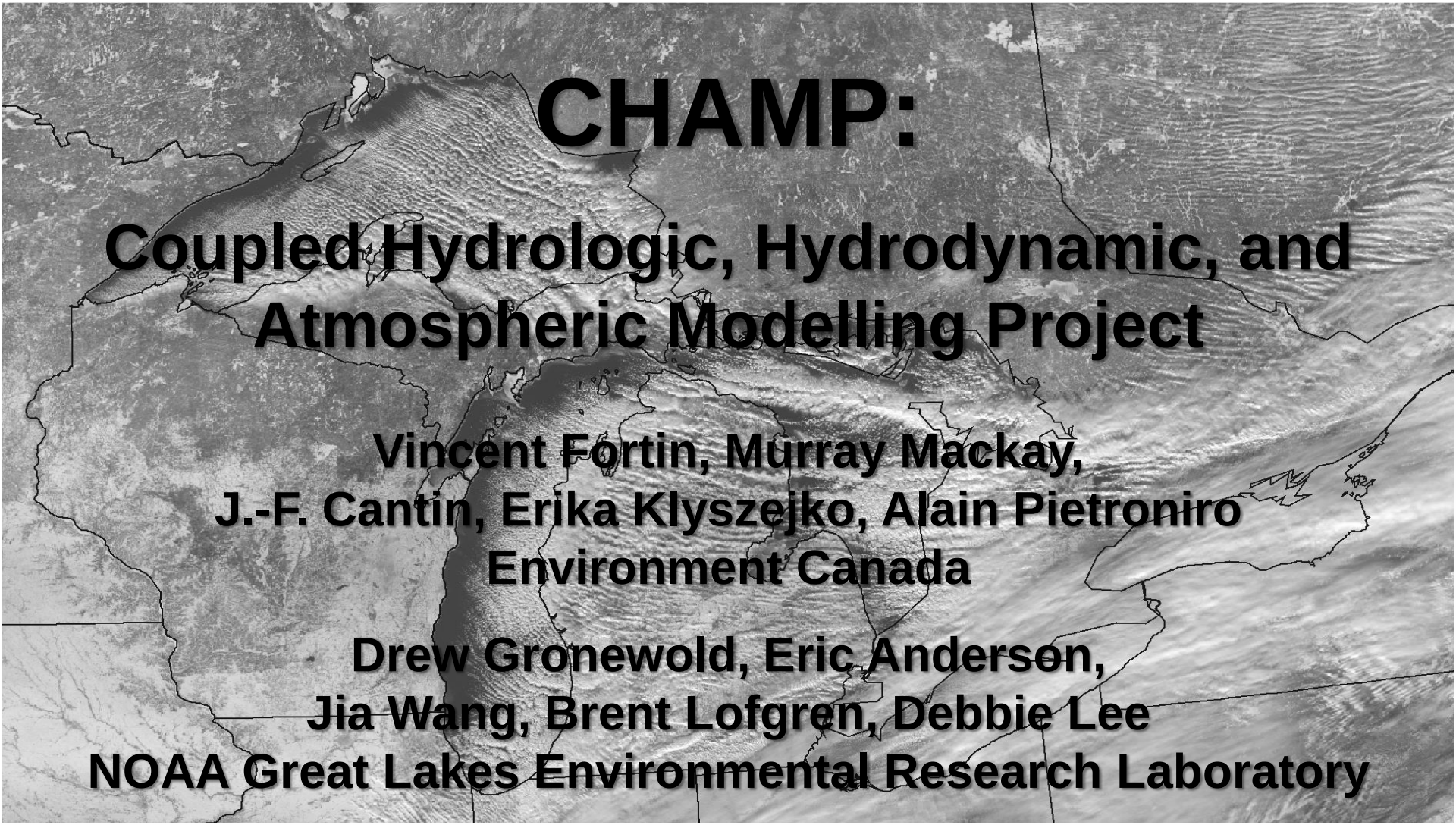

Environment Canada Environnement Canada

Canada

CHAMP:

Coupled Hydrologic, Hydrodynamic, and Atmospheric Modelling Project

Vincent Fortin, Murray Mackay,
J.-F. Cantin, Erika Klyszejko, Alain Pietroniro
Environment Canada

Drew Gronewold, Eric Anderson,
Jia Wang, Brent Lofgren, Debbie Lee
NOAA Great Lakes Environmental Research Laboratory

NOAA National Oceanic and Atmospheric Administration U.S. Department of Commerce

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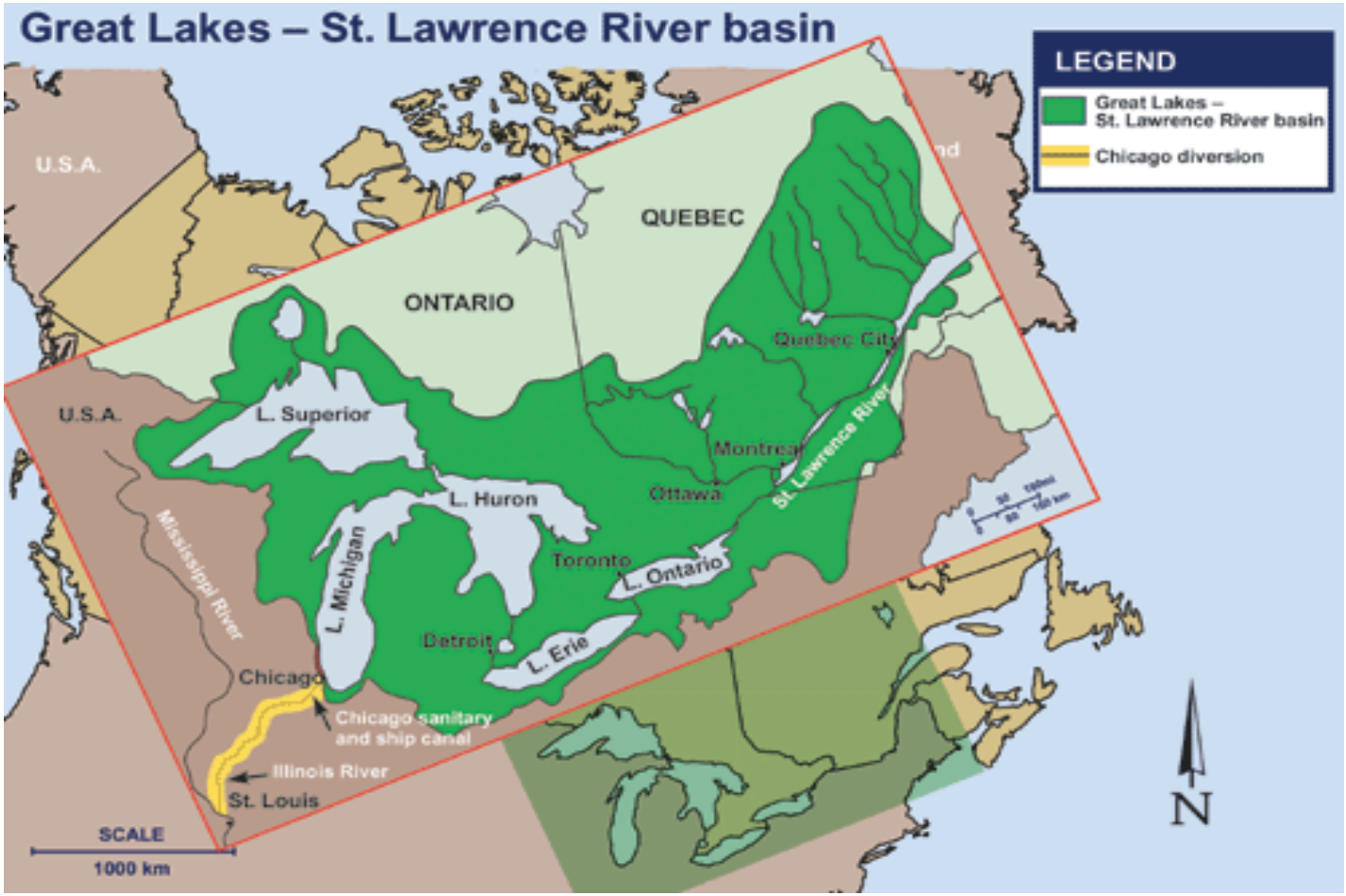
Great Lakes - St. Lawrence basin



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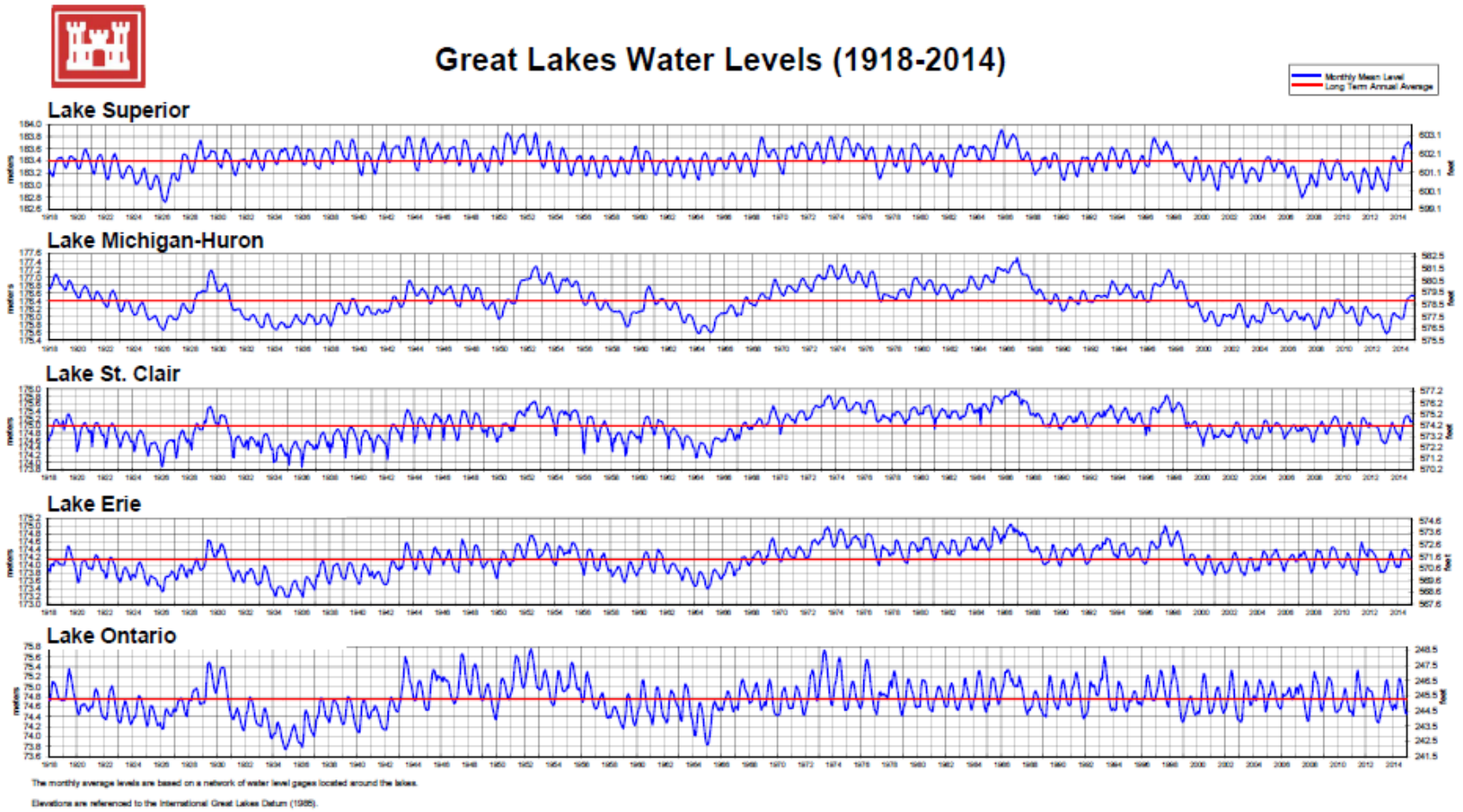
In Mohawk: *Kaniatarowanenneh*
"The big waterway"

