Environment Canada Environnement Canada

Canada

Using atmospheric models and land surface schemes for hydrological prediction (hindcasting and forecasting)

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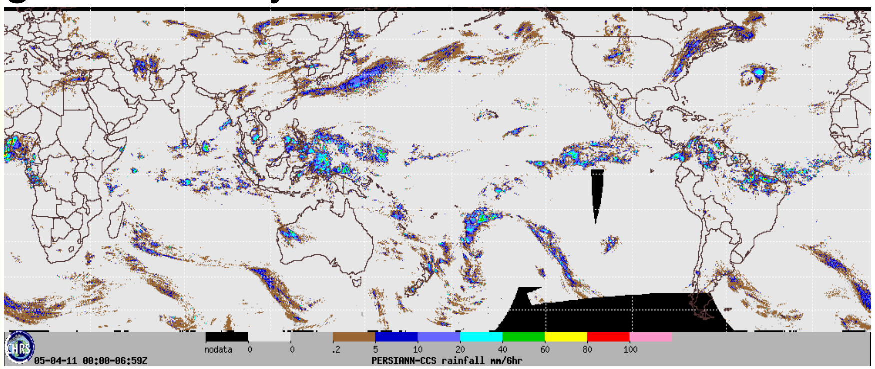
Environnement Canada

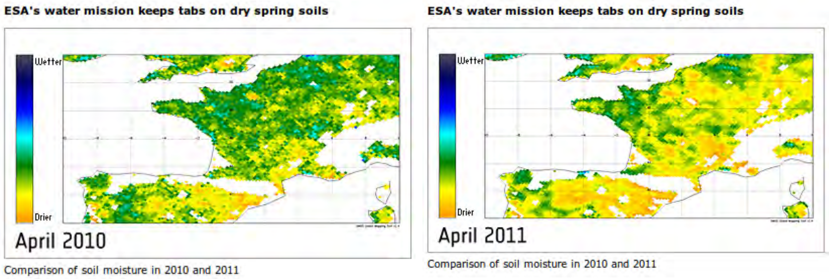
P3: Putting PUB into Practice
May 13, 2011
www.iahs-pub.org/pub2011

There might soon be no such thing as a truly ungauged basin

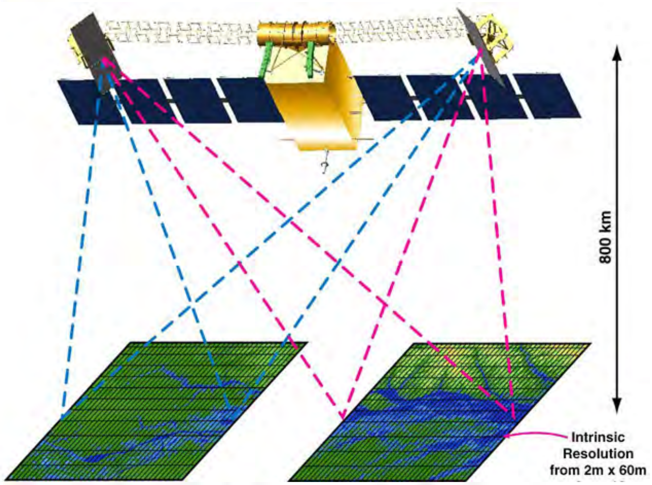
PERSIANN rainfall estimated from geostationary satellites



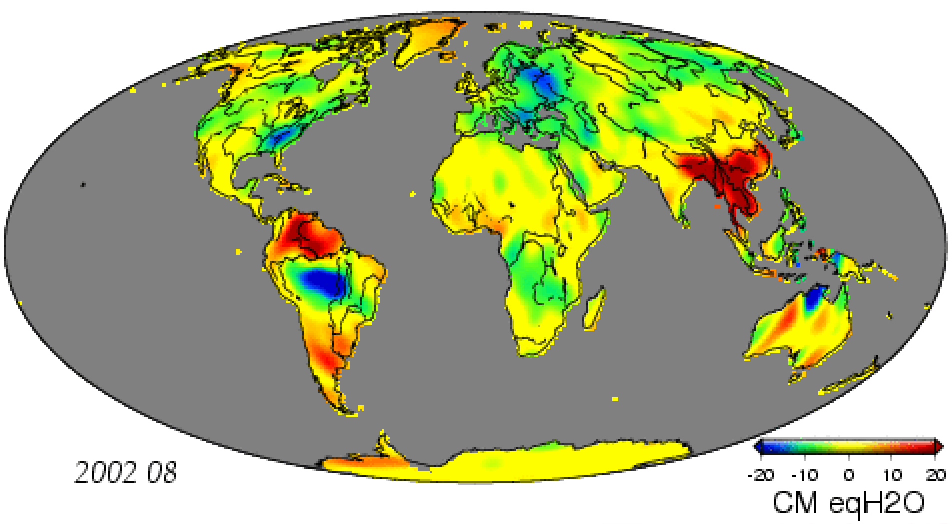
SMOS: surface soil moisture



SWOT altimeter (2020)



Water storage anomalies from GRACE satellite



Modelling the atmosphere over your basin is easier than you think

- Landscape

Saskatchewan

Northern Territories

Toronto

Central Quebec

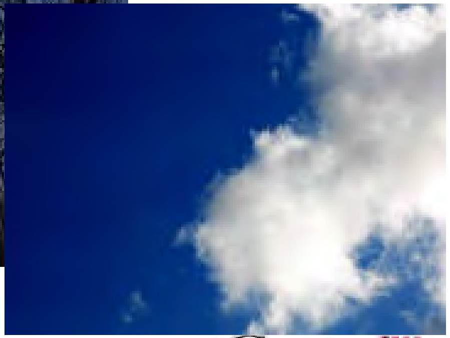
- Atmosphere

Saskatchewan

Northern Territories

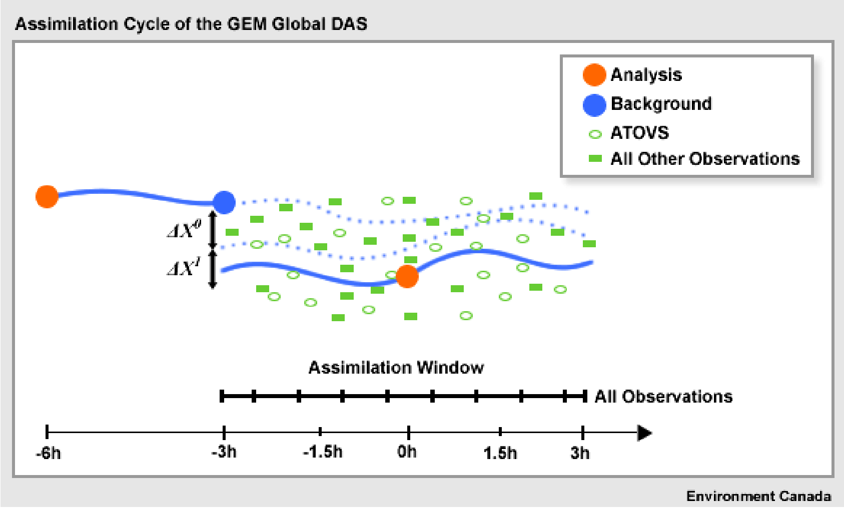
Toronto

Central Quebec



Consider using atmospheric (re-)analysis products for your prediction problems

- Modern data-assimilation systems ingest massive amounts of data on the state of the atmosphere and provide physically-based gridded datasets which can be used for hydrological prediction
- Real-time products with global or regional coverage as well as reanalysis products are available from many atmospheric prediction agencies around the world

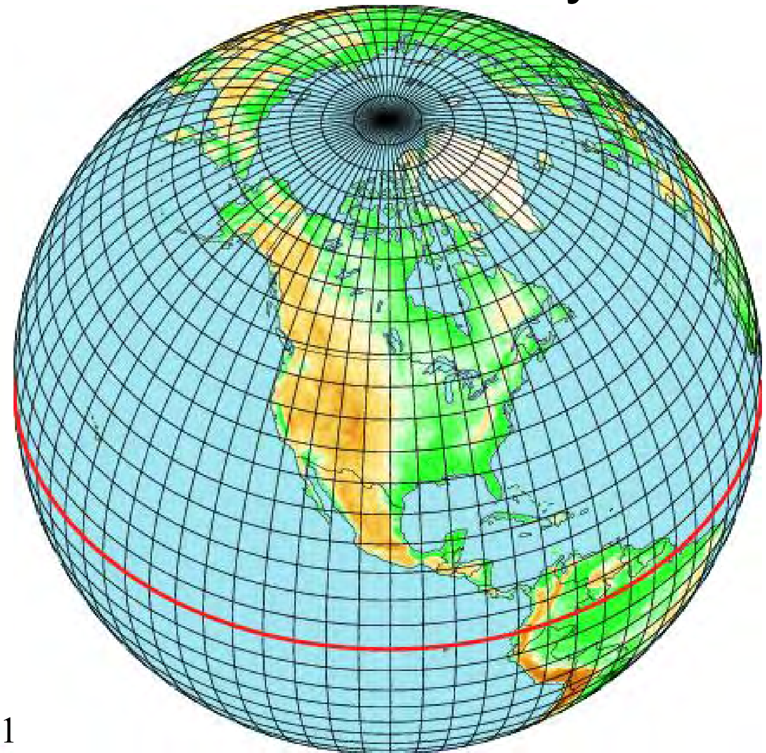


Outline

- EC's Numerical Weather Prediction System based on the **GEM** atmospheric model
- **CaPA**: a near real-time precipitation analysis system
- **MESH**: a framework for surface and hydrology prediction
- Using **GEM**, **CaPA** and **MESH** for predicting changes to water level in the Great Lakes basin
- Accessing **GEM**, **CaPA** and **MESH** (products and code)

Numerical weather prediction: Think globally, predict locally

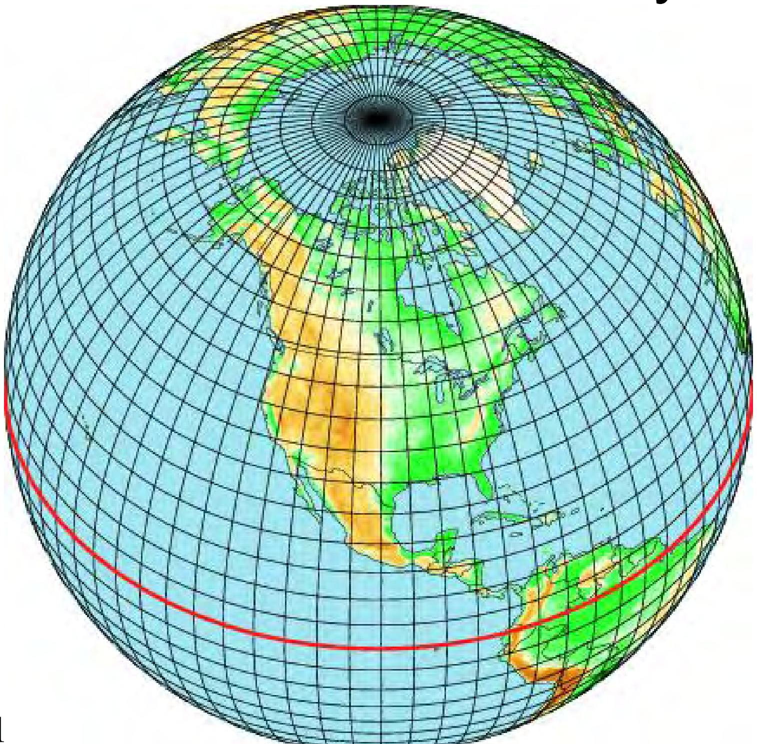
The only (proven) method
to forecast the weather
for more than a few days
is to forecast it everywhere



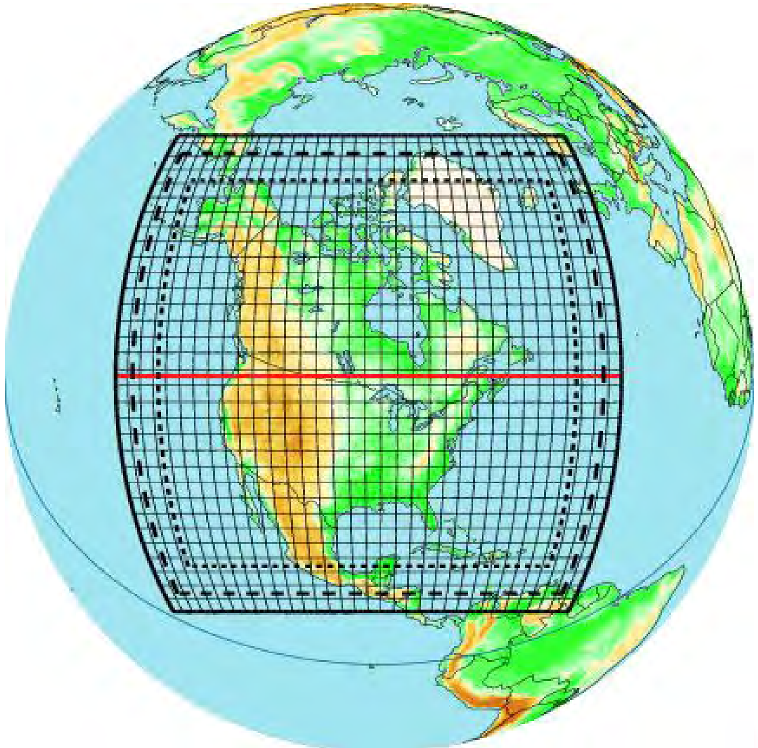
This is done by
running a numerical weather
prediction model (NWP)
from initial conditions
estimated from observations
of the earth's atmosphere,
oceans, and land surface

Numerical weather prediction: Think globally, predict locally

There are limits to what we can afford in terms of horizontal resolution: CMC: 33km for 10 days

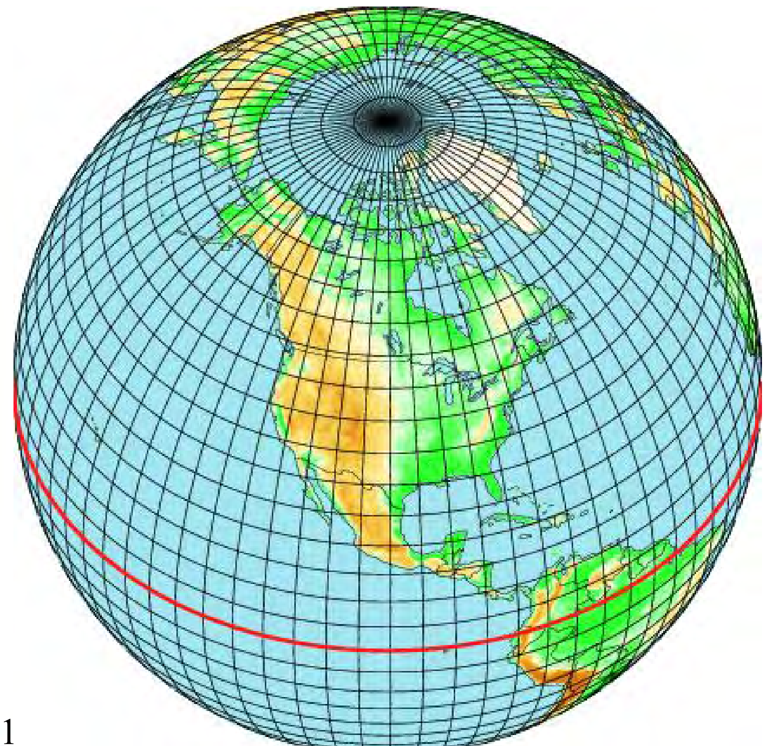


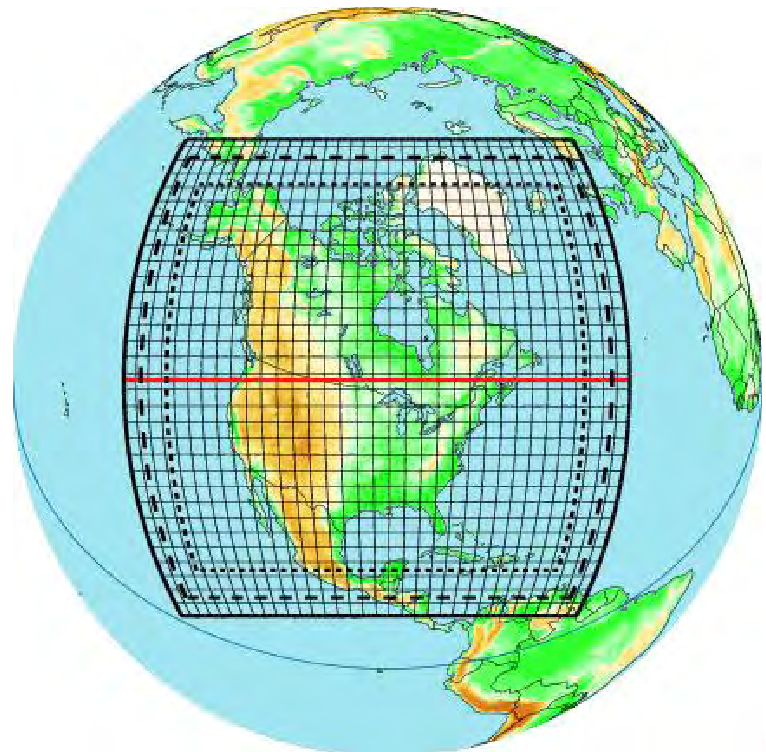
But we can zoom on a region of interest using a limited-area model (LAM)



Numerical weather prediction: Think globally, predict locally

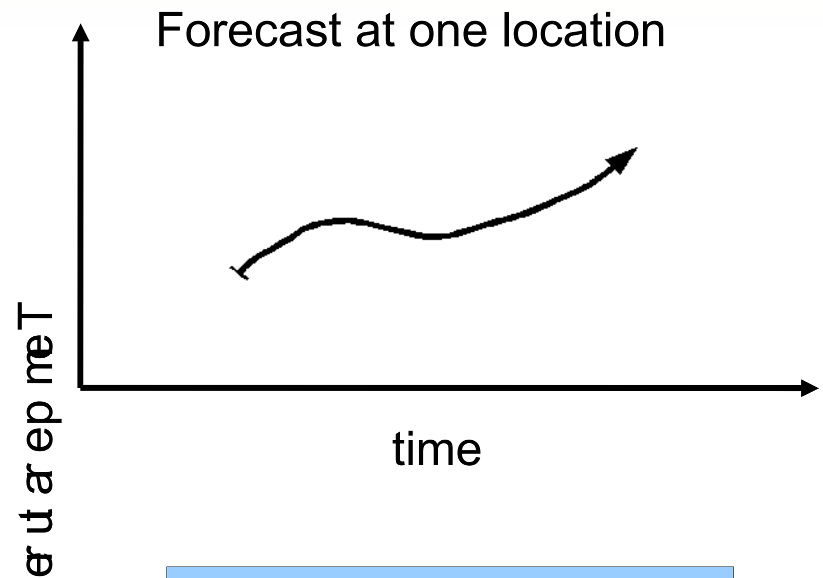
The Global Environmental Multiscale (GEM) model
developed by Environment Canada
is one of the few NWP models which can do both





Deterministic forecasting

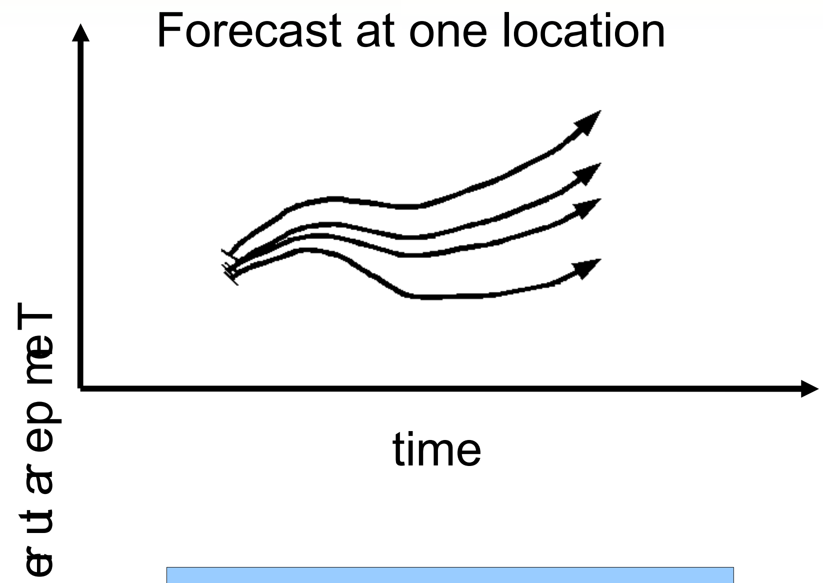
- Single estimate of initial conditions
- Single model
- Single forecast
- That does not mean a perfect forecast:
  - observations are uncertain and coverage is limited
  - numerical models are fairly simple approximations of the actual physical processes
  - computers have limited capacities



Uncertainty
can be estimated
from forecast errors
(a posteriori)

Ensemble forecasting

- Multiple
  - initial conditions
  - numerical models
  - weather forecasts
- Ensemble forecasting aims to represent uncertainty dynamically
- Differences in forecasts should reflect uncertainty
  - in our estimates of initial conditions
  - in the limitations of our numerical models



Uncertainty
can be estimated
from divergence
of forecasts (a priori)

Environment Canada's Deterministic forecasting systems

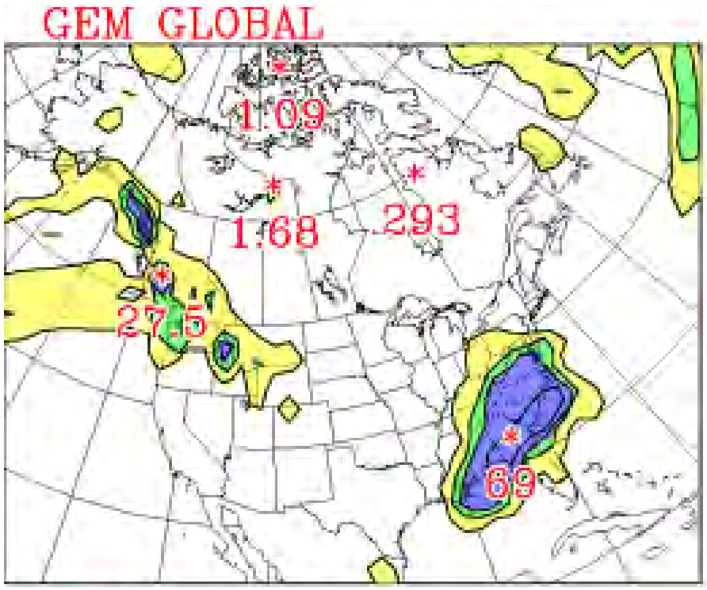
- Global Deterministic Prediction System (GDPS)
  - 10 days, 33 km horizontal resolution at mid latitudes
  - 2 runs per day
- Regional Deterministic Prediction System (RDPS)
  - North America (Canada + US + Mexico)
  - 2 days, 15 km horizontal resolution
  - 4 runs per day
- High-Resolution Deterministic Prediction System (HRDPS)
  - 1 day, 2.5 km horizontal resolution on smaller domains
  - 1 run per day
  - Currently: Quebec-Windsor corridor, Southern BC, Atlantic, Arctic
  - System can easily be run anywhere within the RDPS domain, and at higher resolutions given adequate computing power

Environment Canada's Ensemble forecasting systems

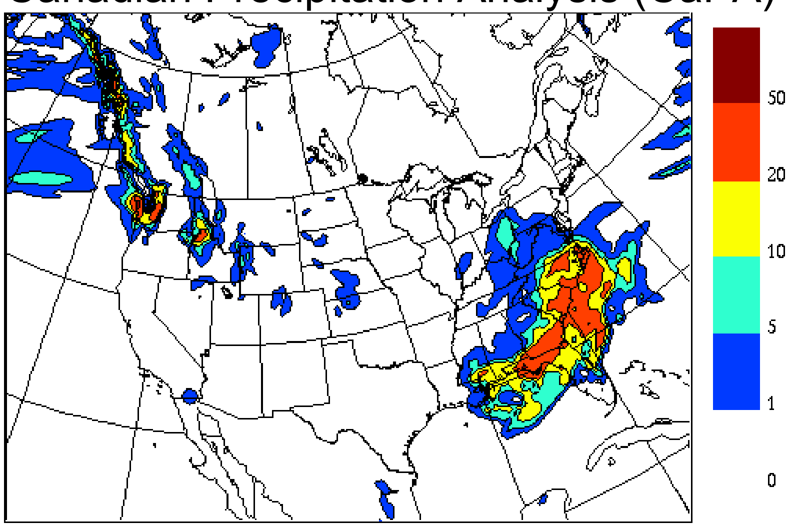
- Global Ensemble Prediction System (GEPS)
  - 15 days, 100 km horizontal resolution (soon 60 km)
  - 20 members in order to represent uncertainty in initial conditions and in GEM's physical parameterizations
  - 2 runs per day
  - Every ten days a 30-day forecast is made (experimental)

- Regional Ensemble Prediction System (REPS)
  - North America (Canada + US + Mexico)
  - 3 days, 15 km horizontal resolution
  - 20 members
  - 2 runs per day

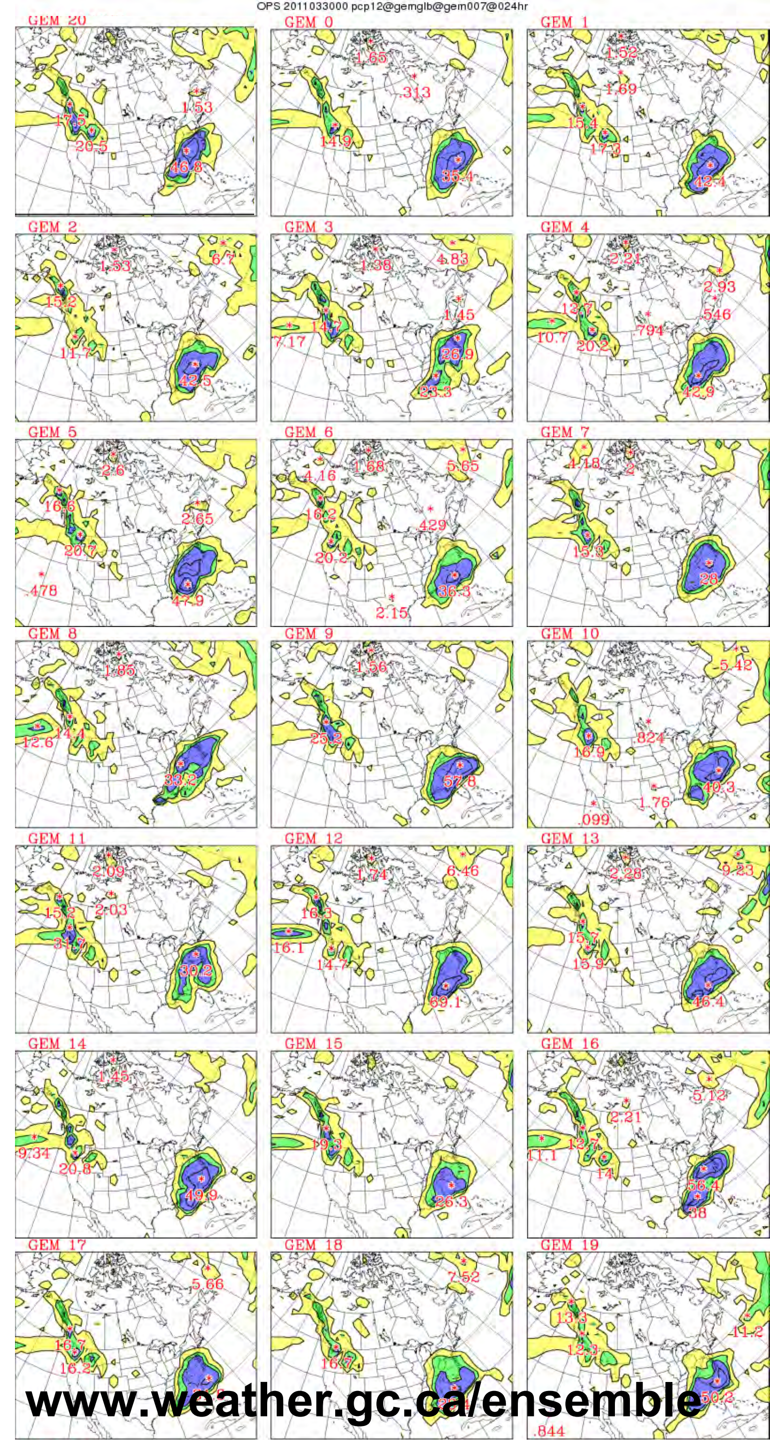
12h precipitation accumulation
24h forecast valid on Mar 31, 2011 00 UTC



Verification:
Canadian Precipitation Analysis (CaPA)



Analyse valide 00:00Z le 31 mars 2011



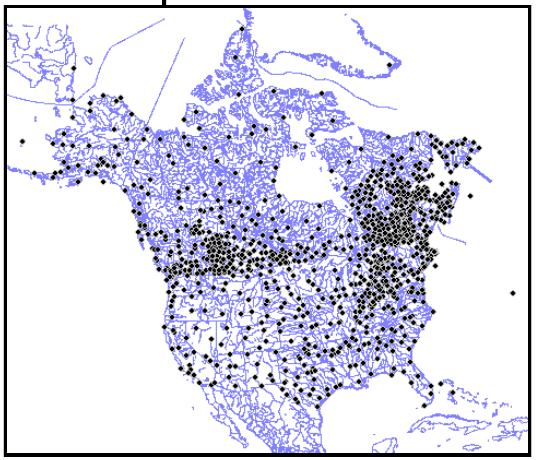
www.weather.gc.ca/ensemble

Forecasts of the past are almost as useful as forecasts of the future!

