Processing outputs from a weather forecasting system in order to get ensemble streamflow predictions for free: do we get more than what we paid for?

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How many parameters in your hydrological forecasting system?

- Lumped hydrological models with few free parameters often outperform more complex distributed models for the purpose of simulating stream flow at the outlet, e.g. Smith et al. (2012), DMIP2 project.

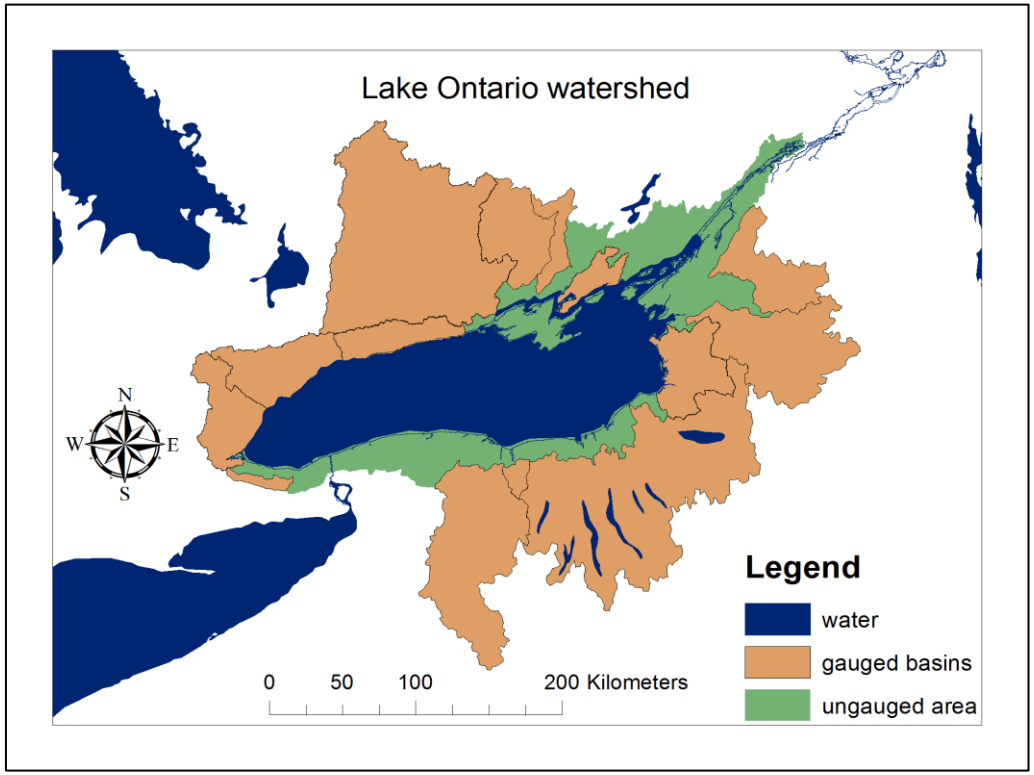
- Lumped hydrological models are still being installed in operations for short-term hydrological forecasting applications, e.g. GR4 in Australia (Bennett et al., 2013).

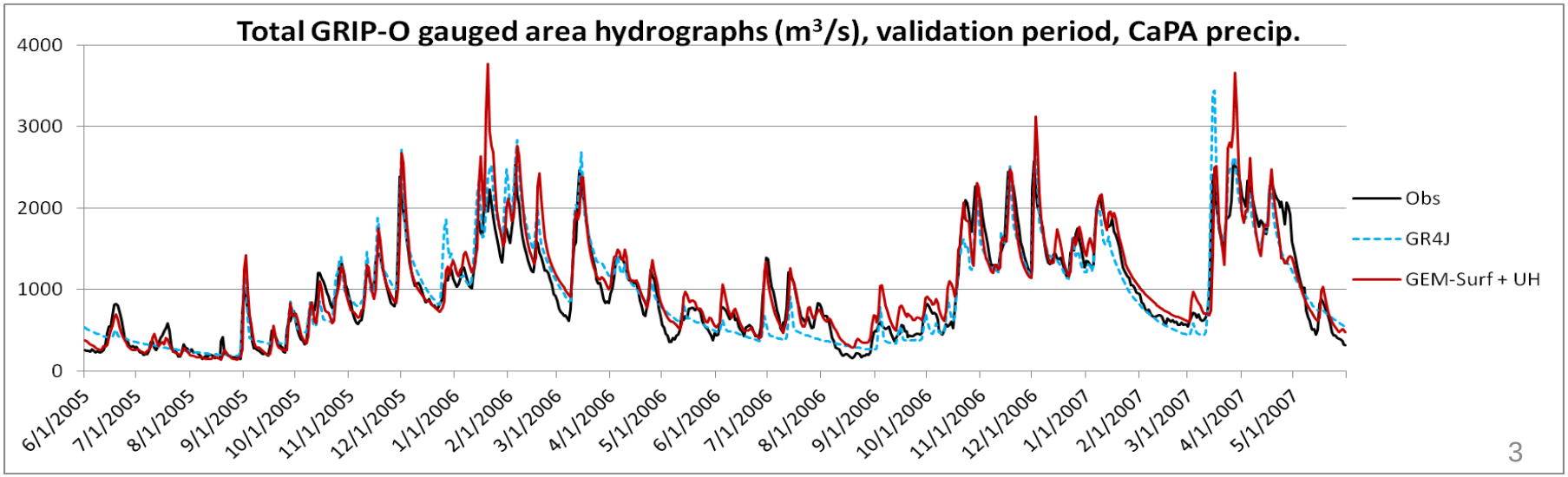
- I will argue that we can do just as well as GR4 (or other lumped models) with a single-parameter model...

