Environnement Canada Environment Canada

Canada

Great Lakes & St.Lawrence Testbed Report

3rd HEPEX workshop

Stresa, Italia

Vincent Fortin and Alain Pietroniro

Environnement Canada

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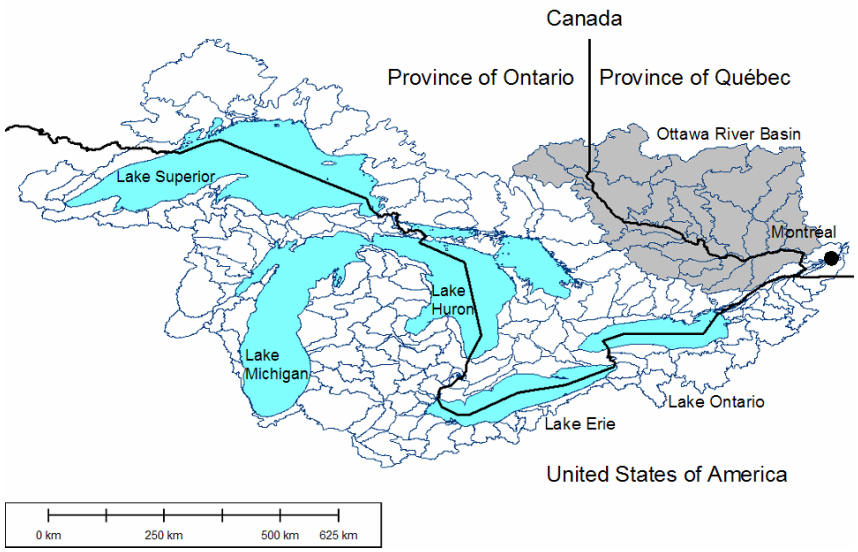
Great Lakes and St.Lawrence basin

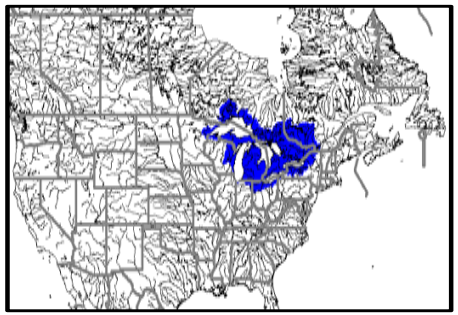
Largest lake group in the world:

- lake area: 250 000 km²
- watershed area: 1 000 000 km²
- population: 40 millions
  - 30% of Canada's population
  - 10% of US population



Regulated according to an international agreement between Canada and the US

- implemented by the International Joint Commission



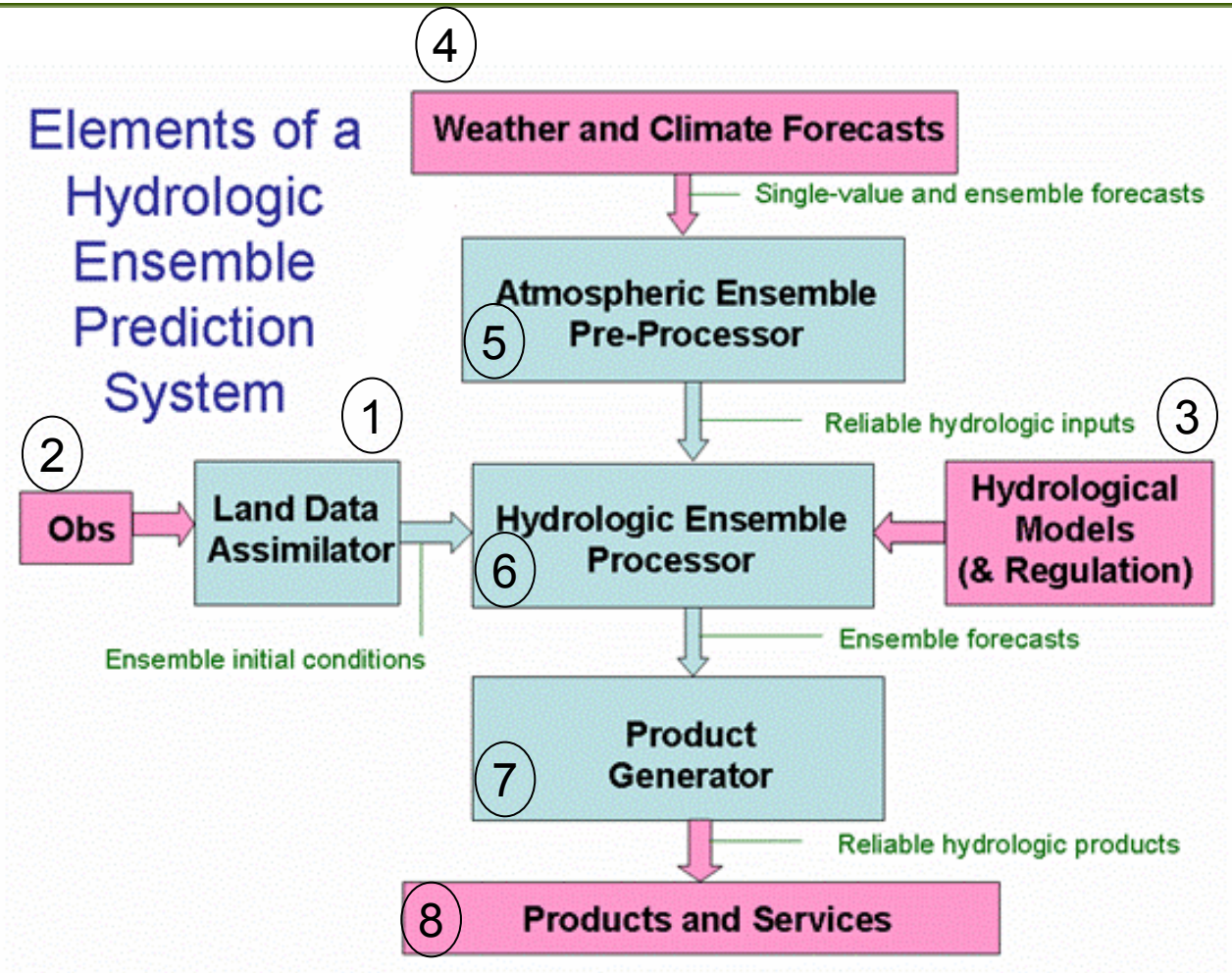
Key objectives of the testbed

- Long-term
  - Demonstrate the importance of detailed atmospheric and hydrologic modeling for medium-range forecasting on large basins.
  - Evaluate the North American Ensemble Forecasting System (NAEFS), compared to only using ensemble forecasts from the individual centers (CMC and NCEP)
  - Evaluate the added economic value of using ensemble weather predictions instead of climatology for lead times of up to two weeks
- Short-term (last two years!)
  - Implement an ensemble hydrological forecasting system for the Great Lakes based on ensemble weather forecasts
  - Begin to verify and score the forecasts