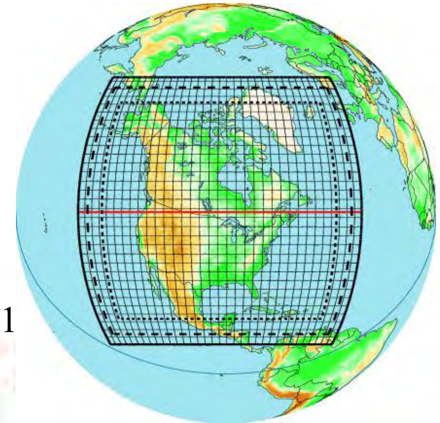
- Environment Canada keeps outputs from its operational forecasting system for five years
- They provide a consistent estimate of the state of the atmosphere and of the land-surface
- Past forecasts can be combined with existing observations to obtain a better estimate than either forecasts or observations alone (data assimilation)
- The Canadian Precipitation Analysis (CaPA) is a simple example of what data assimilation can do in data-sparse regions for estimating precipitation in near real-time

CaPA: operational configuration

Precipitation network



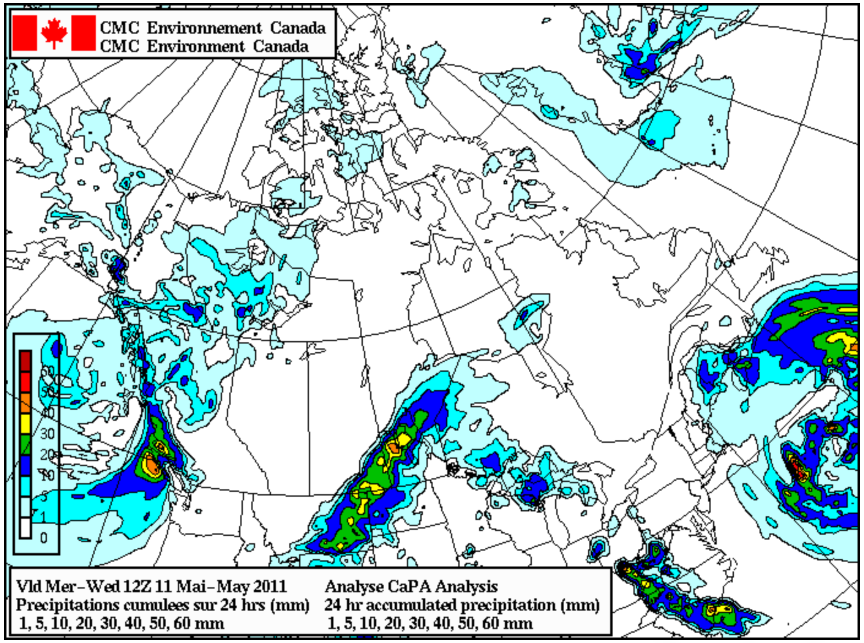
Short-term precip. forecast (6-12h), GEM model (RDPS)



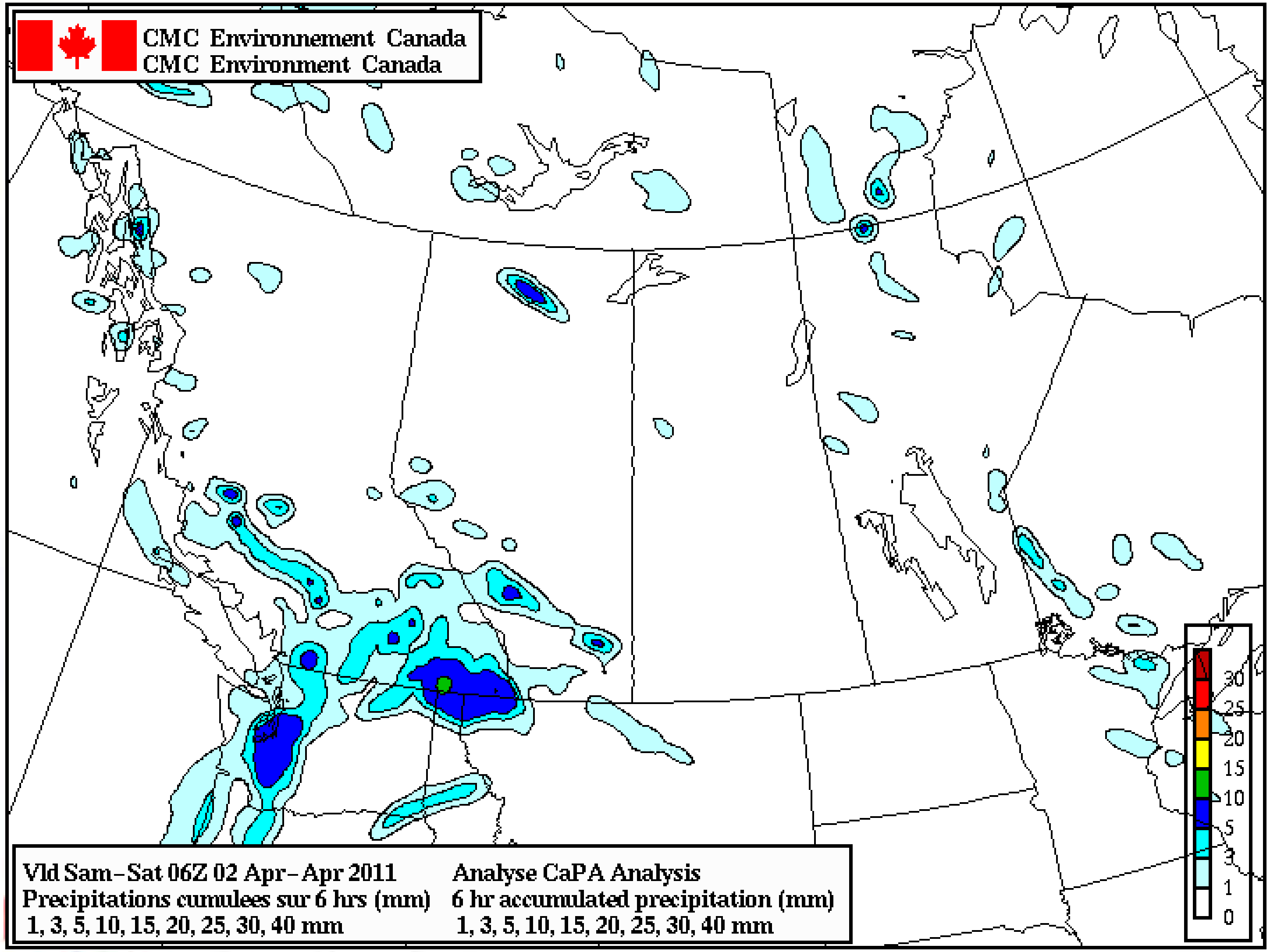
Analysis valid at 12Z, 12 May 2011 combining observations with GEM model

24h accumulation shown here

6h and 24h accum. available



Precipitation as seen by CaPA: April 2nd - 3rd, 2011



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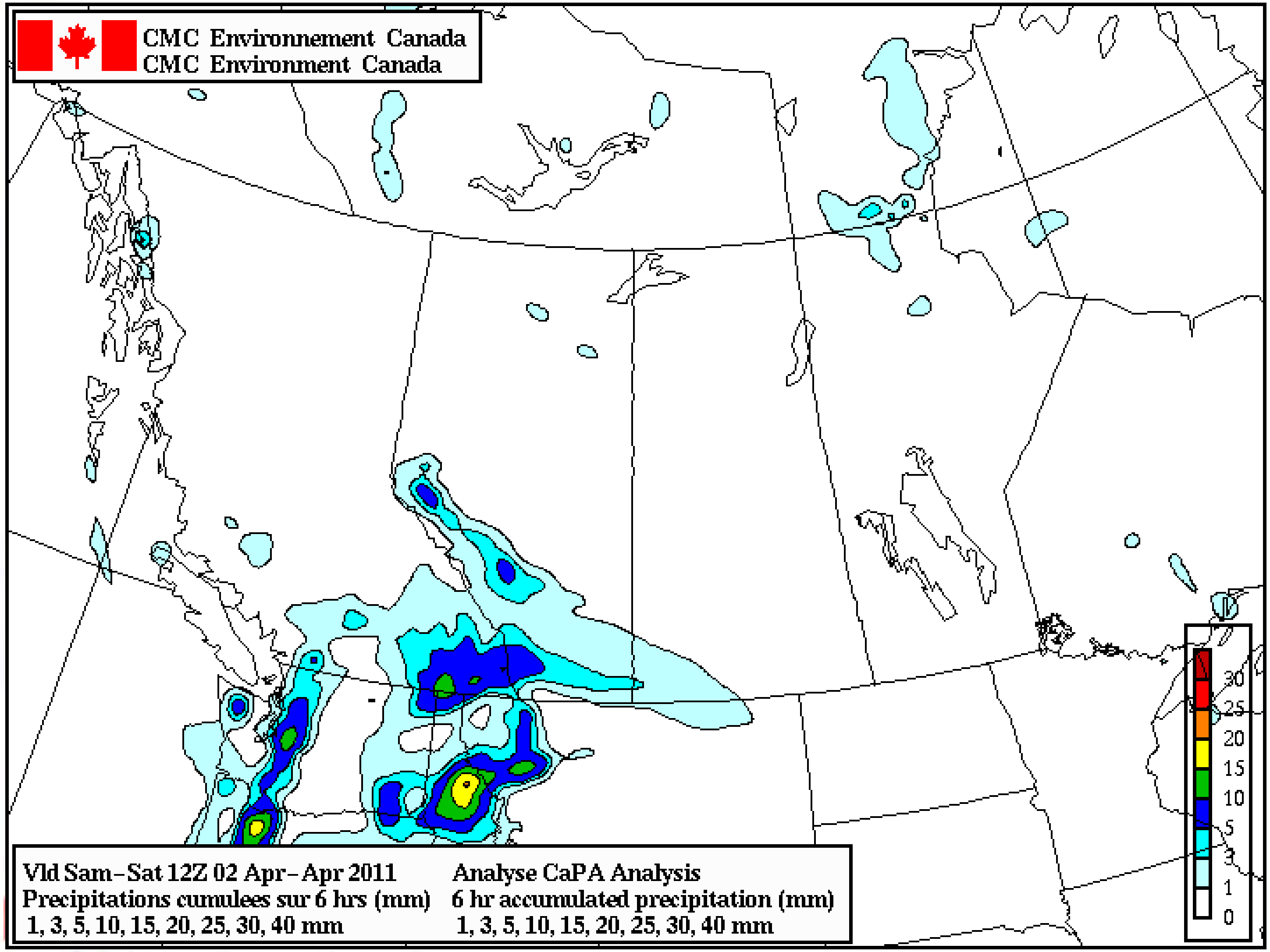

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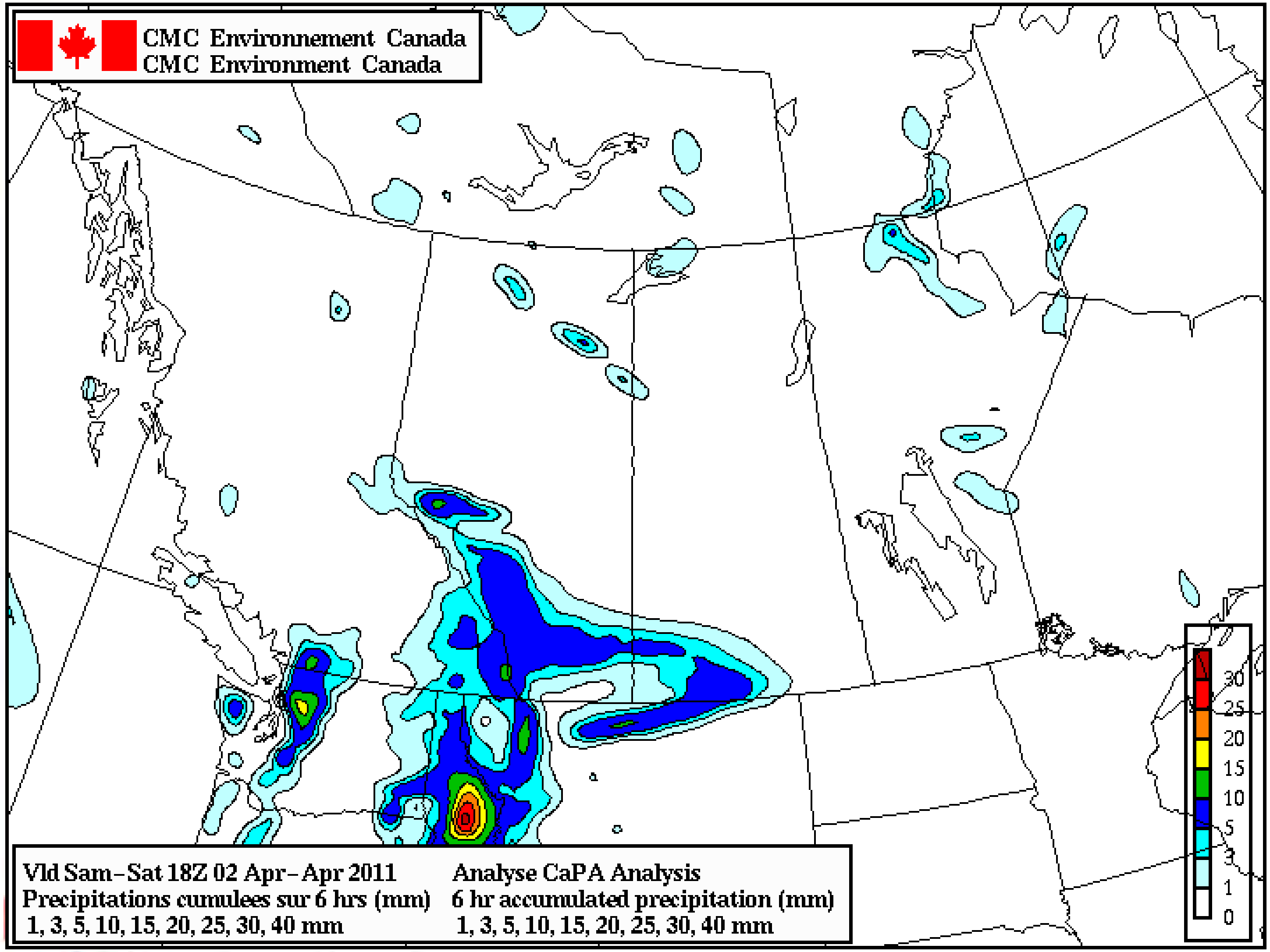

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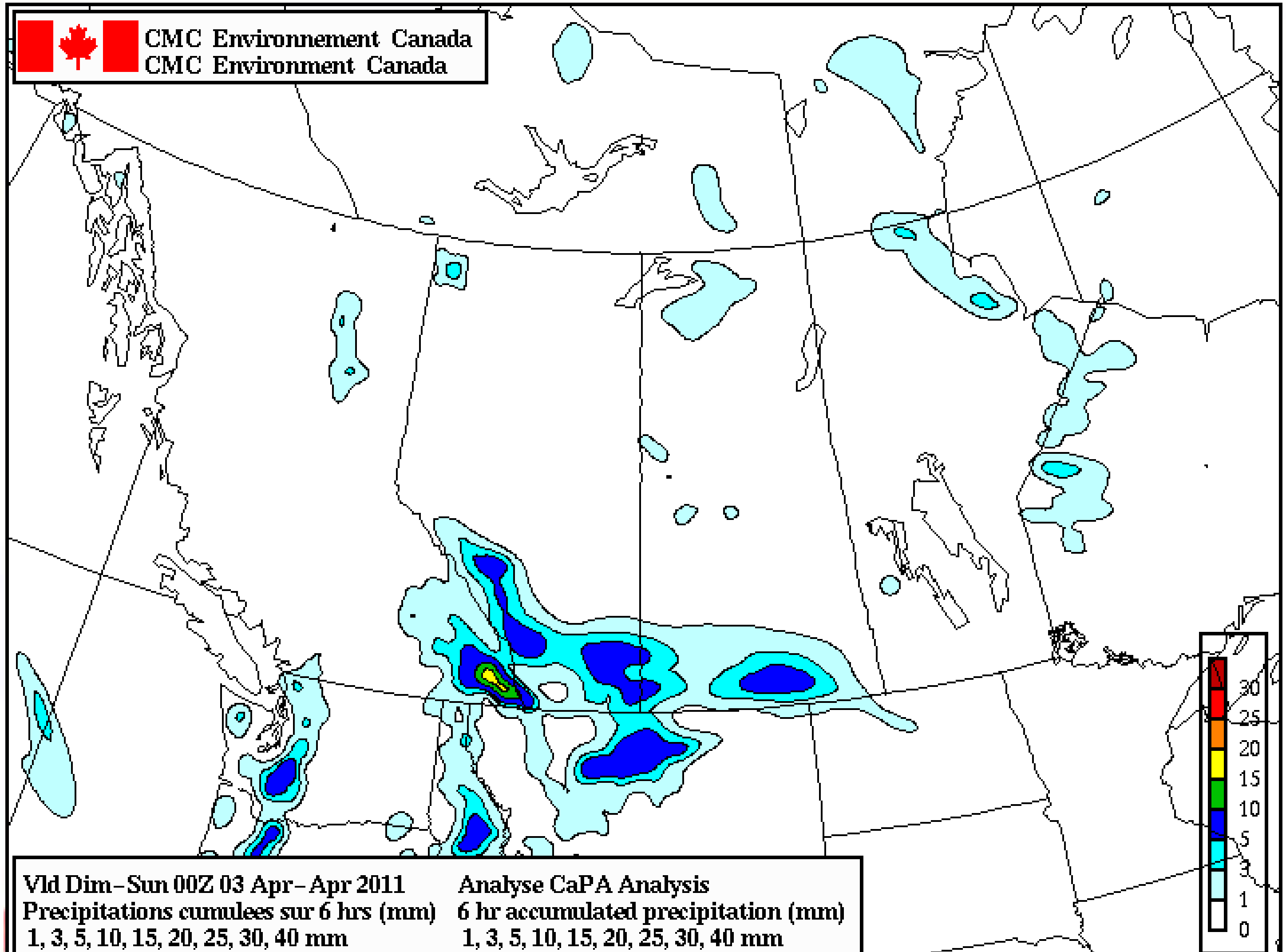

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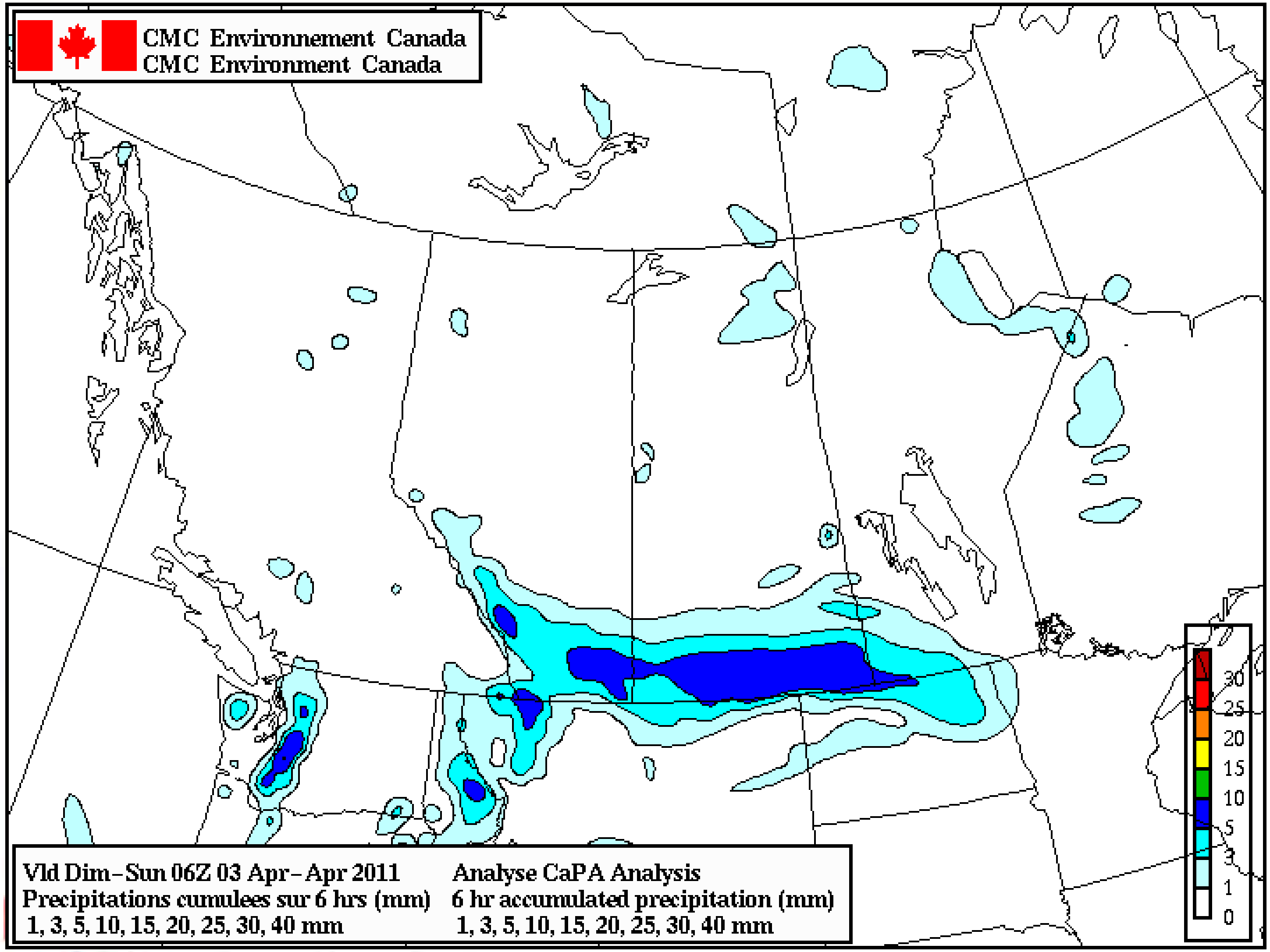

