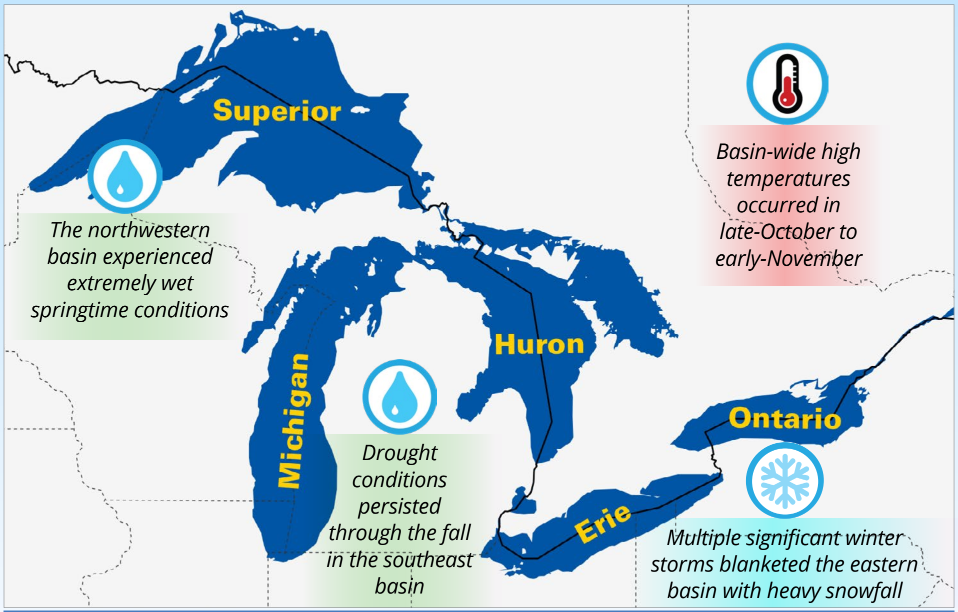
2022 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

During the 2022 reporting period, air temperatures were near normal and precipitation varied widely across the Great Lakes basin. Heavy springtime precipitation in the northwest was contrasted with fall drought conditions in the southeast. Both contributed to rapid seasonal shifts in Lake Superior and Ontario water levels, respectively. Water levels remained predominantly above average, with the exceptions of the beginning of 2022 for Lake Superior and the latter half of 2022 for Lake Ontario. At 56.1% areal coverage, Great Lakes maximum ice cover in 2022 was above the long-term average.



**Arrows indicate how 2022 average values compare to long-term average for the overall Great Lakes, though many 2022 values were near normal or varied by lake.*

Air Temperature	Basin Precipitation	Water Temperature	Ice Cover	Water Levels
↑	↓	↑	↑	↑

↑ *Above* ↓ *Below* ↕ *Variable*

2022 Highlights

Wet and Dry Conditions

After dry conditions in recent years, the northwest portion of the basin experienced an extremely wet springtime. Conversely, the southeast portion of the basin experienced drought conditions for the second half of 2022, negatively impacting crop yields.

Warm Fall in a Moderate Year

Though annual air temperatures were near average across the basin, fall temperatures were above normal. An extremely warm period occurred from late-October through mid-November that kept lake temperatures warmer than usual, and contributed to delayed ice formation and a major lake-effect snowstorm in mid-November for the southeastern basin.

Rapid Seasonal Water Level Shifts

Spring wet conditions in the northwest contributed to an extremely rapid springtime rise in Lake Superior water levels. Dry fall conditions in the southeast contributed to a sharp decline in Lake Ontario water levels. With the exception of Lake Ontario, water levels on all lakes ended above average by the end of 2022.

Photo: Cornfield damaged by drought conditions in Stouffville, Ontario (Credit: Creative Touch Imaging Ltd./NurPhoto via Getty Images).

Photo: November snowstorm in Hamburg, NY, near Buffalo (Credit: John Normile/Getty Images).

