HYDROLOGIC MODELS IDENTIFICATION FOR ADAPTIVE ENSEMBLE FLOOD FORECASTING AND CAFFEWS INTEGRATION

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FloodNet NSERC

Introduction

Operational and semi-operational flood forecasting centres are increasingly shifting from deterministic forecast to probabilistic flood forecasts using Ensemble Prediction Systems (EPS) (Cloke & Pappenberger, 2009).

The use of ensemble flood forecasting is a great achievement for researchers and scientists in estimating flood risks under uncertainties (Michaels, 2015). This study will address the recent developments in ensemble flood forecasting with enhanced and adaptive application of multiple models and verification methods in the Canadian context. It aims to generate several ensembles for each source of uncertainties and cascading through multiple hydrologic and hydraulic models to produce ensemble streamflow forecasts at several lead times and quantifying their probability distribution function.

The ensemble verification and performance metrics will be able to identify which model and combination of models perform well for which hydro-meteorological region in Canada. Multiple models will be compared with well calibrated benchmark or reference models by basic criteria, categorical forecast verification and probabilistic forecast verification. The study areas are selected from Eastern, Western and the Prairie regions.

The outcomes of this study will be integrated into Canadian Adaptive Flood Forecasting and Early Warning System (CAFFEWS) by providing the most reliable hydrologic and hydraulic models for better flood mitigation in Canada.

Methodology

✓ **Ensemble generation approaches**
- Ensembles based on meteorological ensemble prediction systems (M-EPS)
- Ensembles based on several combinations of model parameters sets
- Ensembles based on multiple hydrological models

✓ **Hydrologic and Hydraulic model identification techniques**
- Site Specific Model Identification (General Criteria)
  - Hourly and Sub-hourly time step
  - Data requirement
  - Source Code Availability
  - Ability to customize easily and complexity
- Pre-Evaluation (using binary events or flood thresholds)
  - Contingency Table
  - Categorical Verification Measures
- Ensemble Verification statistics and skill scores

Study Areas

East Canada
- Humber and Don River Basins (ON)

Central Canada (The Prairies)
- Assiniboine and Qu' Appelle River Basins (SK/MB)

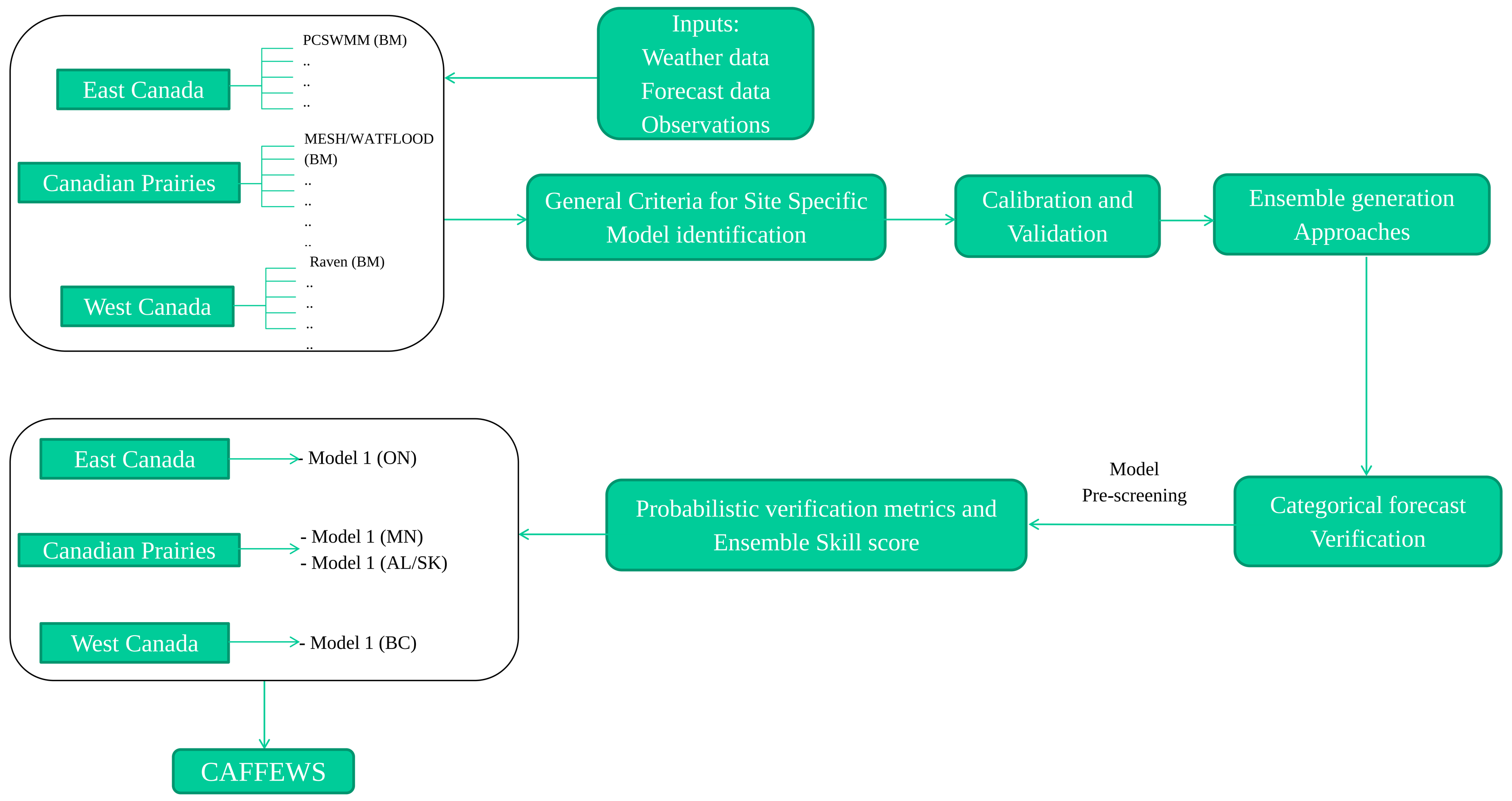
West Canada
- Upper Fraser River Basin (BC)

