# FloodNet Highlights: Tolson research group (Project 2-1 and others)

Dr. Bryan Tolson

University of Waterloo

My HQP co-authors: Julie Mai, Hongli Liu, Konhee Lee, plus the other co-authors listed

# Overview of Case Studies

- Humber River (ON.) → TRCA
- Kaministiquai River (ON.) → OPG
- Lake of the Woods (ON.)→ LWCB
- 20 Quebec catchments → MELCC



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# Humber River (ON.) - TRCA

- SWMM5 Hydrologic model employed by TRCA required calibration
- We compared various event-based calibration approaches for selecting representative semi-distributed hydrologic model parameters



Advances in Water Resources 118 (2018) 12–27

Contents lists available at ScienceDirect

Advances in Water Resources

journal homepage: www.elsevier.com/locate/advwatres

Event-based model calibration approaches for selecting representative distributed parameters in semi-urban watersheds

Frezer Seid Awol [a,*], Paulin Coulibaly [b], Bryan A. Tolson [c]



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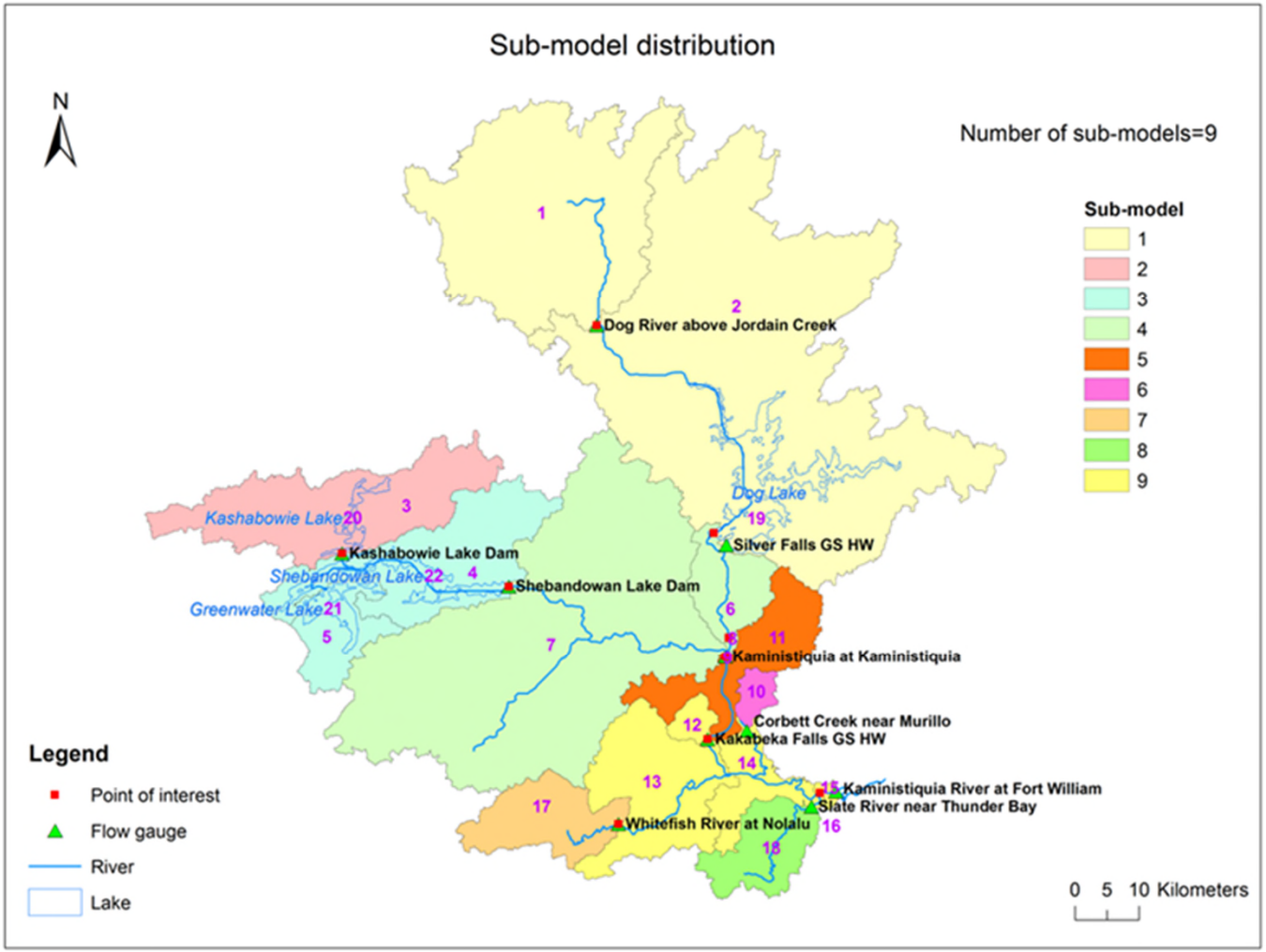
# Kaministiquai River (OPG)

- No pre-existing hydrologic model
- In collaboration with OPG, we built a new semi-distributed Raven-based model for Canadian shield
- GR4J with routing (in Raven) and then a more physically-based Raven model considering the shield environment



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# Kaministiquai River (OPG)