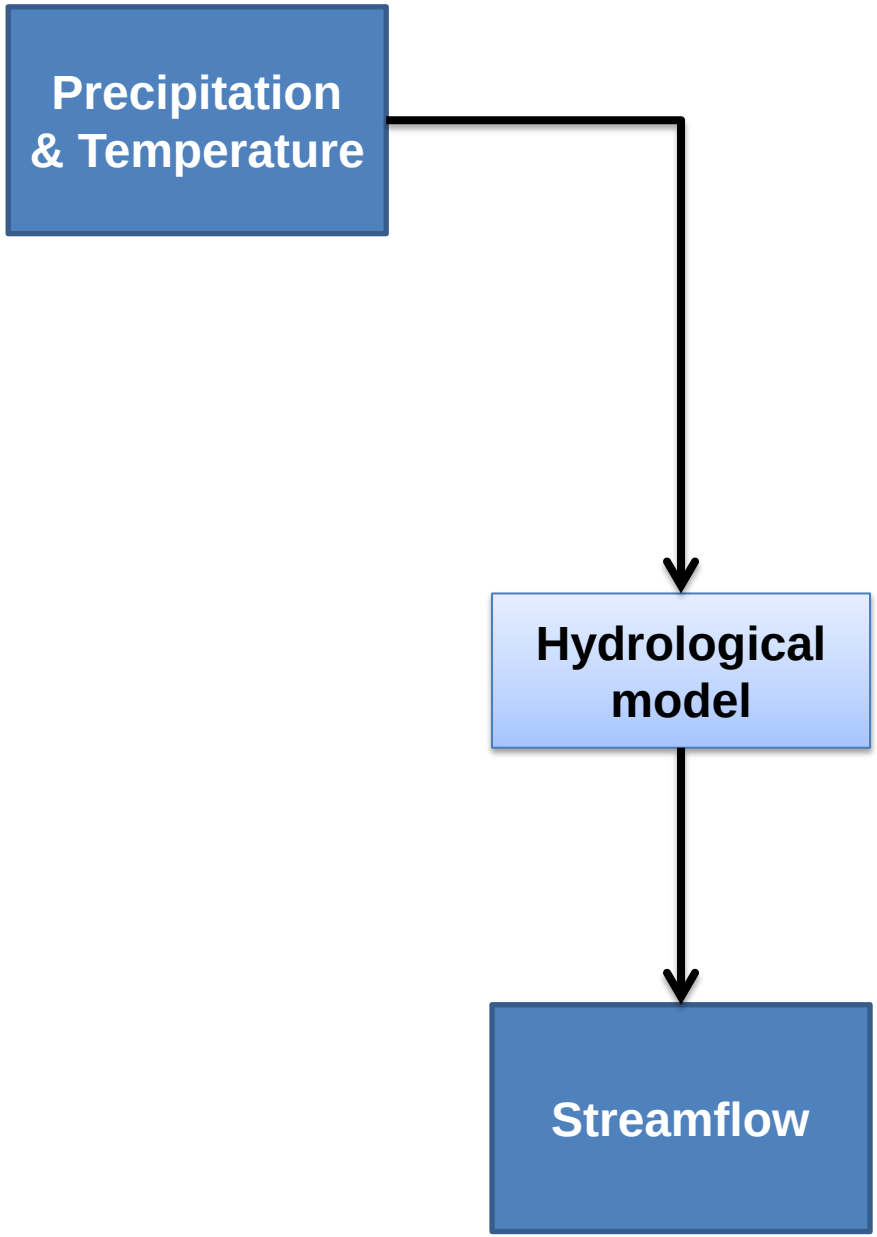
Lake Ontario watershed

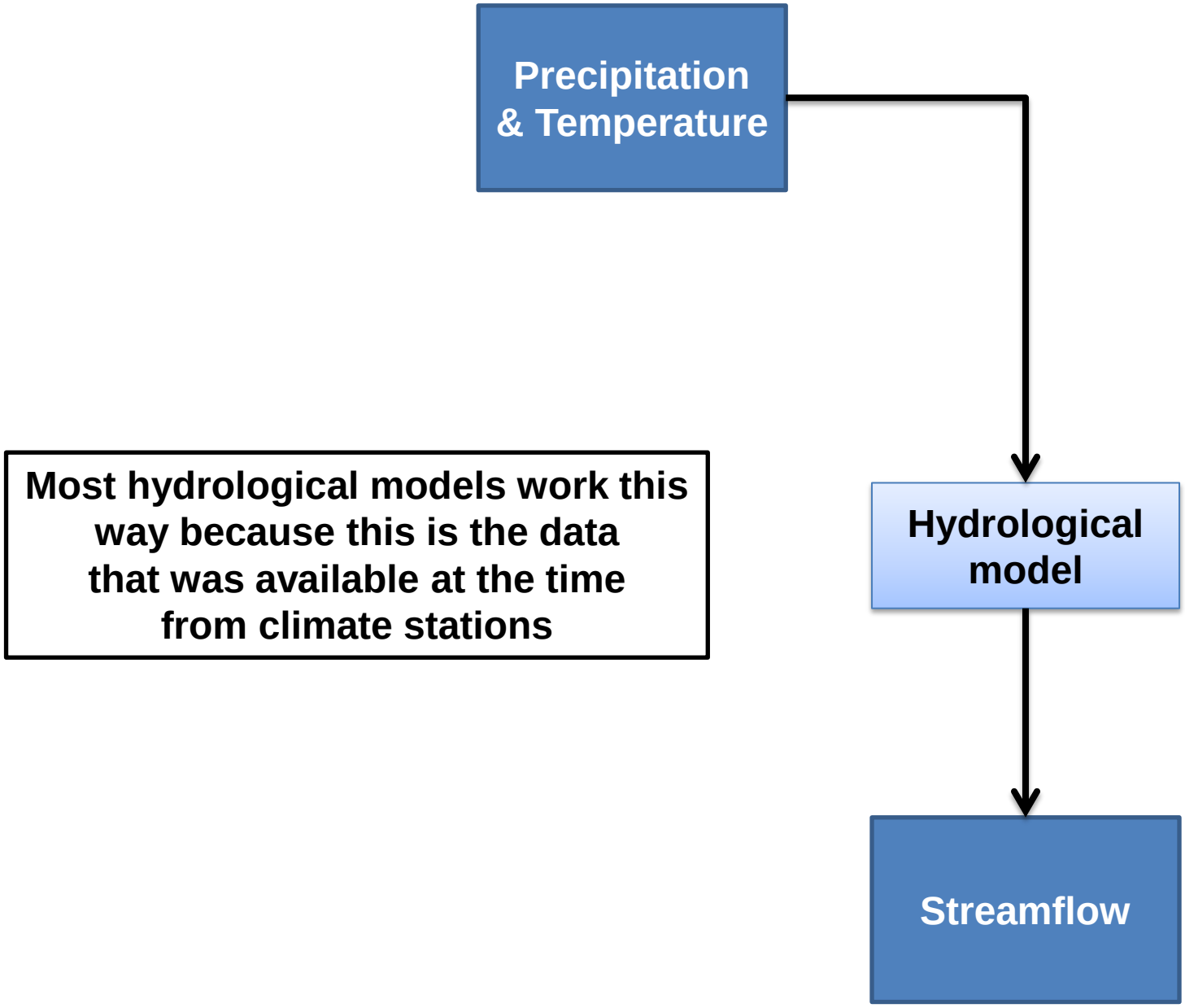
watershed area: 68 000 km²
lake area: 19 000 km²
(upstream area: 684 000 km²)

Black: obs.
Blue: GR4J+CEMANEIGE (6 parameters)
Red: 1 parameter model

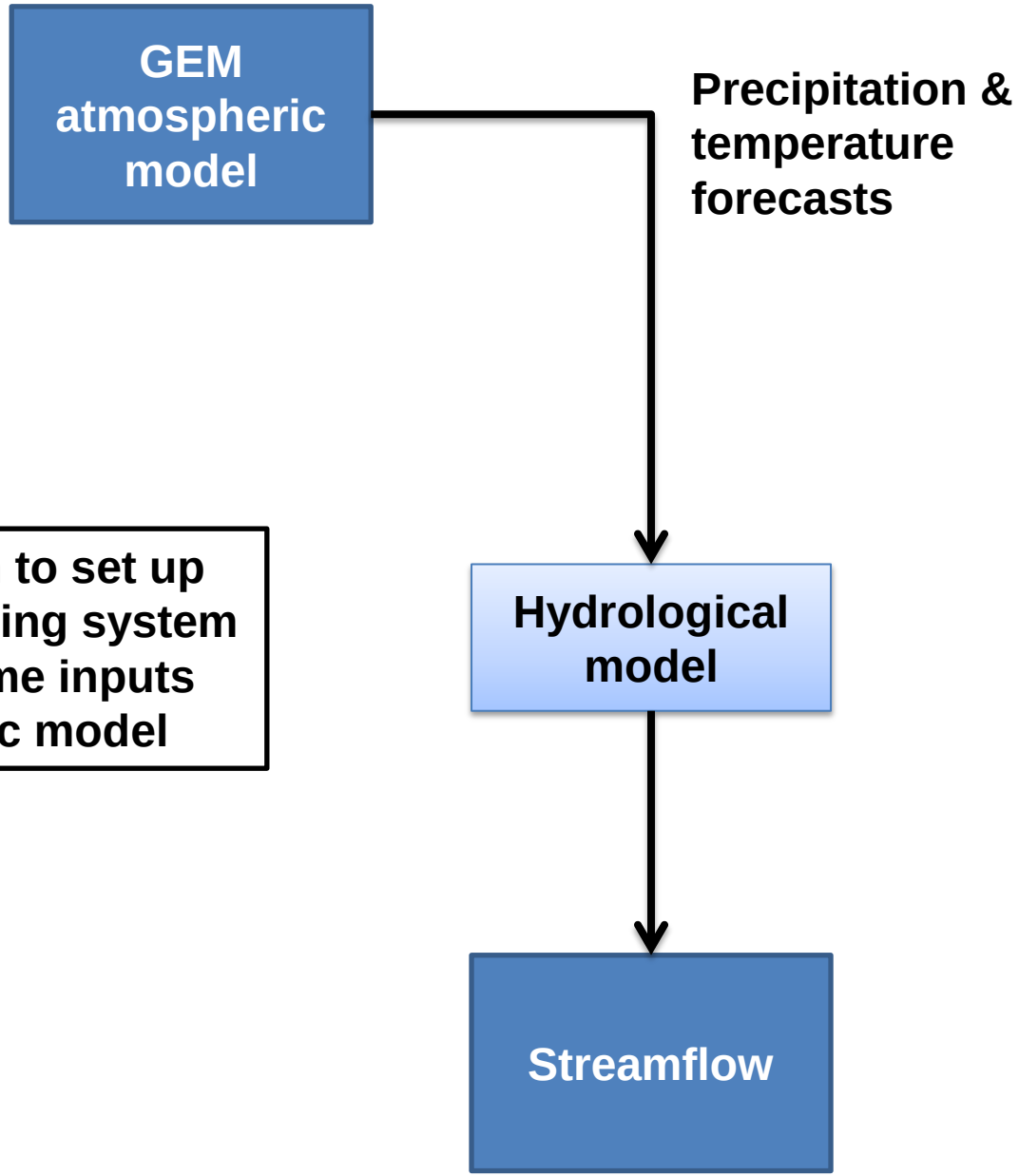





Precipitation
& Temperature
Hydrological
model
Streamflow



Most hydrological models work this way because this is the data that was available at the time from climate stations



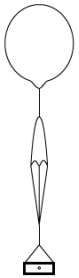
The simplest solution to set up a hydrological forecasting system was to obtain the same inputs from an atmospheric model

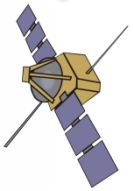
Data assimilation system

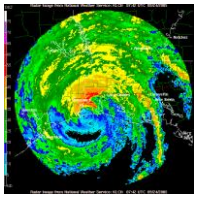
GEM atmospheric model

Land-surface model

Precipitation & temperature forecasts



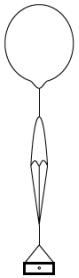


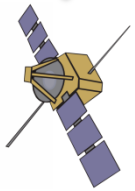


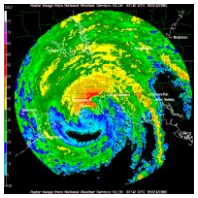
A fairly complex system is required to get these two inputs, including global EOS, data assimilation and land-surface modelling

Hydrological model

Streamflow







Data assimilation system

GEM atmospheric model

Precipitation & temperature forecasts

Land-surface model

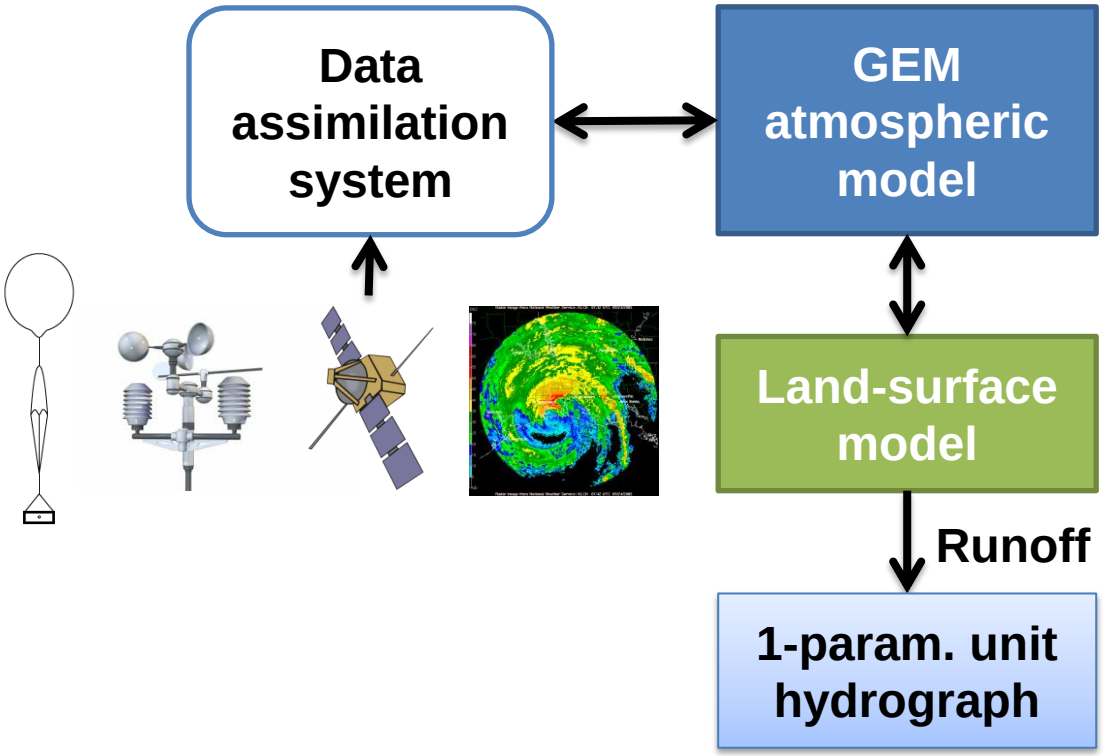
Runoff

Routing model

Hydrological model

Streamflow

Modern land-surface models all provide, as an output, an estimate of the grid runoff, i.e. the water that does not infiltrate or else percolates through the soil column. This can serve as an input to a routing model.