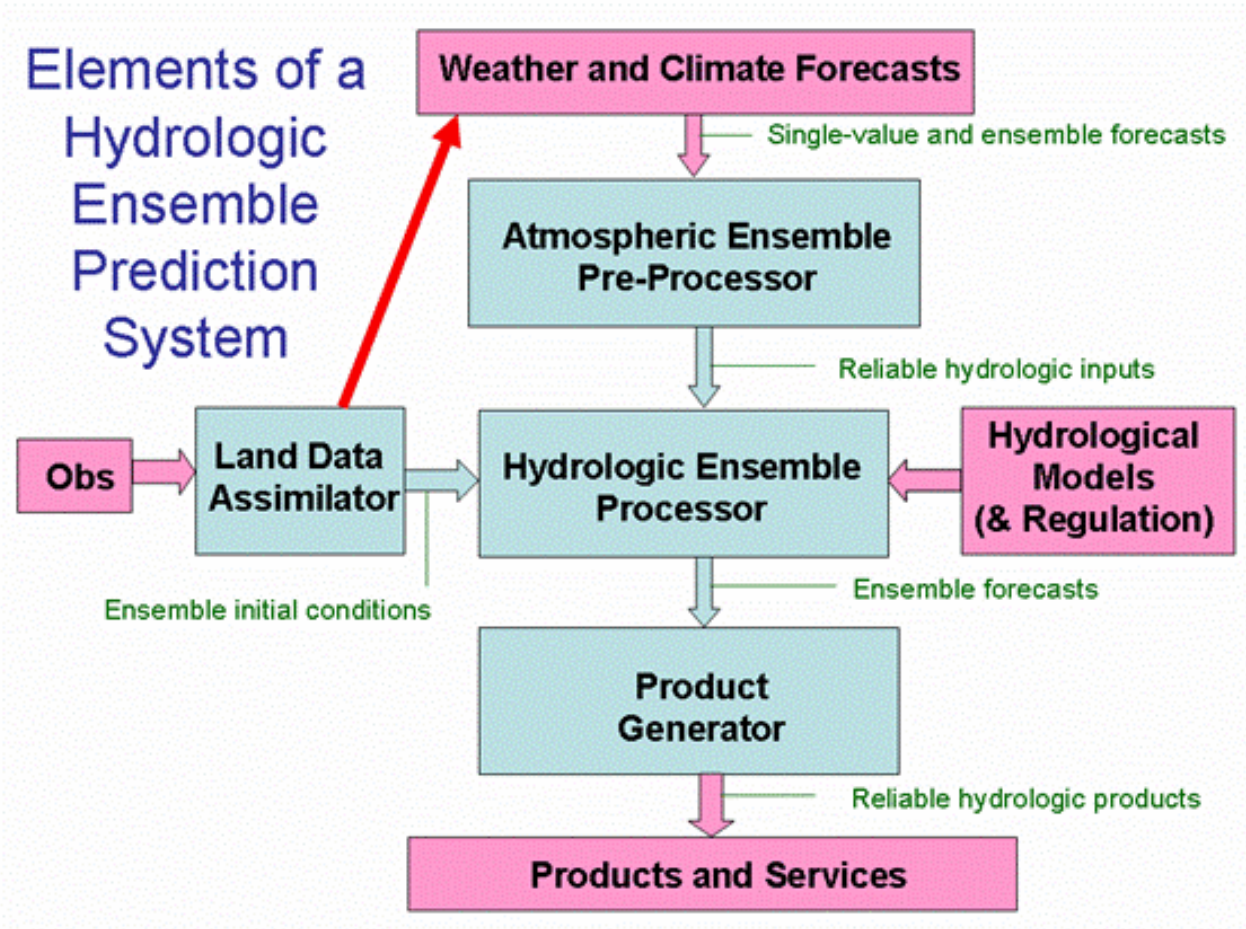
Testbed participants

- Lead
  - Atmospheric Science and Technology, Environment Canada
  - Water Survey of Canada
- Investigators
  - Pr. N. Kouwen and E.D. Soulis, University of Waterloo, Ontario
  - Pr. François Anctil, Université Laval, Québec
  - Pr. Anne-Catherine Favre, INRS-ETE, Québec
  - David Toll, NASA/GSFC
- Users
  - Rob Caldwell, Great Lakes – St. Lawrence Regulation office
  - Richard Turcotte, Centre d'Expertise Hydrique du Québec
  - Dr. Noël Evora, Hydro-Québec research institute (IREQ)

