Lake surface temperature [in "State of the climate in 2015"]

Article

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Lake surface temperature [in "State of the Climate in 2015"]

Authors

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Lake summer surface water temperatures (LSSWT) in 2015 strongly reflected the decadal patterns of warming noted in the scientific literature. Northern Hemisphere summer refers to July–September whereas Southern Hemisphere summer refers to January–March. A recent worldwide synthesis of lake temperatures (O'Reilly et al. 2015) found that LSSWTs rose by, on average, 0.034°C yr^{-1} between 1985 and 2009, ~1.4 times that of the global surface air temperature (SAT) in general. Data from lakes in various regions collated here show that during 2009–15 lake temperatures continued to rise.

During 2015, LSSWT of many lakes exceeded their 1991–2010 averages by 1°C or more (Online Fig. S2.6; Plate 2.1c). Strong warm anomalies in LSSWT were most prominent in central Europe [Austria, Switzerland, and Poland (data from the Institute of Meteorology and Water Management, Poland)], where anomalies above 1°C were recorded. The hot central European summer (JJA) of 2015 (sections 2b6 7f, and Sidebar 7.1) is reflected in relatively high mean LSSWTs in three Austrian lakes (Mondsee, Neusiedler See, Wörthersee; Fig. 2.6; Online Fig. 2.6) with anomalies up to +1.6°C. Similarly, satellite-based LSSWT anomalies of 25 European lakes in and near the Alps were in excess of 1.0°C in 2015 (Fig. 2.7a), the second warmest anomaly year since the record summer of 2003 (Beniston 2004). High LSSWTs were also observed in other regions of the world (Plate 2.1c; Online Fig. 2.6), with anomalies for lakes in Seattle [Washington (state), U.S.], for example, up to +1°C in 2015.

LSSWTs are influenced by a combination of broad climatic variability and local characteristics, so regional and subregional differences in LSSWTs are common. LSSWTs in Britain and Ireland during 2015 were ~0.6°C below average, in contrast to central Europe. This likely reflects cool anomalies in SAT in early and mid-2015 (e.g., www.met.ie/climate/Monthly Weather/clim-2015-ann.pdf).

Although the Great Lakes (United States and Canada) have warmed faster than SAT in recent decades, the 2015 LSSWTs were relatively cool. This is attributable to above-average winter ice cover during 2014/15, which shortened the warming season. The annual maxima of percent ice cover (Great Lakes

Environmental Research Laboratory; www.glerl.noaa.gov/) in 2014 (92.5%) and 2015 (88.8%) were substantially above the 1973–2015 average (53.2%). These were the first consecutive high-ice-cover years since the 94.7% maximum ice coverage recorded in 1979. The strong El Niño conditions of 2015 lessen the chance that 2016 will imitate 2014 and 2015.

Despite these recent cooler LSSWTs, the average warming rate for the Great Lakes is approximately 0.05°C yr^{-1} (1979–2015). This rate contrasts with the Dorset lakes in Ontario, Canada (surface areas <100 ha), which do not show a statistically significant trend in LSSWT between 1980 and 2015. In 2015, LSSWT anomalies in these lakes were ~+0.6°C. These lakes display large interannual variation in LSSWT, mainly reflecting interannual differences in SAT, with strong agreement in high and low years.

The relationship between SAT and LSSWT can be complicated by several processes. For Lake Erken, Sweden, LSSWT is strongly influenced by water column mixing and precipitation, leading to a relatively weak relationship between SAT and LSSWT. The LSSWT of New Zealand's largest lake, Lake Taupo, is thought to be influenced by interannual variation in geothermal heating (de Ronde et al. 2002) and shows no significant trend. Furthermore, an analysis of the 47-year record (1969–2015) of LSSWT from Lake Kinneret, Israel, reveals warming of ~1.65°C over the period (~0.036°C yr^{-1}). Two factors explain most of the variability ($r^2 = 0.67$): SAT and water levels (Rimmer et al. 2011; Ostrovsky et al. 2013).

In recent years there has been a strong emphasis on investigating LSSWT warming, with only a few investigations focusing on the winter months (e.g., Dokulil et al. 2014) due to a lack of available data. Winter temperature changes can be quite distinct from LSSWT trends. For example, the regional average warming rate for lakes in Britain and Ireland is substantially higher during winter (0.028°C yr^{-1}; Fig. 2.7b) than in summer (0.018°C yr^{-1}; Fig. 2.6d). Future assessments that focus on all seasons will provide a more complete picture.

