Annual Climate Trends and Impacts Summary for the Great Lakes Basin: Communicating Climate Information to a Binational Audience

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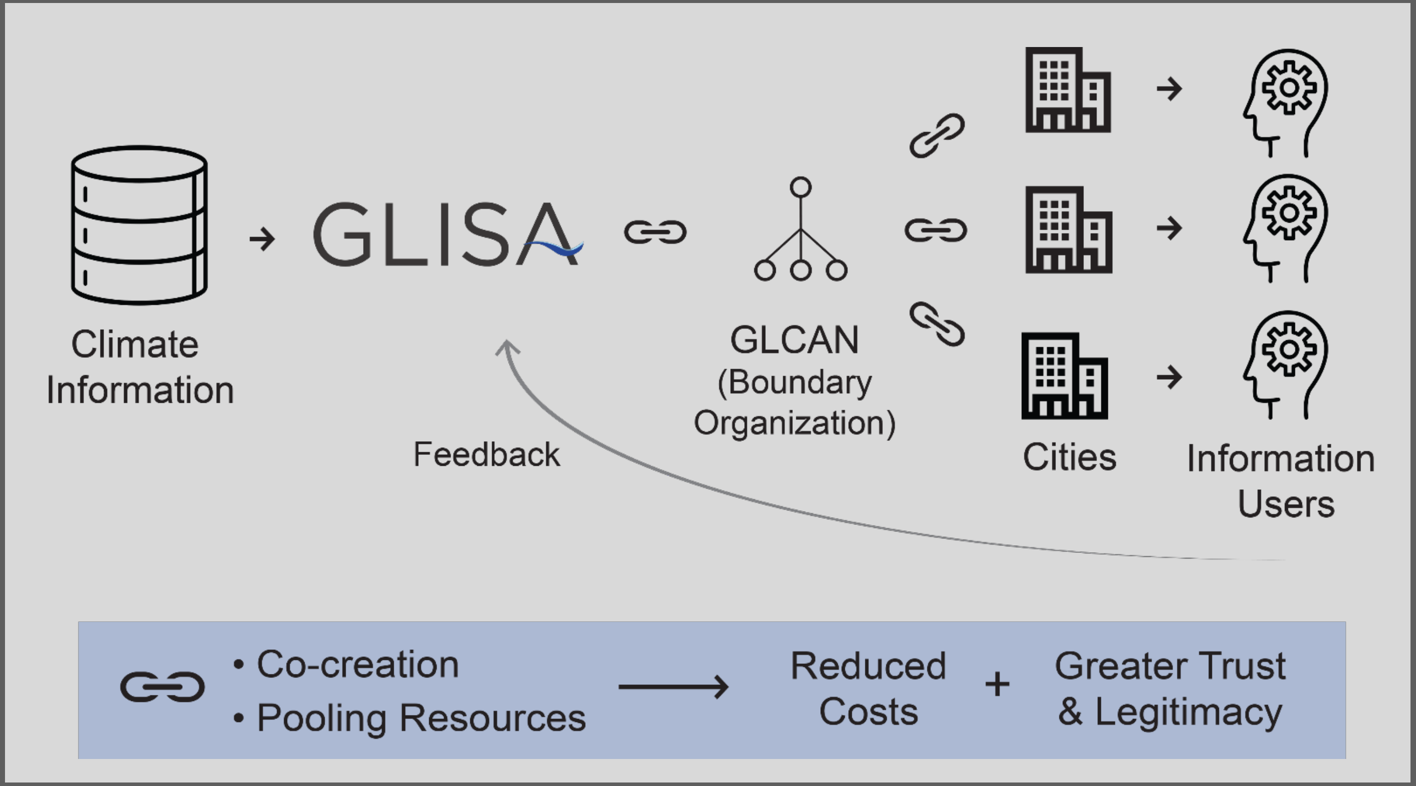
GLISA Approach

- NOAA Regional Integrated Sciences and Assessments (RISA) Program helping nation prepare for and adapt to climate variability and change
- Communicate science and information for the Great Lakes region
  - Interpret existing information and data for stakeholders
  - Provide locally relevant climate synthesis

Successful Communication

- Trusted climate communicators
- Iterative feedback process
- Clear identification of end user needs