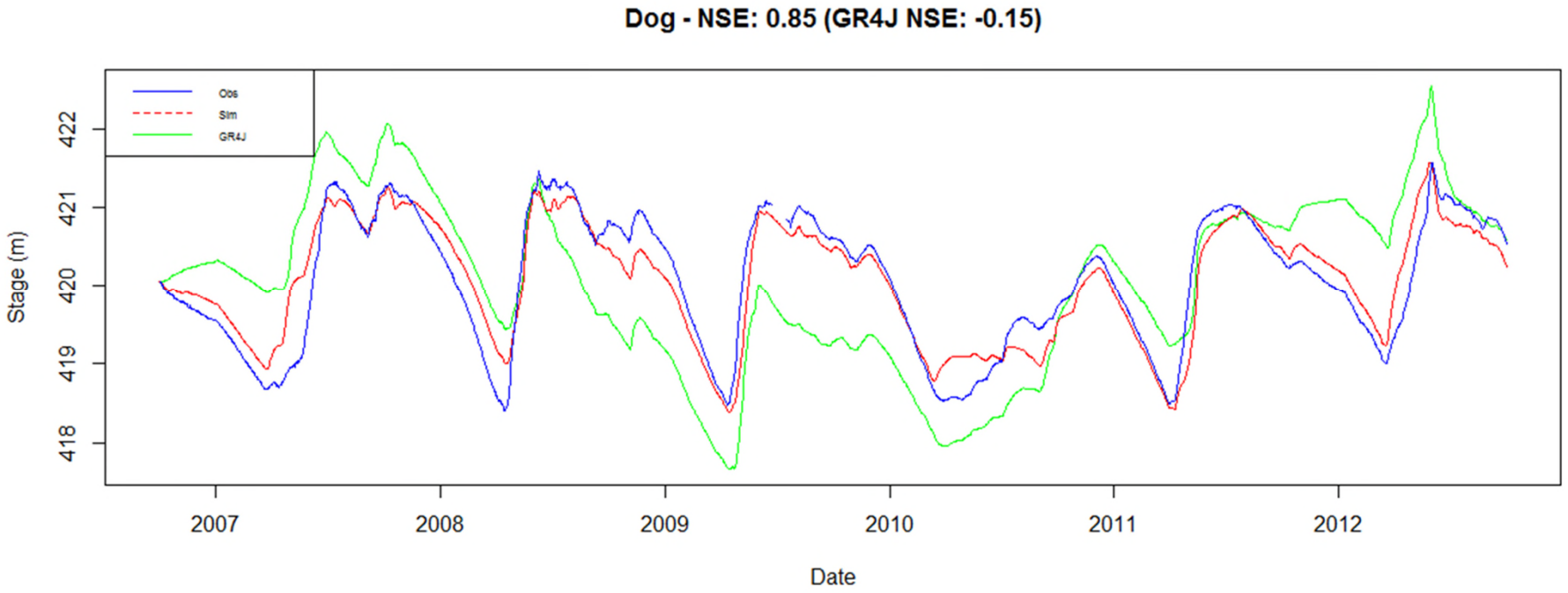





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# Kaministiquai River (OPG)

- Some good results






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# Lake of the Woods (LWCB)

1. Recalibrated a subarea of their watershed using their existing hydrologic model (WATFLOOD) – see Bomhof et al. (submitted)
   - calibrate to both reservoir inflows and streamflow stations
   - Compared multi-objective versus single objective calibration formulations

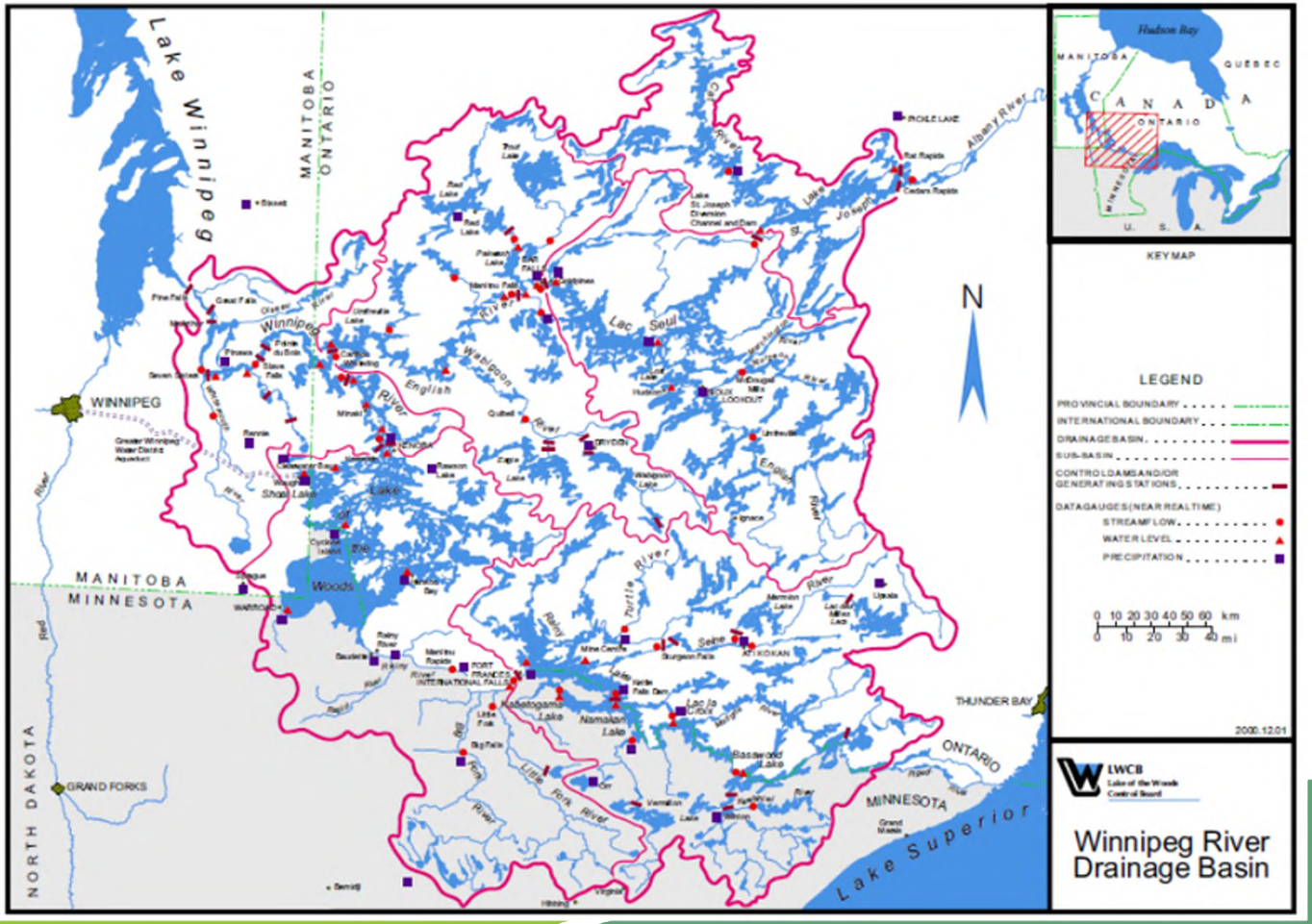
2. Raven model of Canadian shield environment built and compared with WATFLOOD model (Lee et al., 2018)

Bomhof, J., Tolson, B. A., and Kouwen, N. Robust Multi-Objective Calibration of a Distributed Hydrological Model. Submitted 2018 to *Canadian Water Resources Journal*.

