Climate change, lake temperature, and reservoir evaporation

John D. Lenters, Ph.D.
Senior Scientist, LimnoTech

LimnoTech
Water Environment | Scientists Engineers

Jordan S. Read, Sapna Sharma, Catherine M. O'Reilly, Stephanie Hampton, Derek Gray, Peter B. McIntyre, Simon J. Hook, Philipp Schneider, Piet Verburg, Peter D. Blanken, and GLTC Contributors

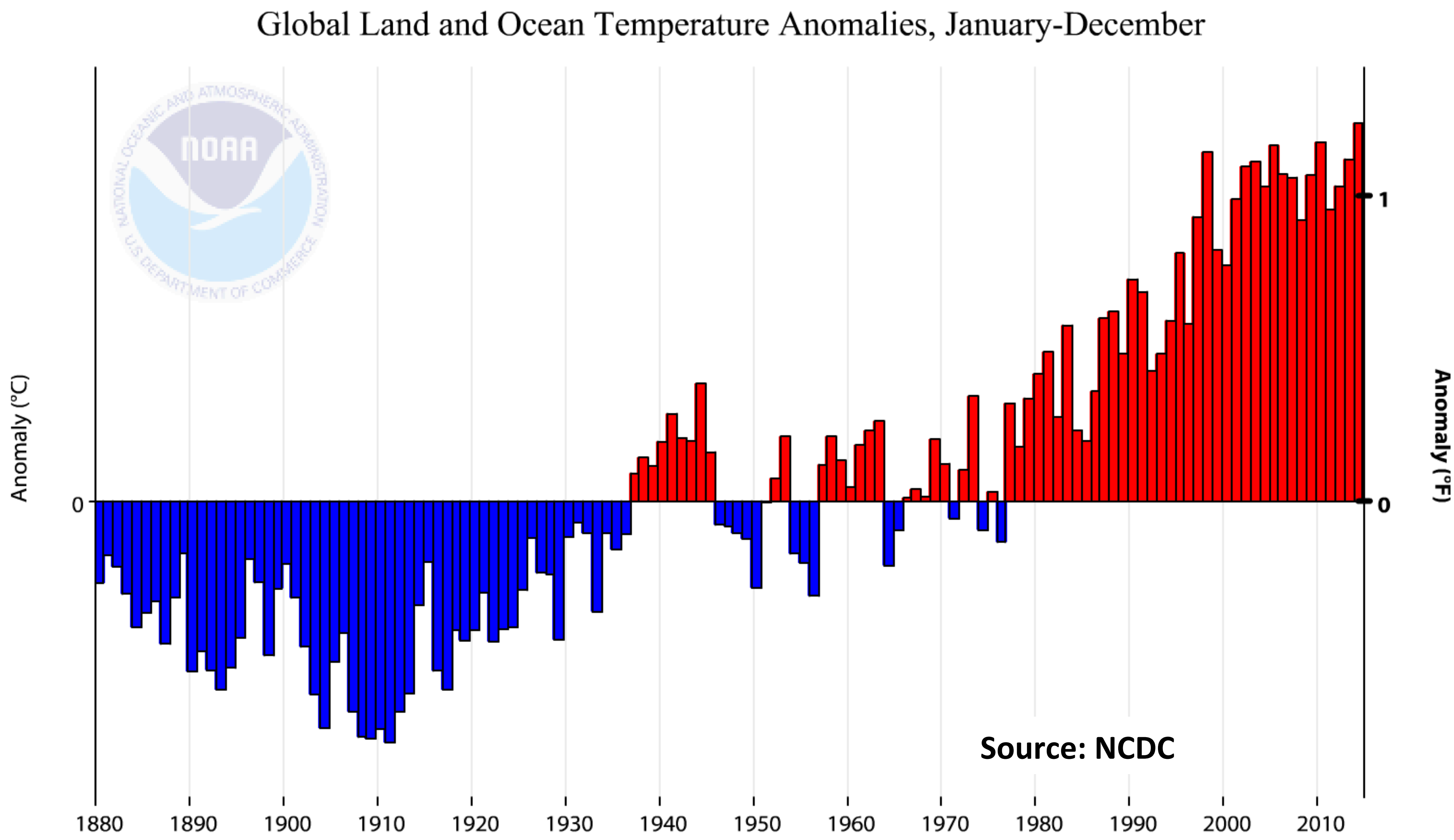
University of Colorado Boulder

GLTC
Global Lake Temperature Collaboration

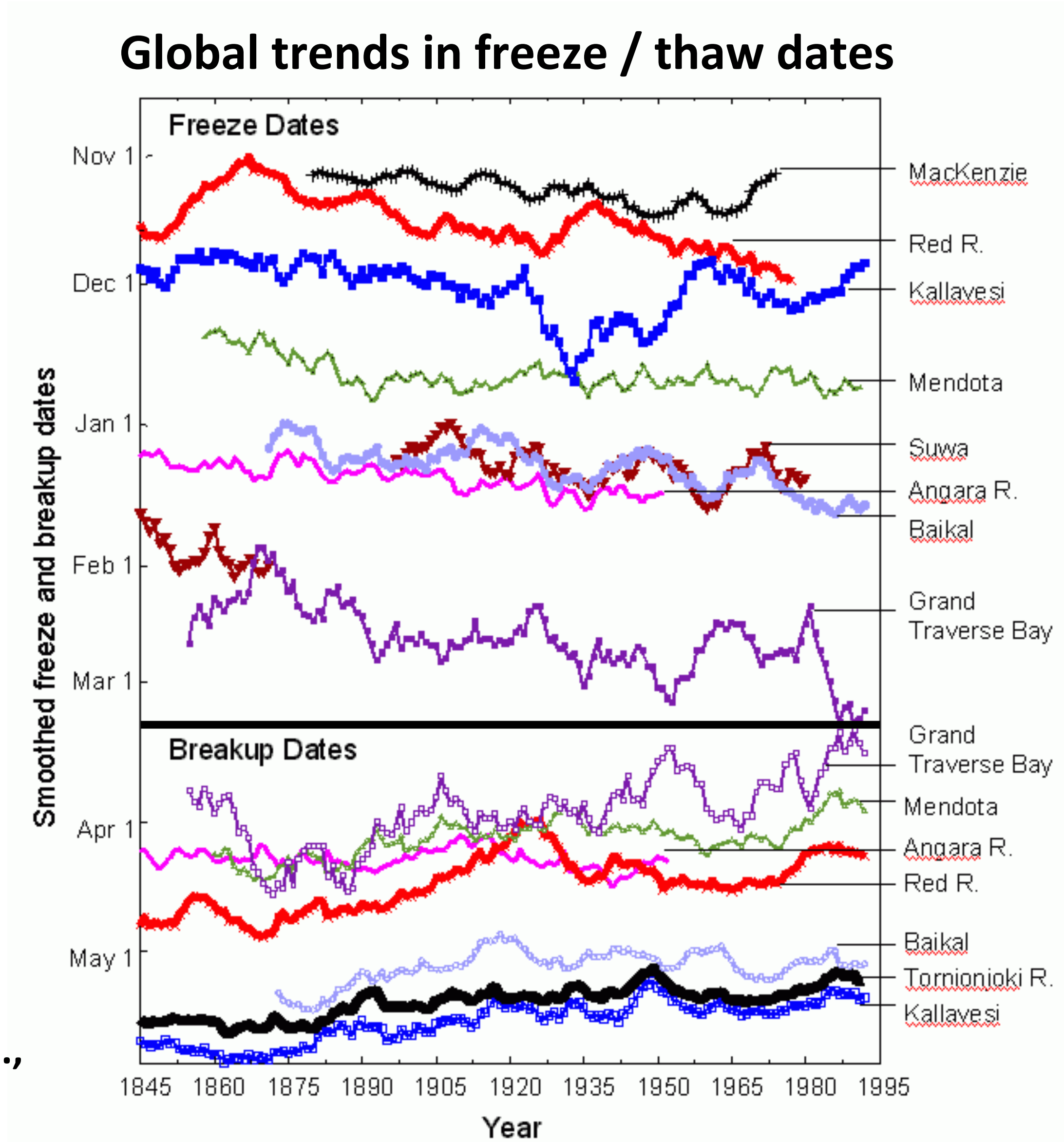
GLTC Contributors

Sapna Sharma, Derek K. Gray, Jordan S. Read, Catherine M. O'Reilly, Philipp Schneider, Anam Qudrat, Corinna Gries, Samantha Stefanoff, Stephanie E. Hampton, Simon Hook, John D. Lenters, David M. Livingstone, Peter B. McIntyre, Rita Adrian, Mathew G. Allan, Orlane Anneville, Lauri Arvola, Jay Austin, John Bailey, Jill S. Baron, Justin Brookes, Yuwei Chen, Robert Daly, Martin Dokulil, Bo Dong, Kye Ewing, Elvira de Eyto, David Hamilton, Karl Havens, Shane Haydon, Harald Hetzenauer, Jocelyne Heneberry, Amy L. Hetherington, Scott N. Higgins, Eric Hixson, Lyubov R. Izmest'eva, Benjamin M. Jones, Küllli Kangur, Peter Kasprzak, Olivier Köster, Benjamin M. Kraemer, Michio Kumagai, Esko Kuusisto, George Leshkevich, Linda May, Sally MacIntyre, Dörthe Müller-Navarra, Mikhail Naumenko, Peeter Noges, Tiina Noges, Pius Niederhauser, Ryan P. North, Andrew Paterson, Pierre-Denis Plisnier, Anna Rigosi, Alon Rimmer, Michela Rogora, Lars Rudstam, James A. Rusak, Nico Salmaso, Nihar R. Samal, Daniel E. Schindler, Geoffrey Schladow, Silke R. Schmidt, Tracey Schultz, Eugene A. Silow, Dietmar Straile, Katrin Teubner, Piet Verburg, Ari Voutilainen, Andrew Watkinson, Gesa A. Weyhenmeyer, Craig E. Williamson, Kara H. Woo, Catherine M. O'Reilly, Sapna Sharma, Derek K. Gray, Stephanie E. Hampton, Jordan S. Read, Rex J. Rowley, Philipp Schneider, John D. Lenters, Peter B. McIntyre, Benjamin M. Kraemer, Gesa A. Weyhenmeyer, Dietmar Straile, Bo Dong, Rita Adrian, Mathew G. Allan, Orlane Anneville, Lauri Arvola, Jay Austin, John L. Bailey, Jill S. Baron, Justin D. Brookes, Elvira de Eyto, Martin T. Dokulil, David P. Hamilton, Karl Havens, Amy L. Hetherington, Scott N. Higgins, Simon Hook, Lyubov R. Izmest'eva, Klaus D. Jöhnk, Külli Kangur, Peter Kasprzak, Michio Kumagai, Esko Kuusisto, George Leshkevich, David M. Livingstone, Sally MacIntyre, Linda May, John M. Melack, Dörthe C. Müller-Navarra, Mikhail Naumenko, Peeter Nõges, Tiina Nõges, Ryan P. North, Pierre-Denis Plisnier, Anna Rigosi, Alon Rimmer, Michela Rogora, Lars G. Rudstam, James A. Rusak, Nico Salmaso, Nihar R. Samal, Daniel E. Schindler, S. Geoffrey Schladow, Martin Schmid, Silke R. Schmidt, Eugene Silow, M. Evren Soylu, Katrin Teubner, Piet Verburg, Ari Voutilainen, Andrew Watkinson, Craig E. Williamson, Guoqing Zhang, John D. Lenters, David M. Livingstone, Catherine M. O'Reilly, Martin T. Dokulil, Gesa A. Weyhenmeyer, Philipp Schneider, Sapna Sharma, Elvira de Eyto, Rita Adrian, Scott N. Higgins, Pierre-Denis Plisnier, Nico Salmaso, Dietmar Straille, Bo Dong, Piet Verburg, George Leshkevich, Peter B. McIntyre, Jordan S. Read, Silke Schmidt, Peeter Nõges, Tiina Nõges, Benjamin M. Kraemer, Mathew Allan, Martin Schmid, Geoffrey Schladow, Sally MacIntyre, David Hamilton, Alon Rimmer, Orlane Anneville, Stephanie E. Hampton, Claude Duguay, Amy L. Hetherington, Dendy D. Lofton, James A. Rusak, Nihar R. Samal, Noemi Barabas, Justin Brookes, Robert C. Wilson, Derek K. Gray, Simon Hook, Mehmet E. Soylu