Data

Meteorological data
- TRCA and EC (observed)
- CaPA, RDPS
- GEM-GEPS and NAEFS (Ensemble)

Hydrological data
- EC (HYDAT)
- Water Survey of Canada

Research Approach



Contingency Table

		Observed		
		Flood	No-Flood	total
Forecast	Flood	$p(f=1, o=1)$: *hits*	$p(f=1, o=0)$: *false alarms*	$p(f=1)$
	No-Flood	$p(f=0, o=1)$: *misses*	$p(f=o, o=0)$: *correct negatives*	$p(f=0)$
	total	$p(o=1)$	$p(o=0)$	

Categorical Verification Metrics

$$Probability\ of\ Detection(POD) = \frac{Hits}{Hits + Misses} * 100$$

$$False\ Alarm\ Ratio(FAR) = \frac{False\ Alarms}{Hits + False\ Alarms} * 100$$

$$Critical\ Success\ Index(CSI) = \frac{Hits}{Hits + Misses + False\ Alarms} * 100$$

Ensemble Verification statistics and skill scores

Mean Absolute Error (MAE)

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|\bar{y}_i - x_i\right|$$

Reliability diagram and ROC

Rank Histogram

Brier skill score

$$BS(t) = \frac{1}{n}\sum_{i=1}^{n}\left(P_{y_i}(t) - 1\{t \geq x_i\}\right)^2 \qquad BSS = 1 - \frac{BS}{BS_{ref}}$$

Mean Continuous ranked probability score (CRPS) and CRPSS

$$CRPS = \int_{-\infty}^{\infty}\left(P(y) - 1\{y \geq x\}\right)^2 dy \qquad \overline{CRPSS} = 1 - \frac{\overline{CRPS}}{\overline{CRPS}_{ref}}$$