Lee, K., R. Chlumsky, J. R. Craig, B. A. Tolson (2018), Modelling Canadian Shield Hydrology, 2018 Joint Meeting of CGU, CSSS, CIG, ES-SSA and CSAFM, June 10-14, Niagara Falls, ON. (Poster).

# Hydrologic Modelling of the Canadian Shield

- Lake of the Woods case study area





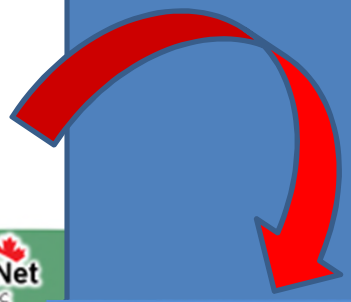

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# Hydrologic Modelling of the Canadian Shield

- Turns out simulating lakes and reservoirs explicitly pretty important
- Due to FloodNet, significant lake and reservoir simulation features added to Raven hydrologic modelling framework (raven.uwaterloo.ca)
- But this also motivated additional post-FloodNet work on lake and river routing

# Hydrologic Modelling of the Canadian Shield

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- Significant lake and reservoir simulation features added to Raven hydrologic modelling framework (raven.uwaterloo.ca) due to FloodNet
- But this motivated additional post-FloodNet work on lake and river routing





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Oct 9, 2018 Meeting at ECCC, Dorval

## Developing a Pan-Canadian Hydrologic Routing Network of Lakes and Rivers

Ming Han[1], Juliane Mai[1], Bryan A. Tolson[1], James R. Craig[1], Etienne Gaborit[2], Konhee Lee[1], Hongli Liu[1]

1 University of Waterloo, Civil and Environmental Engineering Dpt., Waterloo, N2L3G1, Canada

2 Environment Canada, Environmental Numerical Prediction Research (E-NPR), Dorval, H9P1J3, Canada

UNIVERSITY OF WATERLOO
WATERLOO ENGINEERING

LF

GWF

# Overview of Pan-Canadian Lake and River Routing Research

1. **Raven as gridded routing tool for ECCC GEM-Hydro model outputs across Hudson Bay.**
   - compare to current operational routing tool used by ECCC (WatRoute)

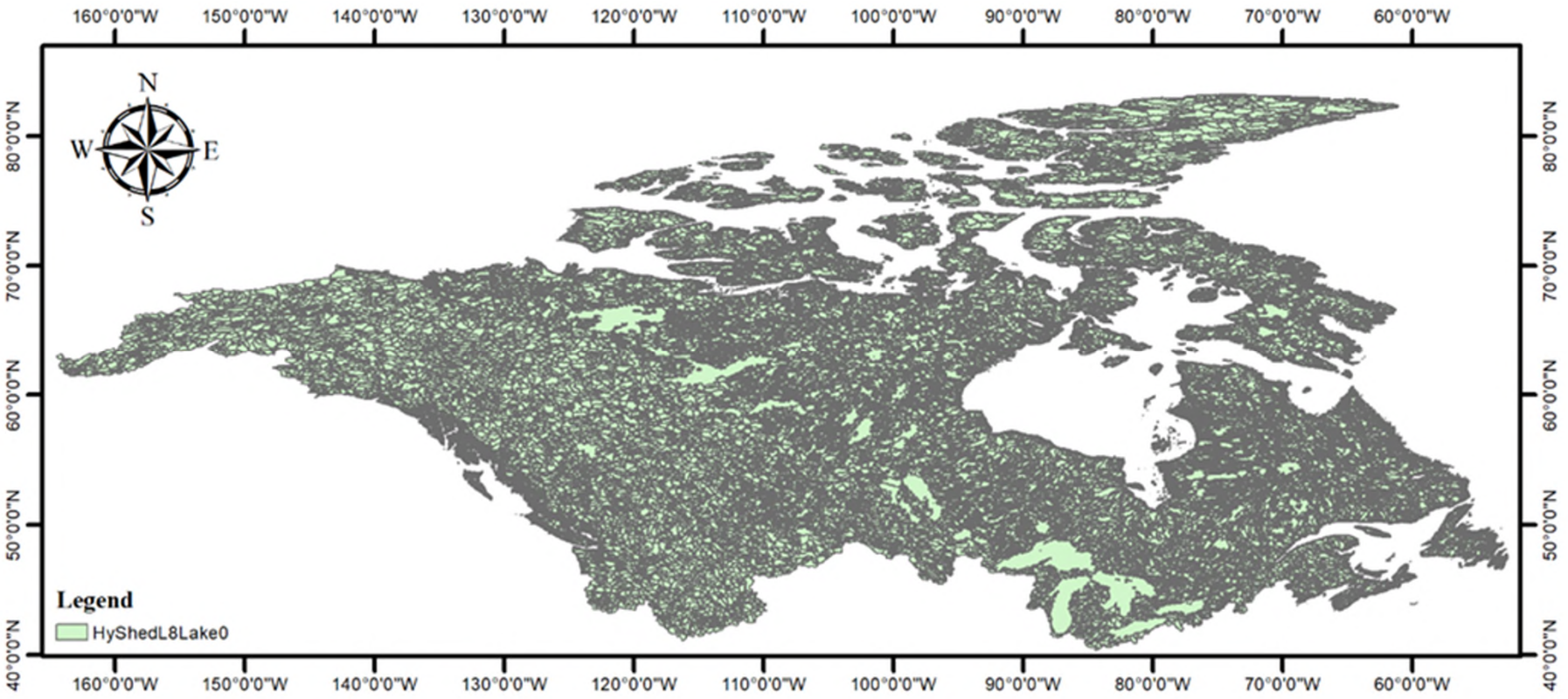
2. **Pan-Canadian lake and river routing product description**
   - combines HydroLakes and HydroSheds spatial data sets across Canada
   - 14 different products available (varying discretization levels) summarized in GIS polygon files