GLISA's Boundary Chain Model



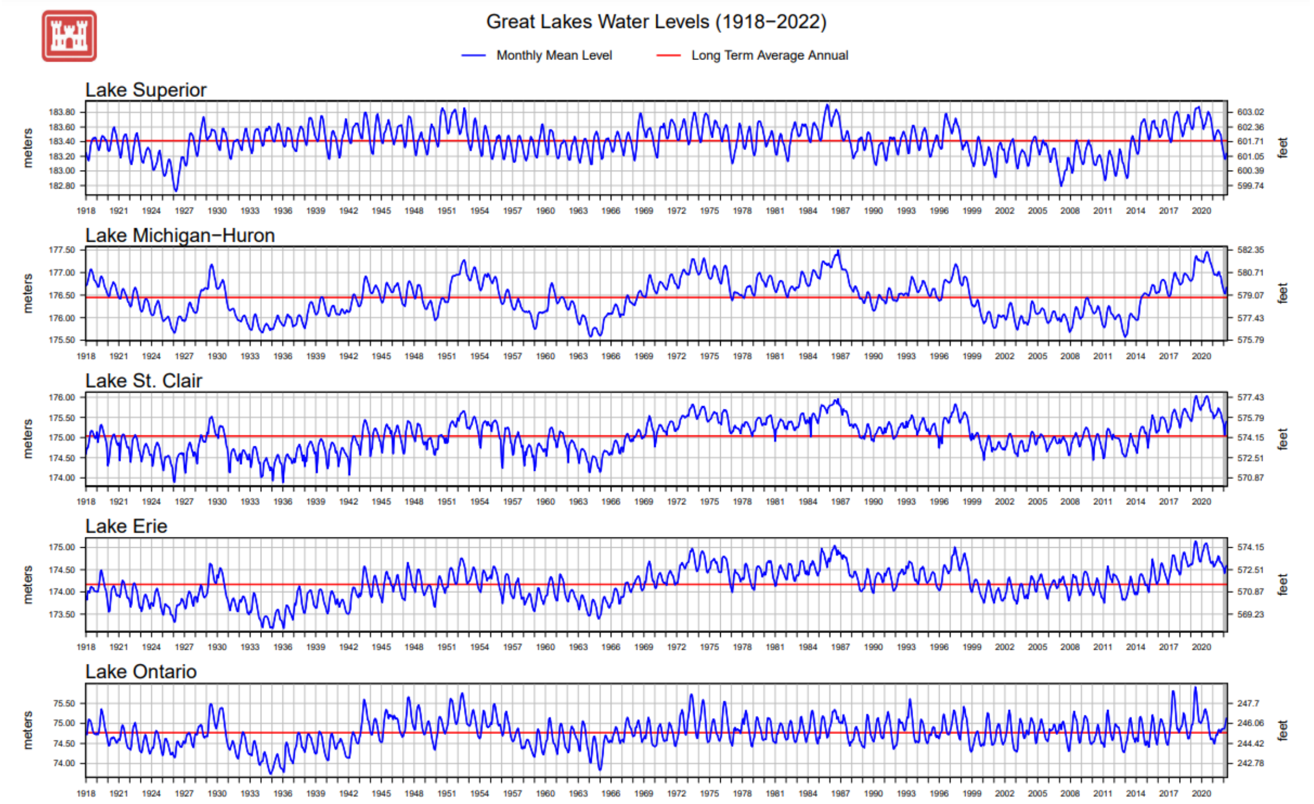
Annual Climate Trends and Impacts Summary for the Great Lakes Basin

- Began in 2017 in response to climate science knowledge gaps identified by the Great Lakes Water Quality Agreement (GLWQA) Climate Change Impacts Subcommittee
- Coordinated by a partnership between climate services organizations in the U.S. and Canada through the U.S.-Canada GLWQA Annex 9 on Climate Change Impacts, and to National Climate Assessment processes in the U.S. and Canada.
- Intended audiences: GLWQA annexes, Great Lakes Executive Committee, policy and decision makers at all levels in the Great Lakes.

Great Lakes levels rose from record or near record lows in 2013 to record or near record high levels in 2019

Old Mission Peninsula, 2011

Old Mission Peninsula, 2019



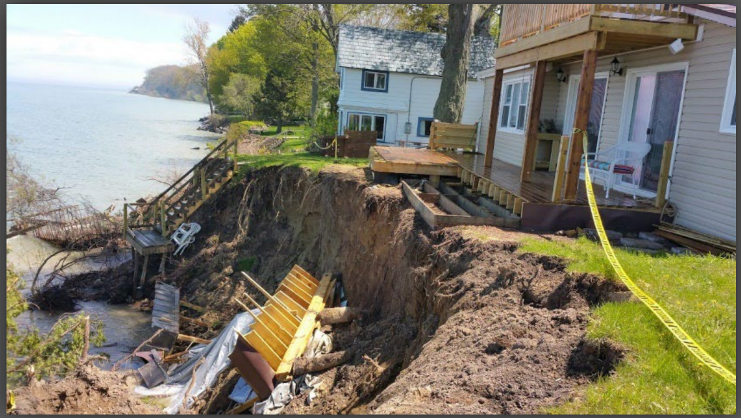
http://lre-wm.usace.army.mil/ForecastData/GLBasinConditions/LTA-GLWL-Graph.pdf

Document Walkthrough

1. Introduction and overview
   - Major annual highlights and records
2. Climate trends
   - Annual overview
   - Highlights: temperature, hydrologic, precipitation
3. Major climatic events
4. New research, applications, and activities

Climate Story of 2017

- Lake Ontario flooding
  - Sustained winter and spring precipitation caused record high water levels on Lake Ontario
  - Millions of dollars in property and infrastructure damage, road closures, shoreline erosion, etc.



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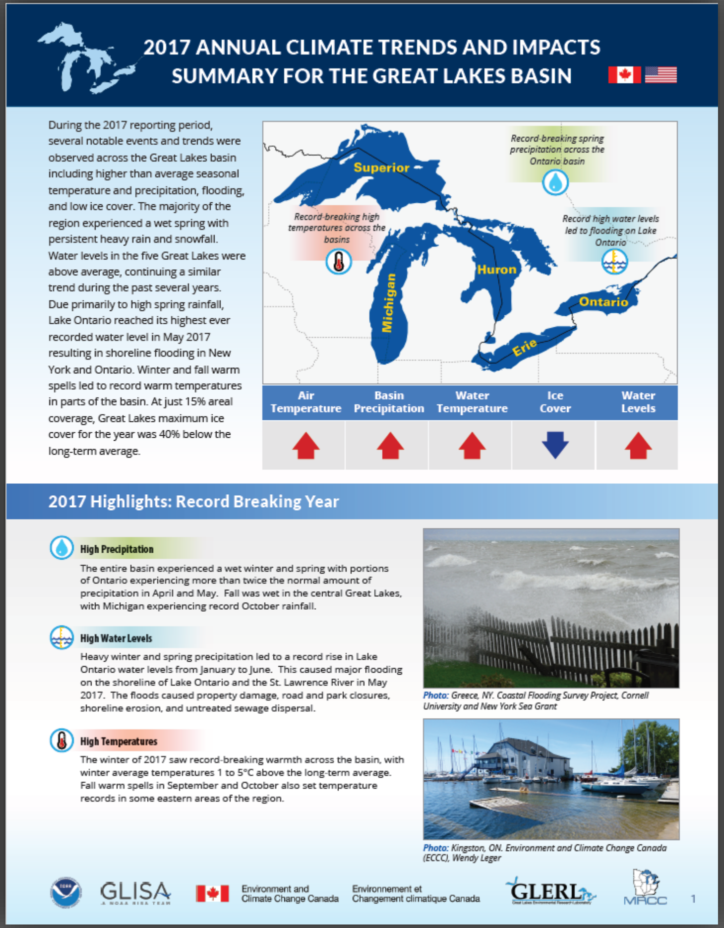

