Title

Global data set of long-term summertime vertical temperature profiles in 153 lakes

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Abstract

Climate change and other anthropogenic stressors have led to long-term changes in lake thermal structure, including surface temperatures, deepwater temperatures, and vertical thermal gradients. Though many studies highlight generally consistent warming of surface water temperatures in lakes around the world, less is known about long-term trends in full vertical thermal structure and deepwater temperatures, which have been changing less consistently in both direction and magnitude. Here, we present a globally-expansive data set of summertime in-situ vertical temperature profiles from 153 lakes, with some time series beginning as early as 1912. We also compiled lake geographic, morphometric, and water quality variables that can influence vertical thermal structure through a variety of potential mechanisms in these lakes. These long-term time series of vertical temperature profiles and corresponding lake characteristics serve as valuable data for understanding changes and drivers of lake thermal structure in a time of rapid global and ecological change.

Background & Summary

Lakes serve as important sentinels of climate and environmental changes[1,2], and also as sources of vital ecosystem services, such as fresh drinking water and fisheries. Several recent regional- to global-scale studies have quantified generally consistent trends of warming surface waters[3,4], though few studies at broad geographic scales have considered changes in the full vertical thermal structure of lakes[5,6,7]. Changes in vertical thermal structure can affect ecological processes in lakes at depth, including vertical mixing[8,9], oxygen depletion[10,11], and productivity[12]. Further, deep waters are areas of critical habitat for many species, and changes in vertical thermal structure at depth can alter population dynamics or trophic interactions based on the quality and availability of suitable habitat[13,14,15].

Drivers of vertical lake thermal structure may include those most important to surface water temperature, including air temperature[3,4], shortwave and longwave radiation[16], wind speed[17], and relative humidity[18]. However, the generally weak interaction between deep waters and the air-water interface underscores the importance of other factors to understanding trends in deepwater temperatures and vertical thermal structure. For example, water clarity is particularly influential on deepwater temperature and strength of stratification due to its control of vertical light and heat distribution throughout the water column[8,19,20,21]. Controls on deepwater temperature and vertical thermal structure can also be moderated by lake morphology due to influences of fetch, basin shape, and depth[5,22], which can also moderate the influence of other drivers on lake thermal structure, such as has been observed for the interaction between lake size and water clarity[23]. The relative balance between stratification, wind stress, and basin morphometry also determines whether incoming heat is retained in the epilimnion or mixed to deeper depths[24]. Hence, drivers of, and changes in, full vertical thermal structure do not necessarily mimic those commonly reported for surface water temperatures, but are important if we are to understand the breadth of ecological consequences associated

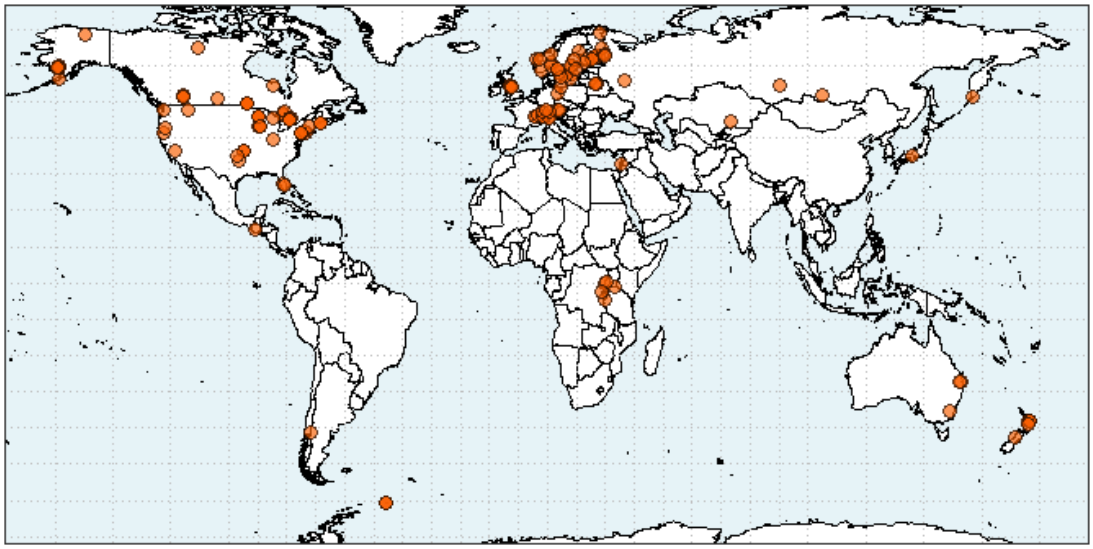

Figure 1. Map showing locations of the 153 lakes with vertical temperature profile data in this data set.

with changing lake thermal structure.

We present here a globally-expansive data set of vertical summertime temperature profiles of 153 lakes spanning 26 countries across all 7 continents (Figure 1). Start and end years vary by lake, with starting years ranging from 1912 to 2002 and ending years ranging from 1986 to 2016 (Figure 2). The median number of years with summertime vertical temperature profiles is 25 years, with a range from 3 to 79 years of data depending on the lake (Figure 2). Lake characteristic data are also provided, including geographic, morphometric, and water quality variables (Table 1).

Our goal was to assemble and publish this globally-expansive data set of lake vertical temperature profiles to expand on prior global data sets of lake surface water temperatures[25], and increase the understanding of changes in deepwater temperatures and the full vertical thermal structure of lakes over time. A collaborative working group at the Global Lake Ecological Observatory Network (GLEON; www.gleon.org) sought to analyze changes in lake thermal structure at a global scale by collecting long-term vertical temperature profile data

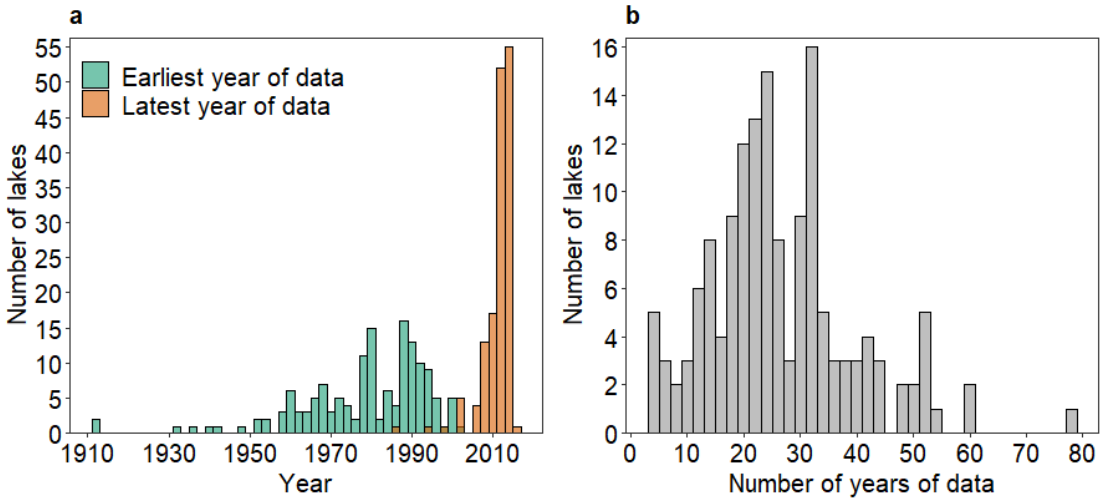

Figure 2. Histograms of temporal coverage for each lake in this data set. (a) Histogram of the earliest year (green) and latest year (orange) with temperature profile data for each lake. (b) Histogram of the total number of years with temperature profile data for each lake.