3. **Raven as stand-alone subbasin routing tool with and without lakes**

   - impact of lakes on routing, using Hudson Bay watershed as a case study

# Example Pan-Canadian Routing Product for Canada

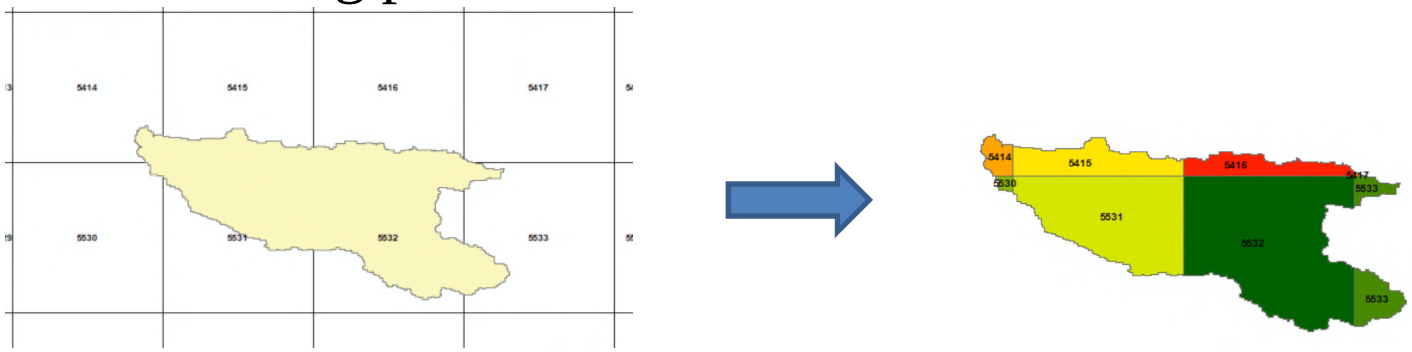
**HydroSHEDS L8 combined with all connected lakes**




**Total # of subbasins: 60278 | Total # of explicit lakes: 30324**
**All required routing data in polygon GIS files**

# Feasibility of Forecasting with these Routing Products

- Raven hydrologic modelling framework used to route ECCC GEM-Hydro fluxes of surface runoff and groundwater through various routing products




- Use Hudson Bay watershed (~40% of Canada) as example

| Product | # of catchments | # of lake catchments | 10-day Raven simulation time (min.) |
|---|---|---|---|
| Level 8 | 26419 | 14975 | 13.4 |
| Level 7 | 15565 | 8191 | 6.0 |
| Level 7 no lakes | 4288 | 0 | 0.7 |

# 20 Quebec Watersheds (MELCC)

- These final few slides summarize the entire PhD of Hongli Liu

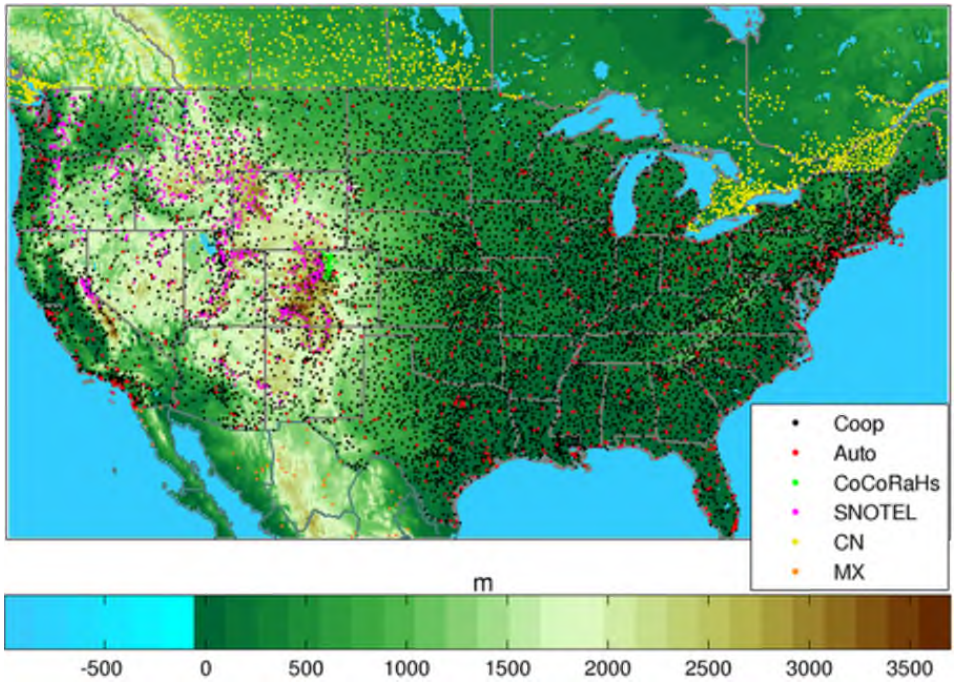
- *Goal: Improve the handling of hydrologic data uncertainty in model calibration and data assimilation by using advanced data uncertainty estimation methods and products*
  - *Measured climate data uncertainty*
  - *Measured flow data uncertainty*



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# Chapter 3: Climate ensemble-based calibration framework for optimizing hydrologic model prediction bound quality

- Motivation
  - Explicitly consider climate data uncertainty in model calibration.
- Newman et al (2015) dataset
  - 100 members (or realizations, time series)
  - Three variables
    - precipitation
    - mean temperature
    - diurnal temperature range
  - 1980-2012
  - Daily, $1/8^{\circ}$ grid ($\approx 14\ km$) resolution



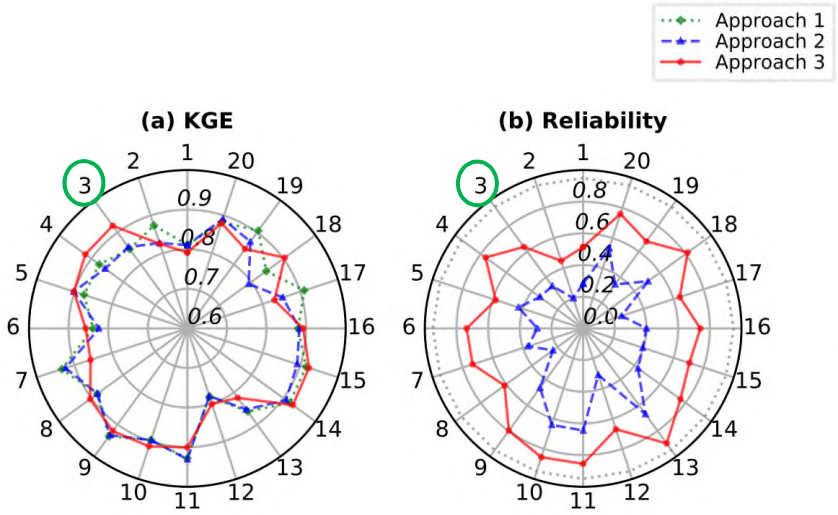

(Image source: Newman, et al. 2015)

