Hydrological Forecasting from a Great Lakes Perspective

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National Oceanic and Atmospheric Administration
and
Department of Civil and Environmental Engineering
University of Michigan

June 2016

Outline

1. Introduction

Outline

Outline

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1. Introduction
2. Challenges facing Great Lakes hydrological science
3. Status of forecasting systems

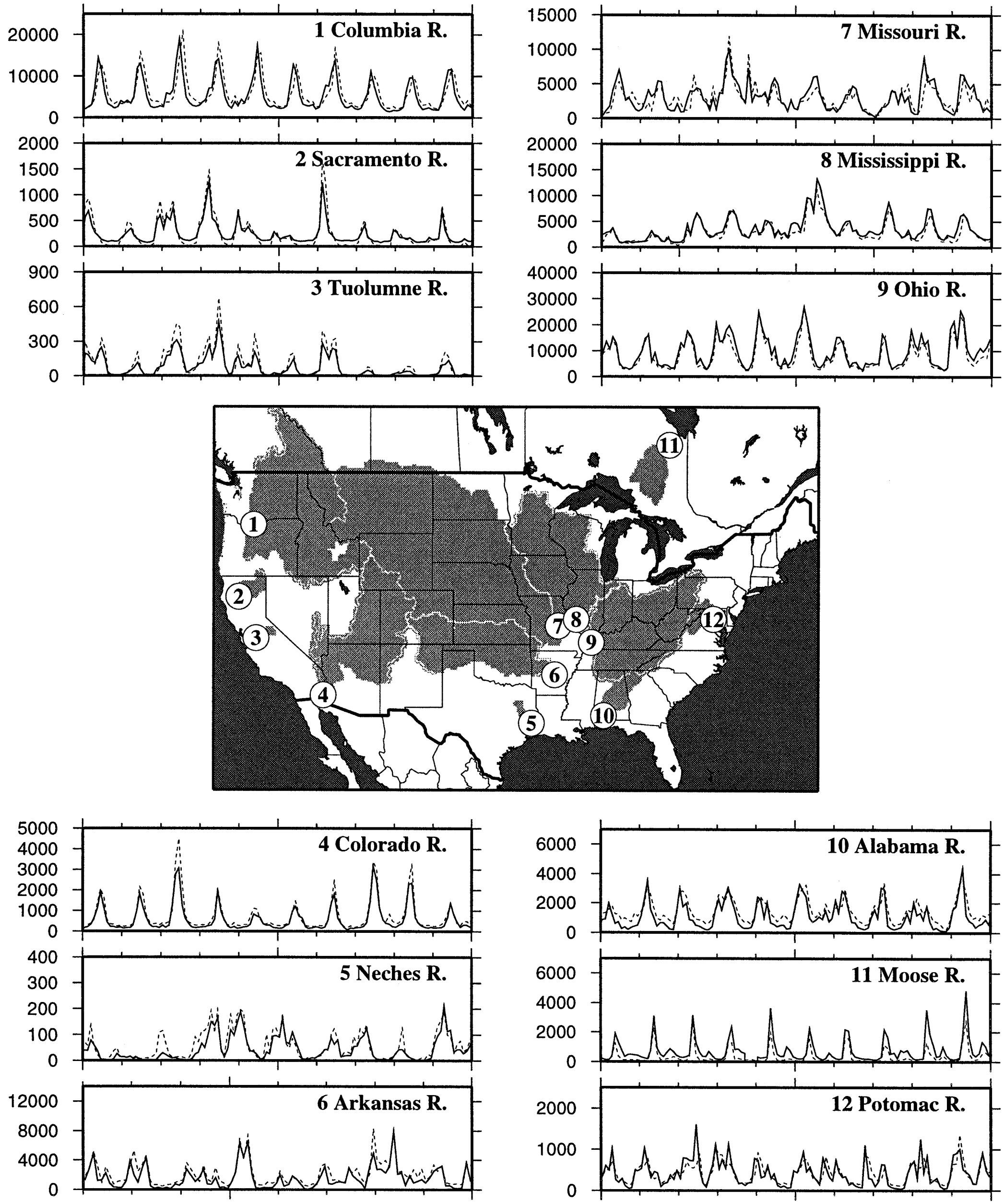
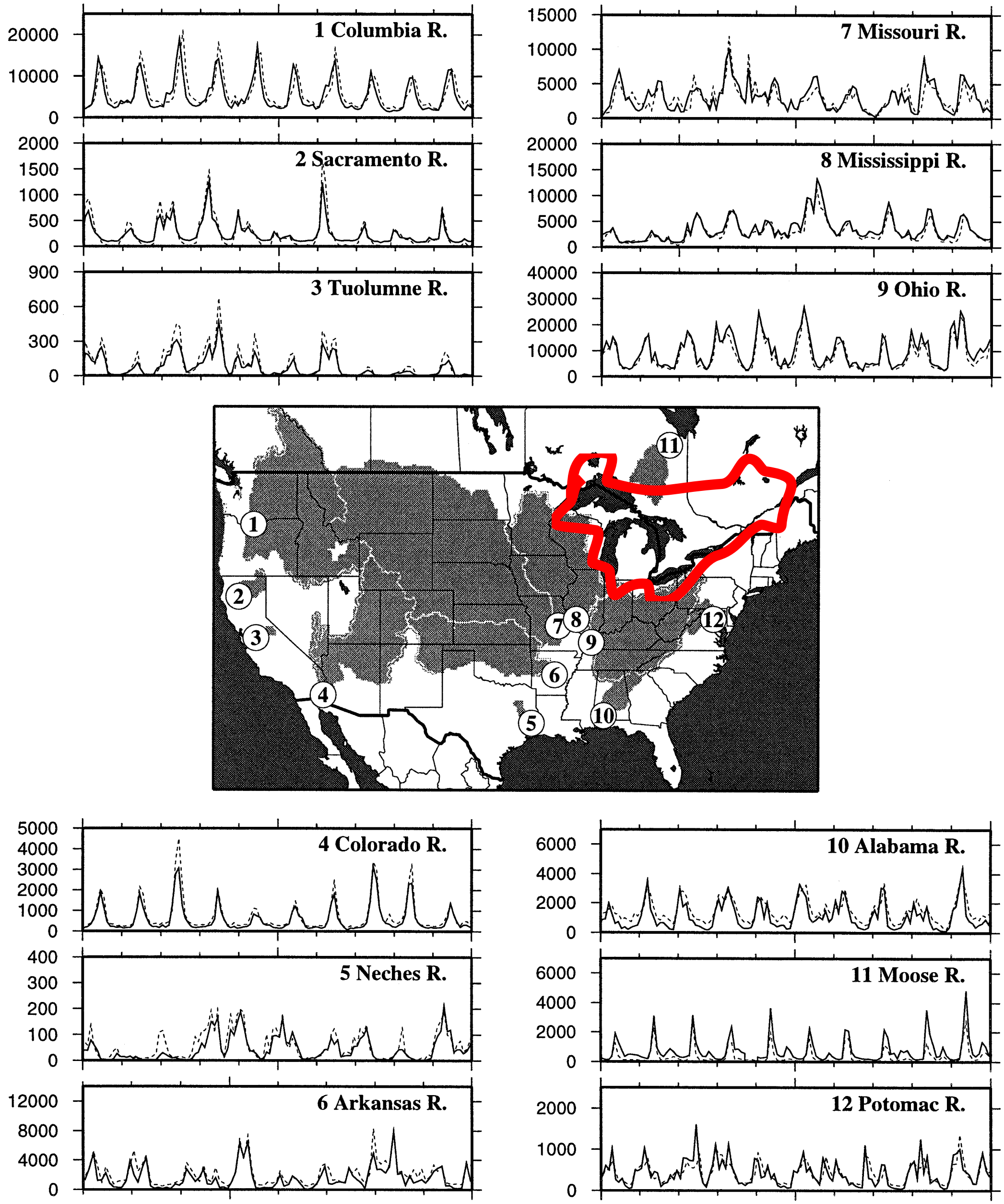


FIG. 3. Comparison of routed simulated runoff (dashed lines) with observed (or naturalized) streamflows (solid lines). Ordinate values are runoff in $m^3 s^{-1}$, abcissa is a 10-yr period, the beginning of which varies by basin, depending on observed flow availability. Shaded areas in center panel are the contributing regions to each identified point.



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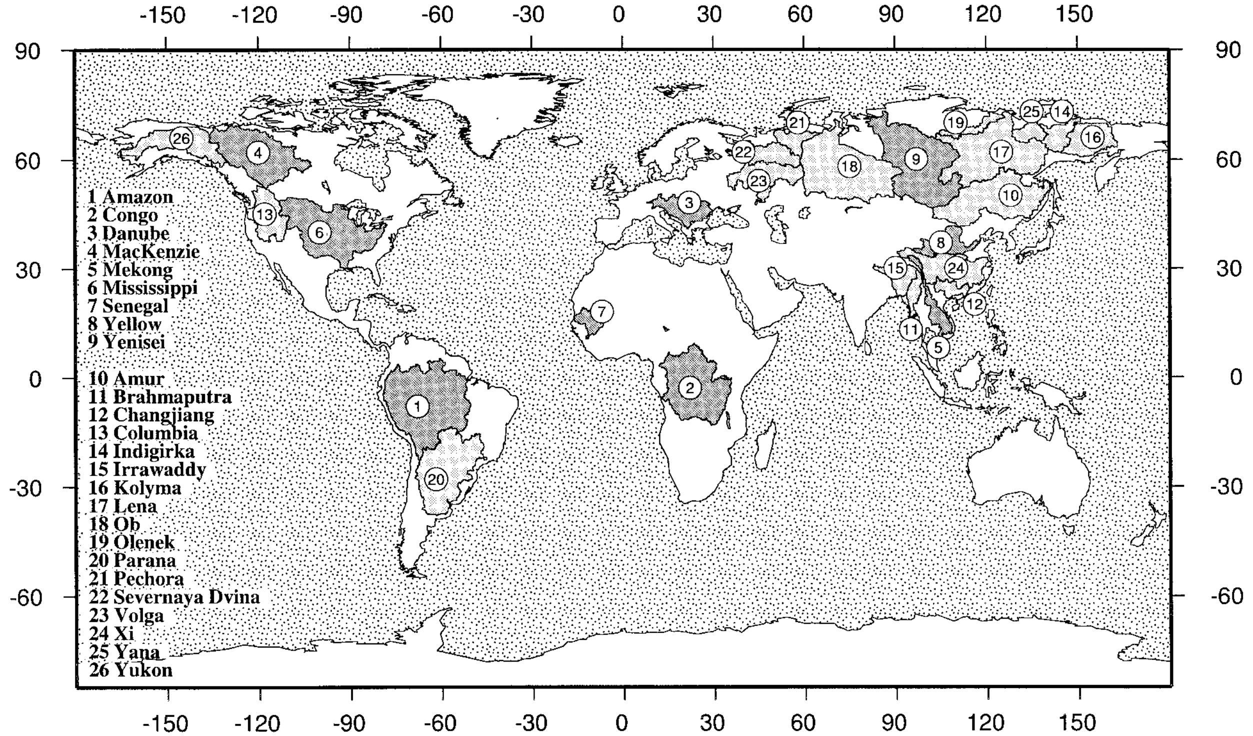