Global air temperature shows long-term, nonlinear warming

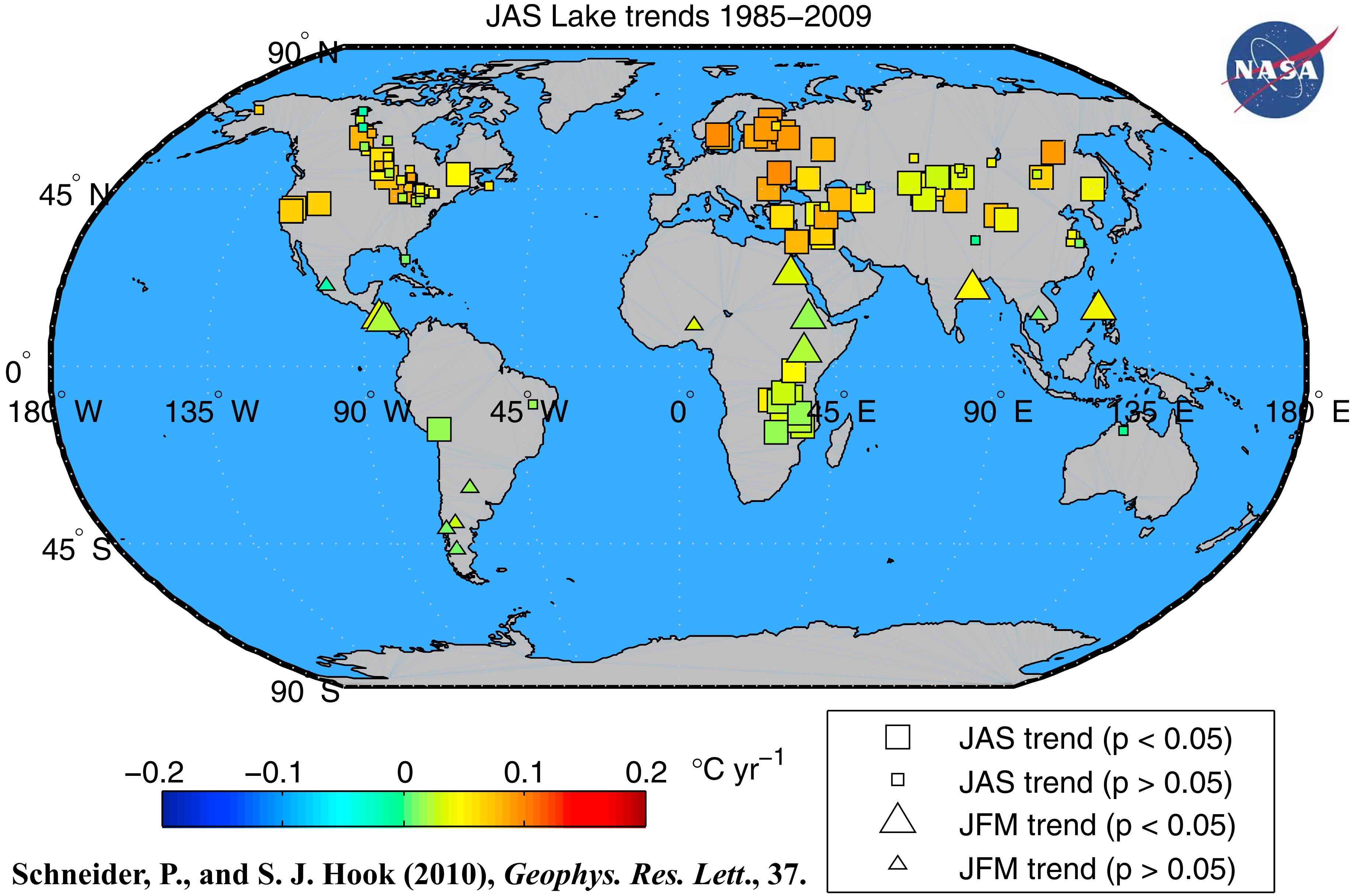


Lakes are responding, and losing ice



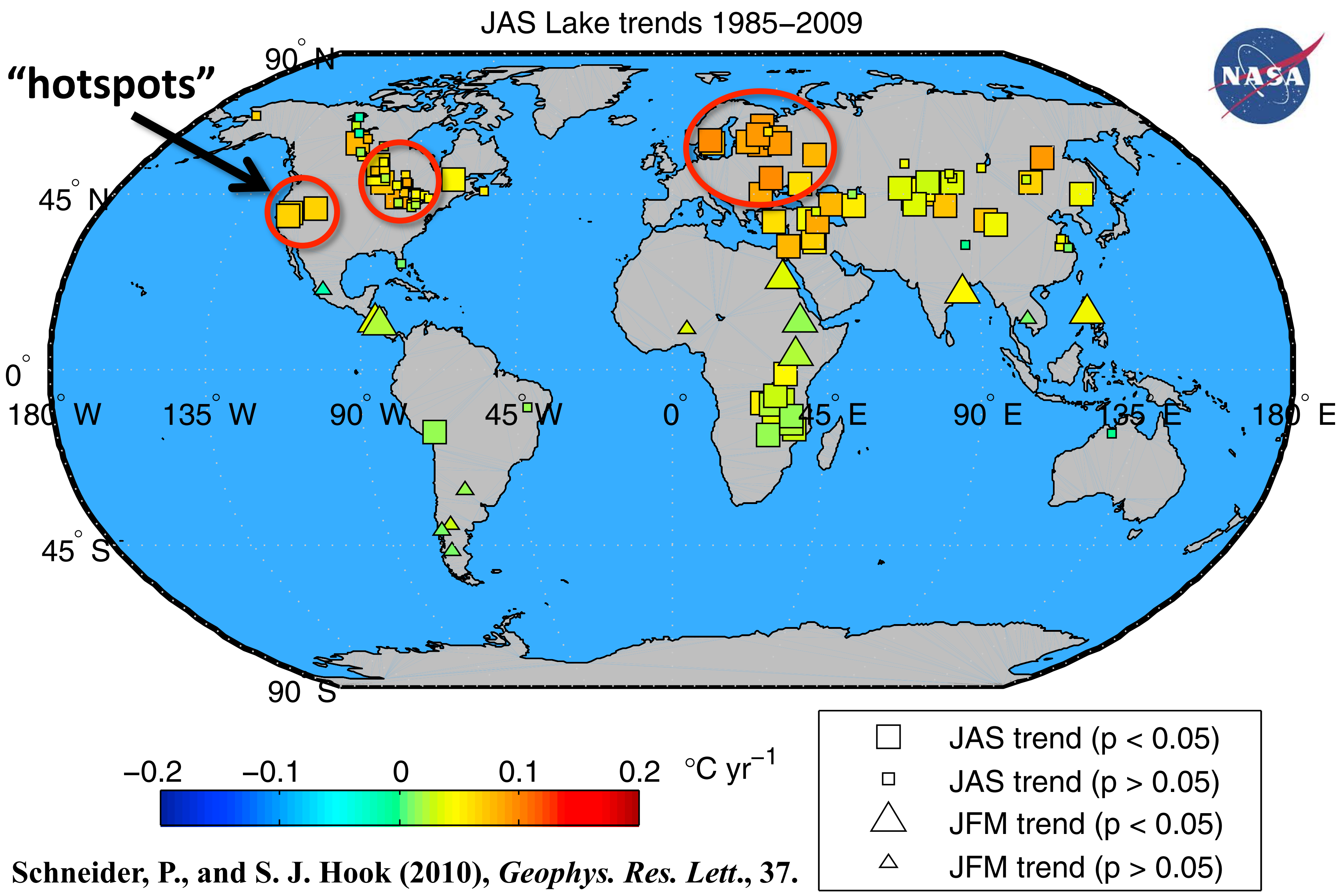
(Magnuson et al., 2000; *Science*)

Lake surfaces are warming



Schneider, P., and S. J. Hook (2010), *Geophys. Res. Lett.*, 37.

Lake surfaces are warming



Schneider, P., and S. J. Hook (2010), *Geophys. Res. Lett.*, 37.

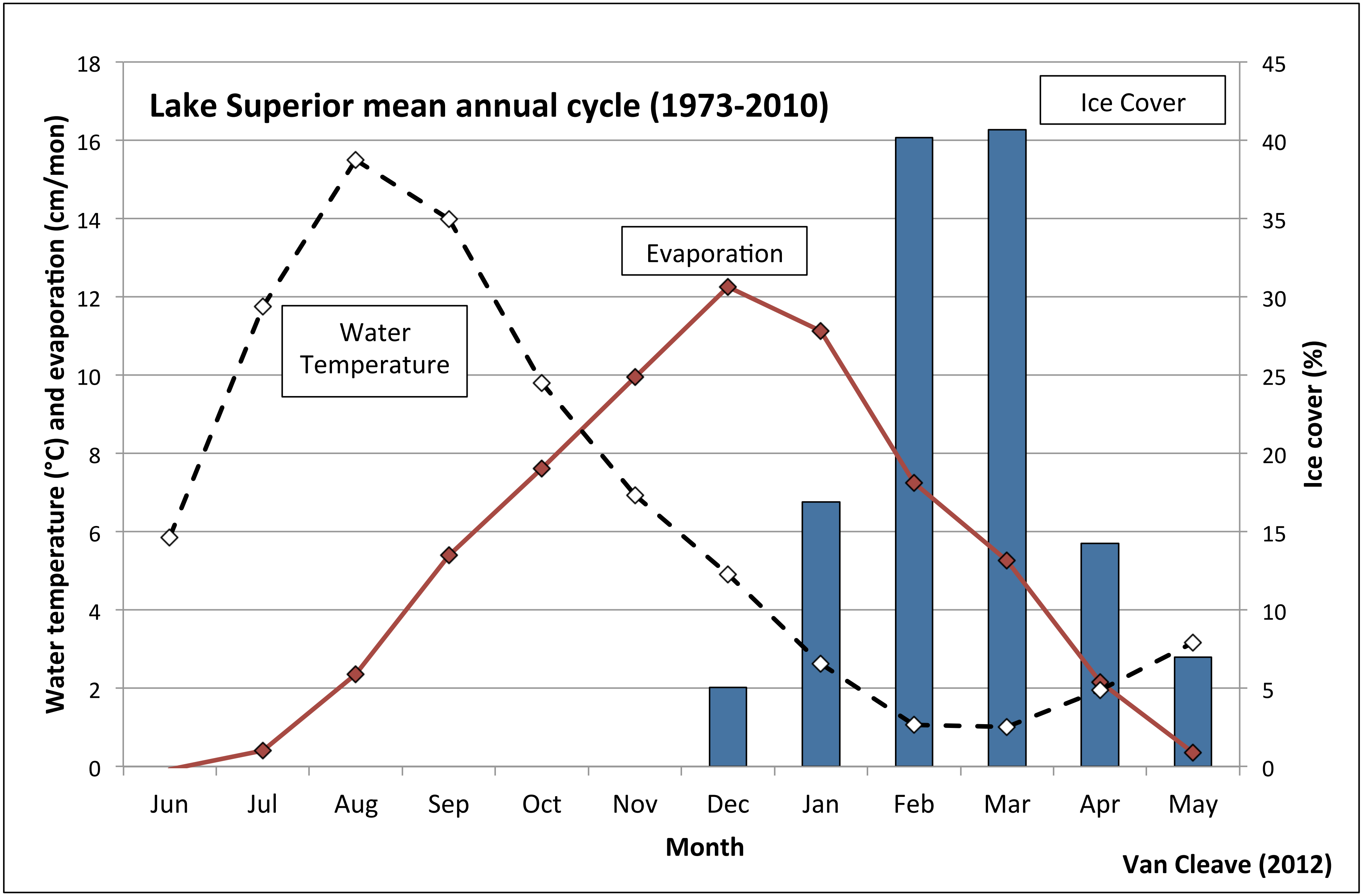
Other impacts are becoming evident

- **Changes in lake evaporation, which also affects …**
  - Water balance
  - Temperature
  - Stratification
  - Lake chemistry
  - Vertical mixing
  - Lake ecology