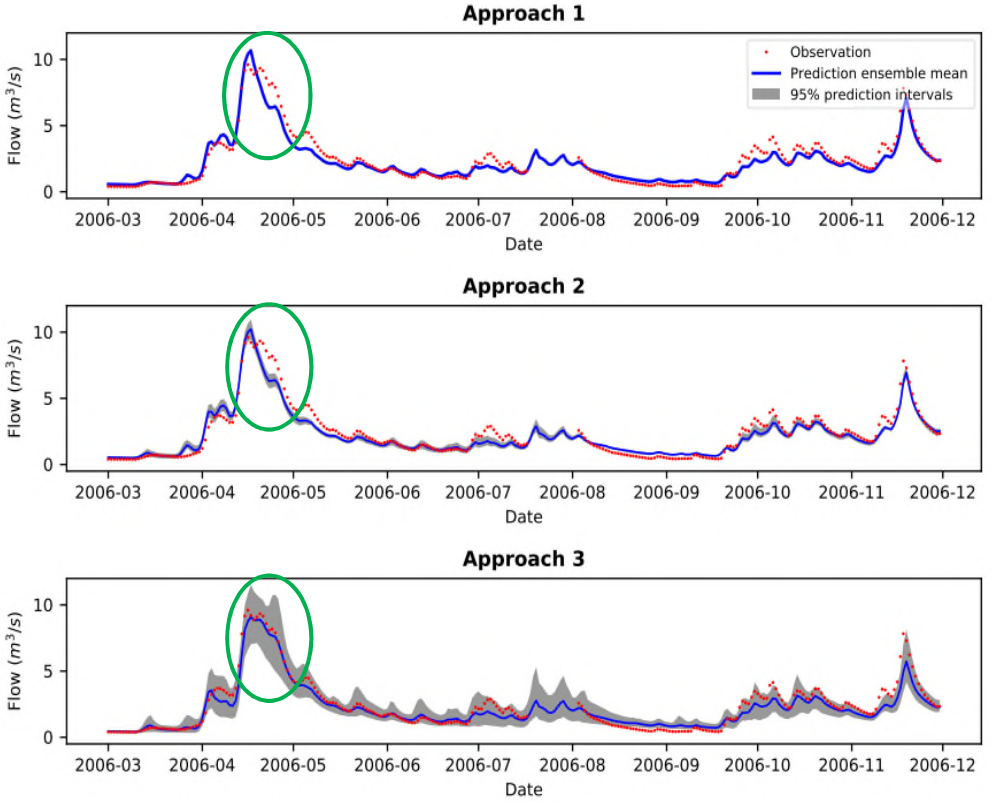
# Case study design

- Research areas
  - 20 catchments in southern Québec, Canada.
- Hydrologic model
  - GR4J
- 6 parameters to be optimized in total



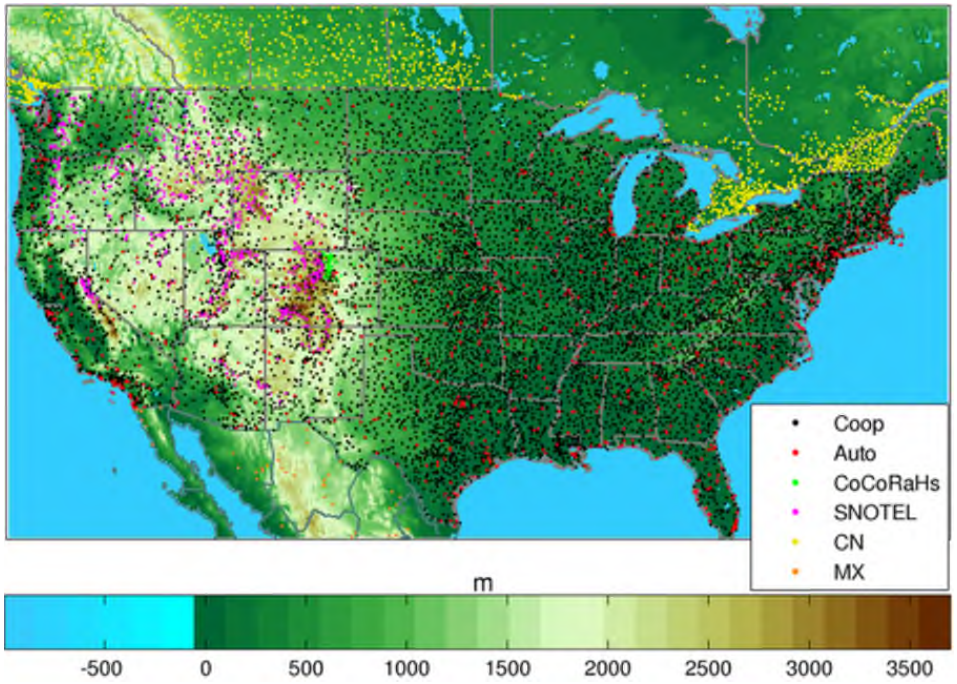
# Flow prediction evaluation results



# Chapter 4: Efficient treatment of climate data uncertainty in ensemble Kalman filter (EnKF) based on an existing historical climate ensemble dataset

- Motivation
  - Use this data set to quantify uncertainty inputs to improve forecasting with EnKF
- Newman et al (2015) dataset
  - 100 members (or realizations, time series)
  - Three variables
    - precipitation
    - mean temperature
    - diurnal temperature range
  - 1980-2012
  - Daily, $1/8^{\circ}$ grid ($\approx 14\ km$) resolution




(Image source: Newman, et al. 2015)

# Ch 4 Results: It worked!

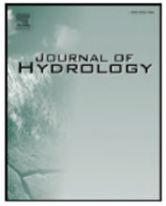
- See here:

Journal of Hydrology 568 (2019) 985–996

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Research papers

## Efficient treatment of climate data uncertainty in ensemble Kalman filter (EnKF) based on an existing historical climate ensemble dataset