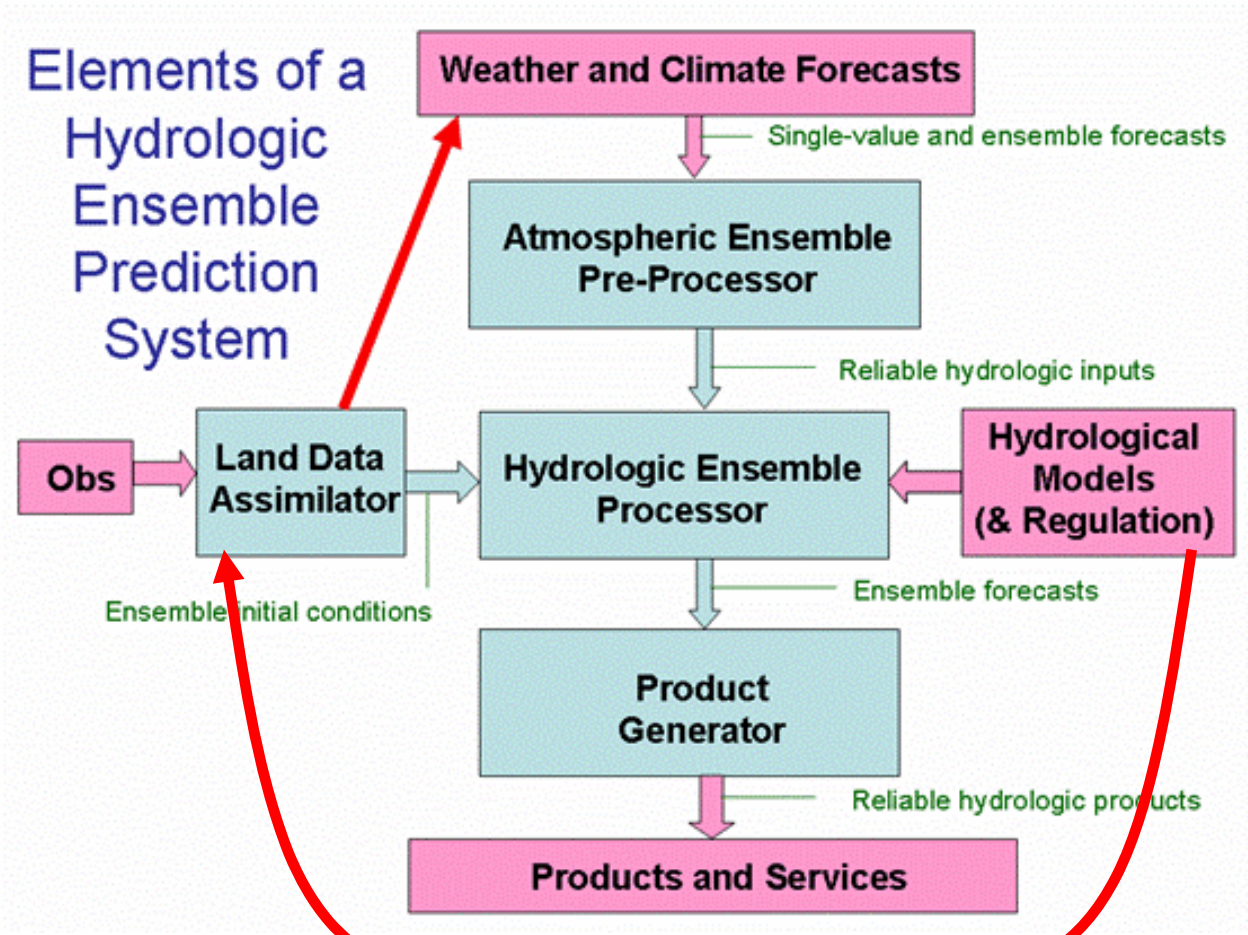
Outline


Elements of a Hydrologic Ensemble Prediction System
4
Weather and Climate Forecasts
Single-value and ensemble forecasts
Atmospheric Ensemble Pre-Processor
5
Reliable hydrologic inputs
3
1
2
Obs
Land Data Assimilator
Hydrologic Ensemble Processor
6
Hydrological Models (& Regulation)
Ensemble initial conditions
Ensemble forecasts
Product Generator
7
Reliable hydrologic products
8
Products and Services

LDAS shared by atmospheric and hydrological modelling systems



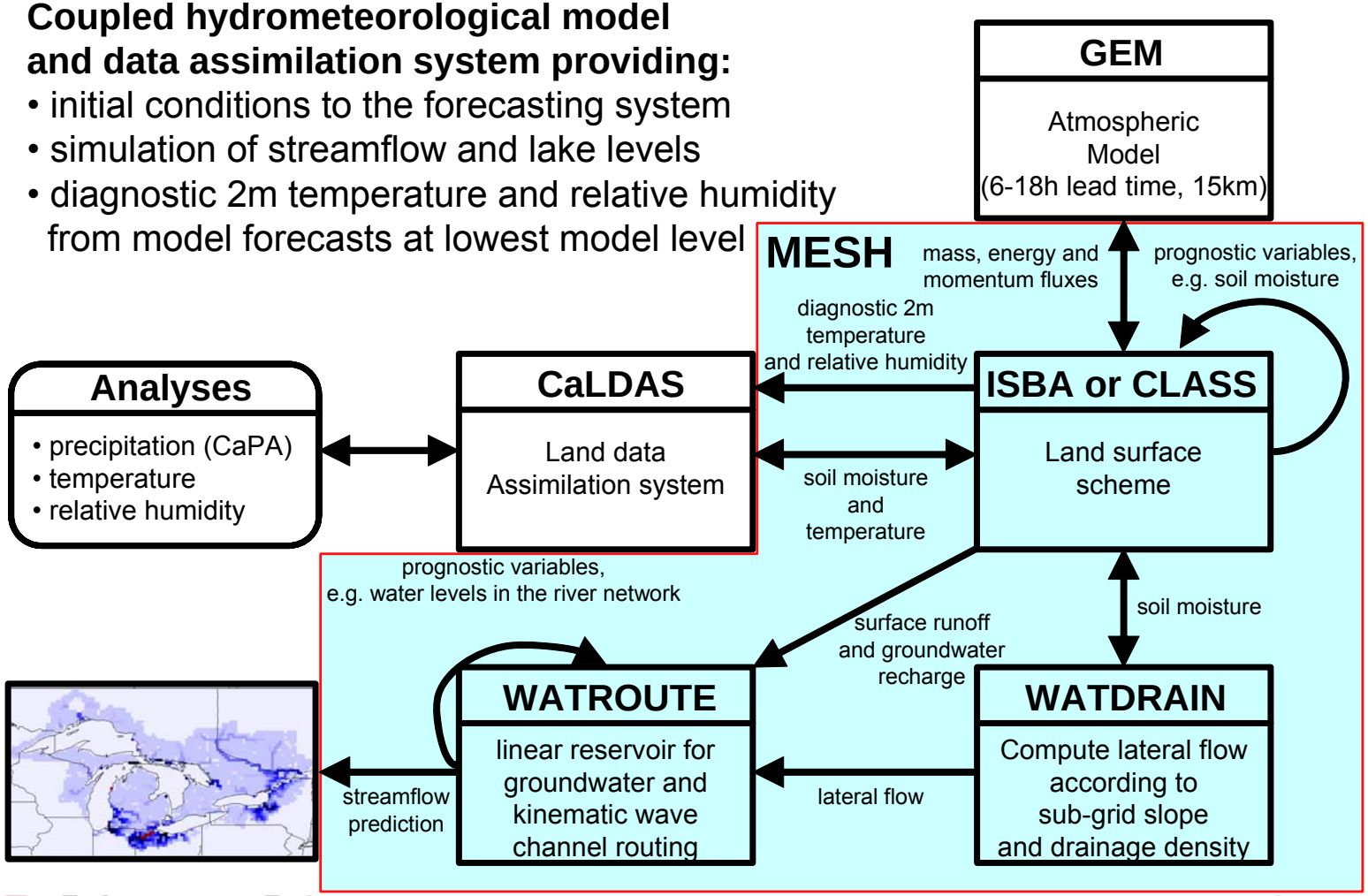
Hydrological model part of the land-surface model used by LDAS