Data assimilation system
GEM atmospheric model
Land-surface model
Runoff
1-param. unit hydrograph

GR4J's UH2

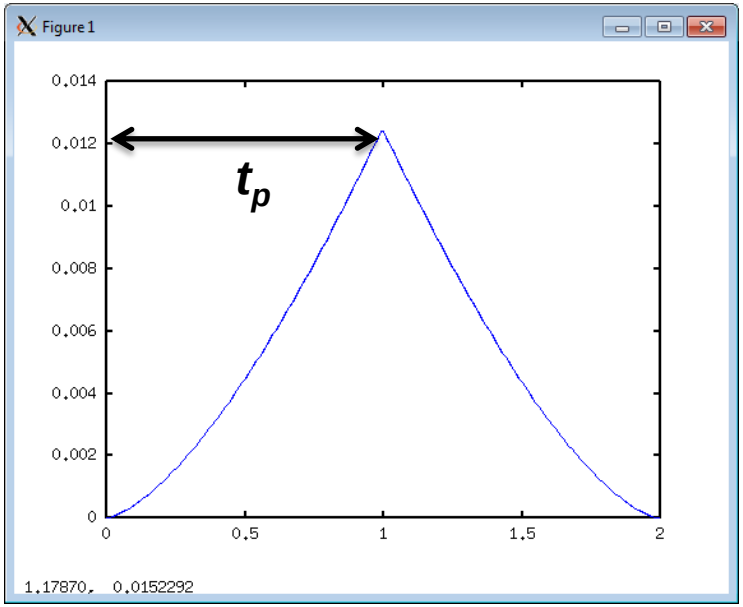
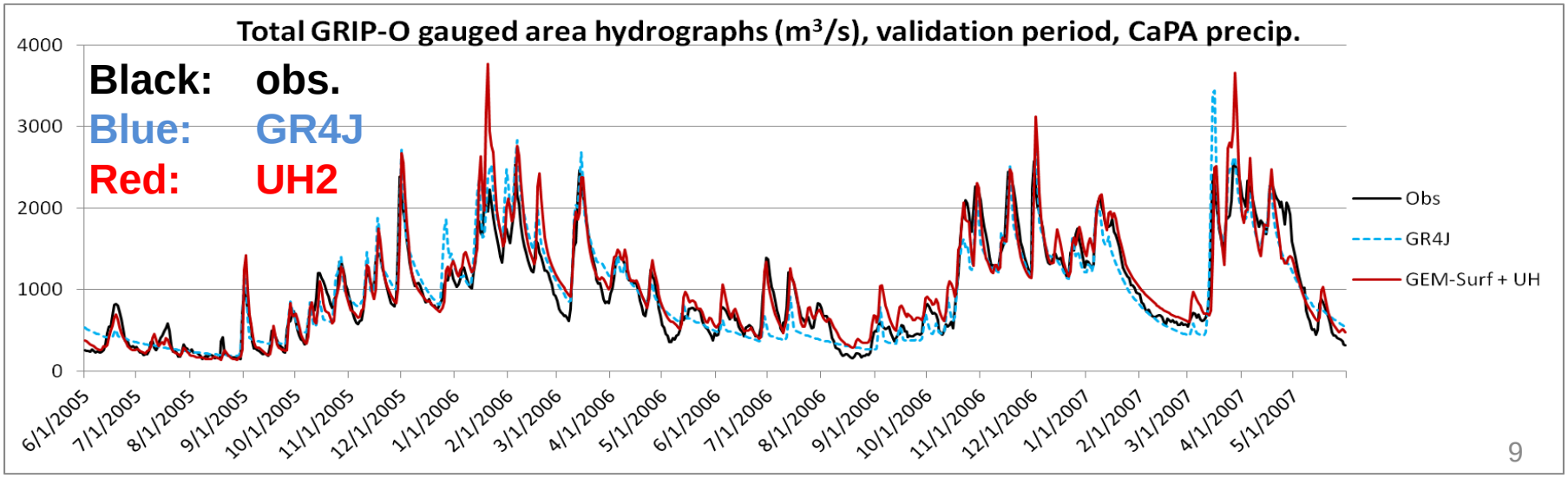


Figure 1
t_p
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
0.5
1
1.5
2
1.17870, 0.0152292


Total GRIP-O gauged area hydrographs (m³/s), validation period, CaPA precip.
Black: obs.
Blue: GR4J
Red: UH2
4000
3000
2000
1000
0
6/1/2005
7/1/2005
8/1/2005
9/1/2005
10/1/2005
11/1/2005
12/1/2005
1/1/2006
2/1/2006
3/1/2006
4/1/2006
5/1/2006
6/1/2006
7/1/2006
8/1/2006
9/1/2006
10/1/2006
11/1/2006
12/1/2006
1/1/2007
2/1/2007
3/1/2007
4/1/2007
5/1/2007
Obs
GR4J
GEM-Surf + UH