FIG. 2. Location of the 26 selected river basins. The nine dark-shaded basins form the primary group, and the light-shaded basins form the secondary group.

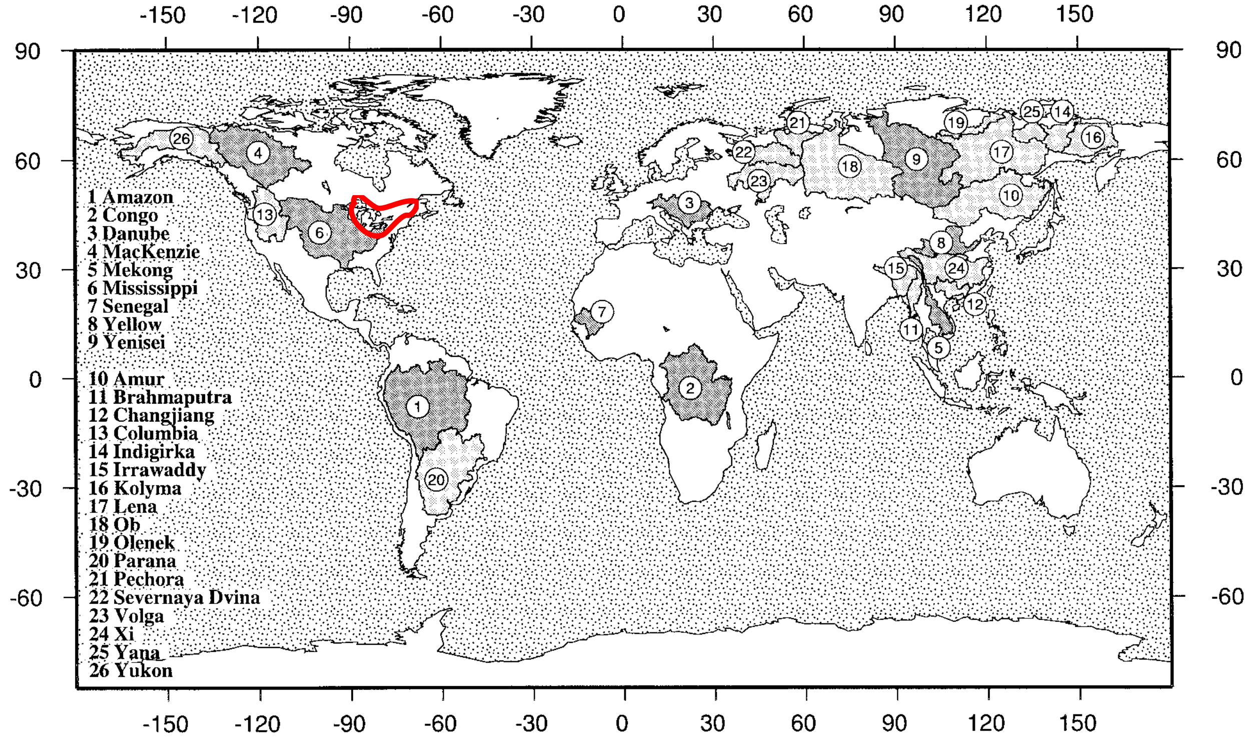
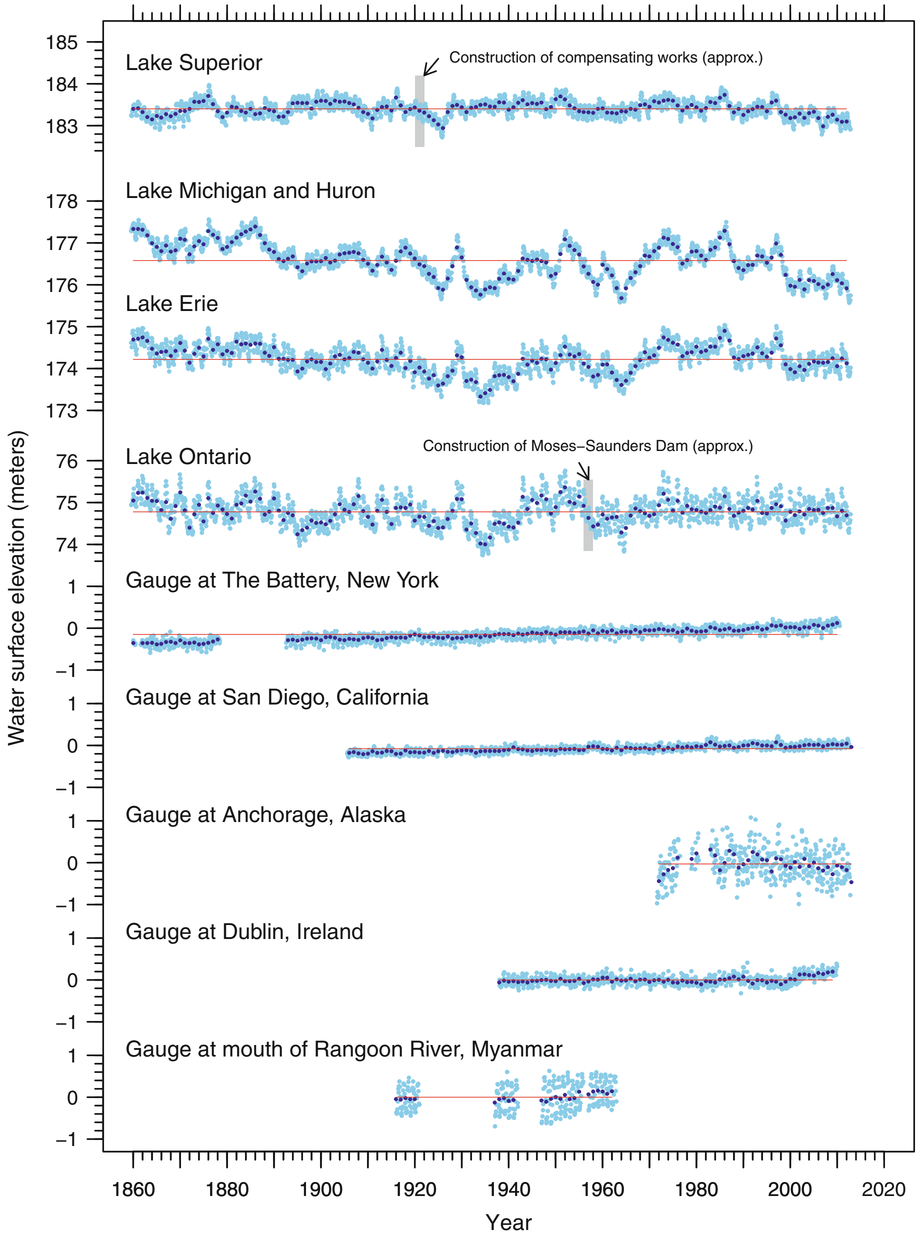
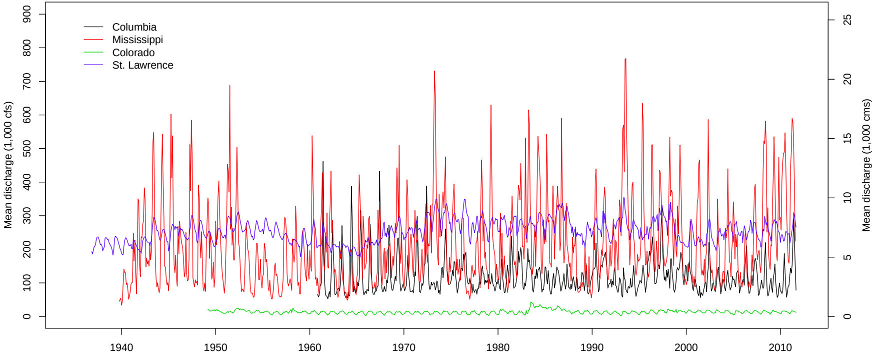


FIG. 2. Location of the 26 selected river basins. The nine dark-shaded basins form the primary group, and the light-shaded basins form the secondary group.