Canadian land data assimilation system (CaLDAS)

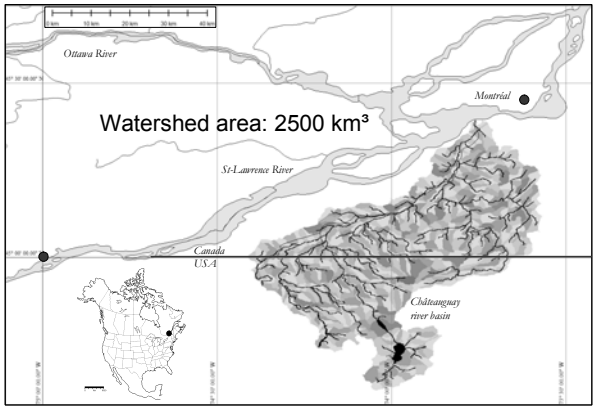
Coupled hydrometeorological model and data assimilation system providing:

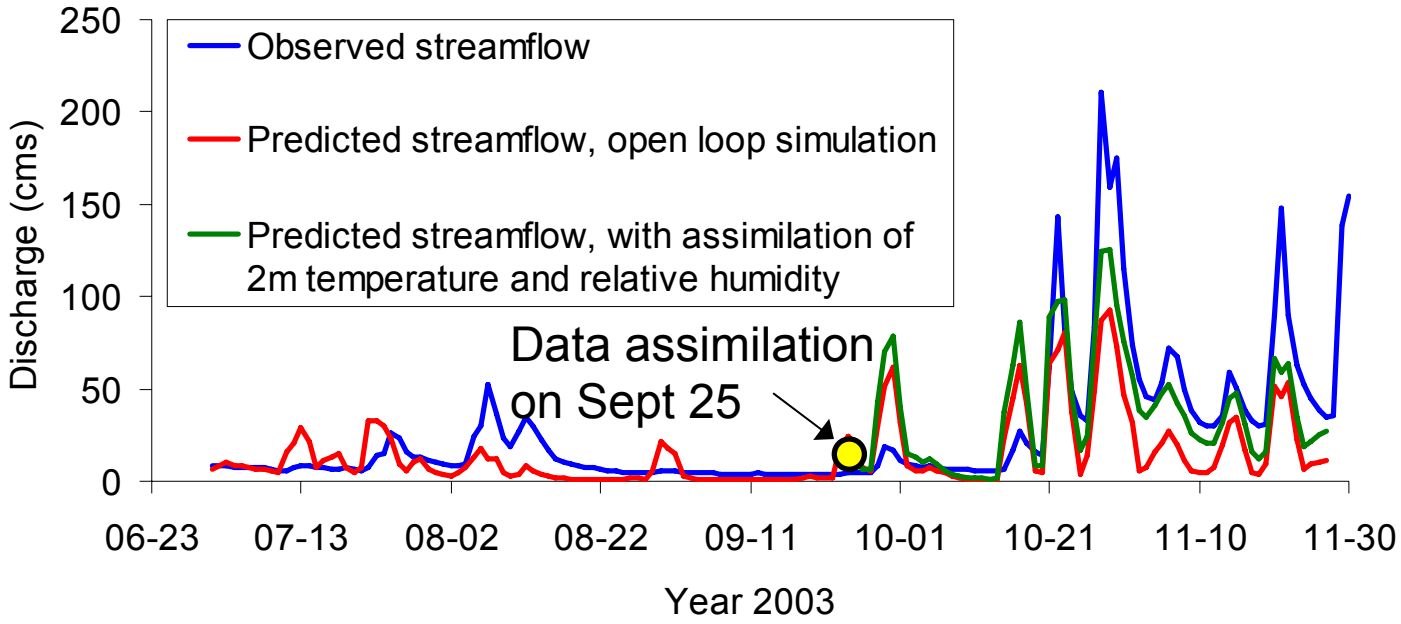
- initial conditions to the forecasting system
- simulation of streamflow and lake levels
- diagnostic 2m temperature and relative humidity from model forecasts at lowest model level



Impact of assimilation on streamflow predictions

- Illustration on Châteauguay watershed
  - Data assimilation of temperature and humidity (not streamflow) improves simulation of base flow
  - Peak flows still underestimated



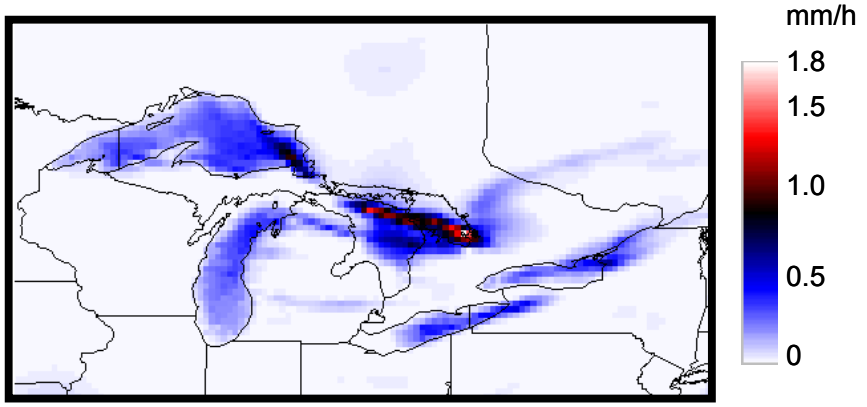


Canada

Canadian Precipitation analysis (CaPA)

- Most important input for CaLDAS
- Combination of multiple sources of information on precipitation using optimal interpolation
  - accumulations and precipitation type from synoptic stations
  - accumulations from coop stations (currently only for Québec)
  - short-term forecast of precipitation and lifting index (convection)
  - rain/no-rain information from ground radar
  - clouds/clear sky information from GOES imagery
  - lightning observations