2017 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

During the 2017 reporting period, several notable events and trends were observed across the Great Lakes basin including higher than average seasonal temperature and precipitation, flooding, and low ice cover. The majority of the region experienced a wet spring with persistent heavy rain and snowfall. Water levels in the five Great Lakes were above average, continuing a similar trend during the past several years. Due primarily to high spring rainfall, Lake Ontario reached its highest ever recorded water level in May 2017 resulting in shoreline flooding in New York and Ontario. Winter and fall warm spells led to record warm temperatures in parts of the basin. At just 15% areal coverage, Great Lakes maximum ice cover for the year was 40% below the long-term average.

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

2017 Highlights: Record Breaking Year

High Precipitation

The entire basin experienced a wet winter and spring with portions of Ontario experiencing more than twice the normal amount of precipitation in April and May. Fall was wet in the central Great Lakes, with Michigan experiencing record October rainfall.

High Water Levels

Heavy winter and spring precipitation led to a record rise in Lake Ontario water levels from January to June. This caused major flooding on the shoreline of Lake Ontario and the St. Lawrence River in May 2017. The floods caused property damage, road and park closures, shoreline erosion, and untreated sewage dispersal.

High Temperatures

The winter of 2017 saw record-breaking warmth across the basin, with winter average temperatures 1 to 5°C above the long-term average. Fall warm spells in September and October also set temperature records in some eastern areas of the region.

Photo: Greece, NY. Coastal Flooding Survey Project, Cornell University and New York Sea Grant

Photo: Kingston, ON. Environment and Climate Change Canada (ECCC), Wendy Leger

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Climate Overview: December 2016 - November 2017

The December 2016 – November 2017 reporting period was overall warmer and wetter than normal, though there was substantial spatial and temporal variation across the region *(Figure 1)*. Mean annual temperatures were -1 to +2 °C below/above average across the region, with the largest departures from average temperature during the winter months. Precipitation was significantly greater than normal (10 to 50%), as seen by the green areas on the map, with some areas of the region setting new monthly and annual precipitation records. Given milder than normal temperatures during the cold season months, snow accumulations and snow cover duration were less than normal. Air temperatures over land in the basin were milder than normal, as were water temperatures.

Given heavy precipitation during much of the reporting period, basin-wide precipitation, runoff, and evaporation totals were also greater than normal. These numbers are generally consistent with observed long-term trends. Over the period from 1981-2010 across the region, air temperature (+0.26°C/decade), precipitation (+23.4mm/decade), evaporation (+19.9mm/decade), and water temperatures (+0.53°C/decade) have all increased. Runoff (-16.8mm/decade) has declined over the same time period. Highlights and links to additional data are given in the sections below.

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

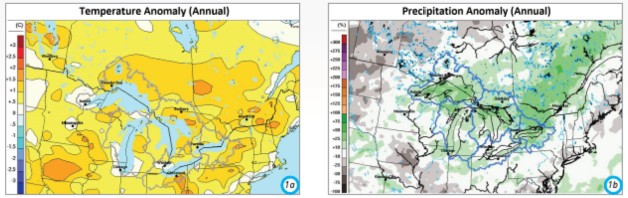

Figure 1. Maps displaying annual anomalies for temperature (1a) and total precipitation accumulation (1b) in the Great Lakes region. Anomalies for temperature are departures from the 1981-2010 mean. Anomalies for precipitation are % departure from the 2002-2016 mean. Data for temperature are from ECCC model output and precipitation data is a merged dataset containing ECCC model and Numerical Weather Prediction (NWP) model data. Figures created by ECCC.

		Superior		Michigan		Huron		Erie		Ontario	
		2017	LTA	2017	LTA	2017	LTA	2017	LTA	2017	LTA
Water Temps (C°)	Max	16.4	16.0	21.5	21.3	21.1	19.9	24.0	23.9	23.2	22.2
	Min	1.3	1.0	2.4	1.5	1.1	0.9	0.7	1.1	2.7	1.8
	Avg	7.0	6.4	10.5	9.5	9.7	8.8	12.0	11.4	11.2	10.1
Ice Cover (%)	Max	18.7	48.6	18.2	28.8	35.4	51.7	35.5	70.1	6.8	20.5

		Superior		Michigan-Huron*		Erie		Ontario	
		2017	LTA	2017	LTA	2017	LTA	2017	LTA
Water Levels (meters)	Max	183.8	183.5	177.0	176.6	174.8	174.3	75.8	75.0
	Min	183.4	183.2	176.5	176.3	174.2	174.0	74.5	74.5
	Avg	183.6	183.4	176.7	176.4	174.6	174.1	75.1	74.8
Precipitation (mm)	Ann Sum	1032.8	711.6	883.6	794.4	963.0	842.4	1258.9	859.2
Evaporation (mm)	Ann Sum	764.8	556.8	843.9	504.0	972.5	896.4	745.0	650.4

