Climate and hydrologic change across the Great Lakes region and other transboundary waters

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Emily Warrender June 23, 2025

Scott Steinschneider, M. Altaf Arain, Paulin Coulibaly, Andrew Gronewold, and Gail Krantzberg, explore climate and hydrologic change across the Great Lakes region in North America and other transboundary waters

Hydroclimate extremes are transforming water landscapes in transboundary regions. These systems are particularly susceptible to hydroclimatic variability due to shared governance structures, interconnected ecosystems, and a wide range of water users.

The Great Lakes basin – one of the world's largest freshwater systems, shared by Canada, the United States, and numerous Indigenous sovereign nations – exemplifies how shifting hydroclimatic conditions are challenging conventional approaches to water management across borders. In this region, the impacts of these changes are evident in increased flooding, shoreline erosion, economic disruption, ecosystem stress, and rising uncertainty surrounding water availability and quality.

At the Global Center for Climate Change and Transboundary Waters, a team of hydrologists is working to better understand and respond to these shifts. The Hydroclimate Cluster (HC) advances predictive hydrologic and hydrodynamic modeling, along with decision-support tools, to strengthen water management and resilience in transboundary regions such as the Great Lakes. By deepening our understanding of hydroclimate dynamics and future risks, the cluster aims to equip communities and institutions with the knowledge they need to navigate evolving water challenges.

The HC's primary goal is to identify and attribute the key mechanisms driving hydroclimate change in the Great Lakes basin, while developing future projections to inform climate adaptation. The cluster also seeks to create climate and hydrologic tools that can be applied to other global transboundary watersheds.

HC research is organized around three core objectives:

1. Understanding drivers of variability:
   Investigate the mechanisms behind water level variability in the Great Lakes, both historically and in recent years, and evaluate how well current models and datasets capture these drivers.
2. Developing future projections and foundational data:
   Produce basin-wide projections of precipitation, evaporation, runoff, water supplies, and other foundational datasets for the Great Lakes region to inform adaptive planning at multiple scales.

3. Supporting adaptation:
    Co-create decision-support tools and analyses with community partners to improve readiness and response to hydroclimatic change.

Ongoing research across the HC spans a diverse set of projects aligned with these objectives. The following highlights offer a snapshot of the breadth and impact of this work.

Understanding drivers of variability

Understanding the historical variability of water levels in the Laurentian Great Lakes is often challenging due to uncertainties in key water balance components, such as over-lake and off-lake precipitation, evaporation, and watershed runoff. These uncertainties hinder efforts to attribute observed trends to specific drivers, an essential step for anticipating future changes in lake levels.

To address this issue, researchers in the HC cluster are working to reduce this uncertainty by improving estimates of runoff at hundreds of gauges around the Great Lakes using emerging methods in deep learning. These models show strong potential for improving estimates of monthly lake-wide runoff, which can then help resolve historical uncertainty in other major water balance components like over-lake precipitation and evaporation.

Work in the HC cluster also utilizes statistical and physical modeling approaches to better understand the drivers of historical variability in Great Lakes ice cover, temperatures, seasonal snowpack, and circulation dynamics. These dynamics are directly tied to water level dynamics within the lakes, but also have substantial implications for aquatic ecosystems and coastal hazards experienced by communities along the shoreline.

Developing future projections and foundational data

The potential impacts of climate change in the Great Lakes region span a wide range, particularly in the frequency and intensity of extreme events such as heavy rainfall, flooding, drought, and water level extremes. These changes pose significant risks to local communities and ecosystems.

To support adaptation planning, the HC is developing an ensemble of projected hydroclimate extremes, drawing on a range of regional climate models, emissions scenarios, and stochastic simulations. This work aims to produce robust, foundational datasets that communities can use to inform decision-making.

A central focus of this effort is the application of advanced statistical techniques to quantify uncertainty in these projections – ensuring that communities are not only equipped with future scenarios, but also understand the full range of possible outcomes they must be prepared to navigate.

Decision-support tools and analyses

Land-water-atmosphere interactions are complex and dynamic, but they play a significant role in how hydrologic systems in the Great Lakes will respond to future climate conditions, both for future water quantity and water quality.

Research in the HC is developing, testing, and applying the next generation of coupled hydrologic-biogeochemical and hydrodynamic models for water, carbon, and nutrient cycling studies in transboundary catchments and coastal zones throughout the Great Lakes region. Using these models, our work explores climate-tailored land use and ecosystem management and restoration practices for forest and agricultural systems, as well as the impacts of these practices on streamflows and water budgets under future climate scenarios.

We are also using these models to better understand the dynamics behind harmful algal blooms in coastal and estuary zones, to support anticipatory actions that can mitigate their impacts. Finally, the HC is developing a framework to account for climate change effects in hydrometeorological network design to meet adaptation needs in the Great Lakes basin.

HC's future plans

Looking ahead, the HC plans to extend its research beyond the Great Lakes region. This expansion is already underway, with initial studies focused on water balance and lake level variability in major African lake systems, as well as reconstructions and projections of hydrologic variability in the Rio Grande basin to explore transboundary water challenges along the U.S.–Mexico border. The HC is also increasing the visibility of its scientific contributions, presenting its first year of work under the five-year Global Center initiative at academic conferences and publishing in leading peer-reviewed journals.

In the coming years, the HC aims to strengthen the connection between its research and the communities it serves. A key priority is working in partnership with Indigenous nations to support and learn from their knowledge and practices for sustainable water management in a changing climate. These partnerships will be a cornerstone of the cluster's work moving forward, ensuring that scientific advancements are grounded in and enriched by diverse ways of knowing.

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