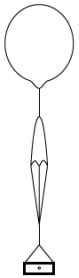
Data assimilation system

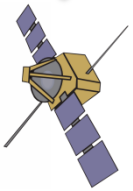
GEM atmospheric model

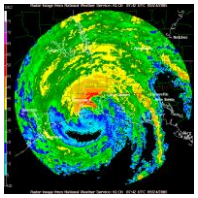
Land-surface model

Runoff

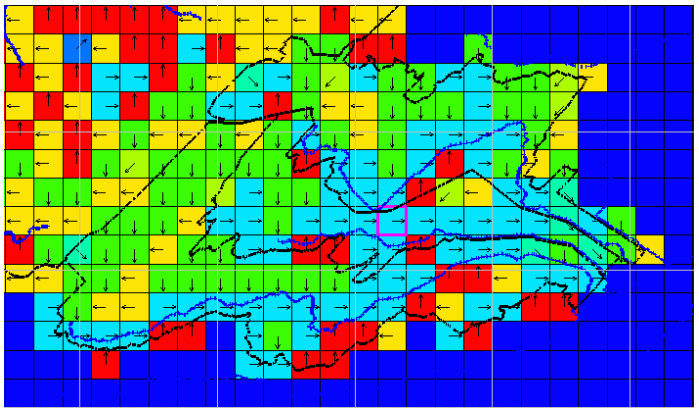
Distributed routing





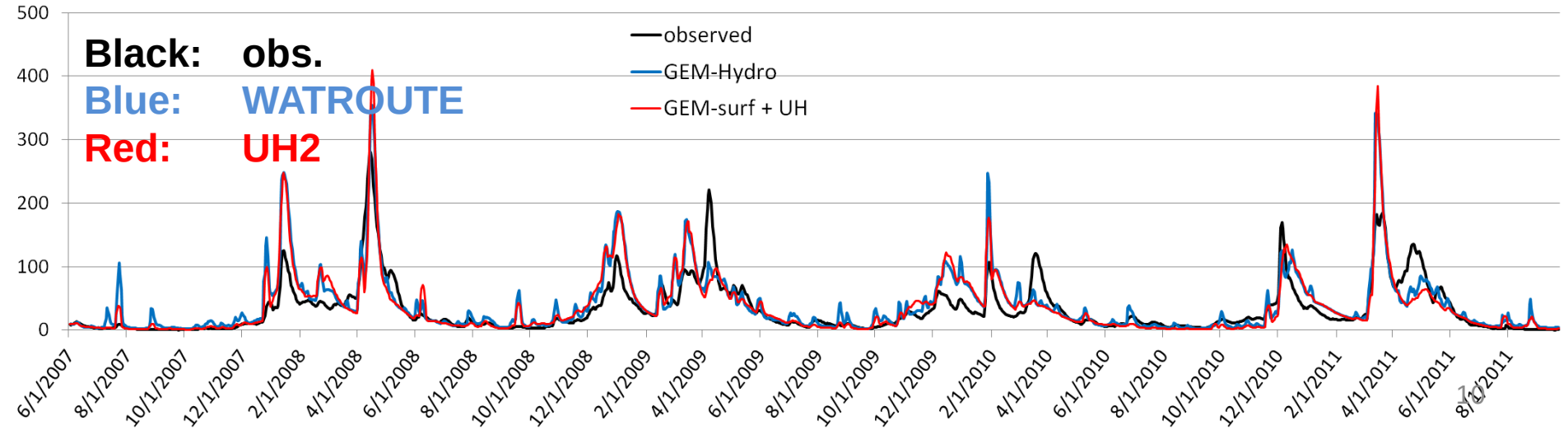


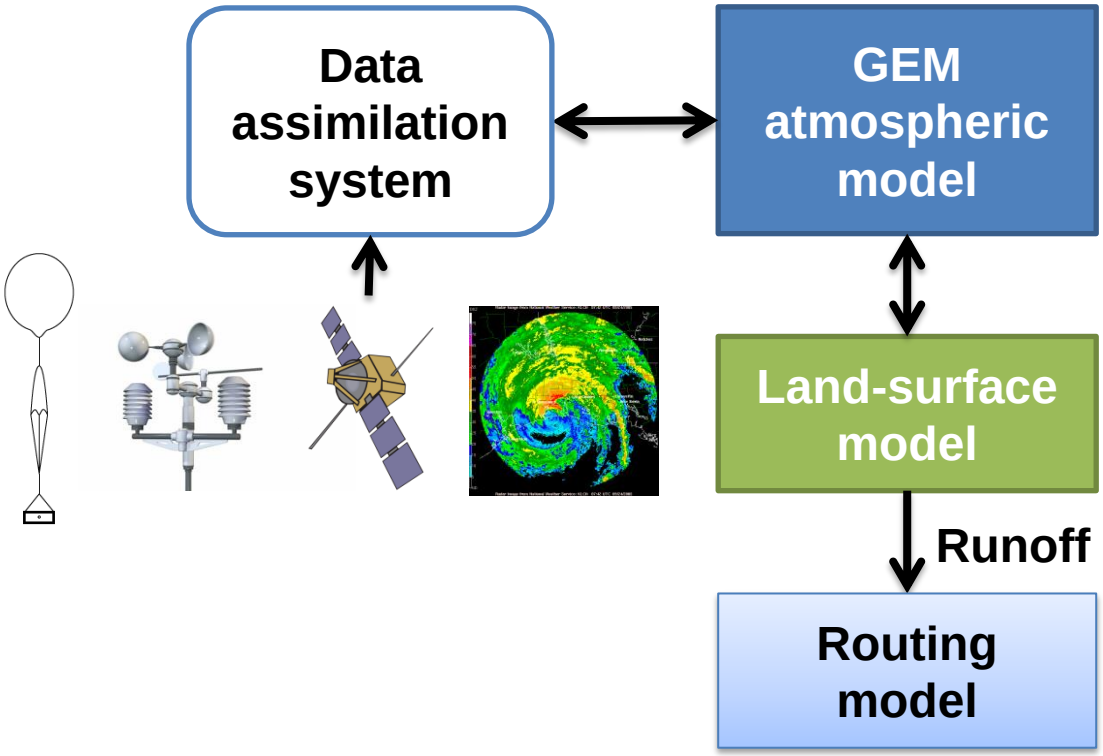
WATROUTE



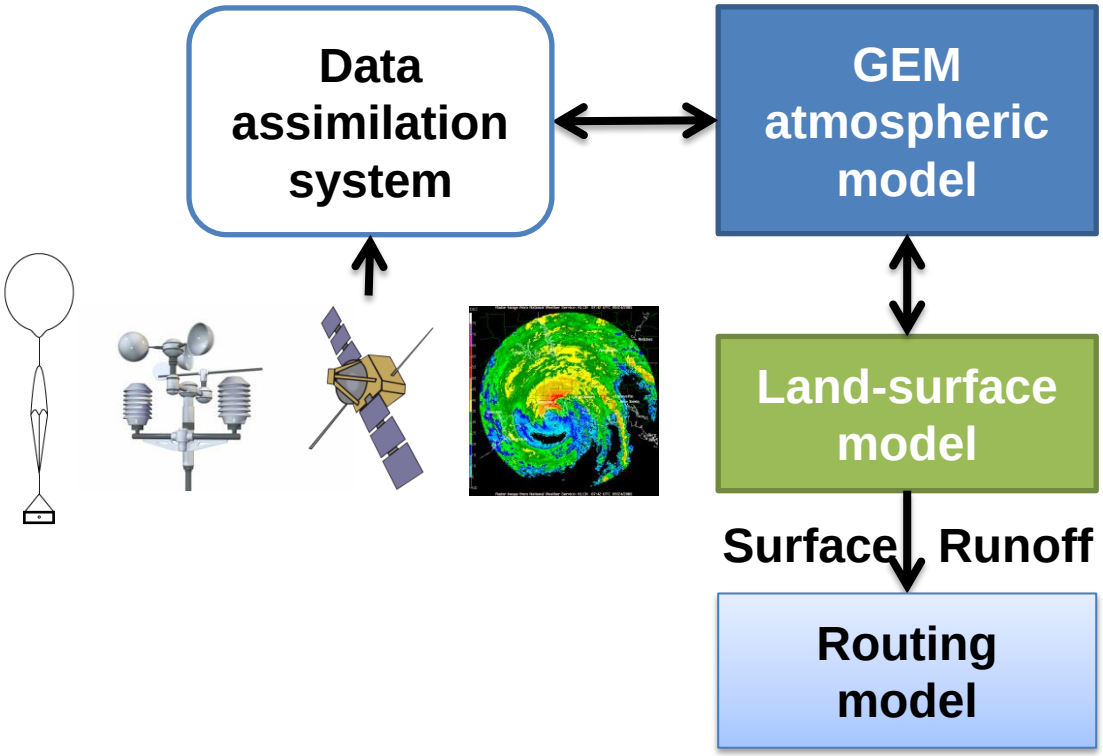
Streamflow (m^3/s)

Moira (CA), 02HL001 - 2582 km^2, regulated, daily streamflow, new SVS, default parameters





Objective	Distributed routing	Unit hydrograph
Estimate flow at the outlet	✓	✓
Flow at the intermediate locations	✓	
Nudging of upstream stations	✓	
Faster run time / larger ensembles		✓
Faster calibration of land-surface scheme		✓
Faster obs. operator for data assimilation		✓

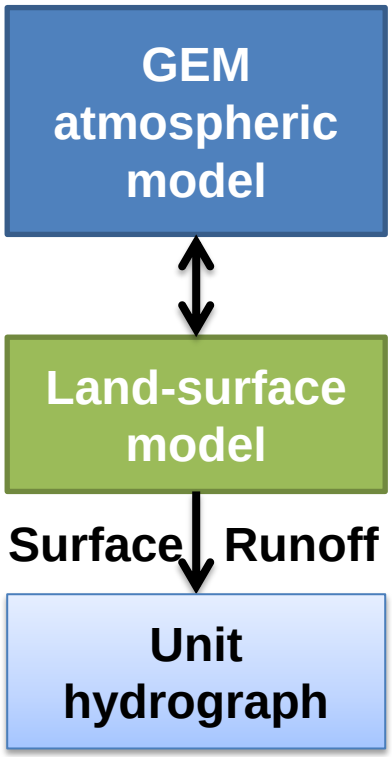


Some atmospheric models only provide surface runoff

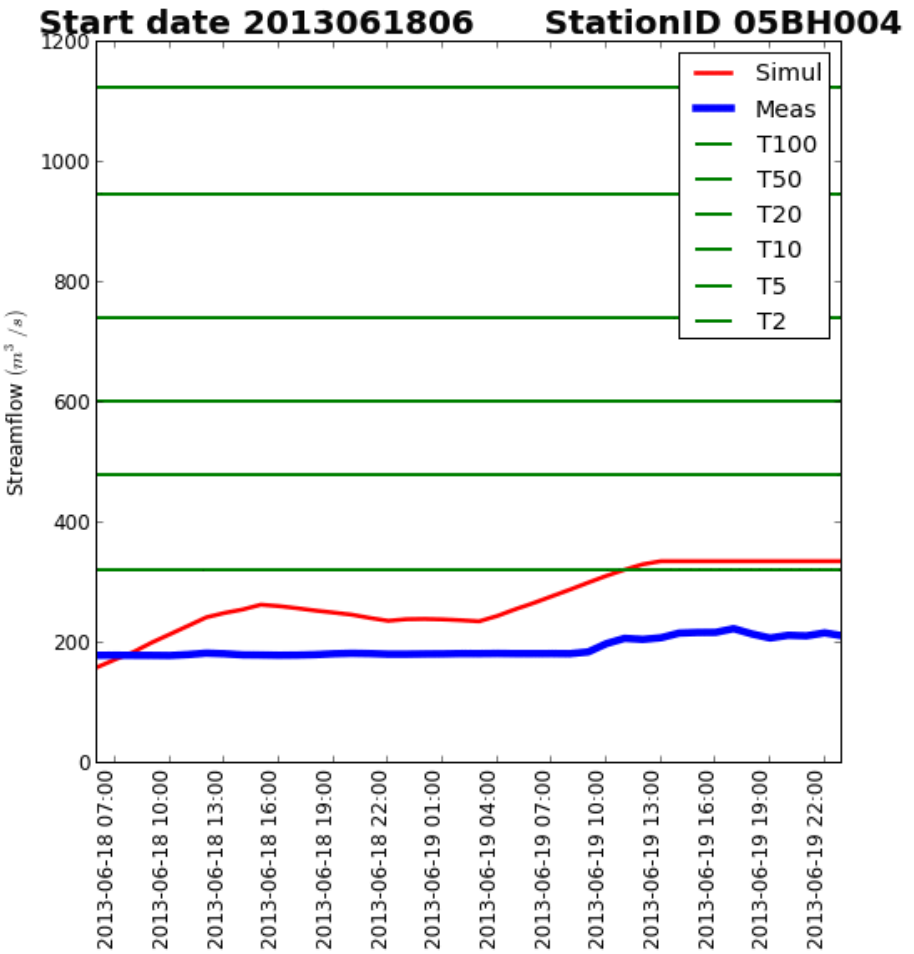
- no lateral flow, groundwater recharge or baseflow
- can still be useful for forecasting high flows

June 2013 Calgary flood

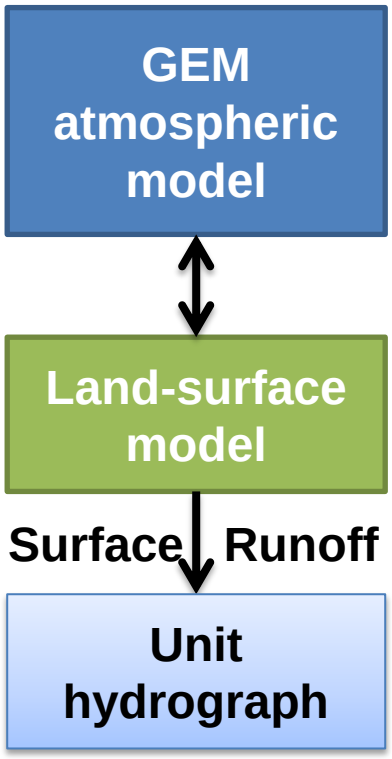
Deterministic flood guidance for Bow River at Calgary (based on GEM@2.5-km)



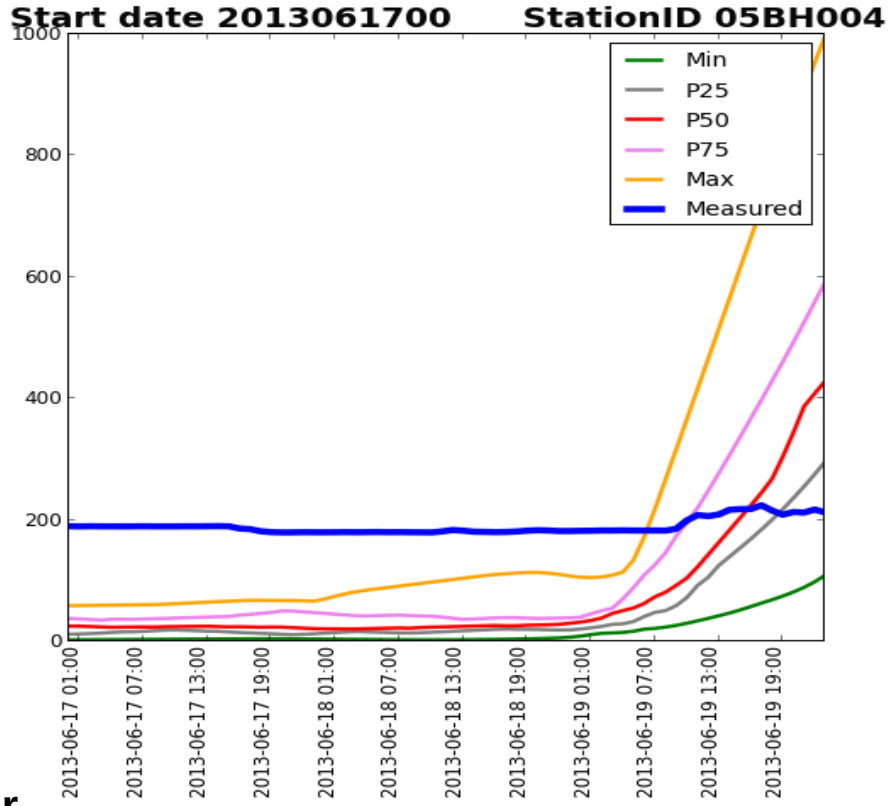
- Obtain basin-average runoff from GEM's land-surface model
- Compute Q(t) using unit hydrograph theory
- Because baseflow is not available, the recession too quick
- For flood warning purposes, compute M(t) = max(Q(1:t))
- Compare M(t) to flood stage
- Issue an alert if M(t) is above flood stage



Ensemble forecast of flow for Bow River at Calgary (based on GEM@15-km)



- Compute M(t) for each ensemble member
- Compute quantiles of M(t)
- Compare quantiles to flood stage
- Issue an alert if some quantile is above flood stage
- Or provide the different quantiles to the end user...