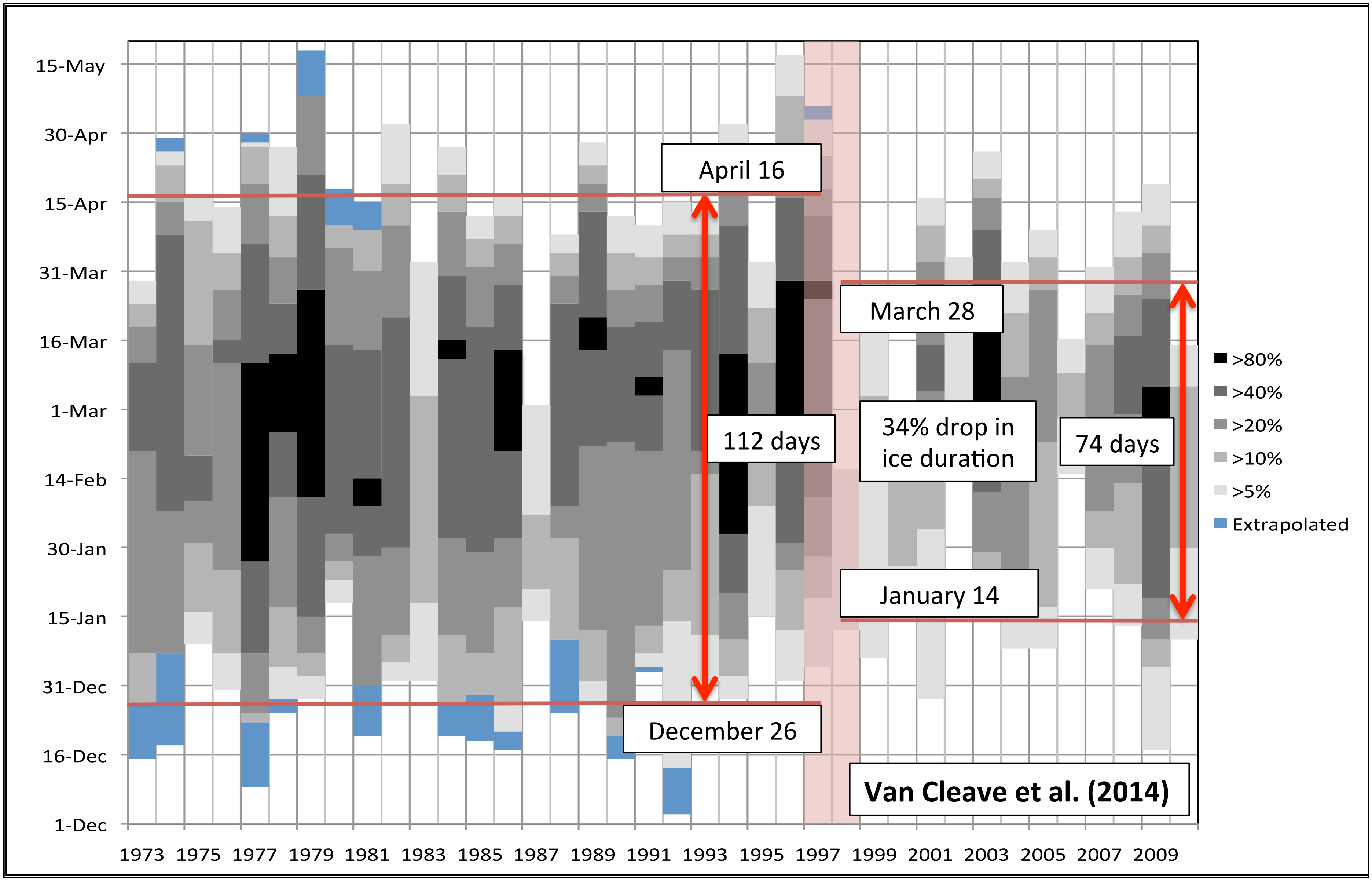
Other impacts are becoming evident

- **Variations in lake level, which also affects …**
  - Water quality / municipal water supplies
  - Recreational boating / fishing
  - Shoreline erosion / flooding
  - Commercial shipping
  - Lake ecology
  - Hydropower
  - Tourism

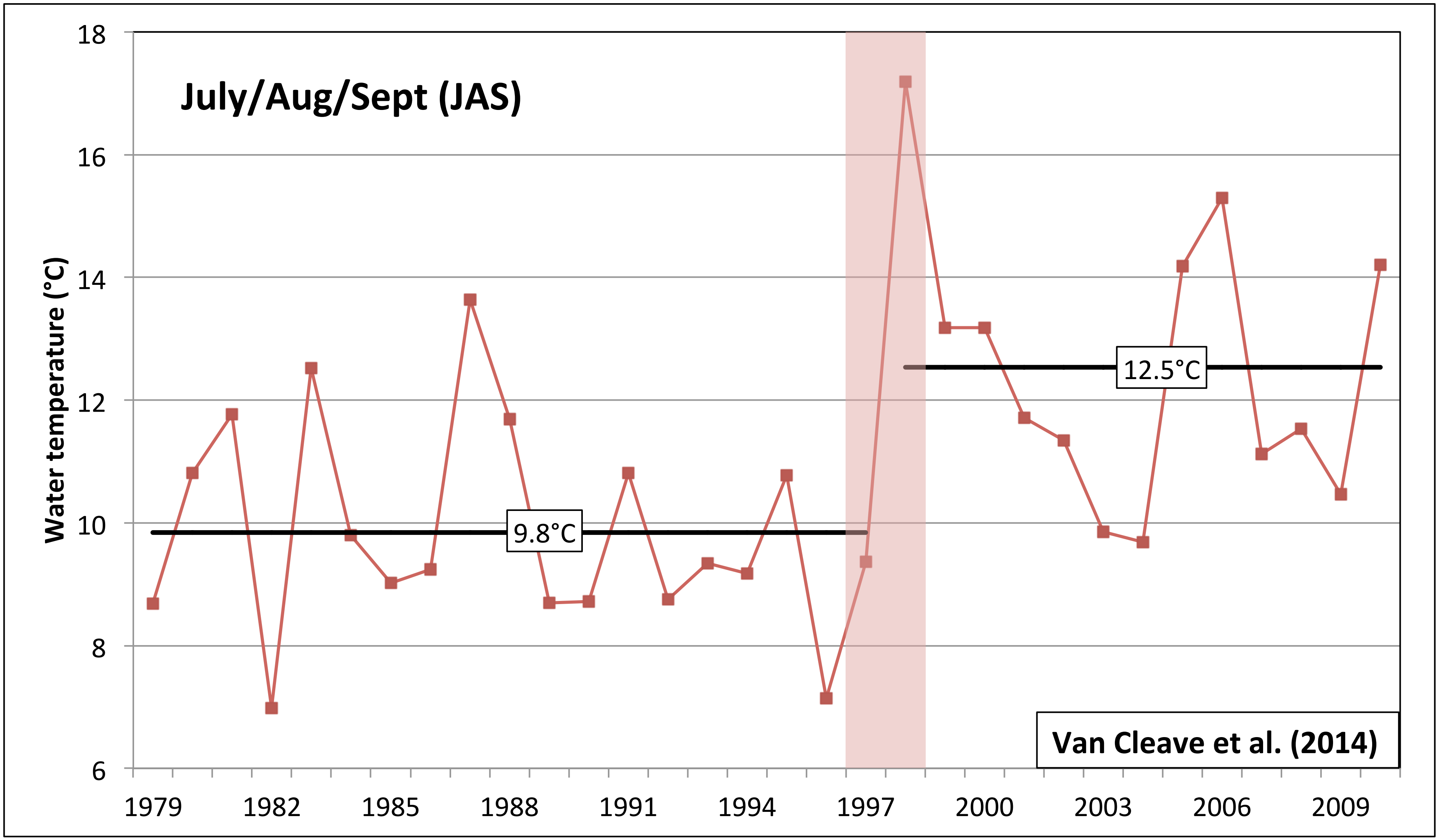
An example from the Great Lakes



Lake Superior is losing ice

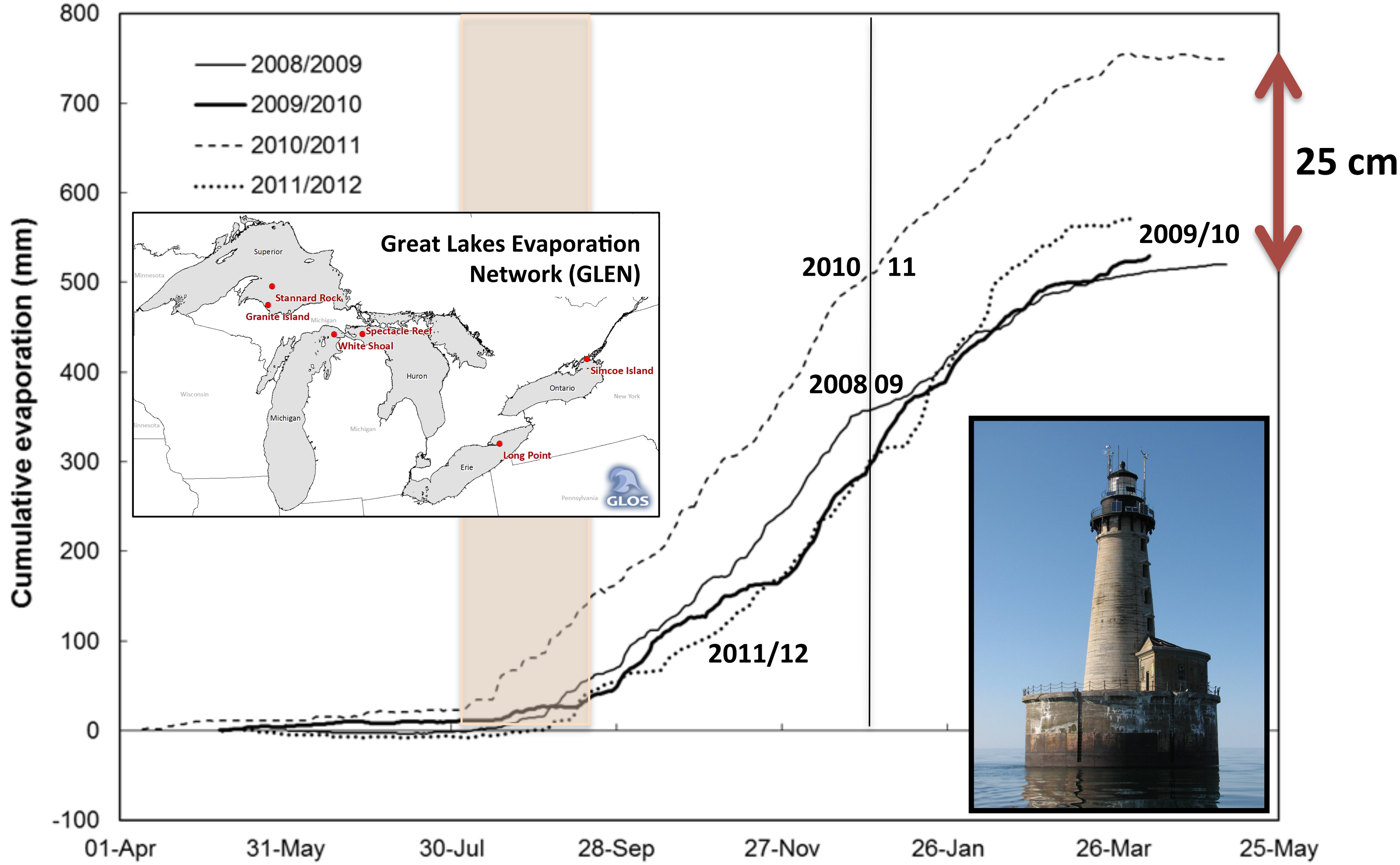


Lake Superior is warming rapidly



Lake Superior evaporation

(direct measurements at Stannard Rock Lighthouse)



