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Editorial: Hydroclimatology of the Great Lakes region of North America

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Editorial on the Research Topic
Hydroclimatology of the Great Lakes region of North America

The Great Lakes region of North America encompasses the Laurentian Great Lakes and the surrounding provinces and states of Canada and the United States. Although the sensitivity of the Great Lakes region to climate variability and change has long been recognized, current understanding of the historical and potential future changes in the regional hydroclimatology, and the consequences for physical and human systems, remains incomplete.

For this Research Topic, we sought submissions that improve our understanding of the trends and projected changes in the various components of the hydrological cycle, with the overall goal of providing novel insights to facilitate climate-related decision making in the Great Lakes region. Below we first provide as context a brief overview of the Great Lakes region, after which we integrate the contributions comprising this Research Topic around four themes: (1) historical trends in precipitation, (2) future projections for fine-scale assessment of regional thermal and hydrological characteristics, (3) lake effect climatology, and (4) challenges and novel approaches to assessing lake level fluctuations.

An introduction to the Great Lakes region

The Laurentian Great Lakes of North America, a series of interconnected freshwater lakes (Lakes Superior, Michigan, Huron, Erie, and Ontario), constitute the largest supply of fresh water in the world with more than 20% of the global total (Quinn, 1988) and with a coastline exceeding 14,000 km in length (Gibb, 2013). The climate of the Great Lakes region is influenced by its continental location, seasonal shifts in the location and configuration of the polar jet stream, and the frequency and tracks of transient midlatitude cyclones (Andresen et al., 2014). The Great Lakes modify the thermal and moisture characteristics of air masses transported into the region, with locations downwind of the lakes generally having a cloudier, wetter, and more moderate climate than those less influenced by the lakes (Andresen and Winkler, 2009).

Over 30% of the population of Canada, and ∼10% of the United States population, currently reside in the Great Lakes region (US EPA, 2021), and the region is home to over 40 Tribal Nations (Gibb, 2013). The availability of iron ore, the region's proximity to energy resources, and access to transportation contributed in the late 1800s and early 1900s to the development of manufacturing surrounding the Great Lakes, and the region remains the focus of the North American automobile industry (Sousounis and Albercook, 2000). Agriculture is the major regional land use (Niyogi and Mishra, 2013). The western portion of the Great Lakes region intersects the fertile North American Corn Belt (Hart, 1986) where corn (i.e., maize) and soybean production dominate (National Agricultural Statistics Service, 2022), whereas the eastern Great Lakes region is known for its diverse agriculture including fruit and vegetable production (Winkler et al., 2002). Tourism is an additional major revenue source and includes sport fishing, hiking and camping, and winter recreation (Shih et al., 2009; Nicholls, 2014). A multimodal transportation system, which includes marine ports and inland waterways, is central to the region's economy (Council of the Great Lakes Region, 2017).

Precipitation trends and mechanisms

Considerable uncertainty surrounds the sign and magnitude of historical trends in precipitation for the Great Lakes region, and several contributions to the Research Topic focus on the computation of robust estimates of regional precipitation trends. Motivated by previous studies that often found contradictory trends even for stations in close proximity, Baule et al. applied multiple quality control procedures to station-level precipitation observations to minimize the influence of station inhomogeneities on trend calculations. Temporal trends computed using the quality-controlled time series were, when significant, almost always positive, suggesting a general increase in recent decades in both high frequency, low magnitude and low frequency, high magnitude precipitation events. In contrast, Paxton et al. removed from trend calculations the autocorrelation in time series of extreme precipitation introduced by the persistence of large-scale modes of climate variability. They, too, found that all significant trends were positive in sign. Both studies, however, show that precipitation trends remain statistically insignificant for substantial portions of the Great Lakes region. Kunkel et al., who calculated temporal trends in extreme precipitation events for four overlapping periods spanning 1908–2020, note that significant trends were more likely for the more recent time periods. Together, these studies suggest a regional-scale trend toward a wetter climate that is emerging from interannual variability. Focusing on proxy measures of precipitation, Trumper et al. found that in the northern Great Lakes region the correlation between latewood tree-ring width from *Pinus resinosa* (red pine) with daily precipitation variability has weakened since the 1980s, limiting the utility of latewood for assessing ongoing trends in the regional hydroclimate.