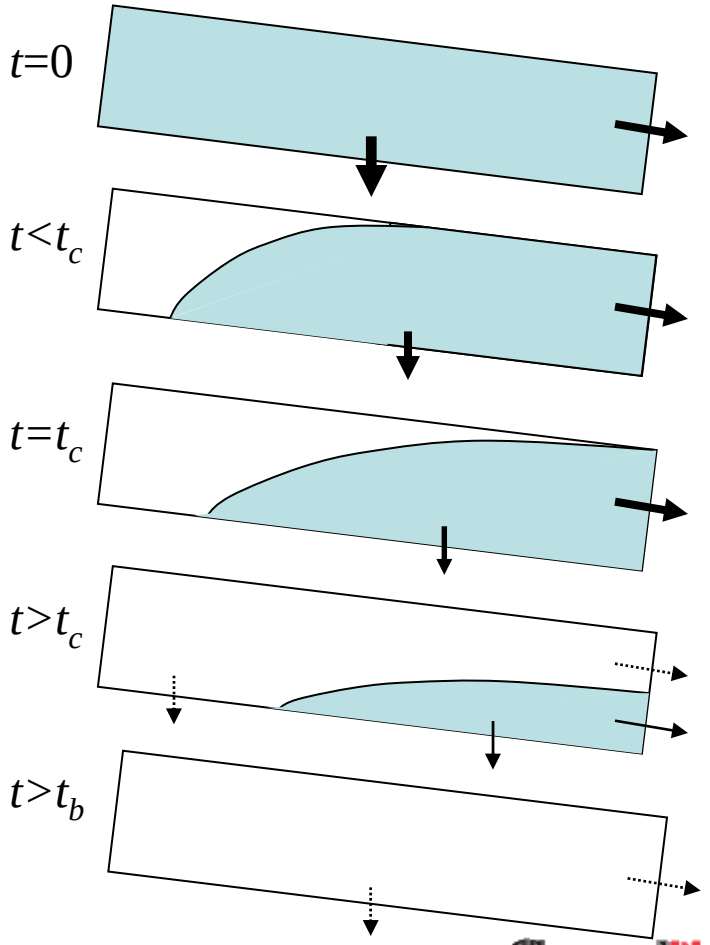
CaPA precipitation analysis, 2007-02-04 00-01Z



Hydrological models

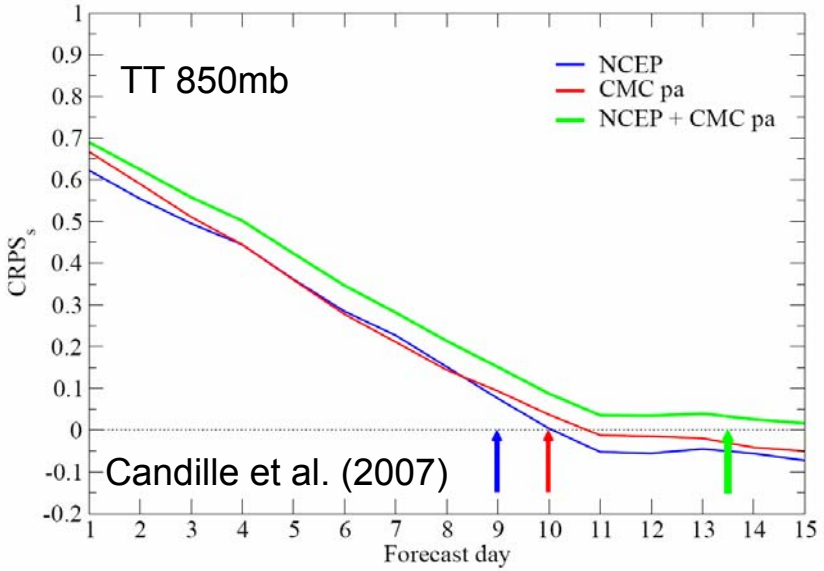
- Combination of a land-surface model, a sub-surface flow model and a routing model
  - Land-surface models:
    - Canadian version of ISBA (Bélair et al., 2003)
    - Canadian Land Surface Scheme (CLASS, Verseghy 2000)
    - WATFLOOD (Kouwen et al., 1993)
  - Subsurface flow model: WATDRAIN (Soulis, 2000)
  - Routing model: WATROUTE (Kouwen, 2006)
- Call to the subsurface flow model added to the GEM atmospheric model

WATDRAIN subsurface flow model



Weather forecasting

- We rely on an operational EPS: the North American Ensemble Forecasting System (NAEFS)
  - 16 (soon 20) members from CMC (Canadian Meteorological Center)
  - 20 members from NCEP (National Centers for Environmental Prediction)



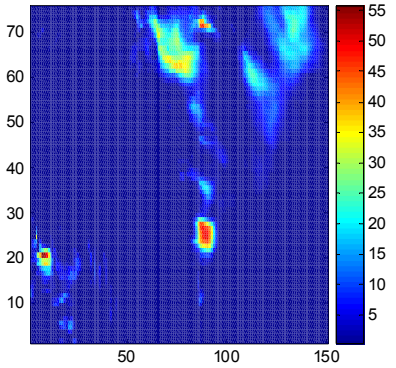
- We are currently using only the CMC members, but should switch to NAEFS this fall
- Recent work by Candille et al. (2007) shows that use of NAEFS increases skill of ensemble forecasts by 1 day for days 4-10 for temperature at 850mb

Atmospheric ensemble preprocessor

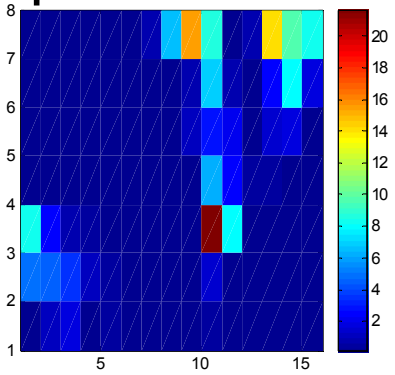
- Literature review of existing ensemble MOS system
- Proposed a modified version of the best member method (Fortin et al., 2006, QJRMS)
- We finally decided to perform no ensemble MOS processing on inputs:
  - because of the distributed nature of the hydrological model
  - because of the lack of a reforecasting experiment
- We focused instead on downscaling of each member from EPS resolution to land-surface resolution
  - Deterministic downscaling based on orography:
    - temperature, humidity pressure, precipitation phase
  - Stochastic downscaling for precipitation

Stochastic downscaling of precipitation: not an easy task...

