

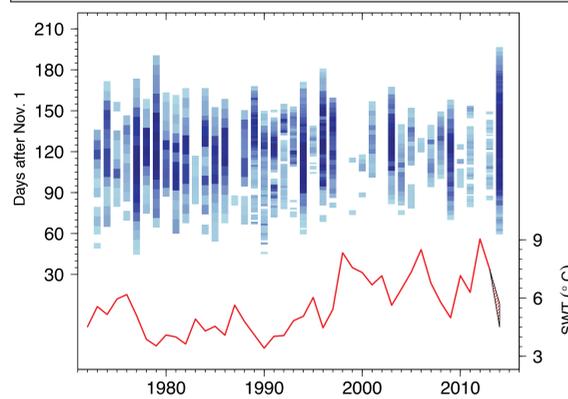
Improving Estimates of Evaporation from Earth's Largest Lake System

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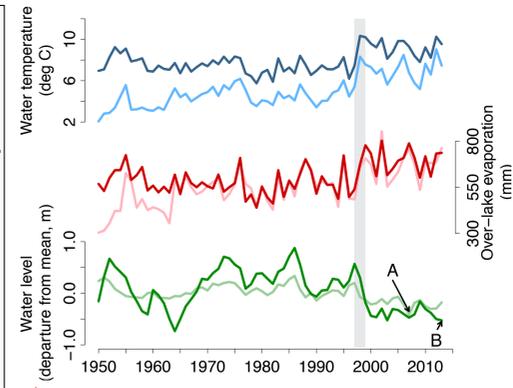


Figure 1. Location of evaporation stations.



Time series of annual-average climate and hydrological variables for Lake Superior (light colors) and Lake Michigan-Huron (dark colors) reflecting long-term trends and abrupt shifts in surface water temperature (blue lines) and over-lake evaporation (red lines). These factors, combined with human intervention (including dredging of channels connecting the Great Lakes) contribute to recent record low water levels on both lake systems (green lines). Vertical gray band indicates approximate period of 1997-1998 El Niño. Adapted from Gronewold and Stow [2014].

Areal extent of daily ice cover (blue columns) and average annual lake-wide surface water temperature (SWT; red line) on Lake Superior from 1972 to 2014. Each column corresponds to the 'ice season' for given calendar year. The darkest shades of blue across all columns indicate ice cover near 100%, while the lightest shades of blue indicate ice cover near 10%. Ice cover and SWT data are from the NOAA Great Lakes ice atlas project [Assel, 2005; Wang et al., 2012] and the NOAA Lake Thermodynamics Model [Croley II and Assel, 1994], respectively. Figure adapted from Clites et al. [2014]



ABSTRACT

The North American Great Lakes constitute the largest freshwater surface in the world. Beginning in the late 1990s – a period that commenced with a strong El Niño event – the Great Lakes experienced a regime shift in winter ice cover and summer water temperatures that resulted in higher summer evaporation rates, followed shortly thereafter by a dramatic decline in water levels. Recent research suggests that evaporation rates over the lakes have remained high since then, due primarily to warmer summer water temperatures and an earlier start to the evaporation season. On the other hand, cold, high-ice winters such as 2013-14 cause occasional deviations from this trend, highlighting the large interannual variability in the Great Lakes system and the continued need for long-term observations. A growing ensemble of in situ measurements – including offshore eddy flux towers, buoy-based sensors, and vessel-based platforms – are being deployed through an ongoing bi-national collaboration to reduce uncertainties in the Great Lakes water balance, provide a more robust basis for short- and long-term projections, and fill a significant gap in over-lake flux measurements and related meteorological data. This collaboration, currently referred to as the Great Lakes Evaporation Network (GLEN), was initiated in response to the need for improved estimates of Great Lakes evaporation and is intended to be of utility to a wide range of applied and basic research needs.