NOAA · Canada · GLISA A NOAA CAP/RISA TEAM · MRCC Midwestern Regional Climate Center · GLERL Great Lakes Environmental Research Laboratory · NRCC · UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

2022 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

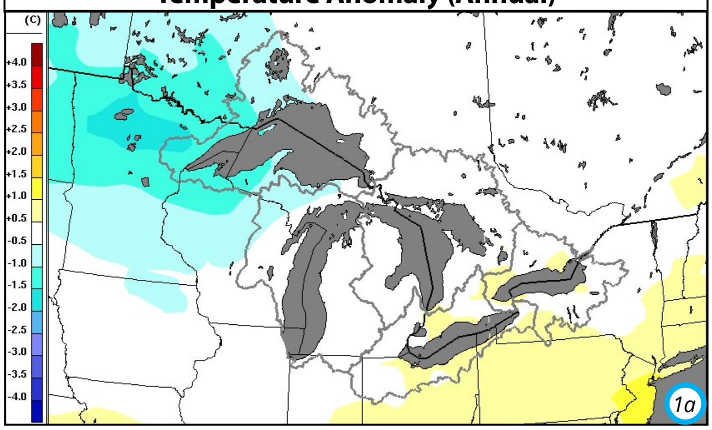
Climate Overview: December 2021 - November 2022

During the December 2021 – November 2022 reporting period* mean annual temperatures were predominately near average across most of the Great Lakes basin (Figure 1a). Exceptions include below-average (-2°C) portions of the western Superior basin and above-average (+0.5°C) areas of the Erie and Ontario basins. Fall was the only season with above-average temperatures for the entire basin. Annual precipitation totals were above normal in the Lake Superior basin, which previously experienced drought conditions through most of 2021, and near or below normal for the southeast portion of the basin (Figure 1b). Dry conditions characterized the winter and spring of 2022 for most of the southern basin, with drought conditions persisting in southern Ontario.

Annual water temperatures were below normal for Lakes Superior and Michigan, and above normal for Lakes Huron, Erie, and Ontario. In 2022, basin-wide precipitation and runoff totals were below average for every lake except Superior. Evaporation totals were above normal on all lakes. Over the period from 1991-2020 across the region, air temperature (+0.14 °C/decade), precipitation (+11.5mm/decade), evaporation (+17.4mm/decade), water temperatures (+0.43 °C/decade), and runoff (+20.1mm/decade) have all increased.

**This report utilizes climatological seasons, which includes December from the previous year as part of the winter season.*

Temperature Anomaly (Annual)



Precipitation Anomaly (Annual)

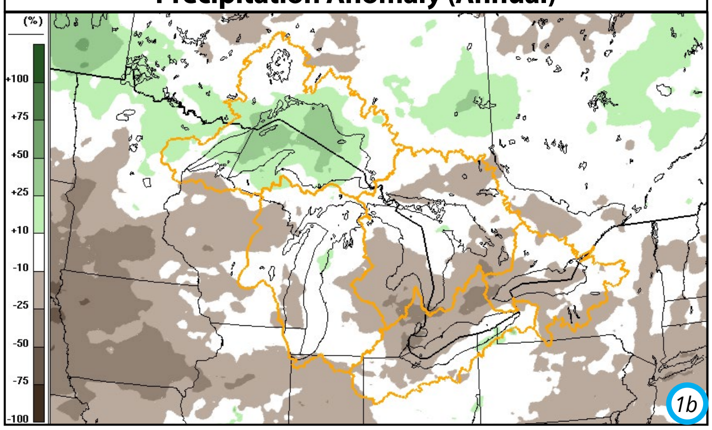


Figure 1. Maps displaying annual anomalies for temperature (1a) and total precipitation accumulation (1b) in the Great Lakes region. Anomalies for temperature are departures from the 1981-2010 mean (°C). Anomalies for precipitation are % departure from the 1991-2020 mean. Gray (1a) and yellow (1b) outlines depict the individual lake basins. Data for temperature are from ECCC and NOAA surface observations and precipitation is a merged dataset containing ECCC model and Numerical Weather Prediction (NWP) model data. Figures created by ECCC.