Table 1: *Summary of hydro-climate variables by lake. Long Term Average (LTA) changes depending on variable: **Water Temps (°C)** - 2017: December 2016 through November 2017, LTA: 1992-2016; **Ice Cover (%)** – 2017: December 2016 through April 2017, LTA: 1973-2016; **Water Levels (meters)** - 2017: December 2016 through November 2017, LTA: Period of Record (1918-2016); **Precipitation (mm)** - 2017: December 2016 through November 2017, LTA: 1981-2010; **Evaporation (mm)** - 2017: December 2016 through November 2017, LTA: 1981-2010*

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

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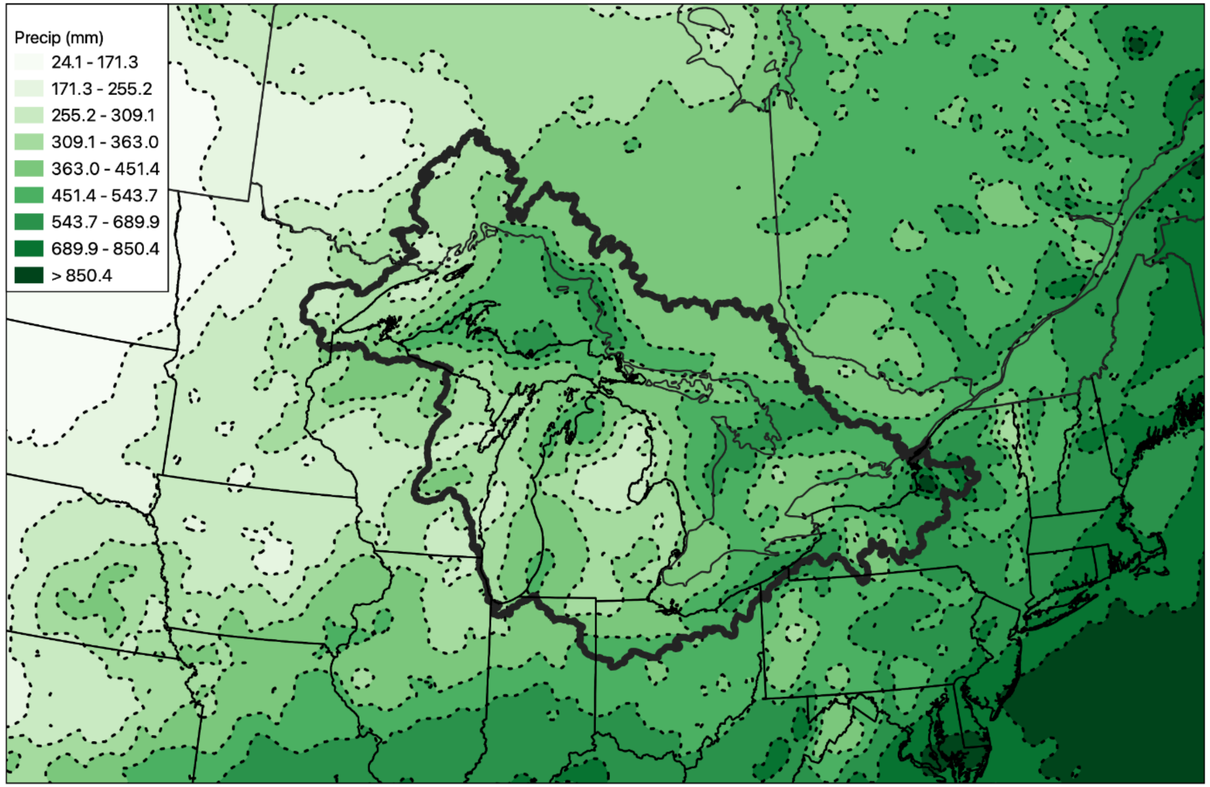
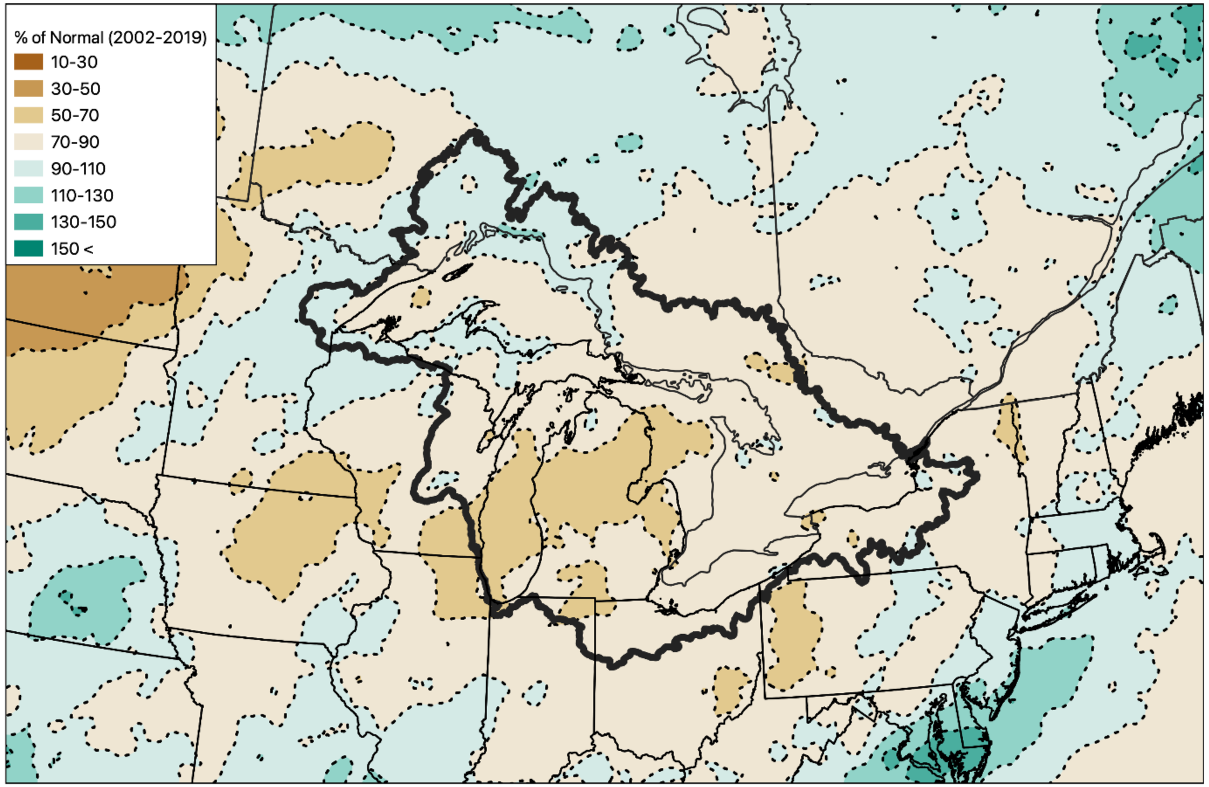
Total Precipitation