from a broad range of lake types in order to address key scientific questions such as: How is vertical lake thermal structure changing over time and depth? What types of lakes are experiencing the most rapid changes in temperature at depth? How do trends in temperature at various depths or other metrics of thermal structure (i.e., mixing depth, strength of stratification) vary among lakes? Through this data set, questions such as these can be more fully addressed. This data set can be paired with meteorological or other climate or environmental data to analyze the drivers of vertical thermal structure in comparison with the established drivers of surface water temperatures, and to assess potential ecological consequences in times of rapid global change. In addition, the data set can be used to calibrate and evaluate lake models, such as the Lake Model Intercomparison Project[26] (LakeMIP) and the Inter-Sectoral Impact Model Intercomparison project[27] (ISIMIP).

Methods

Temperature profiles, sampling methods, and physical descriptions were compiled for 153 globally-distributed lakes. We selected vertical temperature profiles measured in the same location for multiple years, typically the deepest part of the lake, using a single mid-summer profile for each lake and year. Data are presented for all years for which profiles are available. Selected temperature profiles were linearly interpolated or binned to 0.5 m increments throughout the water column. Mid-summer profiles for each lake were selected as described in (7). Briefly, we calculated relative thermal resistance to mixing[28,29] (RTR) for all profiles for each lake for each year. The day of year with the maximum RTR value for each year was selected for each lake, and the median day of year across all years per lake was considered the target day for single mid-summer profile selection. For each lake and year, the temperature profile nearest to this median day of year ± 21 days was selected. If no profile spanning surface to near the maximum lake depth was available, then no profile was selected. Details on sampling methods from each contributing research group follows, organized by major geographic region and alphabetized within geographic region.

Western North America

Castle Lake in California, USA has been sampled annually since 1959. Temperature data were measured between 12:00 and 14:00 at the deepest part of the lake in 1 m depth intervals. Measurements were taken using a reversing thermometer (1959-1975), Hydrolab (1975-1982; 2011-2013), and YSI model 85 (1999-2011) (sampling instrument is unknown for most of the 1980s and 90s).

Crater Lake is located in the northwestern USA at the crest of the Cascade Mountains in Oregon. Temperature data were collected between 8:00 and 17:00 from the middle of the lake in the deepest basin (594 m). From 1988 to present temperature were measured by lowering a Seabird Instruments SBE19 CTD through the water column at a rate of approximately 0.5 m per second, collecting two readings per second. Data are binned to 1 m increments. Prior to 1988, temperature profiles were measured manually with a Montedoro-Whitney thermistor with a 250 m cable.

Temperature profiles were measured in Emerald Lake, California, USA from the deepest part of the lake (10 m) beginning in 1983. Temperature was measured in 1 m increments throughout the water column from 1983 to 2006 using a YSI 58, after which a thermistor chain was deployed with Onset Water Temp Pro spaced at 0.5 to 1 m intervals.

Flathead Lake in northwest Montana, USA is the largest freshwater lake west of the Mississippi River by surface area. Temperature data were collected fortnightly in June, July, and August 1977-2013 with various instruments. In 1977, data were collected with a YSI tele-thermometer; from 1978-1984, collected with a Hydrolab I; from 1985-1993, with a Hydrolab

Surveyor II; from 1993-2003, with a Hydrolab Surveyor III; and from 2003-2001, with a Hydrolab Surveyor IV. Since 2011, data has been collected with a Hydrolab DS5 unit. Measurements were taken between 10:00 and 14:00 at the deepest point of the lake in 1 to 10 m depth intervals throughout the water column, with greater intervals between measurements at deeper depths. The intervals between depths on a given sampling date also change periodically early in the data set before consistent intervals were established. Instrumentation was calibrated before each sampling event to account for the elevation of the sampling site and highly variable barometric pressure.

Washington Lake is located in Washington, USA. Temperature profiles were measured between 9:00 and 16:00 in the main trench of the lake (depth of 63 m). Temperature was measured using various bathythermographs between 1933-1986, a Kahl digital temperature meter 202WA510 beginning in 1974, and a YSI 6600 V2 sonde beginning in 2012. For measurements with the bathythermographs, temperature was measured every 1 m close to the thermocline and every 5 m elsewhere. When the Kahl temperature meter was used, temperature was recorded for every meter through 20 m and in 5 m increments after 20 m depth. Data from the YSI sonde were recorded continuously, so temperature readings were used at similar intervals to those from the previous instruments.

Central North America

Acton Lake, a eutrophic reservoir in southeastern Ohio, USA, resides in a highly agricultural watershed. Temperature was measured in the deepest part of the lake at 0.5 m depth increments from 0-5 m and 1 m increments for the remainder of the water column (7-8 m depending on water level). Temperature data were collected in most cases in the mid-morning, and occasionally in the early afternoon in mid-July of each year from 1992-2009 using a handheld YSI temperature/dissolved oxygen sensor or a YSI sonde.

Lakes Bighorn, Harrison, Pipit, and Snowflake are located along the eastern front range of the Rocky Mountains in the Cascade Valley of Banff National Park (Alberta, Canada). The catchments are non-glaciated and free from human development. Temperature data were collected in the deepest point of the lake in 1 m depth intervals between 10:00 and 15:00 using a MK II Thermistor (Flett Research Ltd, Wpg, Canada) for measurements taken beginning in the 1990s. Earlier measurements (1960s and 1970s) were taken using a YSI Model 425C thermistor thermometer, which was calibrated against a mercury thermometer.

Douglas Lake, a mildly eutrophic glacially formed multiple ice-block kettle lake, is a 13.74 km^2 natural lake in northwestern Cheboygan County, Michigan. It is the 28th largest lake in Michigan by surface area and exists within a 103.07 km^2 watershed. Temperature data were collected from 1913-2014 from at 1 m intervals from 0-24 m in the center of South Fishtail Bay Kettle with a reversing thermometer at approximately 1 m increments (1913-1970), a YSI model 54A oxygen electrode-thermistor thermometer (1971-1982), a Hydrolab MS-5 multiprobe (1983-2009), and an 8-node MHL thermistor string (2010-2014).