Historical water levels



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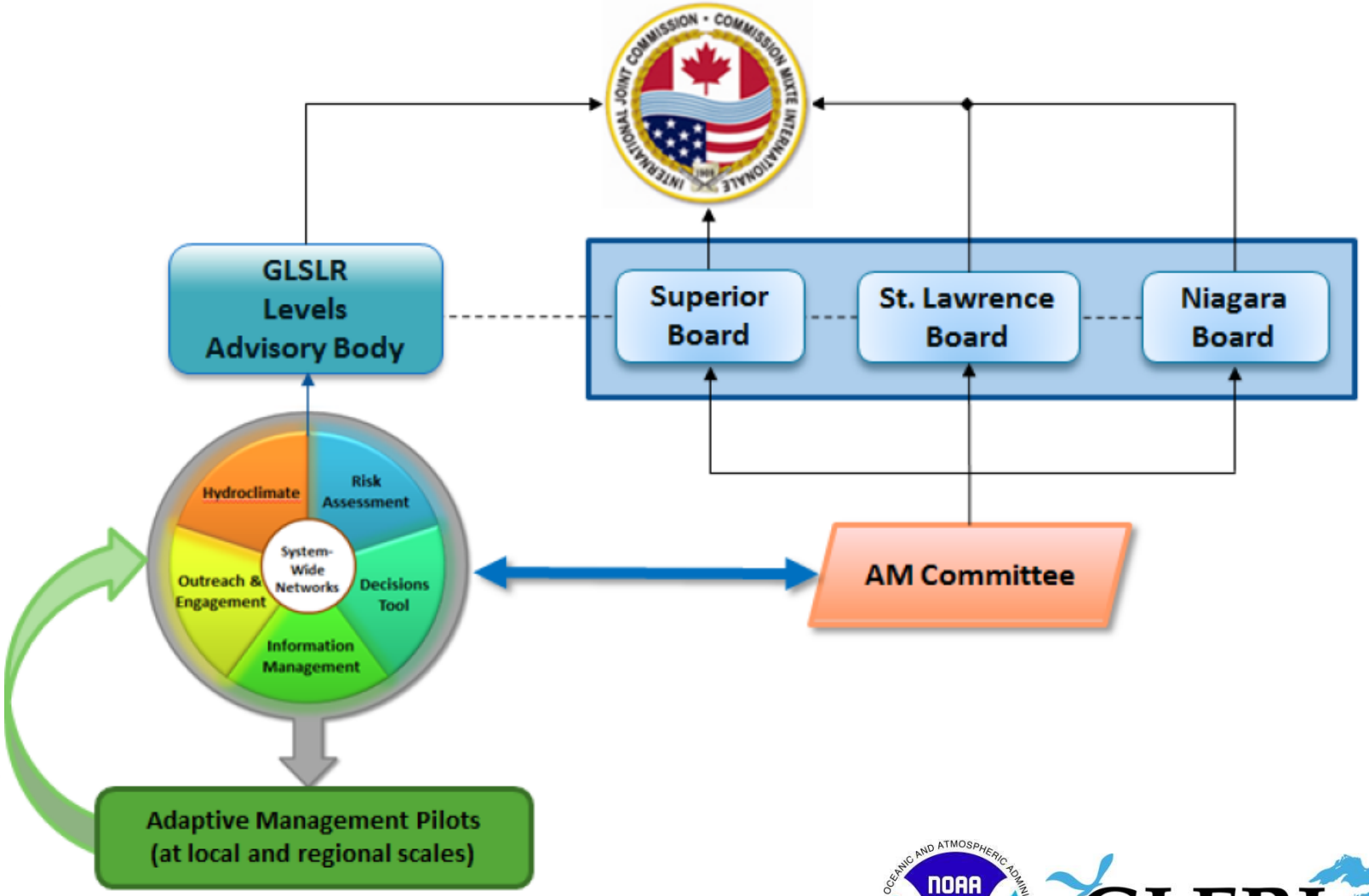
Canada

Water-related challenges in the Great Lakes and St. Lawrence

- Recognized in the 1909 Canada-US Boundary Waters Treaty (in this order):
  1. Water availability for domestic and sanitary purposes
  2. Navigation
  3. Hydro-power and irrigation
- Emerging issues (in no particular order):
  - Recreational use of the water, search and rescue operations
  - Biodiversity and invasive species
  - Climate change
  - Water quality, eutrophication and algae blooms
  - Flood warning and preparedness
  - Urbanization

International Joint Commission and Adaptive management



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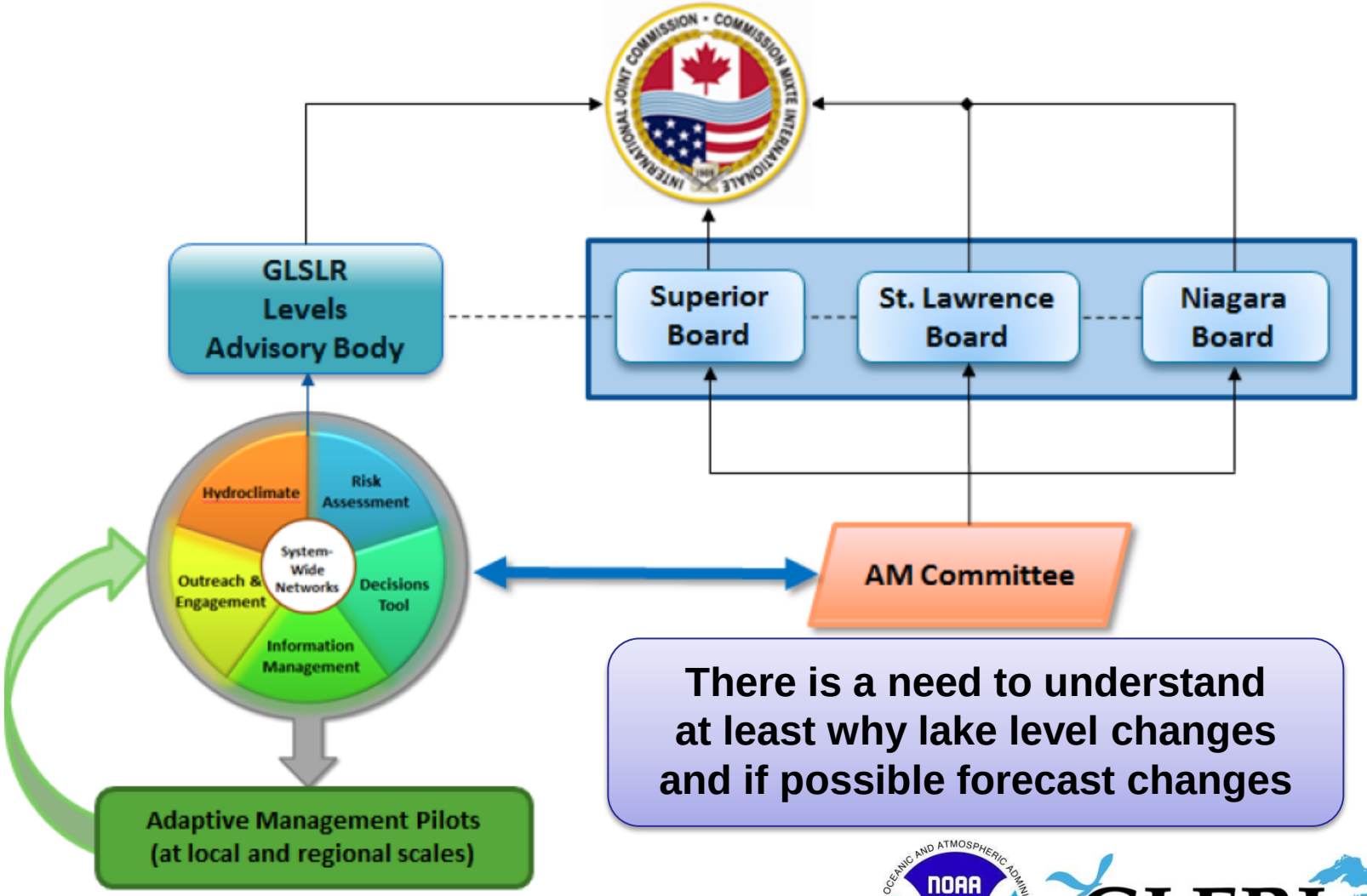
International Joint Commission and Adaptive management



There is a need to understand at least why lake level changes and if possible forecast changes

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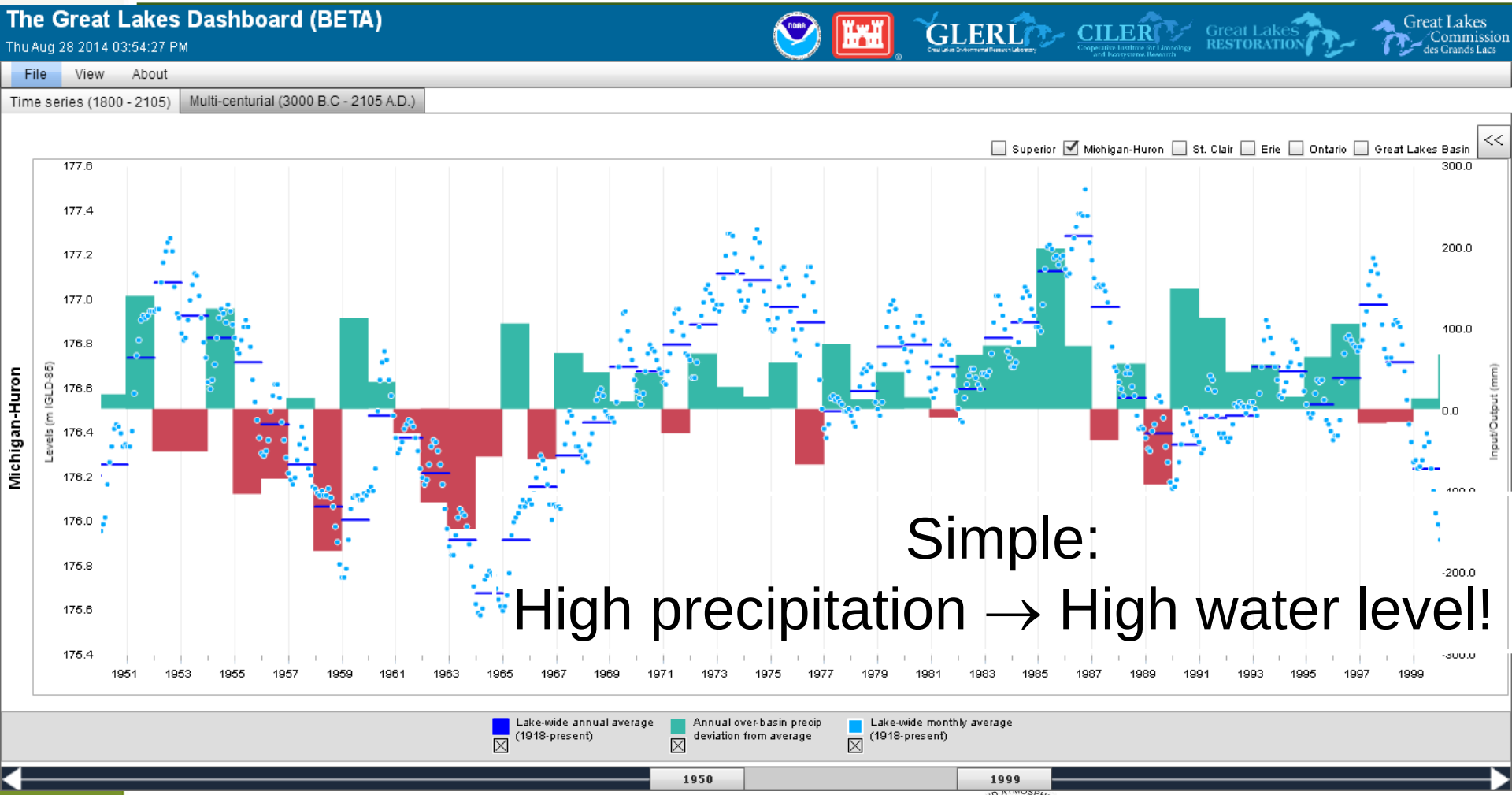
Main drivers of water level changes in the Great Lakes and St. Lawrence

- From short term fluctuations to secular changes:
  - Storm surges and seiches caused by wind set-up
  - Hydropower peaking and ponding
  - Precipitation
  - Evaporation
  - Snow melt
  - Regulation by dams
  - Abstractions and diversions
  - Dredging
  - Climate change
  - Glacial isostatic rebound
- What is the impact of each of these?

Lake Michigan-Huron water level vs precipitation: 1950-2000



Simple:

High precipitation → High water level!

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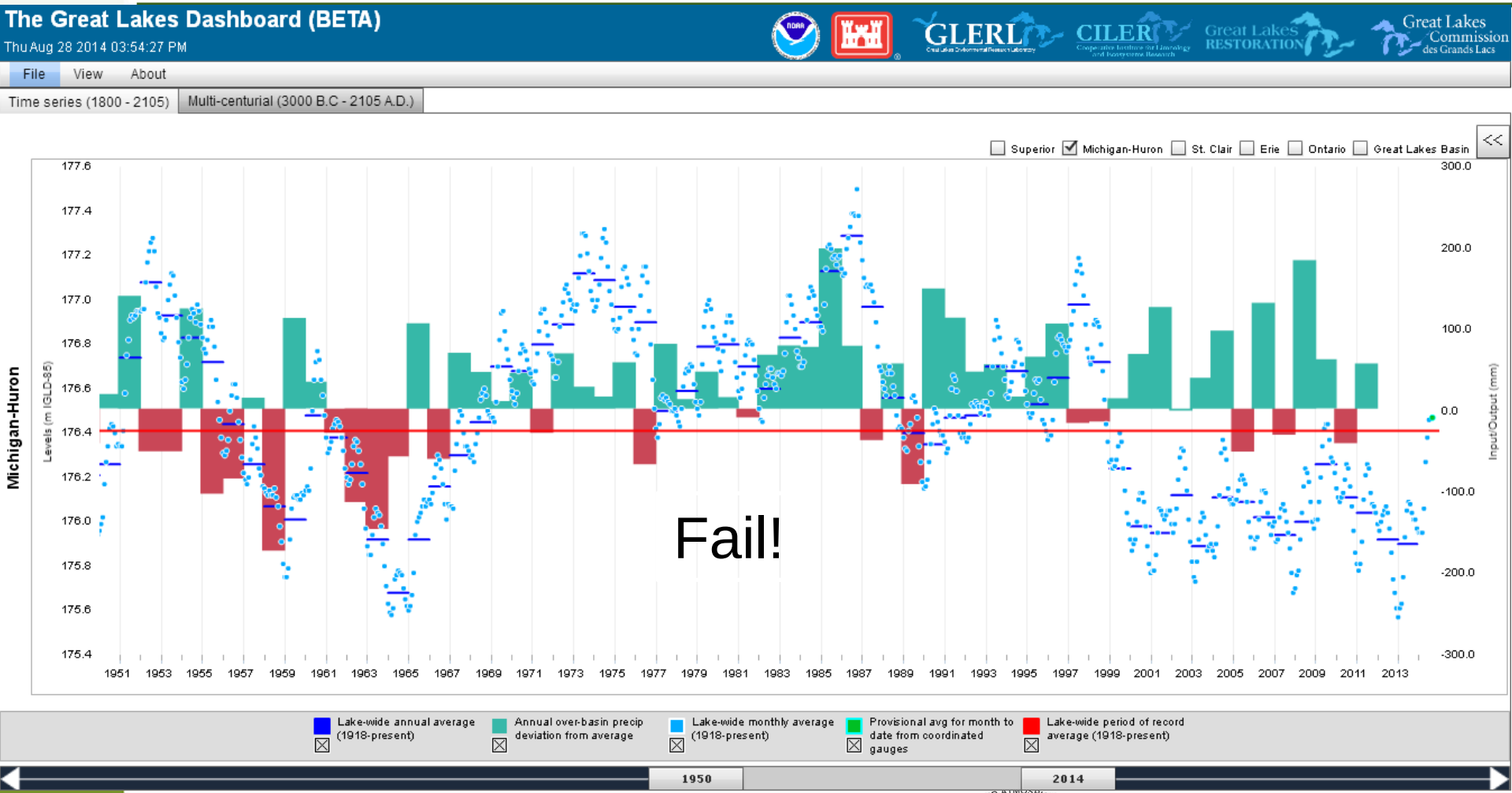
Lake Michigan-Huron water level vs precipitation: 1950-2013