1 NOV 2020 – 30 APR 2021

October 1, 2020 through April 30, 2021 Precipitation Accumulation



Precipitation Percent of Normal October 1, 2020 through April 30, 2021



Data Source: Canadian Precipitation Analysis (Lespinas et al, 2015)

Annual Review: Snow and Ice

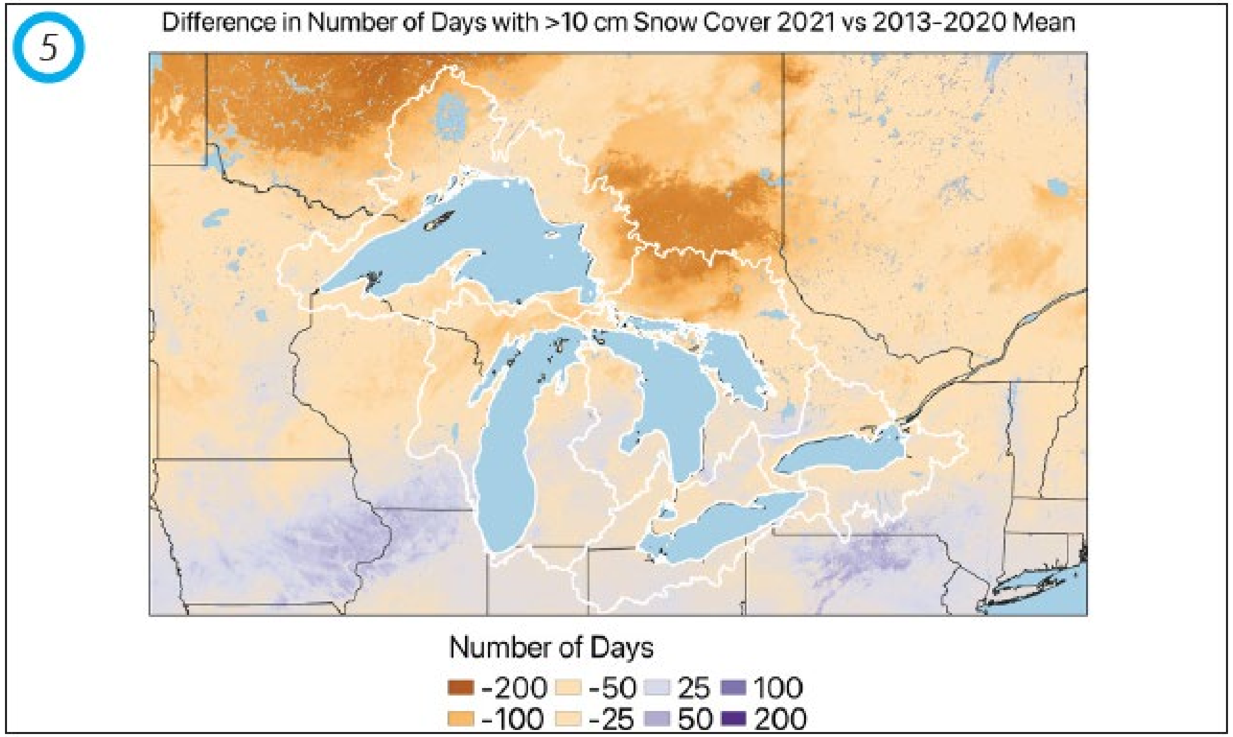


Figure 5. Difference in number of days with > 10 cm snow cover for July 2020-June 2021 compared to the 2013-2020 mean. Yellow outlines depict the individual lake basins. Estimated from the NOAA National Operational Hydrologic Remote Sensing Center (NOAA NOHRSC) model output.