		SUPERIOR		MICHIGAN		HURON		ERIE		ONTARIO	
		2022	LTA	2022	LTA	2022	LTA	2022	LTA	2022	LTA
Surface Water Temps (°C)	Max	16.91	17.65	21.88	22.59	21.71	21.46	25.19	25.06	24.16	23.59
	Min	0.26	0.60	1.52	1.29	0.53	0.60	0.20	0.33	2.01	1.37
	Avg	5.77	6.56	9.85	9.76	9.07	8.93	11.75	11.43	11.07	10.39
Ice Cover (%)	Max	79.55	61.25	37.47	39.83	67.23	64.28	93.76	81.33	29.43	29.63

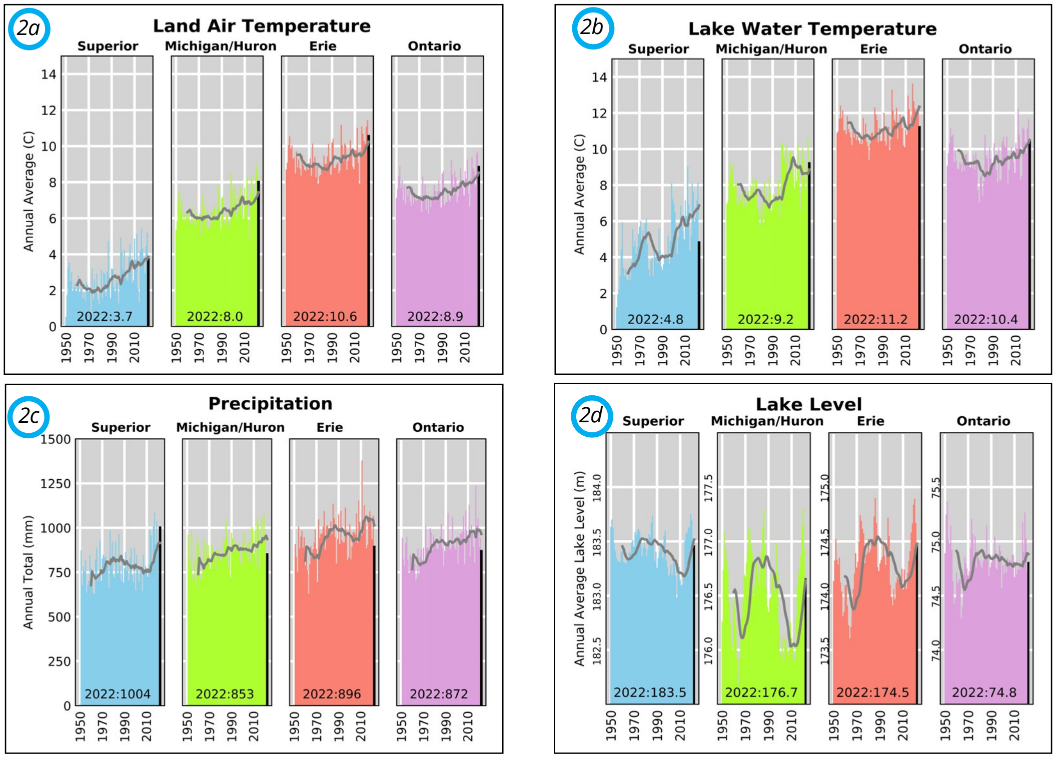
		SUPERIOR		MICHIGAN-HURON**		ERIE		ONTARIO	
		2022	LTA	2022	LTA	2022	LTA	2022	LTA
Water Levels (meters)	Max	183.65	183.58	176.81	176.61	174.68	174.40	75.17	75.10
	Min	183.15	183.23	176.53	176.25	174.25	173.91	74.40	74.42
	Avg	183.44	183.41	176.67	176.44	174.52	174.17	74.84	74.77
Precipitation (mm)	Ann Sum	1004.1	780.5	853.4	888.0	896.6	973.9	872.3	930.7
Evaporation (mm)	Ann Sum	720.1	556.8	682.1	504.0	985.0	896.4	755.6	650.4