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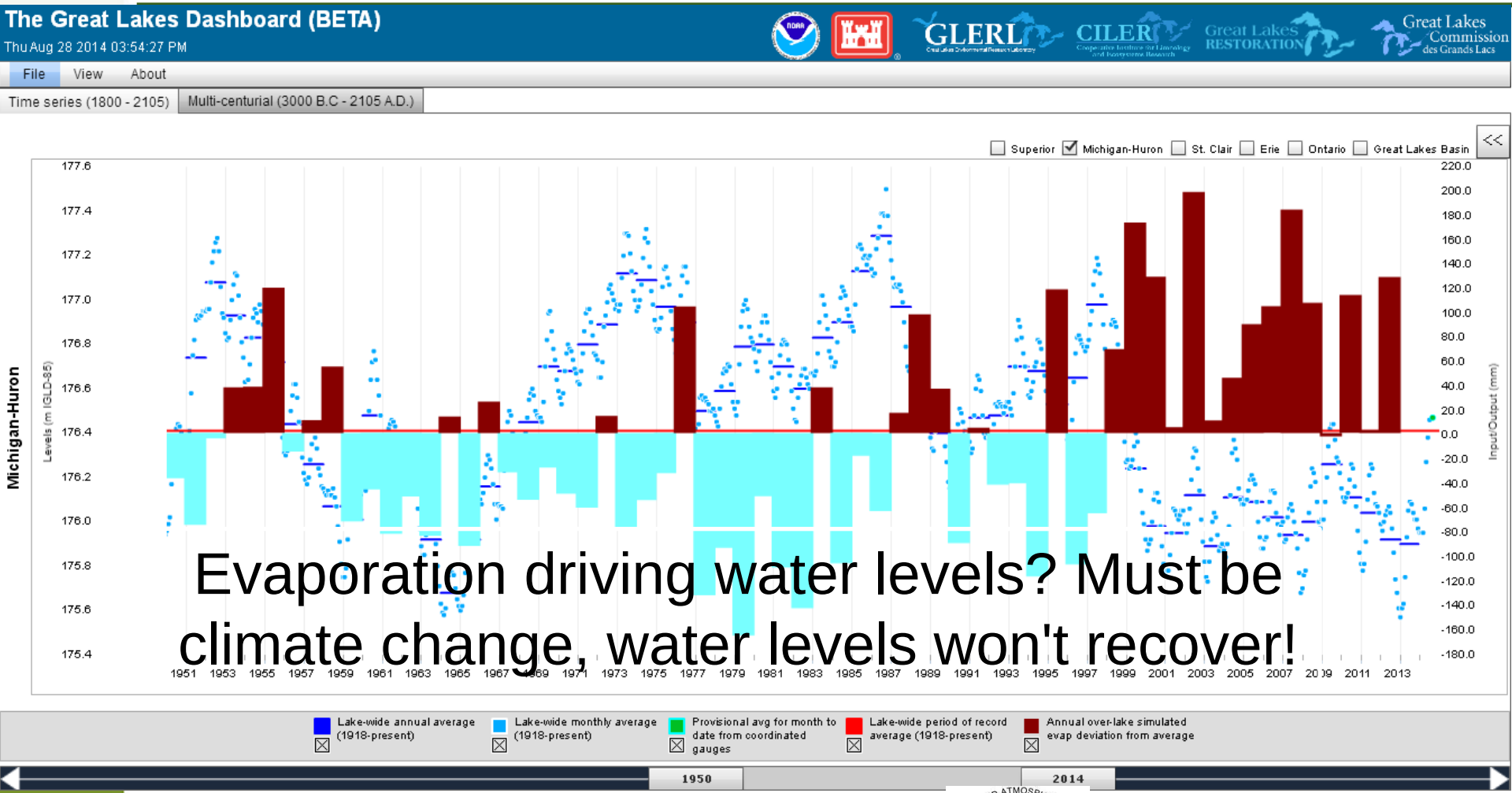
Lake Michigan-Huron water level vs evaporation: 1950-2013



Evaporation driving water levels? Must be climate change, water levels won't recover!

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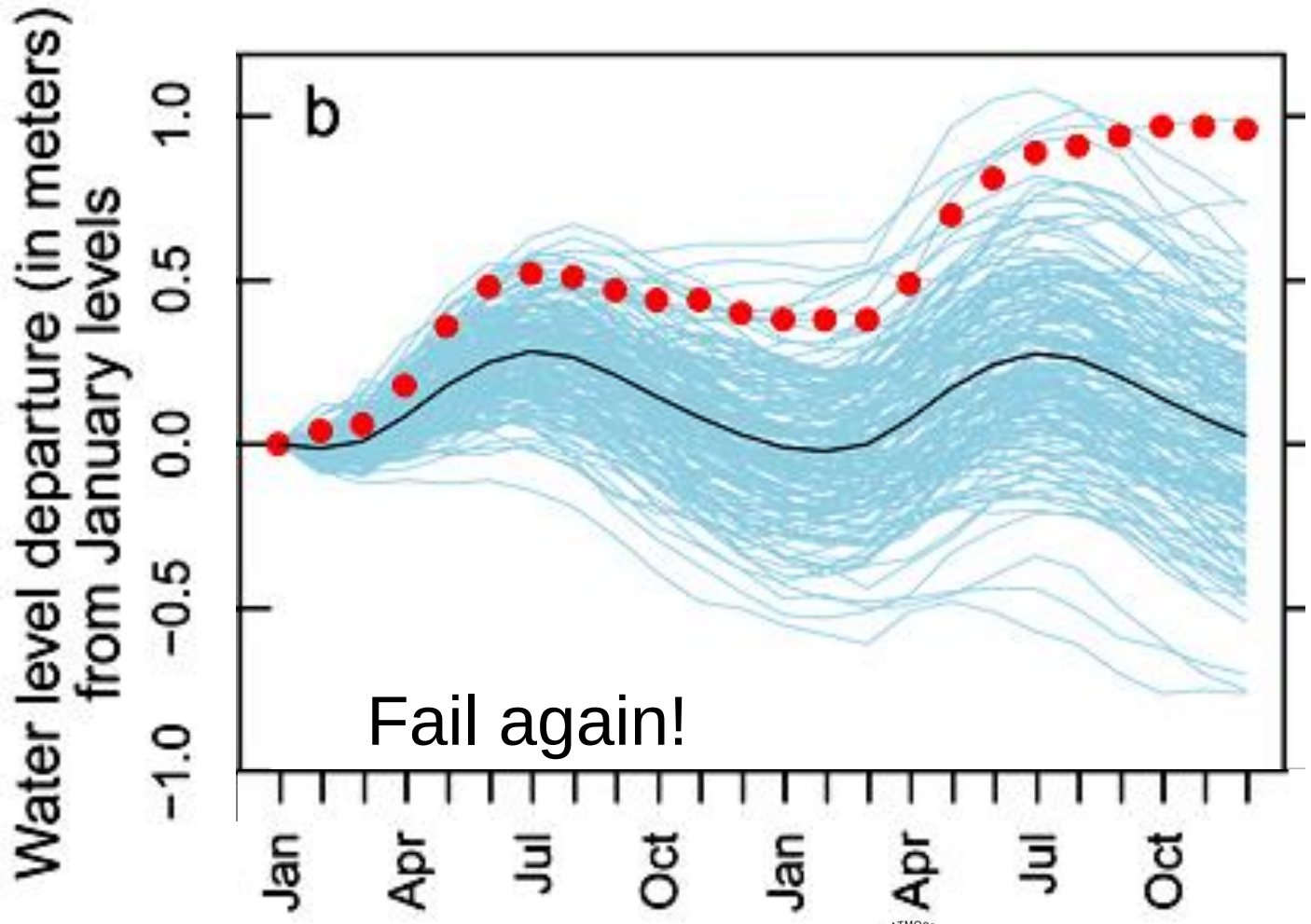
2013-2014: Record rise in water levels for Lake Michigan-Huron!



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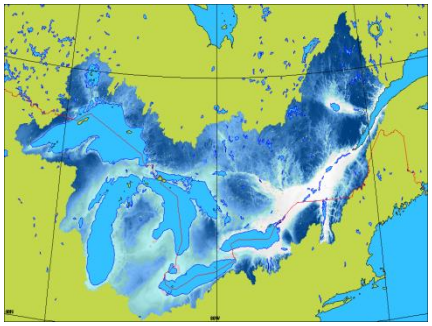
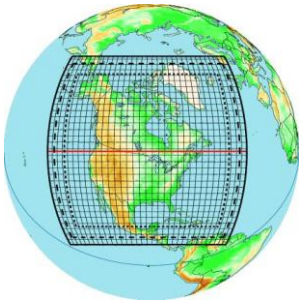
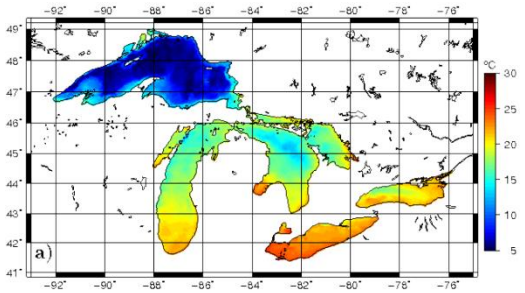
Scientists do it with coupled numerical models...





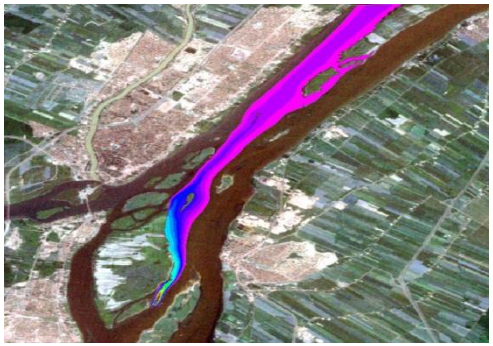
Atmospheric model

Surface, hillslope, and river routing model



Lake model

Ecological forecasting model



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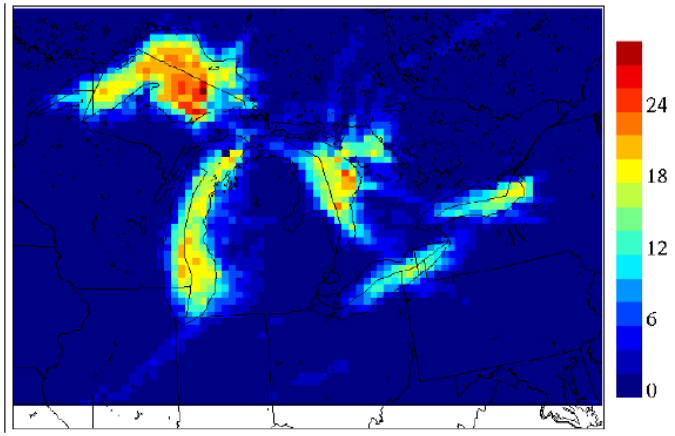
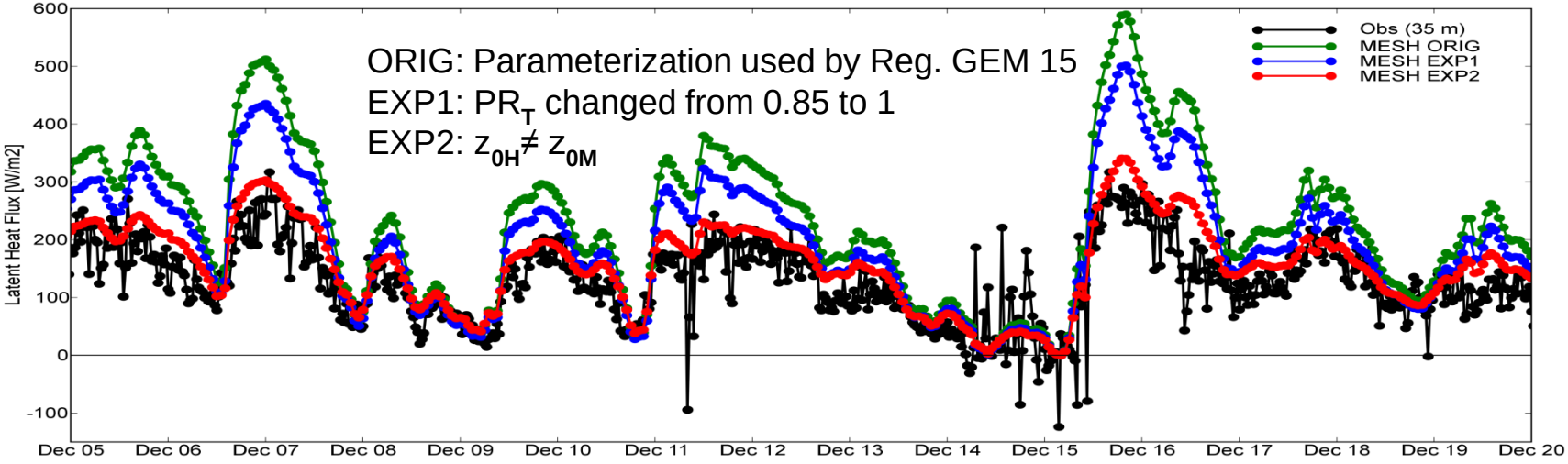
... and with data!

