In the Great Lakes, heat waves and cold spells are on the rise

Modeling of climate data reveals an ongoing phase of longer, more frequent, and more intense lake temperature extremes that began with a record-breaking El Niño event in 1997–98.

A record-setting cold snap hit portions of North America in the first few months of 2014 when a disruption of typical atmospheric circulation patterns extended the range of the polar vortex southward. The prolonged cold spell lowered the surface temperatures of the Great Lakes (shown in figure 1). Evaporation from the lakes slowed for several years, which contributed to a rise in the lake surface level from 2015 to 2020 that produced widespread flooding in the region. With a span of hundreds of kilometers and coastlines that border Indigenous communities and major cities in the US and Canada, the Great Lakes have a widespread impact on humans and ecosystems.

Extreme temperature events leave less time for adaptation than do incremental changes, and they can have radiating effects on water levels, regional climate, and fishery and ecosystem health. Those widely felt impacts motivated Hazem Abdelhady, of the Cooperative Institute for Great Lakes Research at the University of Michigan, and colleagues to take a deeper look at how climate change has affected the frequency and intensity of extreme events.

Comprehensive lake surface temperature data collected by satellites go back only to 1995, so Abdelhady and colleagues turned to another dataset that goes back to 1940. Produced by the European Centre for Medium-Range Weather Forecasts, the ERA5 dataset assimilates historical weather and climate data into physics-based models to estimate historical weather conditions and fill in gaps in global coverage. The dataset was the input to a 3D model of the Great Lakes that accounts for hydrodynamics of the lakes and atmosphere, heat fluxes, ice formation, and albedo changes.

With their model, Abdelhady and colleagues compiled a detailed estimate of lake surface temperatures going back eight decades, as shown in figure 2. To focus their statistical analysis on the extremes, they removed long-term trends, including a gradual temperature increase caused by global warming. They found that both heat waves and cold spells have become more frequent, longer, and stronger. Lake Superior, the deepest and coldest of the lakes, saw the most dramatic jump in heat waves, with a 258% increase in the average of the summed intensity and duration of such events between 1996 and 2022 compared with 1941–96. Lake Erie, the shallowest and warmest of the lakes, showed the greatest increase in cold spells.

The researchers' analysis revealed connections to distant, larger-scale cli-

FIGURE 1. THE FIVE GREAT LAKES, captured in this satellite image from 15 March 2020, form the largest lake system in the world, and they exert considerable influence over the regional climate. Analysis of long-term climate data reveals that large-scale ocean circulation patterns, including El Niños, have driven changes in the temperatures of the inland lake system. (Image created from modified Copernicus Sentinel data and processed by the European Space Agency/CC BY-SA 3.0 IGO.)

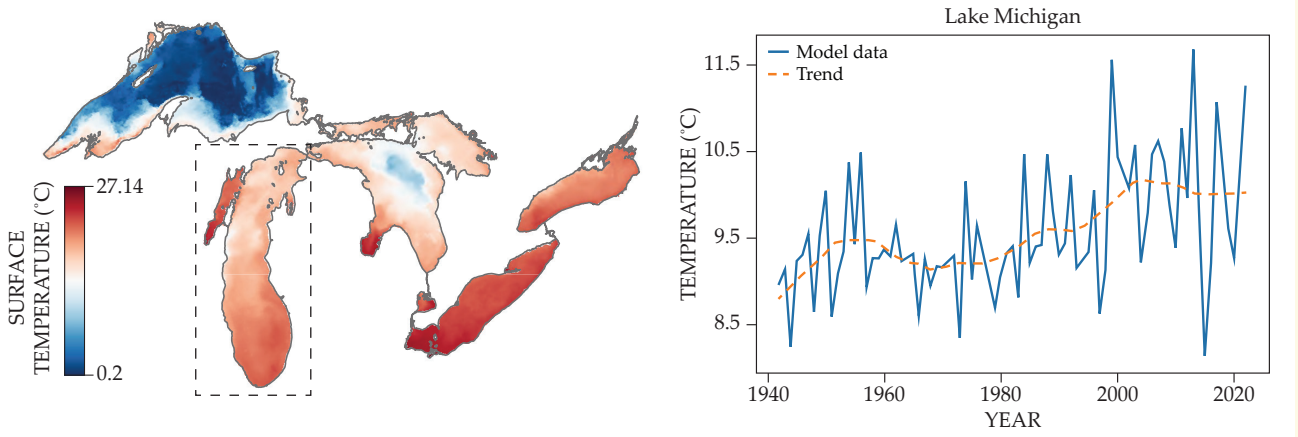

FIGURE 2. A SNAPSHOT OF LAKE SURFACE TEMPERATURES from 18 July 2018 **(left)** from the hydrodynamic–ice model used by researchers to reconstruct the past eight decades of Great Lakes water temperatures. A graph of the average lake surface temperatures for Lake Michigan over the past 80 years **(right)** shows both extreme events and a longer-period trend. (Figure adapted from H. U. Abdelhady et al., *Commun. Earth Environ.* **6**, 375, 2025.)

mate systems. Lake Erie and Lake Ontario both shifted to a phase of greater cold extremes in the mid 1970s, corresponding to a major shift in Pacific Ocean temperature patterns in 1976 that yielded two decades of warmer water off the northwest coast of North America. And all the lakes moved into a phase of more intense heat waves starting in the 1990s. The researchers attribute that phase shift to a record-setting El Niño event in 1997–98.

"The Great Lakes got very, very warm, and they stayed warm all the way until that Arctic polar vortex in 2014," says Andrew Gronewold, who leads the Global Center for Climate Change and Transboundary Waters and was part of the research team.

"It gets at this idea that some of the changes we experience in the Great Lakes as a consequence of global warming are happening in abrupt shifts rather than as a long-term trend," says Gronewold. "From a management and adaptation perspective, that makes a huge difference for our lives, for our safety, and for ecological health." Funding and using forecasts of such shifts could provide guidance for policymakers to inform adaptation strategies for future changes. (H. U. Abdelhady et al., *Commun. Earth Environ.* **6**, 375, 2025.)

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