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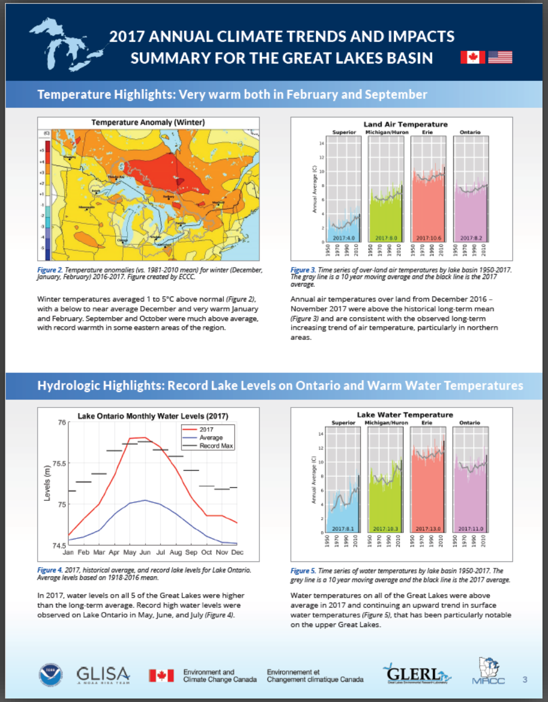

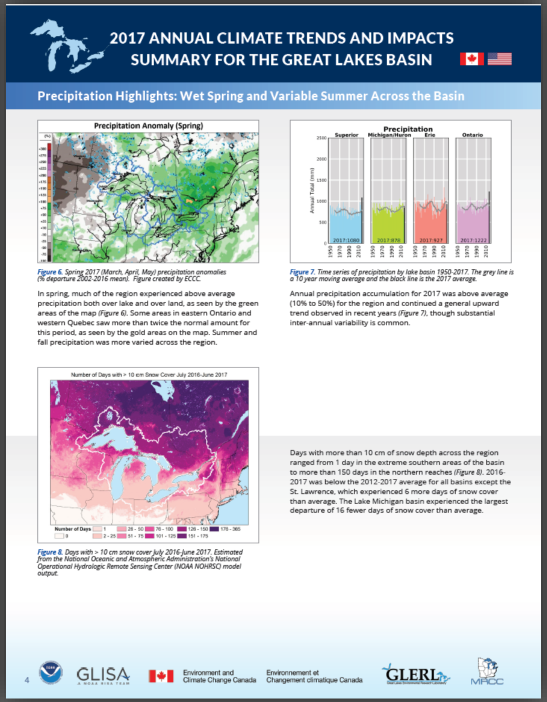

Summary Content: Historical Trends

Historical Trends

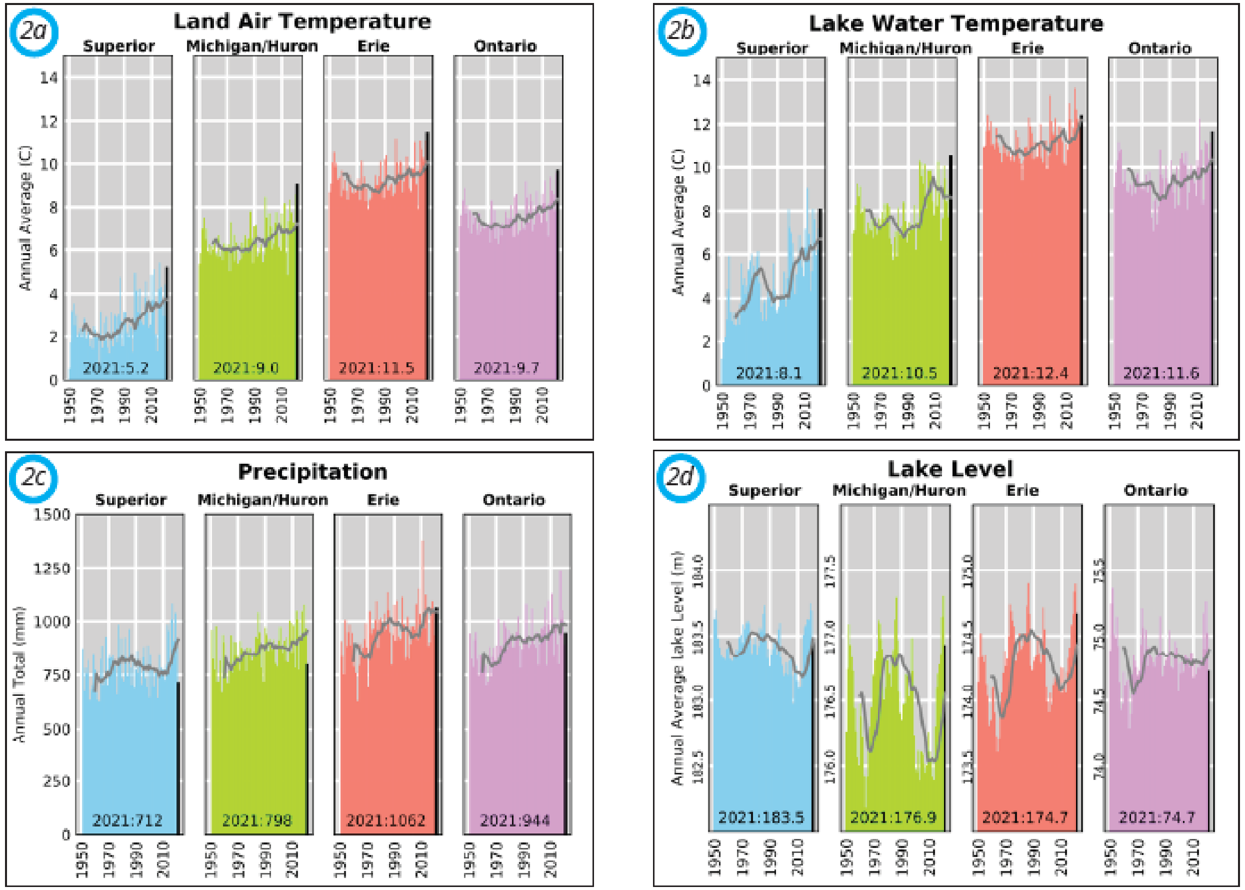

Figure 2. Time series of air temperatures (2a), water temperatures (2b), precipitation (2c), and water levels (2d) by lake basin from 1950-2021. The grey line is a 10-year moving average and the black line is the 2021 average. Estimated from GLERL Great Lakes Monthly Hydrologic Data, and Coordinating Committee on Great Lakes Basin Hydraulic and Hydrologic Data.