Ogoki Diversion
Nipigon River
Long Lac Diversion
Statute Miles
50 0 50 100 150 200
Kilometers
100 0 100 200 300
MINNESOTA
LAKE SUPERIOR
ONTARIO
Duluth
St. Marys River
MICHIGAN
Sault Ste. Marie
Ottawa River
St. Lawrence River
QUEBEC
Cornwall
Massena
GEORGIAN BAY
LAKE HURON
Straits of Mackinac
WISCONSIN
Green Bay
LAKE MICHIGAN
Toronto
LAKE ONTARIO
Milwaukee
MICHIGAN
Welland Canal
Buffalo
NEW YORK
St. Clair River
Niagara River
Detroit
Chicago
Detroit River
LAKE ERIE
ILLINOIS
Chicago Sanitary and Ship Canal
INDIANA
Cleveland
PENNSYLVANIA
OHIO


Lake Superior
Construction of compensating works (approx.)
Lake Michigan and Huron
Lake Erie
Lake Ontario
Construction of Moses–Saunders Dam (approx.)
Gauge at The Battery, New York
Gauge at San Diego, California
Gauge at Anchorage, Alaska
Gauge at Dublin, Ireland
Gauge at mouth of Rangoon River, Myanmar
Water surface elevation (meters)
Year
185
184
183
178
177
176
175
174
173
76
75
74
1
0
−1
1860
1880
1900
1920
1940
1960
1980
2000
2020



Columbia
Mississippi
Colorado
St. Lawrence
Mean discharge (1,000 cfs)
Mean discharge (1,000 cms)
0
100
200
300
400
500
600
700
800
900
0
5
10
15
20
25
1940
1950
1960
1970
1980
1990
2000
2010

Name	Country	Surface area (km^2)	(mi^2)	Volume (km^3)	(mi^3)
Michigan–Huron	U.S. and Canada	117,702	45,445	8,458	2,029
Superior	U.S. and Canada	82,414	31,820	12,100	2,900
Victoria	Multiple	69,485	26,828	2,750	660
Tanganyika	Multiple	32,893	12,700	18,900	4,500
Baikal	Russia	31,500	12,200	23,600	5,700
Great Bear Lake	Canada	31,080	12,000	2,236	536
Malawi	Multiple	30,044	11,600	8,400	2,000
Great Slave Lake	Canada	28,930	11,170	2,090	500
Erie	U.S. and Canada	25,719	9,930	489	117
Winnipeg	Canada	23,553	9,094	283	68
Ontario	U.S. and Canada	19,477	7,520	1,639	393

Table: Water volume and surface area of Earth's largest (ranked by surface area) fresh surface waters.

From: Gronewold, Fortin, Lofgren, Clites, Stow, and Quinn (2013). *Climatic Change*.

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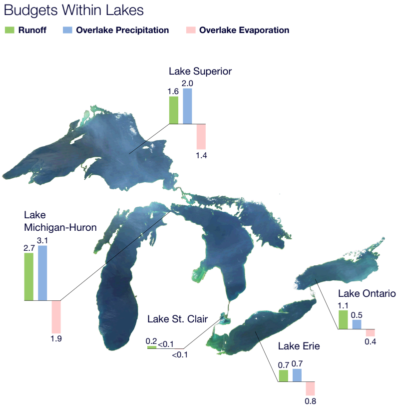
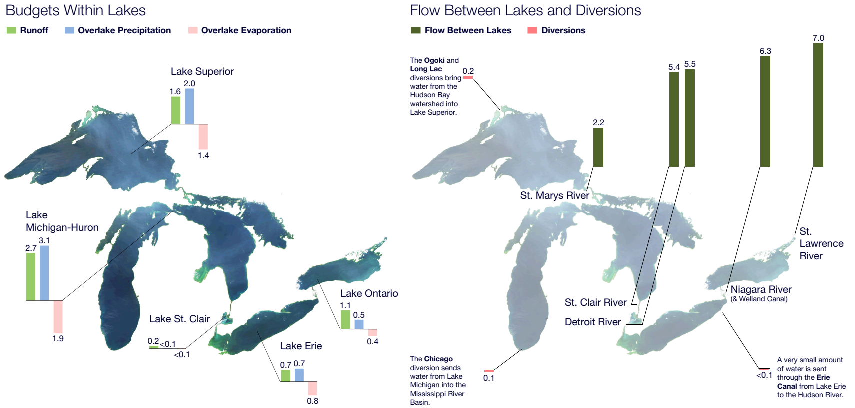
Great Lakes water budget



From: Hunter et al. (2015), *Journal of Great Lakes Research*; Satellite Imagery: NOAA CoastWatch

Great Lakes water budget



From: Hunter et al. (2015), *Journal of Great Lakes Research*; Satellite Imagery: NOAA CoastWatch

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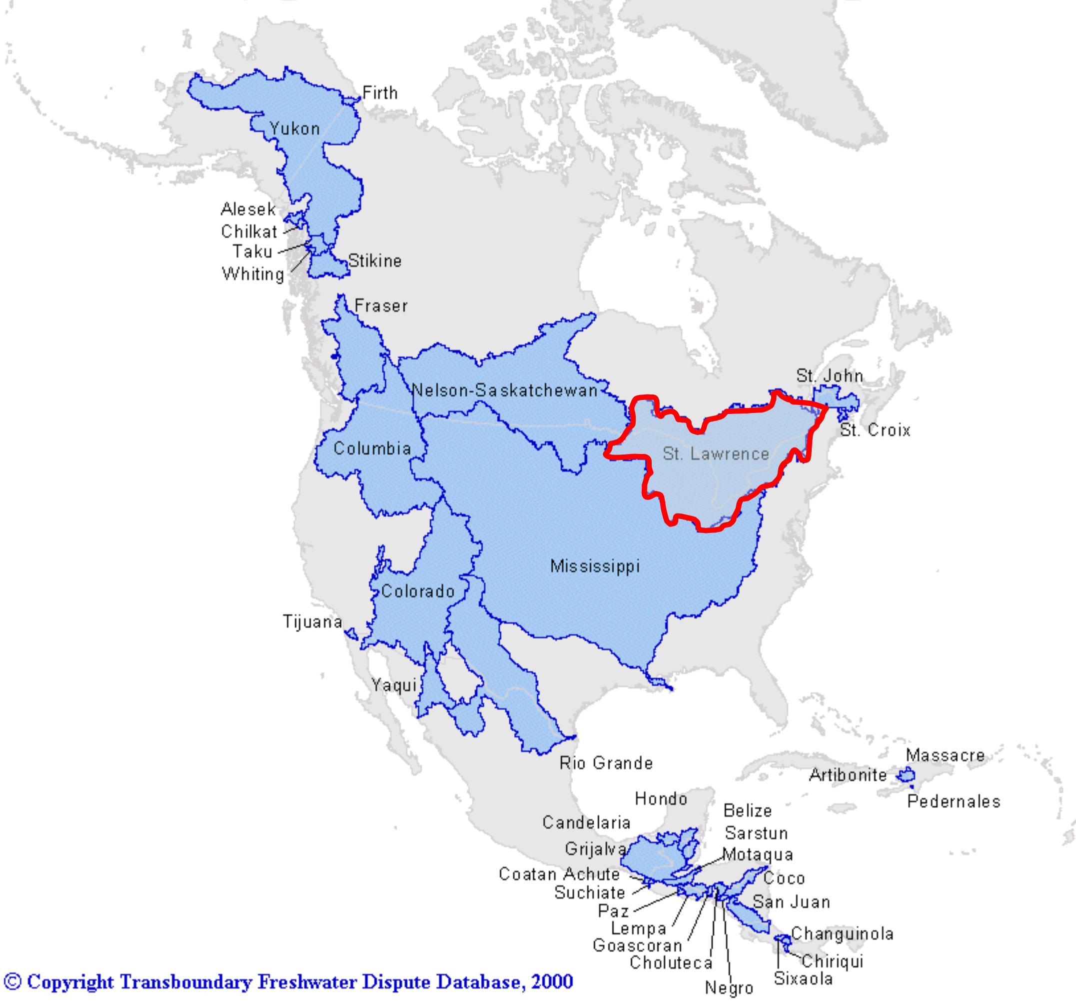
2 Challenges facing Great Lakes hydrological science

3 Status of forecasting systems

International River Basins of

NORTH AMERICA



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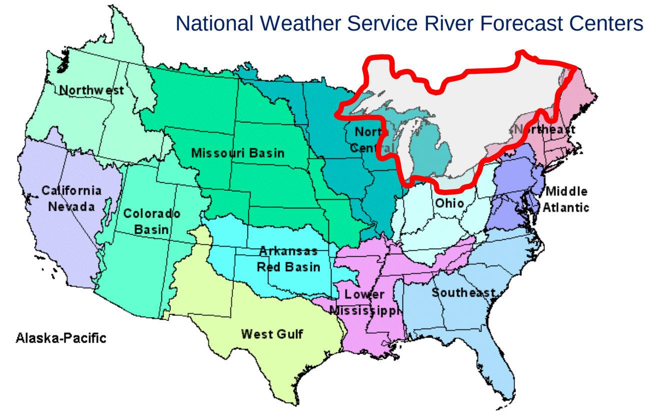
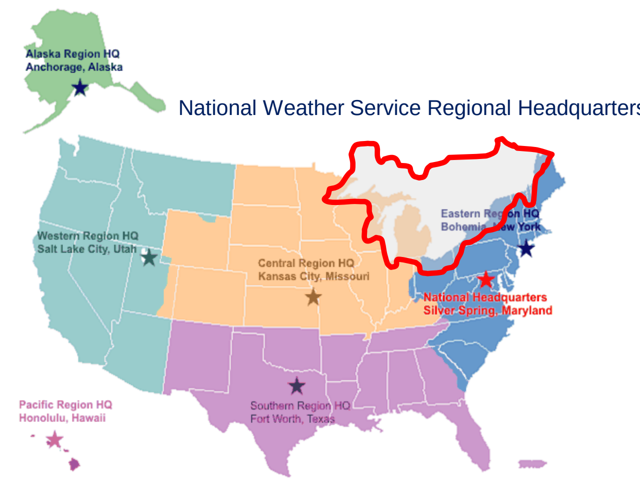
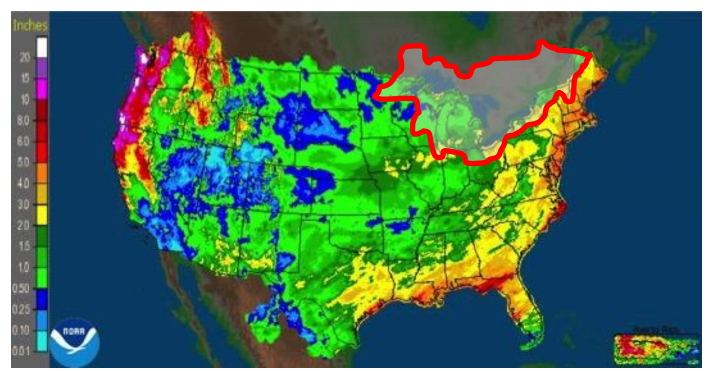
National Weather Service River Forecast Centers