Spence et al. (2013) *Journal of Hydrometeorology*

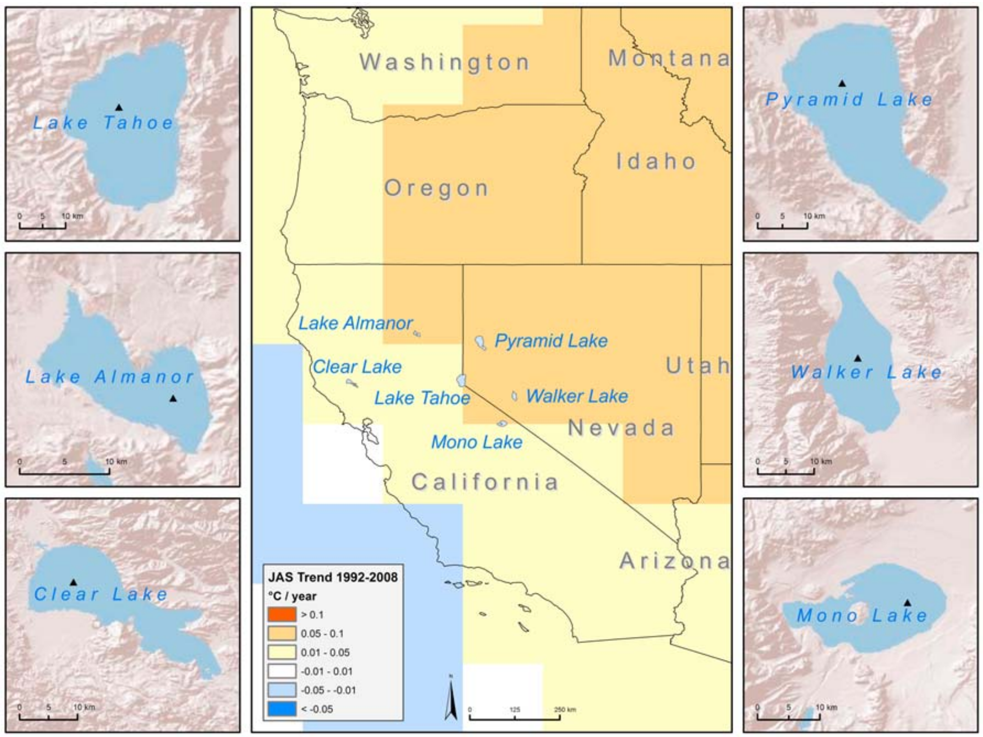
Rapid warming in lakes that don't freeze

GEOPHYSICAL RESEARCH LETTERS, VOL. 36, L22402, doi:10.1029/2009GL040846, 2009

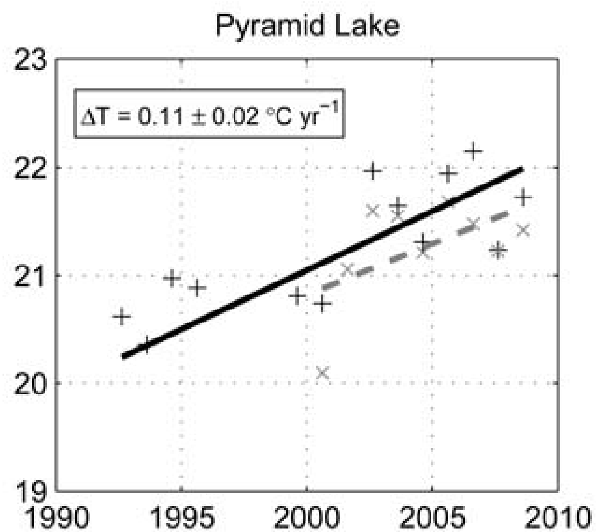
Satellite observations indicate rapid warming trend for lakes in California and Nevada

P. Schneider,[1] S. J. Hook,[1] R. G. Radocinski,[1] G. K. Corlett,[2] G. C. Hulley,[1] S. G. Schladow,[3] and T. E. Steissberg[3]

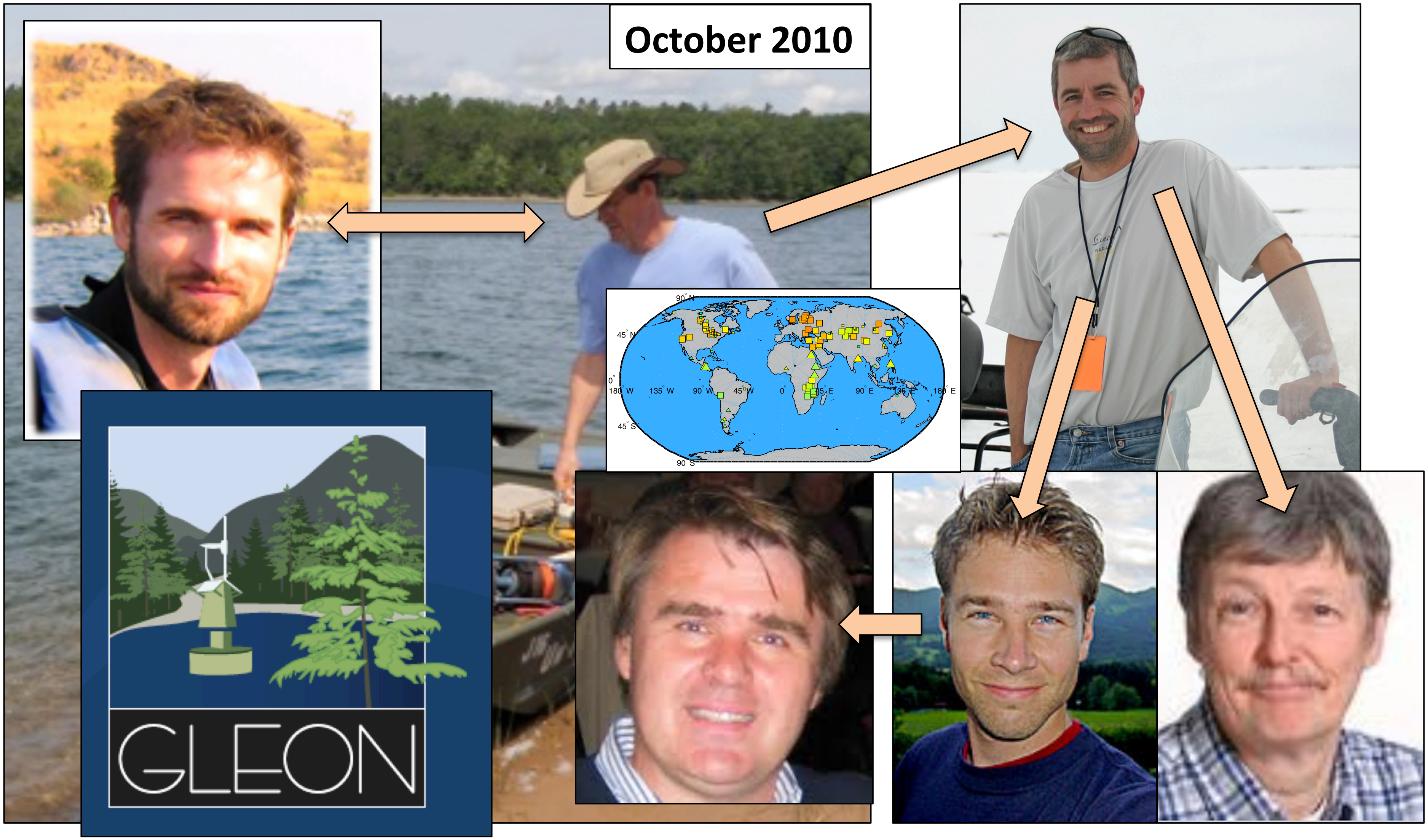
Received 10 September 2009; revised 21 October 2009; accepted 26 October 2009; published 25 November 2009.



Air: dT_{air}/dt ~ +0.5 °C/decade
Water: dT_s/dt ~ +1.1 °C/decade



A new global initiative: The Global Lake Temperature Collaboration (GLTC)



GLTC Workshop (June 2012)

GLTC Workshop (June 2012)


Eos, Vol. 93, No. 43, 23 October 2012

MEETINGS

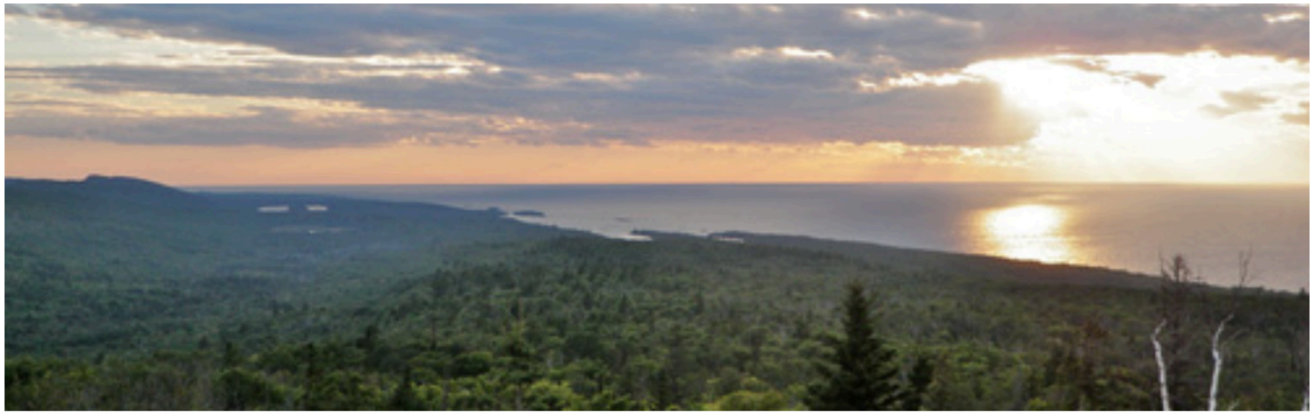
Workshop Examines Warming of Lakes Worldwide

First Global Lake Temperature Collaboration (GLTC) Workshop; Lincoln, Nebraska, 1–5 June 2012

GLTC
Global Lake Temperature Collaboration

http://laketemperature.org/

Home Background Participants Lakes 2012 Workshop Education / Outreach Publications Links



Lake Superior, USA (photo courtesy of John Lenters)

Welcome

The Global Lake Temperature Collaboration (GLTC) began in the fall of 2010 to assemble an international group of investigators with interest in and access to global lake temperature records (both *in situ* and satellite-based). The GLTC group has since grown to over 50 investigators and has recognized the need for a workshop to bring together all international project participants in a common location to share data, examine patterns and trends, perform comparative analysis, compile a global lake temperature database, and publish results from the GLTC project.