Air (Figure 2a) and water temperatures (Figure 2b) were above the 10-year average for each lake basin in 2021. 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 2021 was below the 10-year average for all lake basins except Erie. This is a departure from the general upward trend observed in recent years, though substantial interannual variability is common. Water levels (Figure 2d) remained above the 10-year average on Lakes Michigan-Huron and Erie, near average on Lake Superior, and below average on Lake Ontario. 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.

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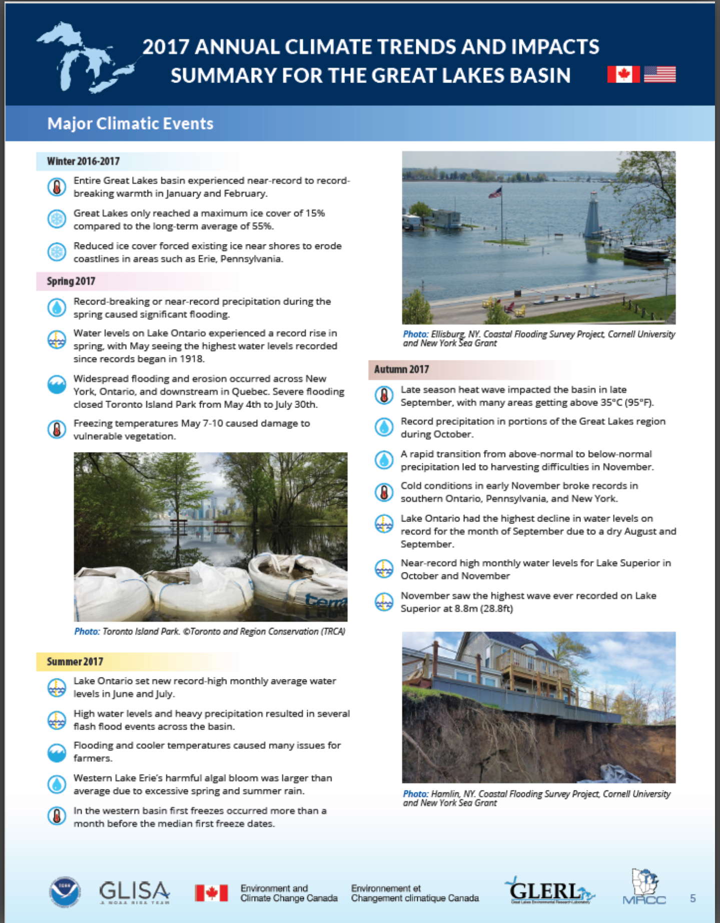

2017 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

Major Climatic Events

Winter 2016-2017

- Entire Great Lakes basin experienced near-record to record-breaking warmth in January and February.
- Great Lakes only reached a maximum ice cover of 15% compared to the long-term average of 55%.
- Reduced ice cover forced existing ice near shores to erode coastlines in areas such as Erie, Pennsylvania.

Spring 2017

- Record-breaking or near-record precipitation during the spring caused significant flooding.
- Water levels on Lake Ontario experienced a record rise in spring, with May seeing the highest water levels recorded since records began in 1918.
- Widespread flooding and erosion occurred across New York, Ontario, and downstream in Quebec. Severe flooding closed Toronto Island Park from May 4th to July 30th.
- Freezing temperatures May 7-10 caused damage to vulnerable vegetation.

Photo: Toronto Island Park. ©Toronto and Region Conservation (TRCA)

Summer 2017

- Lake Ontario set new record-high monthly average water levels in June and July.
- High water levels and heavy precipitation resulted in several flash flood events across the basin.
- Flooding and cooler temperatures caused many issues for farmers.
- Western Lake Erie's harmful algal bloom was larger than average due to excessive spring and summer rain.
- In the western basin first freezes occurred more than a month before the median first freeze dates.

Photo: Ellisburg, NY. Coastal Flooding Survey Project, Cornell University and New York Sea Grant

Autumn 2017

- Late season heat wave impacted the basin in late September, with many areas getting above 35°C (95°F).
- Record precipitation in portions of the Great Lakes region during October.
- A rapid transition from above-normal to below-normal precipitation led to harvesting difficulties in November.
- Cold conditions in early November broke records in southern Ontario, Pennsylvania, and New York.
- Lake Ontario had the highest decline in water levels on record for the month of September due to a dry August and September.
- Near-record high monthly water levels for Lake Superior in October and November
- November saw the highest wave ever recorded on Lake Superior at 8.8m (28.8ft)

Photo: Hamlin, NY. Coastal Flooding Survey Project, Cornell University and New York Sea Grant