Take home messages

- Take a look at the runoff from your preferred NWP system. It might soon not be necessary to run your own land-surface model for hydrological prediction!
- Although this runoff is distributed spatially, a lumped 1–parameter routing model can make hydrological forecasting quite simple, if all you care about is streamflow at the outlet.
- Would be possible to obtain multi-model ensemble hydrological forecasts by using multiple NWP systems
- Also, "zero-parameter" hydrological models are coming, as weather forecasting systems start to simulate flow directly as part of their numerical guidance

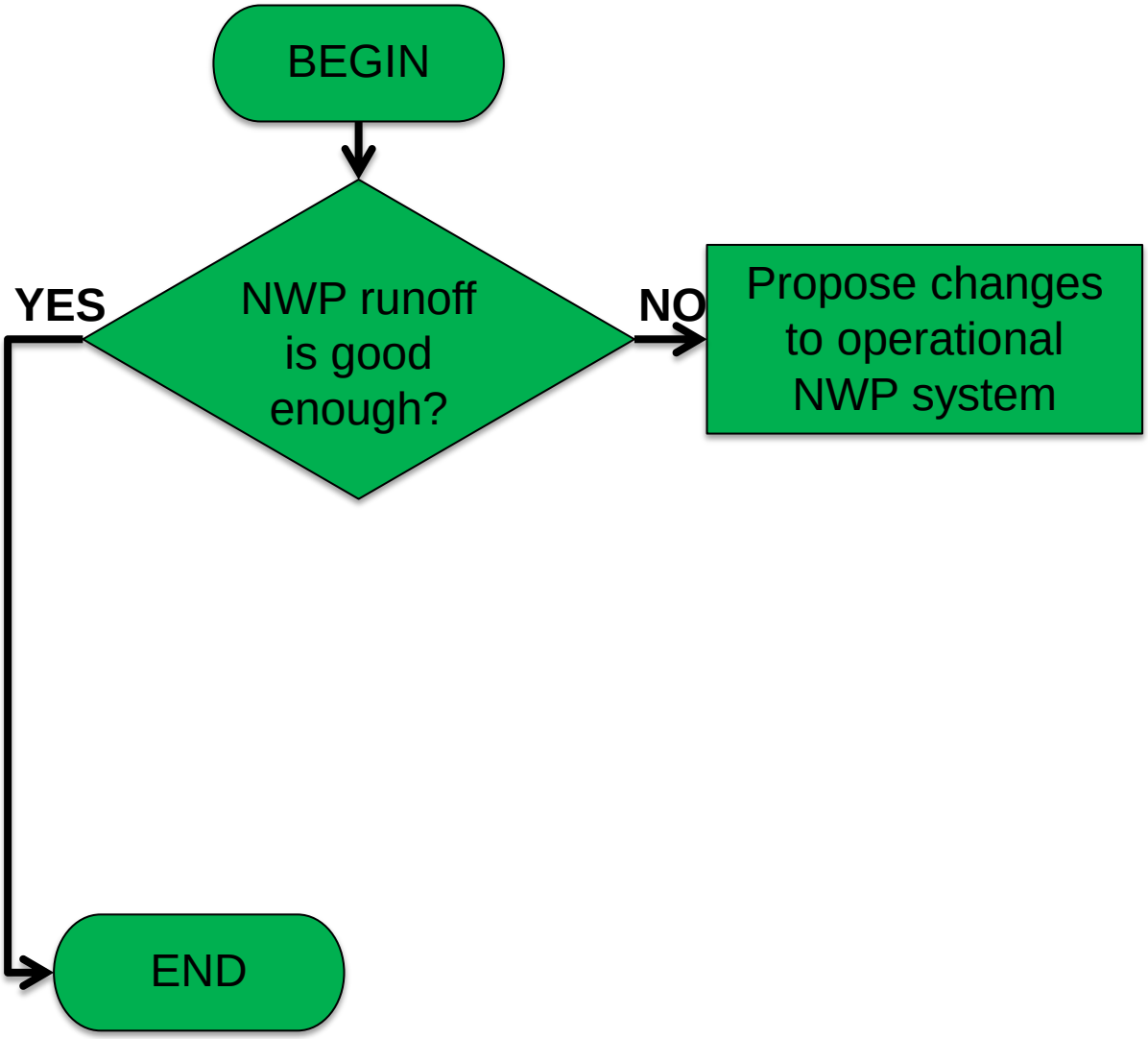
What if you don't like what you find?

- Because land-surface models in NWP systems are optimized for weather forecasting, runoff - even if available - might not be of sufficient quality for hydrological forecasting applications

- Meteorologists can be hard to convince that it's worth it for them to improve their model *simply to get better streamflow forecasts...*

- One solution is to make your own weather and runoff forecast!

What if you don't like what you find?



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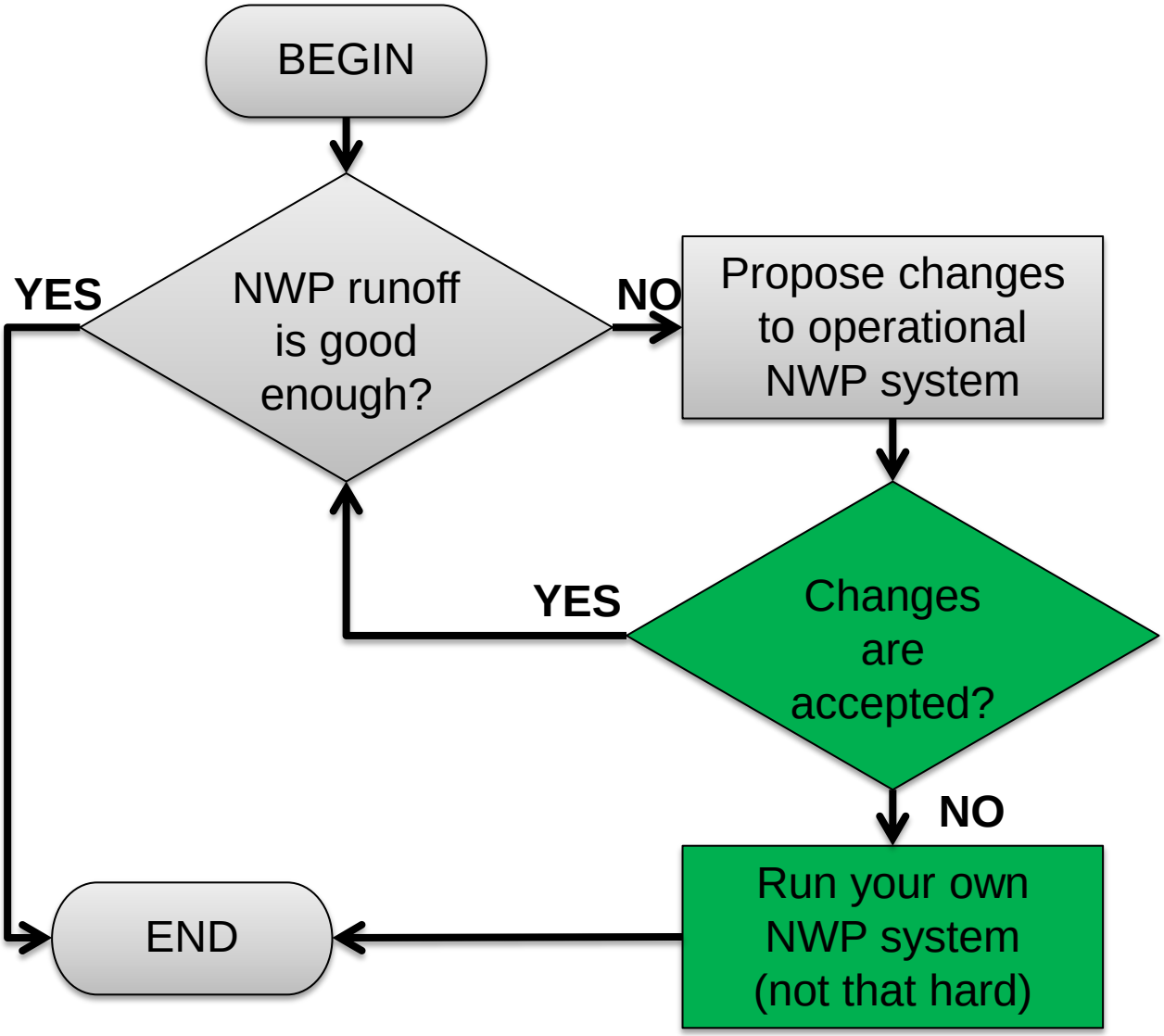
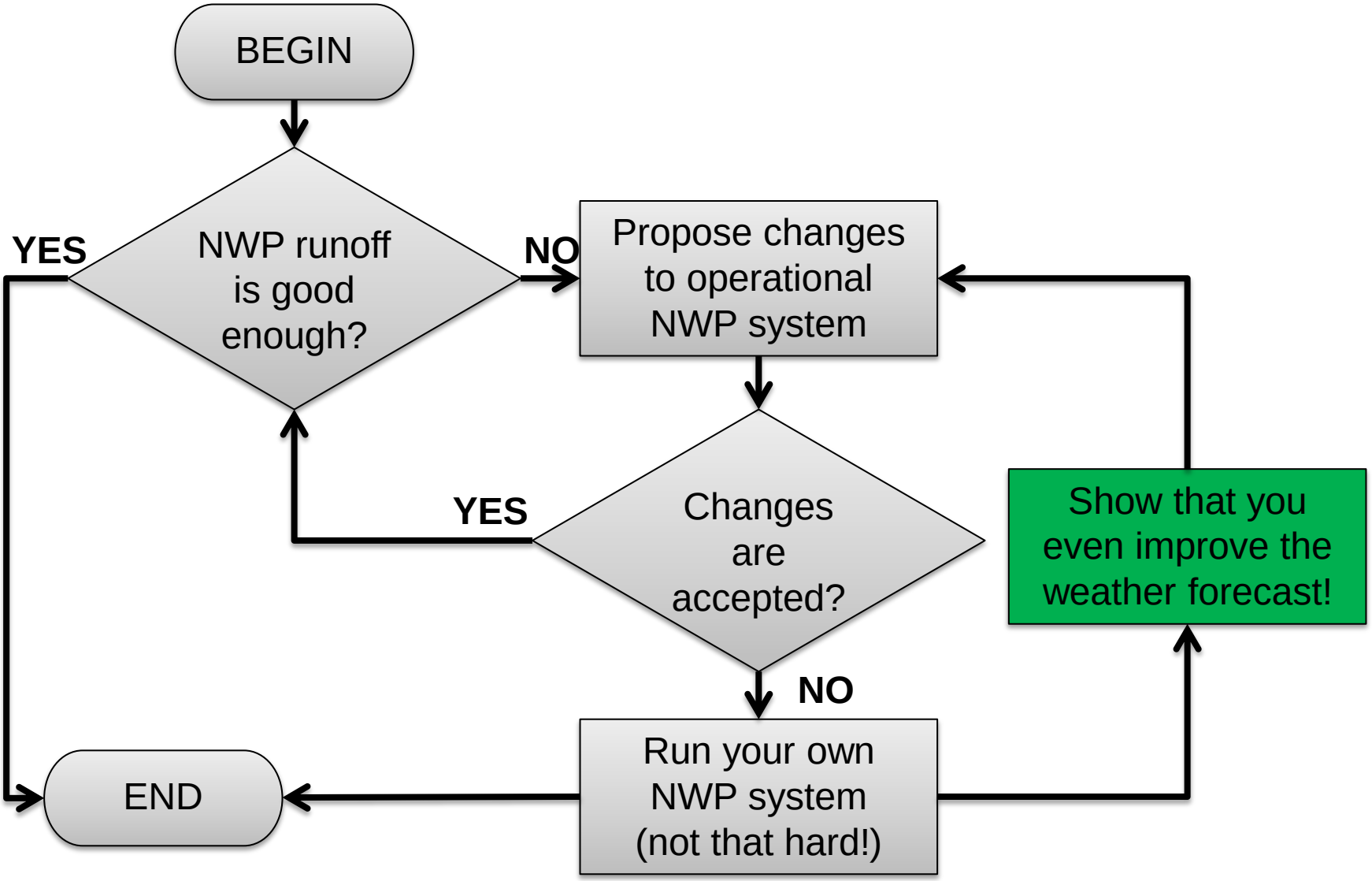
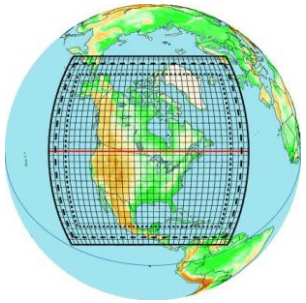