NEW publications from the GLTC project

Download the GLTC Informational Poster:

English

French

Italian

Upcoming Events:

SIL

July 31 - August 5, 2016
Turino, Italy Website »

European Geosciences Union, General Assembly

April 17 - 22, 2016
Vienna, Austria Website »

American Geophysical Union, Fall Meeting

December 14 – 18, 2015
San Francisco, California, USA
Website »

News:

December 16, 2015 – Climate Change Rapidly Warming World's Lakes

AGU Press Release Story »
AGU Press Release Video »

November 19, 2015 – On Thin Ice: Big Northern Lakes Are Being Rapidly Transformed

Read more »

Fundamental question:

What are the patterns, mechanisms, and impacts of global lake warming / cooling?

(from both satellite and *in situ* measurements)

GLTC

Global Lake Temperature Collaboration – http://laketemperature.org/

Figure 1: Map of the lakes included in the GLTC dataset.

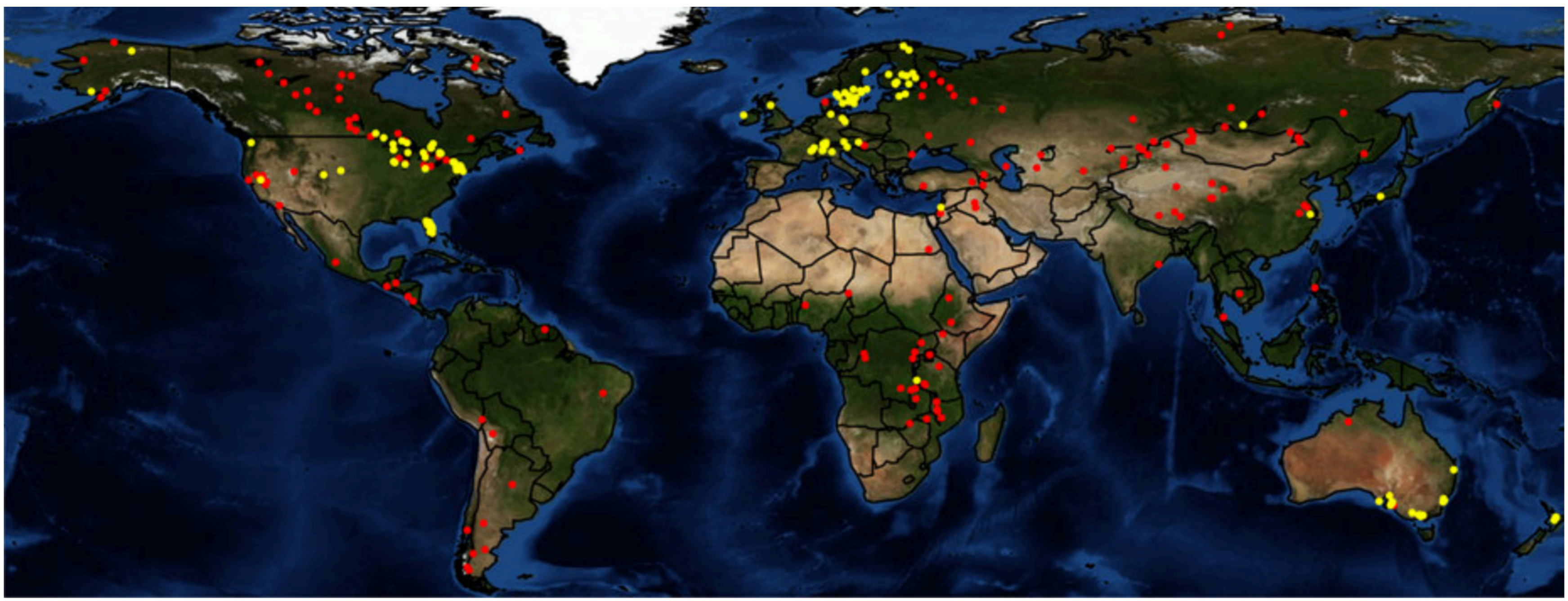
From

A global database of lake surface temperatures collected by *in situ* and satellite methods from 1985–2009

Sapna Sharma, Derek K Gray [...] Kara H Woo

Scientific Data **2**, Article number: 150008 (2015) | doi:10.1038/sdata.2015.8

Received 17 November 2014 | Accepted 13 February 2015 | Published online 17 March 2015



Yellow—*in situ* sampled lakes; Red—satellite sampled lakes.

AGU PUBLICATIONS

Geophysical Research Letters

RESEARCH LETTER

10.1002/2015GL066235

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

Catherine M. O'Reilly, Sapna Sharma, Derek K. Gray, and Stephanie E. Hampton joint first authors

Catherine M. O'Reilly[1], Sapna Sharma[2], Derek K. Gray[3], Stephanie E. Hampton[4], Jordan S. Read[5], Rex J. Rowley[1], Philipp Schneider[6], John D. Lenters[7], Peter B. McIntyre[8], Benjamin M. Kraemer[8], Gesa A. Weyhenmeyer[9], Dietmar Straile[10], Bo Dong[11], Rita Adrian[12], Mathew G. Allan[13], Orlane Anneville[14], Lauri Arvola[15], Jay Austin[16], John L. Bailey[17], Jill S. Baron[18], Justin D. Brookes[19], Elvira de Eyto[20], Martin T. Dokulil[21], David P. Hamilton[22], Karl Havens[23], Amy L. Hetherington[24], Scott N. Higgins[25], Simon Hook[26], Lyubov R. Izmest'eva[27], Klaus D. Joehnk[28], Kulli Kangur[29], Peter Kasprzak[30], Michio Kumagai[31], Esko Kuusisto[32], George Leshkevich[33], David M. Livingstone[34], Sally MacIntyre[35], Linda May[36], John M. Melack[37], Doerthe C. Mueller-Navarra[38], Mikhail Naumenko[39], Peeter Noges[40], Tiina Noges[40], Ryan P. North[41], Pierre-Denis Plisnier[42], Anna Rigosi[19], Alon Rimmer[43], Michela Rogora[44], Lars G. Rudstam[24], James A. Rusak[45], Nico Salmaso[46], Nihar R. Samal[47], Daniel E. Schindler[48], S. Geoffrey Schladow[49], Martin Schmid[50], Silke R. Schmidt[12], Eugene Silow[27], M. Evren Soylu[51], Katrin Teubner[52], Piet Verburg[53], Ari Voutilainen[54], Andrew Watkinson[55], Craig E. Williamson[56], and Guoqing Zhang[57]

Key Points:

- Lake surface waters are warming rapidly but are spatially heterogeneous
- Ice-covered lakes are typically warming at rates greater than air temperatures
- Both geomorphic and climate factors influence lake warming rates

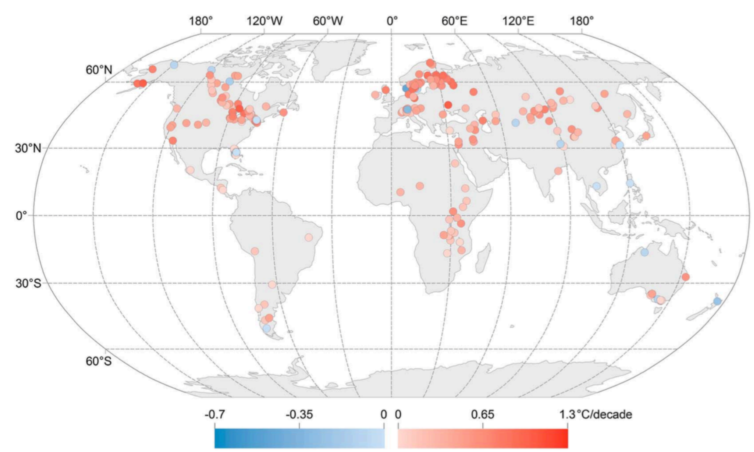
Supporting Information:

- Figures S1–S4 and Tables S1–S4

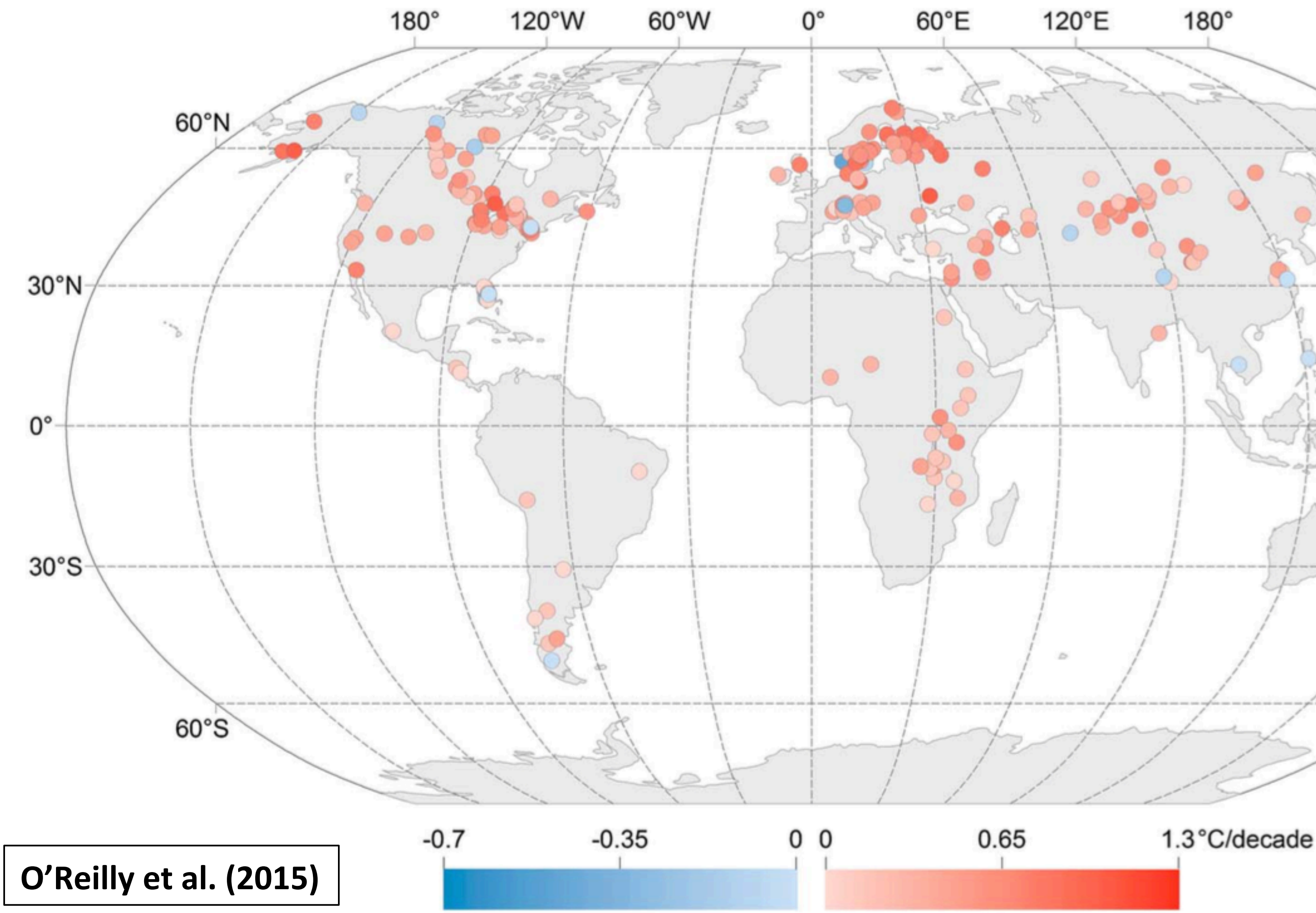
Correspondence to:
C. M. O'Reilly,
oreilly@ilstu.edu

Citation:
O'Reilly, C. M., et al. (2015), Rapid and highly variable warming of lake surface waters around the globe, *Geophys. Res. Lett.*, *42*, doi:10.1002/2015GL066235.