National Weather Service Regional Headquarters





ADVANCING GREAT LAKES HYDROLOGICAL SCIENCE THROUGH TARGETED BINATIONAL COLLABORATIVE RESEARCH

BY ANDREW D. GRONEWOLD AND VINCENT FORTIN

As one of the Earth's largest surface freshwater resources, the North American Laurentian Great Lakes are an ideal test bed for understanding water balance dynamics of large hydrologic systems and for establishing effective protocols for collaborative binational water resources and ecosystem services research. To leverage ongoing and future federal government research efforts in the Great Lakes region, representatives from the National Oceanic and Atmospheric Administration (NOAA), the Cooperative Institute for Limnology and Ecosystems Research (CILER), and Environment Canada (EC) convened a workshop on Great Lakes hydrological modeling with an emphasis on improving regional hydrological and hydrodynamic science. Workshop presentations and discussions collectively underscored the following three motivating themes for current and future research:

IMPROVING HYDROLOGICAL MODELING PREDICTIONS IN THE GREAT LAKES

WHAT: More than 20 scientists from the United States and Canada met to assess and recommend strategies for advancing the state of the art in Great Lakes regional climate, hydrological, and hydrodynamic modeling

WHEN: 11–13 October 2011

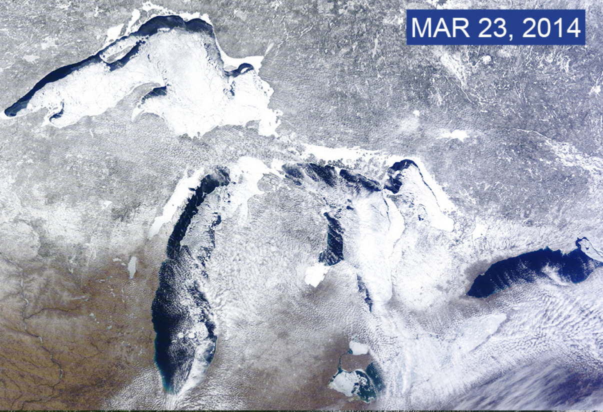
WHERE: Ann Arbor, Michigan

AFFILIATIONS: GRONEWOLD—NOAA/Great Lakes Environmental Research Laboratory,* Ann Arbor, Michigan; FORTIN—Environmental Numerical Prediction Research Section, Environment Canada, Dorval, Quebec, Canada
*Great Lakes Environmental Research Laboratory Contribution Number 1627.
CORRESPONDING AUTHOR: Andrew D. Gronewold, 4840 South State Road, NOAA/Great Lakes Environmental Research Laboratory, Ann Arbor, MI, 48108
E-mail: drew.gronewold@noaa.gov

DOI:10.1175/BAMS-D-12-00006.1

In final form 27 April 2012

1) utilizing investments in monitoring infrastructure and model development from the recently completed International Upper Great Lakes Study (IUGLS), a binational, multiagency, multimillion dollar effort intended to improve understanding of water-level dynamics and evaluate alternative plans for regulating Lake Superior water levels;
2) identifying appropriate roles for NOAA, CILER, and EC in post-IUGLS "adaptive management" research, while leveraging ongoing efforts and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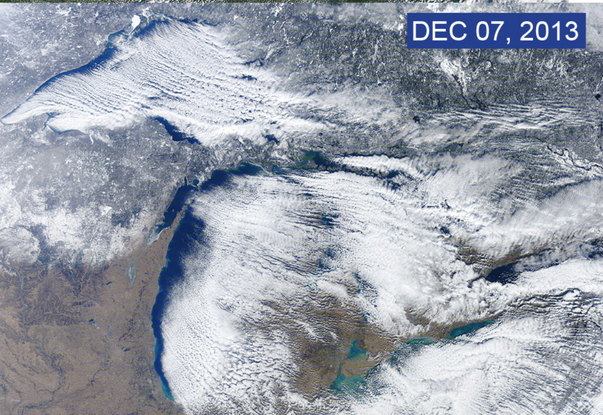
AUG 11, 2008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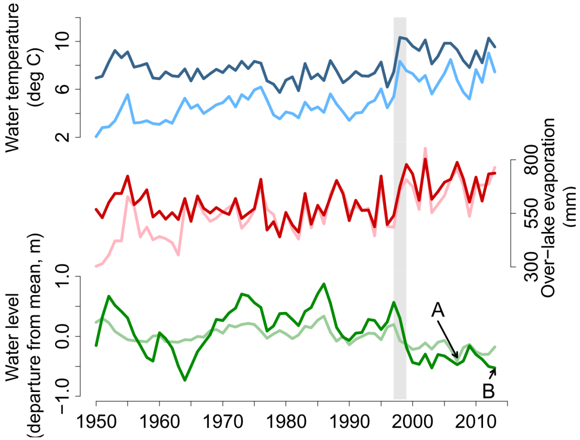

From: Gronewold & Stow (2014), *Science*

See also: Sellinger, Stow, Lamon, and Qian (2007), *ES&T*

Great Lakes Hydro-Climate Dashboard
Dashboard portal
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All lakes IO
Superior
Michigan-Huron
St. Clair
Erie
Ontario
Surface water elevation (meters; IGLD 85)
Superior
Michigan-Huron
Lake input/output (mm)
183.8
183.6
183.4
183.2
183.0
182.8
182.6
182.4
182.2
182.0
181.8
181.6
181.4
181.2
181.0
176.8
176.6
176.4
176.2
176.0
175.8
175.6
175.4
175.2
175.0
174.8
174.6
174.4
174.2
174.0
400.0
300.0
200.0
100.0
Zoom
Pan
2/02 5/02 8/02 11/02 2/03 5/03 8/03 11/03 2/04 5/04 8/04 11/04 2/05 5/05 8/05 11/05 2/06 5/06 8/06 11/06 2/07 5/07 8/07 11/07 2/08 5/08 8/08 11/08 2/09 5/09 8/09 11/09 2/10 5/10 8/10 11/10 2/11 5/11 8/11 11/11 2/12 5/12 8/12 11/12
Legend and menu
Clear all
Water level observations
Monthly level forecasts
Multi-decadal level forecasts
Paleoclimate reconstructions
Hydrological/Climatological data
Ice cover
Ice cover: All lakes except Michigan
Ice cover: Lake Michigan
Ice data is reported as a percentage of total cover. There is no vertical axis for these data. The total range for each graph is 0-100%, bottom to top, at a linear scale (not logarithmic).
Ice Data begin in 1973
Info on ice cover
Default colors
Flip series
Chart background color
Timespan
2003
2012
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3
Equalize vertical scale
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Environmental Modelling & Software 49 (2013) 34–39

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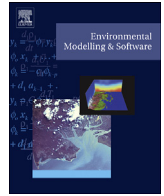

Short communication

A dynamic graphical interface for visualizing projected, measured, and reconstructed surface water elevations on the earth's largest lakes

Andrew D. Gronewold [a,*], Anne H. Clites [a], Joeseph P. Smith [a,b], Timothy S. Hunter [a]

[a] Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration, Ann Arbor, MI 48108, USA
[b] Cooperative Institute for Limnology and Ecosystems Research, University of Michigan, Ann Arbor, MI 48109, USA

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Water levels
Great Lakes
Climate change
Data access

A B S T R A C T

There is a growing need within the international water research and water resources management community, and the general public, for easy access to time-series of projected, measured, and reconstructed marine and freshwater coastal surface water elevations. There is also a need for effectively communicating variability among different surface water elevation data sets, as well as the intrinsic uncertainties in surface water elevation forecasts. Here, we introduce an interactive web-based interface, the Great Lakes Water Level Dashboard (GLWLD), designed to address this need for the North American Laurentian Great Lakes, the largest assemblage of unfrozen fresh surface water bodies on planet Earth, and one with a coastline of over 16,000 km (roughly 10,000 miles). The GLWLD is a Flash-based tool that can simultaneously display time-series of measured monthly and annual water level data and seasonal forecasts for each of the Great Lakes, reconstructed lake levels from paleoclimate research, and decadal lake level projections under alternative climate scenarios. By employing a suite of novel data transfer, processing, and visualization tools, the GLWLD allows users to seamlessly transition not only between alternate displays of Great Lakes water levels over different temporal scales, but between different data sets and forecasts as well. Furthermore, the unique GLWLD interface can help users understand the extent to which decisions regarding the use of the lakes depend on an appreciation of uncertainty and variability within, and between, different sources of Great Lakes water level information.

