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Cold Water and High Ice Cover on Great Lakes in Spring 2014

Very cold temperatures across much of North America caused by the recent anomalous meridional upper air flow—commonly referred to in the public media as a polar vortex (for details, see *Blackmon et al.* [1977] and National Climatic Data Center, State of the climate: Synoptic discussion for January 2014, http://www.ncdc.noaa.gov/sotc/synoptic/2014/1)—have contributed to extreme hydrologic conditions on the Great Lakes. The Great Lakes are the largest system of lakes and the largest surface of freshwater on Earth—Lake Superior alone is the single largest lake by surface area.

Data collected and compiled by the Canadian Ice Service, the National Ice Center, the National Oceanic and Atmospheric Administration (NOAA) CoastWatch Program [*Leshkevich et al.*, 1996], and the NOAA Great Lakes Ice Atlas [*Assel*, 2003; *Wang et al.*, 2012a] indicate that very cold surface water temperatures and a relatively high areal extent of ice cover persisted across the Great Lakes well into May 2014. (Lake Superior wasn't ice free until 6 June, according to the National Ice Center.) Comparable ice cover across the Great Lakes for the same time of year has never been seen in the 40 years of recorded data.

At the end of April 2014, for example, roughly 23% of Lake Huron and 10% of Lake Michigan were covered in ice, whereas more than half of Lake Superior (roughly 51%) was covered in ice (Figure 1). Prior to 2014, the highest percentage of late spring ice cover on Lake Superior was recorded (at roughly 30%) in April 1979 (Figure 2); at that time, ice cover on the other Great Lakes was at or very close to 0%. At no time in the 40-year record has there been significant ice cover on Lakes Michigan, Erie, and Ontario in late April, and in only a few years has significant ice cover been reported in late April on Lake Huron.

Although spring 2014 conditions on the Great Lakes contrast sharply with those of the 40-year record, they are particularly unusual relative to conditions over the past 15 years, a period scientists believe to have

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Fig. 1. Satellite image of the Great Lakes from 23 April 2014 showing the areal extent of ice cover across the upper Great Lakes. Courtesy of the National Oceanic and Atmospheric Administration's (NOAA) CoastWatch Great Lakes Program.

Real-Time Oceanographic Data: From Safety to Science

Coastal areas such as bays and estuaries host 30%–50% of the global human population and shipping ports that handle 80% of world trade. These areas are increasingly vulnerable to chemical and biological contamination and to storm surge in the short term and to sea level rise in the long term.

The dynamics of such coastal areas are complex and difficult to predict, being influenced by local characteristics of tides, winds, insolation, freshwater discharge, shoreline morphology, and bottom bathymetry. As the human population grows and threats to coastal populations and their marine transportation systems increase, there is a need for reliable observational data to aid in protection, restoration, and adaptation strategies.

The Physical Oceanographic Real-Time System (PORTS), managed by the National Oceanic and Atmospheric Administration (NOAA), collects and disseminates real-time meteorological and oceanographic data 24 hours a day in 23 locations on the coast and Great Lakes of the United States (http://tidesandcurrents.noaa.gov/ports.html; see Figure 1). Though the primary function of PORTS is to help maintain the safety and efficiency of maritime operations, the data gathered have proven scientific applications. PORTS data are being used to examine a growing set of critical issues related to a diverse range of research topics in coastal science and management, from estuarine circulation to biological hazards to climate.

Tracking the Movement of Freshwater

The movement of freshwater through an estuary is essential for maintaining optimal salinity for various marine organisms as well as the overall ecological health of the estuary. Changes to the freshwater input from rivers, as anticipated to occur in a changing climate, can create a cascade of impacts, affecting salinity, nutrient fluxes, estuarine biology, and water quality.

In Delaware Bay, PORTS data were used in conjunction with data from other monitoring programs to examine changes in salinity during a large freshwater river discharge event. Changes to the salinity field coincided with an unusually large transport of nutrients into the lower bay, resulting in a phytoplankton bloom and loss of dissolved oxygen in the system [*Voynova and Sharp*, 2012].