What if you don't like what you find?



Great Lakes and St. Lawrence Water Cycle Prediction System based on GEM-Hydro

GEM RDPS v5 (10 km) atmospheric model



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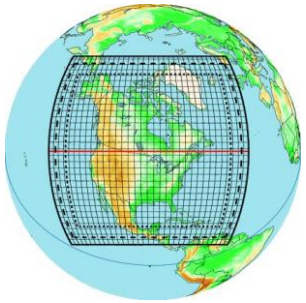
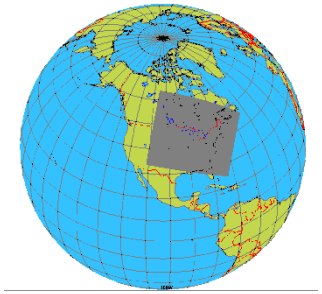
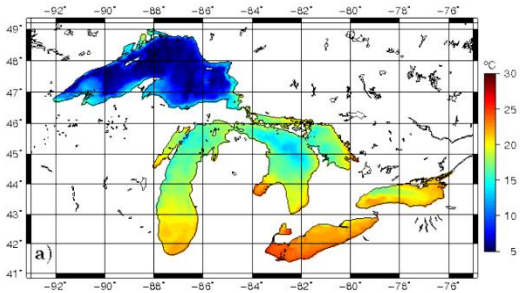


GEM LAM (10 km) atmospheric model (ISBA land-surface scheme)

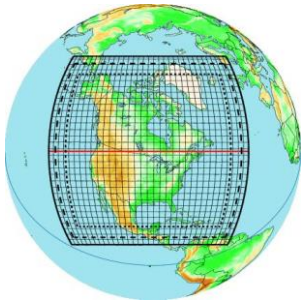




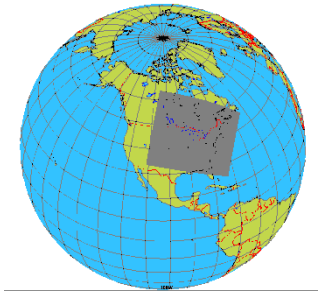
NEMO+CICE (2 km) ocean-ice model

Great Lakes and St. Lawrence Water Cycle Prediction System based on GEM-Hydro

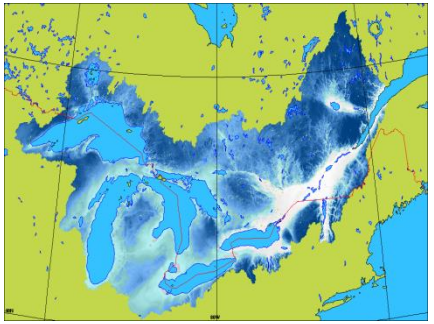
GEM RDPS v5 (10 km)
atmospheric model

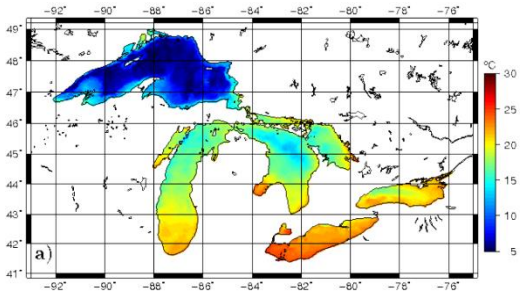


GEM LAM (10 km)
atmospheric model
(ISBA land-surface scheme)



WATROUTE
routing model (1km)





NEMO+CICE (2 km)
ocean-ice model

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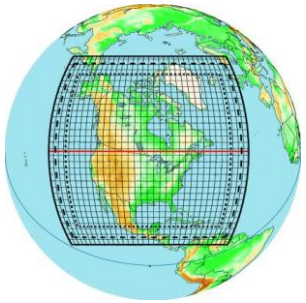
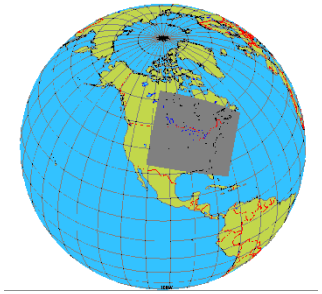
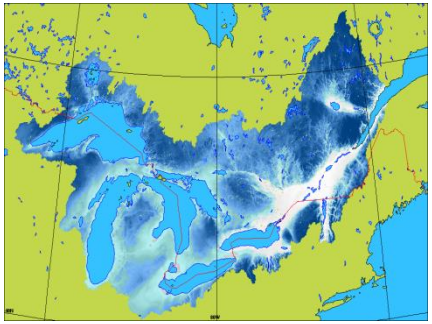
GEM RDPS v5 (10 km) atmospheric model

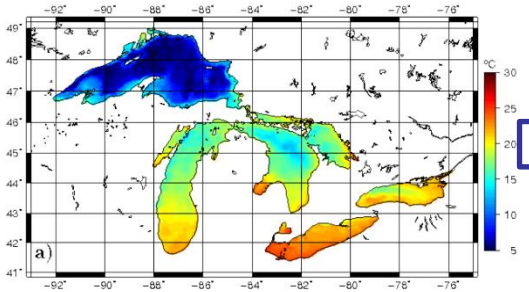


GEM LAM (10 km) atmospheric model (ISBA land-surface scheme)

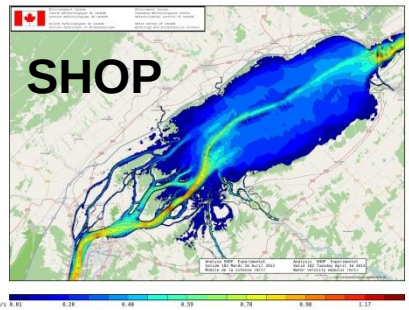


WATROUTE routing model (1km)





NEMO+CICE (2 km) ocean-ice model

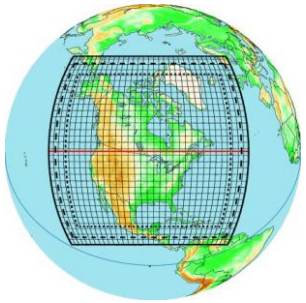


H2D2 finite element hydrodynamic model

Environnement et Changement climatique Canada

Great Lakes and St. Lawrence Water Cycle Prediction System based on GEM-Hydro

GEM RDPS v5 (10 km) atmospheric model



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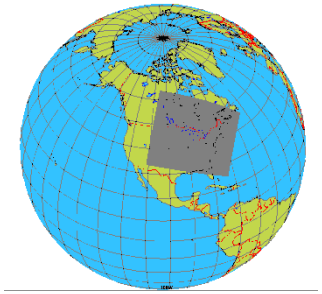
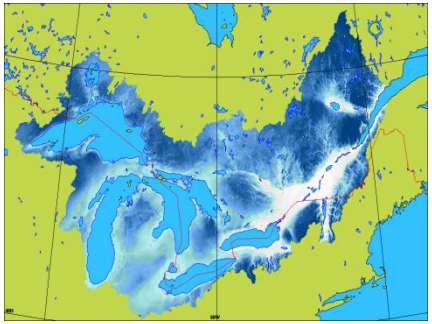
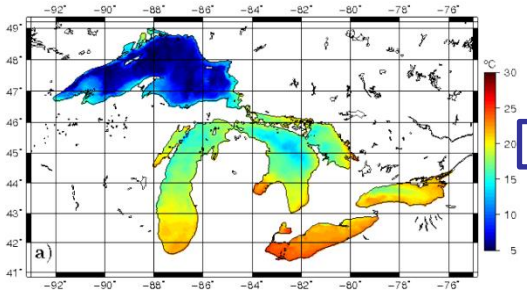


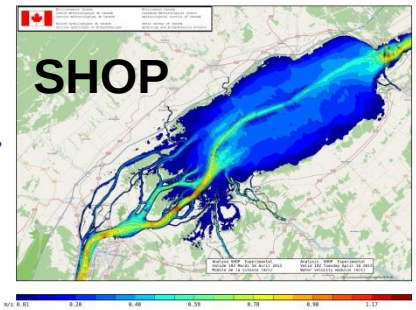
WATROUTE routing model (1km)



- 2 forecasts/day (00Z and 12Z)
- 84-h forecasts
- Assimilation cycle: direct insertion of RADARSAT ice cover and WSC streamflow