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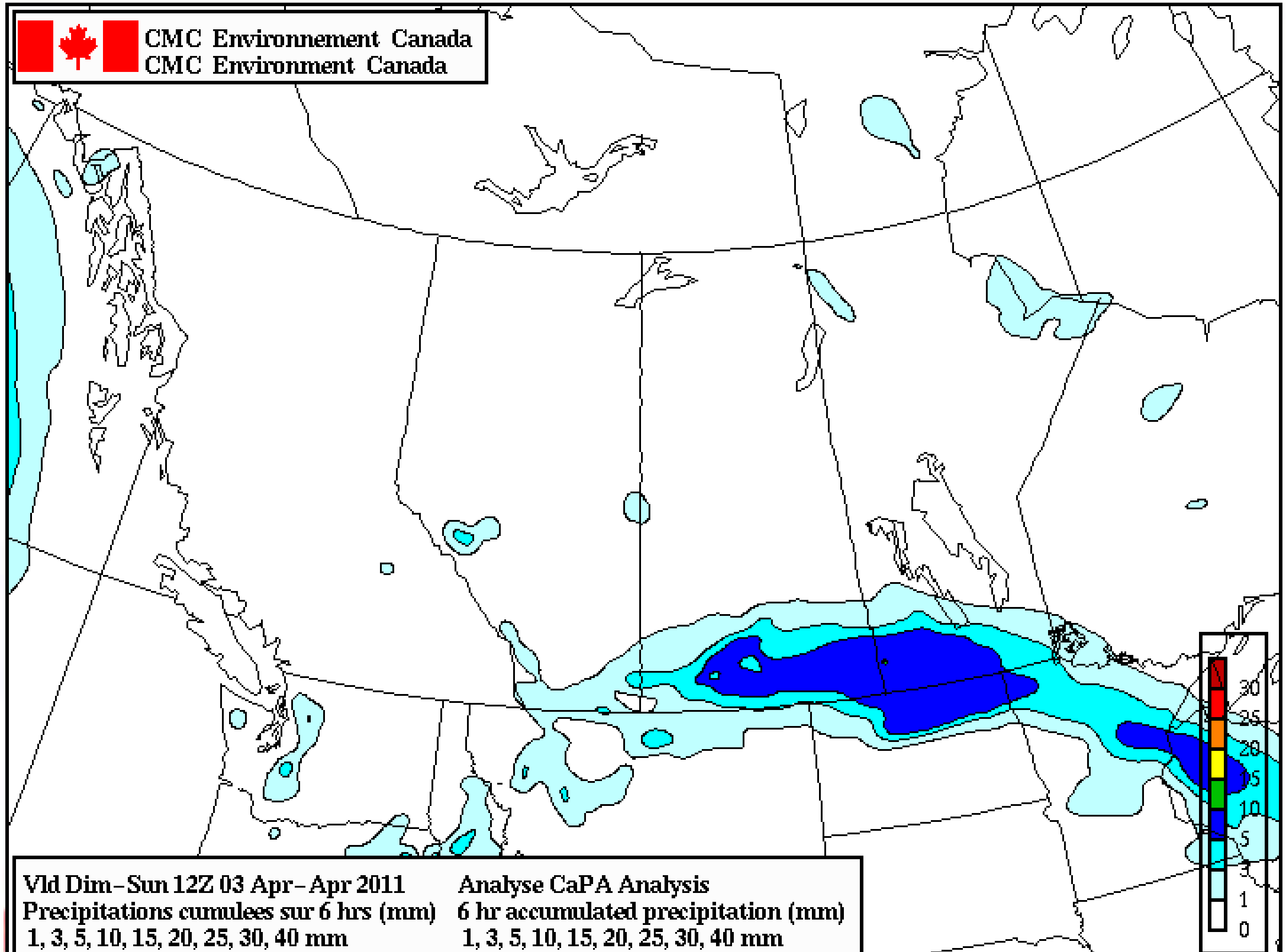

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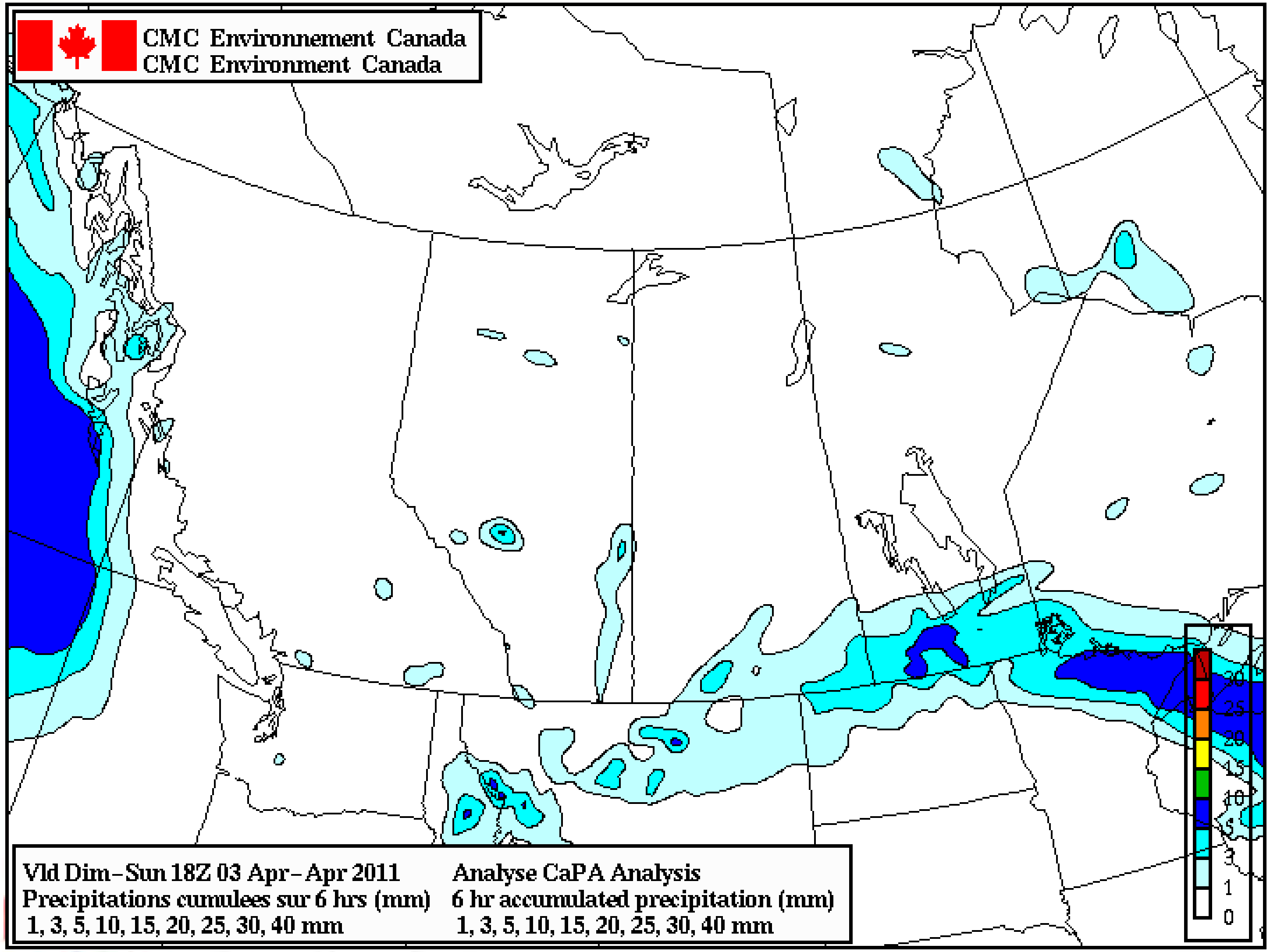

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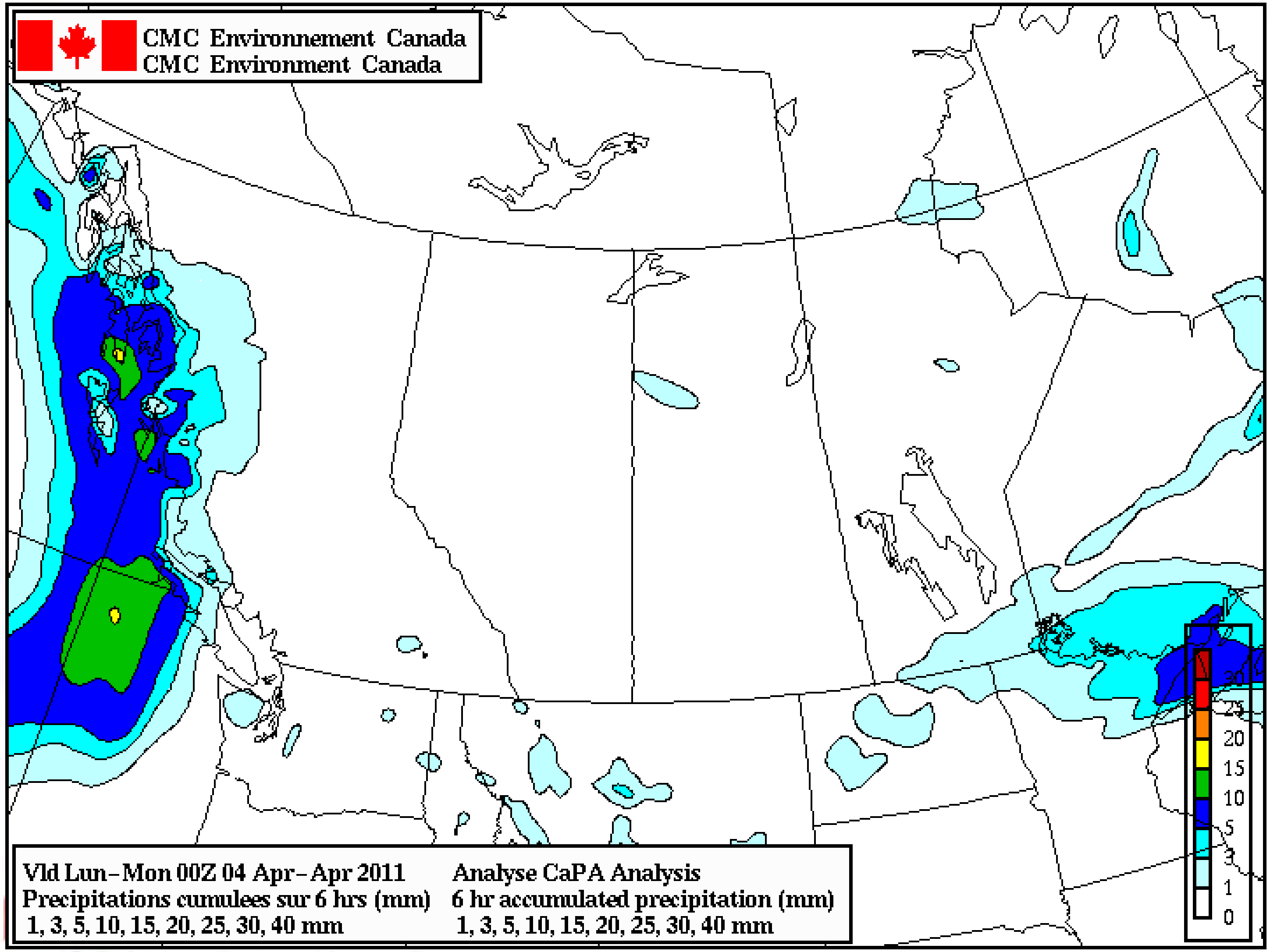

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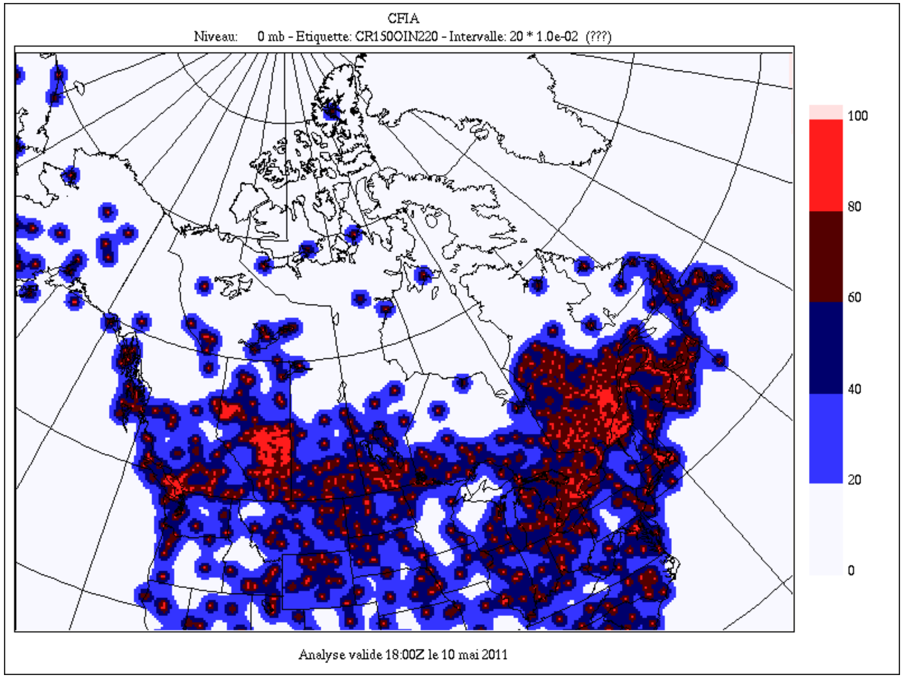
Skill, bias and uncertainty in CaPA products

- Verifications against gauges are made through data-denial experiments
- Strict quality control for solid precipitation
  - bias correction algorithms currently being tested
  - for now we end up rejecting most automatic gauges in winter
- Confidence index based on kriging variance provided

CFIA, 2011-05-10 18Z

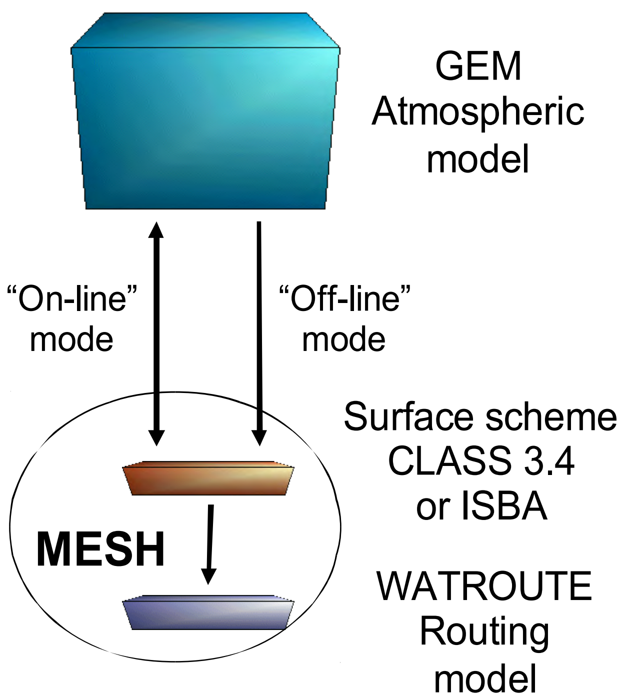


MESH

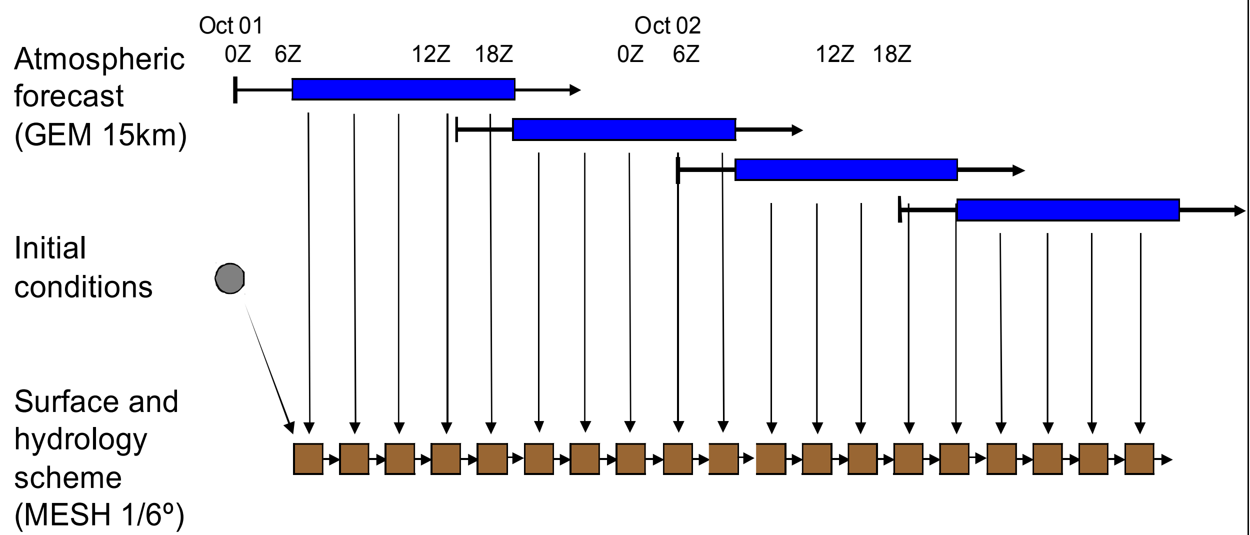
Modélisation Environnementale Couplée : Surface et Hydrologie
Coupled Environmental Modelling: Surface and Hydrology

Land surface models provide surface runoff and groundwater recharge, and include a parameterization for lateral flow along hillslope
Routing model includes surface runoff routing, river routing and baseflow estimation

Hydrological forecasting with MESH

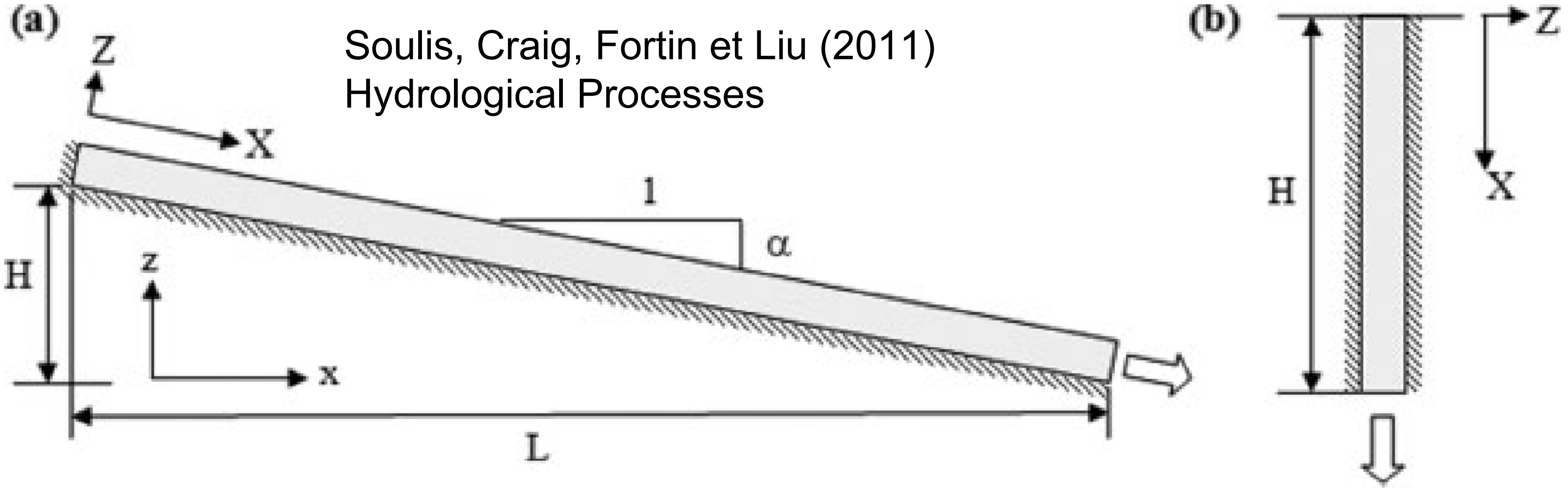


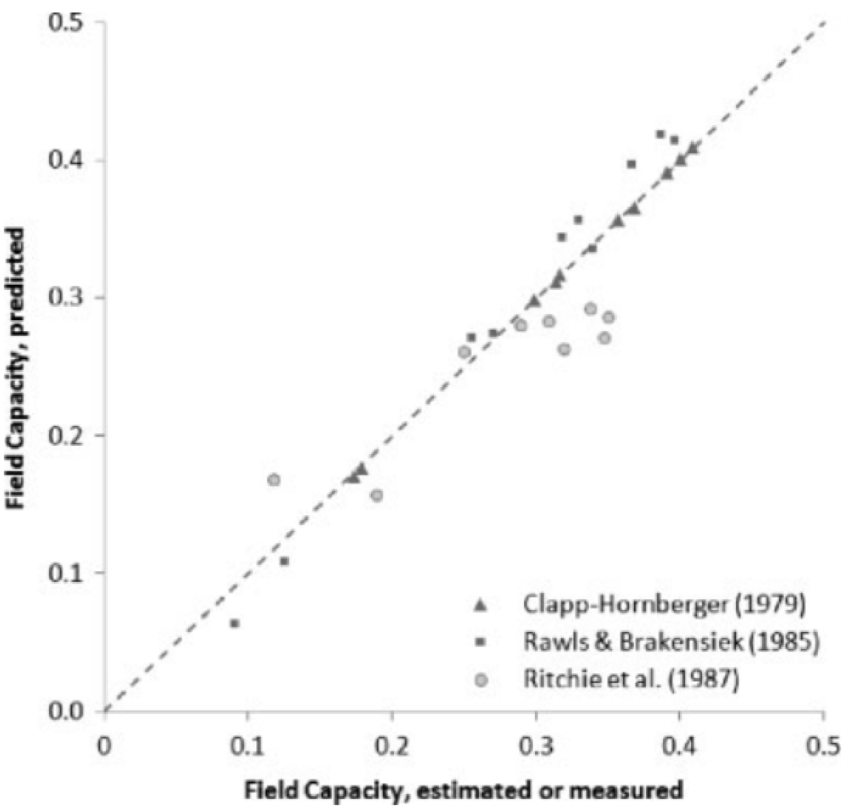
Offline mode: forcing with short-term forecasts (with precipitation forecast replaced by an analysis)