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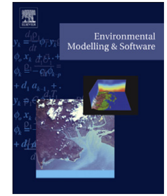

An expandable web-based platform for visually analyzing basin-scale hydro-climate time series data

Joeseph P. Smith [a,*], Timothy S. Hunter [b], Anne H. Clites [b], Craig A. Stow [b], Tad Slawecki [c], Glenn C. Muhr [b], Andrew D. Gronewold [b,d]

[a] *Cooperative Institute for Limnology and Ecosystems Research, University of Michigan, Ann Arbor, MI 48109, USA*
[b] *Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration, Ann Arbor, MI 48108, USA*
[c] *LimnoTech, Ann Arbor, MI 48108, USA*
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ABSTRACT

Growing demand from the general public for centralized points of data access and analytics tools coincides with similar, well-documented needs of regional and international hydrology research and resource management communities. To address this need within the Laurentian Great Lakes region, we introduce the Great Lakes Dashboard (GLD), a dynamic web data visualization platform that brings multiple time series data sets together for visual analysis and download. The platform's adaptable, robust, and expandable Time Series Core Object Model (GLD-TSCOM) separates the growing complexity and size of Great Lakes data sets from the web application interface. Although the GLD-TSCOM is currently applied exclusively to Great Lakes data sets, the concepts and methods discussed here can be applied in other geographical and topical areas of interest.

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Dashboard portal
HTML 5
Great Lakes Hydro-Climate Dashboard
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All lakes IO
Superior
Michigan-Huron
St. Clair
Erie
Ontario
Surface water elevation (meters; IGLD 85)
Superior
Michigan-Huron
Lake input/output (mm)
Legend and menu
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Ice Data begin in 1973
Info on ice cover
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Flip series
Chart background color
Zoom
Pan
Timespan
2003
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Equalize vertical scale
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Legend and menu
Clear all
Water level observations
Monthly level forecasts
Multi-decadal level forecasts
Paleoclimate reconstructions
Hydrological/Climatological data
Total monthly precipitation over lake
Total annual lake precip's dev. from avg
Total monthly evaporation over lake
Total annual over lake evap's dev. from avg
Precip - evap: monthly (over lake)
Precip - evap: annual dev. from avg
Total monthly runoff
Total annual runoff's deviation from average
Monthly Net Basin Supplies (NBS)
Total annual NBS' deviation from average
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White Shoal Lighthouse: Lake Michigan
Photo courtesy Dick Moehl
(Lighthouse Keepers Association)

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GREAT LAKES WATER LEVELS SURGE

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The Social Contract Between Science and Society

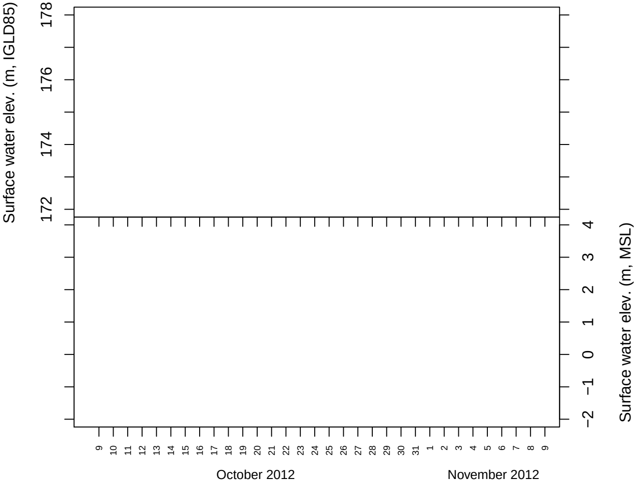
AGU
American Geophysical Union

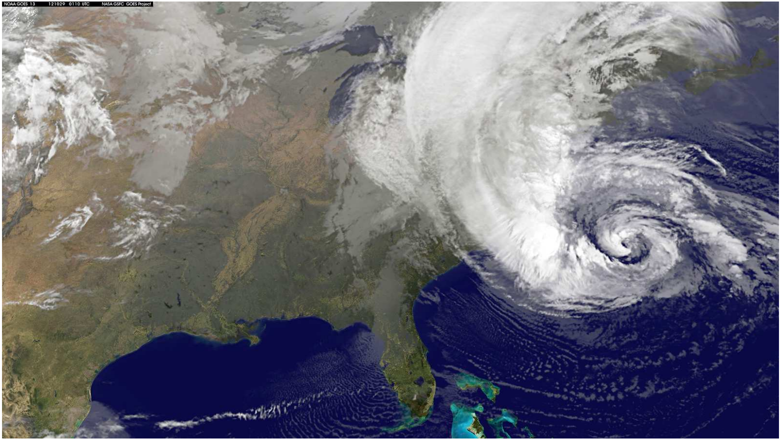
Outline

Great Lakes basin-wide forecasting systems

Great Lakes basin-wide forecasting systems

Model origin	US		Canada	
Spatial domain	US	Canada	US	Canada
Short-term				
- meteorological forcings	HRRR		GEM	
- lake physics	FVCOM		NEMO	
- land surface hydrology	WRF-Hydro		GEM-Hydro	


Surface water elev. (m, IGLD85)
178
176
174
172
4
3
2
1
0
−1
−2
Surface water elev. (m, MSL)
9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9
October 2012
November 2012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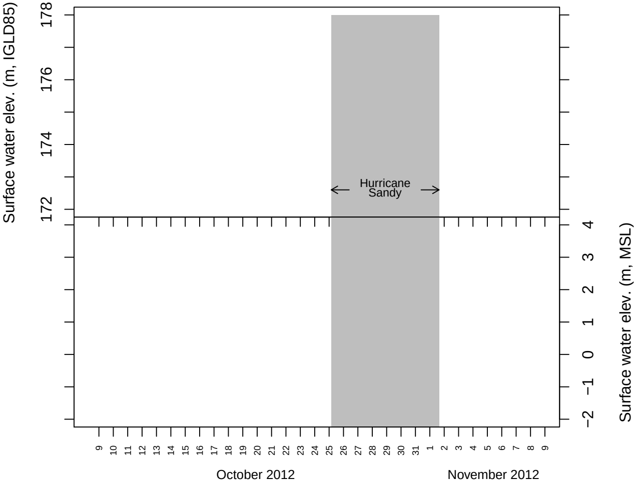
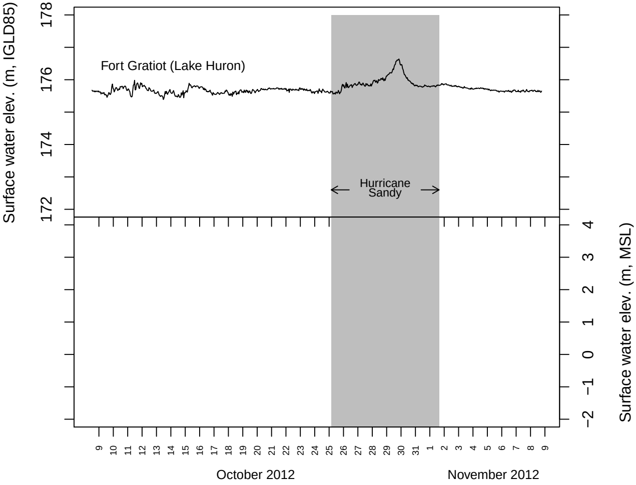
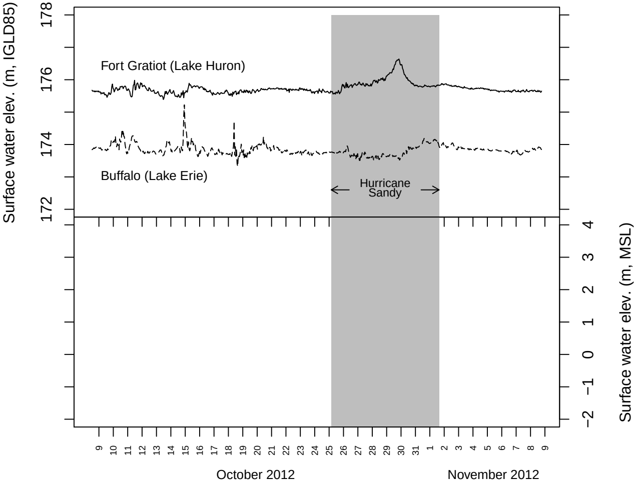
NASA GSFC GOES Project


Surface water elev. (m, IGLD85)
178
176
174
172
Hurricane Sandy
4
3
2
1
0
−1
−2
Surface water elev. (m, MSL)
9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9
October 2012
November 2012


Surface water elev. (m, IGLD85)
178
176
174
172
Fort Gratiot (Lake Huron)
Hurricane Sandy
4
3
2
1
0
−1
−2
Surface water elev. (m, MSL)
9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9
October 2012
November 2012


Surface water elev. (m, IGLD85)
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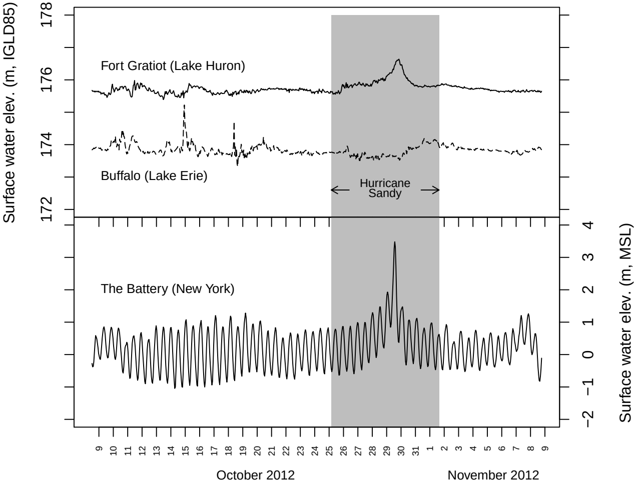

From: Gronewold et al (2013), *Climatic Change*

Great Lakes basin-wide forecasting systems

Model origin	US		Canada	
Spatial domain	US	Canada	US	Canada
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Seasonal				
- meteorological forcings	NCEP/CPC		-	
- lake physics	LLTM		-	
- land surface hydrology	LBRM		-	