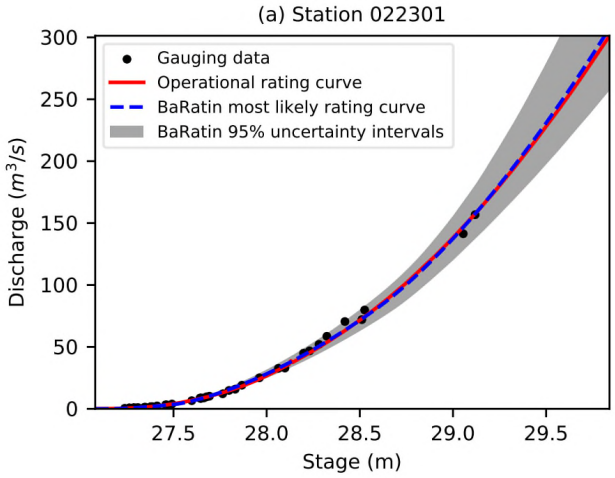
Hongli Liu[a,*], Antoine Thiboult[b], Bryan Tolson[a], François Anctil[b], Juliane Mai[a]

[a] Department of Civil and Environmental Engineering, University of Waterloo, Waterloo, Ontario, Canada
[b] Department of Civil and Water Engineering, Université Laval, Québec, Canada

- Read this paper if you are using EnKF for data assimilation

# More findings of interest from Hongli

- Chapter 6: Flow ensemble-based calibration framework using Baratin (Le Coz et al., 2014)




- Demonstrate generating hydrograph observation uncertainties and then calibrating models with them



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# More findings of interest from Hongli

- Chapter 7: comparing multi-model forecasting results versus single model forecasting results (both use EnKF)
  - Multi-model considers only model uncertainty (20 models)
  - Single model explicitly considers *historical* climate data uncertainty

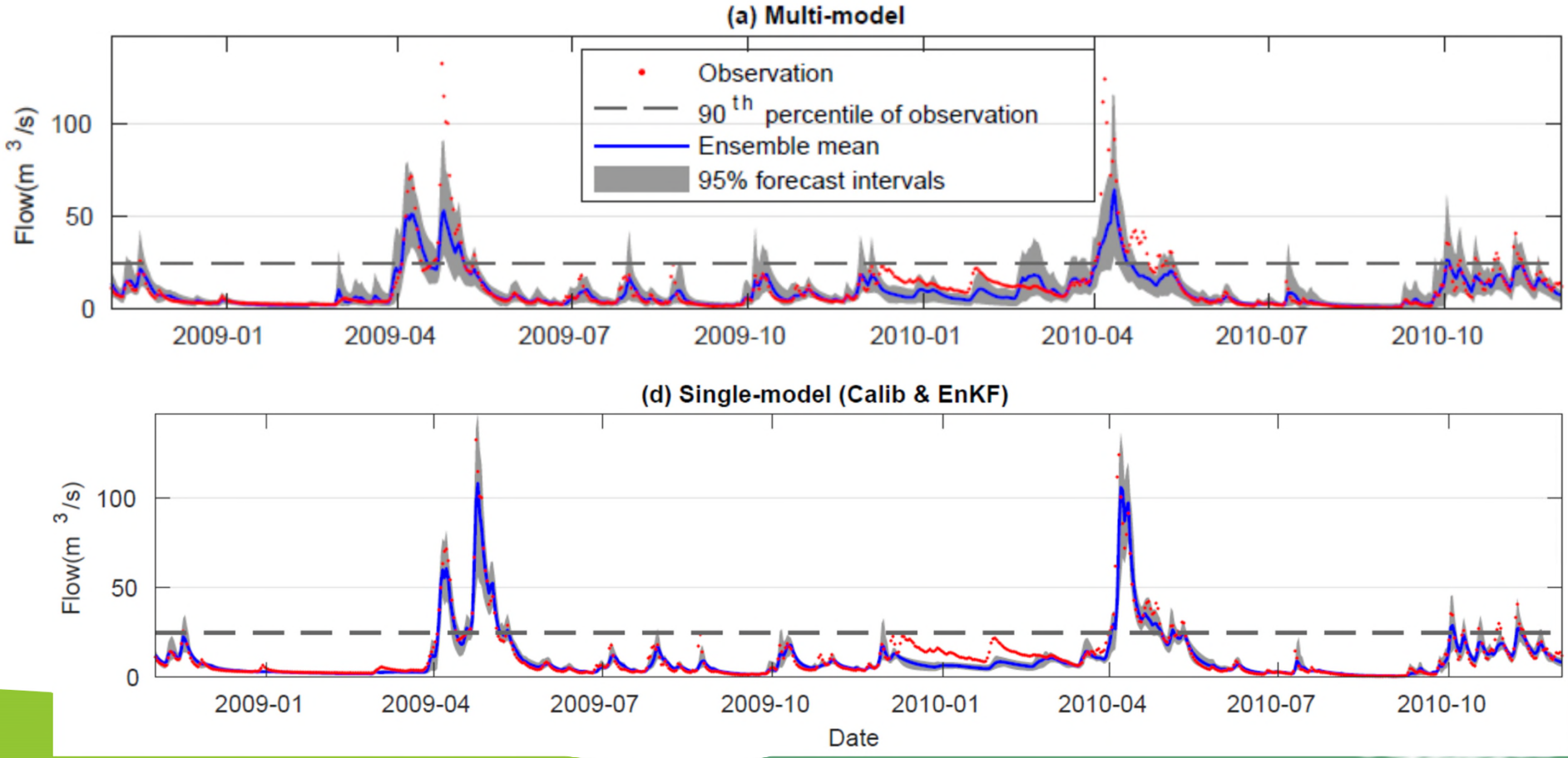
- Turns out these appear to be comparable quality with improved forecasts of highest flows
- Eg. …



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# More findings of interest from Hongli

- Chapter 7: 1 day lead time forecast results






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# Conclusions

- So much more work and findings from FloodNet that we did not show
- More work to continue in the future