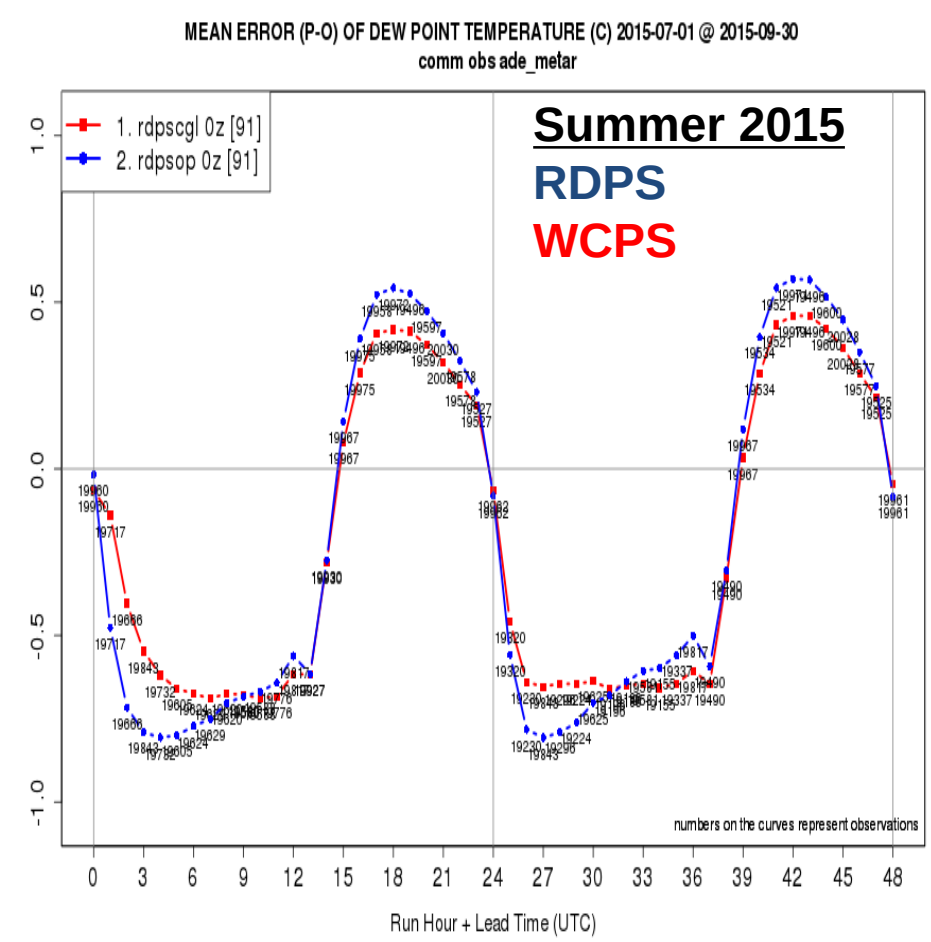


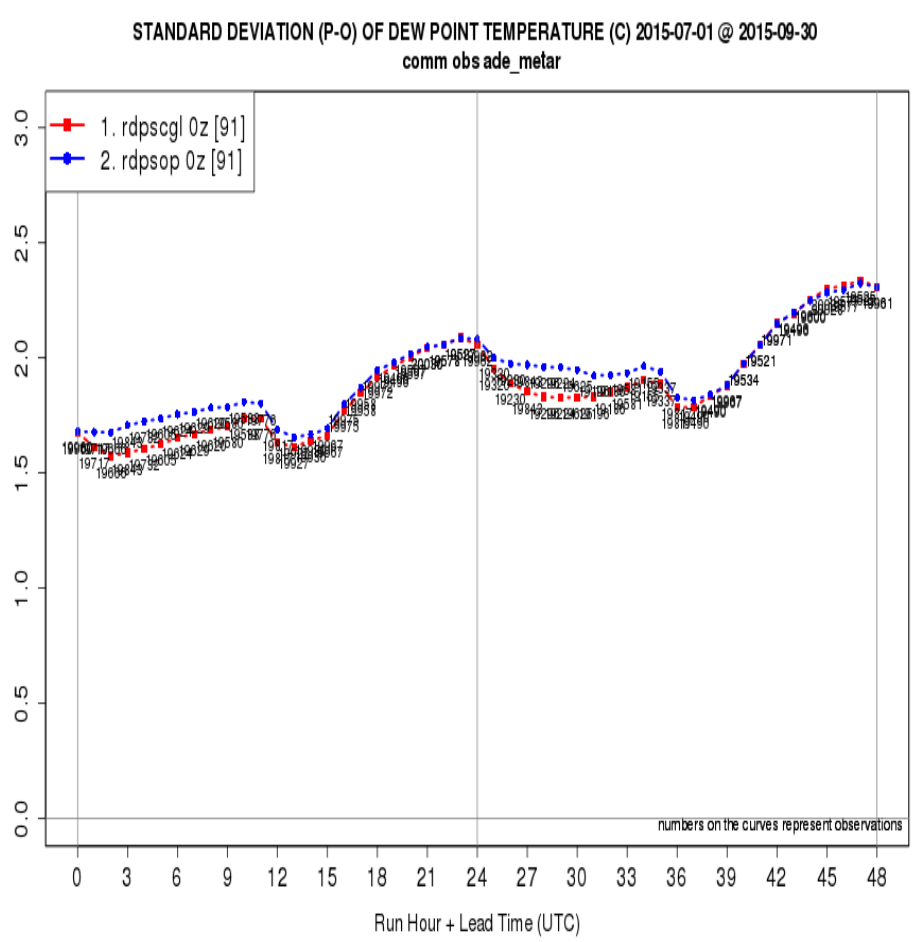
NEMO+CICE (2 km) ocean-ice model

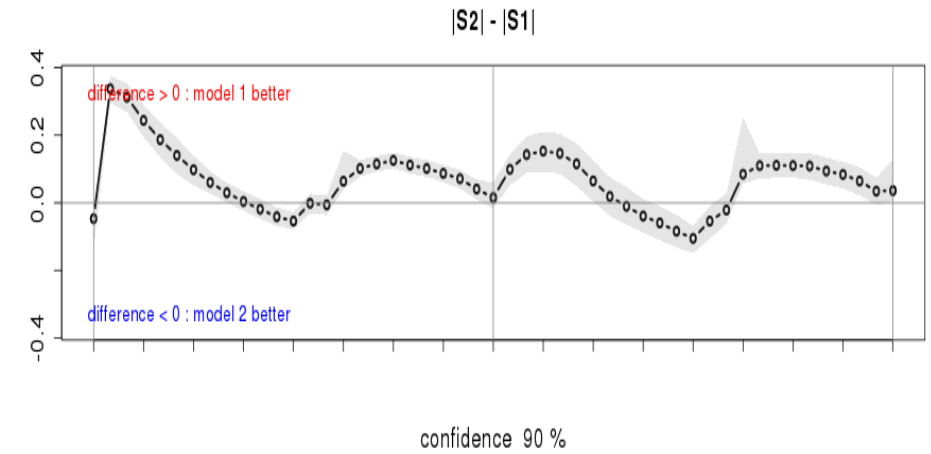


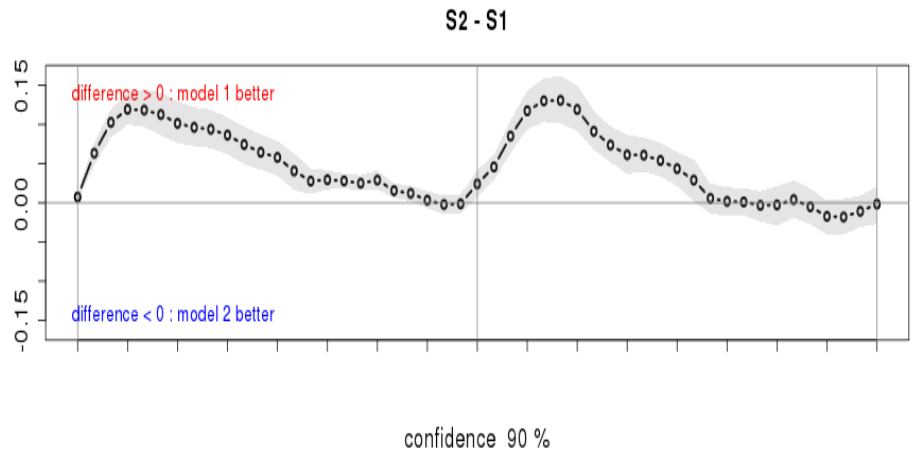
H2D2 finite element hydrodynamic model

Environnement et Changement climatique Canada

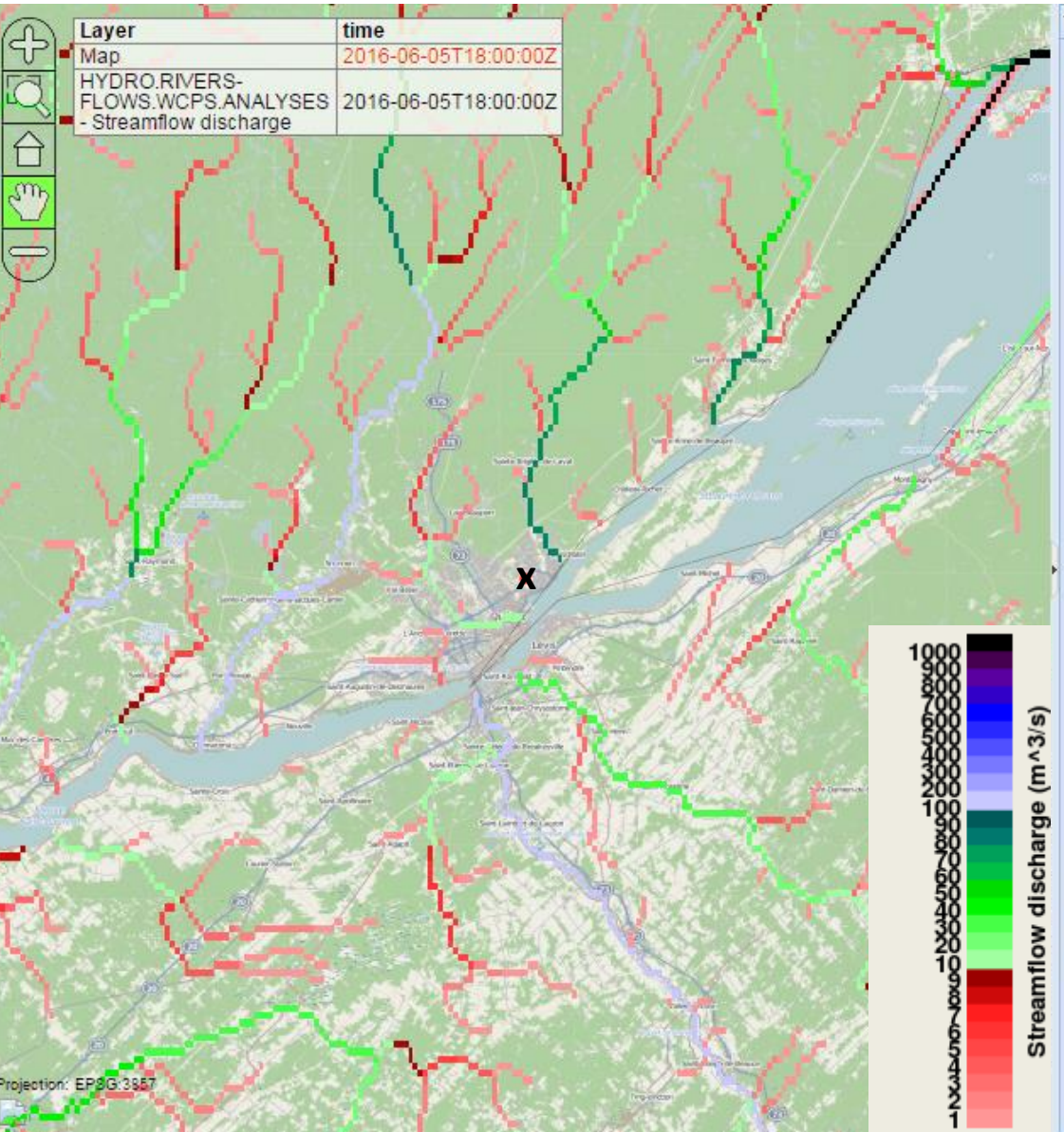

MEAN ERROR (P-O) OF DEW POINT TEMPERATURE (C) 2015-07-01 @ 2015-09-30
comm obs ade_metar
1. rdpscgl 0z [91]
2. rdpsop 0z [91]
Summer 2015
RDPS
WCPS
numbers on the curves represent observations
Run Hour + Lead Time (UTC)

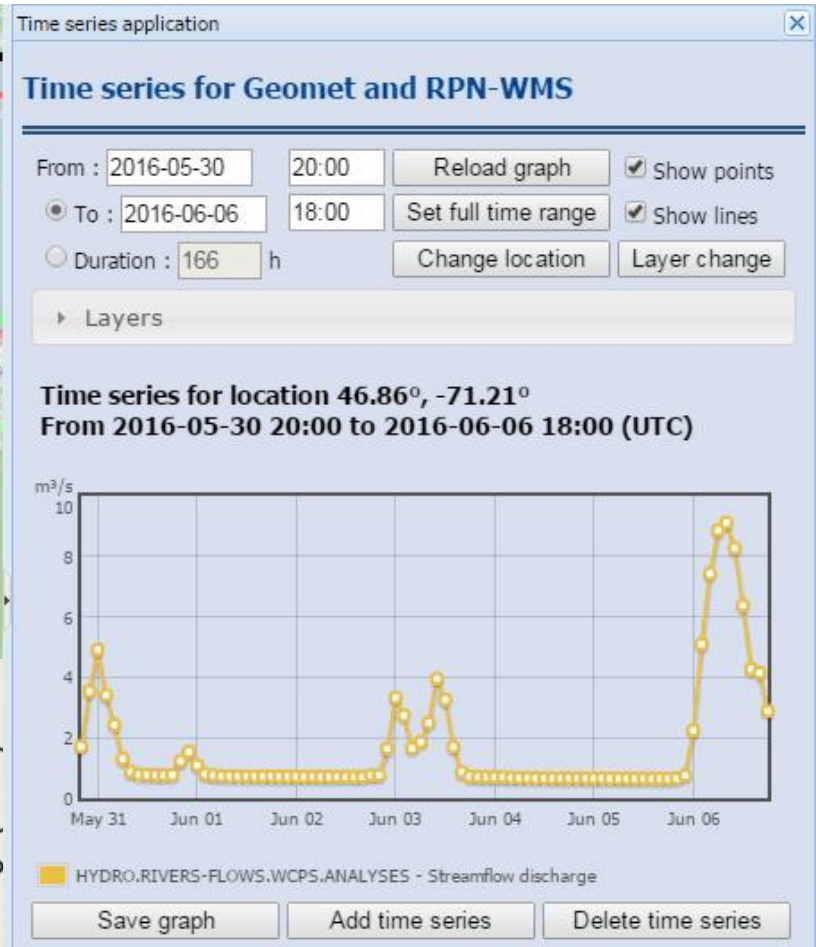

STANDARD DEVIATION (P-O) OF DEW POINT TEMPERATURE (C) 2015-07-01 @ 2015-09-30
comm obs ade_metar
1. rdpscgl 0z [91]
2. rdpsop 0z [91]
numbers on the curves represent observations
Run Hour + Lead Time (UTC)


|S2| - |S1|
difference > 0 : model 1 better
difference < 0 : model 2 better
confidence 90 %


S2 - S1
difference > 0 : model 1 better