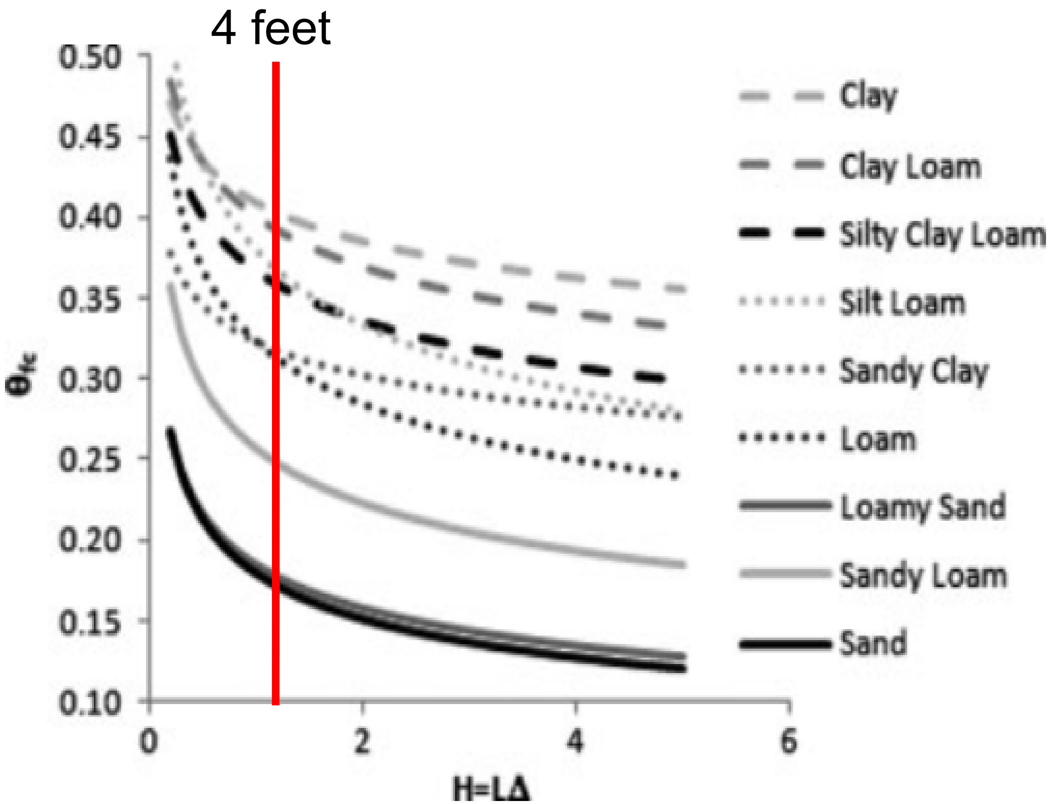


Community model, source code available upon request

Soulis, Craig, Fortin et Liu (2011)
Hydrological Processes



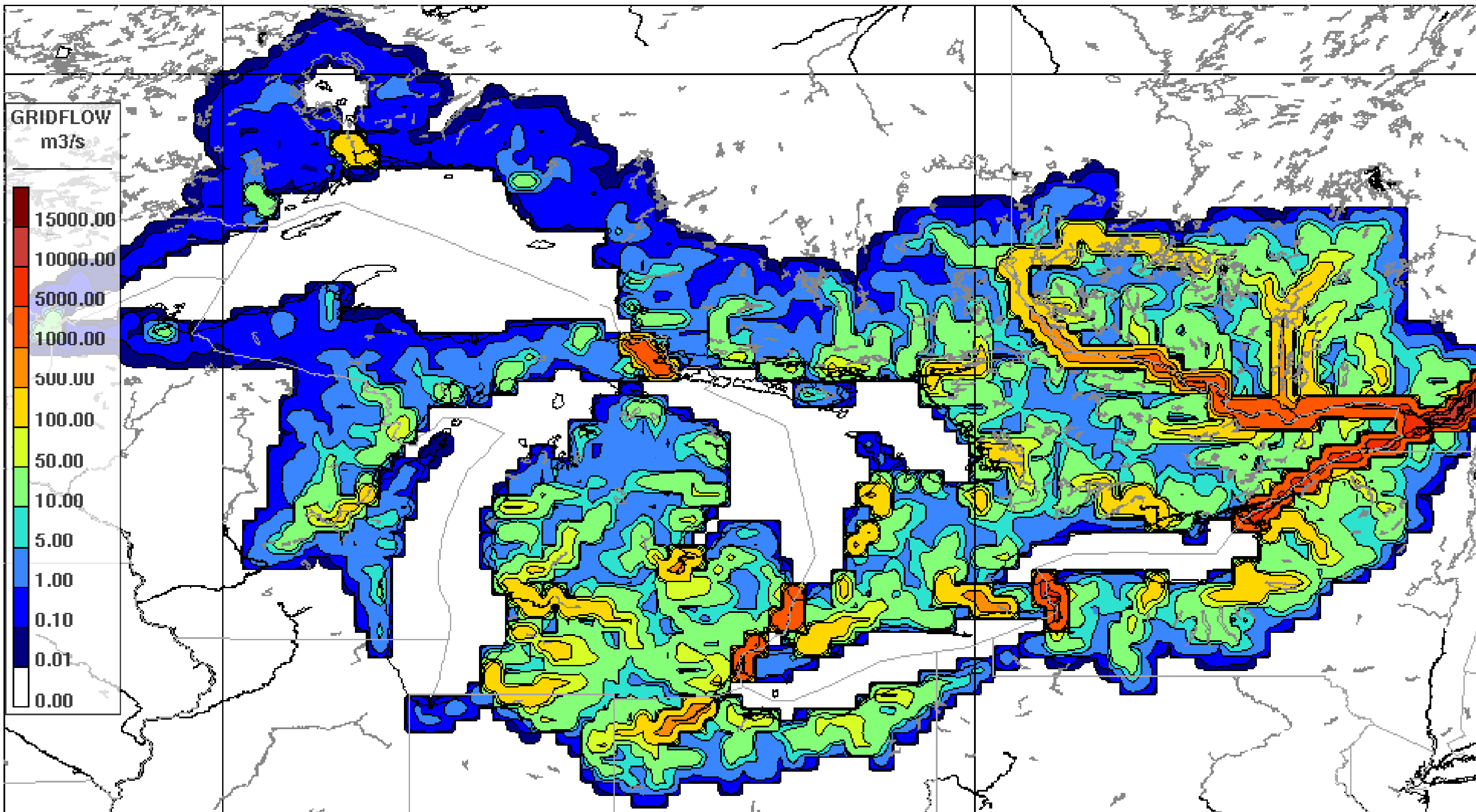




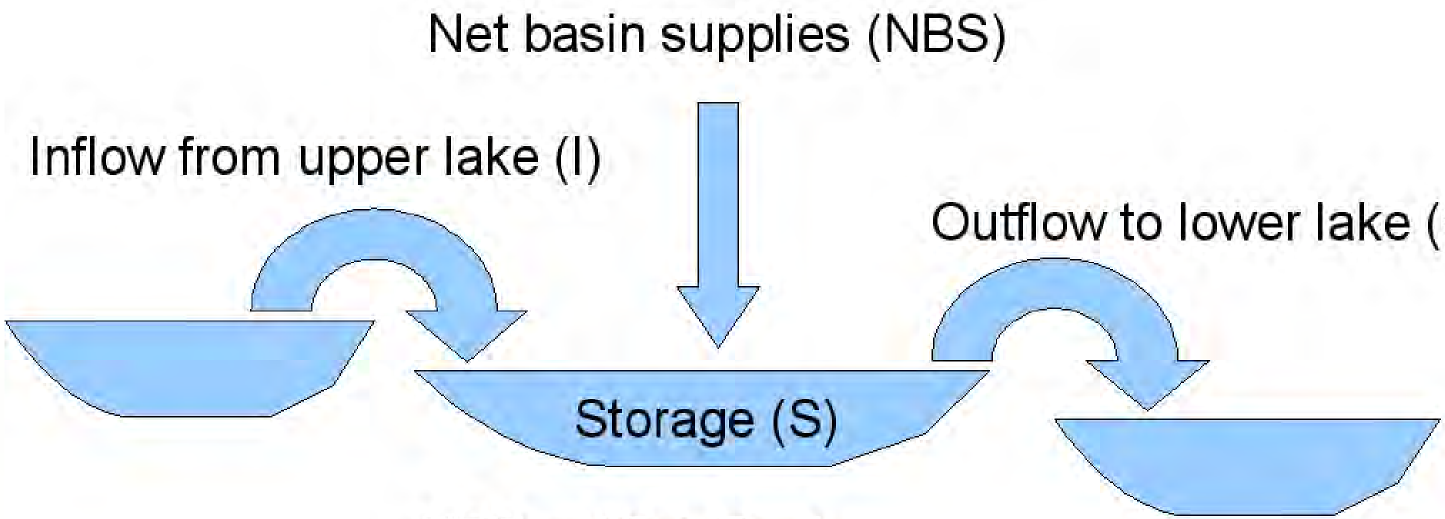
Using MESH on the Great Lakes to predict net basin supply

Environment Canada Environnement Canada

Grid cell size: ~ 225 km²
Land surface scheme: ISBA



Net basin supplies: component vs residual method



Residual $NBS = \Delta S + O - I$

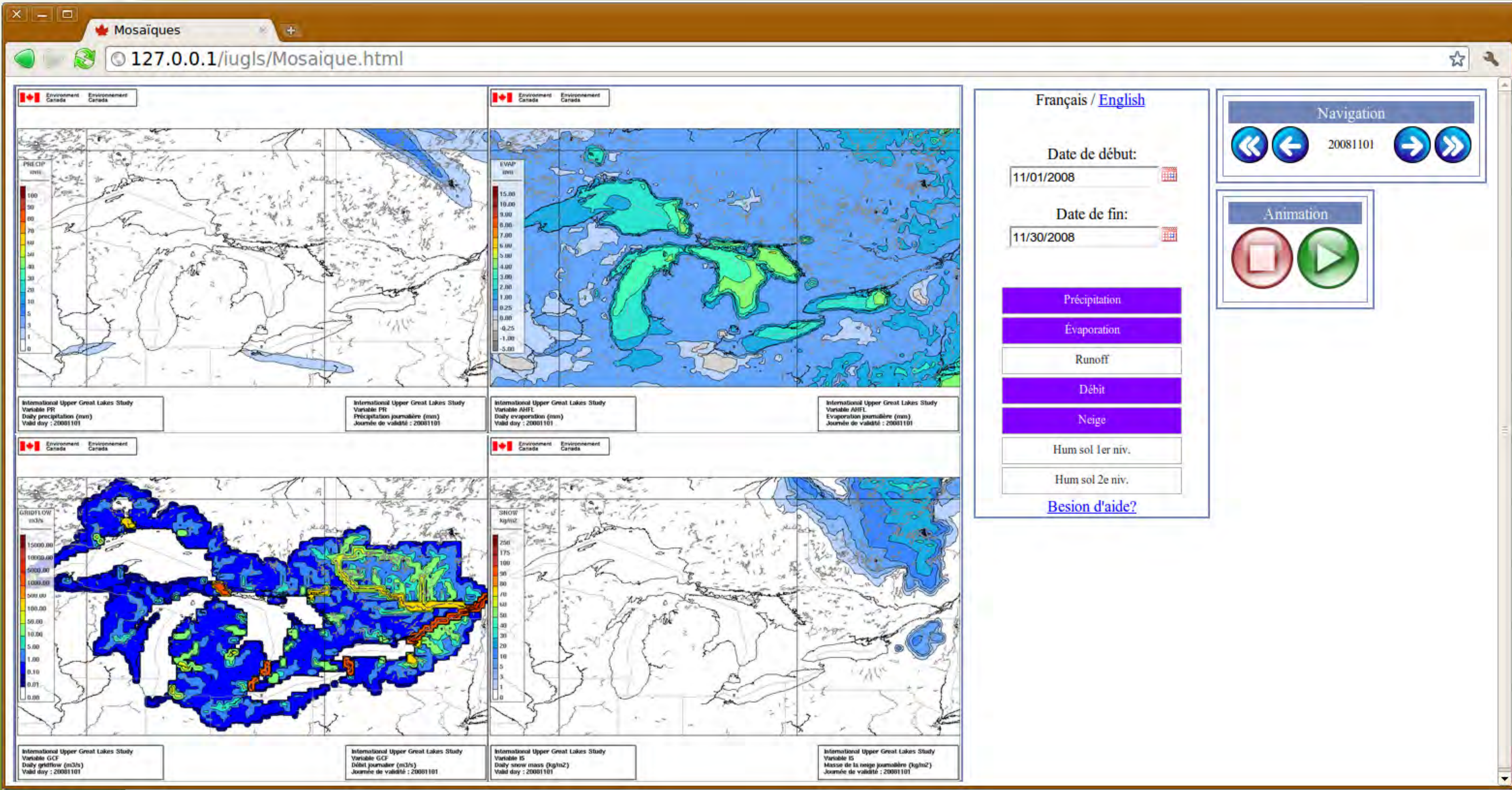
Component $NBS = P_{Lake} - E_{Lake} + R_{Basin}$

Component NBS makes it possible to gain understanding as to why lake levels, are changing and (eventually) forecast these changes.

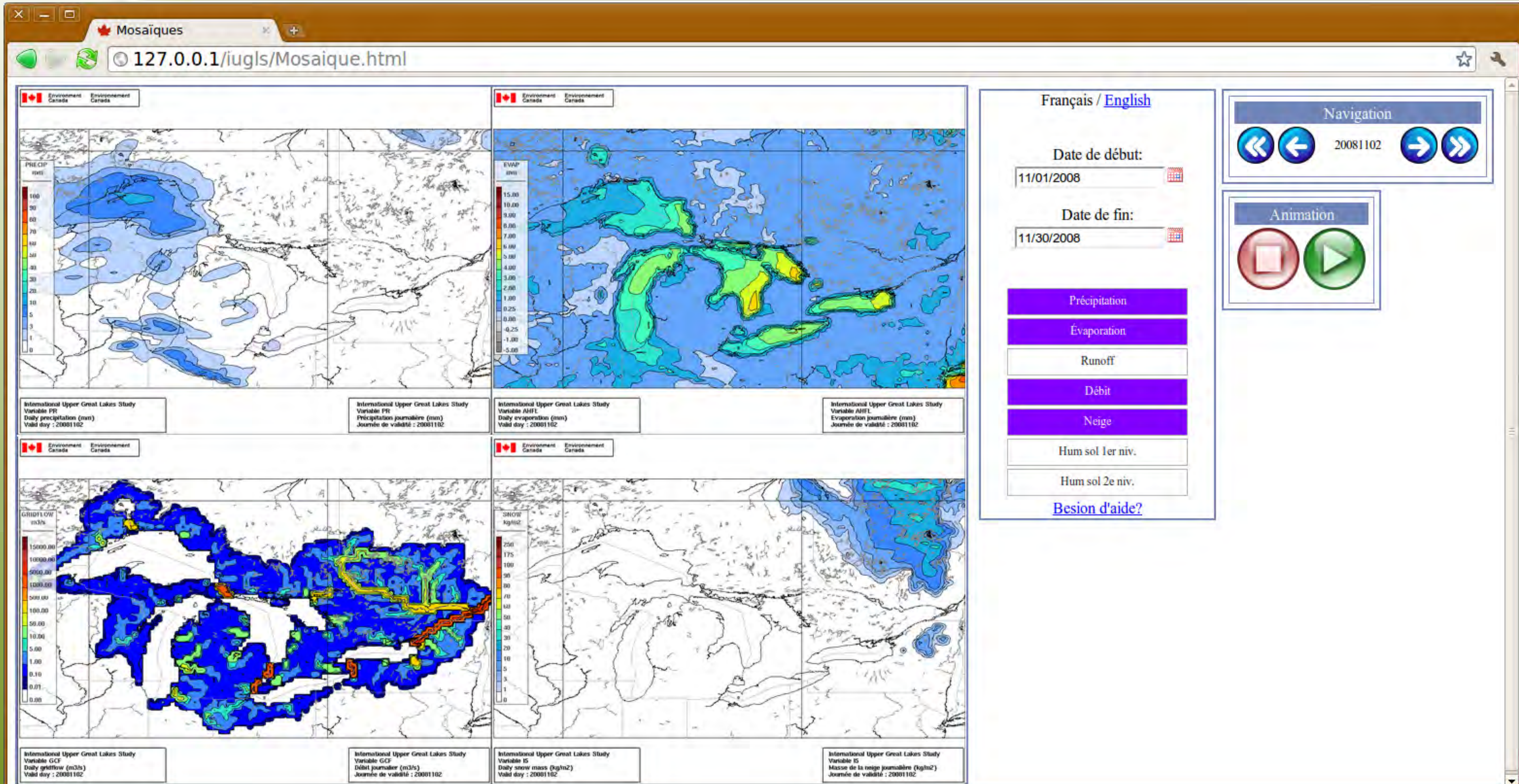
Objectives of the project

- Build a gridded dataset covering a 5-year period (June 2004 to May 2009) describing the spatial and temporal evolution of the watershed
  - contribute to explaining why lake levels dropped
- Assess whether it is possible using GEM and MESH to close the water balance of the Great Lakes on a monthly time scale, given the uncertainty in each term of the water balance
  - build confidence in the residual method for estimating NBS
  - compare components (especially P and E) to estimates from other sources (in particular GLERL)
- Assess whether it is possible using GEM and MESH to forecast net basin supplies

MESH - the movie: November 1-20, 2008



MESH - the movie:
November 1-20, 2008



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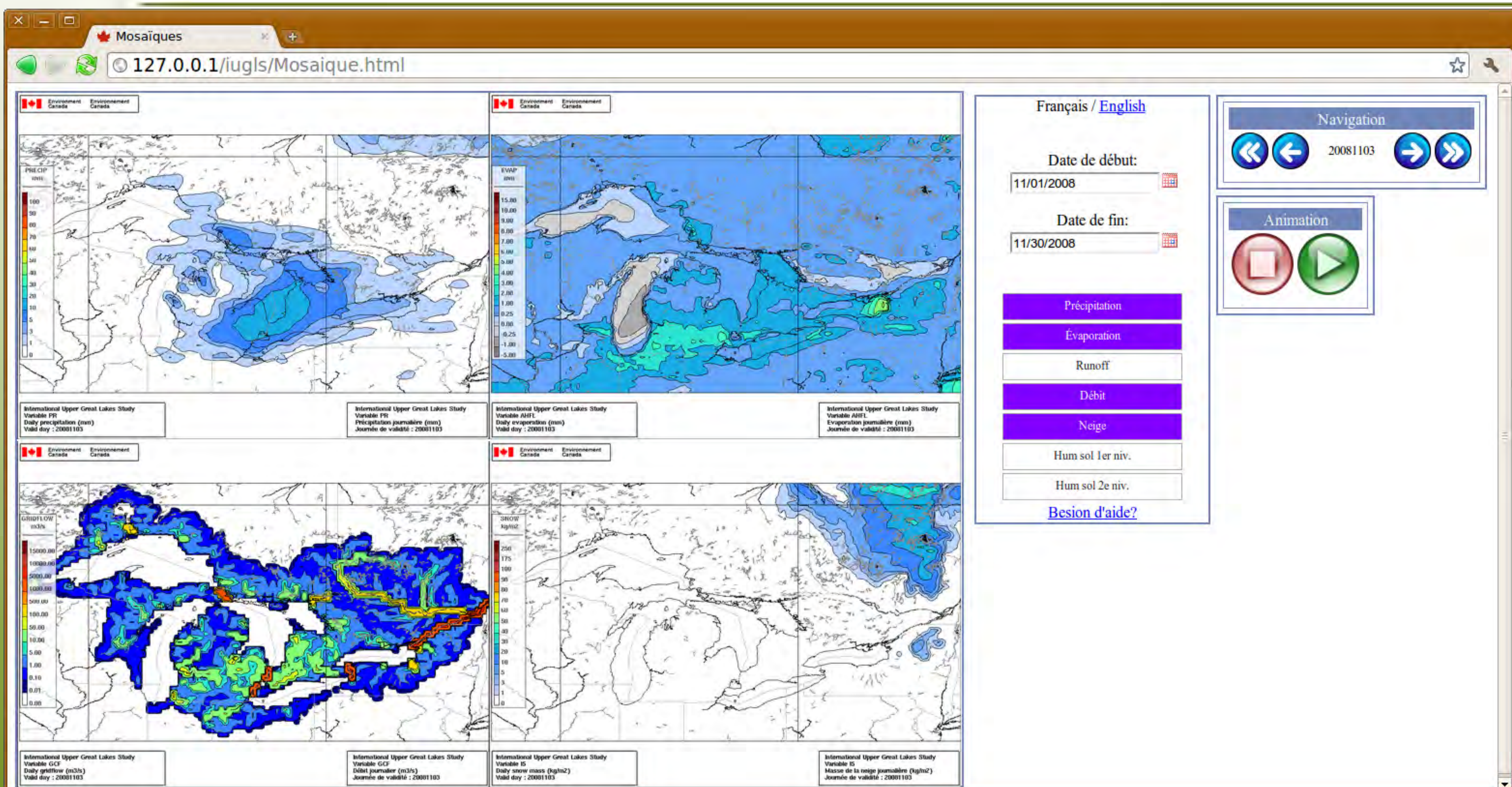

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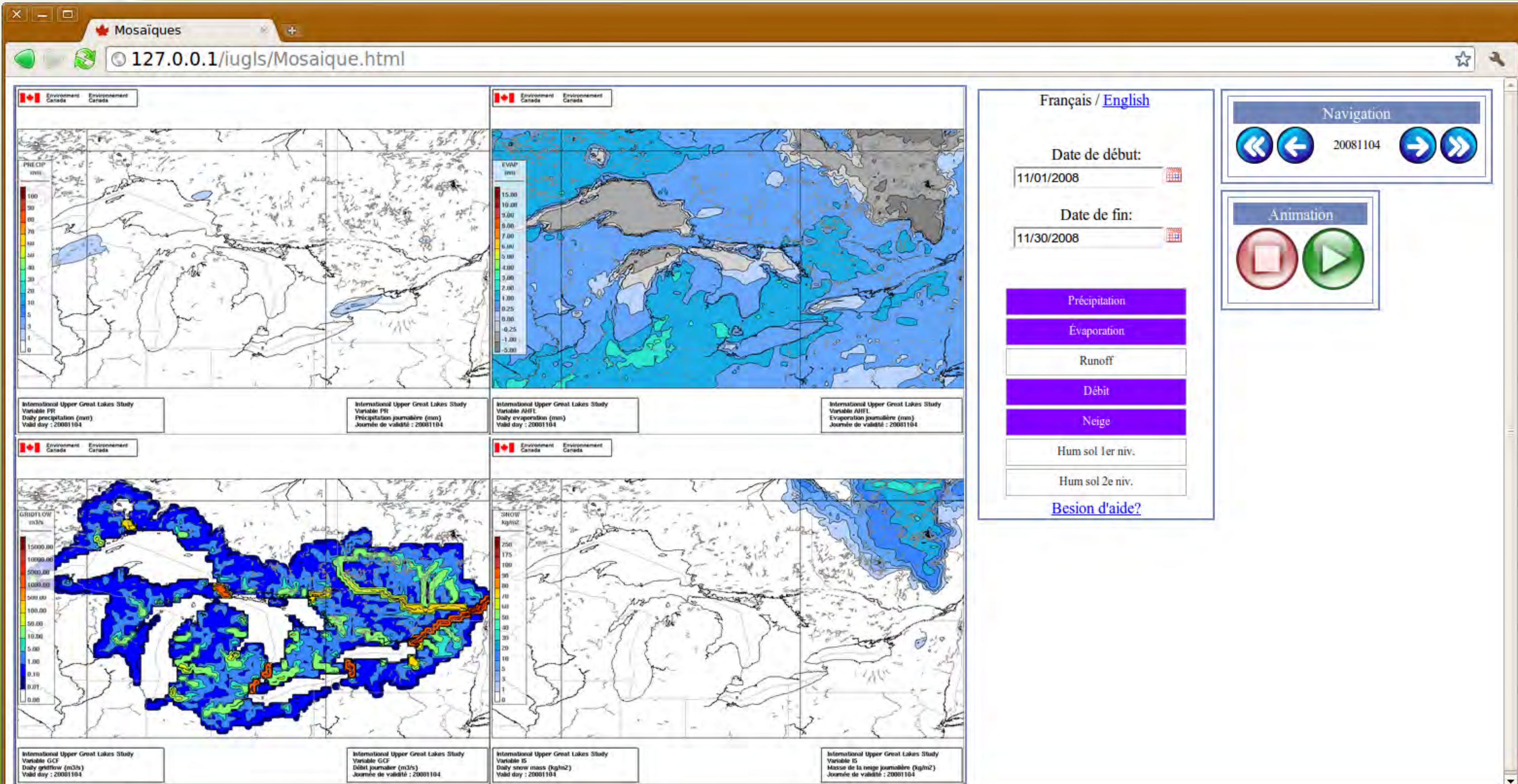

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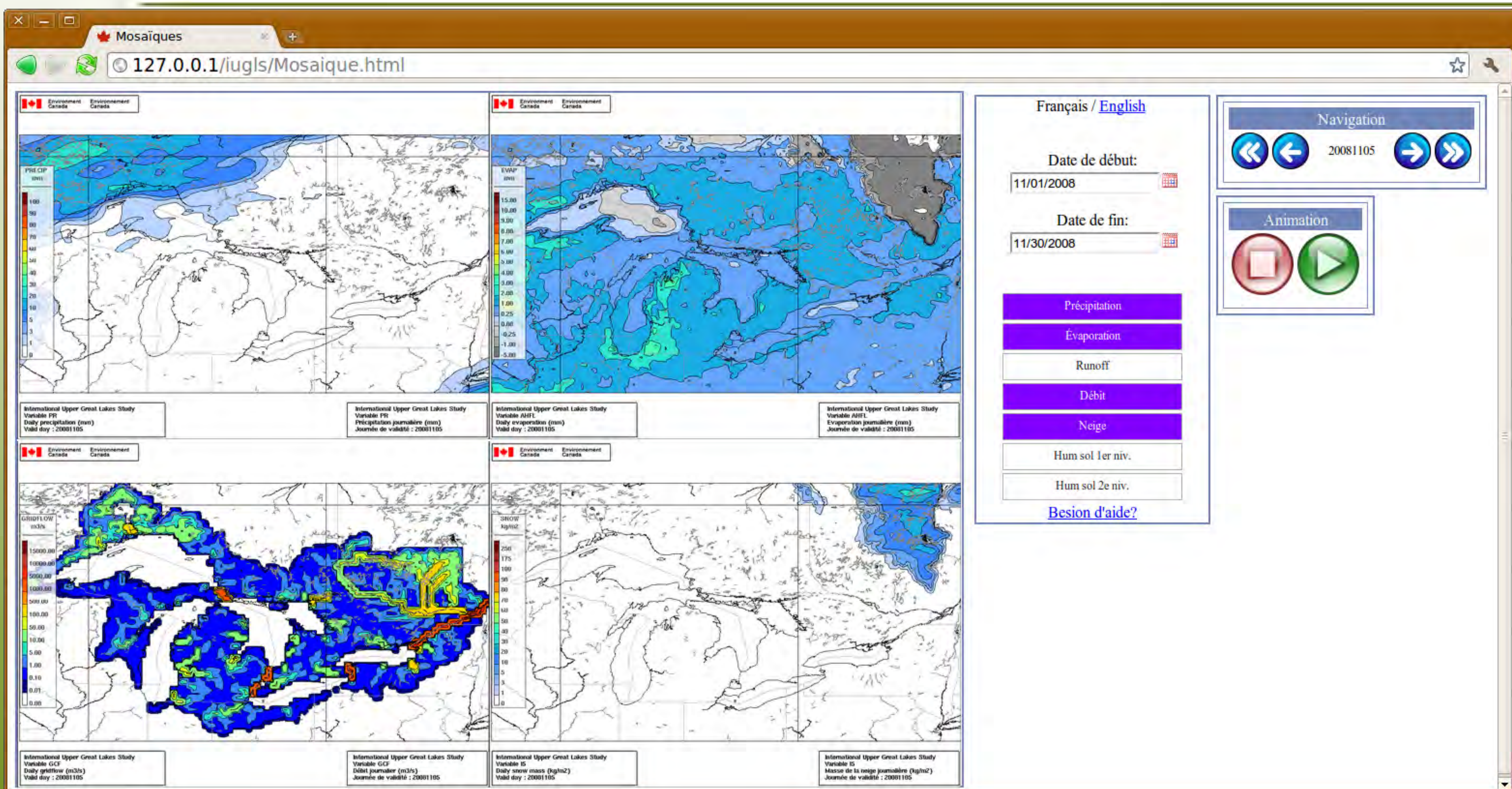

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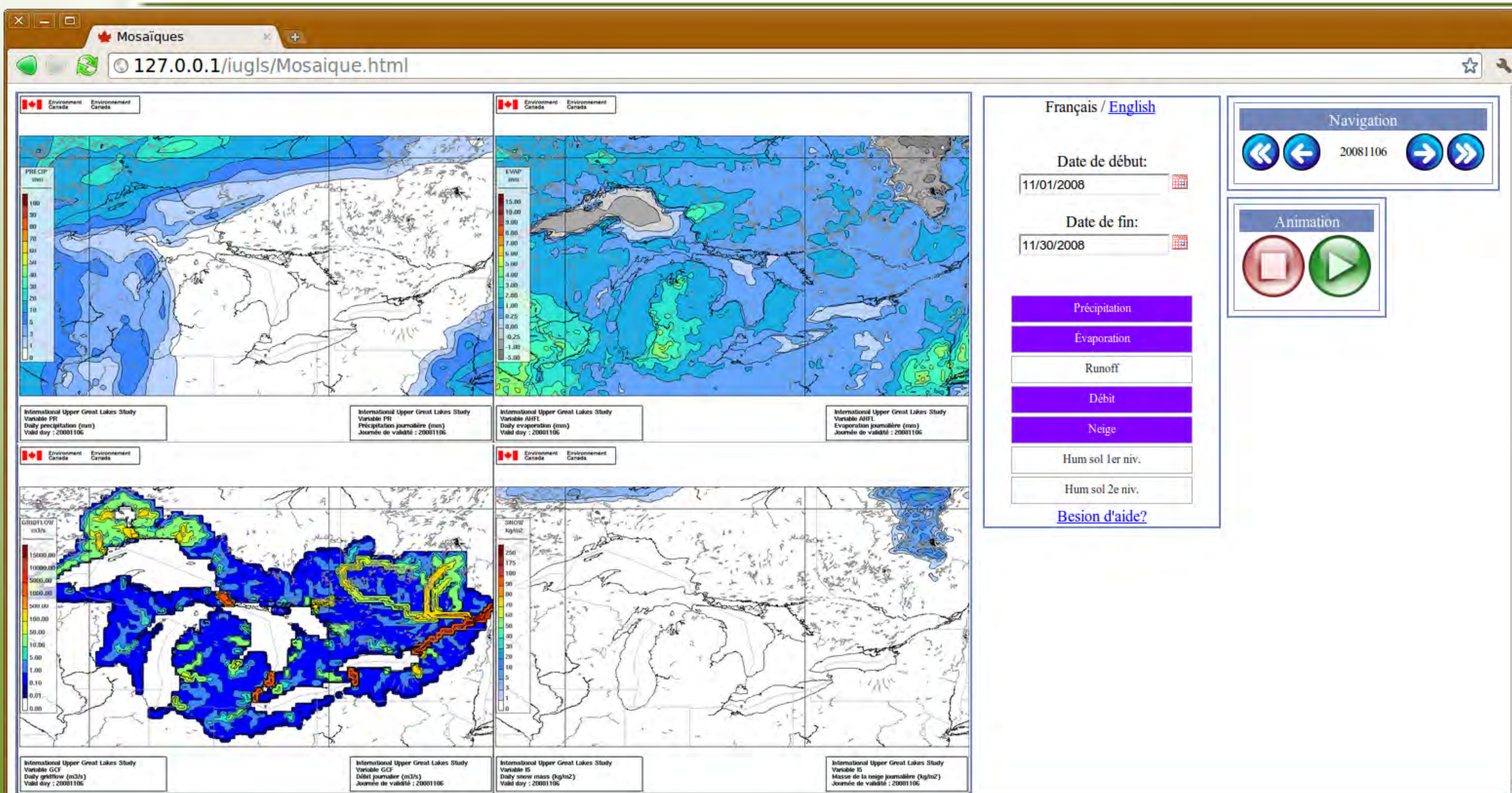