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- SWITCH OVER



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# The Future of CaSPAr

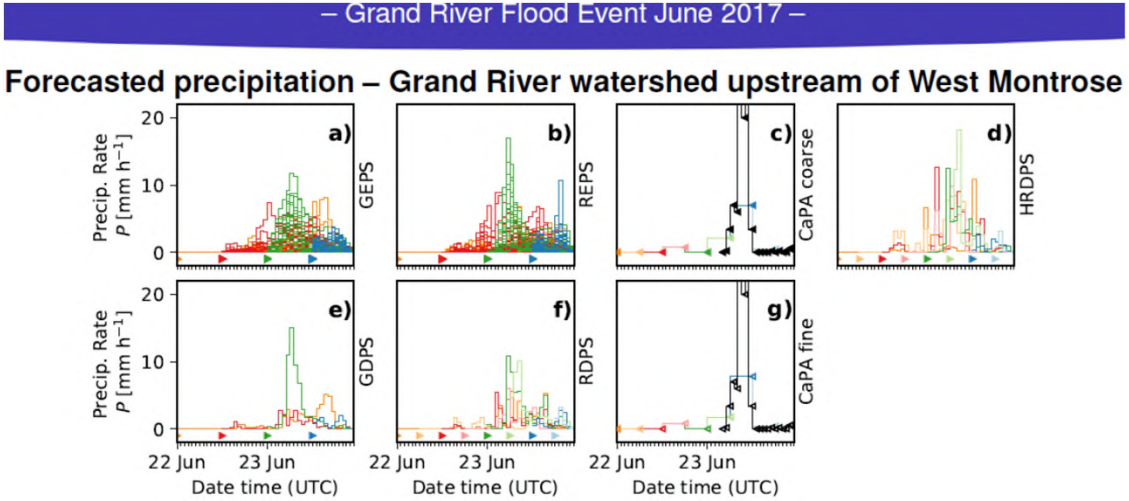
- CaSPAr (version 1.0) is a research product
  → *CaSPAr-research*
- Beyond flow forecasting researchers, *CaSPAr-research* is a valuable tool for forecasting agencies:
  1. Archived data are required to develop new forecasting systems
  2. Archived data are required to test new forecasting approaches (e.g., using HRDPS)
  3. Forecasting agencies can look back at suite of ECCC numerical weather products on past events like we did on June 2017 Grand River flood event

# The Future of CaSPAr

- The FloodNet team decided to build CaSPAr to improve Flood Forecasting in Canada
  - Originally we believed archived access to ECCC forecasts would be enough
  - Now, we believe more can and should be done to improve the operational distribution of ECCC numerical weather forecasts
  - Julie and I want to help do this somehow (e.g., with rest of CaSPAr-FloodNet team in future FloodNet2 grant)

# The Future of CaSPAr

- Why is there more to be done? Recall this slide:




  - Seems not all hydrologic forecasting agencies know or can access above forecasts
- How feasible is it to operationalize CaSPAr?
  - From a purely code modification perspective – super easy!
  - Successful <u>implementation</u> within reach provided there is some support and a desire to do this



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# Our vision: 1. *CaSPAr-operational ver 1.0*

- *CaSPAr-operational* would be an operational weather forecast data distribution system
  - Must be distinct from CaSPAr-research (which is housed on a 95% reliable Compute Canada cluster)
  - NetCDF CF-1.6 compliant forecasts (equivalent to CaSPAr-research)
  - No front-end required (JSON string derived from CaSPAr-research)
  - Ideally housed at ECCC (e.g., in addition to current DataMart)

# Our vision: 2. *CaSPAr-research ver 2.0*

- *CaSPAr-research ver 2.0* would continue to function as ECCC NWP archive and would:
  - Include pre-processing tools for bias correction, interpolation etc.
  - Incorporate new NWPs from ECCC (e.g., radar rainfall fields, experimental NWPs for efficient sharing across and/or outside ECCC)
  - Customized output file formats for directly feeding forecast systems (e.g., avoid all local pre-processing)*
- Any and all of this functionality would be readily ported into *CaSPAr-operational* system if desired



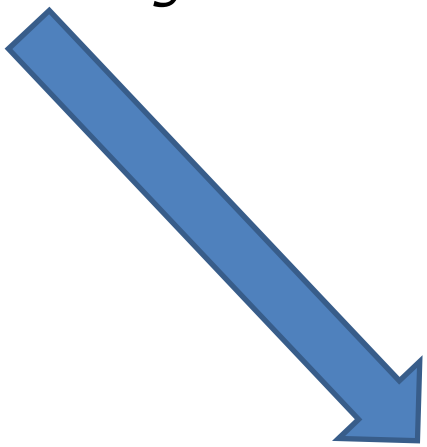
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# Discussion Starter

## CaSPAr

*Optimized to output NetCDF*

*CF-1.6 compliant gridded climate*



## HYDROLOGIC MODEL

(e.g., MESH, Raven, VIC, SUMMA)

*Optimized to read NetCDF*

*CF-1.6 compliant gridded climate*



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# Discussion Starter

## CaSPAr

*Optimized to output NetCDF*
*CF-1.6 compliant gridded climate*

## FEWS & thus CAFFEWS

As we understand it currently, utilizing the FEWS system requires two conversions:

A) converting NetCDF CF-1.6 to FEWS input format AND
B) conversion of FEWS output format to NetCDF CF-1.6 gridded format (*to take advantage of optimized model input handling)

## HYDROLOGIC MODEL

(e.g., Raven, MESH, VIC, SUMMA)

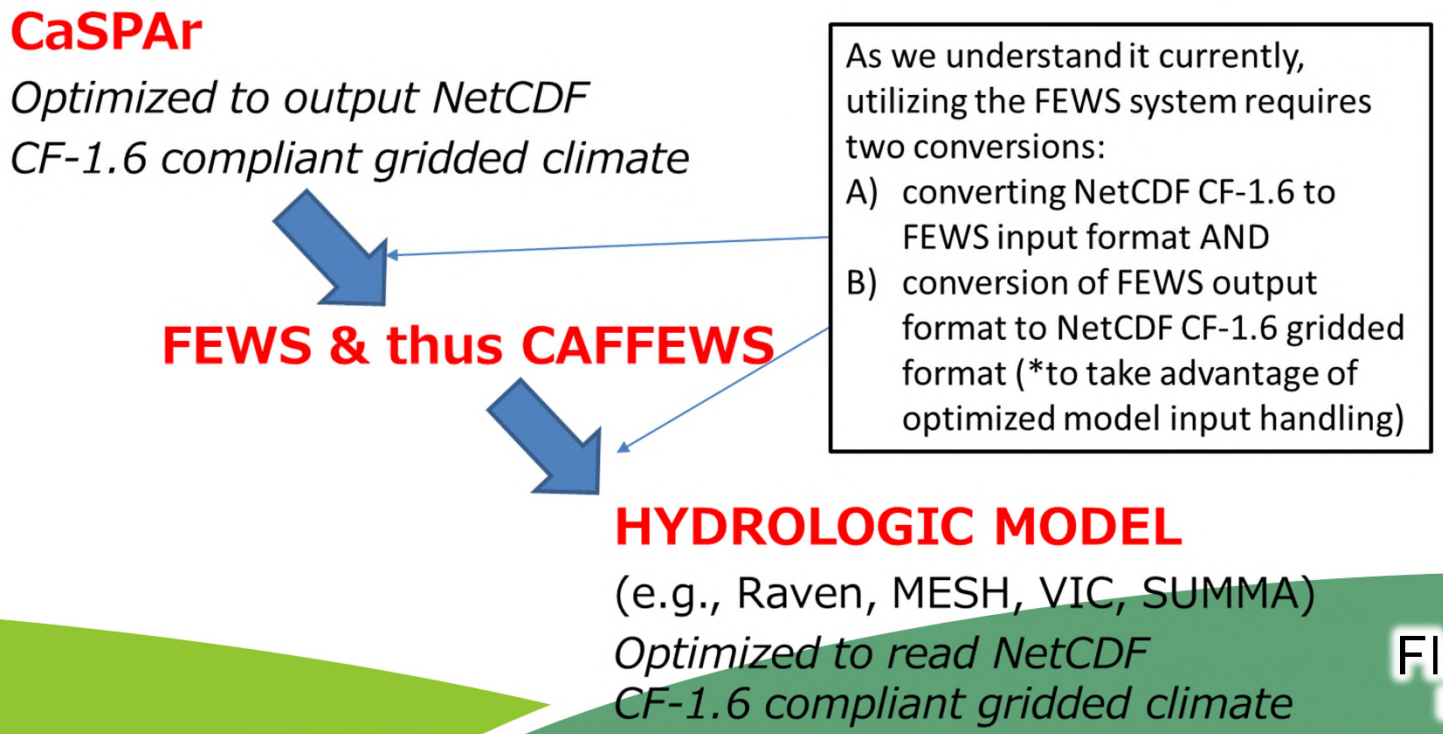
*Optimized to read NetCDF*
*CF-1.6 compliant gridded climate*