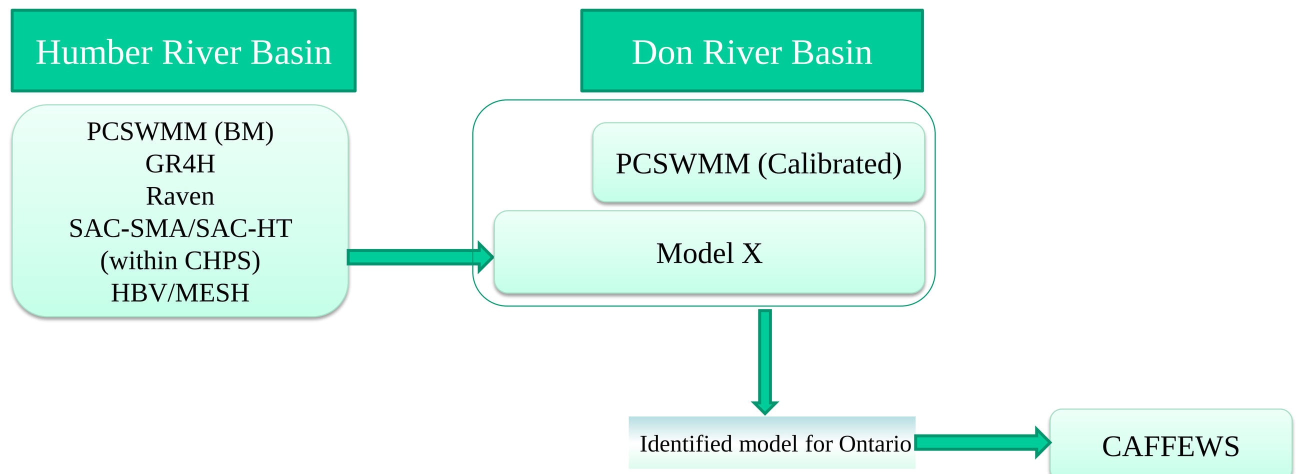
Peak-Box approach (Zappa et al. 2012) (Peak discharge and timing of peak flow)

$$PB_{FULL} = (p_{100} - p_0).(t_{100} - t_o)\frac{3.6}{A} \ [\text{mm}] \qquad D_{FULL} = \left|p_{50} - p_{obs}\right| \ [\text{m}^3.\text{s}^{-1}] \qquad S_{FULL} = \frac{D_{PEAK}}{HQ_{50} - HQ_5} \ [-]$$

$$PB_{IQR} = (p_{75} - p_{25}).(t_{75} - t_{25})\frac{3.6}{A} \ [\text{mm}] \qquad D_{TIME} = \left|t_{50} - t_{obs}\right| \ [\text{h}] \qquad S_{TIME} = \frac{D_{TIME}}{(t_{50}/4)} \ [-]$$

$$PB_{REF} = (HQ_x - HQ_y).(\frac{t_{50}}{4})\frac{3.6}{A} \ [\text{mm}]$$

Short Term Plan



Current Progress

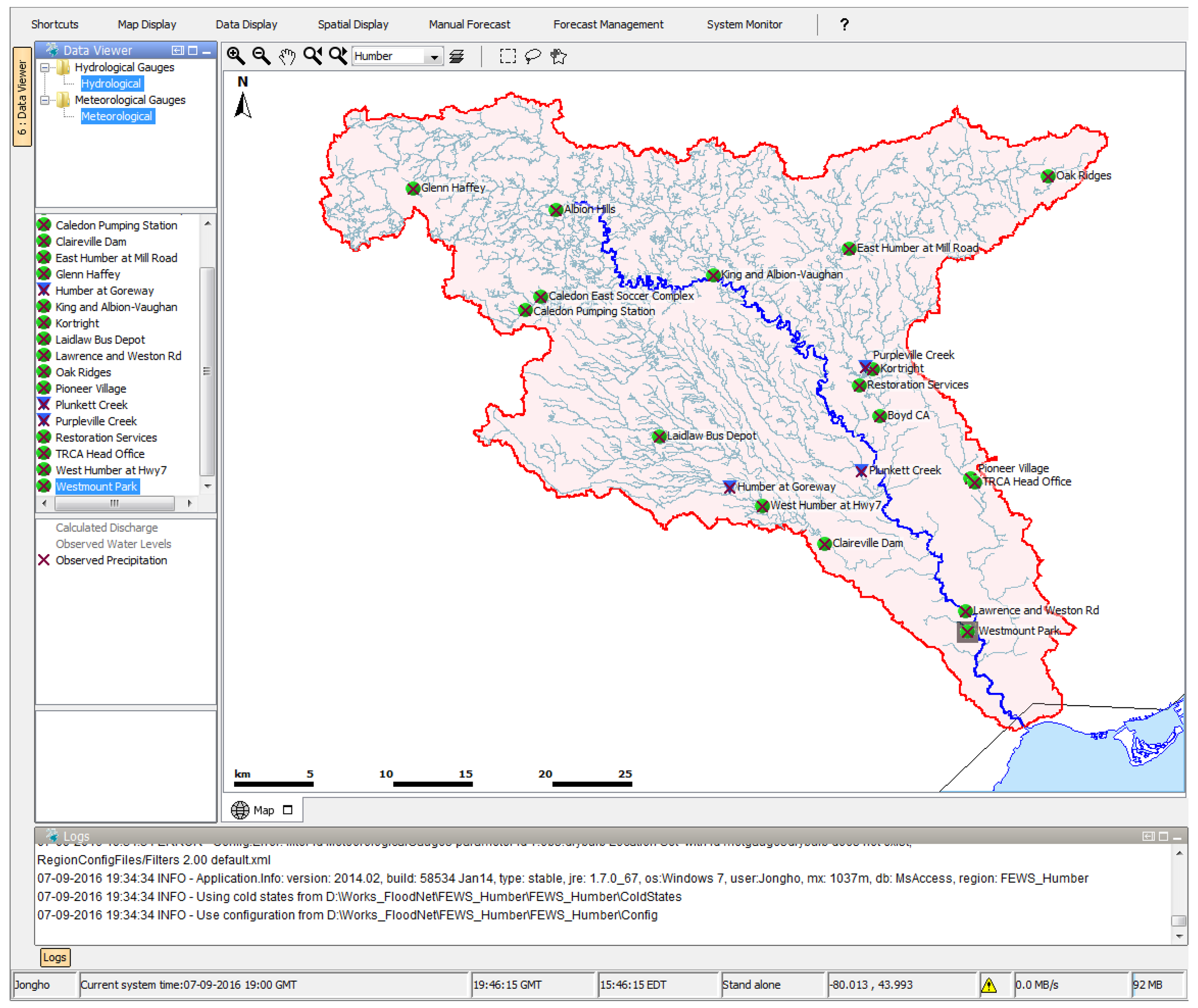
- Summary of Proposed models (Based on general site specific criteria)