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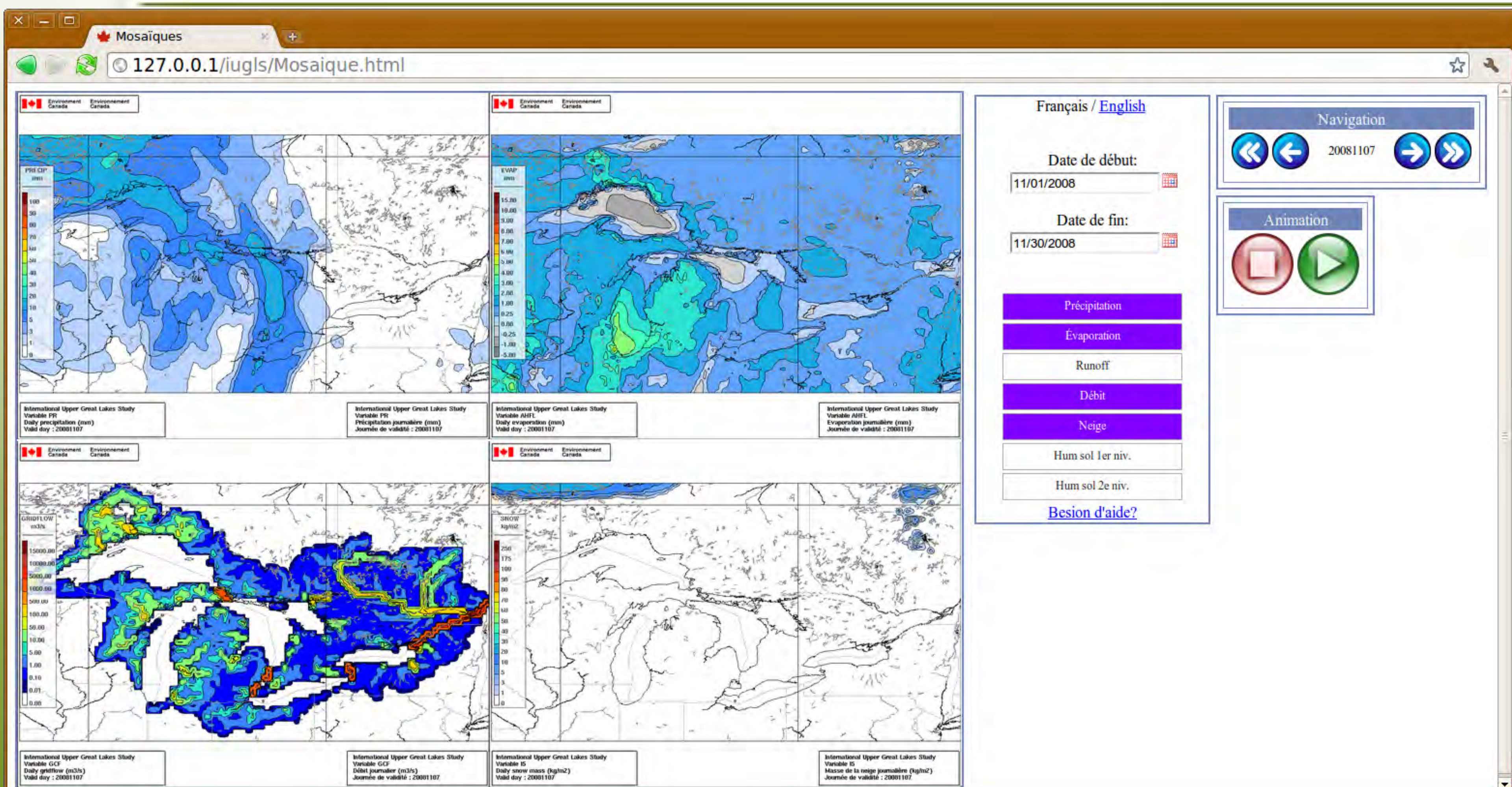

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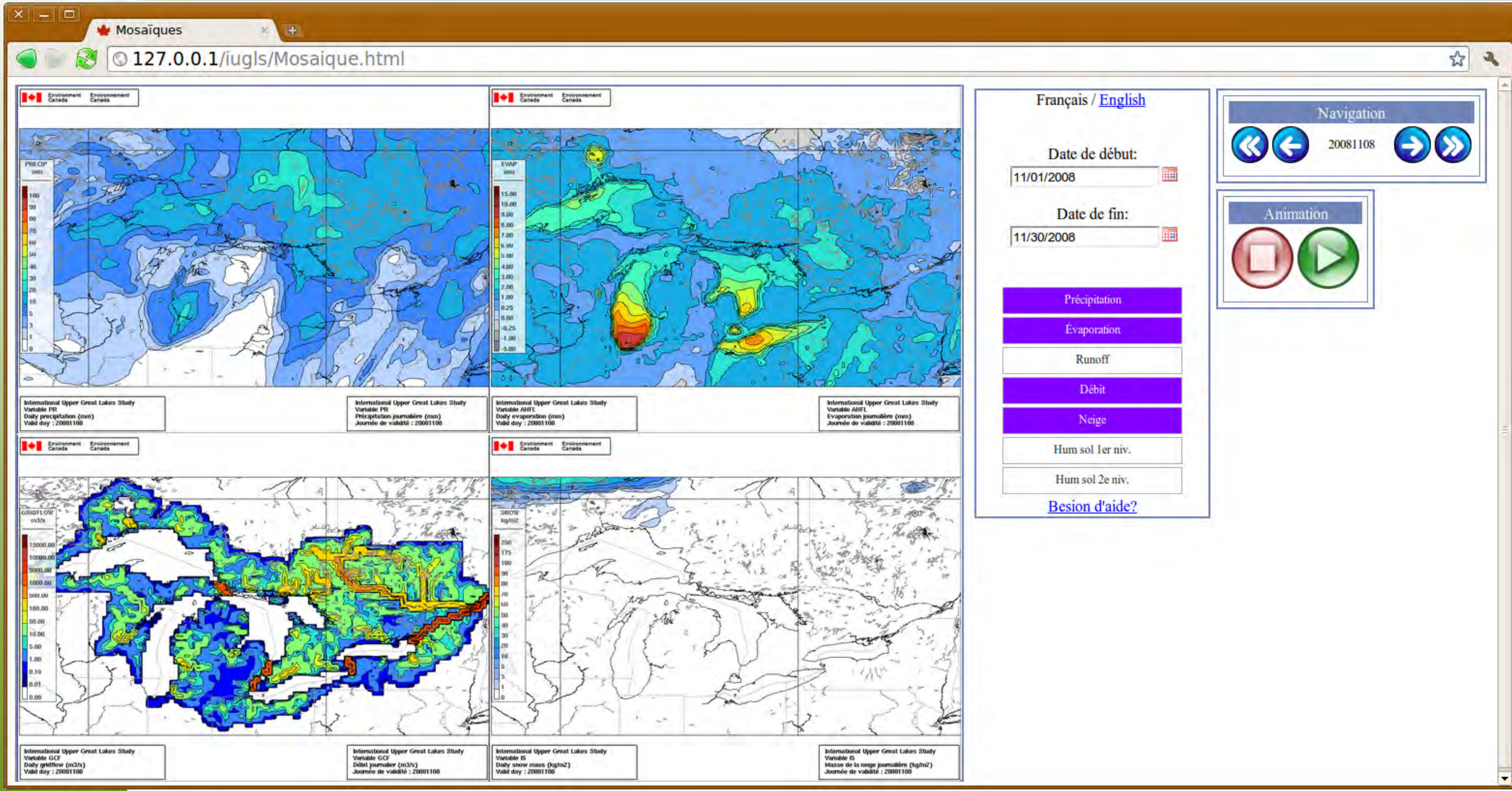

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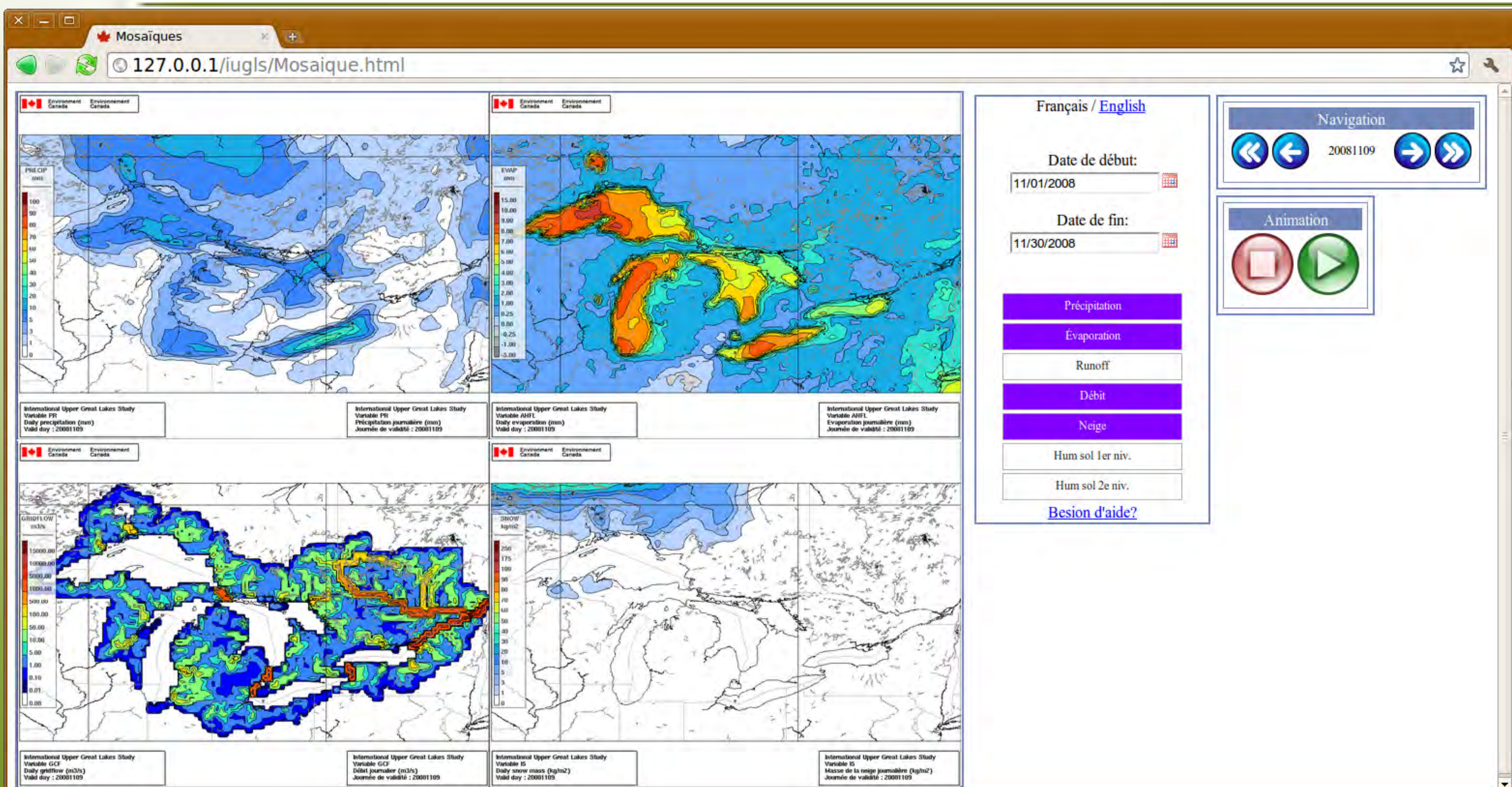

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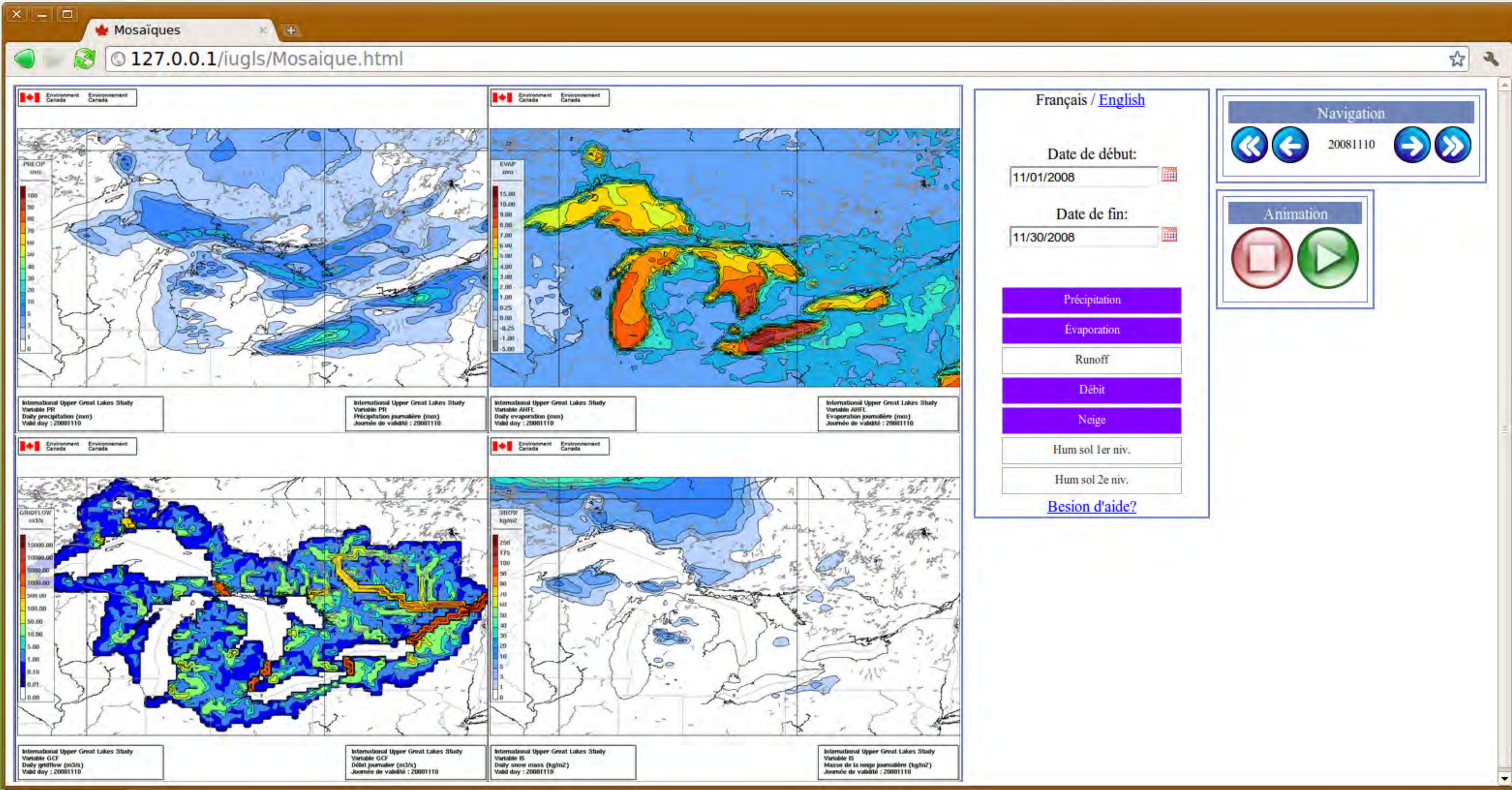

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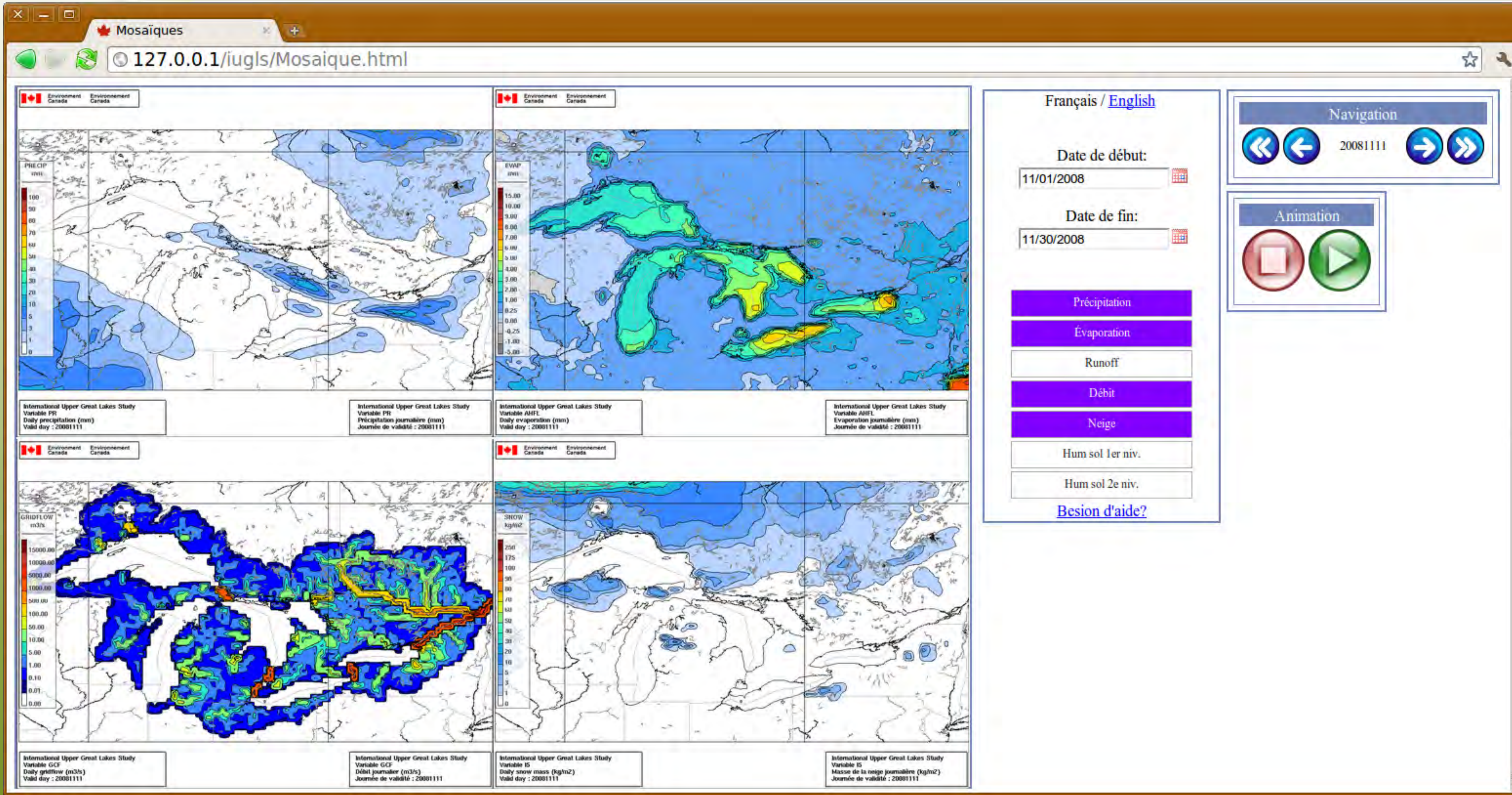

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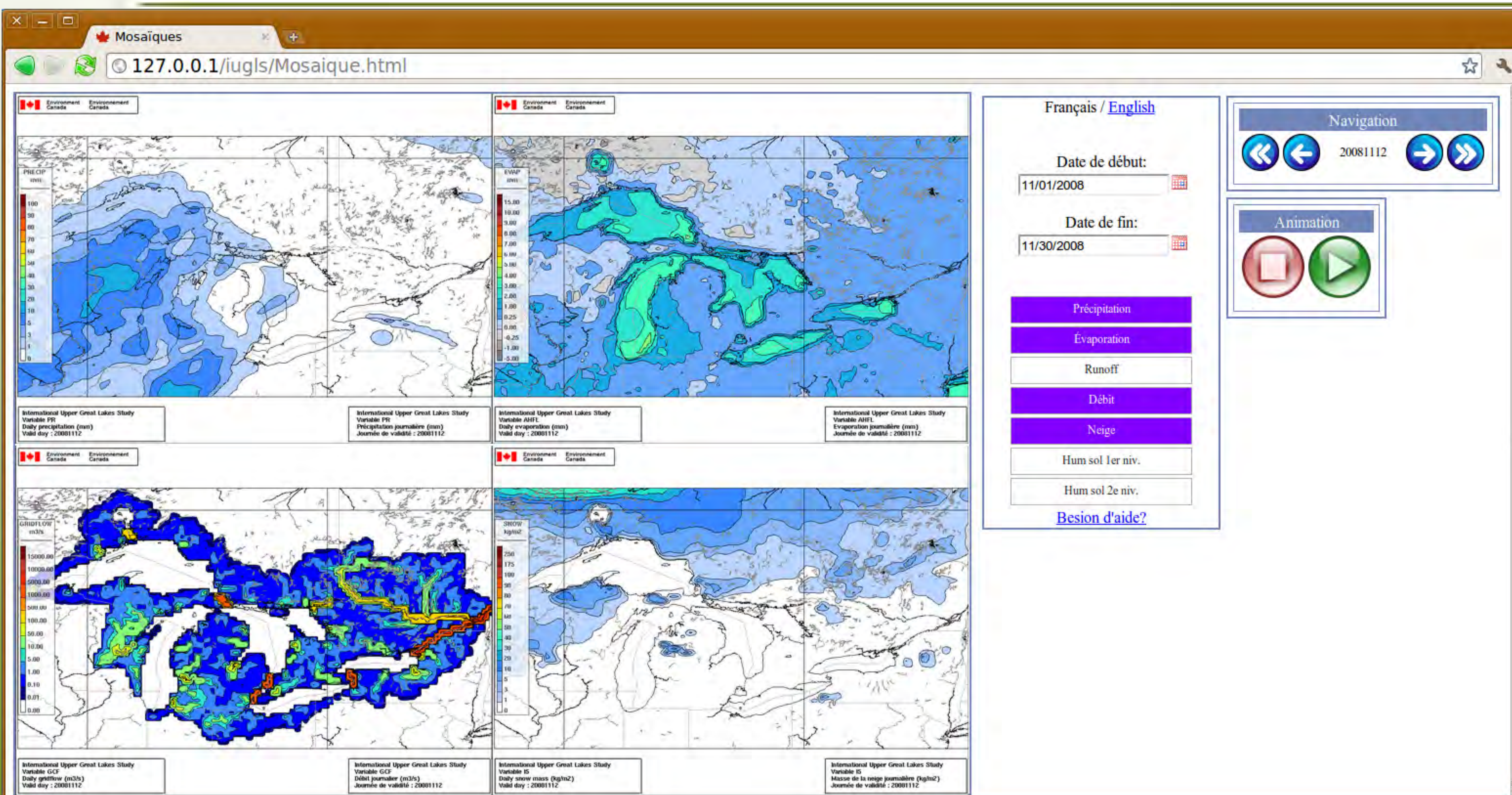

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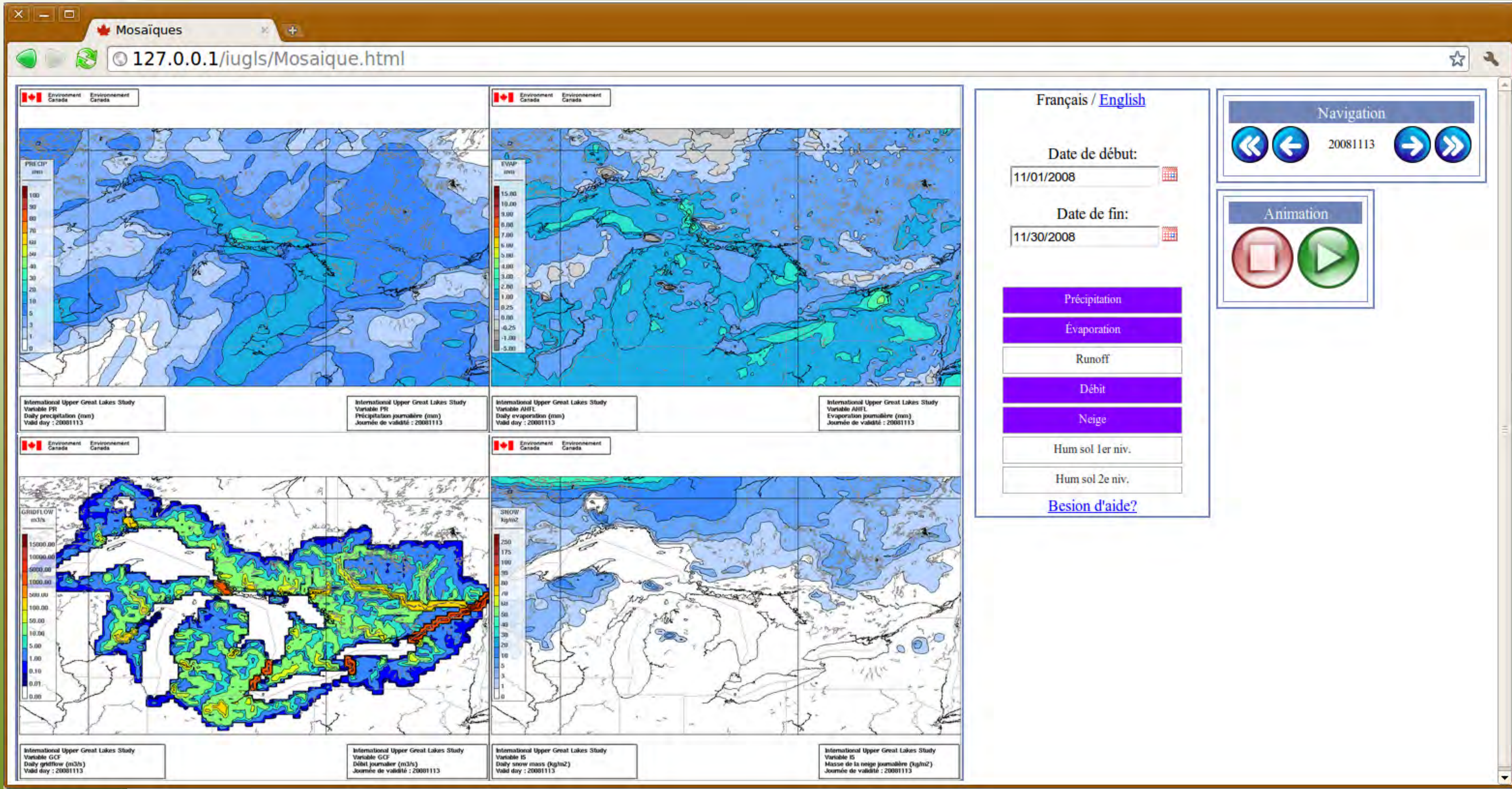