Eddy-covariance data used to improve evaporation prediction

Impact of precipitation forecast (sum of 31 daily forecasts, Dec 09)



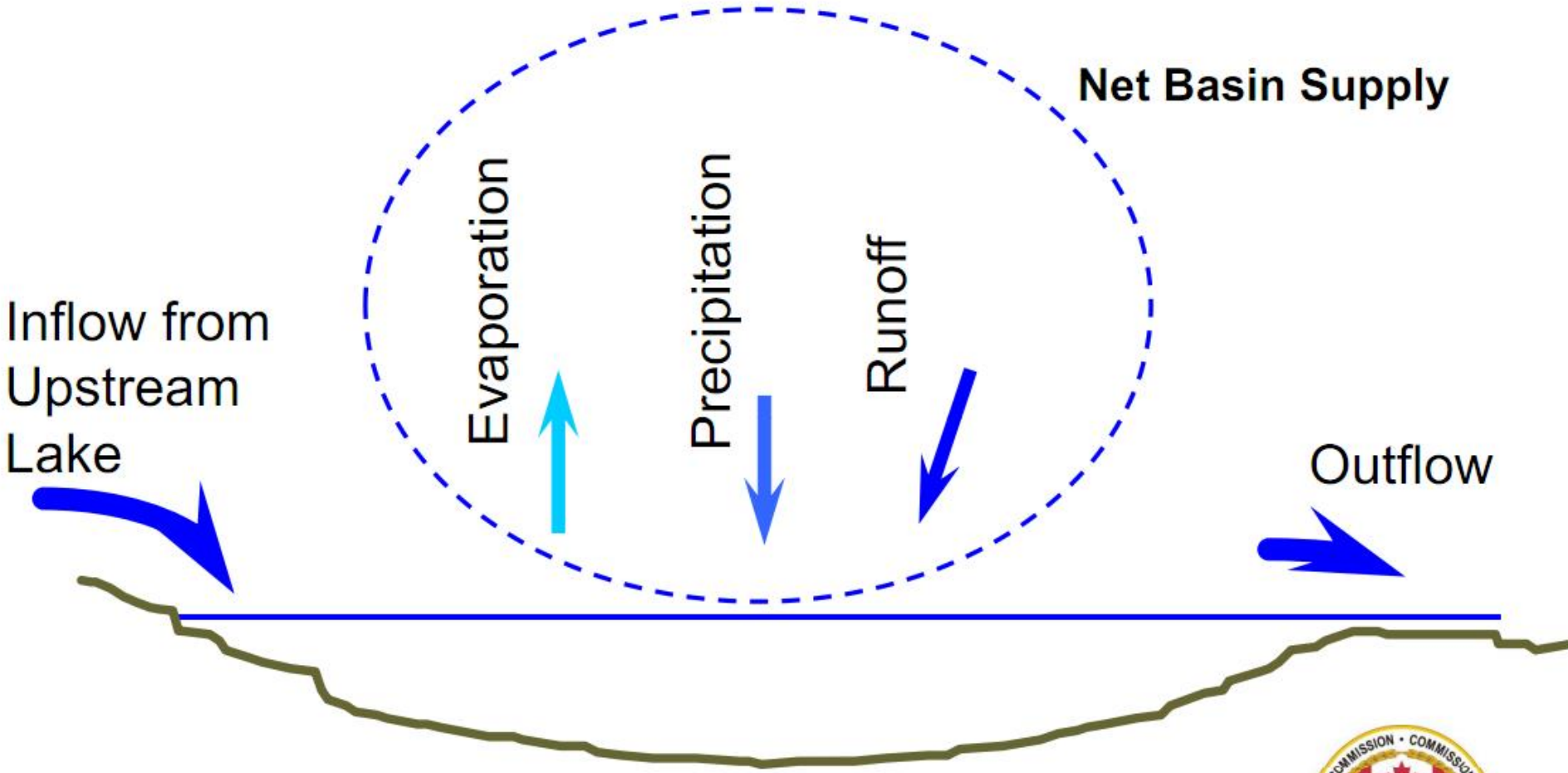


EC vs NOAA model components

Component	Environment Canada	NOAA/GLERL
Atmosphere	GEM	WRF
Hydrology	GEM-Hydro MESH	WRF-Hydro LBRM
River model	H2D2 (2D)	FVCOM (3D)
Lake model	NEMO (FDM, 3D)	FVCOM (FEM, 3D) AHPS (1D)
Ice model	C-ICE	C-ICE
Wave model	WaveWatch 3	WaveWatch 3

Great Lakes Water Supplies

(Factors Affecting Water Levels)



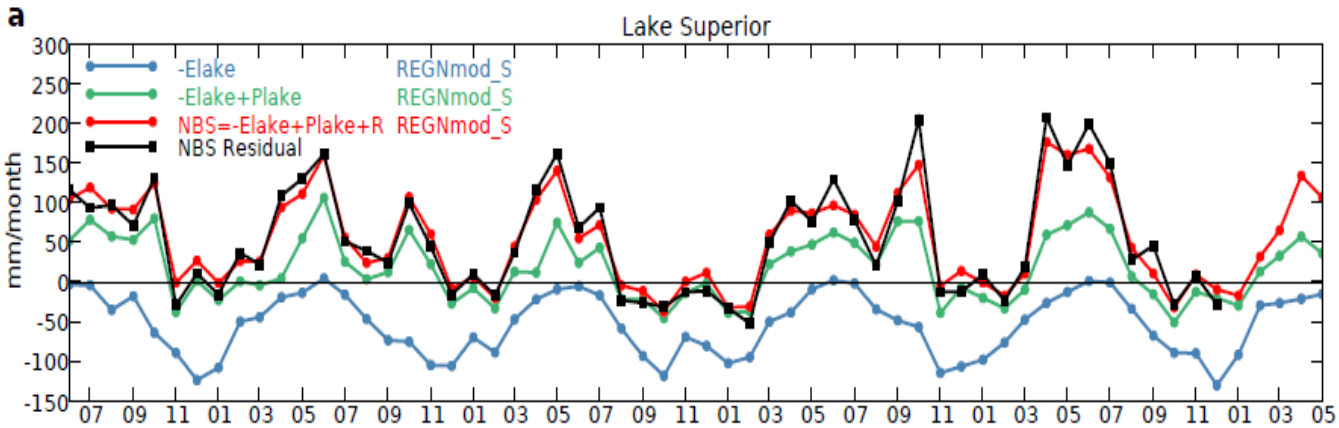
International Lake Superior Board of Control

30 August 2011

Predicting net basin supplies to Lake Superior with GEM-Hydro

- **Overlake evaporation (-E)**
- **Net overlake precipitation (P-E)**
- **Net basin supplies (NBS=P-E+R)**
- **Resid: residual calculation of NBS from lake levels obs. and lake outflow**

World's largest lake by area:
- Lake area: 82 000 km²
- Watershed: 128 000 km²



Deacu et al. (2012) J. Hydromet.

Environnement Canada

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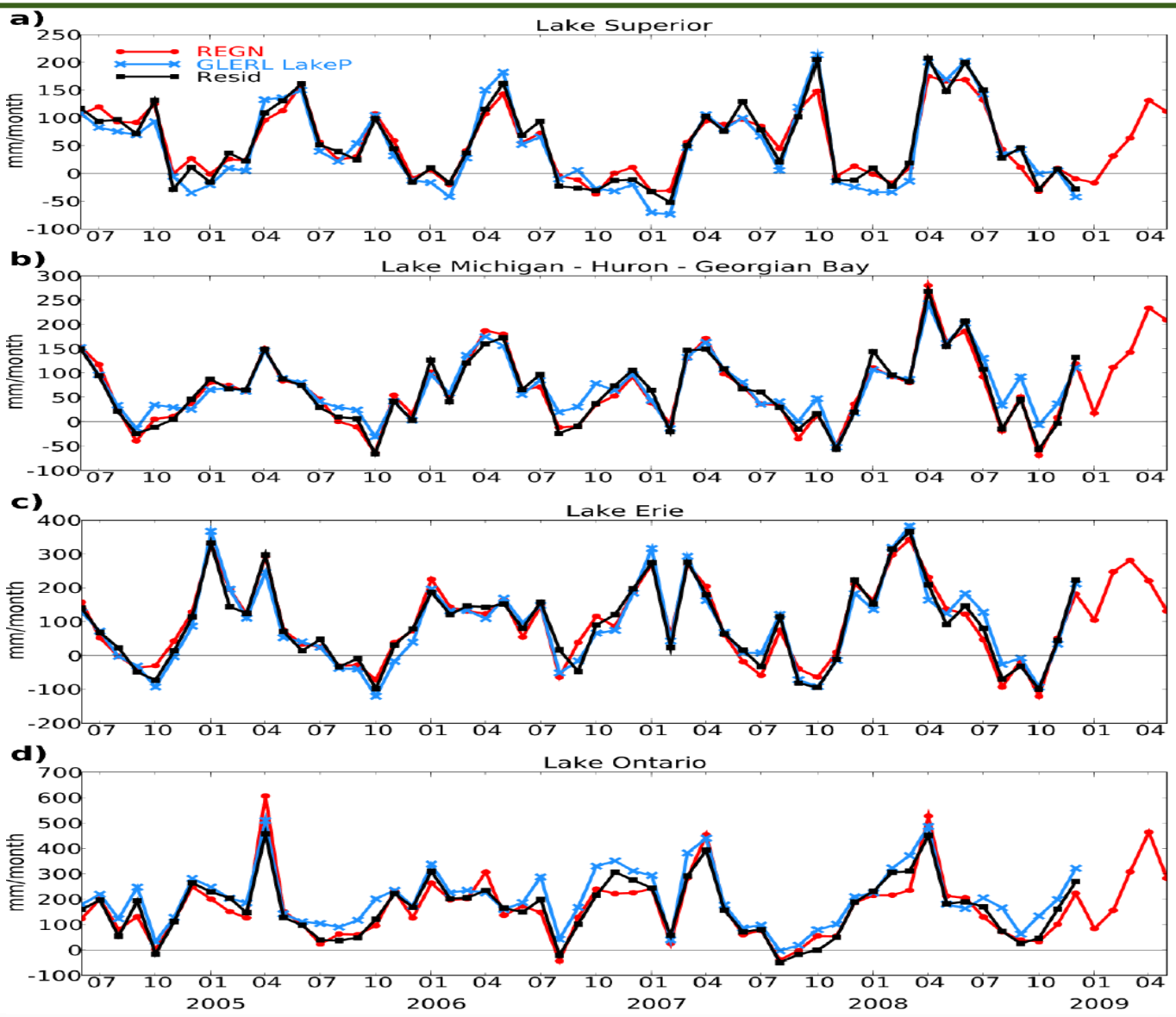
Predicting monthly net basin supplies to the Great Lakes

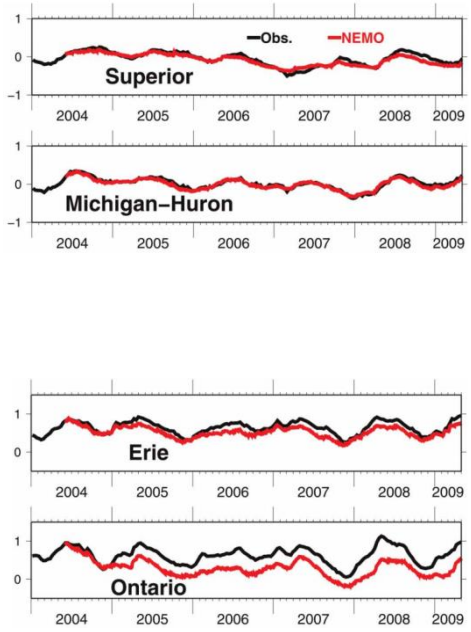
- **REGN:** EC's experimental GEM-Hydro outputs (with assimilation of streamflow)
- **GLERL LakeP:** NOAA-GLERL operational NBS hindcasting system
- **Resid: residual calculation from lake levels obs.**



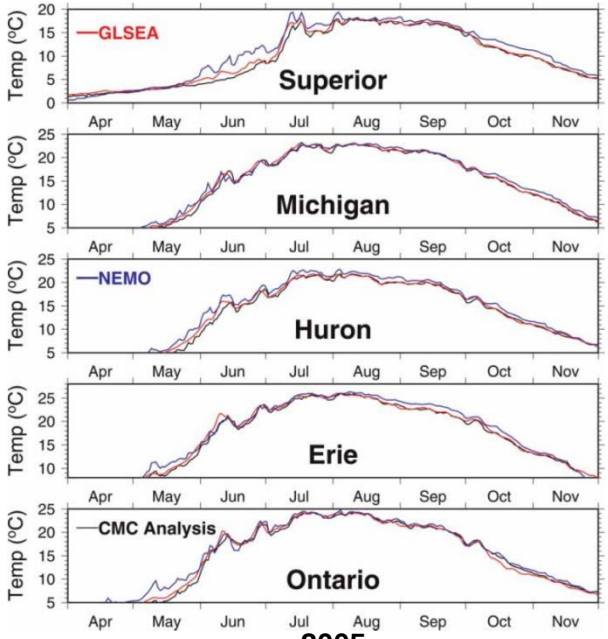
Deacu et al. (2012)
J. Hydromet.