Lakes Eucha, Grand Lake O' the Cherokees, Spavinaw, Texoma, and Thunderbird are reservoirs located in Oklahoma, USA. Temperature profiles were measured at the deepest point in these reservoirs between morning and mid-day with various sensors. YSI temperature probes were used for all samples collected in Lake Thunderbird, through 1991 in Grand Lake O' the Cherokees, through 1995 in Lakes Eucha and Spavinaw, and through 2000 in Lake Texoma. Beginning in 2000 in Lake Texoma, Hydrolabs were used for temperature measurements, with a Hydrolab H2O through 2008, and Hydrolab DSX5 thereafter. A Hydrolab was used for measurements in Grand Lake O' the Cherokees from 2011-2013. Lakes Eucha and Spavinaw were sampled with a Hydrolab H2O through 2005, a YSI 6930 V2 for samples from 2006-2012,

and a YSI EXO1 for samples after 2012.

Katepwa Lake is a eutrophic, riverine site located in the Qu'Appelle River drainage basin in southern Saskatchewan, Canada. The lake has been sampled since 1994 as part of the Qu'Appelle Long-term Ecological Research network (QU-LTER). Temperature data were collected from a standard site over a deep region of the lake (22 m depth) in 1 m intervals between 10:30 and 13:00 using a YSI 85 or similar multi-parameter probe.

Northeastern North America

Temperature profiles were collected beginning in 1968 for 6 lakes (Lakes 222, 224, 239, 240, 373, and 442) at the IISD Experimental Lakes Area (International Institute for Sustainable Development, Northwestern Ontario, Canada). Profiles were measured in the deepest part of the lake in 1 m intervals, except in the thermocline where temperature was measured every 0.25 m. Montedoro-Whitney thermistors (models TC-5A and TC-5C) were used through 1983, a Flett Research Mark II digital telethermometer was used for temperature measurements from 1984-2009, and a RBR XRX620 multifunction probe with integrated temperature sensor for measurements beginning in 2010.

The Dorset "A lakes", Blue Chalk, Chub, Crosson, Dickie, Harp, Heney, Plastic, and Red Chalk Main Lakes are located in the Muskoka-Haliburton region of south-central Ontario, Canada. The study sites are primarily small (< 1 km^2) headwater lakes, with the exception of Red Chalk Lake which is located downstream of Blue Chalk Lake. Temperature data were collected from the deepest point in each lake using a YSI 58 temperature/dissolved oxygen meter (or occasionally a digital YSI 95 meter) beginning in the late 1970s. Measurements were collected between 9:00 and 16:00, with readings taken every meter from the lake surface (0.1 m depth) to within approximately 1 m of lake sediments.

Bubble Pond, Eagle Lake, and Jordan Pond are located on Mount Desert Island off the coast of Maine, USA. Temperature data were collected from the location of maximum depth, as determined through bathymetric surveys and the use of an electronic depth finder and Global Positioning System unit. Temperature measurements were collected at 1 m increments using a YSI 600XL multiparameter water-quality monitor (sonde) from 2006 to present and a YSI 54ARC before this time.

Lake Champlain is located in the northeastern USA, on the border of Vermont and New York state and partly extending into Quebéc. Temperature data were collected from a sampling station in Mallet's Bay beginning in 1992. Measurements of temperature were taken at 1 m intervals between 8:00 and 17:00 beginning in 1992 using a Hydrolab MS-5 multi-probe sonde. This site was chosen for the temperature profile data because it is deep enough to have clear dimictic stratification, but is isolated from the main basin of Lake Champlain, so does not experience the large seiche which affects the main basin and could complicate comparative analyses of temperature profiles.

Clearwater, Sans Chambre, and Whitepine Lakes are located in northeastern Ontario, and Hawley Lake is in the Hudson Bay Lowlands area of subarctic Ontario. Temperature profiles were measured from near the area of maximum depth in these lakes beginning in the 1970s. Measurements were taken in 1 m intervals through the water column between 12:00 and 17:00. Clearwater, Sans Chambre, and Whitepine Lakes' temperature profiles we measured using various YSI temperature/dissolved oxygen meter (models 50B, 51B, 52, 54, or 58) beginning in 1998, with a YSI model 54 temperature/dissolved oxygen meter used for Sans Chambre and Whitepine for most earlier years' measurements. In Clearwater Lake, a YSI model 432D telethermometer was used through 1975, a Montedoro-Whitney TC-5C

thermistor from 1976-1981, and a Mark II Telethermometer from 1982-1998. In Hawley Lake, various YSI temperature probes were used in earlier years, and since 2009, a YSI Pro ODO meter was used to measure water temperature.

Lakes Giles and Lacawac are located in the northeastern USA (Poconos Mountains region, Pennsylvania). Temperature data were collected from the deepest point in the lake on a single date in late July or early August each year beginning in 1988, between 9:00 and 16:00. Temperature measurements were measured manually in 1 m increments using a YSI 58 temperature/dissolved oxygen meter (1988-1992), or with a rapid recording Biospherical Instruments PUV 500 (1993-2003) or BIC 2104P (2004-present) recording at 4 Hz while being lowered through the water column. Profiles taken with the YSI were linearly interpolated to half meter depth increments, and profiles taken with the PUV and BIC were binned to half meter depth increments.

Lake Lillinonah is a hydroelectric reservoir on the Housatonic River located in western Connecticut, USA. Temperature data were collected at the deepest point of the lake between 9:00 and 17:00 beginning in 1996. Water temperature monitoring was conducted by First Light Power as part of the water quality monitoring mandated in their license from the Federal Energy Regulatory Commission (FERC). Measurements were collected every 5 m using a YSI 58 temperature/dissolved oxygen meter.

Mohonk Lake is a small (0.07 km^2) glacial lake with a single deep basin (max depth = 18.5 m) located in the northeastern USA (Shawangunk Ridge, New York). Temperature data were collected from the northern end of the lake from 1983-2013 during daytime. Temperature measurements were measured manually in 1 m increments using Digi-sense Economical Thermistor 400 series (Model #93210-00). Additional temperature weekly profiles are publicly available[30].

Temperature profiles were compiled from 11 lakes from the North Temperate LTER in Wisconsin, USA. Fish, Mendota, Monona, and Wingra Lakes are located in southern Wisconsin, and Allequash, Big Muskellunge, Crystal Bog, Crystal Lake, Sparkling, Trout Bog, and Trout Lakes are in northern Wisconsin. Temperature profiles were measured in 1 m increments from the surface to lake bottom at the deepest location in each lake since 1982 (northern lakes) and 1996 (southern lakes). Various temperature/dissolved oxygen probes were used to collect these data, and were calibrated in the field prior to data collection. For the northern lakes, a Montedoro Whitney CTU-3B sensor was used for some data collected between 1982-1986, a Whitney TC-5C for 1982-1983, Whitney DOR-2A in 1984, YSI-57 in 1983 and 1985, and a YSI-58 for 1985 onward. Temperature data in the southern lakes were collected with a YSI-58 temperature/dissolved oxygen sensor.