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Provisional coordinated avg for month to date
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Lake-wide annual average (1918-present)
Annual average (1860-1917)
Master gauge annual average (1860-present)
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www.glerl.noaa.gov/data/wldb
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Record highs (1918-2013)
Record lows (1918-2013)
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Quinn, Sellinger (1990) Mi-H 1819-1859
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Multi-decadal				
- meteorological forcings	CMIP5/WRF		CMIP5/CanRCM	
- lake physics	WRF/FVCOM		‘Goyette’	
- land surface hydrology	WRF-Hydro		WATFLOOD/GEM-Hydro	

RECONCILING ALTERNATIVE APPROACHES TO PROJECTING HYDROLOGIC IMPACTS OF CLIMATE CHANGE*

BY BRENT M. LOFGREN AND ANDREW D. GRONEWOLD

Progress in the projection of hydrologic impacts of anthropogenic climate change (ACC) call for reassessing and documenting the state of the art. At this workshop, we placed a particular emphasis on understanding how consistency in the surface energy budget can be maintained, or lost, depending on how general circulation models' internal calculations of hydrologic variables mesh with offline hydrologic models driven by their climatic variables (Lofgren et al. 2011; Sheffield et al. 2012). The science of projecting hydrologic impacts of climate change links the disciplines of meteorology (applied to long-term climate) and hydrology, yet these disciplines typically employ different perspectives on surface hydrological processes, leading to different modeling methods and means of linking models (Gronewold and Fortin 2012). To begin to resolve these inconsistencies, the workshop was structured around the following organizing questions:

THE WORKSHOP ON METHODOLOGY FOR PROJECTION OF HYDROLOGIC IMPACTS OF CLIMATE CHANGE

WHAT: Forty-one hydrologists and meteorologists discussed the intersection of these disciplines, especially as applied to issues and impacts of climate change.

WHEN: 27–29 August 2012

WHERE: Muskegon, Michigan

1) How do we bridge the gap between climate projection and hydrologic projection?
2) How do we serve the data needs of the hydrologic and meteorological communities in a mutually consistent way?
3) What is the role of empirical and process-based models in a nonstationary regime?
4) How do we educate researchers and the general public about relevant caveats in simulations of hydrologic impacts of climate change?

BRIDGING CLIMATE AND HYDROLOGICAL SCIENCE. Efforts to converge on a consistent answer to the question of how to bridge the gap between projections of climate and hydrology have important implications for human and environmental health, ranging from an understanding

AFFILIATIONS: LOFGREN AND GRONEWOLD—National Oceanic and Atmospheric Administration/Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan
CORRESPONDING AUTHOR: Brent M. Lofgren, National Oceanic and Atmospheric Administration/Great Lakes Environmental Research Laboratory, 4840 South State Road, Ann Arbor, MI 48108
E-mail: brent.lofgren@noaa.gov
DOI:10.1175/BAMS-D-13-00037.1

* Great Lakes Environmental Research Laboratory Contribution Number 1660

In final form 19 March 2013

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Methodological Approaches to Projecting the Hydrologic Impacts of Climate Change*

Brent M. Lofgren[+] **and Andrew D. Gronewold**

NOAA/Great Lakes Environmental Research Laboratory, Ann Arbor, Michigan

Anthony Acciaioli

Cooperative Institute for Limnology and Ecosystems Research, Ann Arbor, Michigan

Jessica Cherry

International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, Alaska

Allison Steiner

Department of Atmospheric Oceanic and Space Sciences, University of Michigan, Ann Arbor, Michigan

David Watkins

Department of Civil and Environmental Engineering, Michigan Technological University, Houghton, Michigan

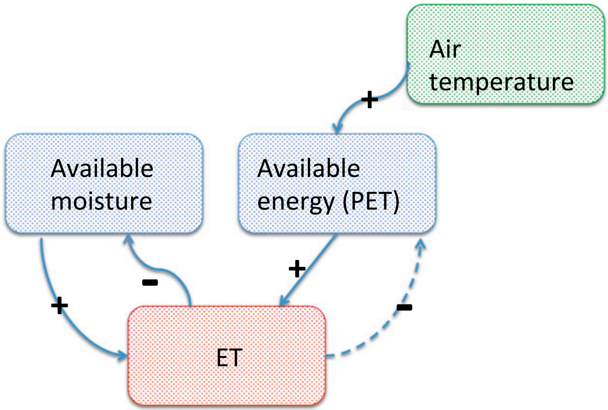


Figure 2. Causal loop diagram of surface energy and moisture budget components. An increase in a variable causing an increase in another is indicated by a plus sign, and an increase in a variable causing a decrease in another is indicated by a minus sign. Temperature proxy–based PET methods neglect the negative (balancing) feedback that ET has on available energy, which is shown as a dashed line.

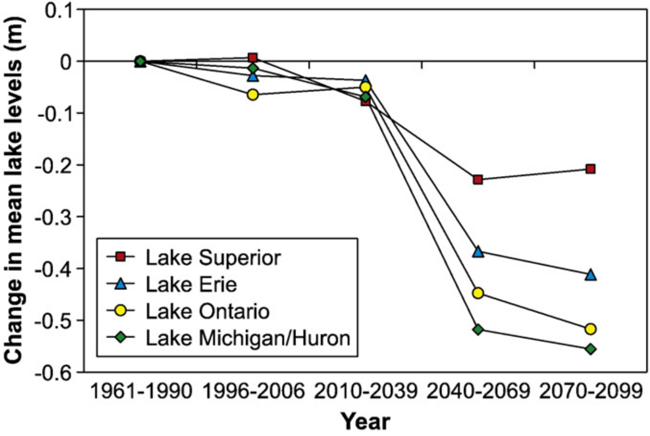
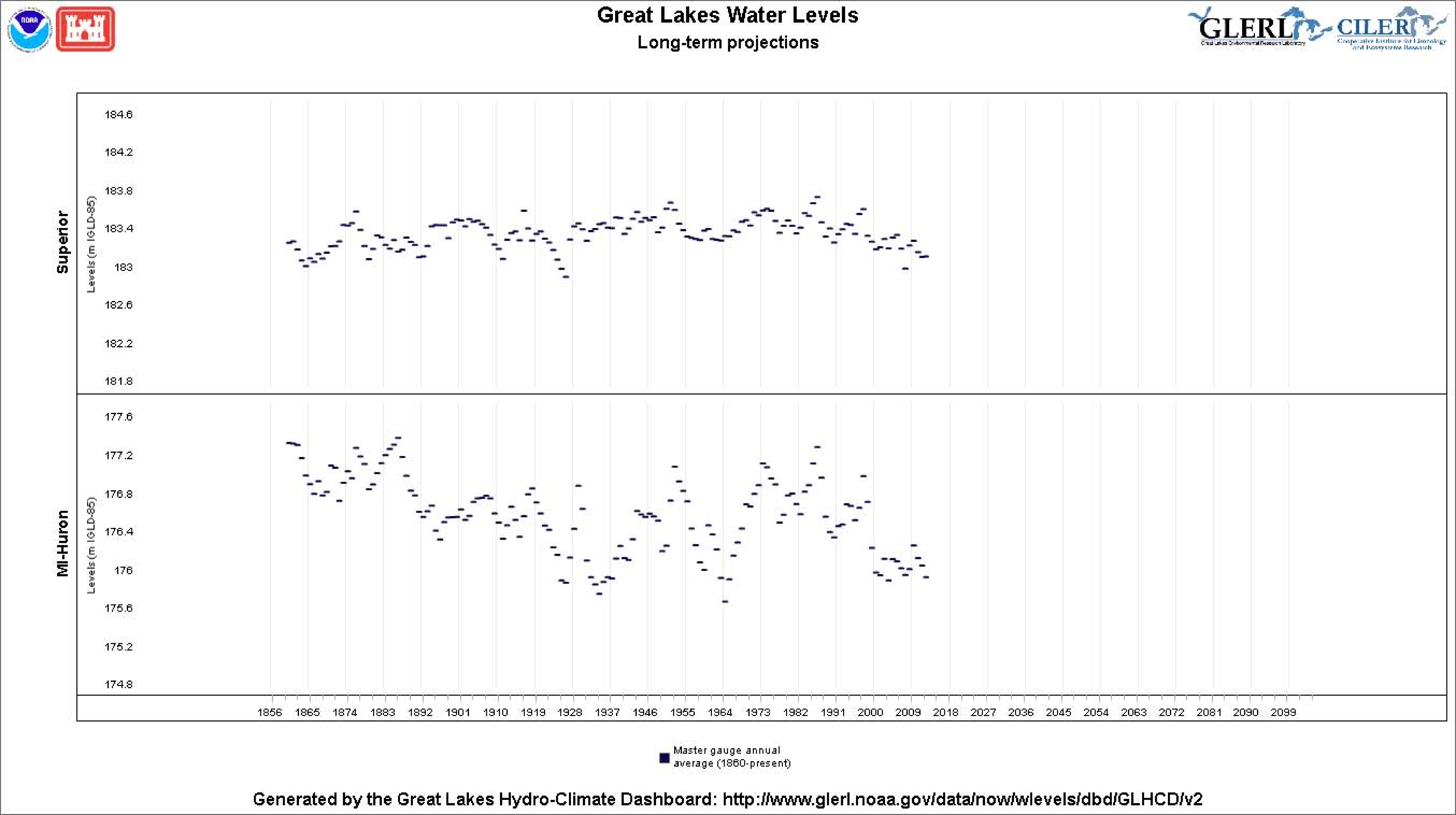


Fig. 10. Average Great Lakes levels depend on the balance between precipitation and corresponding runoff in the Great Lakes Basin and evaporation and outflow. The SRES B1 lower emissions scenario with less warming (not shown) projects little change in lake levels over the coming century. Under the SRES A1fi higher emissions scenario (shown here), decreases on the order of 0.5 up to nearly 2.0 ft are projected towards the end of the century.