Simulating Great Lakes physical behaviour using NEMO

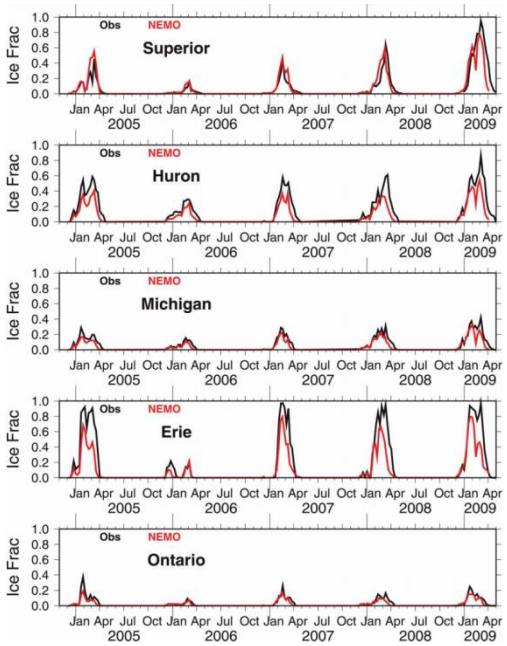
Water level change [m]



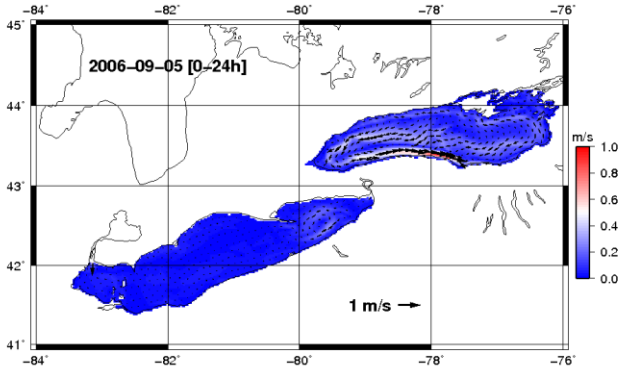
Surface temperature [C]



Ice fraction

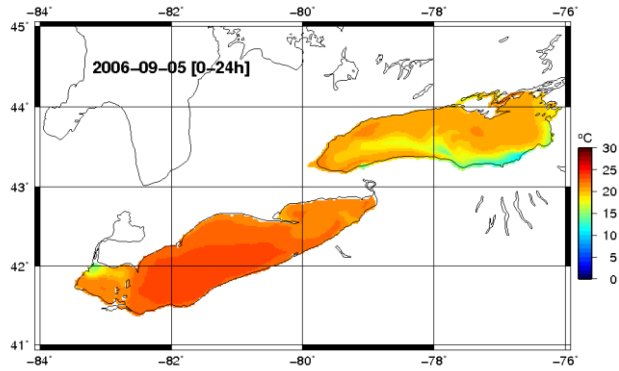


2005



← Surface currrents [m/s]

Surface temperature [C] →



Dupont et al. (2012) WQRJC

Water-related challenges in the Great Lakes and St. Lawrence

- Existing models have been designed to address long-standing issues:
  1. Water availability for domestic and sanitary purposes
  2. Navigation
  3. Hydro-power and irrigation
- ... but are not always up to the task for emerging issues, which require more spatial and temporal resolutions, more physical processes and more lead time:
  - Recreational use of the water, search and rescue operations
  - Maintaining biodiversity and fighting invasive species
  - Water quality, eutrophication and algae blooms
  - Climate change impact and adaptation studies
  - Flood warning and preparedness
  - Urbanization

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Five CHAMP science questions to better address emerging issues

1. Two-way coupling: can coupled numerical models significantly improve forecasts of both the atmosphere and the hydrosphere at the regional scale?
2. What is the relative contribution of forcing, parameter and initial conditions errors?
3. What horizontal resolution and level accuracy is necessary for each application?
4. Can forecast errors be reduced further through targeted monitoring and assimilation?
5. What is the best approach to long-term forecasting given that so little is known about future precipitation?

CHAMP implementation plan

- In both U.S. and Canada, implement an operational (24/7) chain of coupled numerical models that issues real-time forecasts of the physical state of the hydrosphere (different models in each country)
- Link them with habitat and water quality models
- Work on the comparison and evaluation of these systems for different purposes, identify weaknesses
- Identify and support targeted monitoring activities aimed at improving the models
- Share data and models with scientists and stakeholders
- Develop and issue joint products and services

CHAMP focus areas: monitoring, modelling and services

1. Water flux and water level monitoring
2. Short and long term hydrological forecasting:
   - tributary flow
   - areal mean lake water level
3. Hydrodynamic forecasting:
   - storm surge and seiches
   - currents and temperature
   - ice and waves
   - evaporation and turbulent fluxes
4. Ecological forecasting
5. Bi-national products and services

CHAMP focus areas: monitoring, modelling and services

1. **Water flux and water level monitoring**
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   - tributary flow
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3. Hydrodynamic forecasting:
   - storm surge and seiches
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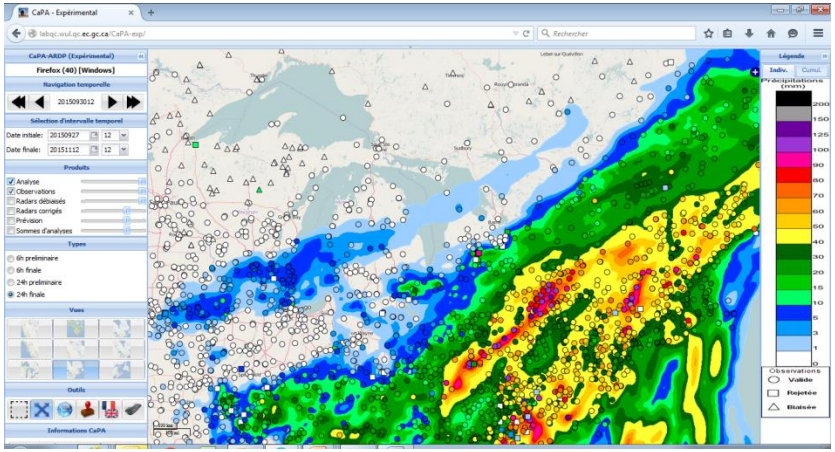
   - ice and waves
   - evaporation and turbulent fluxes
4. Ecological forecasting
5. **Bi-national products and services**

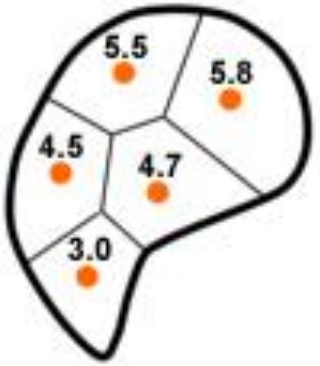
See suppl. material for more details

1 a) Monitoring of precipitation

- Optimal interpolation:
  - Canadian Precipitation Analysis, real-time
  - EC is working on a 30-year hindcast



- Thiessen polygons
  - Historical data going back to 1900, daily mean precipitation and temperature available per subwatershed



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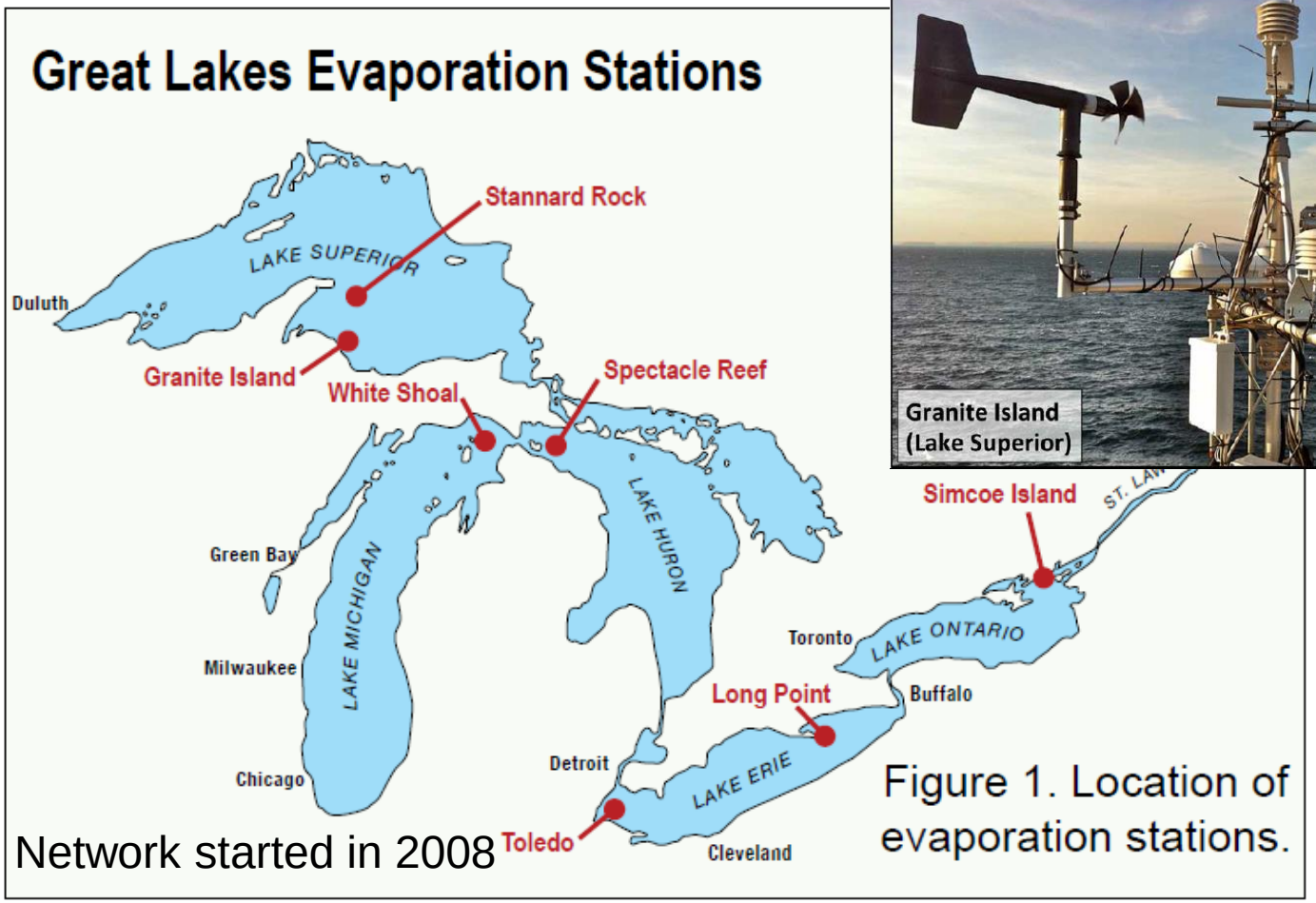
1 b) Monitoring of evaporation



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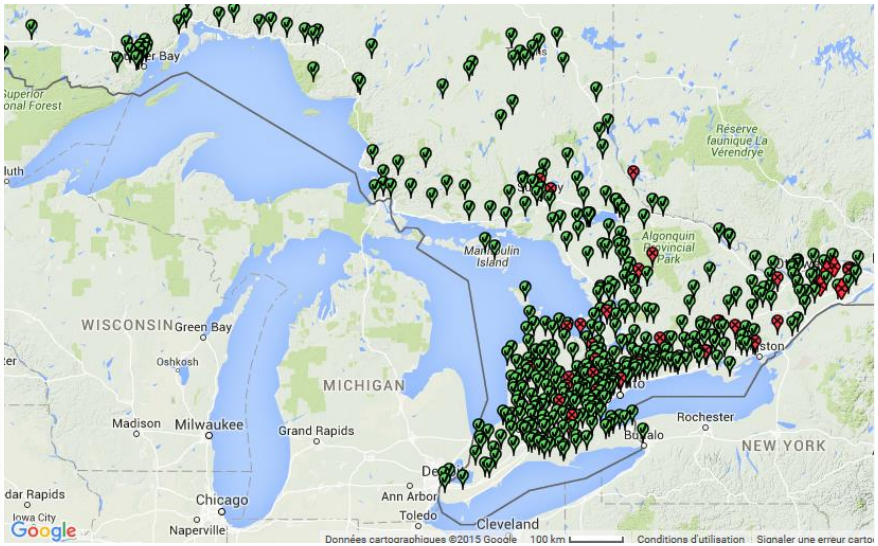
1 c) Monitoring of streamflow