Lake Opeongo is the largest oligotrophic deepwater lake in Algonquin Provincial Park, Ontario, Canada. Temperature data were collected by Ontario Ministry of Natural Resources and Forestry staff at Harkness Fisheries Research Station in the west basin of Opeongo's South Arm in midsummer (July-August) in 1958-1965, and 1998-2014 between 9:00 and 16:00. Temperature loggers (Hobo Tidbits, 1998-2004; Onset Water Temperature Pro V1, 2004-2008; and Onset Pro V2, 2009-2014) were installed after ice out in the same location at approximately 1.5 m intervals to a 15 m depth, with a deepwater thermistor placed at approximately 20 m. Temperatures were recorded at high temporal resolution (10-15 minute intervals) throughout the summer using these temperature strings. Earlier (1958-1965) temperature profiles were measured using handheld thermistors.

Lake Sunapee is located in the northeastern USA and is the fifth largest lake located within

New Hampshire. Temperature data were collected in the morning from the deepest point of the lake in the central basin beginning in 1986. Temperature measurements were measured manually in 1 m increments using a YSI 52 temperature meter.

Lake Wallenpaupack is a reservoir in northeastern Pennsylvania, USA, in the Pocono Mountains region. Temperature profiles were measured in the center of the lake (approximately 12 m) during daytime hours, with measurements taken every 0.5-1 m. Temperature was measured with various YSI (Yellow Springs Instruments) instruments including a YSI 610-DM/600XL (2002-2005), YSI 85 (2008-2010), YSI 600XL sonde with 600D datalogger (2011-2018), and various temperature sensors prior to 2002.

Southeastern North America

Lake Annie is located in the southeastern USA (Lake Wales Ridge region, Florida). Temperature data were collected from the deepest point in the lake on a monthly basis between 9:00 and 16:00 beginning in 1984. Temperature measurements were measured manually in 1 m increments using a Montedoro Corporation Thermistor Model TC-5c (1984-2008) and a YSI Pro Plus (2009-2014) with values measured while lowering the meter to the bottom of the lake and again when raising it to the surface. The data reported are the means of the two depth-specific values.

Temperature profiles were measured in Lake Okeechobee in Florida, USA beginning in 1973. Profiles were measured in half meter intervals between 8:00 and 12:00 using a Hydrolab through 1995 and a YSI 58 temperature sensor from 1996-2014.

Subarctic

Aleknagik, Beverley, Chignik, Hidden, Kulik, Little Togiak, Lynx, and Nerka Lakes are located in Alaska, USA. Temperature profiles have been measured on these lakes since the 1960s (Aleknagik, Beverley, Kulik, Little Togiak, and Nerka Lakes), and since the early 2000s (Chignik, Hidden, and Lynx Lakes). Measurements were taken during the day, typically between 10:00 and 19:00. A bathythermograph was used for temperature measurements through 1967, a digital thermistor from 1968-1998, a YSI 660 sonde for samples from 1999-2012, and a YSI Castaway beginning in 2013, with the exception of samples from Chignik Lake, for which a handheld thermometer was used to measure the water temperature from Van Dorn casts.

Toolik Lake is a kettle lake located in Alaska, USA. Temperature data were collected between June and August in the south basin of the lake between 9:00 and 11:00. Temperature was recorded in 1 m increments throughout the water column with a Hydrolab profiler sampling Surveyor 4a datalogger and a datasonde 4a multiprobe[31,32,33,34].

Vulture Lake is located in the sub-Arctic region of the Northwest Territories, Canada. Temperature data were collected from one of the deeper parts of the lake in late July or early August during the open-water season from 1997 to 2014. Temperature measurements were recorded using a multi-probe sonde (e.g., YSI 6820) at 0.5 m or 1 m increments (every 1 m for most years, except 1999 [every 0.5 m] and 2009 [every 0.2 m]). The probes were allowed to stabilize at the surface before being lowered slowly through the water column. The corresponding depth was measured using the readings from the depth sensor. Measurements were collected continuously from just below the lake's surface to approximately 0.5 m above the water-sediment interface. Sensors equipped on profiling instruments were calibrated following the manufacturer's recommended frequency and methods to ensure accurate and reliable operation of the sensors in the field. Data from the multi-probe sonde was downloaded to a computer once the field equipment was returned to the field-based laboratory.

Central and South America

Lake Atitlán is a deep (324 m) tropical mountain lake, situated 1562 m above sea level in the Guatemalan highlands, sampled in 1968-1969 and 2010-2011. Temperature profiles at the lake center were measured manually between 7:00 and 13:00 in variable increments (1-5 m) in the first 30 m using a YSI 51 or YSI 95 temperature/dissolved oxygen meter. For depths below 30 m, samples were collected using a Van Dorn bottle and temperature was measured immediately upon the sample reaching the surface.

Lake Mascardi is located in the North Patagonian Andes in Argentina. Temperature data were collected near the deepest point in the Catedral arm of the lake on a single date in mid-summer (January-February) between 12:00 and 14:00 beginning in 1994. Temperature measurements were taken using rapid recording Biospherical Instruments PUV 500 (1994) or PUV 500B (1996-2014) recording at 4 Hz while being lowered through the water column.

Africa

Lake Kivu is located on the border between Rwanda and the Democratic Republic of Congo, and is one of the seven African Great Lakes. Temperature data were collected at the Ishungu basin beginning in 2002 between 9:00 and 16:00. Temperature was measured manually in 5 m increments using a YSI 55 temperature/dissolved oxygen meter (2002-2005), or with a suite of instruments (YSI 6600 V2, Hydrolab DS4a, DataSonde 4a 42071, Sea and Sun 725 and 257) recording at high frequency while being lowered through the water column. All temperature profiles were vertically interpolated to a regular vertical grid with 1 m increments down to 90 m using piecewise cubic Hermite interpolation[18,26].

Lakes Nkugute is located in Uganda. Temperature data for Lake Nkugute were collected in the deepest part of the lake at a depth intervals of 1-5 m using a handheld liquid-in-glass thermometer in 1964 with the contemporary (2002-present) data being measured with a YSI sonde.

Lake Nkuruba is located in western Uganda, in the vicinity of Kibale National Park (northern sector). Temperature data were collected beginning in 1992 from the deepest part of the lake in 1 m increments through a depth of 30 m. Temperature was measured manually using a YSI 50 or 51B temperature/dissolved oxygen meter.

Lake Tanganyika has temperature profile data dating back to the early 1900s. Temperature profiles in this lake were typically measured in the morning, between 9:00 and 12:00 from the north basin of the lake near Kigoma, Tanzania. As these temperature profiles represent a century of work, temperature profiles over this time have been taken using a multitude of instruments. Since 1993 temperature profiles have been measured using a YSI 6600 V2 sonde, titanium RBRduo TD, Seacat Profiler V3.1b, Onset HOBO U22 temperature loggers, CTD Seabird 19, STD-12 Plus CTP profiler, and a YSI 58 temperature/dissolved oxygen meter. Prior to 1993 various data loggers, mercury thermometers, and reversing thermometers were used.

Lake Victoria is located in Kenya. Temperature data for Lake Victoria were collected from stations across the lake during acoustic surveys each year in 2000-2001 and from 2005-2009 using a submersible Conductivity Temperature-Depth profiling system (CTD, Sea-bird Electronics, Sea Cat SBE 19).