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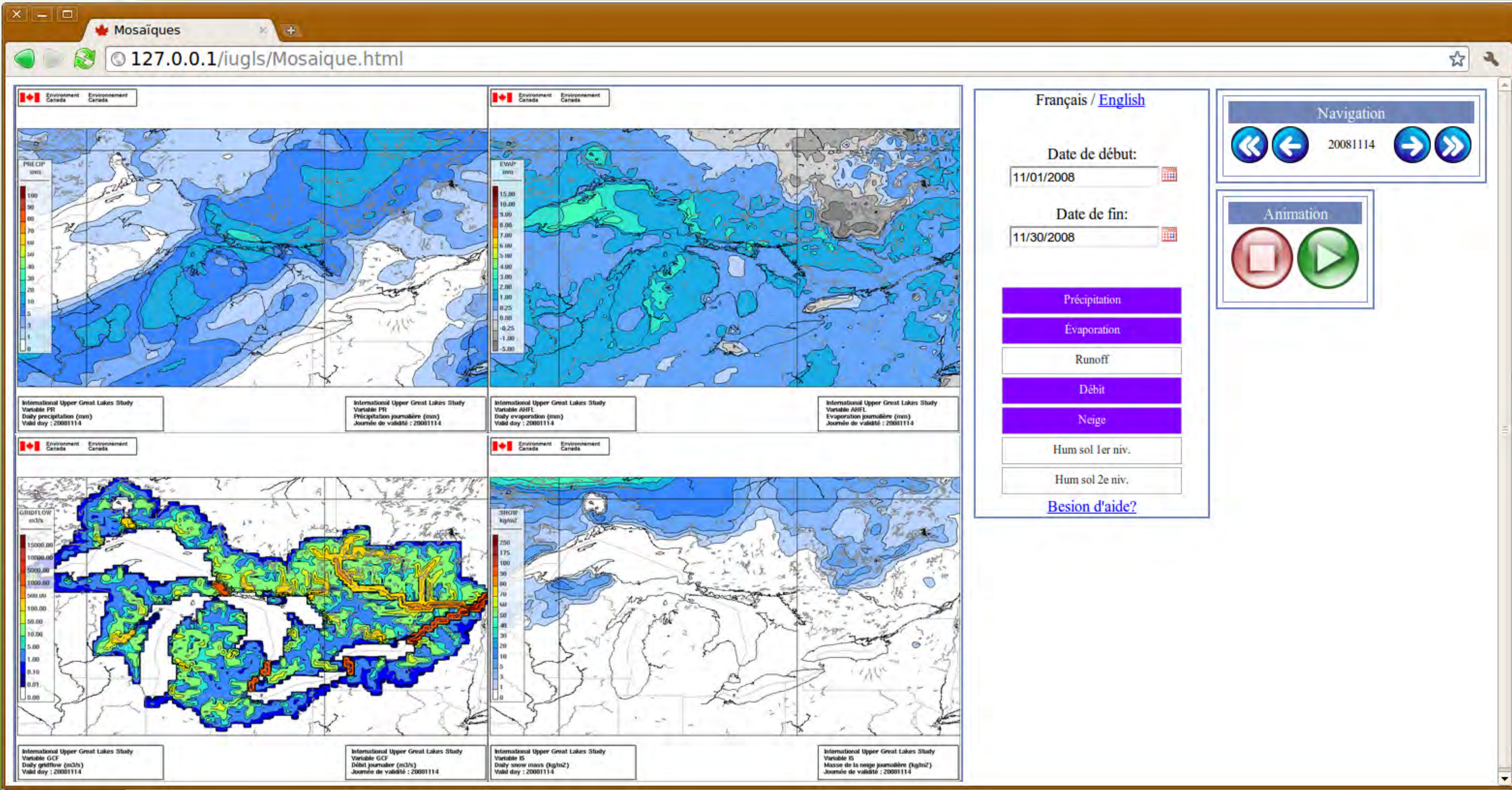

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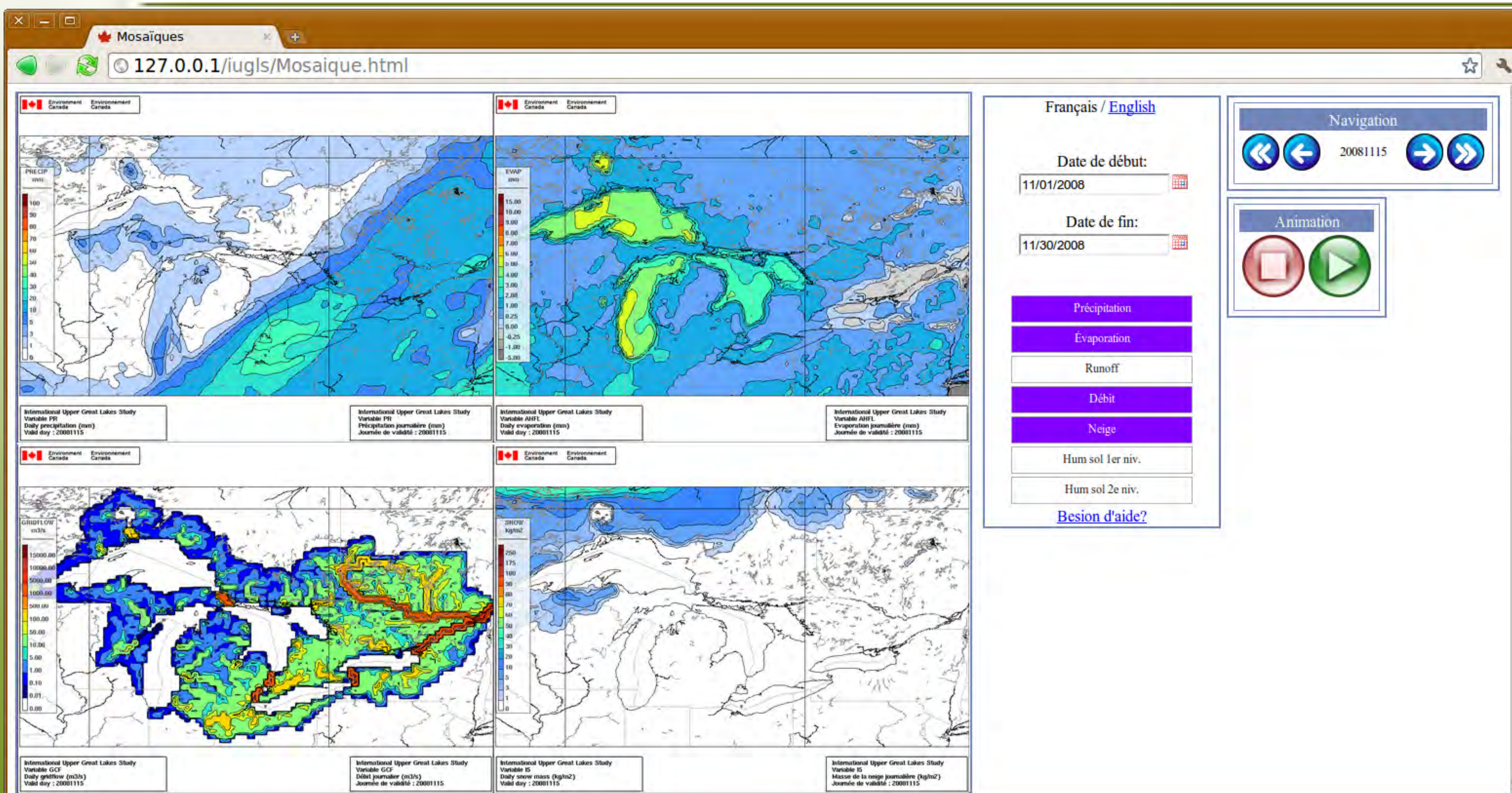

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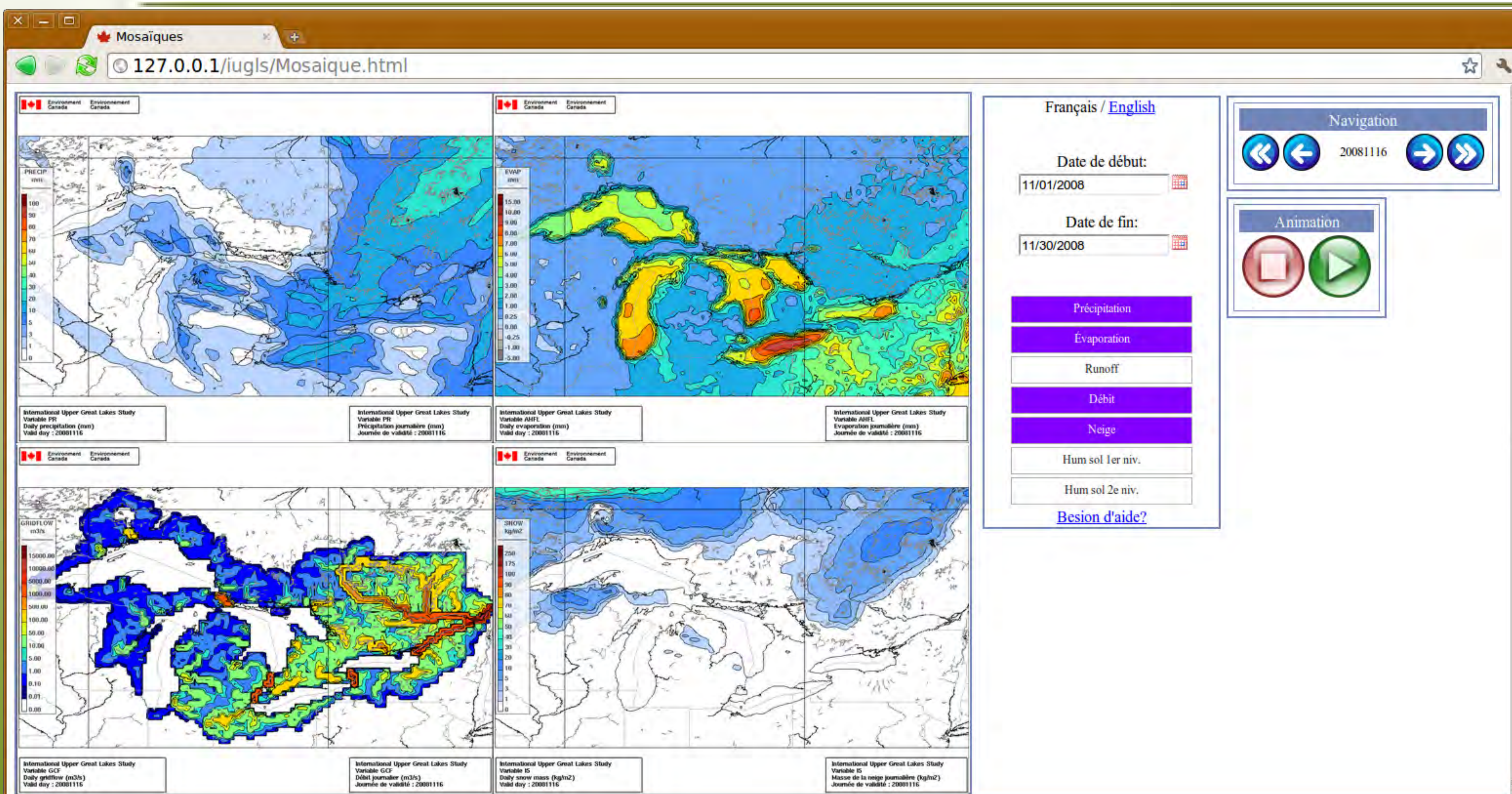

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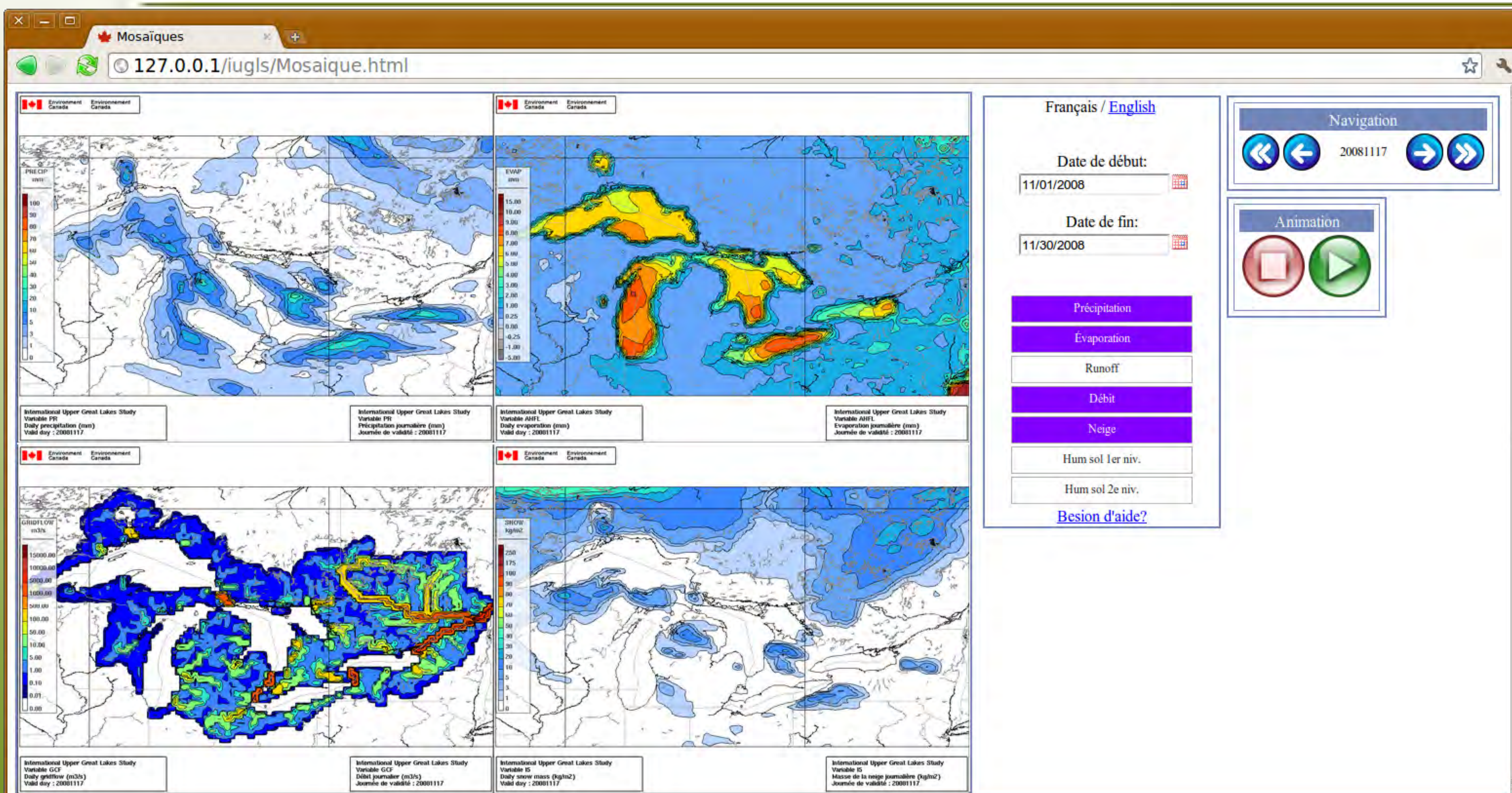

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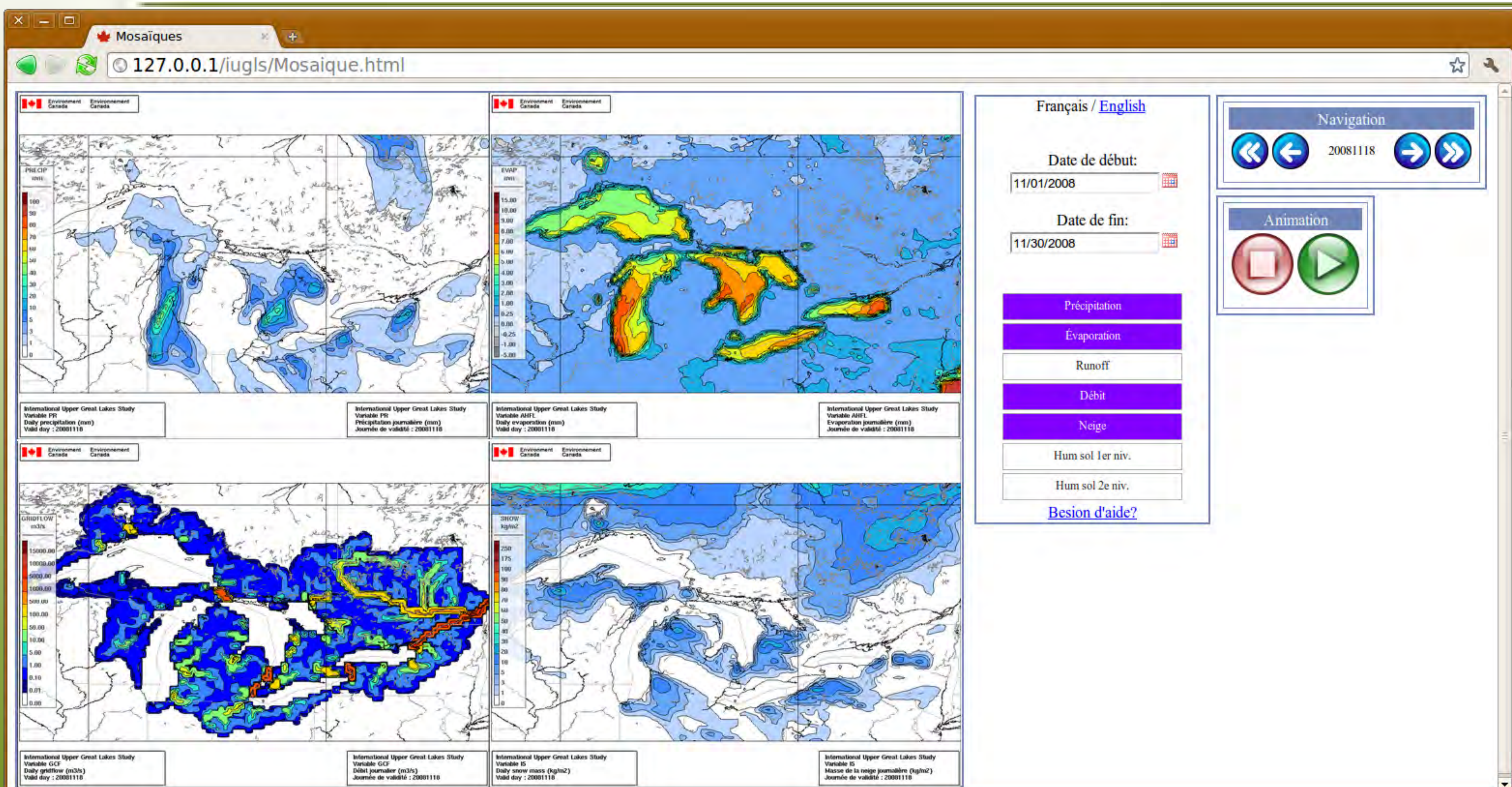

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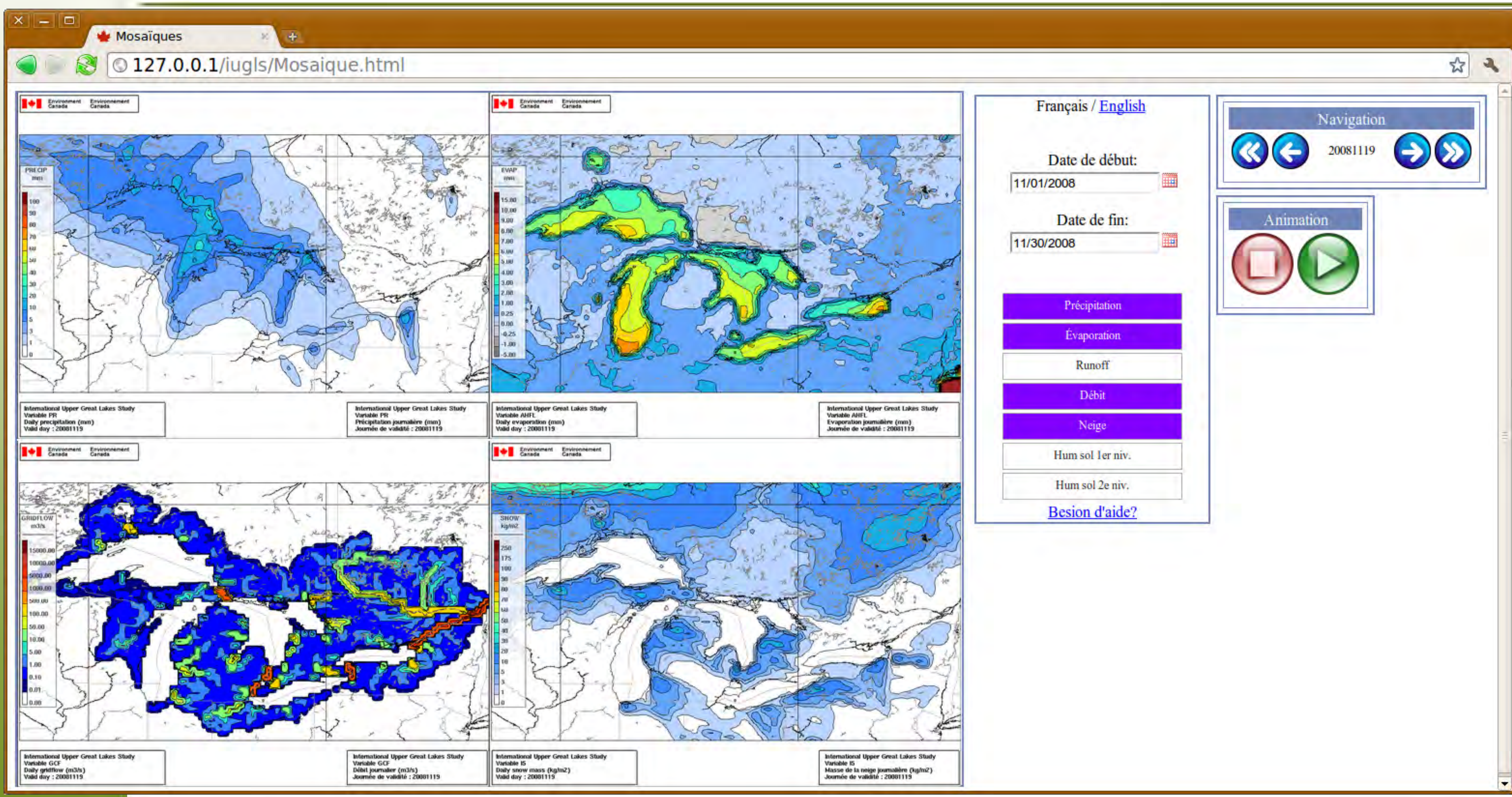