These authors also consider atmospheric processes contributing to the precipitation trends. Both Kunkel et al. and Baule et al. explore the relationship between precipitable water and precipitation, with Kunkel et al. finding that precipitation amounts increase with precipitable water depths greater than 30 mm, whereas the insignificant temporal trends in precipitable water found by Baule et al. for large portions of the Great Lakes region point to cautious interpretation of the relationship between precipitable water trends and precipitation trends. On the other hand, Paxton et al.'s findings suggest that regional trends in extreme precipitation are associated with changes in the strength and frequency of jointly-considered 500 mb geopotential height and 850 mb relative humidity fields, as identified using bivariate self-organizing maps. Furthermore, Kunkel et al. found that over 78% of daily extreme precipitation events in the Great Lakes region occur along frontal boundaries of midlatitude cyclones.

Future projections of hydroclimatological variables

Future economic development of the Great Lakes region is greatly dependent on projected future changes in the temperature and precipitation climatology. Evaluating these changes on finer temporal and spatial scales by using local and regionally specific projections is imperative for successful planning for future resilience and adaptation. Several papers of this Research Topic (Grady et al., Kluver and Robertson, Xie et al., Shrestha et al.) address projected future changes in temperature and precipitation at a variety of spatial scales within and around the Great Lakes region. All of these papers base their investigation on dynamically downscaled projections using mostly the high emissions scenario RCP8.5.

Similar to existing research, the papers agree on the projected increases of temperatures in the future, e.g., rise in average daily maximum and minimum temperatures over the Saginaw Bay watershed (Kluver and Robertson) or in annual mean temperature over the Great Lakes region (Shrestha et al.). In parallel with these findings, Xie et al. show that extreme high temperature days are expected to increase exponentially with rising temperatures within the region, and this projected change is independent of physics parameterizations and global climate model (GCM) forcing.

Mean annual precipitation is projected to increase, mostly due to higher intensity as found, for example, over smaller areas such as the Saginaw Bay watershed in Michigan by Kluver and Robertson. These changes in annual precipitation are also corroborated over the larger Great Lakes Basin by Shrestha et al. who indicate that the projected future changes in highest one-day precipitation and number of wet days may indicate increases in extreme precipitation in the region. Furthermore, Shrestha et al., considering additional land hydroclimatology characteristics, indicate that annual runoff is also expected to increase despite the fact that snowpack is projected to decrease and actual evapotranspiration, especially in summer, is projected to rise.

The seasonal and monthly projected changes in precipitation and runoff are dependent on the season and to an extent the location, as indicated by Grady et al. and Shrestha et al. For example, Grady et al. identify for the spring season good model agreement indicating an increase in precipitation amount and intensity, and a decrease in the length of dry spells and the number of dry days. For summer, however, projections of precipitation amount and intensity do not show such strong consensus in sign and strength and display smaller changes with higher spatial variability. Considering compound risk events such as dry summers following wet springs, a combination which can be highly detrimental to corn and soybean yields, Grady et al. find that the risk is projected to be small by mid and late-century.

Lake effect climatology

Lake effect snow (LES) plays an important role in the hydroclimatology of the Great Lakes region. A number of papers within the Research Topic explore LES climatology and revisit several questions that have been raised previously, yet remain unanswered. One such question involves the contribution of LES to the overall snow climatology of the region. Although LES is an important contributor to snowfall, significant snow is also associated with synoptic-scale systems. Separating the influence of each requires that snow events be linked to a storm type, such as lake effect, synoptic, or some combination. We see a number of different approaches represented in this special collection. Jones et al. used a dataset published by Laird et al. (2017) that was based on an examination of daily GOES imagery. Direct observation of lake effect precipitation structures was also used by Hartnett, who classified snow events using a combination of reanalysis data and radar observations. Ellis and Suriano used the Temporal Synoptic Index (TSI) developed by Suriano and Leathers (2017) and the Spatial Synoptic Classification (SSC) from Ellis et al. (2021) to build a record of lake effect days. Neither dataset represents direct observations of lake effect cloud bands or precipitation, but the TSI provides a record of days that possess the synoptic conditions most associated with LES and the SSC provides insight into the way air masses are modified as they cross the Great Lakes.