Great Lakes Water Levels
Long-term projections
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Master gauge annual average (1860-present)
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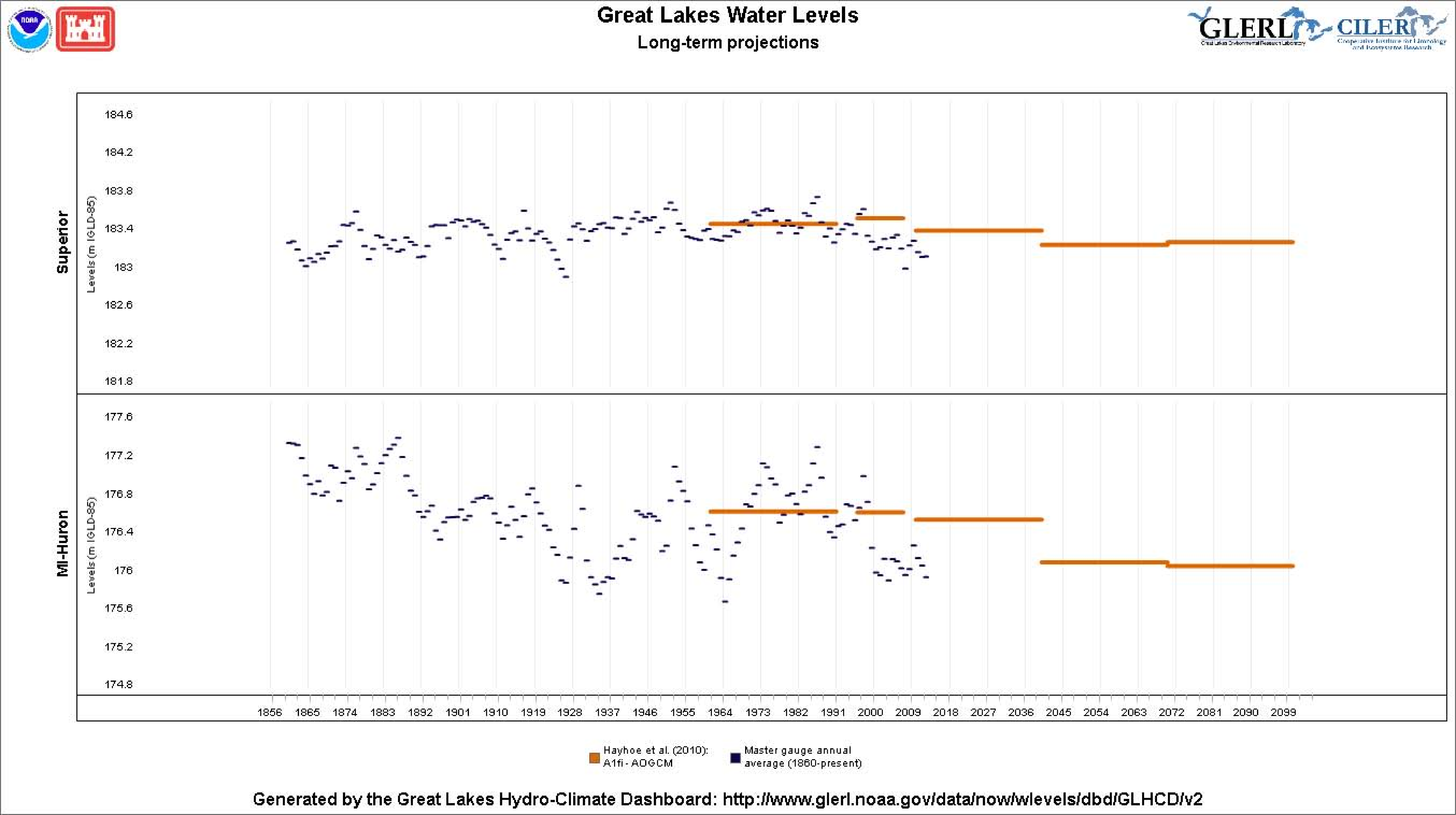

Great Lakes Water Levels
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Hayhoe et al. (2010): A1fi - AOGCM
Master gauge annual average (1860-present)
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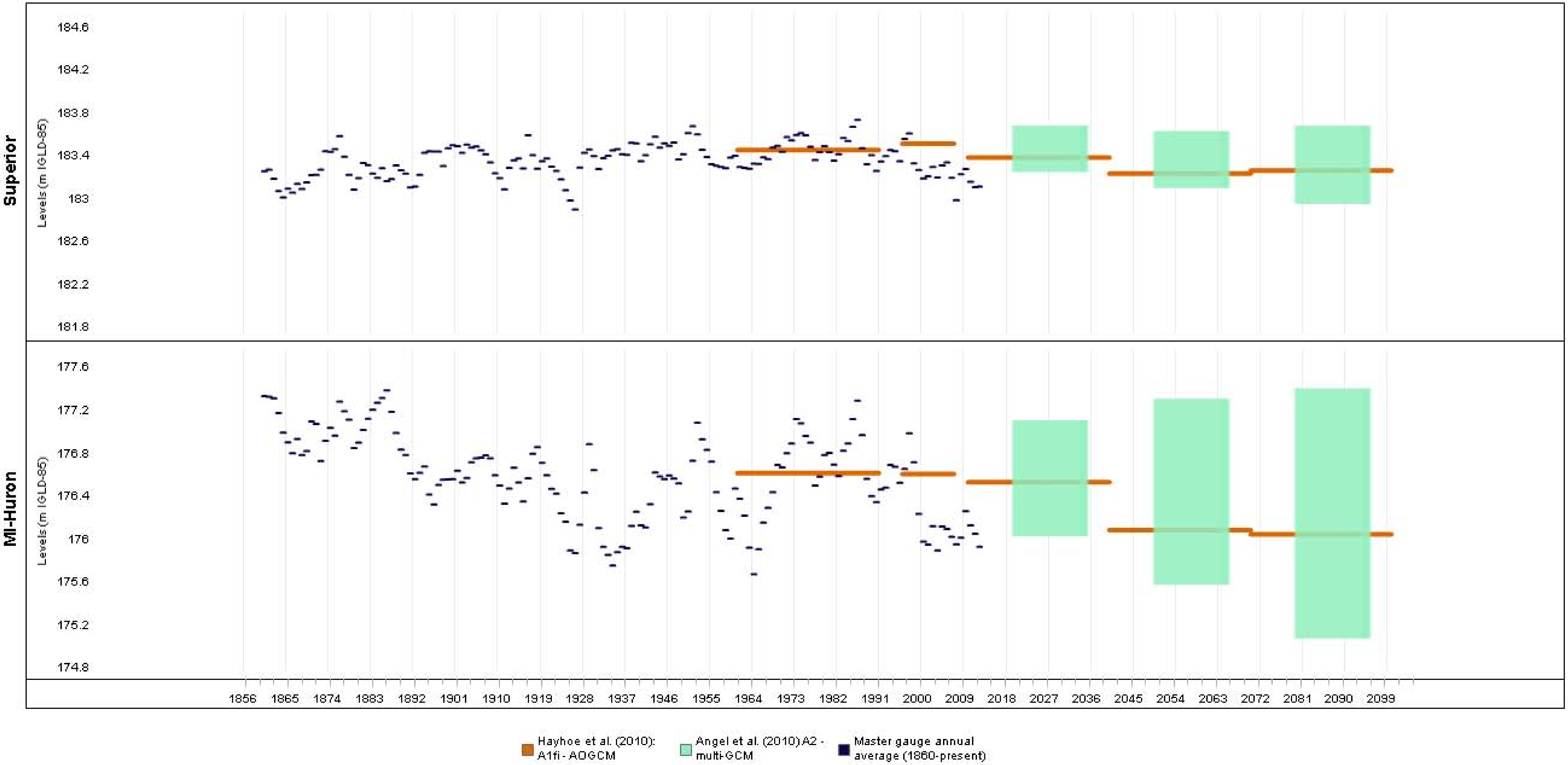
Great Lakes Water Levels

Long-term projections



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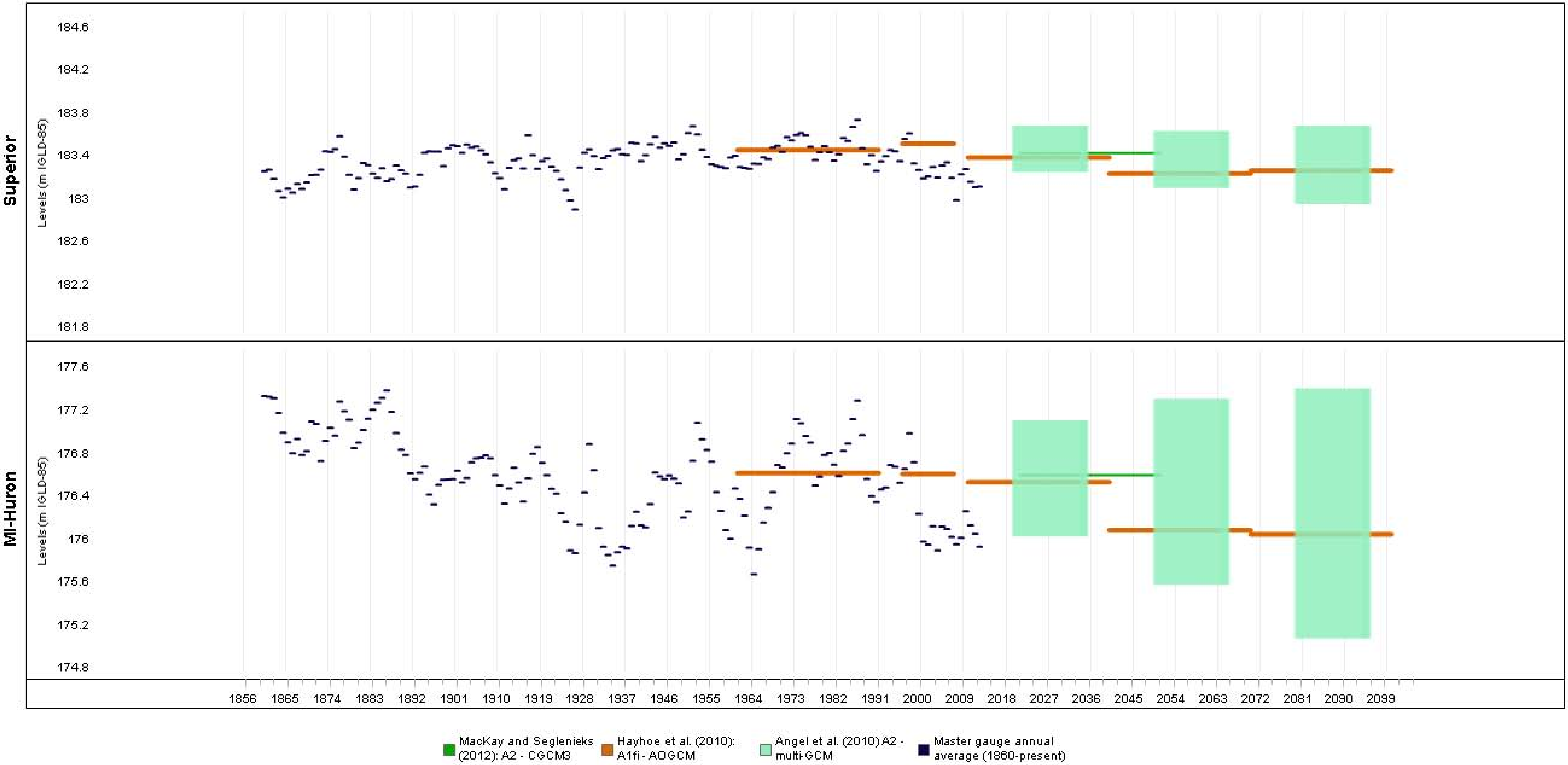
Great Lakes Water Levels