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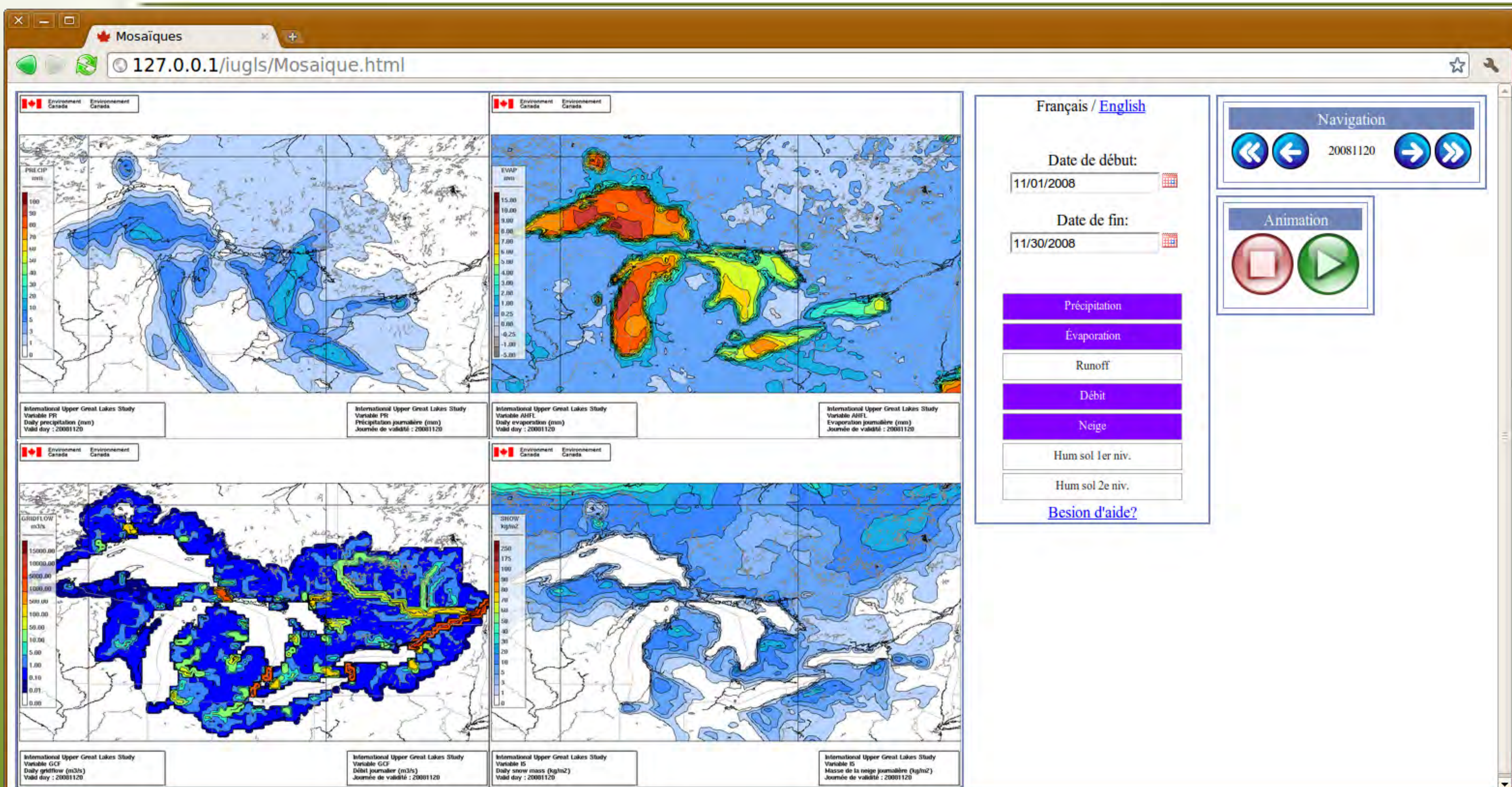
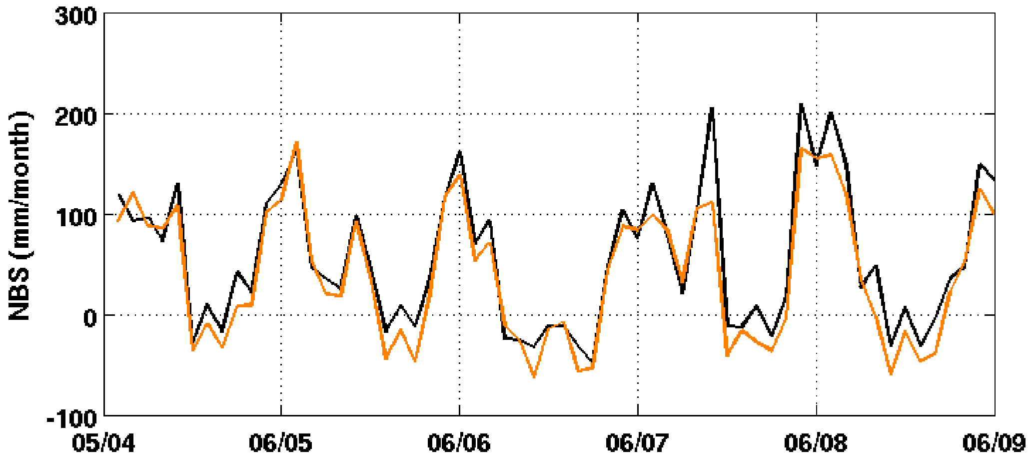
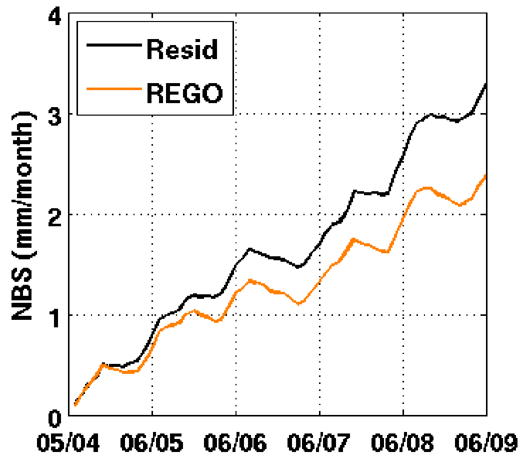


MESH “calibration”

- **REGO:** Initial results, GEM forcings from CMC archive
- **Resid:** Residual NBS (from lake levels)



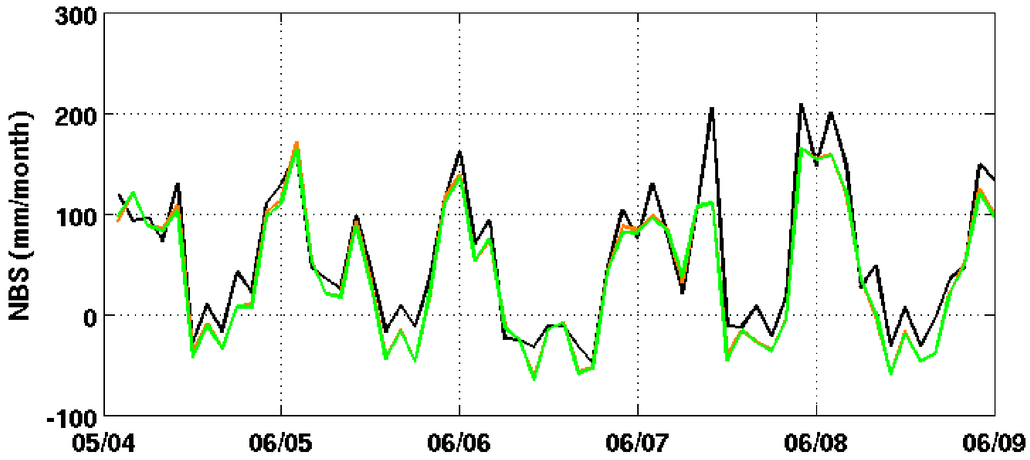
Lake Superior monthly Net Basin Supplies



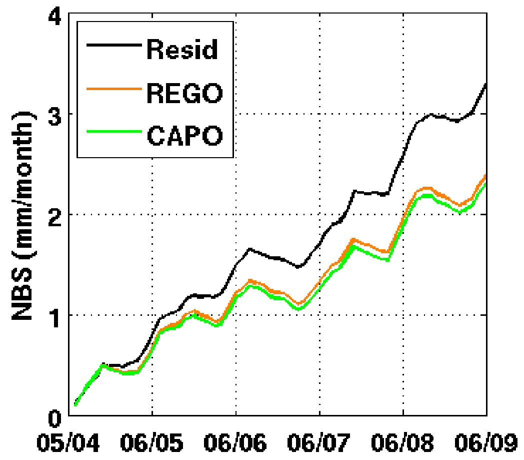
Cumulative NBS

MESH “calibration”

- **REGO:** Initial results, GEM forcings from CMC archive
- **CAPO:** CaPA methodology used to improve precip
- **Resid:** Residual NBS (from lake levels)



Lake Superior monthly Net Basin Supplies



Cumulative NBS

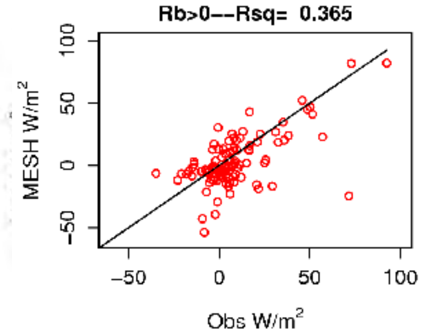
Verification of Overlake Evaporation

Eddy-correlation system

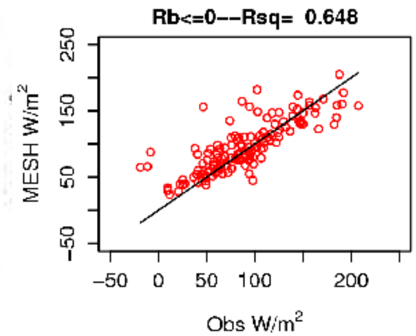
Observations courtesy of Chris Spence, NWRI

Verification of daily mean flux (June 2008 – January 2009)

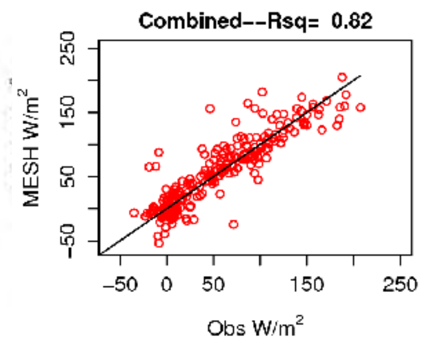
Stable conditions



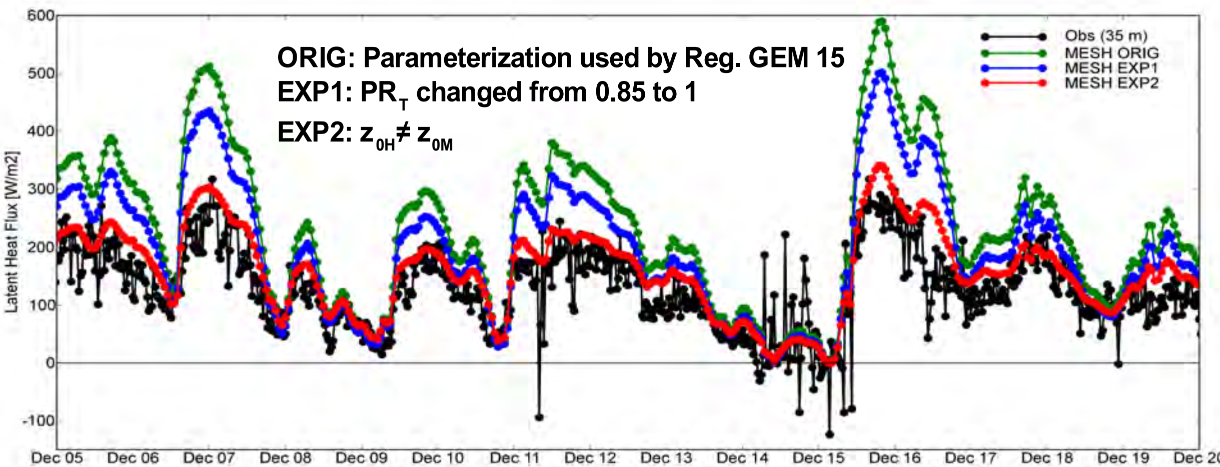
Unstable conditions



All cases



Verification of half-hourly fluxes for December 2008: changes to operational configuration were required



MESH "calibration"

- **REGO:** Initial results, GEM forcings from CMC archive
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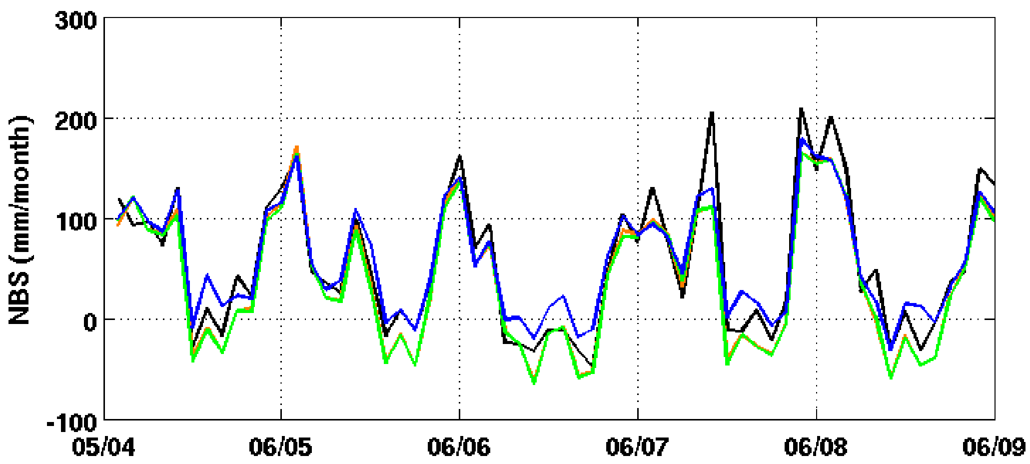
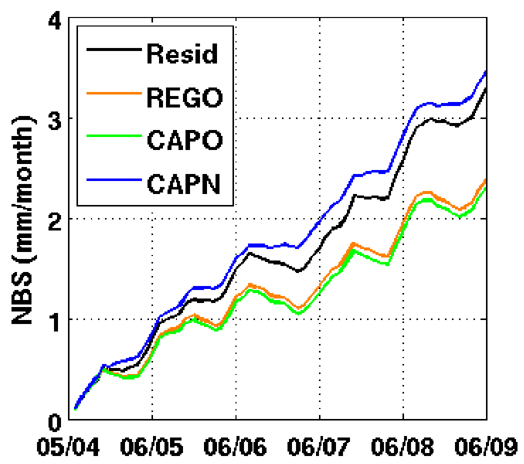
- **CAPN:** Improved overlake evaporation in MESH
- **Resid:** Residual NBS (from lake levels)



Lake Superior monthly Net Basin Supplies



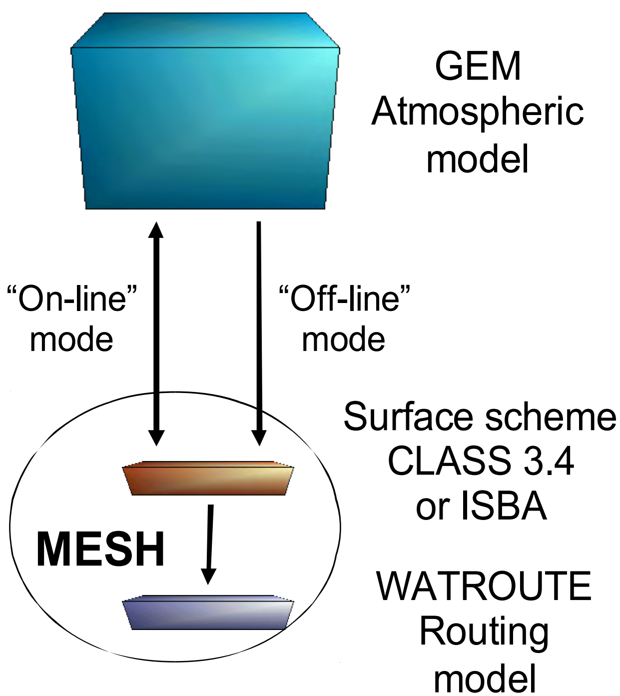
Cumulative NBS

MESH

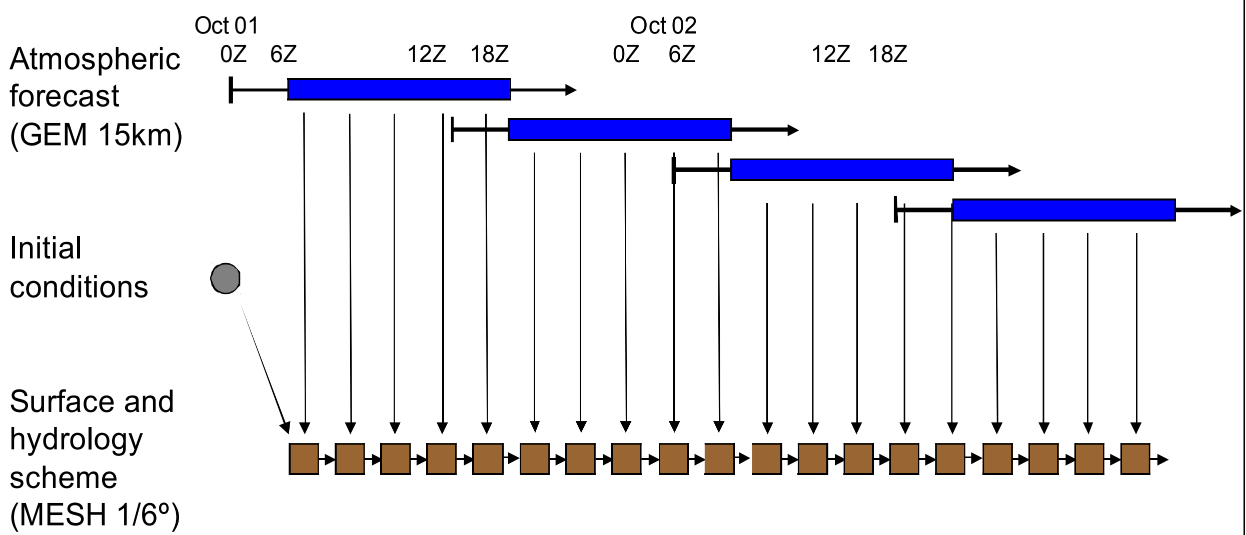
Modélisation Environnementale Couplée : Surface et Hydrologie
Coupled Environmental Modelling: Surface and Hydrology

Land surface models provide surface runoff and groundwater recharge, and include a parameterization for lateral flow along hillslope
Routing model includes surface runoff routing, river routing and baseflow estimation

Hydrological forecasting with MESH



Offline mode: forcing with short-term forecasts (with precipitation forecast replaced by an analysis)



Community model, source code available upon request

MESH “calibration”

- **REGO:** Initial results, GEM forcings from CMC archive
- **CAPO:** CaPA methodology used to improve precip
- **CAPN:** Improved overlake evaporation in MESH
- **REGN:** Improved overlake evaporation in GEM
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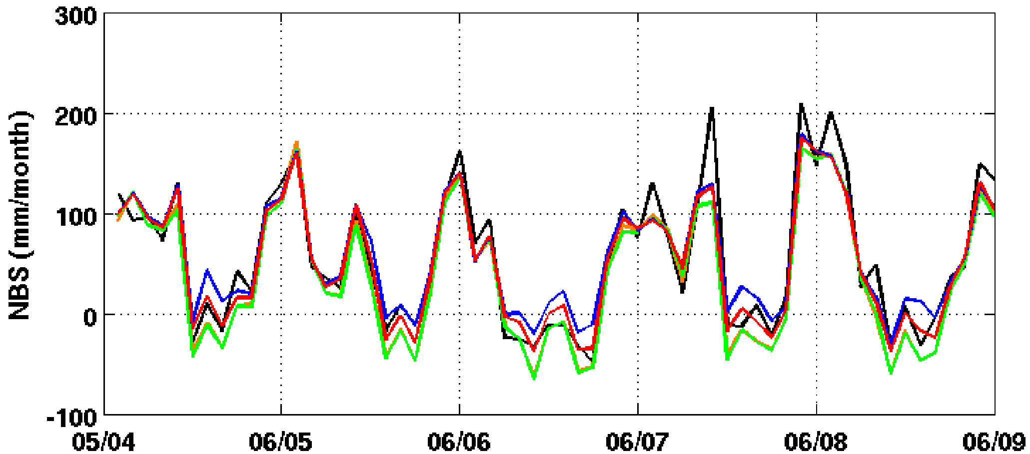
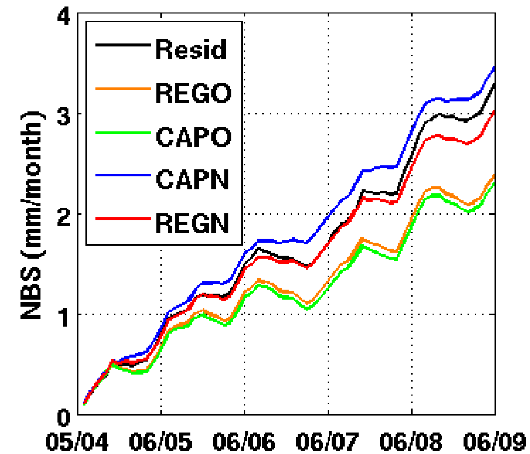


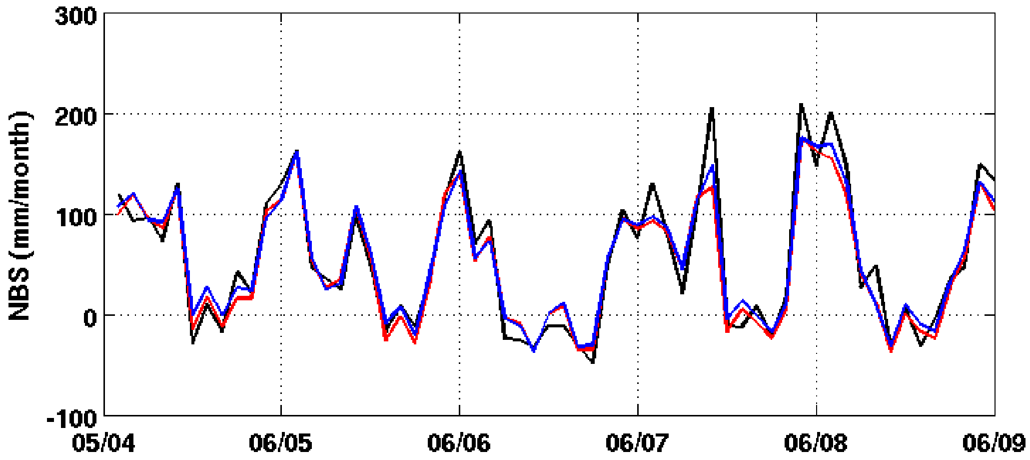
Lake Superior monthly Net Basin Supplies



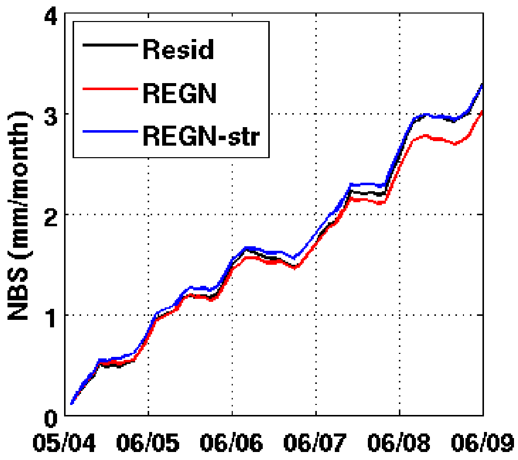
Cumulative NBS

An additional trick for the final hindcast: streamflow nudging

- Simulated flows replaced by observations where there is a gauge
  - 169 locations accross the basin, 2/3 of the basin
- Flows are still predicted by MESH for the ungauged portion of the watershed
  - including downstream of a gauge

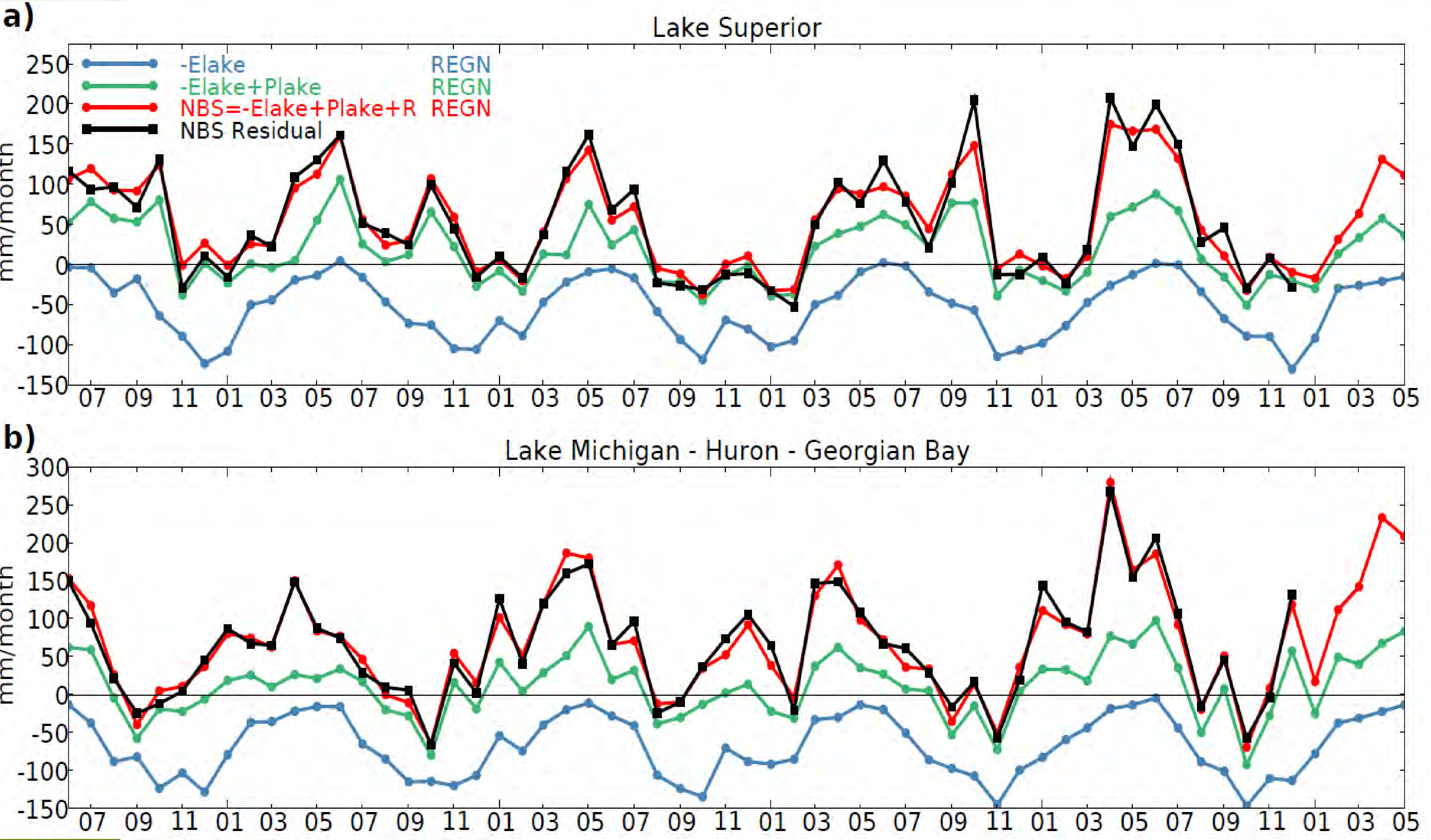


Lake Superior monthly Net Basin Supplies

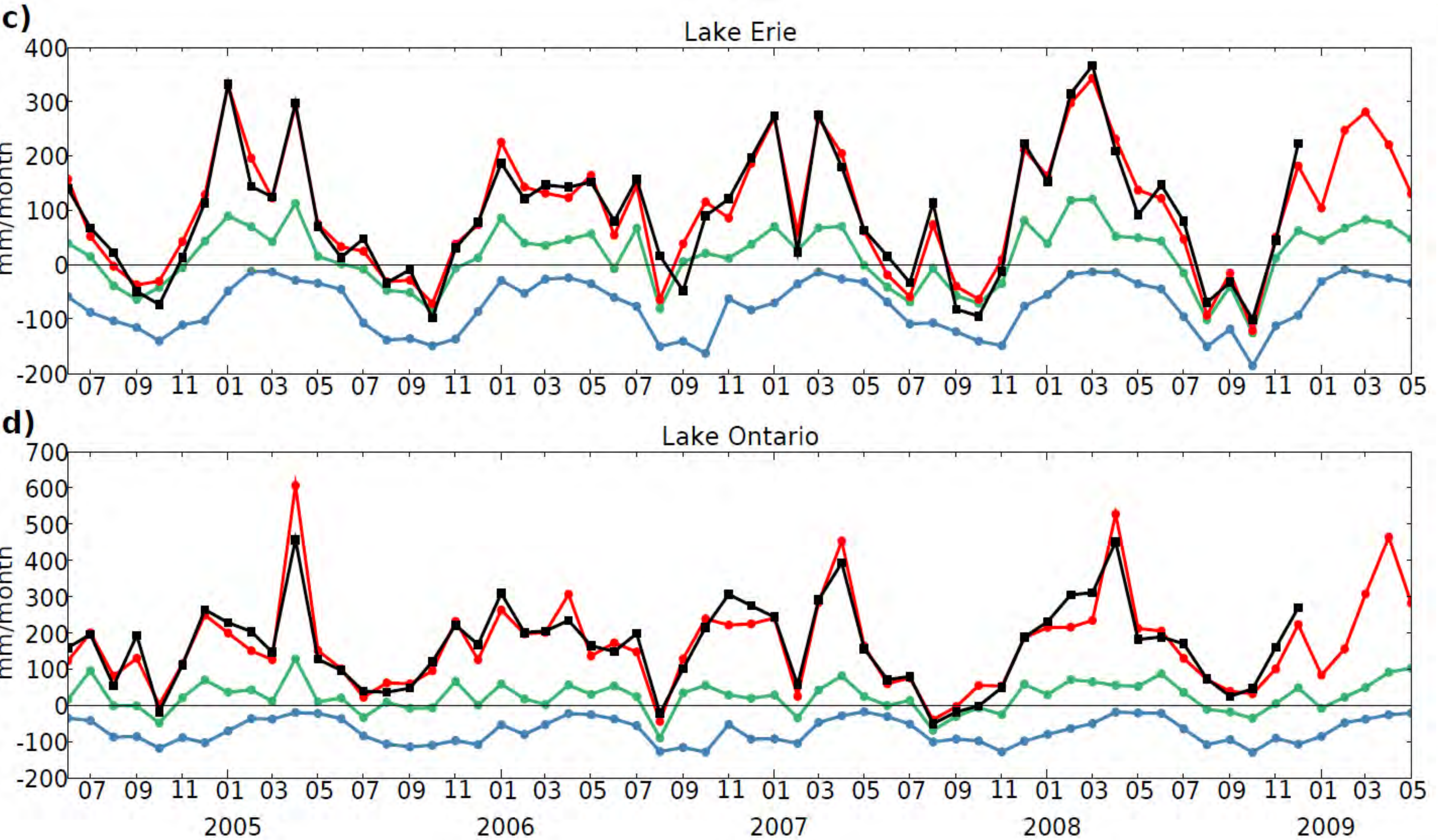


Cumulative NBS

MESH vs residual NBS: Superior and Michigan-Huron



MESH vs residual NBS: Erie and Ontario



How do GEM+MESH compare to a hindcast based on obs. alone?