*Table 1: Summary of hydro-climate variables by lake. Long-Term Average (LTA) changes depending on variable: **Water Temps (°C)** - 2022: December 2021 through November 2022, LTA: 1995-2021; **Ice Cover (%)** – 2022: December 2021 through May 2022, LTA: 1973-2021; **Water Levels (meters)** - 2022: December 2021 through November 2022, LTA: Period of Record (1918-2021); **Precipitation (mm)** - 2022: December 2021 through November 2022, LTA: 1981-2010; **Evaporation (mm)** - 2022: December 2021 through November 2022, LTA: 1981-2010. Estimated from NOAA Great Lakes Surface Environmental Analysis (water temps), NOAA GLERL CoastWatch (ice cover), US Army Corps of Engineers (lake levels), NOAA GLERL Great Lakes Hydrologic Data (precipitation and evaporation).*

***Lakes Michigan and Huron are treated as one unit for water levels, precipitation, and evaporation since there is no physical separation between the lake bodies.*

2022 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

Historical Trends



Air temperatures (Figure 2a) were near or slightly above the 10-year average for each lake basin in 2022. Water temperatures (Figure 2b) varied by lake, with Superior being well under the 10-year average. There has been an upward trend in both air and water temperatures in recent years that is particularly notable in the upper Great Lakes and their basins. Annual precipitation accumulation (Figure 2c) in 2022 was below the 10-year average for all lake basins except Superior. This is a departure from the general upward trend observed in recent years, though substantial interannual variability is common. Water levels (Figure 2d) were near the 10-year average on all lakes. Lake levels had risen since 2013 after a period of low lake levels lasting from the 1990s to the mid-2000s, and are now falling again.

Figure 2. Time series of air temperatures (2a), water temperatures (2b), precipitation (2c), and water levels (2d) by lake basin from 1950-2022. The gray line is a 10-year moving average and the black line is the 2022 average. Estimated from GLERL Great Lakes Monthly Hydrologic Data, and Coordinating Committee on Great Lakes Basic Hydraulic and Hydrologic Data.