difference < 0 : model 2 better
confidence 90 %

Yesterday's forecasted streamflow, Quebec City

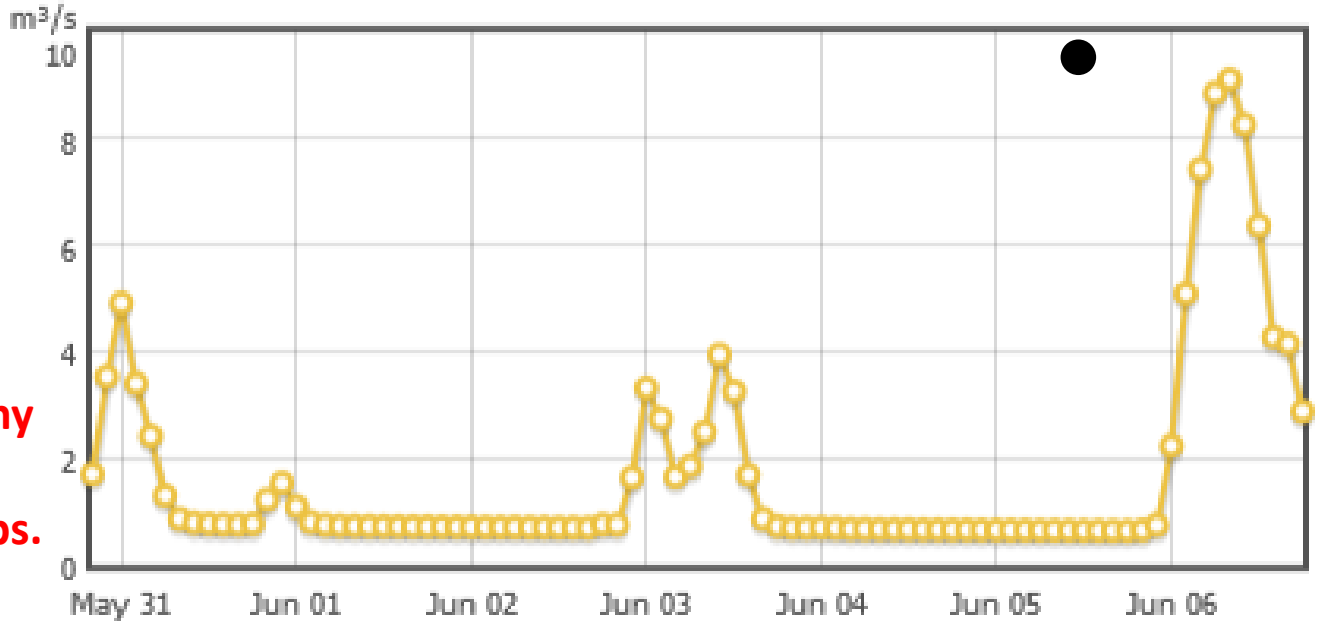




Time series for location 46.87°, -71.21°
From 2016-05-30 20:00 to 2016-06-06 18:00 (UTC)

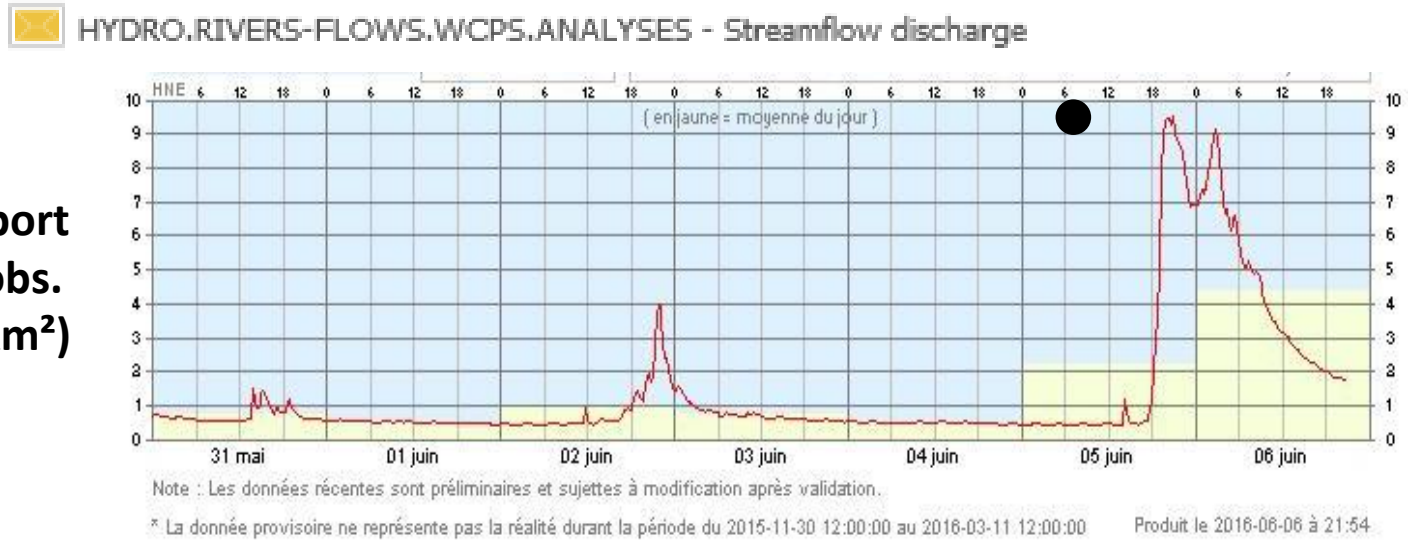
GEM-Hydro forecast (6-18h lead time)

NOT assimilating any
- rainfall obs.
- streamflow obs.



10 8 6 4 2 0

Rivière Beauport streamflow obs. (054001, 24 km²)



10 6 2

Next steps

- Great Lakes and St. Lawrence River water cycle prediction system based on GEM-Hydro should become operational at the Canadian Meteorological Centre on June 14th, 2016
- Similar technology to be deployed across Canada
- Ensemble version almost ready (30 days), envisioning one day an international multi-model ensemble, following in the steps of the NAEFS and the NMME
- 30 year reforecast based on ERA-Interim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