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# Discussion Starter

- Should we be striving for a system where all three components can utilize the same file formats for climate?
- If so, how do we get there?






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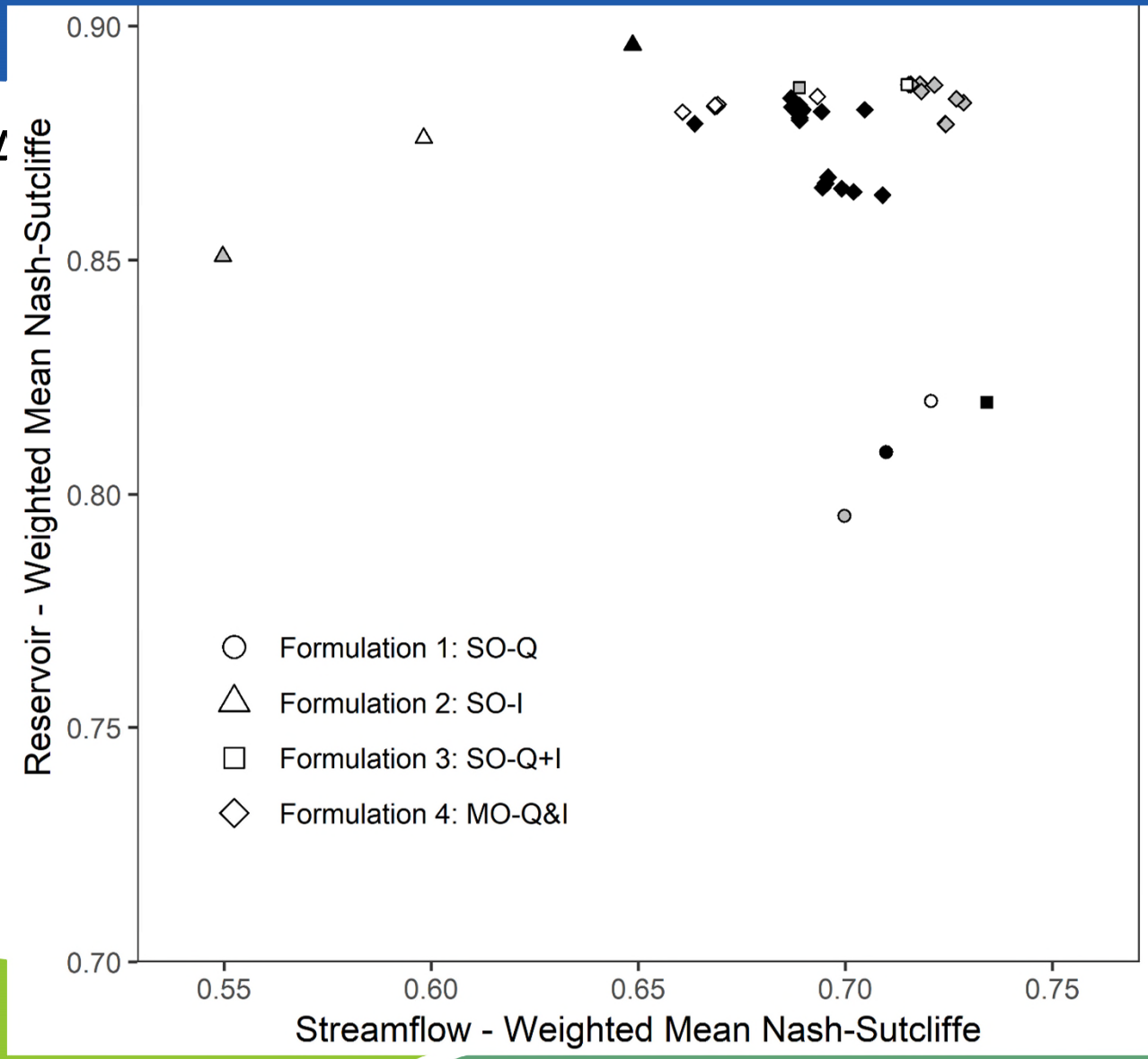
- EXTRA SLIDES



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# Lake of the Woods (LWCB)

- WA
  - ir inflows
  -






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# Lake of the Woods (LWCB)

- Compared WATFLOOD with Raven at key reservoirs for 6-yr calibration period performance:

| Gauge Name | Object | WATFLOOD | RAVEN |
|---|---|---|---|
| | | Running Avg NSE | Running Avg NSE |
| Lake of the Woods | Inflow | 0.91 | 0.86 |
| Rainy | Inflow | 0.93 | 0.94 |
| Lac La Croix | Inflow | 0.76 | 0.81 |
| Namakan | Inflow | 0.82 | 0.79 |

- RUNTIMES: 4 min 11 sec



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