References

Beniston, M., 2004: The 2003 heat wave in Europe: A shape of things to come? An analysis based on Swiss climatological data and model simulations. *Geophys. Res. Lett.*, **31**, L02202, doi:10.1029/2003GL018857.

de Ronde, C. E. J., and Coauthors, 2002: Discovery of active hydrothermal venting in

Lake Taupo, New Zealand. *J. Volcanol. Geotherm.*, **115**, 257–275, doi:10.1016/S0377-0273(01)00332-8.

Dokulil, M. T., A. Herzig, B. Somogyi, L. Vörös, K. Donabaum, L. May, and T. Nõges, 2014: Winter conditions in European shallow lakes: A comparative synopsis. Est. *J. Ecol.*, **63**, 111–129, doi:10.3176 /eco.2014.3.01.

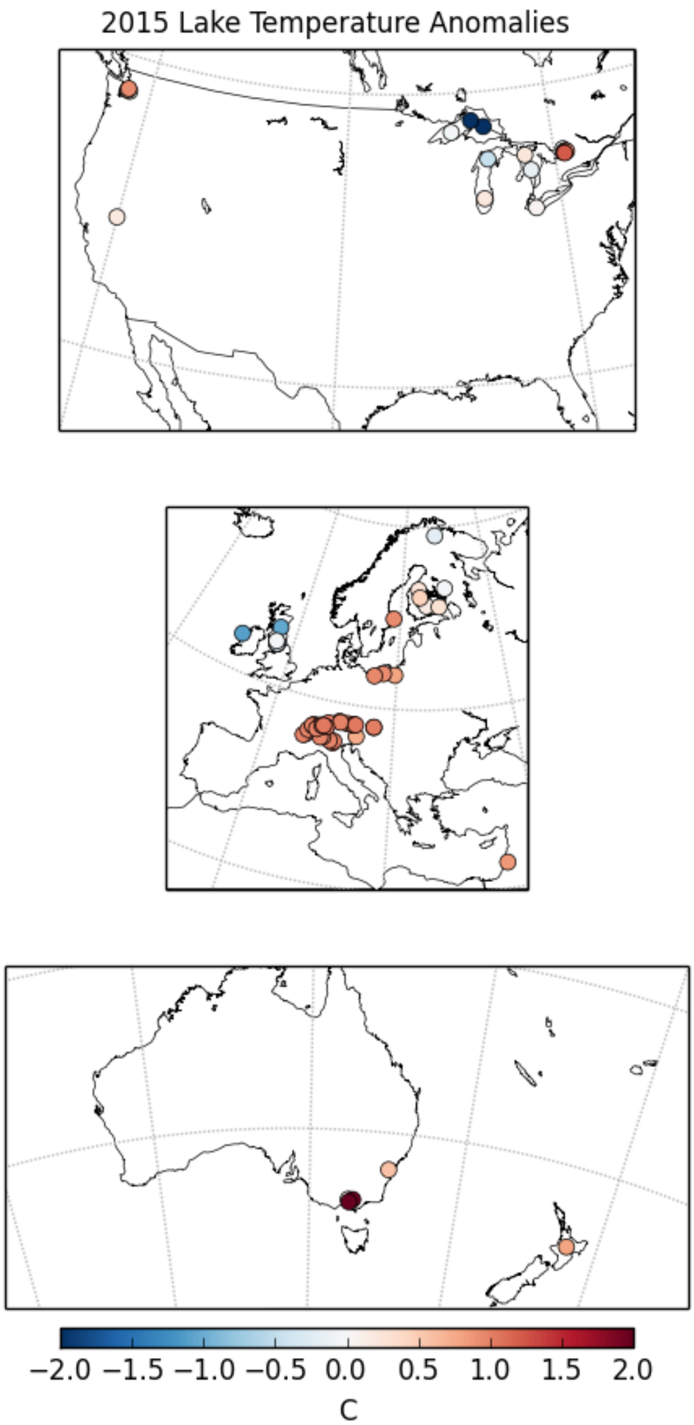
O'Reilly, C. M., and Coauthors, 2015: Rapid and highly variable warming of lake surface waters around the globe. *Geophys. Res. Lett.*, **42**, 10 771–10 781, doi:10.1002/2015GL066235.