Scandinavia and Northern Europe

Lakes Allgjuttern, Brunnsjön, Fiolen, Fracksjön, Övre Skärjön, Remmarsjön, Rotehogstjärnen, St. Skärsjön, Stensjön, and Stora Envättern are relatively small, boreal lakes in Sweden. In

contrast, Lake Vänern is the largest lake in Sweden with a surface area of 5648 km^2. Temperature data have been collected since 1988 (since 1973 for Lake Vänern) between morning and mid-afternoon. Manual measurements of temperature were taken from the deepest point in each lake from the surface through 1 m above the lake bottom at depth intervals varying between 1 up to 10 m in Lake Vänern.

Lakes Byglandsfjorden, Hornindalsvatnet, Mjøsa, Øyeren, Selbusjøen, and Strynevatnet are all large and deep lakes located in the central region of western Norway. Temperature profiles were measured in the deepest part of the lake between 9:00 and 16:00 beginning in the mid-1990s. Temperature was measured using an Aanderaa 4060 every meter in the upper part of the water column, with greater than 1 m intervals between measurements in depths below 20 m. For the past 2-3 years of data collection, a Castaway CTD was applied, recording temperatures while lowered. Data collection was made by The Norwegian Water Resources and Energy Directorate (NVE).

Temperature data were collected from Sweden's Lake Erken from the deepest point in the lake in 1 m intervals between 7:30 and 9:30 beginning in 1940. Temperature was measured manually at 1 m intervals using a variety of instruments. In early years a thermometer inside a transparent Ruttner sampler was read to obtain the temperature of water collected from different depths. Later, underwater thermistors were used from a variety of manufacturers. In recent years combined temperature and dissolved oxygen sensors have been used to collect water temperature measurements: a YSI model 52 (1996-2006), WTW Oxi 340i (2006-2012), and Hach HQ40d sensor system (2012-present).

Lakes Inarijärvi, Kallavesi, Konnevesi, Näsijärvi, Päijänne, Pielinen, and Pyhäjärvi are generally large lakes (surface area > 150 km^2) located throughout Finland, from southern Finland to the northern-most part of the country (Lapland). Lake Pesiöjärvi in the same area has a significantly smaller surface area than others (12.7 km^2). Lakes Konnevesi and Päijänne have two different temperature profile sites (Konnevesi: Näreselkä and Pynnölänniemi, Päijänne: Linnasaari and Päijätsalo). Temperature data were typically collected in the deepest part of the lake, or in case of large fragmented lakes, the deepest part of that particular area of the lake. Temperature measurements were collected manually using various instruments. Before the 1980s mercury thermometers were used, and measurements were collected every 5 m before and every 10 m after a depth of 20 m. Since 1980-1981, measurements have been made in 1 m intervals from the surface through 20 m, every 2 m from 20 to 50 m, and every 5 m past 50 m. HL Hydrolab Ab PT77A (approximately 1980-1995), DeltaOhm HD8601P (1995-2005), and HT Hydrotechnik Type 110 (2005-present) were used to collect temperature data. Unfortunately, site-specific documentation of devices used during different years are not available.

Lake Pyhäselkä (Pyhaselka) is a large, humic lake located in North Karelia, Finland. It is the northernmost basin of the Saimaa lake system. Temperature data were collected from the deepest point in the lake (Kokonluoto) in 5 m depth intervals beginning in 1962 between 8:00 and 16:00 using a thermometer in a Ruttner water sampler.

Central Europe

Lakes Annecy, Bourget, and Geneva are located in eastern France[35]. Temperature data were collected from the deepest point in the lake on a single date in late July or August each year between 9:30 and 11:00, beginning in 1991 for Lake Annecy, in 1984 for Lake Bourget, and in 1974 for Lake Geneva. In Lake Annecy, various multiparameter probes, including Meerestechnik Elektronik (1991-2001), CTD 90 (2003-2005), CTD 90M (2008-2011, 2013), and RBR (2012) were used for temperature measurements at depth intervals between 0.01 and

1.8 m. Temperature profiles were measured in Lake Bourget at depth intervals between 0.01 and 10 m using various multiparameter probes, including ISMA probe DNTC (1984-1985), Meerestechnik Elektronik ECO 236 (1986-1998), CTD SBE 19SeaCAT Profiler (1992-2002), and CTD SBE 19plus V2 SeaCAT (2003-2013). In Lake Geneva, water temperature was measured manually with a thermometer until 1990 from discrete depths of 5 to 10 m intervals through 50 m depth and approximately 50 m intervals for the rest of the water column. After 1990 various multiparameter probes were used for temperature measurements, including Meerestechnik Elektronik (1991-2001), CTD 90 (2002-2007), CTD 90M (2008-2011, 2013), and RBR (2012). Data for Annecy, Bourget, and Geneva are available[36] at https://data.inrae.fr/dataset.xhtml?persistentId=doi:10.15454/YOLA0Y.

The Cumbrian lakes in the English Lake District, Bassenthwaite Lake, Blelham Tarn, Derwent Water, Esthwaite Water, Grasmere, and Windermere North Basin, are located in northwest England. Temperature data were collected in midsummer (weeks 29-30) at the deepest point of each between 9:00 and 14:00 beginning in 1991. Temperature profiles were measured manually at depth intervals judged in the field depending on the stratification pattern and depth of the lake. Temperature was measured with various combined temperature/oxygen sensors, including a YSI 58 (1991-2002) and WTW Oxi 340 (2002-2013) in Windermere North Basin, and a YSI 58 (1991-2002), WTW Oxi 340i (2002-2010), and Hach HQ 30d and LDO probe (2010-2013) in all other lakes.

Lake Constance is located on the border of Germany, Switzerland, and Austria. Temperature profiles were measured at the deepest part (251 m) of the central basin (Upper Lake Constance) of the lake beginning in 1964, with measurements taken between 9:00 and 10:00 using a thermometer. Depth intervals between samples increased with depth, with measurements taken every 2.5-5 m through 20 m, every 10 m through 50 m, and every 50 m down to a depth of 250 m[37].

Lake Mondsee is located in the Lake District “Salzkammergut” of Austria. Temperature data were collected from the deepest point of the lake approximately monthly near noon beginning in 1968. Temperature measurements were usually measured at depth intervals of 2 m in the epilimnion and 5 to 10 m intervals in the hypolimnion using a thermometer housed in a Schindler sampler prior to 1998. Beginning in 1998, data were extracted from continuous YSI 6920 profiler readings, with a YSI 6600 used beginning in 2008 and a thermistor chain from 2010-2013.

Lake Müggelsee, located in Berlin, Germany was sampled weekly beginning in 1978 between 8:00 and 9:00. Temperature was measured every 0.5-1 m at the deepest part of the lake using a Hydrolab H2O sensor beginning in 1992, and a thermistor probe for years prior to 1992.

Lake Piburgersee is located in Tyrol, Austria. Temperature was measured using a calibrated thermometer every 3 m throughout the water column in the deepest part of the lake, beginning in 1970[38].