Received 16 OCT 2015
Accepted 14 NOV 2015

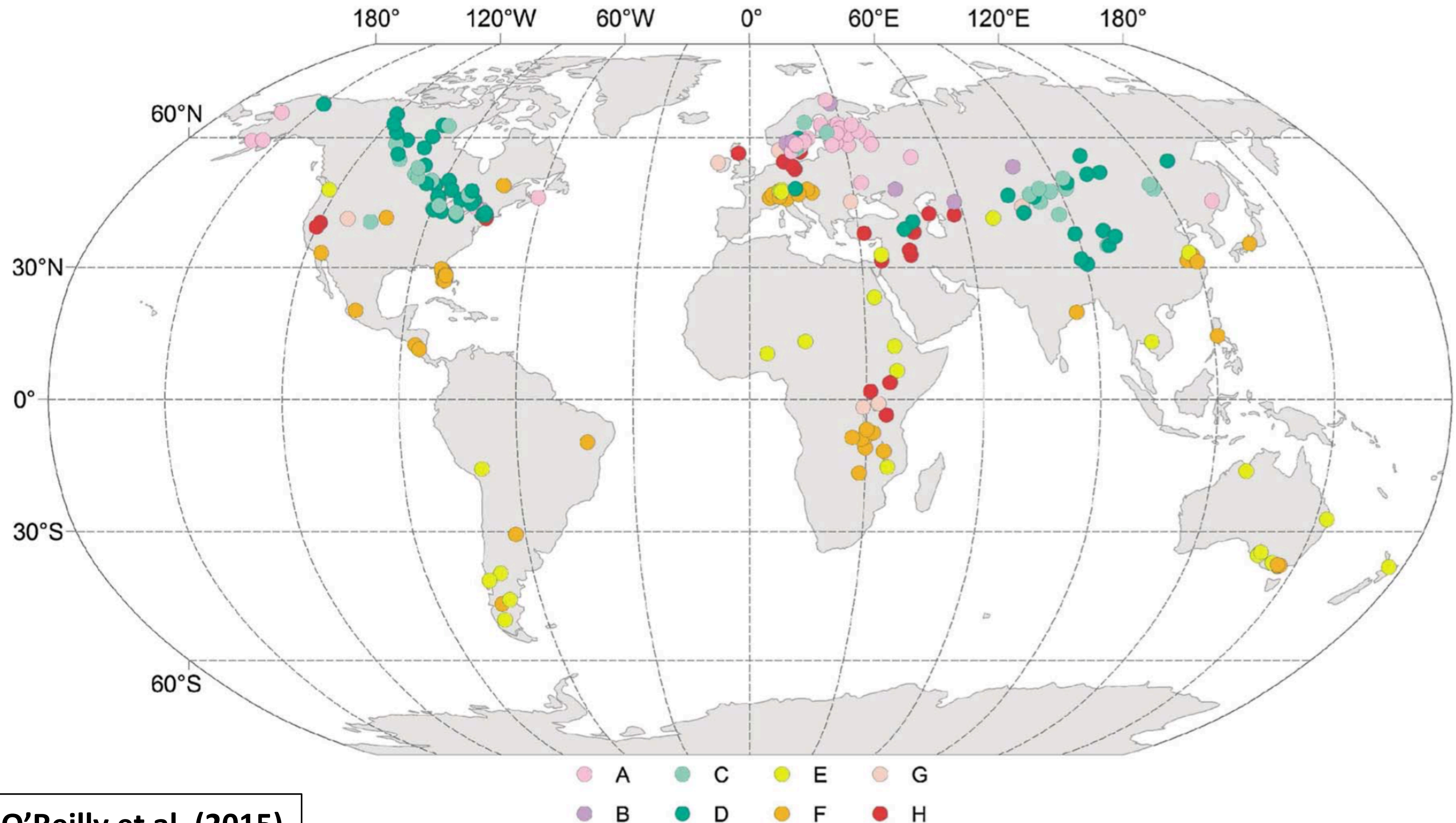


Lake surface temperature trends
(1985-2009; summer only)



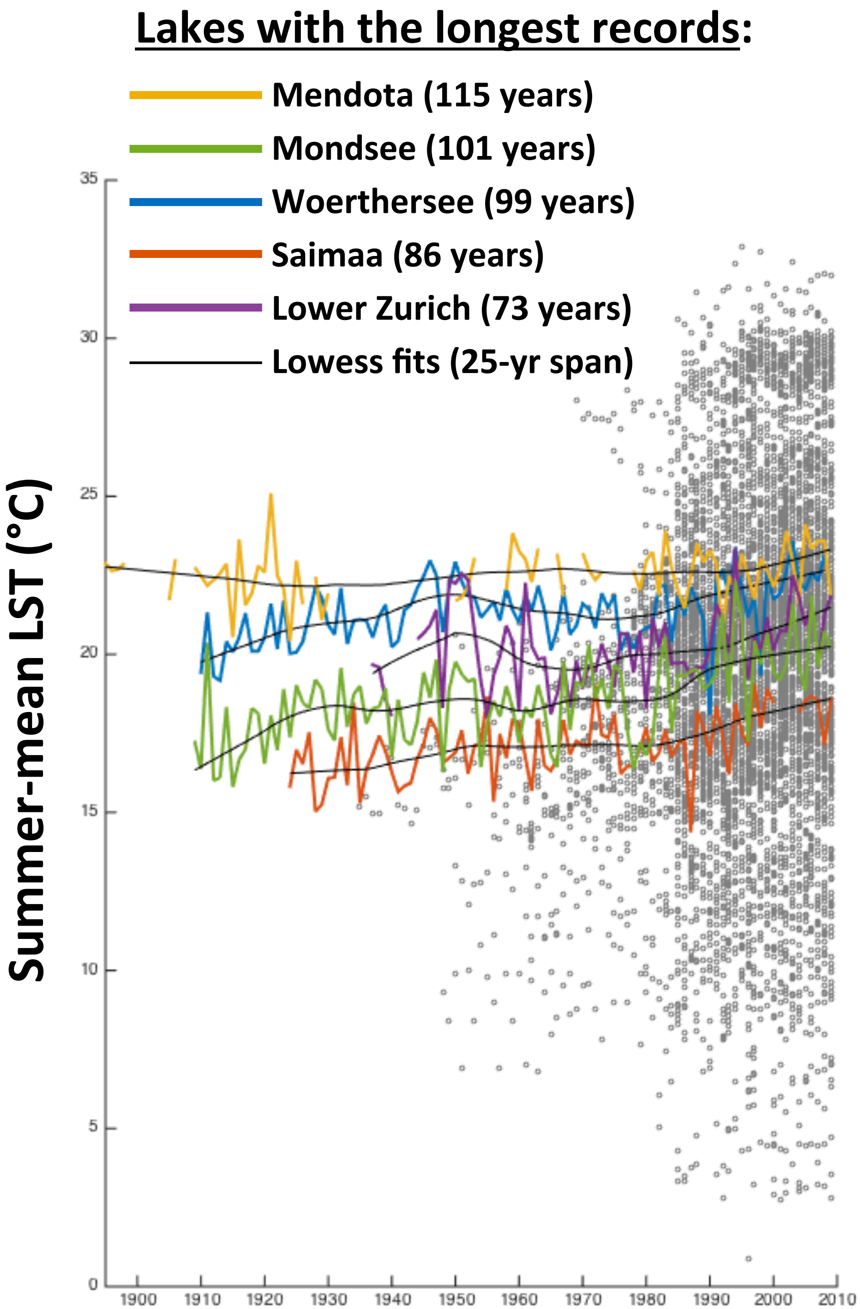
O'Reilly et al. (2015)