- Environment Canada
- United States Geological Survey



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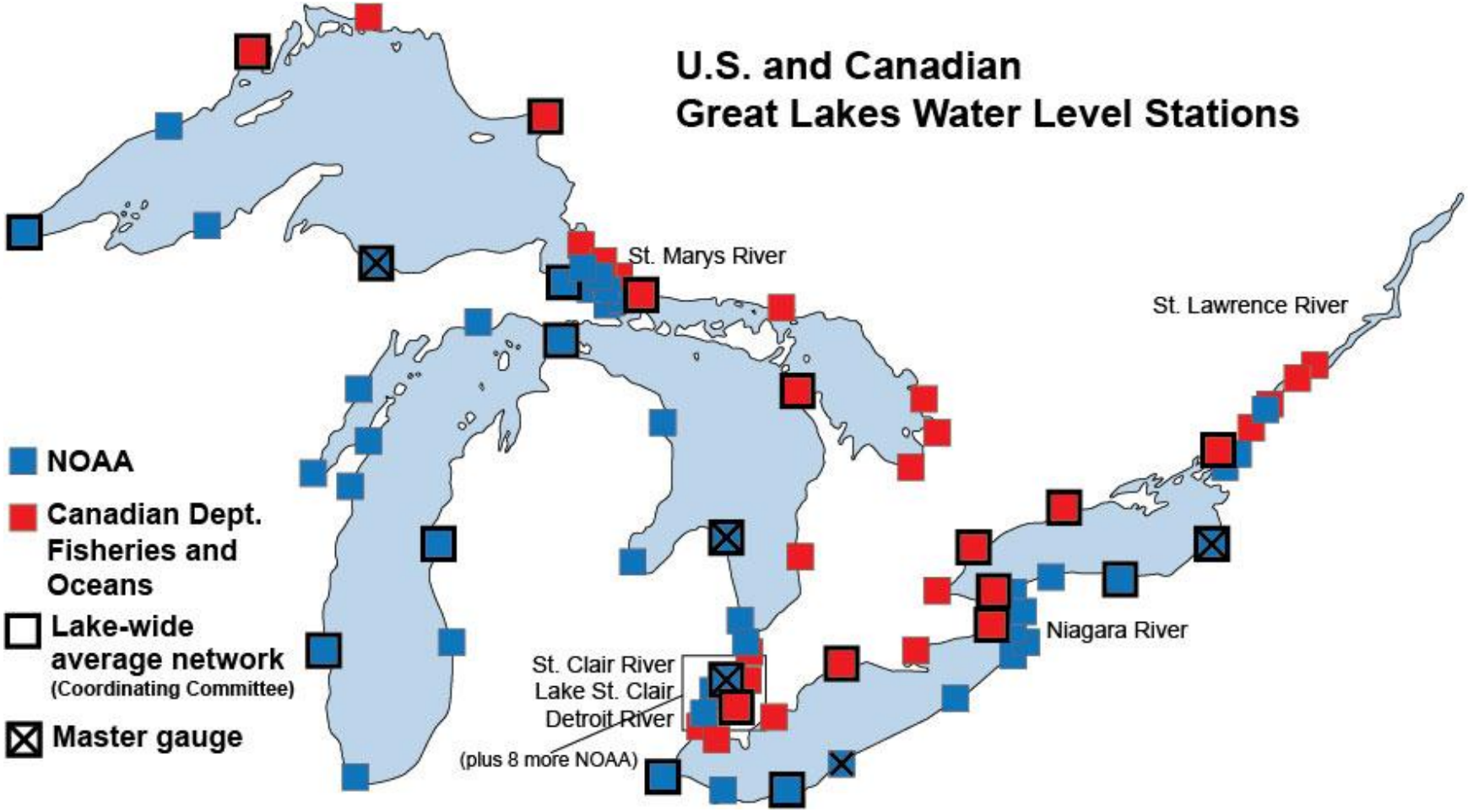
1 d) Monitoring of water levels



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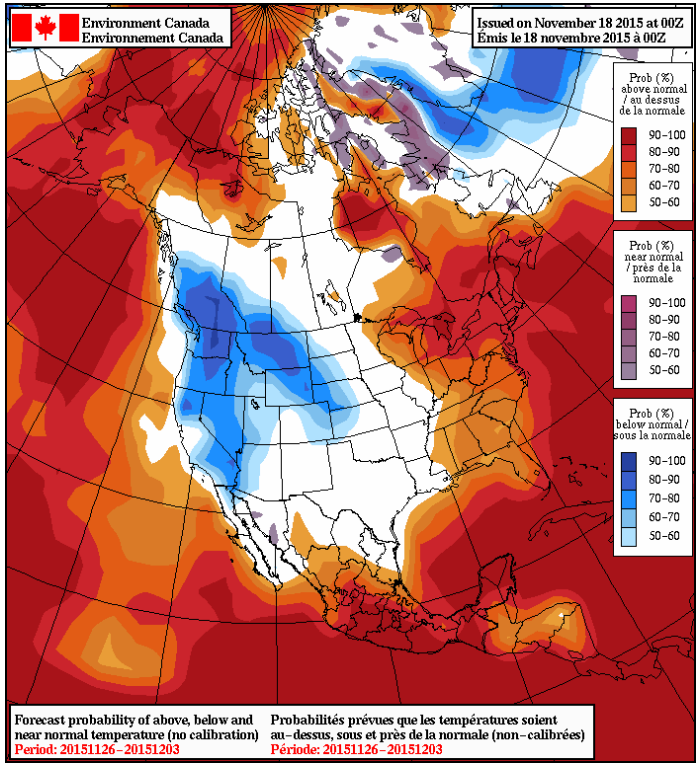
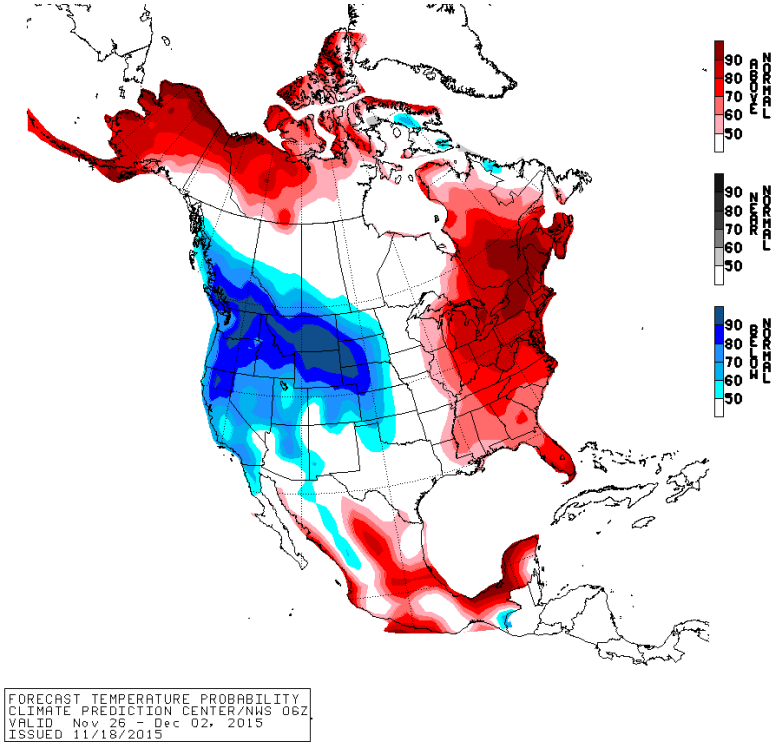
5. Binational products and services

- Build on the successes of the North American Ensemble Forecasting system





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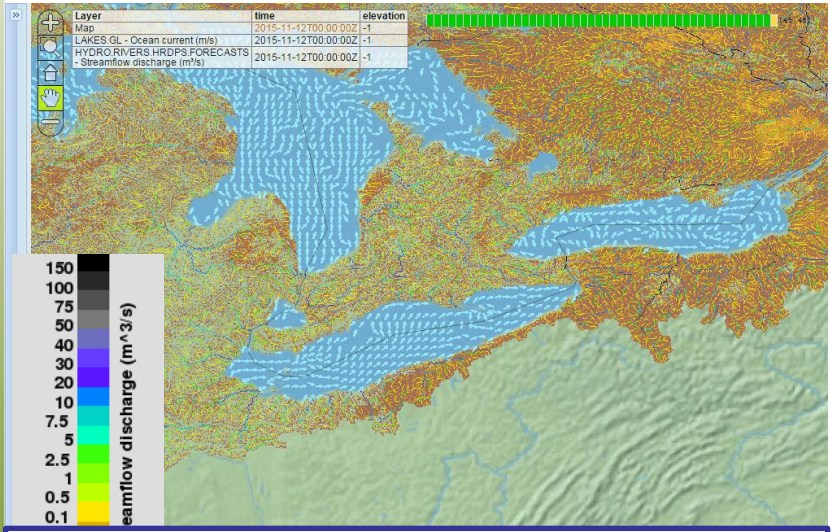
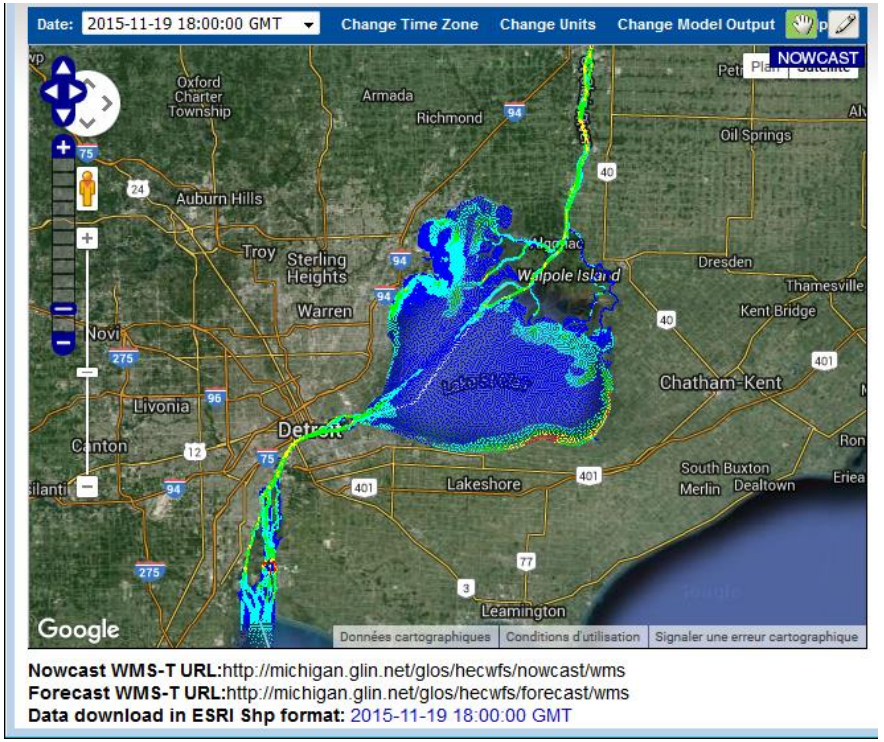
5. Binational products and services

- Dissemination of experimental and operational products through web mapping services



OPS: http://geo.weather.gc.ca/geomet
EXP: http://collaboration.cmc.ec.gc.ca/rpn-wms



Nowcast WMS-T URL:http://michigan.glin.net/glos/hecwfs/nowcast/wms
Forecast WMS-T URL:http://michigan.glin.net/glos/hecwfs/forecast/wms
Data download in ESRI Shp format: 2015-11-19 18:00:00 GMT

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Ongoing activities

- Monitoring of overlake evaporation using flux towers
- Intercomparison of precipitation analysis techniques applicable to the Great Lakes
- Intercomparison of U.S. and Canadian hydrological models
- Intercomparison of water level forecasts issued by U.S. and Canada hydrodynamic models of the Great Lakes
- Reconciling water flux measurements (precipitation, evaporation, runoff, flow from lake to lake) with observed water levels
- Coordinated, probabilistic forecasts of net basin supplies to the Great Lakes
- Coordinated HAB monitoring

Expected deliverables

- Recommendations as to:
  - how to set up a hydrometeorological network that, combined with numerical models, (a) helps close the water balance, (b) improves forecasts at the regional scale and (c) builds confidence in model outputs
  - how to compare environmental models in data scarce environments (e.g. over water)
  - how to prepare useful binational products and services that faithfully depict the situation, including its uncertainty
  - model coupling strategies that improve atmospheric, hydrological and hydrodynamic prediction skill
- Improved numerical models of the hydrosphere for operational applications in U.S., Canada and elsewhere
- New products and services

Project timeline

- Phase I: 2014-2016
  - Project initiation
  - Identification of key science questions
  - Inventory of existing datasets (weather, hydrometric, vegetation, soil texture)
- Phase II: 2016-2017
  - Drafting of the science and implementation plans
  - Identification of co-leads and investigators
- Phase III: 2017-2022
  - Implementation phase, including possible enhanced observation periods in the cold season

Main collaborators

Environment Canada Environnement Canada

- Alain Pietroniro, co-lead
- Vincent Fortin, hydrology
- Murray Mackay, atmosphere-lake interactions
- Jean-François Cantin, ecohydraulics
- Erika Klyszejko, hydrometry
- Debbie Lee, co-lead
- Drew Gronewold, hydrology
- Eric Anderson, hydrodynamic modelling
- Jia Wang, ice modelling
- Brent Lofgren,climate modelling

Open data and open source code policy
WMO member countries are invited to participate and contribute!