Similarly, current speeds from a PORTS acoustic Doppler current profiler have been used to estimate volume flux from the Hudson River into the coastal zone and the formation of a freshwater "bulge." This feature restricted mixing with the coastal current, temporarily creating an isolated biological community and altering the transport of nutrients into the surrounding coastal waters [*Chant et al.*, 2008].

Monitoring and Predicting Water Levels

Storm surge generated by extreme weather events can bring devastation to coastal communities when low atmospheric pressure or high winds raise the ocean water levels and overwhelm the coastline. For example, nontidal water levels in Galveston Bay were shown to be affected by local surface winds and remotely generated water levels at the bay mouth using PORTS tide gauge and wind data. These data were then treated as inputs in a neural network model that made accurate predictions of water levels within the bay [*Guannel et al.*, 2001].

In addition, data from several tide gauges in the PORTS program have been used to demonstrate an increase in the seasonal cycle of water level in the eastern Gulf of Mexico, with implications for estimating storm surge [*Wahl et al.*, 2014].

Refining Circulation Models

One of the common uses of PORTS data is to provide boundary conditions for numerical models of coastal regions. The subtidal circulation of Tampa Bay, the site of the original PORTS system in 1991, was shown to vary according to the level of freshwater being discharged by local rivers [*Meyers et al.*, 2007] and to deviate from the theoretical vertically sheared structure [*Hansen and Rattray*, 1965]. Those results supported new understandings of estuarine circulation emerging around that time [*Valle-Levinson et al.*, 2003].

Estuarine response to hurricane conditions is important for many coastal areas, particularly those along the Atlantic coast and the Gulf of Mexico. The volume of Tampa Bay was shown, using both PORTS data and a numerical model partly driven by the same data, to swing by 40% in less than 24 hours during Hurricane Frances [*Wilson et al.*, 2006].

Harmful algal blooms (HABs), which produce toxins that kill marine life and can cause respiratory distress in adjacent human communities, can also be tracked with numerical circulation models [*Havens et al.*, 2010].

Operational circulation models [*Aikman et al.*, 2008] that include PORTS data in their boundary conditions have been implemented by NOAA for 13 U.S. harbors (http://tidesandcurrents.noaa.gov/models.html).

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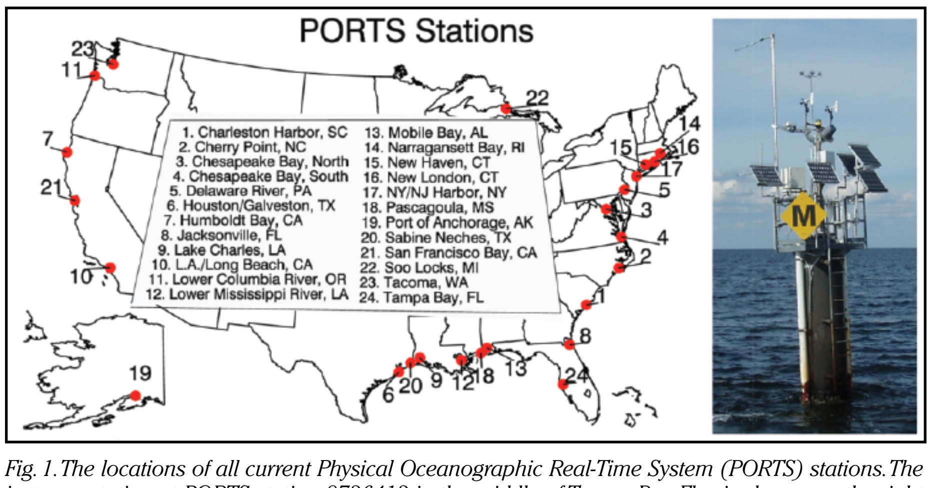

Fig. 1. The locations of all current Physical Oceanographic Real-Time System (PORTS) stations. The instrumentation at PORTS station 8726412 in the middle of Tampa Bay, Fla., is shown on the right.

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been strongly influenced by the 1997–1998 El Niño [*McPhaden*, 1999] and subsequent increases in Great Lakes surface water temperatures and diminished ice cover (Figure 2), accelerated over-lake evaporation, and rapid water level declines [*Assel et al.*, 2004; *Gronewold and Stow*, 2014; *Van Cleave et al.*, 2014].