Plusssee (Plußsee) is located in northern Germany (Schleswig-Holstein). Temperature data were collected from the deepest point of the lake between 9:00 and 15:00 beginning in 1971. Temperature was measured manually in 1 m increments (from 0-15 m) or in 5 m increments (from 15-25 m) using a thermometer mounted into a Ruttner sampler prior to 1976, and after 1976 with a WTW temperature/dissolved oxygen probe.

Traunsee is a large and deep oligotrophic lake in the Salzkammergut lake district of Austria. Temperature data were collected at the deepest point of the lake between 9:00 and 12:00

beginning in 1965. Temperature was measured at 2 to 5 m intervals through 20 m, and at 20 m intervals through the rest of the water column using a mercury thermometer mounted in a 5-liter water sampler.

Lower Lake Zurich is located in Switzerland. Temperature profiles were measured at the deepest part of this lake (136 m) between 8:30 and 12:00 beginning in 1936. Measurements were taken at the deepest point in the lake using a range of sensors, mainly NTC thermistors (1936-2000). Beginning in 2001 various sondes were used, including FLP-10 multisonde (2001-2008), multisonde Hydrolab DS5 (2008-2015) at 0.5-1 m intervals through 30 m, 5 m intervals through 50 m, and 10 m intervals throughout the rest of the water column.

Southern Europe

Lake Garda is one of the largest lakes in Europe, and the largest Italian lake (368 km^2). Owing to its deep depth (350 m), Lake Garda is characterized by long periods of incomplete vertical winter water circulation, which are interrupted by full mixing of the water column after the occurrence of harsh winters. Limnological investigations have been carried out since 1991 in a pelagic station located at the point of maximum depth of the northwest basin. Profiles of water temperature were recorded during the summer months using multiparameter probes, namely Idronaut Ocean Seven 401 (1991-1997), Seacat SBE 19–03 (1998-2008), and Idronaut Ocean Seven 316Plus since 2009[25].

Lake Iseo is located in northern Italy (Lombardy Region). It is a deep mesotrophic lake (251 m), characterized by long periods of incomplete vertical winter water circulation[39]. Temperature was measured at the deepest point in the lake using an automatic thermistor probe coupled with an oxygen sensor from 1993 to 2011 with Microprocessor Oximeter WTW OXI 320 and from 2012 to 2016 with Microprocessor WTW multi 3410. Temperature was measured at discrete depths (at least 10 points) and all measurements were regularly checked with mercury-filled Celsius reversing thermometer.

Lake Lugano is located at the foothill of the Central Alps, on the border between Switzerland and Italy. The lake is divided into a northern and southern basin, which are separated by a causeway (built on a natural moraine). Due to reduced connectivity[40] (flow of approximately 0.38 km^3 $year^{-1}$ from north to south) and different morphometric characteristics, the two basins were considered separately in the data set. Temperature profiles were collected at sites near the deepest point of each basin. Temperature was measured using reversing thermometers from 1974 to 1979 and multiparameter probes thereafter (Hydropolyester HTP 77 during 1980-1985, Ocean Seven 401 during 1986-1993, Ocean Seven 316 during 1994-2015). As an exception, temperatures at depths greater than 100 m were also measured using a reversing thermometer between 1980-1985. Temperature was measured at discrete depths (at least 9 points for the northern basin and 7 points for the southern basin) from 1974-1986, whereas full temperature profiles with vertical resolution of 0.5-1 m were measured between 1987 and 2015.

Lake Maggiore is a deep lake located in northwestern Italy, south of the Alps. The lake lies almost totally in Italy while the watershed is shared almost equally between Italy and Switzerland. Lake Maggiore can be classified as holo-oligomictic, with complete overturns only occurring at the end of particularly cold and windy winters. Temperature data have been collected at the deepest point of the lake since 1981, usually between 10:00 and 12:00 (Ghiffa station, 360 m deep). Temperature has been measured at discrete depths of 0, 5, 10, 20, 30, 50 m, and every 50 m through 360 m using mercury-filled thermometers connected to the bottle used for water sampling[41].

Eastern Europe

Lakes Batorino, Myastro, and Naroch are located in the northwest part of Belarus, in the glacial landscape. Temperature data were collected monthly in the center of the lake during the vegetative season of May to October beginning in the 1950s and 60s. Measurements of water temperature were taken every 2 to 4 m through the water column between 9:00 and 14:00 with a mercury deepwater thermometer with a scale resolution of 0.1°C.

Russia

Lake Baikal is located in Siberia, Russia. Temperature data were collected from a station situated 2.8 km from the shoreline at a depth of 800 m near the Bolshie Koty settlement at depths of 0, 5, 10, 25, 50, 100, 150, 200, and 250 m between 9:00 and 12:00 from 1948-2016. Temperature was measured with a mercury thermometer inside a Van Dorn bottle.

Lake Glubokoe is located in Central European Russia, Moscow Province. Temperature profile data were collected from the deepest point of the lake from the surface through the maximum depth of the lake (30.9 m), with measurements every 5 m towards the bottom of the water column and every meter in the upper 10 m. Since 1982, water temperature was measured with a mercury thermometer; instrumentation prior to 1982 is unknown.

Kurilskoye Lake in Kamchatka, Russia was sampled beginning in 1942. Temperature profiles were measured in the deepest part of the lake (maximum depth 316 m) between 8:00 and 15:00. Various temperature sensors were used over time, including a reversing thermometer (1942-1965), bathythermograph (1980-2003), Hydrolab (2004-2008), and RINKO profiler (2009-2014).

Lake Shira is located in the south of Siberia, Russia. Temperature profiles were measured in the deepest part of the lake between 11:00 and 15:00 from the surface to the depth of 20-24 m with various temperature sensors including multisonde Hydrolab 4A (2000-2008), YSI 6600 (2009-2014), YSI Exo (2019-2020).

Middle East

Lake Kinneret is located in Israel (Jordan Valley). Temperature data were collected near the deepest point of the lake (Station A, approximately 42 m deep) between 7:00 and 16:00 from 1969-2013, measured every centimeter with an error of ±0.005°C, and averaged to every 1 m. Temperature measurements were taken from 1969 to 1986 using an underwater thermometer (Whitney-Montedoro), from 1987 to 2003 using a STD-12 Plus (Applied Microsystems), and from 2003 to 2013 using AML Oceanographic Minos•X.

Asia

Lake Biwa is located in the central part of the Japanese Archipelago (Shiga Prefecture, Japan). Temperature data were collected from a station near the deepest part of the lake (77 m, 35°18’34.2” N, 136°07’19.1” E) from 1958-2010. Temperature was mostly measured between 9:00 and 12:00 at 5 m intervals from 1959-2005 and at 1 m intervals beginning in 2006. Measurements were made using an electric thermometer (Murayama Denki ltd.) from 1958 to 1970, a thermistor thermometer (Shibaura electronics, HCB III) from 1970 to 1994, a CTD profiler (Alec electronics, ABT-1) from 1994 to 2006, and a CTD profiler (JFE Advantech, compact-CTD) from 2007 to 2010.