Ideal Conditions for a Powerful Lake-Effect Snow Storm

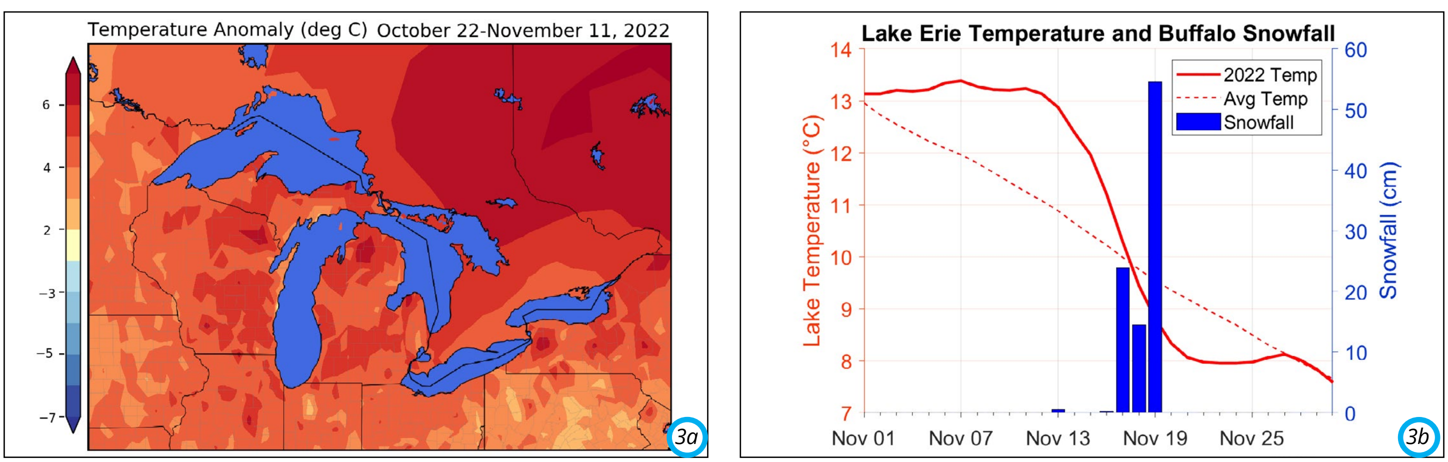


Figure 3. Map displaying temperature anomalies for October 22 , 2022-November 11, 2022 (3a) and chart displaying November 2022 Lake Erie surface water temperatures with snowfall totals (3b) in Buffalo, NY. Data is from the Northeast Regional Climate Center (3a) and NOAA Great Lakes Surface Environmental Analysis (3b).

There were numerous periods of extreme temperature and storms throughout the Great Lakes in 2022. A prominent event occurred in the fall, when extremely warm air temperatures were observed from late-October through mid-November (Figure 3a). Such warm air temperatures caused the usual fall decline in Lake Erie surface water temperatures to plateau for several weeks and remain well above the long-term average for that time of year.

A sudden cold-air surge, combined with warm surface temperatures in Lake Erie and cross-lake winds, created ideal conditions for a strong lake-effect snowstorm that swept across Lake Erie to the Buffalo, NY area on November 17-20 (Figure 3b). The storm dropped over 93 cm of snowfall onto Buffalo, with some surrounding areas receiving even more. During this cold surge, Lake Erie surface water temperatures dropped rapidly to below the long-term average.

2022 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

Seasonal Precipitation Extremes

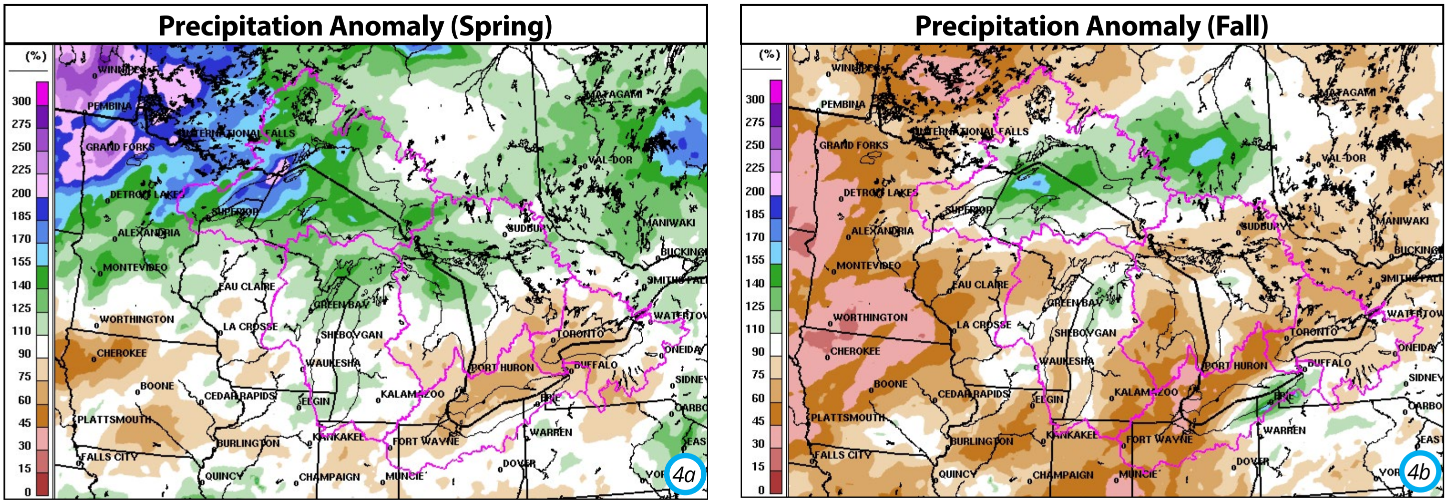


Figure 4. Maps displaying anomalies of total precipitation accumulation for Spring (4a) and Fall (4b) in the Great Lakes region. Anomalies are % departure from the 1991-2020 mean. Figures created by ECCC.

