.706	0.571	0.674	0.007	0.82	1.77
β-1992	4.615	2.28E-04	-1.84E-03	-7.01E-06	-0.006	0.005	0.690	0.739	0.825	0.012	0.83	1.97
β-1993	2.403	1.79E-05	-1.81E-03	-6.47E-06	-0.006	0.011	3.122	1.609	0.823	0.005	0.83	1.89
β-1994	1.898	-1.31E-04	-2.58E-03	-8.52E-06	0.013	-0.005	4.109	-0.007	0.765	0.053	0.81	1.99
β-1996	-1.526	-2.27E-04	-2.35E-03	-2.46E-06	0.019	0.001	4.159	1.787	0.780	0.024	0.82	2.07
β-1997	0.033	-3.82E-04	-1.96E-03	-3.46E-06	0.019	0.005	5.121	0.025	0.711	0.017	0.82	2.02
β-1998	3.141	-3.71E-04	-2.49E-03	-2.47E-07	0.007	0.007	3.480	0.494	0.694	0.028	0.86	1.80
β-1999	-1.451	-5.01E-04	-3.24E-03	-2.58E-06	0.024	0.005	6.435	-0.084	0.710	0.013	0.85	1.68
β-2000	2.511	1.91E-04	-2.11E-03	-1.22E-05	0.013	-0.010	3.246	-0.157	0.799	0.046	0.84	1.92
β-2001	3.517	-2.38E-04	-2.84E-03	-6.55E-06	0.009	0.002	2.672	-1.121	0.777	0.016	0.82	1.98
β-2002	4.028	-5.02E-05	-2.13E-03	-3.67E-06	0.006	0.003	2.063	-0.792	0.767	0.007	0.82	1.95
β-2003	2.247	-8.29E-05	-2.33E-03	-3.78E-06	0.007	0.000	2.742	2.275	0.751	0.031	0.81	2.11
β-2004	1.070	-2.81E-04	-2.11E-03	-6.93E-06	0.006	0.012	2.201	1.740	0.788	-0.024	0.85	1.82
β-2005	2.626	2.74E-05	-2.37E-03	-7.23E-06	0.008	-0.003	2.241	1.075	0.781	0.025	0.81	2.01
β-2006	3.665	-5.53E-05	-1.93E-03	-1.26E-05	0.000	0.003	1.817	1.311	0.774	0.020	0.83	1.86
β-2007	1.194	1.23E-04	-1.65E-03	-7.07E-06	0.013	0.000	3.545	-0.395	0.779	0.022	0.85	1.95
CV_{annual}	0.884	-1.90E+00	-2.53E-01	-4.96E-01	1.337	2.021	0.556	1.335	0.063	0.910		

Table S3. Validating predictor selection. Before analyzing influences on LSSWT trends, we used preliminary models of interannual variation in LSSWT to test whether the available set of environmental variables offers reasonable predictions of surface temperature in any given lake for any given year. Predictors included winter and summer mean air temperature, % cloud cover, and shortwave radiation, as well as geomorphic characteristics of the lakes (elevation, surface area, and maximum depth). We tested three approaches. First, we developed a general linear model where all predictors were treated as fixed factors in a multiple regression framework, and lake identity was not accounted for. This approach results in pseudoreplication of the geomorphic predictors—which are invariant across years—but yields a general model that could be applied to any lake. Standardized regression coefficients (βstd) and hierarchical variance partitioning were used to interpret the relative influence of each variable on annual LSSWT.Hierarchical variance partitioning was performed using the “hier.part” package in the statistical computing program, R *[R Development Core Team*, 2014]. Through hierarchical variance partitioning, we estimated the percent of variance in LSSWT explained by each individual predictor variable. Second, we fitted a mixed effects model that included a lake-specific intercept, yielding a less general model but one that accounts for differences among lakes that are not accounted for by our climate and geomorphic variables. Third, we fitted a general linear model of LSSWT across lakes for each year independently, yielding a suite of general models that do not suffer from pseudoreplication of the geomorphic predictors. The range of slope coefficients from these year-specific models reveals which predictors have consistent effects and which vary widely. The purpose of all three approaches was simply to assess whether the available predictor set produces reasonable estimates of LSSWT, such that analysis of temporal trends in climate variables might plausibly predict temporal trends in LSSWT.