Australia

Lake Burley Griffin is a reservoir constructed in 1963 by damming the Molonglo River. It is located in the geographic center of Canberra, the capital of Australia. Temperature data were collected from the deepest point (17 m), of the reservoir, near the dam wall. Profiles were

measured in 1 m depth intervals (reduced to 3 m intervals in 1992) between 8:45 and 16:15 from 1982-2011 by the National Capital Authority.

Lakes Samsonvale (North Pine) and Somerset are located on the east coast of Australia, in southeast Queensland. Temperature in each lake was measured at a site approximately 100 m from the dam wall. Samsonvale's (North Pine's) temperature was measured using a YSI 6560 sensor on a YSI 6600 V2 sonde beginning in 2009 continuously over a 24-hour period at 1 m intervals. Prior to 2009, temperature was measured via a thermistor string with various unknown instruments. Somerset's temperature profiles from 2000 to February 2009 were measured using temperature sensors on a thermistor string, spaced at 0.5 m intervals through 3 m, 1 m intervals through 7 m, 2 m intervals through 17 m, and 3 m intervals for the rest of the water column. From February 2009, it changed to a VPS (using a YSI 6560 sensor on a YSI 6600 V2 sonde), and in August 2016 to an EXO sensor.

New Zealand

Lakes Brunner and Taupo are located in New Zealand, in the West Coast and Waikato regions, respectively. Temperature profiles were measured at the deepest part of these lakes between 9:00 and 16:00, beginning in the early 1990s. Temperature was measured by lowering CTD profilers through the water column, using an YSI EXO sonde (Brunner) and RBR profiler (Taupo).

Lakes Okareka, Okaro, Okataina, Rerewhakaaitu, Rotoehu, Rotoiti, Rotoma, Rotorua, Tarawera, and Tikitapu are located in Rotorua, Bay of Plenty, New Zealand. Temperature profiles were measured between 10:00 and 14:00 in the central basin using Seatech CTD casts with a Seabird 19Plus or 19PlusV2 beginning in 2003. Temperature was measured at a frequency of 4 Hz during each cast and data were binned to 1 m depth intervals. Profiles before 2003 were measured in 1 m depth intervals with either a YSI Water Quality Logger 3800 or YSI Sonde model 3815.

Antarctica

Lakes Heywood (1962-1995), Moss (1972-2003), and Sombre (1973-2003) are located in the South Orkney Islands, Antarctica. Temperature data from these lakes were collected using a Mackareth-type probe at 1-2 m intervals in the deepest part of the lake. A single profile in December or January was selected per year from each of these lakes.

Data Records

Data are presented in two comma delimited files (Data Citation 1). The first contains the pertinent metadata for each lake ("SiteInformation.csv"), including information about the source and contacts for each lake, sampling details, and the geographic, morphometric, and water quality characteristics (Table 1). The second contains the interpolated vertical temperature profiles from each summer for each lake ("TempProfiles.csv"). These two files can be linked with the LakeID column present in each file. Both files are available at the Environmental Data Initiative, accessible at https://portal.edirepository.org/nis/mapbrowse?scope=edi&identifier=705.

Technical Validation

Quality control and assurance of temperature profile data was completed iteratively at multiple steps to ensure quality of all data. Original data were visually inspected following interpolation and binning to 0.5 m increments using contour maps to assess data accuracy over depth and time. At this stage, any data points that appeared inaccurate were removed and then linear interpolation was re-run to fill in the missing data gaps. We used the same process to visually check vertical temperature data over depth and time following selection of

single summer profiles for each lake. We also visually inspected time series plots of surface and deepwater temperature for each lake over time as an additional quality check. Any suspect vertical temperature profiles were removed, and, when possible, replaced with another temperature profile from the same lake with a similar sampling date.

Code Availability

All data compilation and creation of figures were conducted in R version 4.0.2[42]. R code can be found at https://www.github.com/rmpilla/GlobalTempProfileData.

Acknowledgements

This work was conceived at the Global Lake Ecological Observatory Network (GLEON), and benefited from continued participation and travel support from GLEON. This manuscript is dedicated to the late Karl Havens and Alon Rimmer, who provided data for this manuscript. Funding and support for this work came from the following sources: the Belarus Republican Foundation for Fundamental Research; the IGB Long-term Ecological Research Programme; SOERE OLA, AnaEE-France, INRA Thonon les Bains, SILA (Syndicat Mixte du Lac d'Annecy), CISALB (Comité Intercommunautaire pour l'Assainissement du Lac du Bourget), and CIPEL (Commission Internationale pour la protection des eaux du Léman); Shiga Prefectural Fisheries Experiment Station (SPFES); Castle Lake Environmental Research and Education Program, University of Nevada at Reno and UC Davis; the Flathead Lake Monitoring program funded through a consortium of state and private funds, and thank the generous citizens of Flathead Lake for their continued support of lake monitoring; the Institute for water ecology, fish biology and lake research and the Institute for Limnology of the Austrian Academy of Sciences (until 2011), and acknowledge the sampling efforts by many individuals over the long period of investigation, especially H. Gassner, M. Luger, H. Ficker, and R. Kurmayer; the EC project "Response of European Freshwater Lakes to Environmental and Climatic Change" (REFLECT, ENV4-CT97-0453), the EC-project "Climate Impacts on European Lakes" (CLIME, EVK1-CT-2002-00121), the project "Risk Analysis of Direct and Indirect Climate effects on deep Austrian Lake Ecosystems" (RADICAL) funded by the Austrian Climate and Energy Fund (No. K09ACK00046) – Austrian Climate Research Programme (ACRP, http://www.klimafonds.gv.at); O. Garcia and E. Bocel for data analysis and management; D. Cabrera, M.W. Dix, G. Ochaeta, S. van Tuylen, M. Orozco, E. Symonds for sampling efforts; NSF grant No. 0947096 to E. Rejmankova, U.S. PeaceCorps and Ministerio de Ambiente y Recursos Naturales of Guatemala; H. Swain, L. Battoe, K. Main, N. Deyrup (Archbold Biological Station), the Florida Lakewatch program, E. Gaiser (Florida International University); the Crater Lake National Park Long-Term Limnological Monitoring Program; the City of Tulsa (R. West and A. Johnson), the Grand River Dam Authority (R. M. Zamor), W.M. Matthews and US ACE (T. Clyde), and the Oklahoma Water Resources Board; Bay of Plenty Regional Council; Ministry of Business, Innovation and Employment: Enhancing the Health and Resilience of New Zealand lakes (UOWX1503); the field and laboratory staff of the South Florida Water Management District for collecting and analyzing the samples; the Norwegian Water Resources and Energy Directorate (NVE), by courtesy of Å. S. Kvambekk; the Lake Champlain Long-term Monitoring program (VT DEC and NY DEC); the National Capital Authority, ACT, Australia; Ontario Ministry of Environment, Conservation and Parks; FirstLight Power Resources and Friends of the Lake, especially G. Bollard and R. White; the Finnish Environment Institute SYKE database (Hertta) and S. Mitikka; N. Spinelli and the Lake Wallenpaupack Watershed Management District; Lakes Heywood, Moss, and Sombre: Long-Term Monitoring of Signy Lake Chemistry by BAS 1963-2004. Ref: GB/NERC/BAS/AEDC/00063, and dataset supplied by the Polar Data Centre under Open Government License © NERC-BAS, Lake Nkugute: Beadle (1966), CLANIMAE project funded by the Belgian Science Policy Office; Dr. L. Garibaldi; NSF awards #1418698 and North Temperate Lakes LTER NTL-LTER #1440297; NSERC Canada, Canada Research Chairs, Canada Foundation for Innovation, Province of Saskatchewan, University of Regina, and Queen's University