Ostrovsky, I., A. Rimmer, Y. Z. Yacobi, A. Nishri, A. Sukenik, O. Hadas, and T. Zohary, 2013: Long- term changes in the Lake Kinneret ecosystem: The effects of climate change and anthropogenic factors. *Climatic Change and Global Warming of Inland Waters: Impacts and Mitigation for Ecosystems and Societies*, C. R. Goldman, M. Kumagai, and R. D. Robarts, Eds., Wiley, 271–293.

Riffler, M., G. Lieberherr, and S. Wunderle, 2015: Lake surface water temperatures of European Alpine lakes (1989–2013) based on the Advanced Very High Resolution Radiometer (AVHRR) 1 km data set. *Earth Syst. Sci. Data*, **7**, 1–17, doi:10.5194/essd-7-1-2015.

Rimmer, A., G. Gal, T. Opher, Y. Lechinsky, and Y. Z. Yacobi, 2011: Mechanisms of long-term variations of the thermal structure in a warm lake. *Limnol. Oceanogr.*, **56**, 974–988, doi:10.4319/lo.2011.56.3.0974.

List of Figures



Online Fig. S2.6. Maps of the 2015 *in situ* and satellite-derived lake summer (JAS in northern hemisphere, JFM in southern hemisphere) surface temperatures relative to the 1991-2010 anomaly for North America (top), Europe (middle), and Australia and New Zealand (bottom).

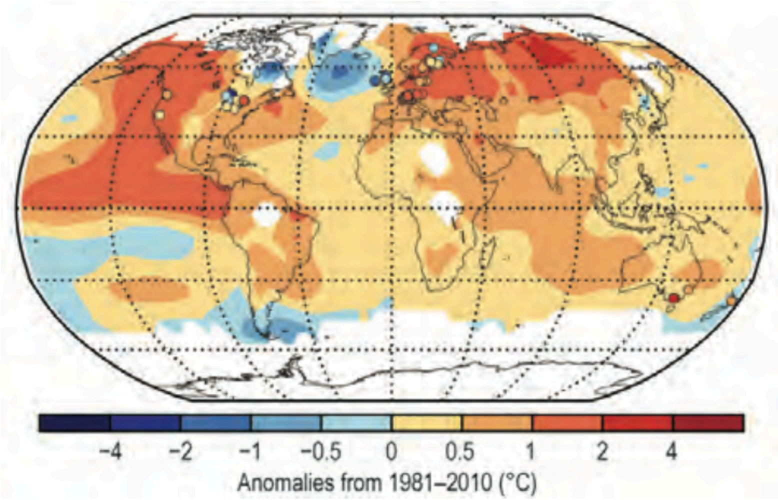


Plate 2.1c. NOAA/NCEI surface temperature (contoured) and lake temperatures (circles).