The table shows the results of the three parallel statistical models for predicting lake summer surface water temperature (LSSWT) based on climate and geomorphic variables (n=235 lakes observed annually between 1985-2009). The interannual multiple regression model yields accurate general predictions of LSSWT (multiple linear regression, R^2=0.82, RMSE=0.416°C) but statistical significance is exaggerated due to psuedoreplication of geomorphic variables. The interannual random effects model accounts for lake-specific differences while fitting linear effects of each climate and geomorphic variable, substantially increasing overall prediction accuracy of LSSWT (R^2=0.98, RMSE=0.66) but narrowing application of the fitted model to only the study lakes. The annual multiple regression models fit all predictors for each year individually, and do not include any pseudoreplication. Their fits were consistently good (R^2 ranged from 0.76 to 0.86, RMSE ranged from1.68 to 2.15), but there was considerable variation among years in the fitted coefficients for most variables.

These three statistical approaches all indicate that summer air temperature is the most important of our variables for predicting LSSWT (β=0.77, β_{std}=0.85, % variance explained =51%). The standardized regression coefficient for air temperature approximates theoretical predictions of approximately 80% heat transfer efficiency [*Schmid et al.*, 2014]. The success of this model in predicting LSSWT across all lakes – even without local factors such as wind, relative humidity, water transparency, and residence time – underscores the fact that climate and geomorphometry are tight controls on variation in lake temperature. Thus, a limited ability to predict rates of LSSWT change does not reflect uncertainty about mechanisms underlying LSSWT, but rather the temporal variability of key climatic factors, perhaps augmented by variation among lakes in the climatic controls on warming.

Leaf ID	n	Lake SSWT trend (°C decade $^{-1}$)	Summer air temperature trend (°C decade $^{-1}$)	Summer shortwave trend (W m^{-2} decade $^{-1}$)	Summer cloud cover trend (% change decade $^{-1}$)	Leaf description	Lakes within Leaf (italicized lakes are those that do not experience ice)
A	30	0.72 ± 0.23	0.70 ± 0.24	6.6 ± 5.0	-3.2 ± 1.4	Cold winter, low elevation (< 141 m), decreasing cloud cover. Also, increasing air temperatures and shortwave radiation in summer. Primarily in northeastern European and western Alaskan.	Aleknagik, Alljuttern, Beloye, Bras D´Or, Erken, Fracksjön, Iliamna, IlMen, Kallavesi, Kevojärvi, Khanka, *Kremenshugskoye*, Kuybyshevskoye, Ladoga, Lappajärvi, Malären, Onegh, Ontario, Päijänne, Peipsi, Pielinen, Pyhäselkä, Rybinkskoye, Saimaa, Segozero, Selawik, St. Skarsjon, Stora Envättern, Vattern, Võrtsjärv
B	7	0.39 ± 0.16	0.59 ± 0.34	3.6 ± 6.5	1.6 ± 2.7	Cold winter, low elevation (< 141 m) with increasing summer cloud cover. Also air temperature increases in both summer and winter.	Aral Sea, Inari, Klundinskoye, Oneida, Rotehogstjärnen, Tsimlyanskoye, Vänern
C	40	0.55 ± 0.20	0.31 ± 0.32	4.7 ± 5.4	-1.8 ± 1.7	Cold winter, higher elevation (>141 m), shallow (<21 m max depth).	Aipi, Allequash, Big Muskellunge, Bosten, Buyr, Claire, Crystal, Dauphin, Dickie, Dore, Fiolen, Fish, Gyaring, Hannah, Harus, Heney, Hulun, L223, L227, L240, L302s, Lohi, Manitoba, Middle, Plastic, Remmarsjön, Saint Clair, Sans Chambre, Sasykkol, Sparkling, Stensjön, Swan, The Loch, Tulemalu, Ulungar, Uvs, Valkea, Winnebago, Winnipegosis, Zaysan