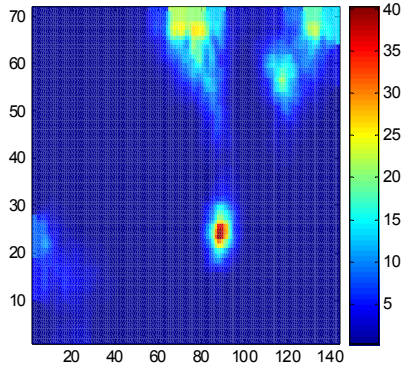
Original 15km forecast

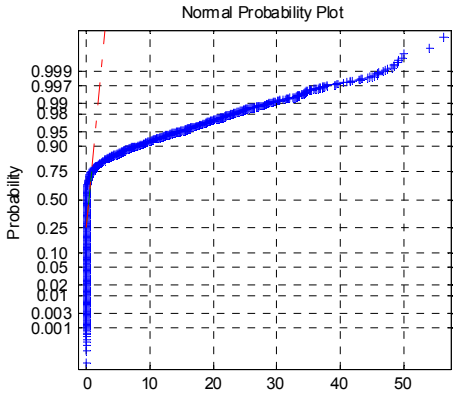


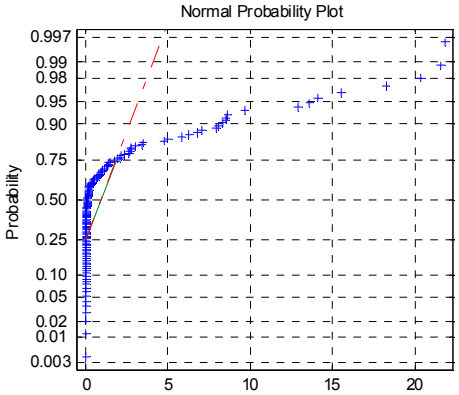
15km forecast upscaled to 1.2°

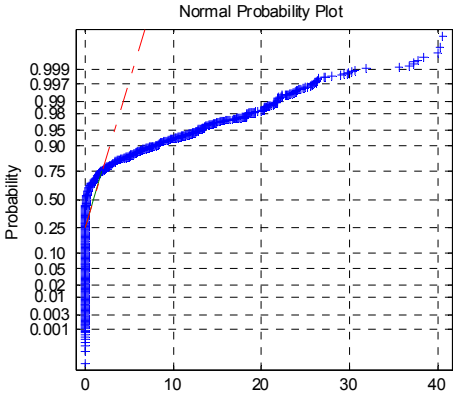


Downscaled forecast



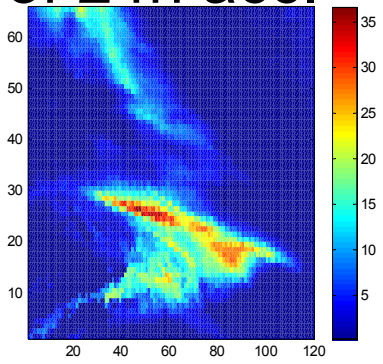




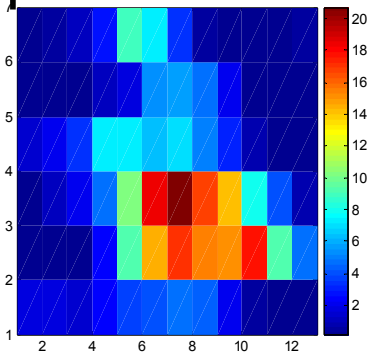


Stochastic downscaling of precipitation: not an easy task...

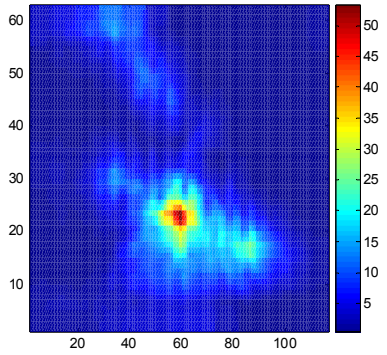
15km forecast of 24h acc.

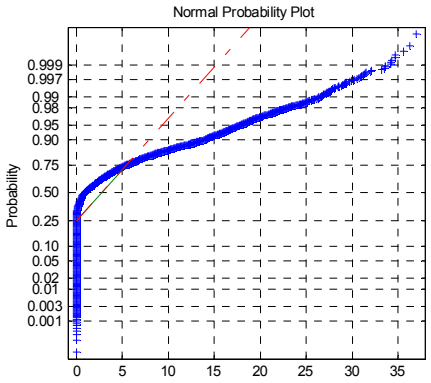


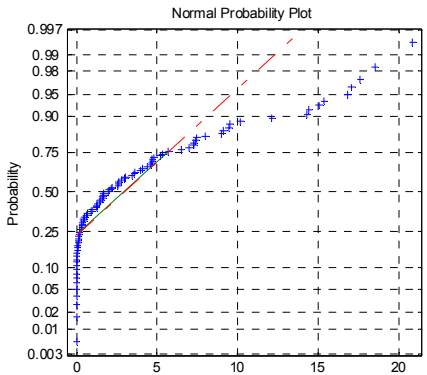
15km forecast upscaled to 1.2°

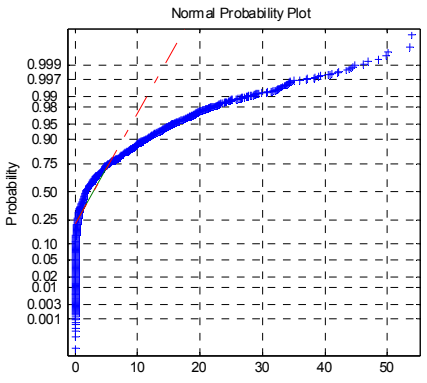


Downscaled forecast









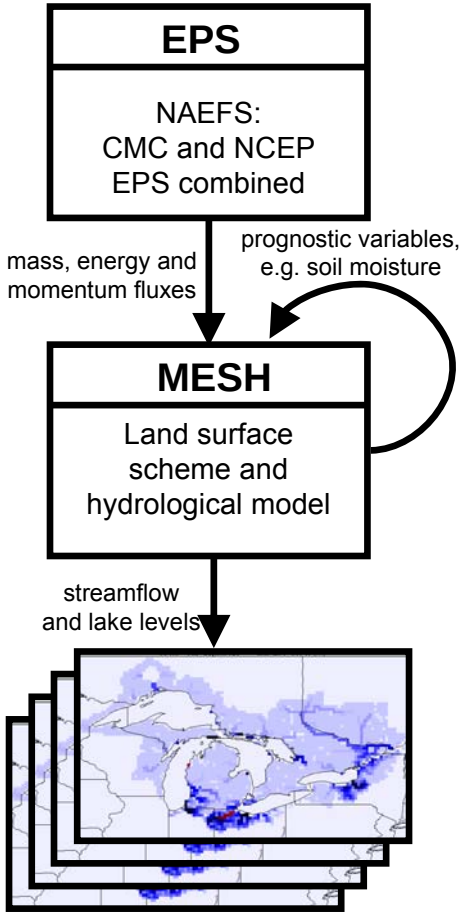
Hydrological ensemble processor

NAEFS* forecasts:
- Lead time of 2 weeks
- Issued twice a day
- 20 CMC† (Canada) + 20 NCEP‡ (US) members
- Resolution of 1.2° (soon 0.9°) at CMC