Long-term projections



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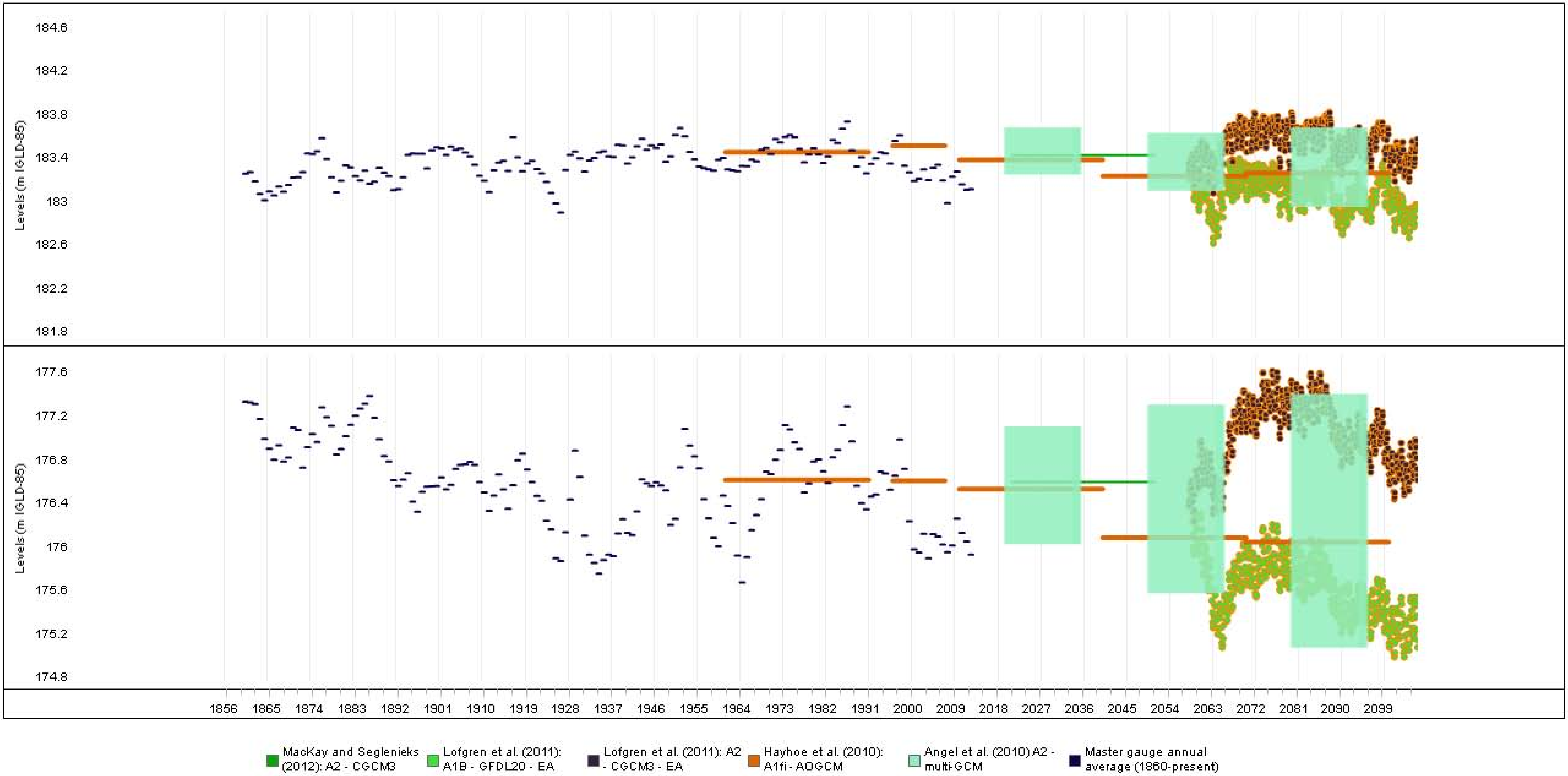
Great Lakes Water Levels

Long-term projections



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Concluding remarks

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- Relevant, regional, or parochial?

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- Uncertainty quantification: simple or complex models

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- Relevant, regional, or parochial?
- Multi-decadal total water projections
- Uncertainty quantification: simple or complex models
- Projections and simulations: “predict” or offer insight?

Acknowledgements

Acknowledgements

- Kaye LaFond, Joe Smith, Anne Clites, Tim Hunter

Acknowledgements

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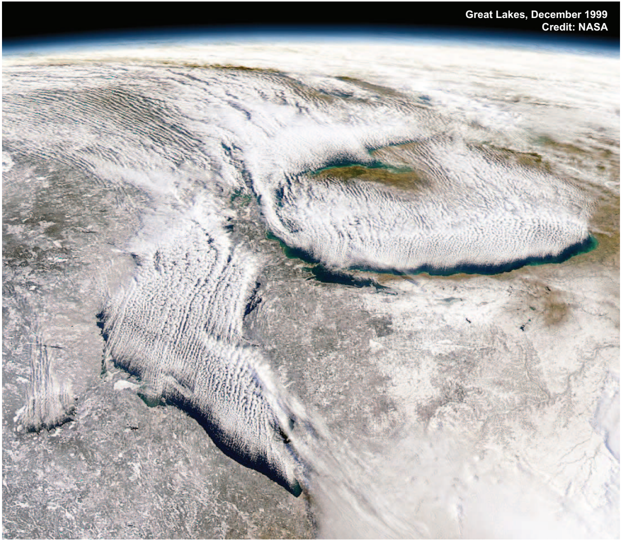
- NOAA, USACE, USGS, Environment Canada, and IJC


Great Lakes, December 1999
Credit: NASA

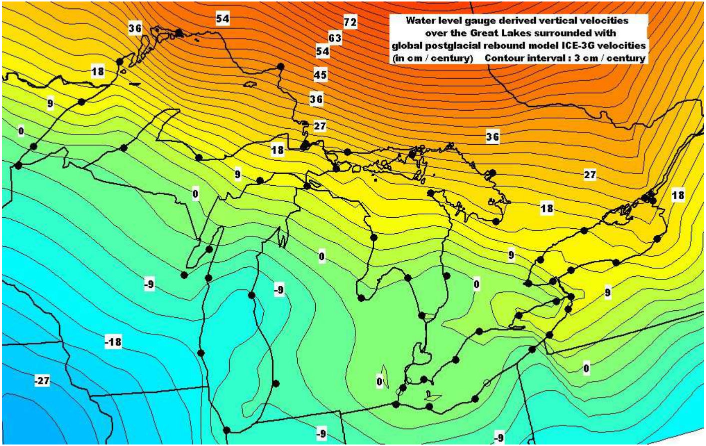
Hydrological Forecasting from a Great Lakes Perspective

Andrew Gronewold, Ph.D., P.E.
drew.gronewold@noaa.gov

Great Lakes Environmental Research Laboratory
National Oceanic and Atmospheric Administration
and
Department of Civil and Environmental Engineering
University of Michigan

June 2016

Glacial isostatic rebound



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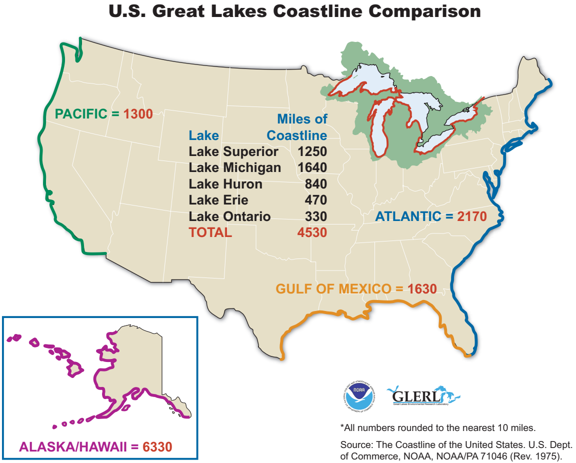
From: NOAA National Ocean Service (CO-OPs) and NOAA-GLERL.



From: Gronewold, Fortin, Lofgren, Clites, Stow, and Quinn (2013). *Climatic Change*.