Northwest portions of the basin experienced well above-average precipitation in the springtime (Figure 4a), contributing to a rapid rise in Lake Superior water levels. This was in contrast to the southeastern portion of the basin, where below-average conditions were experienced during this time.

Below-average precipitation occurred throughout much of the basin in the summer months. Drought conditions developed in portions of southern Ontario and persisted through the fall months (Figure 4b), contributing to a steep drop in Lake Ontario water levels. Windsor, ON, observed its driest year on record since 1940, and other locations observed similarly low precipitation totals for the 2022 climate year.

Rapid Seasonal Water Level Shifts

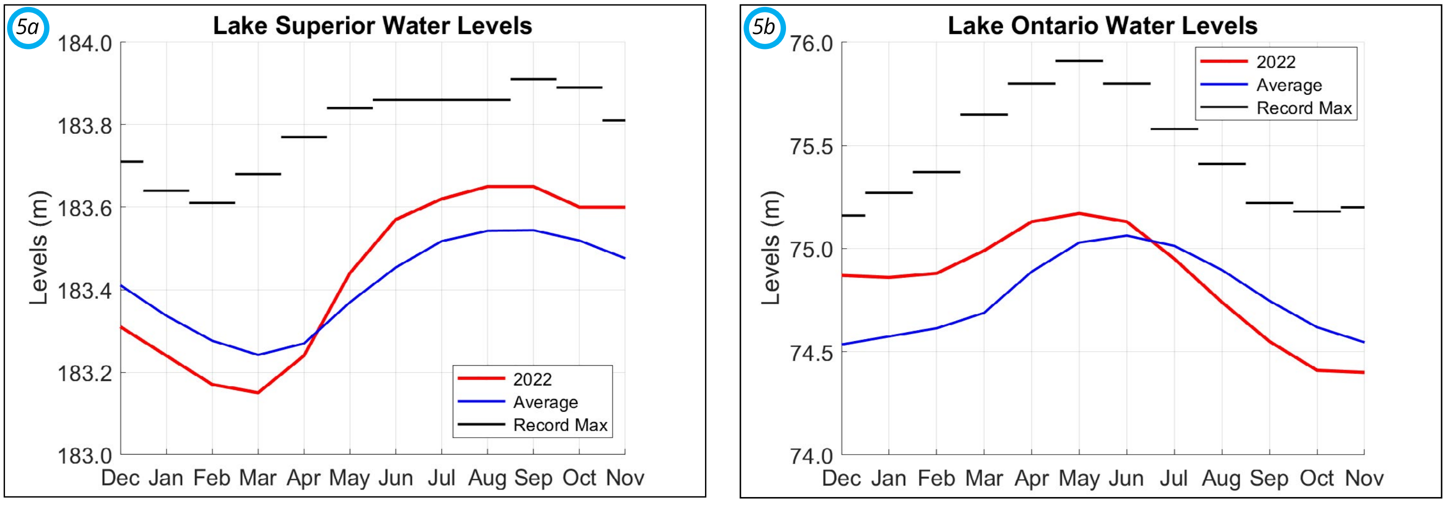


Figure 5. Values for 2022, historical average, and record lake levels for Lake Superior (5a) and Lake Ontario (5b). Average levels based on 1918-2021 mean. Estimated from US Army Corps of Engineers Data.

Varying precipitation conditions throughout the basin contributed to inter-regional variability in the annual cycle of Great Lakes water levels. Water levels on Lake Superior (Figure 5a) were below average in December (start of the Dec. '21 - Nov. '22 climatological year). Lake Superior then tied its 2001 record for greatest March-June water level rise driven by very wet winter and spring conditions in the basin. Drier conditions led to smaller-than-average fall declines, with water levels plateauing in October-November, but still ending the year above average.

Lake Ontario water levels (Figure 5b) began the year above average, but very dry conditions caused them to rapidly drop below average from summer through fall. Unlike the Superior basin, the Ontario basin experienced drought conditions during the summer and fall, contributing to one of the highest rates of water level decline on record. Warm conditions also contributed to a plateau in water levels from October-November. Note that although both Lake Superior and Lake Ontario have regulated outflows, the shifts seen in the water levels were overwhelmingly the result of the incoming water supplies.