MESH setup:
- 2 land-surface schemes
- 1 routing scheme
- Horizontal resolution of 0.16°

80 member ensemble reflecting uncertainty in:
- atmospheric initial conditions
- atmospheric modelling
- land surface modelling

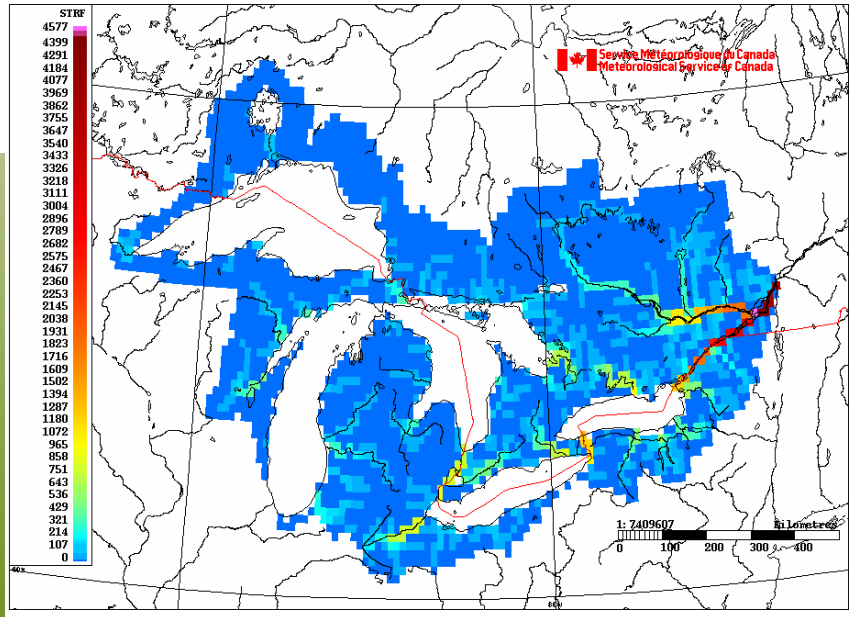
Some of the variables predicted by MESH:
- Soil moisture and temperature
- 2m temperature and humidity
- Snow water equivalent and depth
- Streamflow at each grid point
- Lake levels



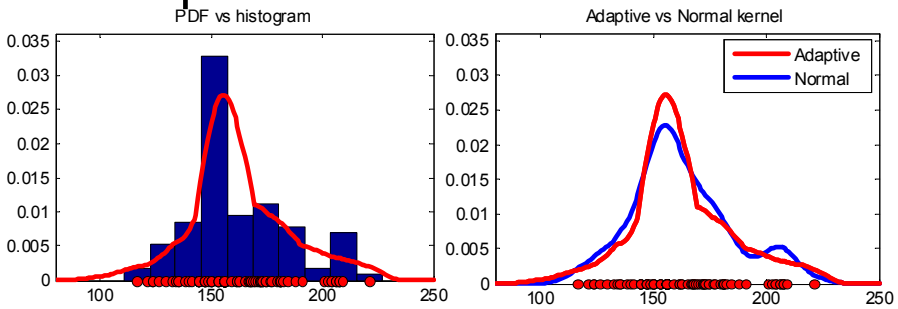
*North American Ensemble Forecasting System
†Canadian Meteorological Center
‡National Centers for Environmental Prediction

Product generator

- SPI (Spherical Projection Interface) open source software used to explore outputs of the system

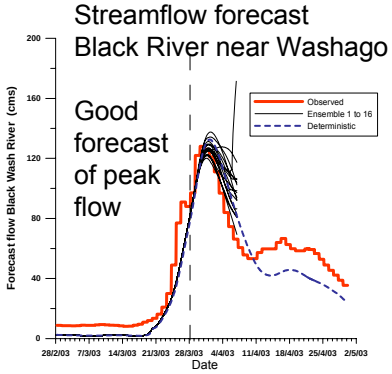


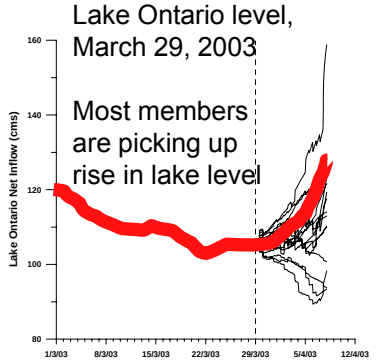
- Smoothing of ensemble pdf at a given point by nonparametric adaptive kernel estimation