Many factors influence warming rates

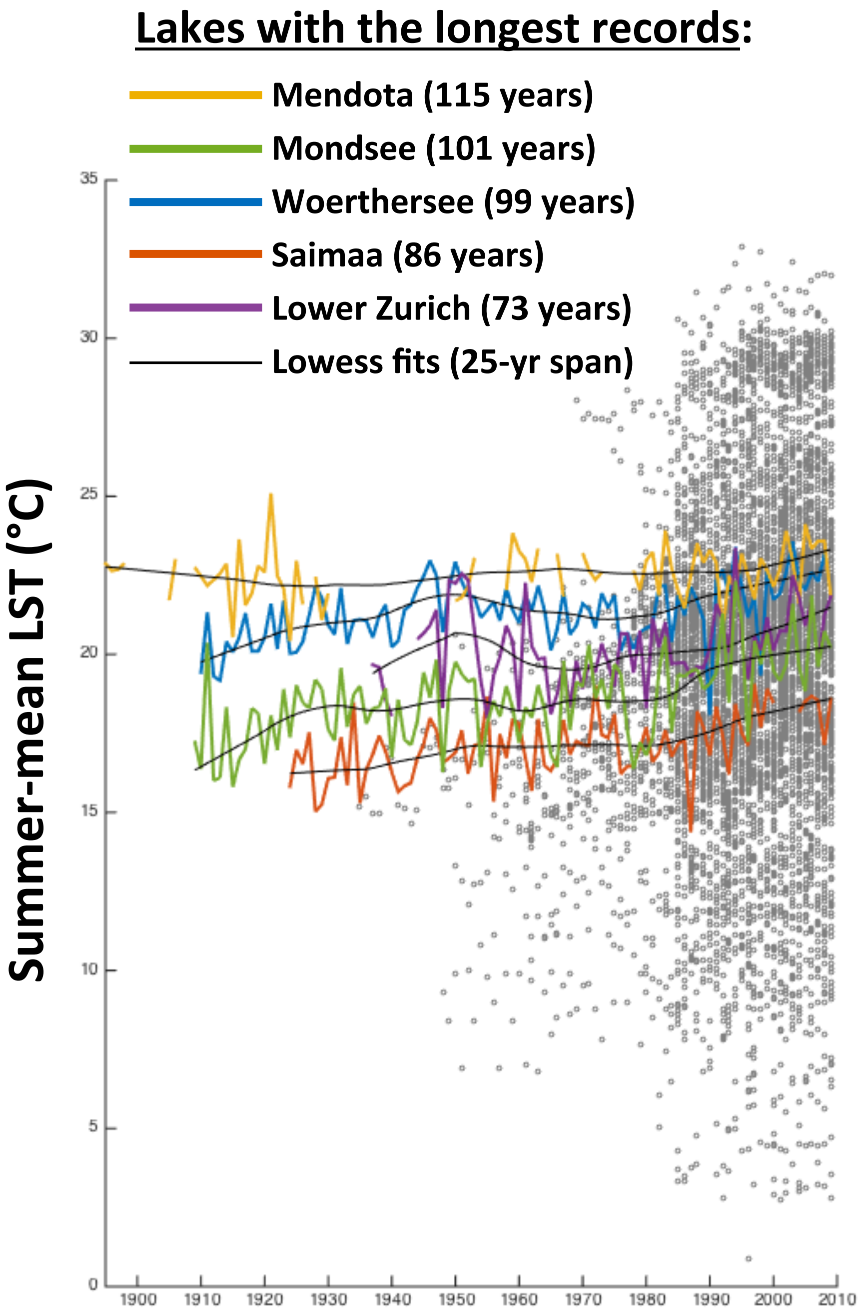


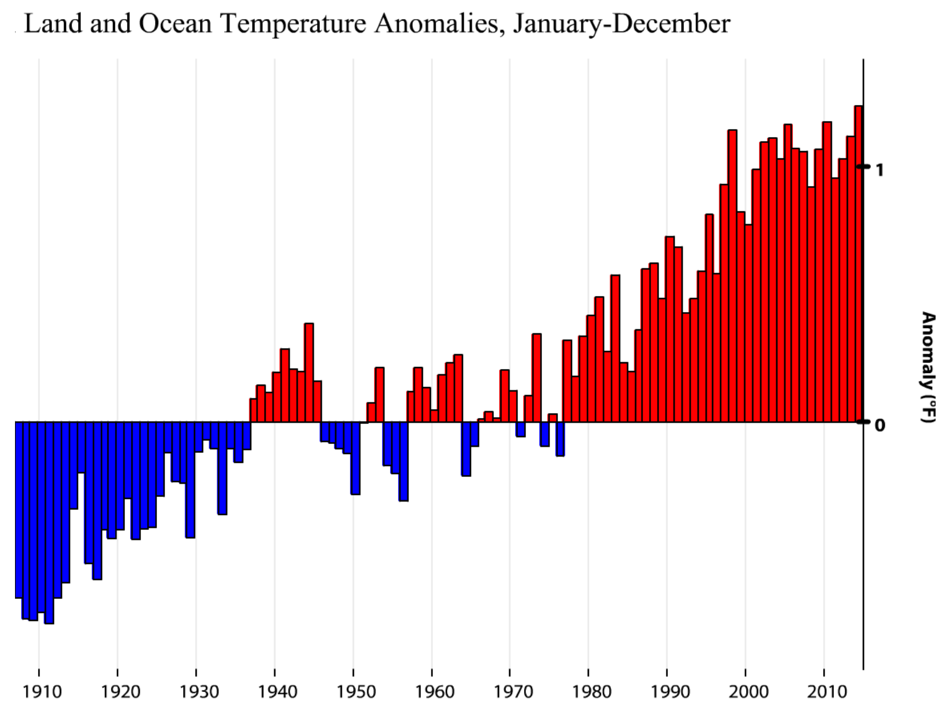
O'Reilly et al. (2015)