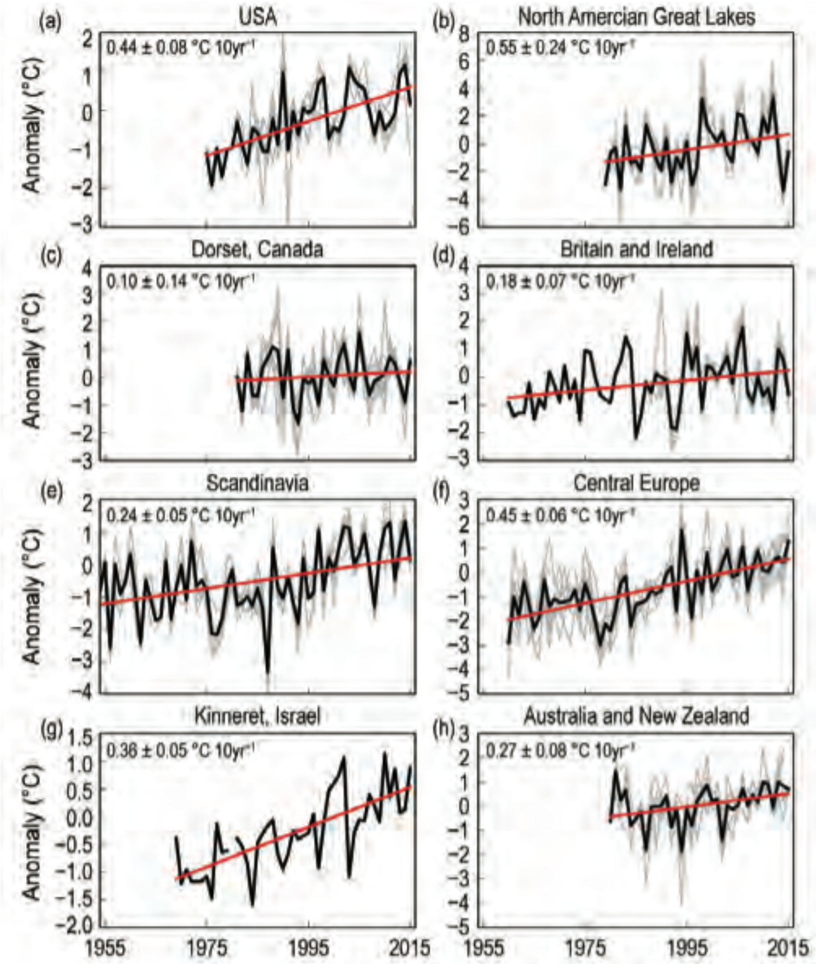


Fig. 2.6. Lake summer (Jul–Sep in Northern Hemisphere, Jan–Mar in Southern Hemisphere) surface water temperature anomalies relative to 1991–2010 for (a) the United States (Washington, Sammamish, Union, and Tahoe); (b) the Laurentian Great Lakes, [Superior (buoys 45001, 45004, 45006), Michigan (buoys 45002, 45007), Huron (buoys 45003, 45008), and Erie (buoy 45005)]; (c) Dorset, Ontario, Canada [Blue Chalk, Chub, Crosson, Dickie, Harp, Heney Plastic, and Red Chalk (East and Main basin)]; (d) Britain and Ireland [Bassenthwaite Lake, Blelham Tarn, Derwent Water, Esthwaite Water, Lough Feeagh, Grasmere, Loch Leven, and Windermere (North and South basins)]; (e) Scandinavia (Erken, Inarijärvi, Kitusjärvi, Lappajärvi, Päijänne, Pielinen, and Saimaa); (f) central Europe (Charzykowskie, Jeziorak, Lubie, Mondsee, Neusiedler See, Wörthersee, and Zurich); (g) Israel (Kinneret); and (h) Australia and New Zealand (Burragorang, Cardinia, Sugarloaf, Taupo, and Upper Yarra). Gray lines indicate the temperature for each individual lake and the thick black line indicates the average lake temperature for the specified region. The trend

for the regionally averaged temperatures is shown in red, and the equation describing the change is presented. Note that the warming rates are not comparable among the different regions due to the different time periods shown.

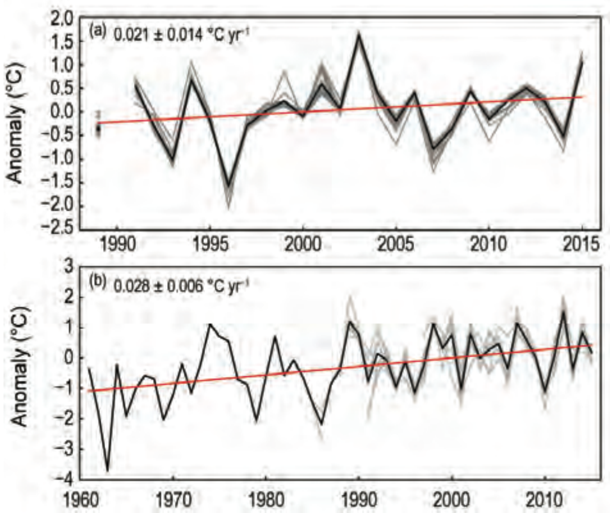


Fig. 2.7. Satellite-derived lake surface water temperature anomalies for (a) summer (Jul–Sep; 1991–2015) for European Alpine lakes (all natural water bodies in or near the Alps larger than 14 km^2; Riffler et al. 2015) and (b) winter (Jan–Mar, 1961–2015) for Britain and Ireland (base period: 1991–2010). Gray lines indicate the temperature for each individual lake and the thick black line indicates the average lake temperature for the region. The trend for the regionally averaged temperatures is shown in red, and the equation describing the change is presented. The lakes included are the same as those shown in Online Fig. 2.6 and Plate 2.1c.