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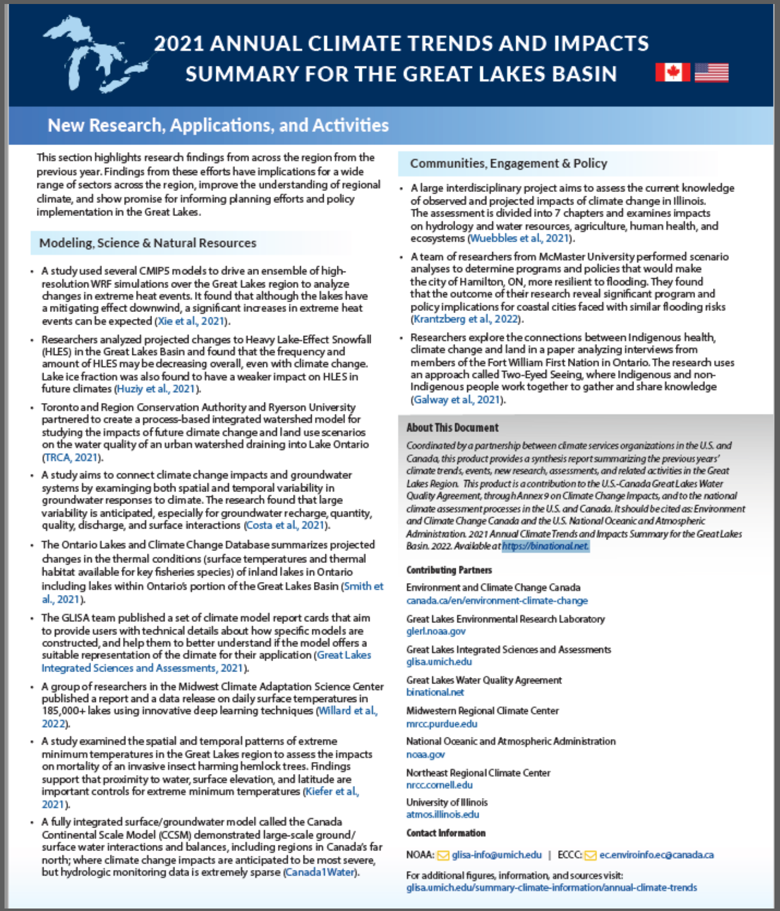

2021 ANNUAL CLIMATE TRENDS AND IMPACTS SUMMARY FOR THE GREAT LAKES BASIN

New Research, Applications, and Activities

This section highlights research findings from across the region from the previous year. Findings from these efforts have implications for a wide range of sectors across the region, 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 study used several CMIP5 models to drive an ensemble of high-resolution WRF simulations over the Great Lakes region to analyze changes in extreme heat events. It found that although the lakes have a mitigating effect downwind, a significant increases in extreme heat events can be expected (Xie et al., 2021).
- Researchers analyzed projected changes to Heavy Lake-Effect Snowfall (HLES) in the Great Lakes Basin and found that the frequency and amount of HLES may be decreasing overall, even with climate change. Lake ice fraction was also found to have a weaker impact on HLES in future climates (Huziy et al., 2021).
- Toronto and Region Conservation Authority and Ryerson University partnered to create a process-based integrated watershed model for studying the impacts of future climate change and land use scenarios on the water quality of an urban watershed draining into Lake Ontario (TRCA, 2021).
- A study aims to connect climate change impacts and groundwater systems by examinging both spatial and temporal variability in groundwater responses to climate. The research found that large variability is anticipated, especially for groundwater recharge, quantity, quality, discharge, and surface interactions (Costa et al., 2021).
- The Ontario Lakes and Climate Change Database summarizes projected changes in the thermal conditions (surface temperatures and thermal habitat available for key fisheries species) of inland lakes in Ontario including lakes within Ontario's portion of the Great Lakes Basin (Smith et al., 2021).
- The GLISA team published a set of climate model report cards that aim to provide users with technical details about how specific models are constructed, and help them to better understand if the model offers a suitable representation of the climate for their application (Great Lakes Integrated Sciences and Assessments, 2021).
- A group of researchers in the Midwest Climate Adaptation Science Center published a report and a data release on daily surface temperatures in 185,000+ lakes using innovative deep learning techniques (Willard et al., 2022).
- A study examined the spatial and temporal patterns of extreme minimum temperatures in the Great Lakes region to assess the impacts on mortality of an invasive insect harming hemlock trees. Findings support that proximity to water, surface elevation, and latitude are important controls for extreme minimum temperatures (Kiefer et al., 2021).
- A fully integrated surface/groundwater model called the Canada Continental Scale Model (CCSM) demonstrated large-scale ground/surface water interactions and balances, including regions in Canada's far north; where climate change impacts are anticipated to be most severe, but hydrologic monitoring data is extremely sparse (Canada1Water).

Communities, Engagement & Policy

- A large interdisciplinary project aims to assess the current knowledge of observed and projected impacts of climate change in Illinois. The assessment is divided into 7 chapters and examines impacts on hydrology and water resources, agriculture, human health, and ecosystems (Wuebbles et al., 2021).
- A team of researchers from McMaster University performed scenario analyses to determine programs and policies that would make the city of Hamilton, ON, 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).
- Researchers explore the connections between Indigenous health, climate change and land in a paper analyzing interviews from members of the Fort William First Nation in Ontario. The research uses an approach called Two-Eyed Seeing, where Indigenous and non-Indigenous people work together to gather and share knowledge (Galway et al., 2021).

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. 2021 Annual Climate Trends and Impacts Summary for the Great Lakes Basin. 2022. Available at https://binational.net.

Contributing Partners

Environment and Climate Change Canada
canada.ca/en/environment-climate-change

Great Lakes Environmental Research Laboratory
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Great Lakes Integrated Sciences and Assessments
glisa.umich.edu

Great Lakes Water Quality Agreement
binational.net

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

Drafting and Review Process

1. Initial drafting stage with product co-authors
2. Internal review period
3. External review period
    - Reviewers included: U.S. and Canadian Universities, research institutions, practitioners, federal, state, and provincial level government entities, regional climate groups, RISAs
4. Revision of draft document
5. Publication and roll-out
    - Shared at conferences (IAGLR, AASC), Great Lakes Executive Committee meeting, online webinar, GLISA and GLWQA websites
    - Translated to French for Canadian audiences

Feedback and Lessons Learned

- Mostly positive response/feedback
  - Intended for annual reproduction
  - Binational coordination presents challenges
- Expedite process
  - Establish parameters/roles early on
  - More streamlined review process
- Positive reception of climate communication format

Summary

- Documents Available at:

glisa.umich.edu/resources/annual-climate-summary

https://binational.net

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