D	54	0.36 ± 0.26	0.23 ± 0.23	3.2 ± 6.8	-1.0 ± 1.8	Cold winter, higher elevation (>141 m), deeper (>21 m max depth).	Alokol, Ashokan East, Ashokan West, Athabasca, Ayakkum, Baikal,Balkhash, Blue Chalk, Bratskoye, Cannonsville, Chub, Clearwater, Crosson, Dubawnt, Erie, Great Bear, Great Slave, Har/Hala, Harp, HovsGol, Huron, Hyargas, *Issykkul*, Kasba, L224, L239, Lake of the Woods, Martre, Mendota, Michigan, *Mondsee*, Monona, NaMu, Neversink, Ngoring, Nipigon, Pepacton, Peter Pond, Qinghai, Red Chalk Main, Reindeer, Rondout, Schoharie, Selin, Sevan, Simcoe, Övre Skärsjön, Superior, Toolik, Trout, *Van*, Whitepine, Winnipeg, Zeyskoye
E	32	0.27 ± 0.31	0.09 ± 0.17	-2.1 ± 5.6	-0.6 ± 2.4	Warm winter, decreasing air temperature trends in summer and decreasing shortwave radiation trends in winter. Also decreases in cloud cover across the year and in shortwave radiation in summer.	Abaya, Argentina, Argyle, Barossa, BoengTonleChhma, Cardinia, Chad, Chardarinskoye, Chilwa, Chocon, Colhue Huapi, Happy Valley, Hongze, Kainji, Kangaroo Creek, Kinneret, Lianquihui, Little Para, Lower Zurich, Millbrook, Mount Bold, Myponga, Constance,Nasser, Rotorua, Sugarloaf, Tana, Titicaca, Samsonvale, Upper Zurich, Walenstadt, Warren, Washington

F	47	0.12 ± 0.27	0.15 ± 016	0.7 ± 5.1	-0.04± 2.5	Warm winter, low air temperature trends in summer and high trends in shortwave radiation in winter. Also increases in shortwave radiation in summer.	Annecy, Annie*, Apopka*, Balaton, Bangweulu, Bay, Beauclair*, Biwa, Blue Cypress*, Bourget, Buenos Aires, Cardinia, Chao, Chapala, Chilka, Chiquita, Chishi, Denham, Gaoyou, Garda, Geneva, George*, Itaparica, Jesup*, Kariba, Maggiore, Malawi, Managua, Maroondah*, McConaughy, Mweru, Neusiedler, Newnans*, Nicaragua, Okeechobee*, Poinsett*, Rukwa, Salton Sea, Silvan, St. Jean, Taihu, Tanganyika, U. Yarra, Upemba, Washington (Florida)*, Woerther, Yan Yean
G	7	0.26 ± 0.34	0.65 ± 0.23	-0.35 ± 1.2	-0.24 ± 1.4	Warm winter, high summer air temperature trends, low summer shortwave trends. Also, increases in winter air temperature, and decreases in winter shortwave radiation.	Feeagh, Great Salt Lake, Kapchagayskoye, Kivu, Limfjorden, Razelm, Victoria

H	18	0.53 ± 0.24	0.77 ± 0.31	7.8 ± 4.5	-0.57 ± 3.2	Warm winter, high summer air temperature trends, high summer shortwave trends. Also, increases in winter air temperature, and increases in winter shortwave radiation.	Albert, Bahral Milh, Beysehir, Brunnsjon, Buhayratattharthar, Caspian Sea, Dead Sea, Eyasi, Kensico, Loch Leven, Muggelsee, Plusssee, Pyramid, Sarykamyshskoye, Stechlinsee, Tahoe, Turkana, Urmia

Table S4. **Summary of regression tree leaf characteristics.** For each leaf, we present a description and lake names, and including number of unique lakes (n), average lake summer surface water temperature (LSSWT) trend and standard deviation, average summer air temperature trend and standard deviation. The first split in the regression tree, at -0.42 °C mean winter temperature, is considered a proxy for winter ice cover; the near-zero value of this split reflects a previously identified division between lakes that become seasonally covered by ice versus ice-free lakes [*Weyhenmeyer et al.*, 2004]. To verify ice-cover among lakes in our dataset, we used literature searches for most lakes and Google Earth images for a few lakes; lakes that never, rarely, or only sometimes experienced ice are listed in italics. Of the lakes in the cold-winter branch (leaves A-D), 98% did experience ice cover whereas only 6% of the warm-winter lakes did. Of the four lakes that did not experience ice cover but were classified into ‘cold-winter’, Mondsee does experience ice cover on rare occasions [*Jones et al.*, 2010], and images of Kremenshugskoye indicate that parts of this large reservoir do experience ice cover. Issyk-Kul and Van are both saline, potentially contributing to reduced likelihood of ice on these lakes. Thus, we are confident in the use of the -0.42 °C mean winter temperature as an indicator of ice cover. There were no geomorphic differences; ice-covered lakes were not significantly shallower (Wilcoxon, mean depth p<0.87, maximum depth p<0.78) nor smaller (Wilcoxon, surface area p<0.65, volume p<0.45) than ice-free lakes.

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