The recent extreme ice and temperature observations raise compelling questions about not only the extent to which the Great Lakes might transition to a new hydrologic regime characterized by cooler lake temperatures and rising water levels but also the extent to which such a regime might persist as the climate system evolves [*Collins et al.*, 2010].

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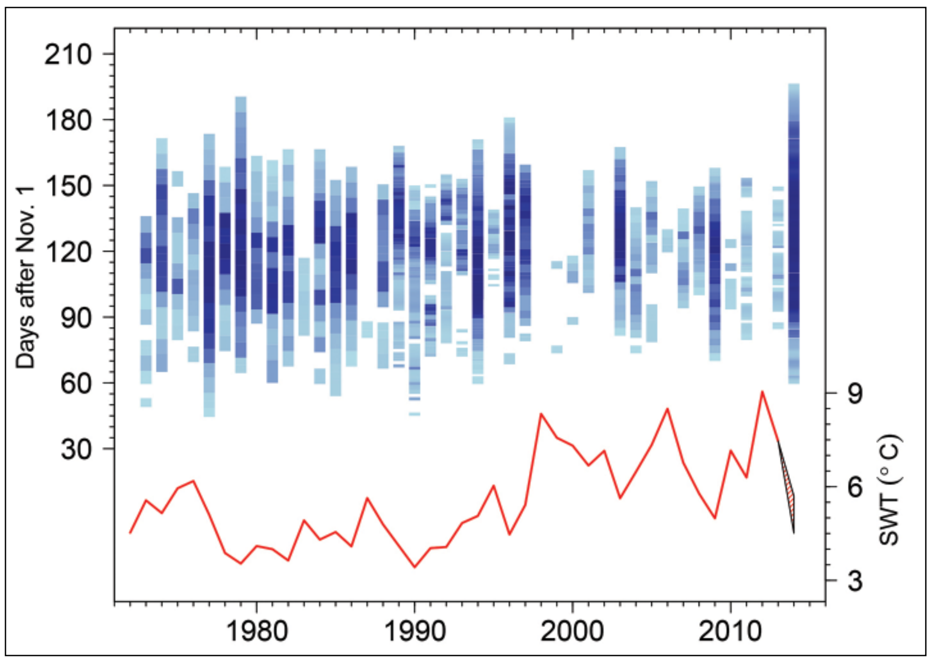

*Fig. 2. Areal extent of daily ice cover (blue columns) and average annual lake-wide surface water temperature (SWT; red line) on Lake Superior from 1972 to 2014 (SWT value for 2014 is a projection, represented by a 90% prediction interval). Each column corresponds to the ice season for the given calendar year. For example, the 1980 column represents ice cover data from roughly November 1979 through April 1980. The darkest shades of blue across all columns indicate ice cover near 100%, whereas the lightest shades of blue indicate ice cover near 10%. Ice cover and SWT data are adapted from the NOAA Great Lakes Ice Atlas project [*Assel, *2003, 2005;* Wang *et al.*, 2012a, 2012b*] and the NOAA Lake Thermodynamics Model [*Croley and Assel, *1994*], respectively.*

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These models provide maps of marine variables such as currents, water temperature, salinity, and winds across their domains in near real time as well as 48 hours into the future.

This information is useful for planning the transit of commercial and recreation vessels and in cleanup of hazardous materials by supporting more focused protection strategies to be applied to areas most at risk. They also provide short-term forecasts of water level (the National Weather Service provides the preferred storm surge forecast), allowing for more efficient and perhaps life-saving preparation and evacuation. HAB forecasts have recently been added to these models.

Monitoring Goes Global

PORTS-style scientific observational systems have been replicated at offshore sites and at sites around the world, providing new sources of regular, quality-controlled data. The Coastal Ocean Monitoring and Prediction System (COMPS) operates instruments on the West Florida Shelf. COMPS is now part of both the Southeastern Coastal Ocean Observing Regional Association (SECOORA) and the Gulf of Mexico Coastal Ocean Observing System (GCOOS), 2 of the 11 regional observing systems contributing to the Integrated Ocean Observing System (IOOS), which has more than 2500 monitoring sites around the globe.

As climate change drives an uncertain future, real-time monitoring will assume an even greater role in protecting coastal environments and their surrounding communities.

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