Environment Canada Environnement Canada

Canada

Supplementary material on:

1. Hydrological forecasting models
2. Hydrodynamic forecasting models
3. Ecological forecasting approach

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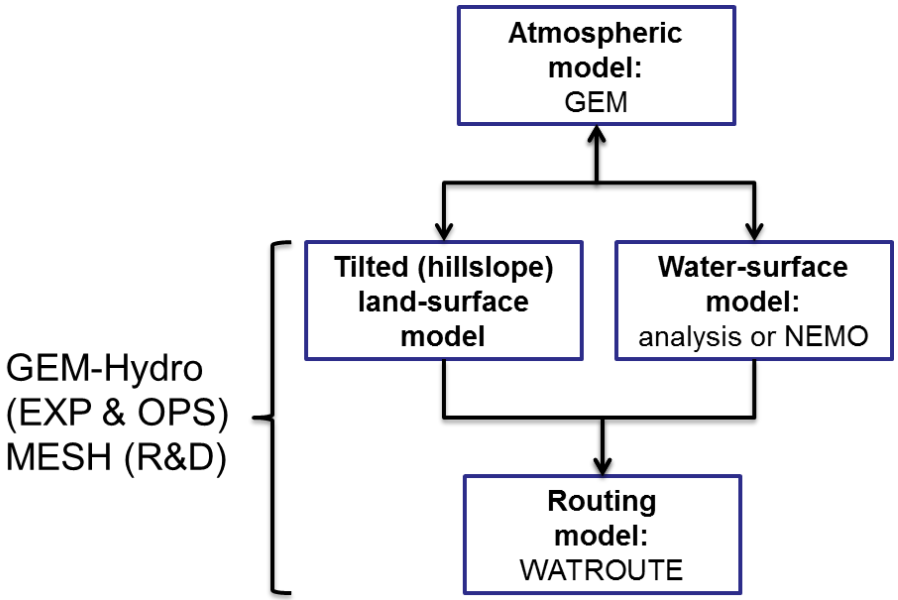
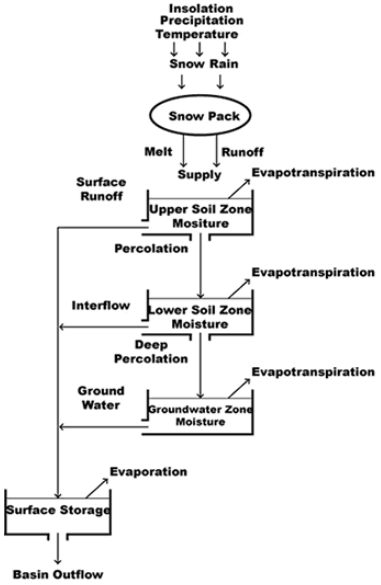
2. Hydrological forecasting: Modelling frameworks

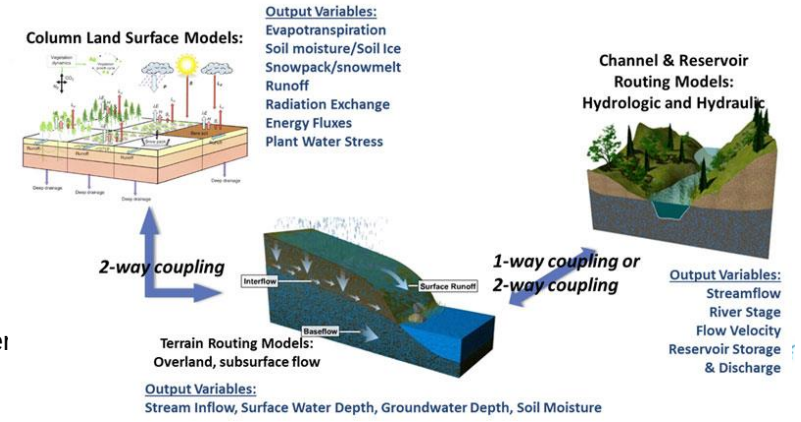
- GEM-Hydro and MESH



- LBRM

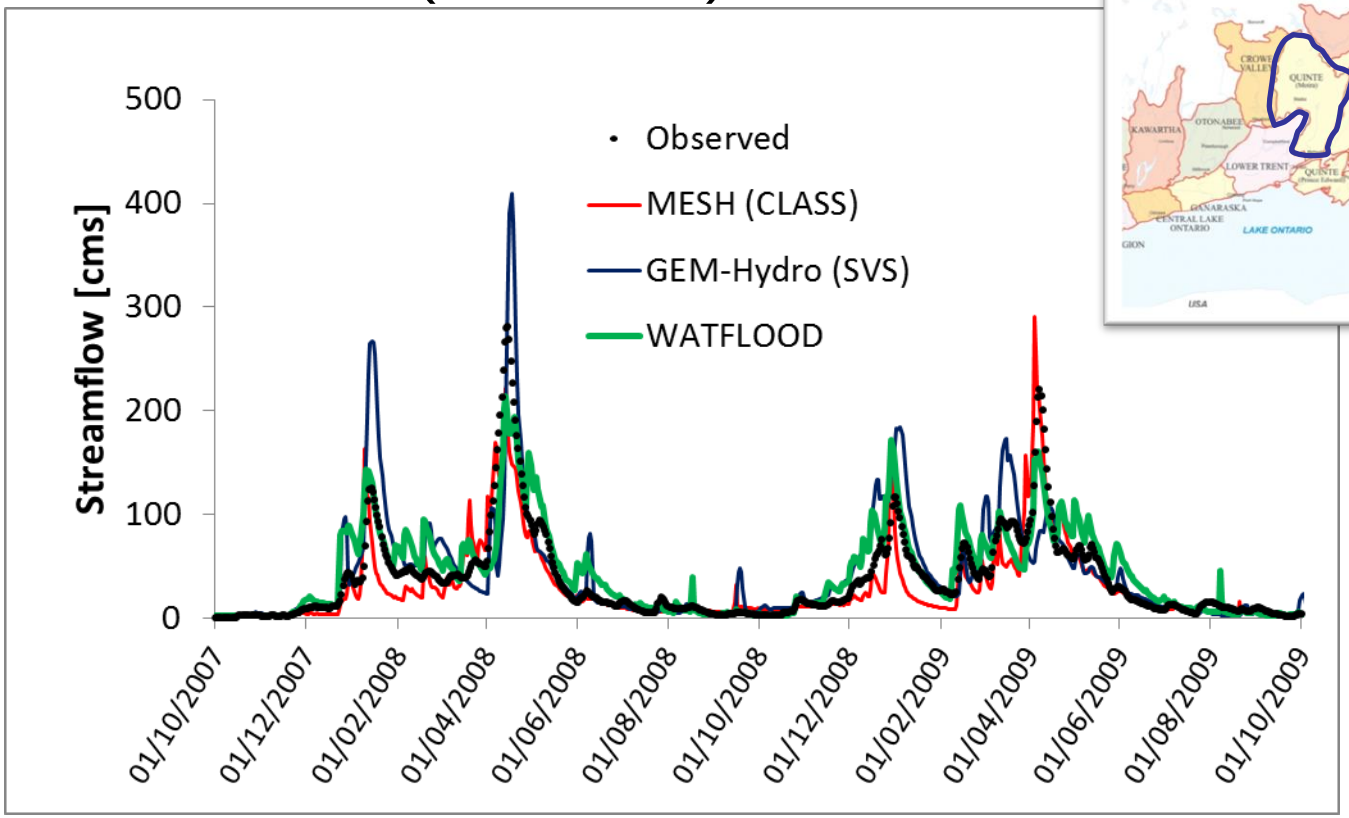


- WRF-Hydro



Assessing hydrological model skill for daily streamflow prediction

- Comparison of 3 Canadian models
- Moira River (2582 km^2)



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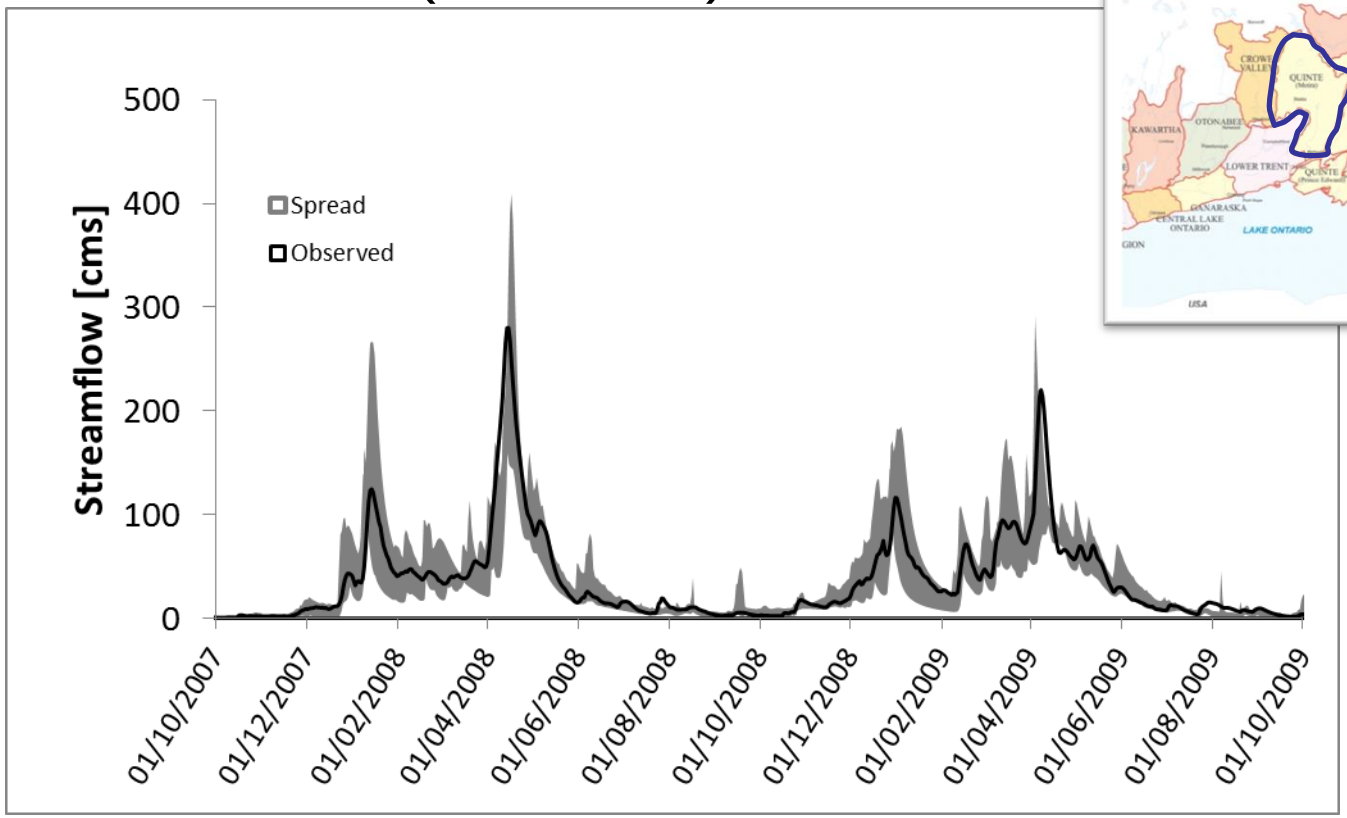
Model uncertainty alone can explain model errors!

- Spread of 3 Canadian models
- Moira River (2582 km^2)



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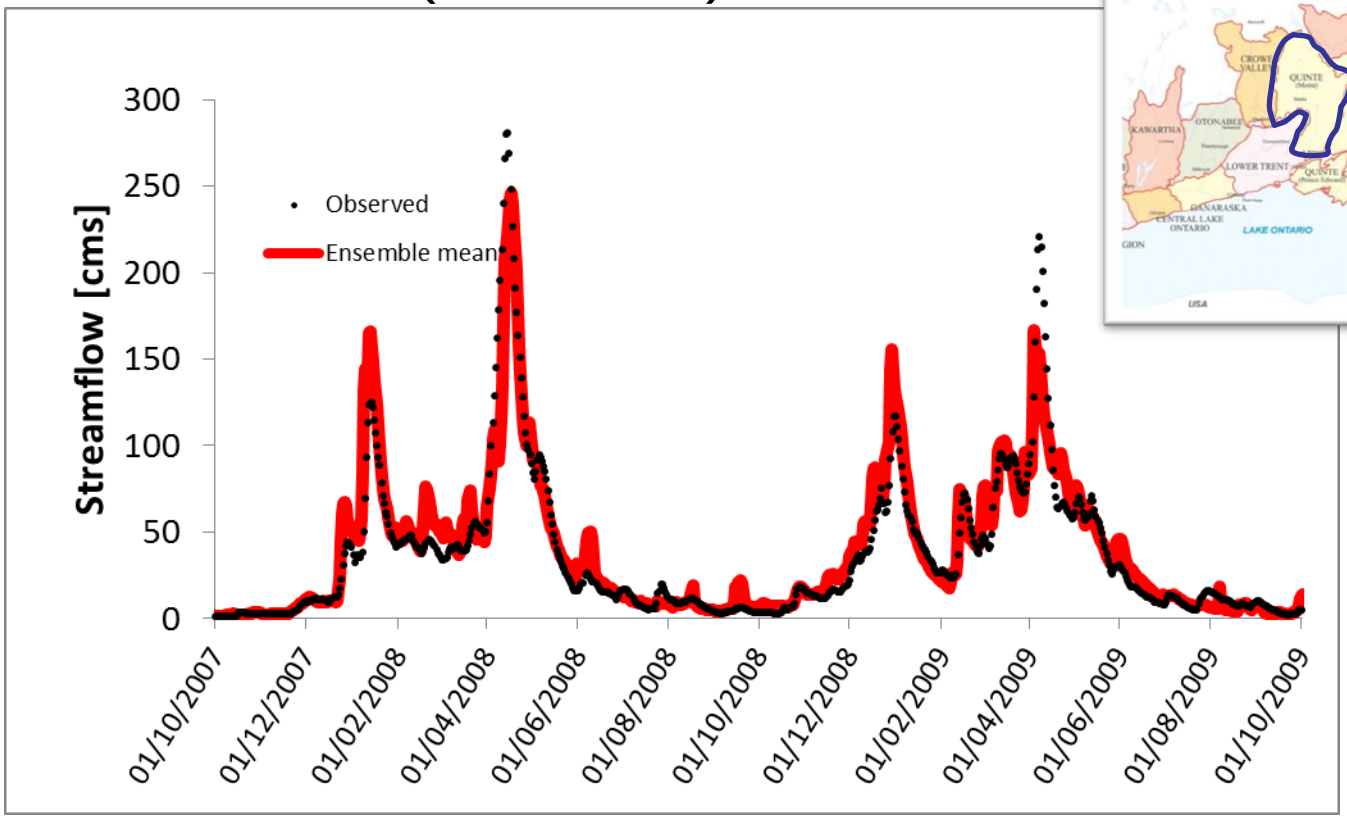
Multi-model prediction is promising

- Average of 3 Canadian models
- Moira River (2582 km^2)