Belfast; Commissione Internazionale per la protezione delle acque italo-svizzere, Ufficio della protezione delle acque e dell'approvvigionamento idrico del Canton Ticino; KamchatNIRO scientists; Natural Environment Research Council award number NE/R016429/1 as part of the UK-SCaPE programme delivering National Capability; U.S. NSF Arctic LTER DEB-1637459; Belgian Science Policy (Choltic, Climlake, Climfish); Ontario Ministry of Natural Resources' Harkness Laboratory of Fisheries Research, especially T. Middel; ax-Planck-Institute for Limnology Plön; staff at Erken Laboratory; Mohonk Preserve and D. Smiley; Lake Sunapee Protective Association; KLL database; International Commission for the Protection of Swiss-Italian Waters (CIPAIS) and the LTER (Long Term Ecological Research) Italian network, site ''Southern Alpine lakes'', LTER_EU_IT_008; staff and students at MECP's Dorset Environmental Science Centre; the LTER (Long-Term Ecological Research) Italian network, site ''Southern Alpine lakes'', IT08-005-A (http://www.lteritalia.it), with the support of the ARPA Veneto; Prof. L. Chapman, McGill University (Montréal, Québec, Canada); Amt für Abfall, Wasser, Energie und Luft (AWEL) of the Canton of Zurich; grants of RSCF project # 18-44-06201 and # 20-64-46003, of Russian Ministry of Higher Education and Research (projects № FZZE-2020-0026; № FZZE-2020-0023), and of Foundation for support of applied ecological studies «Lake Baikal» (https://baikalfoundation.ru/project/tochka-1/); National Science Foundation Long Term Research in Environmental Biology program (DEB-1242626); the National Park Service (the Inventory and Monitoring Program as well as the Air Resources Division) and Acadia National Park and the Acadia National Park monitoring program; Gordon and Betty Moore Foundation, the Andrew Mellon Foundation, the US National Science Foundation and the Bristol Bay salmon processors; J. Franzoi, G. Larsen, and S. Morales, and the LTSER platform Tyrolean Alps, which belongs to the national and international long-term ecological research network (LTER-Austria, LTER Europe and ILTER); Institut für Seenforschung, Langenargen (Internationale Gewässerschutzkommission für den Bodensee - IGKB); University of Michigan Biological Station (A. Schubel) and Cooperative Institute for Great Lakes Research (R. Miller); the Belgian Science Policy Office (BELSPO) is acknowledged for supporting research on Lake Kivu through the research project EAGLES (CD/AR/02A); US National Science Foundation awards 9318452, 9726877, 0235755, 0743192 and 1255159; West Coast Regional Council, the Bay of Plenty Regional Council, and Waikato Regional Council, and NIWA; D. Schindler (funding and data access) and B. Parker (logistical support and data management); Swedish Infrastructure for Ecosystem Science (SITES) and the Swedish Research Council under the grant no 2017-00635; NSF DEB 1754276 and NSF DEB 1950170, and Lacawac Sanctuary and Biological Field Station; Russian Foundation for Basic Research, grant № 19-04-00362A and № 19-05-00428.

Author contributions

R.M.P. led development of the manuscript, and organized, processed, verified, and collated data. E.M.M. led acquisition and organization of lake characteristic information and methods, and data deposition. C.E.W. led initial data acquisition. R.M.P., E.M.M., and C.E.W. wrote the manuscript. C.E.W., B.V.A., R.A., O.A., E.B., S.B., S.C., W.C.-M., S.P.D., M.A.D., M.T.D., N.A.F., H.F., N.K.F., E.E.G., S.F.G., M.J.G., K.D.H., D.P.H., K.H., D.O.H., H.H., S.N.H., T.H.H., H.H., P.D.F.I., K.D.J., W.B.K., J.K., L.B.K., J.K., N.M.K., O.K., B.M.K., P.R.L., B.L., F.L., E.V.L., N.R.L., M.S.L., S.C.M., S.M., C.M., P.M., S.J.M., B.M., D.M.-N., L.P., D.C.R., A.R., M.G., D.Y.R., J.A.R., O.O.R., S.S., NS., J.E.S., J.S., É.S.-T., D.E.S., S.V.S., E.A.S., L.M.S., R.S., D.S., K.E.S., H.S., J.M.T., W.T., M.A.T., A.P.T., K.T., M.J.V., P.T., R.D.V., J.W., K.W., G.A.W., E.S.Z., and T.V.Z provided lake temperature profile data, lake characteristics data, summarized sampling methods, and provided feedback on the manuscript.

Competing interests

The authors declare no competing interests.

Tables

Table 1. Column names and descriptions of site metadata file ("SiteInformation.csv").

Header	Description
SiteID	Identifying number given to each lake or set of lakes whose data were managed by the same group
LakeID	Identifying number given to each lake. This ID is unique to each lake, and can be used as a primary key to link the SiteInformation table to the data in the TempProfiles table
LakeName	Name (most common) by which lake is known
AlternateLakeName	Alternate names by which lake is known (if relevant)
LakeOrReservoir	Defines if body of water is identified as a natural lake or human-made reservoir
CountryOfLake	Country in which lake can be found
Region	Geographical region in which lake can be found
Latitude	Latitude of lake/approximate sampling site
Longitude	Longitude of lake/approximate sampling site
Elevation_m	Elevation of lake above sea level in meters
SurfaceArea_km2	Surface area of lake in square kilometers
Volume_km3	Volume of lake in cubic kilometers
MaxDepth_m	Maximum depth of lake in meters
MeanDepth_m	Mean depth of lake in meters
Secchi_m	Average Secchi depth of lake in meters (representative of recent years)
Chlorophyll_ug_L	Average chlorophyll concentration of lake in micrograms per liter (representative of epilimnion/surface waters in recent years)
TotalPhosphorus_ug_L	Average total phosphorus concentration of lake in micrograms per liter (representative of epilimnion/surface waters in recent years)
DissolvedOrganicCarbon_mg_L	Average dissolved organic carbon concentration of lake in milligrams per liter (representative of epilimnion/surface waters in recent years)
Contributor	Name(s) of data set contributor(s). If more than one main data contributor, names are separated by

	semicolons
ContributorContact	Contact (e-mail) of data set contributor(s). If more than one main data contributor, e-mails are separated by semicolons
ContributorInstitution	Institution(s) with which contributor(s) are associated. If more than one main data contributor, institutions are separated by semicolons

Data Citations

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