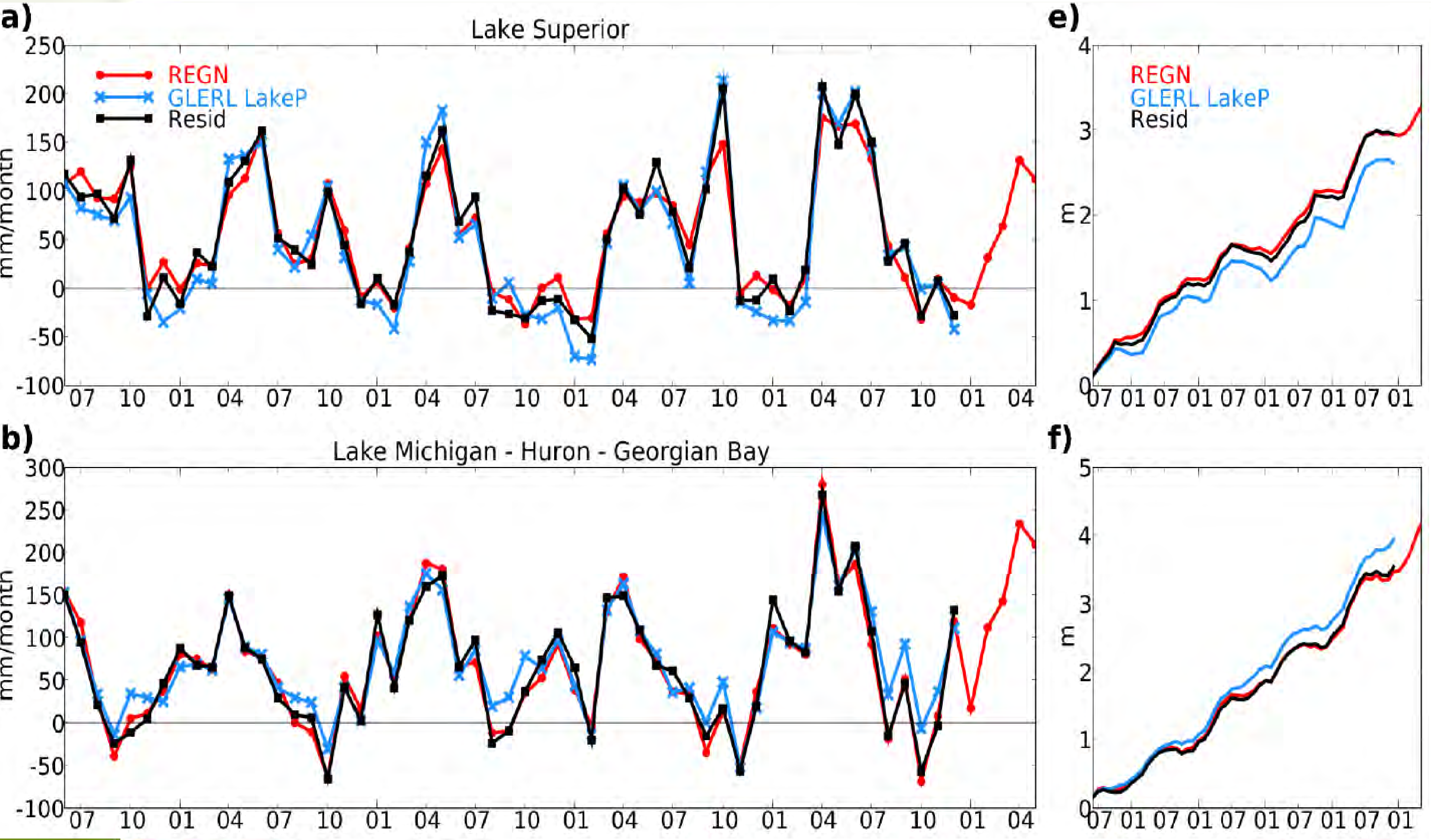
GEM+MESH hindcast:

- Overlake precip:
  - short-term forecast (6-18h)
  - CaPA not helping much
- Overlake evaporation:
  - short-term forecast (6-18h)
- Runoff:
  - ISBA land-surface scheme
  - WATROUTE routing model
  - Streamflow nudging (optional, but does give better results)

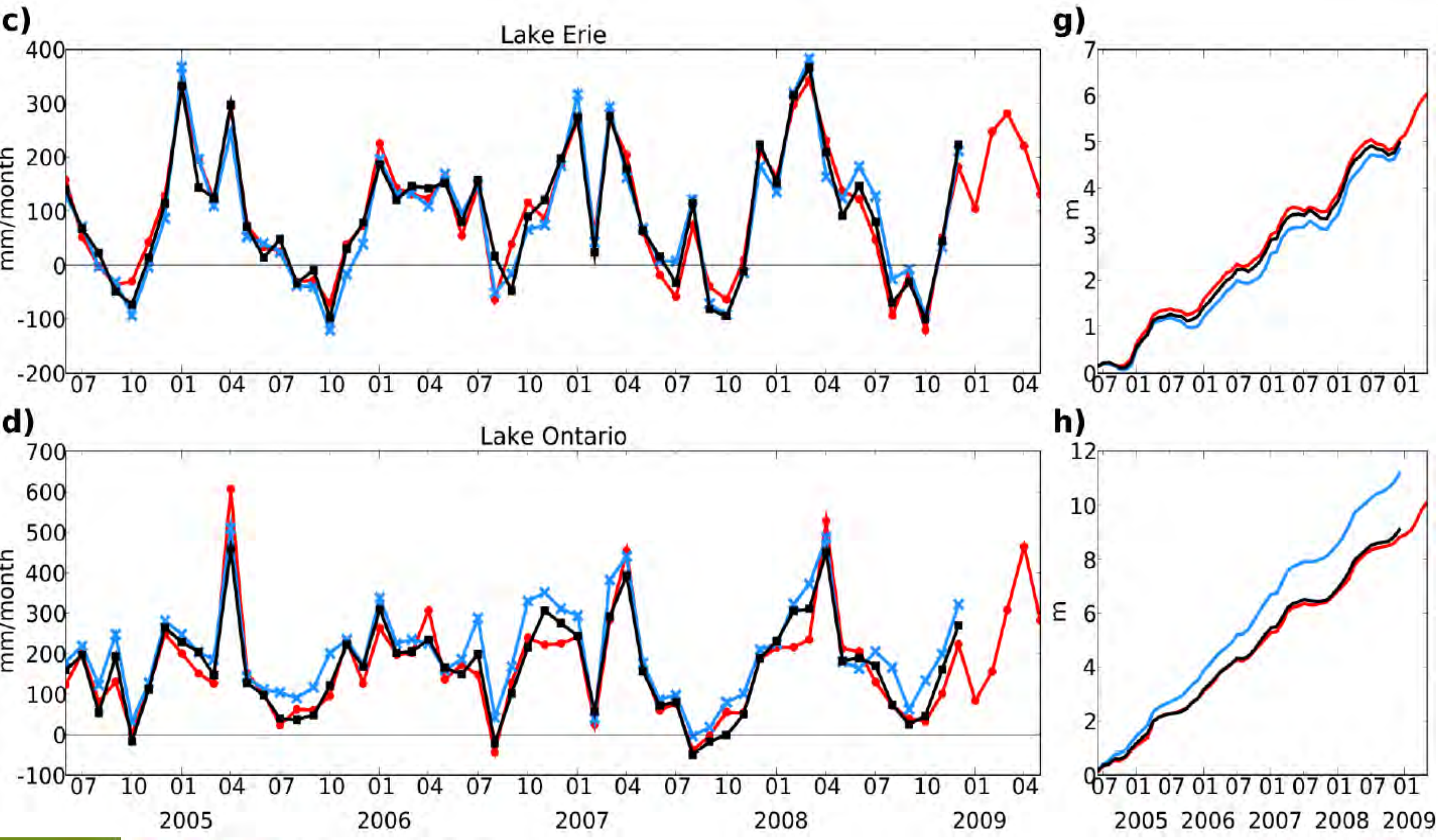
GLERL hindcast (NOAA):

- Overlake precip:
  - Thiessen polygons using near-shore stations
- Overlake evaporation:
  - Empirical model based on observations of wind and temperature from near-shore stations
- Runoff:
  - Pro-rating by area of observed streamflow to estimate runoff from the whole watershed

MESH vs GLERL component NBS: Superior and Michigan-Huron

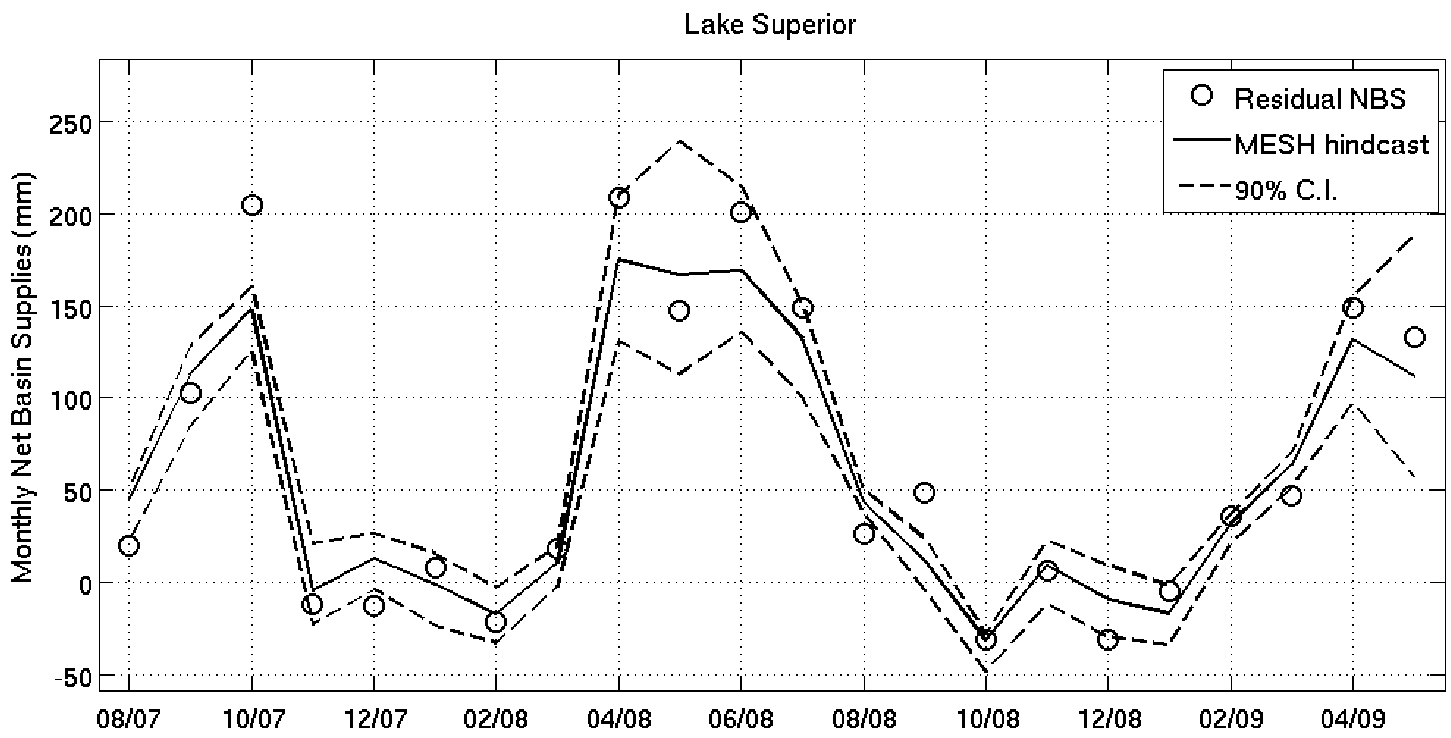


MESH vs GLERL component NBS: Erie and Ontario



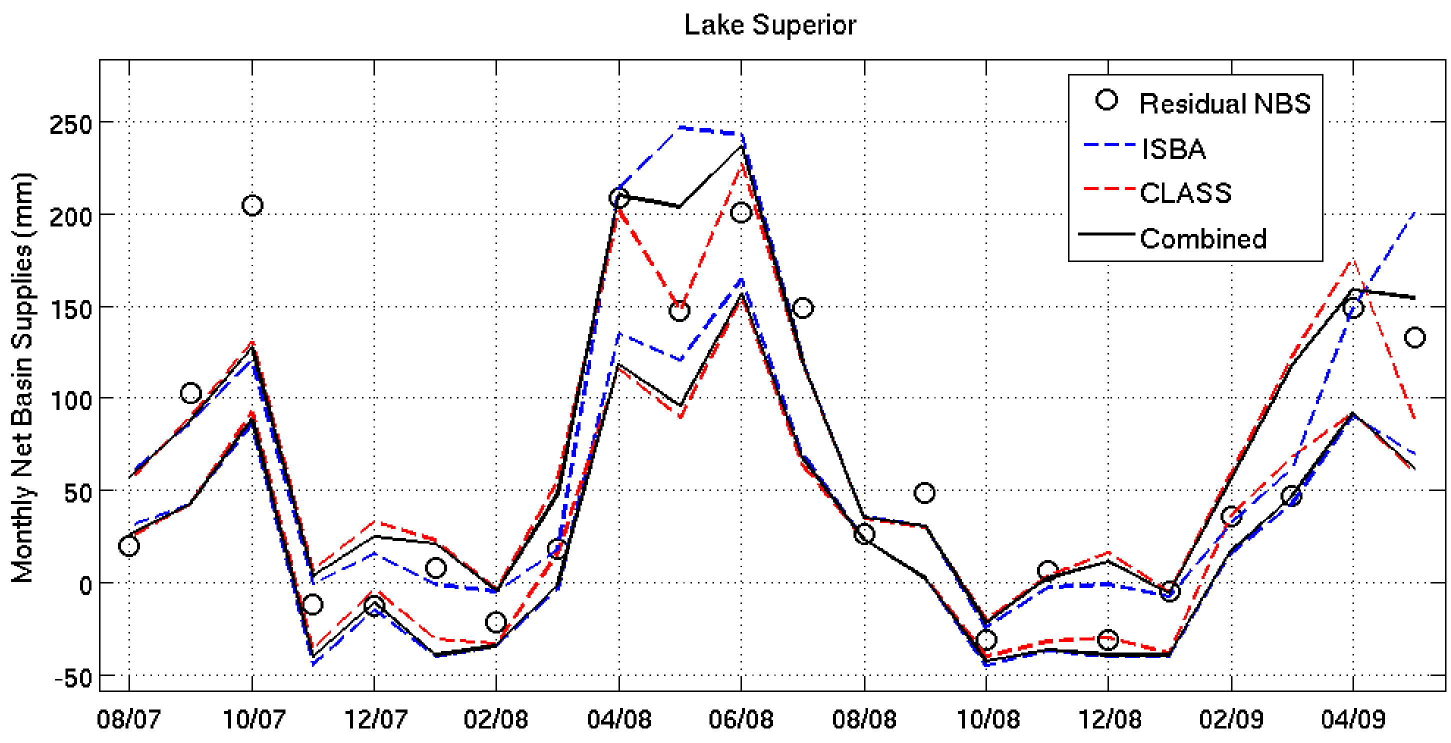
Can errors be explained by uncertainty in atmospheric forcings?

- Probabilistic hydrological prediction:
  - Uncertainty in (deterministic) hindcast estimated from variability of day-1 ensemble forecasts of NBS
- 90% C.I. too often fails to cover the obs.



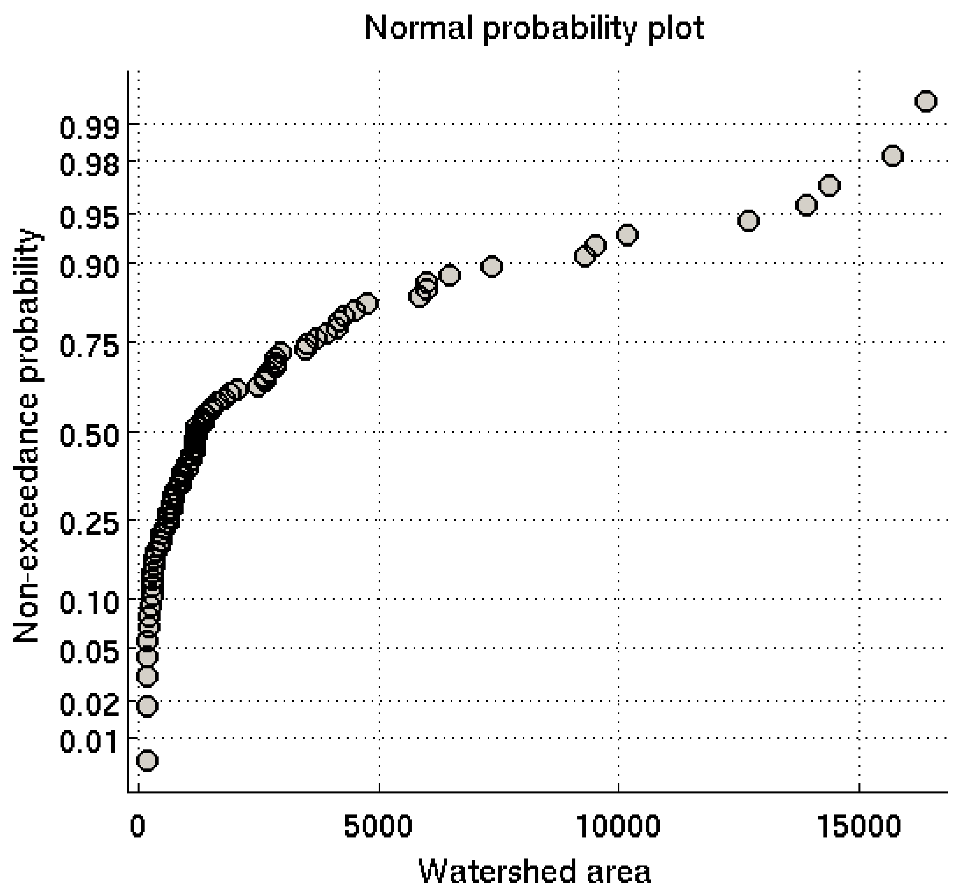
What difference does the land-surface model make?

- Both land-surface models available in MESH lead to confidence intervals of similar quality
- Best results are obtained from multi-model ensemble



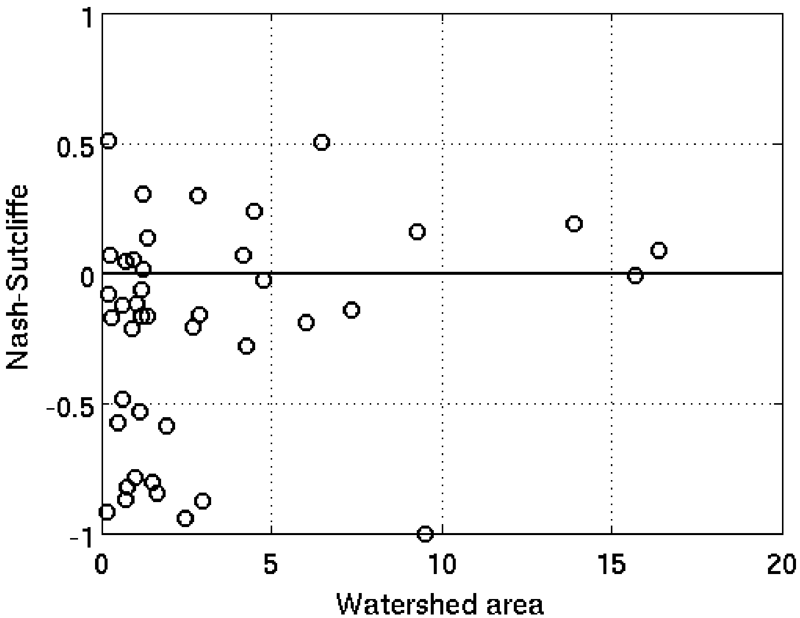
Predicting daily flows

- 81 non-regulated gauged watersheds identified



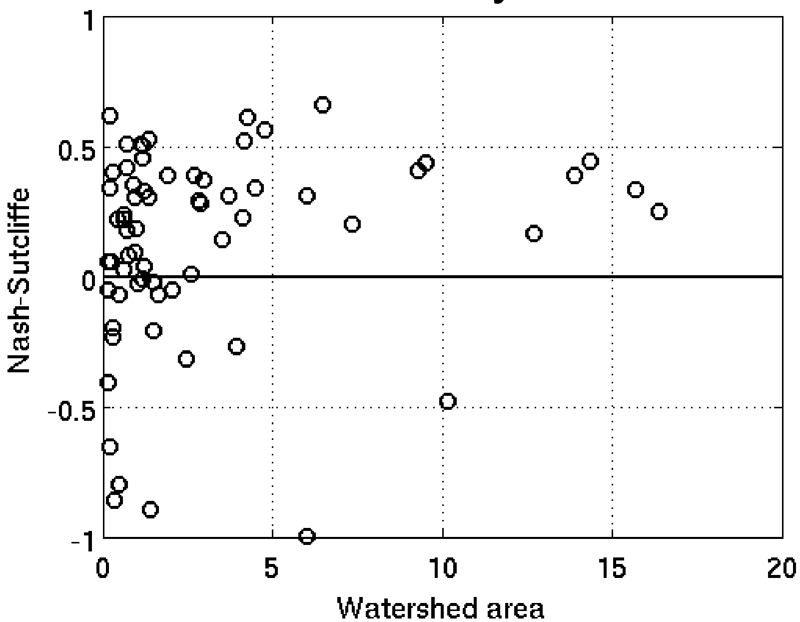
Nash-Sutcliffe of daily mean flow (4 year verification period)

- Raw forecast
  - Hydrographs are too flashy



39 basins off the chart

- After post-processing
  - Unit hydrograph calibrated based on 1st year of data



14 basins off the chart

There is still room for improvement!

Access to Environment Canada's models, analyses and forecasts

- **Product guide:**
  http://collaboration.cmc.ec.gc.ca/cmc/CMOI/product_guide
- **Images:** the Analysis & Modelling web page
  http://www.weatheroffice.gc.ca/charts/
- **Gridded forecasts:** the datamart
  http://dd.weatheroffice.gc.ca/
- **GEM model** and utilities for pre- and post-processing:
  http://collaboration.cmc.ec.gc.ca/science/rpn.comm/wiki/
- **CaPA products (until the next update to weatheroffice):**
  http://collaboration.cmc.ec.gc.ca/cmc/CMOI/product_guide/submenus/capa_e.html
- **MESH model:**
  http://halfront.wxe.sk.ec.gc.ca/html/documents/store/