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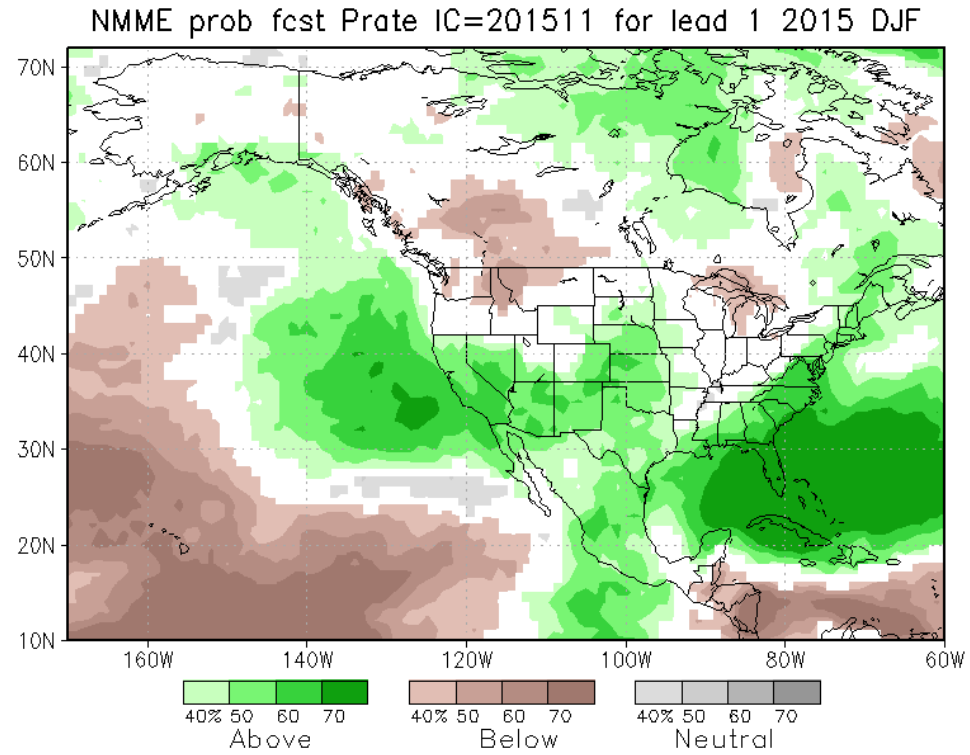
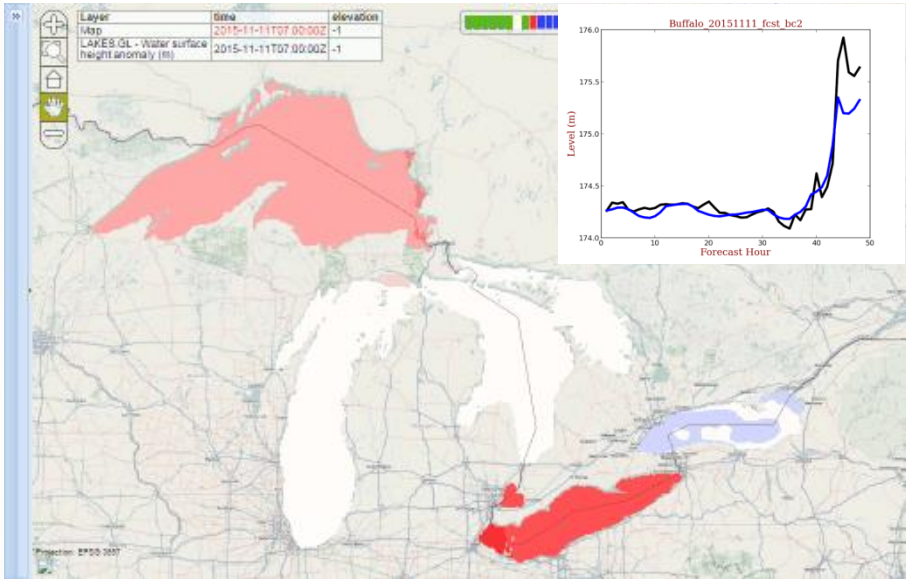
Long-term hydrological forecasts: Any skill in precipitation forecasts?

- Representation of the lakes in the atmospheric models used for seasonal forecasting?
- Precipitation recycling is tricky; with warmer air temperature comes:
  - lower overlake evaporation
  - lower overlake precipitation
  - net P-E impact?
- Would dynamical downscaling (with 3D lake model) help?

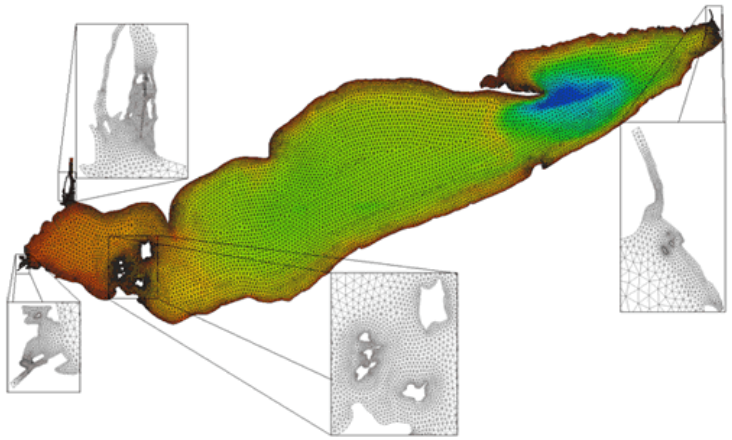


3. Hydrodynamic forecasting: lakes

- NEMO



- FVCOM



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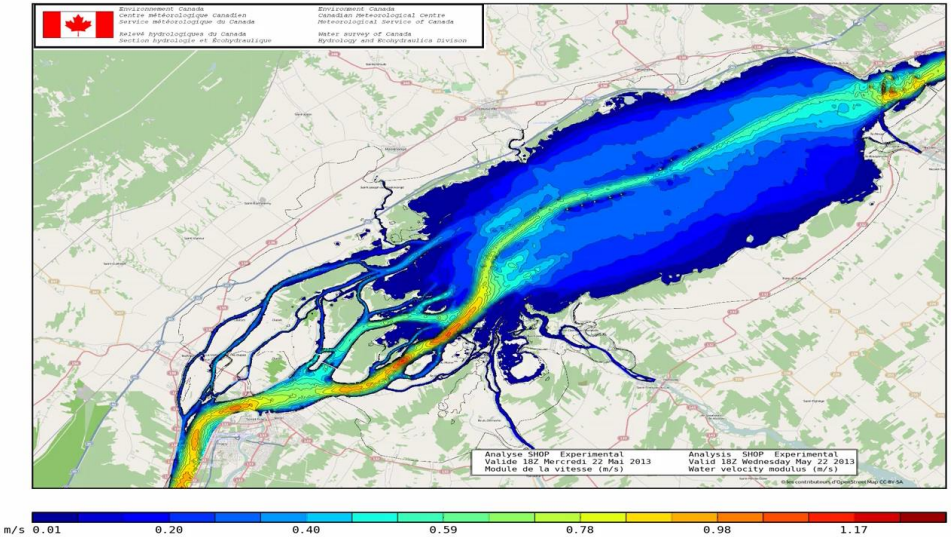
3. Hydrodynamic forecasting: rivers and connecting channels

- H2D2



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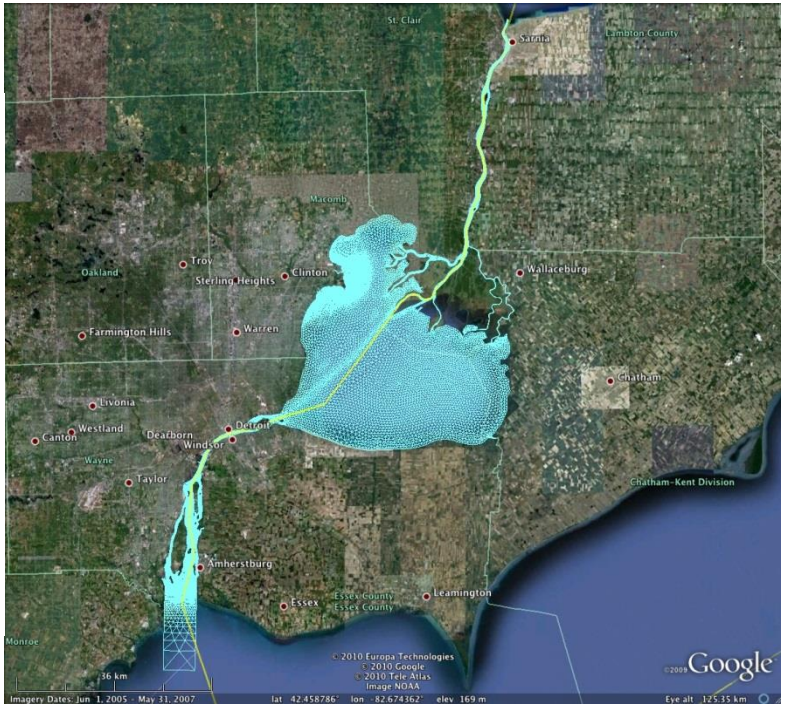

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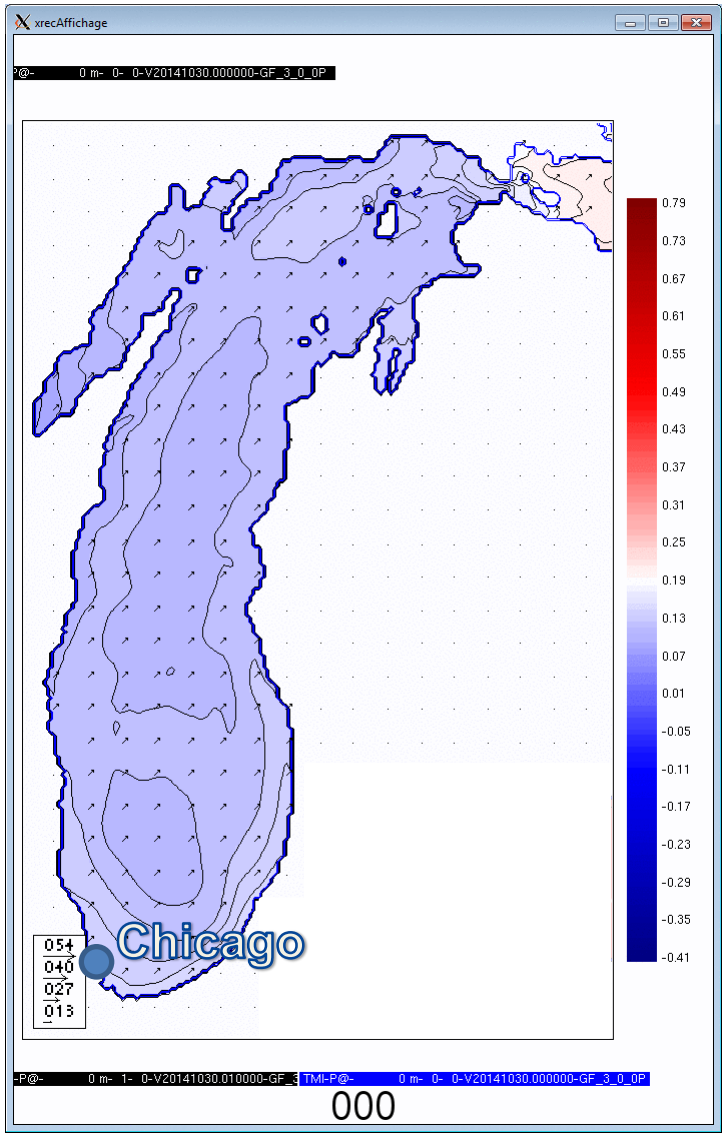
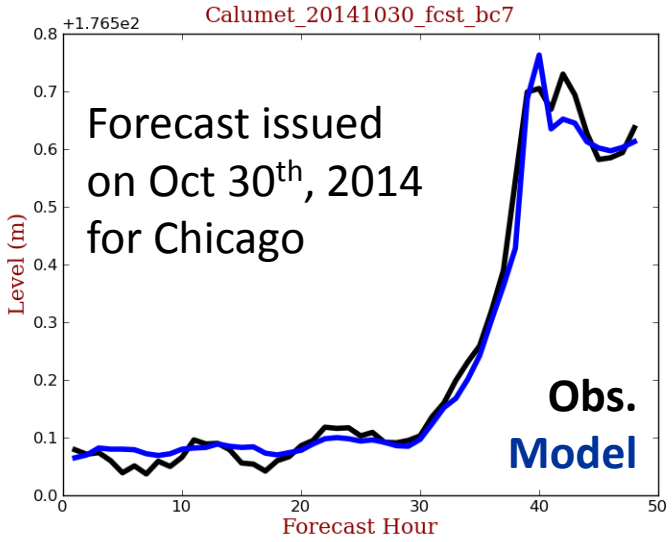
Forecasting storm surges

- 2014 Halloween storm, Chicago

Halloween storm, 2014: NEMO forecast

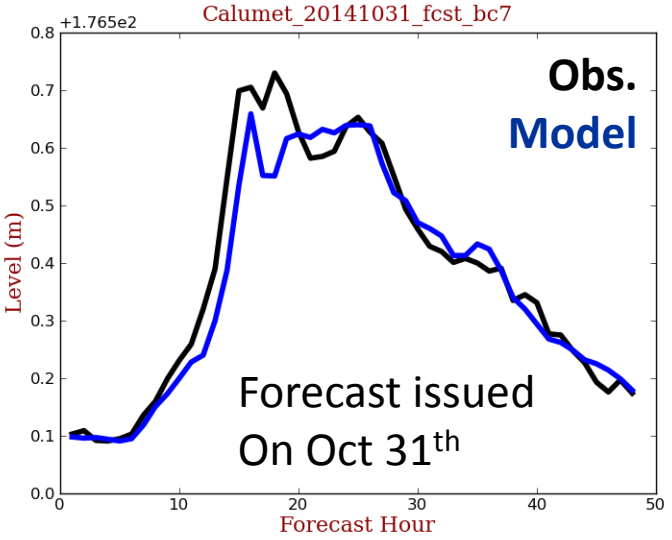


+80 cm
+60 cm
+40 cm
+20 cm



0h 24h 48h

+80 cm
+60 cm
+40 cm
+20 cm



4. Ecological forecasting

An integrated approach to studying HABs

Developing Predictive Models to Improve Coastal and Human Health and Beach Forecasting - HAB Component