Ensemble forecast of mean monthly outflow for Lake Superior

- Spaghetti plots



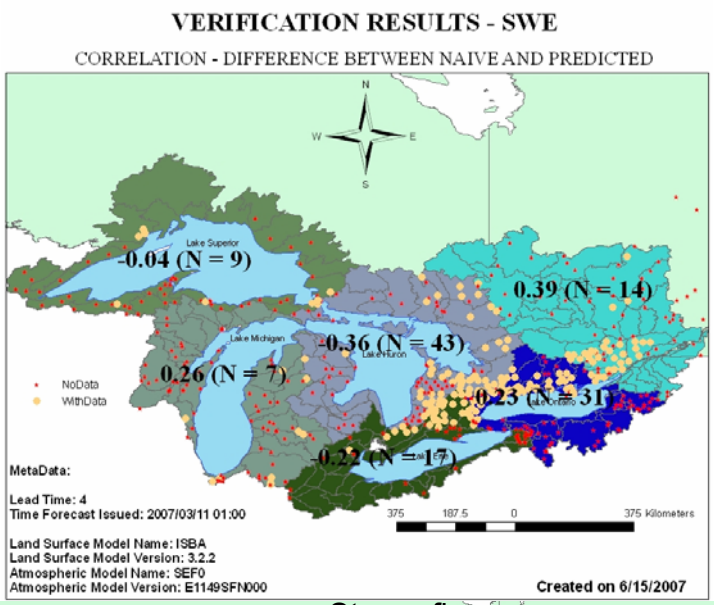


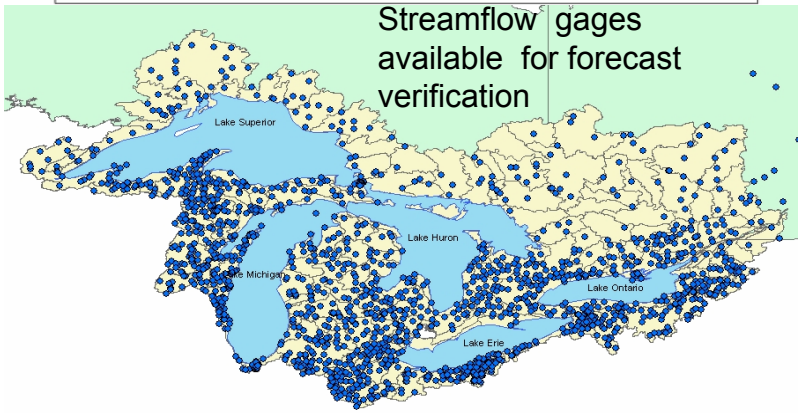
Reliability of generated products

- Difficult to assess reliability of products without a reforecasting experiment
- Research proposal on an empirical evaluation of ensemble MOS techniques applied to ensemble streamflow prediction submitted to the National Science and Engineering Research Council of Canada by Pr. Favre but not funded
- For theoretical reason, we will instead focus on implementing only one: the Bayesian processor of ensemble (Krzysztofowicz, 2004)

Forecast verification

- Ensemble forecasts of snow water equivalent (SWE), snow depth and streamflow stored in an relational database
- Database can be queried to compute deterministic and probabilistic skill scores
  - Large number of categorical and continuous skill scores available
  - For probabilistic skill scores we focus on CRPS and ROC
- Database linked to a GIS to map the results and create reports



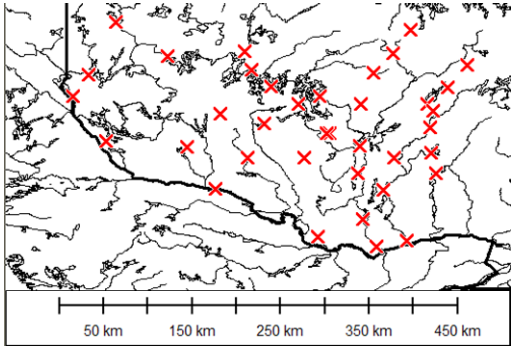


Verification of SWE predictions by individual ensemble members

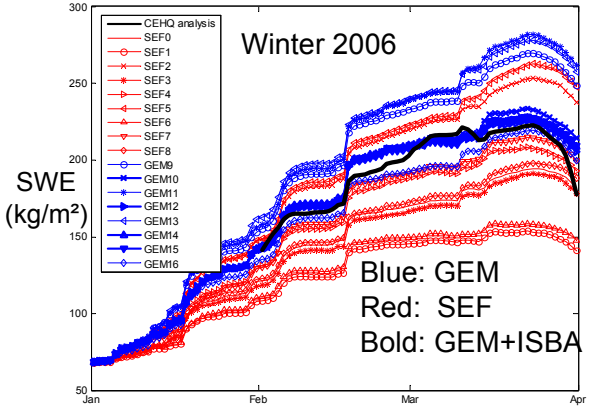
CMC operational EPS for winter 2006

- Atmospheric models:
  - 9 SEF (older model)
  - 8 GEM (more recent model)
- Land surface models:
  - 9 force-restore (older model)
  - 8 ISBA (more recent model)
- **4 members with GEM+ISBA**

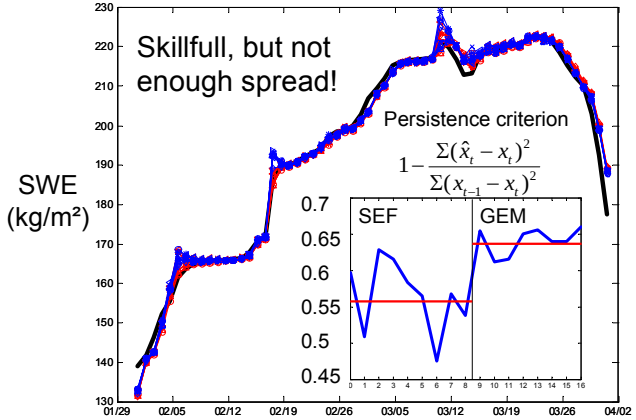
Snow survey network, Ottawa river basin



24h lead-time prediction without land-data assimilation to see bias



Bias-corrected predictions to see if we improve upon persistance



- The four GEM+ISBA members have much less bias in snow water equivalent (SWE)
- The GEM members have more skill (SEF members should be dropped in 2007)

User feedback

- **Monthly** forecasts needed to influence management of the Great Lakes
- Short-term (48h), **higher resolution** forecasts needed on smaller basins
- Users are ready for risk-based decision making from **reliable** forecasts
  - International Joint Commission will move to ensemble forecasting on the Great Lakes, but using climatology as future meteorological scenarios instead of an ensemble of weather forecasts
  - Will make it easier to implement an ensemble prediction system based on weather forecasts

Meeting user requirements

- Monthly forecasts:
  - Compare skill of MESH forced with downscaled seasonal prediction and climatology for weeks 3 and 4
- Short-term forecasts:
  - Couple MESH to regional ensemble prediction systems
  - Improve land-surface and water-surface modelling
    - Increase horizontal resolution of the surface model (up to 1 km)
    - Include a thermodynamical lake model
  - Data assimilation of observed streamflow, lake levels and reservoir releases
- Reliable forecasts:
  - Difficult to prove without a **reforecasting** experiment
  - Implement the **Bayesian processor of ensemble**

Conclusion

- Last two years have been dedicated to getting the forecasting and verification systems up and running
  - Forecasts now issued on a weekly basis
- Although they show interest, end users still have to be convinced that ensemble weather forecasts can improve their hydrological forecasts
- Plan for the next 3 years:
  - Improve the forecasting system to meet user requirements
  - Use NAEFS forecasts instead of only CMC forecasts
  - Compare results with NASA Land Information System (LIS)
  - Turn this experimental forecasting system into an operational system