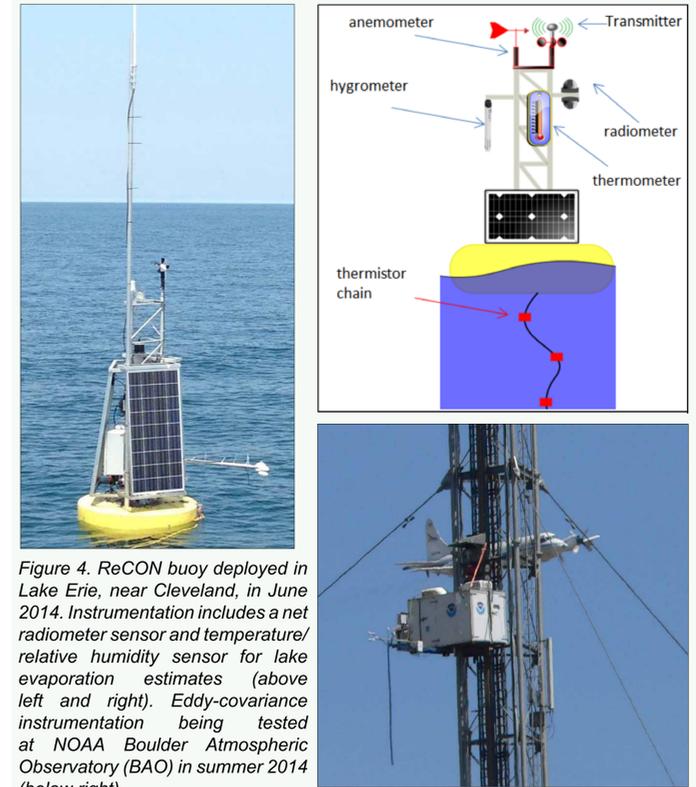


Figure 4. ReCON buoy deployed in Lake Erie, near Cleveland, in June 2014. Instrumentation includes a net radiometer sensor and temperature/relative humidity sensor for lake evaporation estimates (above left and right). Eddy-covariance instrumentation being tested at NOAA Boulder Atmospheric Observatory (BAO) in summer 2014 (below right).

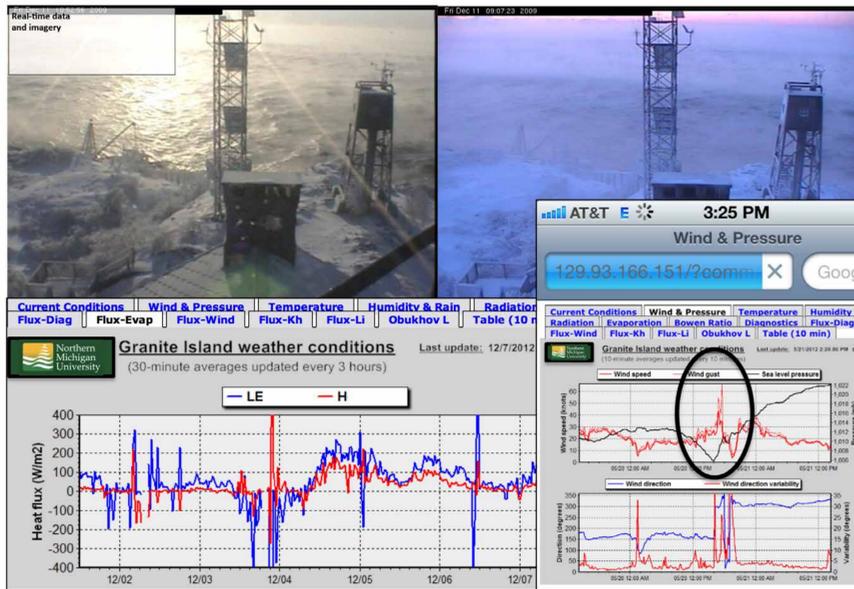


Figure 2.

Seven flux sites are in operation on the Great Lakes (Figure 1), with most sites providing real-time data and imagery (Figure 2). Eddy covariance and energy balance instrumentation is shown below (Figure 3), with three sites (Stannard Rock, Granite Island, and Toledo) providing continuous measurements of CO₂ concentration and fluxes. Additional buoy-based deployments are being tested, with ship-based platforms planned for 2015 (Figure 4).



Figure 3.

GLEN-related publications:

- Assel, R.A. Great Lakes weekly ice cover statistics. NOAA Technical Memorandum GLERL-133. NOAA, Great Lakes Environmental Research Laboratory, Ann Arbor, MI, 27 pp. (2005).
- Blanken, P.D., Spence, C., Hedstrom, N., and Lenters, J.D. (2011) Evaporation from Lake Superior: 1. Physical controls and processes. *Journal of Great Lakes Research*, 37(4), 707-716. doi:10.1016/j.jglr.2011.08.009.
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- Lenters, J.D., Anderton, J.B., Blanken, P.D., Spence, C. and Suyker, A.E. (2013). Assessing the Impacts of Climate Variability and Change on Great Lakes Evaporation. In: *2011 Project Reports*. D. Brown, D. Bidwell, and L. Briley, eds. Available from the Great Lakes Integrated Sciences and Assessments (GLISA) Center: http://glisacclimate.org/media/GLISA_Lake_Evaporation.pdf
- Spence, C., Blanken, P.D., Hedstrom, N., Fortin, V., and Wilson, H. (2011). Evaporation from Lake Superior: 2. Spatial distribution and variability. *Journal of Great Lakes Research*, 37(4), 717-724. doi:10.1016/j.jglr.2011.08.013.
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- Van Cleave, K. (2012) Interactions among evaporation, ice cover, and water temperature on Lake Superior: Decadal, interannual, and seasonal variability. Dissertations & Theses in Natural Resources. Paper 52. 97 pp. Available from: <http://digitalcommons.unl.edu/natresdiss/52/>.
- Van Cleave, K., Lenters, J. D., Wang, J., and Verhamme, E.M. (2014). A regime shift in Lake Superior ice cover, evaporation, and water temperature following the warm El Niño winter of 1997-98. *Limnology and Oceanography*, 59(6), 1889-1898.
- Wang, J., R.A. Assel, S. Walterscheid, A.H. Clites, and X. Bai. Great Lakes ice climatology update: Winter 2006-2011. Description of the digital ice cover dataset. NOAA Technical Memorandum GLERL-155. NOAA, Great Lakes Environmental Research Laboratory, Ann Arbor, MI, 37 pp. (2012).