Ongoing GLTC work: Temporal variability

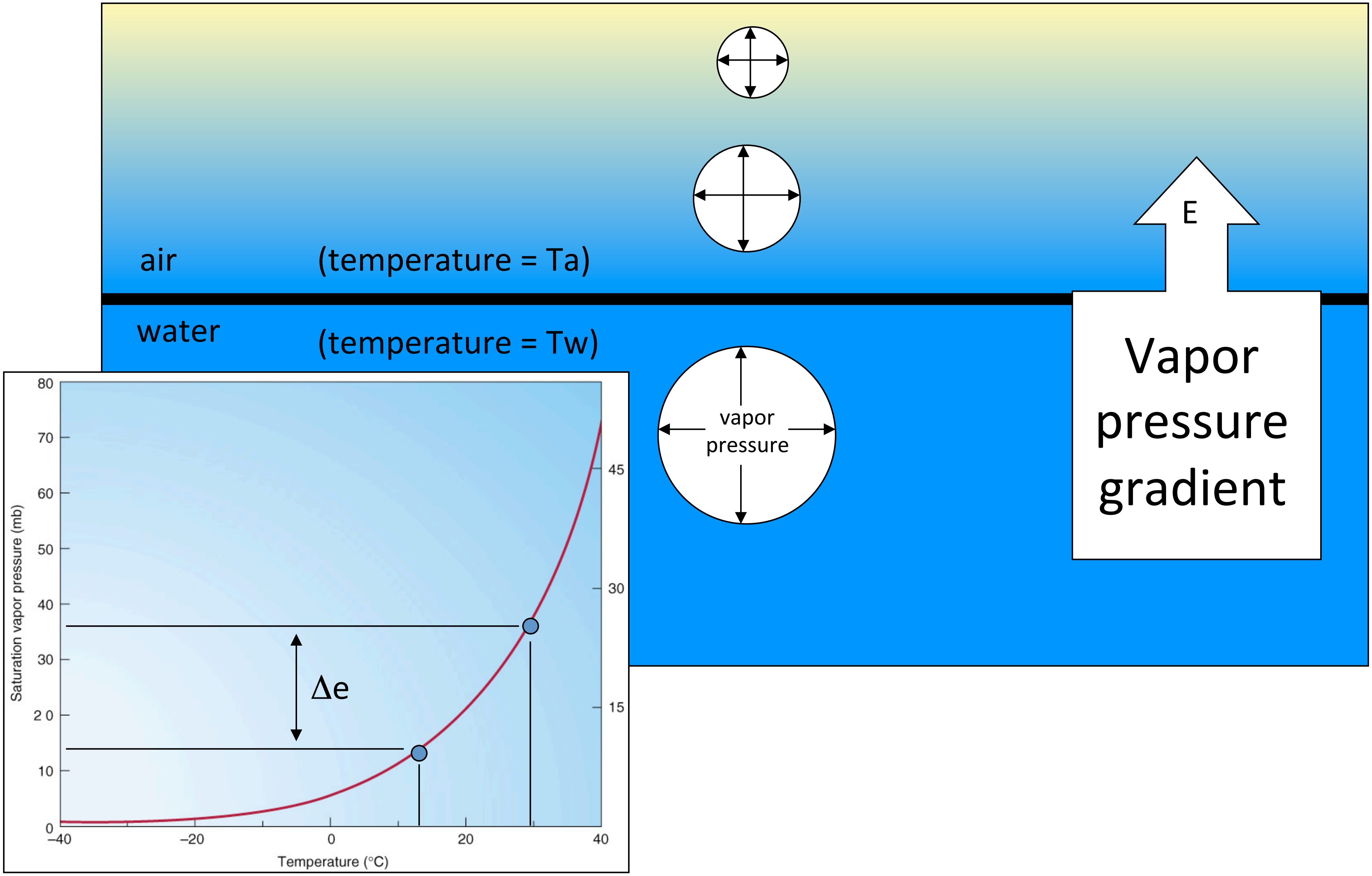


Ongoing GLTC work: Temporal variability

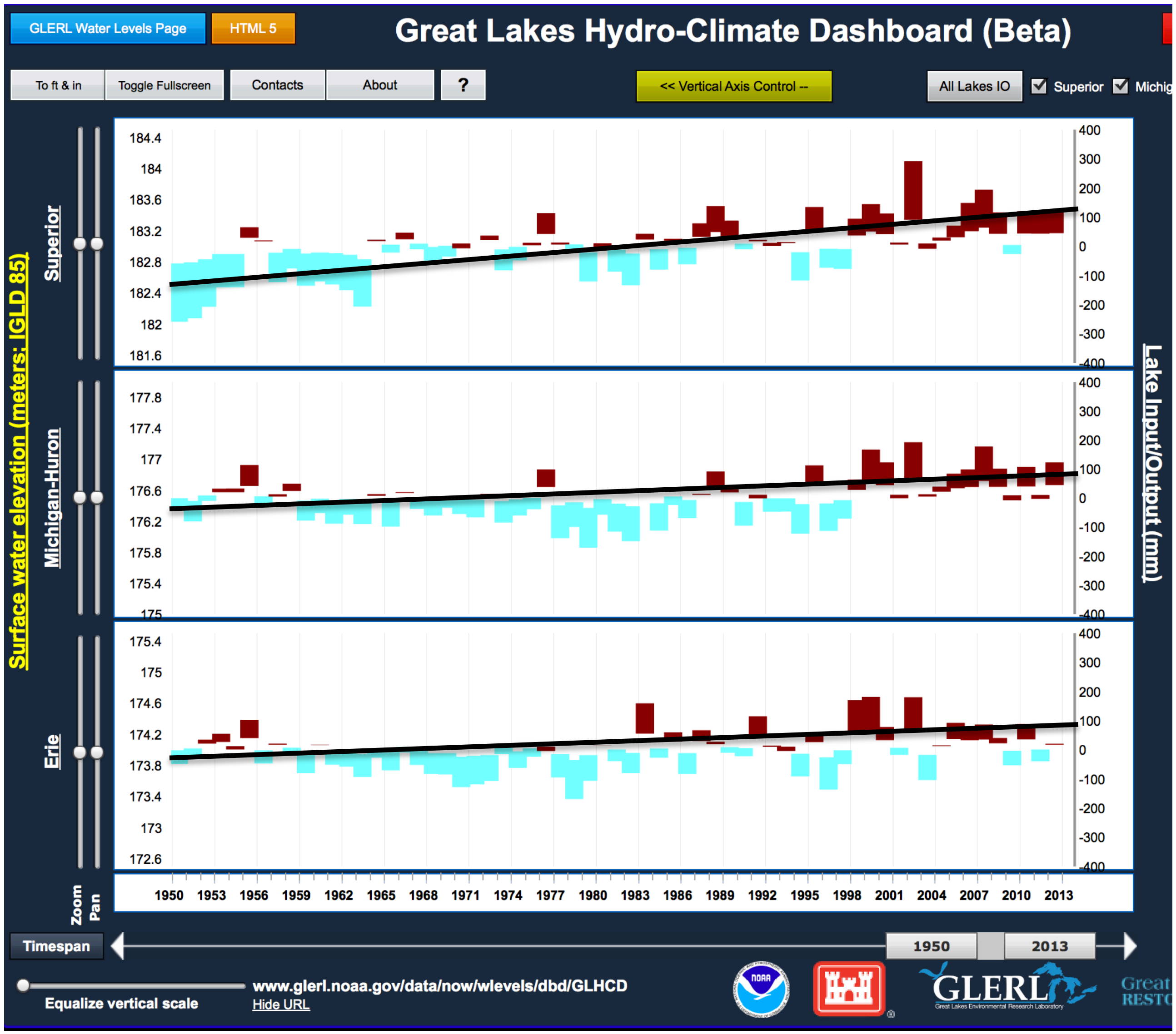




Impacts on reservoir evaporation



Great Lakes evaporation is increasing



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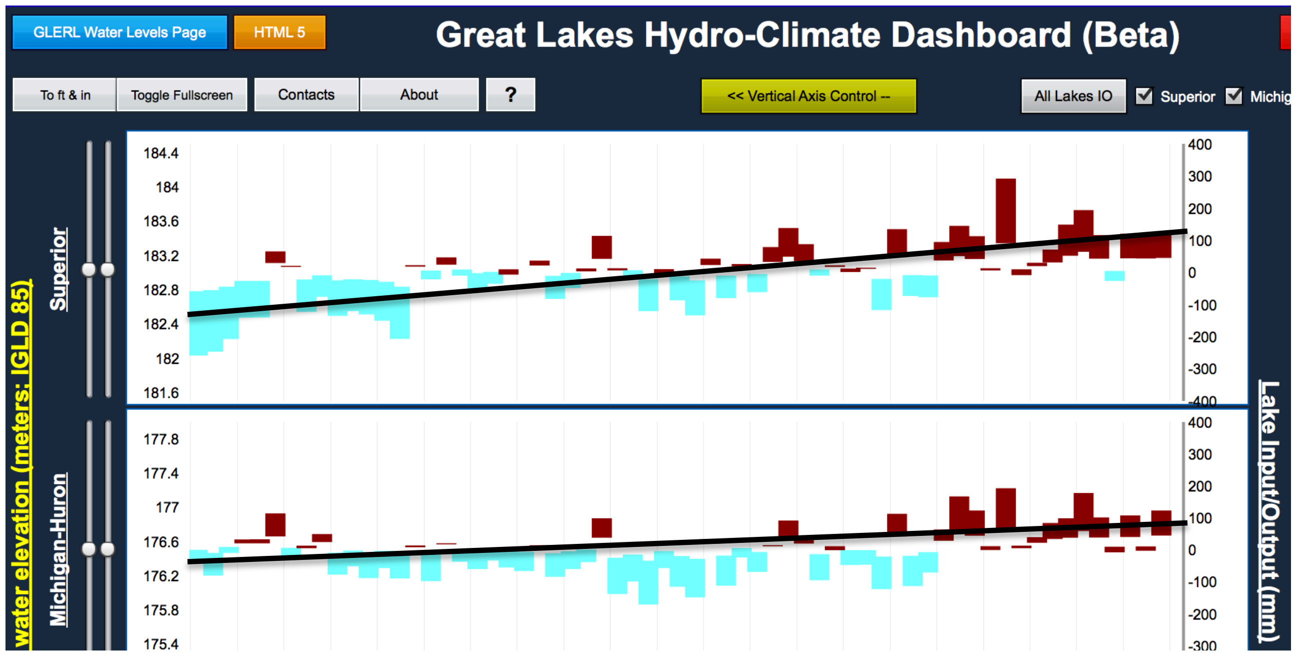
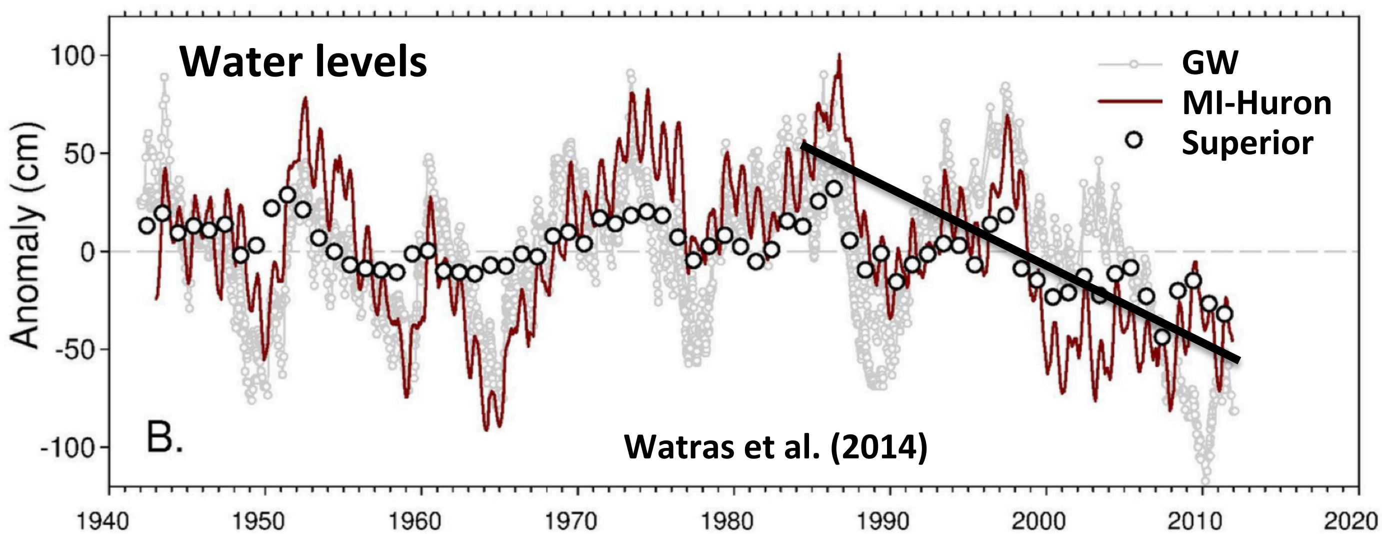
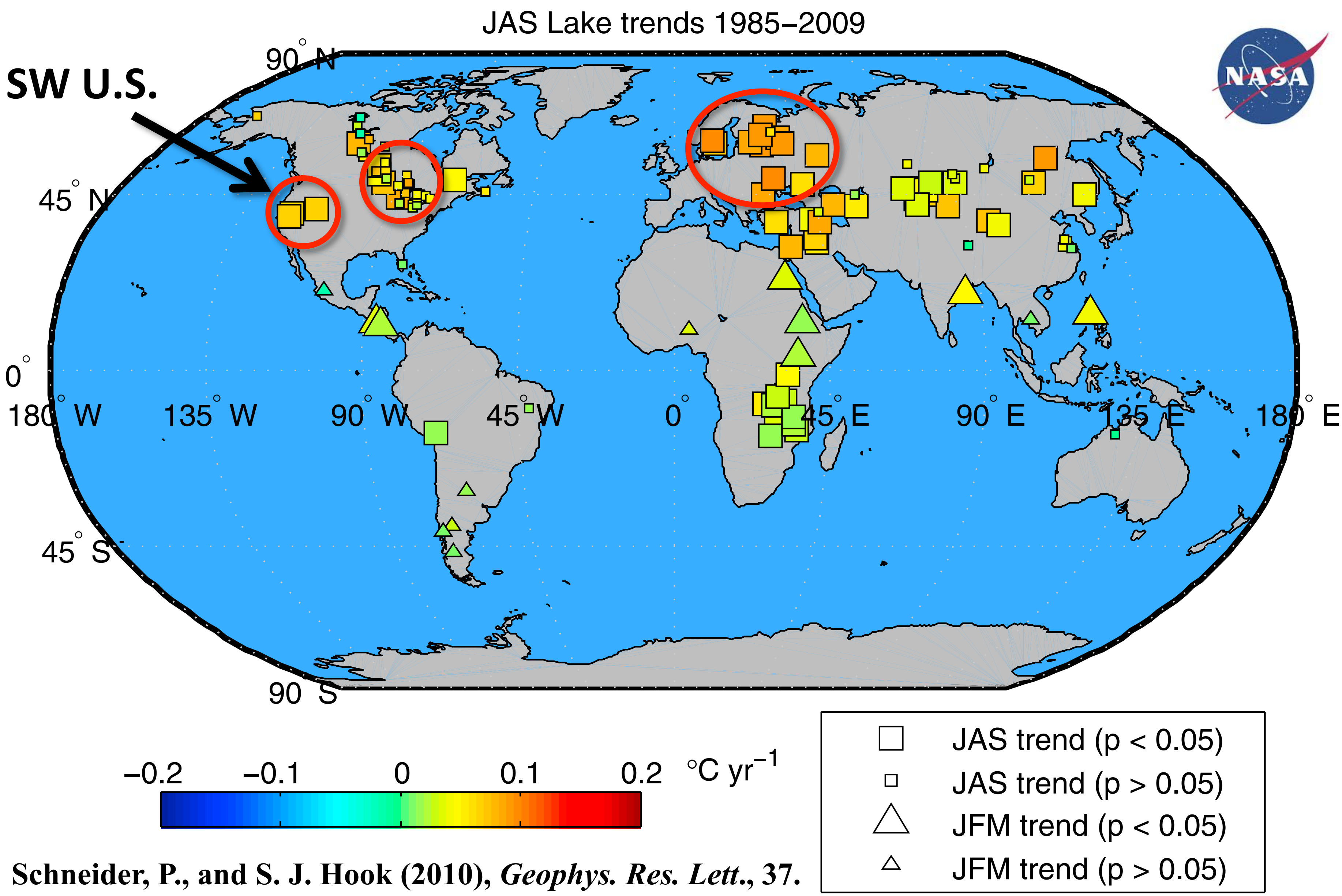




Other hotspots of warming



Schneider, P., and S. J. Hook (2010), *Geophys. Res. Lett.*, 37.

Reservoir Evaporation Workshop - 22-23 Oct. 2015, CU Boulder

Reservoir evaporation has been perceived as a negligible component of the water cycle within the water resource infrastructure of the arid and semi-arid western United States. This is partly due to both practical and logistical challenges and large uncertainties in its estimation. Reservoirs act as critical buffers to meet agricultural and municipal water deliveries, mitigate flooding, and for hydroelectric power production. However, evaporation from open water can be substantial and represents an important variable for the future of water management in the west.

Lake Powell

The reasons for its importance are:

- Increasing water demands due to population growth
- Broad uncertainties in precpitation and snowmelt with climate change
- The occurrence of recent and historical decades-long, intense droughts

This increase in demand coupled with uncertain precipitation within a changing climate and earlier runoff driven by warming will require more storage in new or augmented reservoirs. Thus, the net evaporative loss represents a key management issue that heretofore has been estimated with outdated estimation procedures and reservoir management.

This workshop will focus on reservoir evaporation, bringing together recognized experts in the field of atmospheric science, hydrology, land use, and water resource managers. A subsequent workshop, based on the outcome of this one, will reengage the scientific group involved with the on-going research with water-law professionals, water managers, state and basin officials, the environmental community, and other stakeholders in order to scope a viable plan to mitigate reservoir evaporation and provide evaporation information and forecasts to the water managers.

The Denver Post

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ENVIRONMENT A VIEW FROM 5280

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December 28, 2015, 5:29 pm

West's water reservoir managers wrestle with evaporation

By Bruce Finley
The Denver Post

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Rich Miles patrols the shores of Chatfield Reservoir in this 2012 file photo. *Seth A. McConnell, YourHub*

Water equivalent to roughly **10 percent of the annual flow in the Colorado River is lost each year to evaporation from just two massive reservoirs**, Lake Powell and Lake Mead, according to researchers at the University of Colorado in Boulder.

"That's about 500 billion gallons, perhaps **ten times what metro Denver residents consume in one year**," said hydrologist Ben Livneh of CU's Department of Civil, Environmental and Architectural Engineering and the Boulder-based Cooperative Institute for Research in Environmental Sciences.

Summary

- First global compilation of satellite / *in situ* lake temperature data
- 250+ lakes in the GLTC database; most covering at least 25 years
- ~90% of the lakes in the database are warming (1985-2009)
- Average warming rate of ~0.34 °C dec^{-1}, some more rapid than air
- Hotspots of warming in the Great Lakes, northern Europe, and southwest U.S.
- Impacts on lake evaporation, water levels becoming evident
- Renewed interest in reservoir evaporation for western U.S.

Acknowledgements

- Many thanks to the **numerous scientists and institutions** that contributed data and expertise to the GLTC project (http://laketemperature.org/).
- Special thanks to the GLTC data analysis sub-group: Derek Gray, Stephanie Hampton, Peter McIntyre, Catherine O'Reilly, Jordan Read, Sapna Sharma, Noemi Barabas, Dendy Lofton, R. J. Rowley, Evren Soylu, and Piet Verburg
- We gratefully acknowledge NSF, NASA, and the University of Nebraska-Lincoln for funding the GLTC workshop, as well as other institutions for their support.

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Questions?