2022 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

Major Climatic Events

Winter 2021-2022

December temperatures as much as 4°C above normal delayed the onset of snowfall and reduced monthly snowfall totals before abnormally-cold temperatures settled across the region in January.

A significant winter storm on January 16-17 blanketed the eastern basin with 25-61 cm of rapidly falling snow.

An above-normal number of fast-moving "clipper" systems led to higher-than-normal snowfall in the northwest portion of the basin. Elsewhere, the Michigan-Huron basin had its driest January on record, and Green Bay, Wisconsin, had its second-driest January to February.

Rapid temperature swings, heavy rainfall, and snow melt during the second half of February created favorable conditions for ice jam flooding in the eastern basin.

Photo: Damage from an EF-3 Tornado that struck Gaylord, MI, on May 20th, 2022 (Credit: Jake May, MLive).

Spring 2022

Record-setting spring precipitation was widespread in the northwest. Portions of the Lake Superior basin measured 2-3 times above normal precipitation in April.

Extremely warm and humid air affected the central Great Lakes region May 9-14, with high temperatures over 11°C above normal and low temperatures up to 8°C above normal.

A cold front pushed across the Great Lakes on May 19-21, prompting damaging storms across the southeast basin. On May 20, an EF-3 tornado struck Gaylord, Michigan, becoming only the 5th deadly tornado to affect northern Michigan. An intense wind event (derecho) developed May 21, bringing widespread wind gusts over 120 kph across Ontario from Sarnia to Quebec City.

Summer 2022

Dry, warm conditions settled across the basin in June along and south of an axis from Duluth, Minnesota, to Buffalo, New York. Drought stress stunted corn and reduced hay yields in western New York and lowered Michigan wheat yields.

Unstable weather brought high heat and damaging winds to the southern and eastern basin in mid-June. A long-duration wind event on June 13 blanketed an area from southern Wisconsin to Ohio with 80-121 kph winds, knocking out power for days as heat index values rose to 38°C along the southern basin.

Another round of intense heat and humidity settled across the southern and eastern basin on June 20-22. For only the second time on record in June, Toronto, Ontario, exceeded 35°C on two consecutive days (June 21-22).

On July 28, an EF-2 tornado touched down in Wyoming County, New York, marking the 4th tornado on record and first in over 20 years.

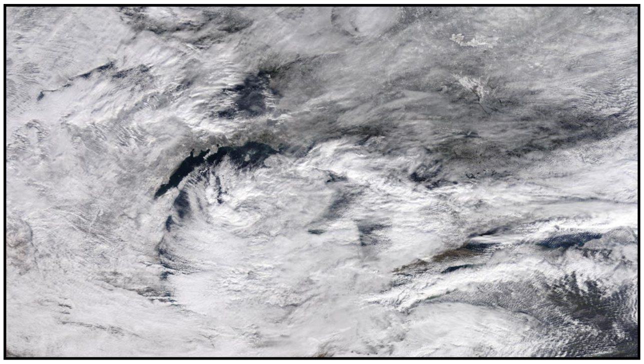


Photo: Satellite image of mid-November snowstorm over the Great Lakes (Credit: NASA/Terra-MODIS).

Autumn 2022

The harmful algal bloom that developed in Lake Erie was rated as "moderately severe" and the sixth worst bloom since 2002. For the first time on record, the bloom lasted into November, which is about a month longer than usual.

Drought conditions in the central basin persisted into fall, with some areas of southern Ontario intensifying to severe drought. Detroit, Michigan, had its 5th driest fall dating back to 1874.

From November 4-6, temperatures were up to 17°C above normal in the eastern basin. On November 5, Toronto, Ontario, had its warmest November day on record, reaching 25.1°C.

Water temperatures in Lakes Huron, Erie, and Ontario were unusually stable (not decreasing) in October, leading to near-record water warmth by early November.