Proposed hydrologic models	Proposed Hydraulic models	Selection Criteria for Hydrologic models: Sub-hourly (hourly) time step	Data requirement	Source code availability	Complexity	Site specific model	Application example for flood forecasting
PCSWMM	PCSWMM (Integrated)	YES (Sub-hourly)	HIGH: Fully distributed	YES: SWMM code in C++	MEDIUM	NO	Don and Humber river; TRCA
SAC-SMA /SAC-HT/ (within CHPS)	HEC RAS (Via FEWS)	YES (hourly and subhou⌡rly)	MEDIUM: Conceptual model with Heat Exchange and Frozen Ground component, Class based	YES: Java code	MEDIUM	NO	NOAA for operational flood forecasting
RAVEN	TELEMAC 2D (linked externally)	YES (Sub hourly)	MEDIUM : (Class/Process based semi-distributed)	YES: Upon request	MEDIUM	NO	BC Hydro, EC, OPG, Transalta
GR4H	TELEMAC 2D (linked externally)	YES: (Hourly)	LOW: (only 4 parameters, lumped conceptual)	YES: R and Fortran	LOW	NO	IRSTEA, France; BoM, Australia
WARNS (UBCWM)	MIKE 11/MIKE FLOOD	YES: (Hourly)	MEDIUM: Elevation band; semi-distributed	YES: UBCWM code upon request	MEDIUM	YES: Mountainous hydrology (BC)	Successfully being used by BC RFC
MAC-HBV/HBV Light/ HBV ensemble	HEC RAS (externally)	YES (hourly)	LOW: Conceptual lumped models	YES: matlab and R code	LOW	NO	Tested for Humber river basin by Tara and Coulibaly 2013
MESH (WATFLOOD-CLASS)	TELEMAC 2D (externally)	YES: (30minutes to 1 hour)	HIGH: 7 meteorological forcing inputs, land surface CLASS parameters	YES: upon request	HIGH	YES: model setup for Canadian land surface	Laurentian Great Lakes
HSPF	HEC RAS	YES (Hourly and subhourly)	MEDIUM	YES: Fortran and python	HIGH	NO	Manitoba Infrastructure and transportation

CAFFEWS

✓ **Case Study**
- Platform: Delft-FEWS
- Study Area: East Canada – Humber River Basin in Ontario
- Hydrometric Networks: 3 Streamflow stations and 17 Precipitation stations

✓ **Plans**
- Develop an adapter for PCSWMM and other hydrologic models
- Combine with the OpenDA and a hydrologic model with CAFFEWS
- Build CAFFEWS with CaPa data / Radar information / Real-time water level



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