These differing approaches in determining LES, along with the varying influence of each lake, contribute to highly variable estimates of the climatological contribution of LES. Jones et al. compared the very active lake effect winter of 2012/13 to the relatively inactive 2009/10 winter and found that LES contributions in the vicinity of Lakes Michigan, Erie, and Ontario ranged from 10 to 70%. Hartnett found that 13–48% of snowfall in central and northern New York was lake effect in origin, although this result varied throughout the winter season. Finally, Ellis and Suriano, using a hybrid lake effect dataset that combined the TSI and SSC classifications for the eastern Great Lakes, estimated that 31% of snow was lake derived. Although these percentages are generally consistent with those of earlier research (see Jones et al. Table 2), the substantial differences in LES estimates highlight the continuing uncertainty in the climatological contribution of LES.

Temporal trends in LES also have received considerable prior attention (e.g., Hartnett et al., 2014) and are further evaluated in this Research Topic, although the findings are contradictory. Meng et al. examined eight quality controlled snow records from western and central Michigan and found that seven exhibited statistically significant increases from 1932–2015. In contrast, Ellis and Suriano's hybrid lake effect dataset showed a declining trend in lake effect synoptic patterns and air mass signatures from the late 1970s to the early 2000s. The persistence of this question reflects the difficulty in assessing snowfall records and the role that snow data quality, period of analysis, and methodology all play in the conclusions.

Clark et al. presented an analysis of snow band structure and snowfall along the southern end of Lake Michigan and linked these structures to wind and temperature characteristics. Chief among their findings is that bands parallel to the wind are most common and determine much of the spatial distribution of snowfall in this region. However, the less common shore parallel bands account for some of the largest snowfalls in the area. They also found that upstream inversion heights, which are an indicator of the depth through which lake effect convection operates, were not significantly correlated with snowfall, perhaps due to the erosion of the inversion with over-lake passage.

Lake level trends and projections

In spite of both record low and record high Great Lakes water levels observed during the early twenty-first century (Gronewold and Rood, 2019), long-term trends in lake levels remain poorly documented. Fry et al. argue that a constraining factor is the limited availability of appropriate hydroclimate data sources for large-scale hydrological modeling, in part due to discontinuities from the Canadian-U.S. international border and the sparse observations across the surface area of the Great Lakes. In addition, currently available datasets lack appropriate documentation for their shared use by water managers and the earth system modeling community, arguing for greater engagement of these two communities. Moreover, the limitations of downscaling GCM simulations to the scale of the Great Lakes basin make assessing future lake level fluctuations challenging. VanDeweghe et al. illustrate an approach that links a lake-to-lake routing model to monthly values of the environmental components contributing to net basin supply that were estimated using a parametric regular vine copula. Application of these methods to two plausible water supply scenarios (one a continuation of current net basin supply trends and the other a blend of existing trends with downscaled projected trends from regional climate models) suggests only a modest increase, but continued large variability, in Great Lakes water levels.

Concluding remarks

This suite of papers point to the many complexities and uncertainties surrounding the historical and projected future changes in the hydroclimatology of the Great Lakes region of North America, as highlighted by the careful consideration of data issues (e.g., availability and inhomogeneities), the application of multiple methodologies, and the spatial variations that exist in many of the hydroclimate processes examined in this Research Topic. The submissions reflect the continuing efforts to improve our understanding of the fundamental components of the hydrological cycle in the Great Lakes region and to provide stakeholders with useful information for decision making.

Author contributions

JW, AB, and GG edited the Research Topic and wrote the editorial. All authors contributed to the editorial and approved the submitted version.

Conflict of interest

Author GG was employed by Met Office.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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