Fueled by a cold snap over unusually warm water, a record-setting lake-effect snow event on November 16-21 dumped 206 cm of snow east of Lake Erie. Buffalo, New York, had 92.96 cm of snow from November 17-19, ranking as its second-largest three-day snow for November.

2022 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

New Research, Applications, and Activities

This section highlights research findings and relevant activities from across the region from the previous year. Findings from these efforts have implications for a wide range of sectors, improve the understanding of regional climate, and show promise for informing planning efforts and policy implementation in the Great Lakes.

Modeling, Science & Natural Resources

- A set of five retrospective and prospective summaries were developed to mark the 50th anniversary of the Great Lakes Water Quality Agreement. The retrospectives provide an overview of past climate and lake trends for each Great Lake, and the prospectives provide an overview of future climate trends and impacts for each lake and its basin. (GLISA 2022)
- Researchers assessed the performance of the high-resolution HighResMIP global climate models at capturing lake-effect processes in the Great Lakes region and determined that the models inadequately represent lake temperatures and ice cover, often leading to insufficient annual snowfall in the lake-effect zones. (Notaro et al. 2022)
- Environment and Climate Change Canada used data from several CMIP5 GCMs downscaled as part of the CORDEX experiment to project future water levels for the Great Lakes. It was found that more extreme lake levels would be seen with higher changes in Global Mean Temperature. (Seglenieks and Temgoua 2022)
- A study by ECCC investigated the changes in various hydroclimate variables such as temperature, precipitation, runoff, and snow water equivalent over the land surface of the Great Lakes based on projections from the CORDEX experiment using downscaled CMIP5 GCMs. (Shrestha et al. 2022)
- A study evaluated ERA5 and MERRA2 precipitation estimate products over the Great Lakes basin, using hydrological modeling techniques. They found that ERA5 overestimates precipitation but captures the effect of the lakes, and MERRA2 has more bias and struggles to capture lake-effect precipitation. (Xu et al. 2022)
- A new statistical modeling approach for projecting water supplies and water levels on the Great Lakes replicates important water level dynamics and hydrological components. (VanDeWeghe et al. 2022)
- An advanced 3D regional climate modeling system for the Great Lakes region significantly improved the simulation of net basin supply components, particularly lake evaporation, when compared to previous 1D lake level modeling efforts. (Kayastha et al. 2022)

Communities, Engagement & Policy

- GLISA partnered with Great Lakes city adaptation practitioners to produce a set of plausible climate scenarios to aid in city and local planning. The scenarios can be used as a starting point for thinking about a future that may look different than the past and to develop ideas, recommendations, and plans to better prepare for that future. (GLISA 2022)
- A team of researchers from McMaster University performed scenario analyses to determine programs and policies that would make the city of Hamilton, Ontario, more resilient to flooding. They found that the outcome of their research reveal significant program and policy implications for coastal cities faced with similar flooding risks. (Krantzberg et al. 2022)
- Strategies for Adapting Great Lakes Coastal Ecosystems to Climate Change presents a menu of adaptation actions to help natural resource practitioners move from general concepts to tangible, targeted adaptation tactics for their system. (Schmitt et al. 2022)
- Toronto and Region Conservation Authority developed a standardized approach to retrieve and analyze region-specific climate projections to the end of the century for municipal partners within its jurisdiction. This innovative approach supports policy and program development. (TRCA 2022)

About This Document

Coordinated by a partnership between climate services organizations in the U.S. and Canada, this product provides a synthesis report summarizing the previous years' climate trends, events, new research, assessments, and related activities in the Great Lakes Region. This product is a contribution to the U.S.-Canada Great Lakes Water Quality Agreement, through Annex 9 on Climate Change Impacts, and to the national climate assessment processes in the U.S. and Canada. It should be cited as: Environment and Climate Change Canada and the U.S. National Oceanic and Atmospheric Administration. 2022 Annual Climate Trends and Impacts Summary for the Great Lakes Basin. 2023. Available at https://binational.net.

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For additional figures, information, and sources visit: glisa.umich.edu/summary-climate-information/annual-climate-trends