Probabilistic inflow forecasting with the Raven modelling platform

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Outline

BC Hydro FEWS implementation (2014-2016).

- The Raven modelling platform
- Raven and FEWS
- Short Range probabilistic Forecasting
- Points for discussion
BC Hydro - Quick Facts

- Provincial crown corporation
- Serves 95% of BC (1.8 million customers)
- 11,300 MW capacity (3rd largest in Canada)
- 99% hydroelectric and 1% thermal
- 85% of generation from Peace and Columbia
BC Hydro System - watersheds

21 watersheds over a range of hydroclimates

- Short range deterministic forecasts
- Short range probabilistic forecasts
- Long range ensemble forecasts
- Forecasts during construction work
- Climate change projections
Raven – a modular hydrologic modelling framework
The RAVEN Development Team

- **Primary Author**
  James Craig, Ph.D., jrcraig@uwaterloo.ca (its his baby….)

- **Contributing Authors**
  Andrew P. Snowdon (Many process routines; iterative global algorithms)
  Martin Serrer (Linux port; code optimization; I/O management)

- **Other Development Team Members:**
  Ayman Kheydr (Custom Output; Pedotransfer functions)
  Susan Huang (Routing Benchmarking, Input QA routines)
  Wayne Jenkinson (Development Planning & Coordination)
  Georg Jost (Planning)
  Graham Stonebridge (Evapotranspiration Benchmarking)
  Sylvie Spraakman (Technical Documentation)
  Bryan A. Tolson (Ideas and Recommendations)
  Stuart Pearson (Time Series Utilities)
  Cloud Zhang (GIS Utilities)
  Nicholas Zorn (Code Documentation; Doxygen port)
Raven Framework

- More than just another hydrological model
- Modelling platform
  - extensive library of process algorithms
  - Flexible spatial discretization
  - parameter autogeneration
  - powerful & intuitive I/O
  - robust error-checking, etc., etc.
- Build different models on the fly
- Build your own model by choosing from library of process algorithms
- Build your own model by adding your own equations to library of process algorithms
What makes Raven different?

- By choosing a particular model, we already let someone else make most of our decisions!
  - These aren’t necessarily the right decisions.
- Flexibility encourages hypothesis testing about system behaviour
- Flexibility supports stepwise modelling where complexity is added *when justified by data*
Raven: Flexible discretization

From lumped to fully distributed and anything in-between

(a) Catchment Discretization

(b) Grid Cell / LSM Discretization
Raven: Flexible discretization
Raven: Process description

Select from a library of built-in process representations or add your own

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<tr>
<th>Precipitation</th>
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<td>Process</td>
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<td>OPEN_WAT</td>
<td>SNOWMELT</td>
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**Soil Processes**

- INF_NATURAL
- INF_SCS
- INF_ALL_INFLATES
- INF_GREEN_LANDPT
- INF_GA_SIMPLE
- INF_UPGRADED_GREEN_LANDPT
- INF_HYD
- INF_URC
- INF_VIC
- INF_VIC_TYPE
- INF_FRI

**Glacier Processes**

- GLOVE_MELT
- GLOVE_LUV
- GLOVE_SACRAMENTO
- GLOVE_CONSTANT

**Other Processes**

- FONDER_RAVEN
- FLOOD
- FLOOD_POT
- FLOOD_LUV

**Atmospheric Variables**

- WIND_SPEED
- WIND_DIRECTION
- DEWPOINT
- HUMIDITY
- PRESSURE

**Evaporation**

- EVAP_ADMIN
- EVAP_LANDPT
- EVAP_SACRAMENTO

**Interception**

- INTERCEPTION
- INTERCEPTION_TO_HYDRO
- INTERCEPTION_TO_LANDPT
Build a model at runtime

Choose an existing model, modify and existing model or build your own.

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### Forcing functions

- RunName: Ash_ws # NRC adapter updated this value
- StartDate: 2016-02-21 00:00:00
- Duration: 20 # NRC adapter updated this value
- TimeStep: 24:00:00
- Method: ORDERED_SERIES
- Interpolation: FROM_FILE Ash_ws_GaugeWeights.txt

- Routing: ROUTE_NONE
- CatchmentRoute: ROUTE_DUMP
- Evaporation: PET_MONTHLY_FACTOR
- GW_Evaporation: PET_MONTHLY_FACTOR
- SW_RadiationMethod: SW_RAD_UBCWM
- SW_CanopyCorrect: SW_CANOPY_CORR_UBCWM
- SW_CloudCorrect: SW_CLOUD_CORR_UBCWM
- LW_RadiationMethod: LW_RAD_UBCWM
- WindSpeedMethod: WINDVEL_UBCWM
- RainSnowFraction: RAINSNOW_UBCWM
- PotentialMeltMethod: POTMELT_UBCWM
- OroTempCorrect: OROCORR_UBCWM
- OroPrecipCorrect: OROCORR_UBCWM2
- CloudCoverMethod: CLOUDCOV_UBCWM

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### Hydrologic process order for UBCWM Emulation

- HydrologicProcesses
  - SnowAlbedoEvolve SNOALB_UBCWM
  - SnowBalance SNOBAL_UBCWM MULTIPLE MULTIPLE
  - Flush RAVEN_DEFAULT PONDED_WATER INT_SOIL2 # moves glacier snowmelt to fast runoff
  - Conditional HRU_TYPE IS GLACIER
  - GlacierMelt GMELT_UBC GLACIER_ICE PONDED_WATER
  - Precipitation PRECIP_RAVEN ATMOS_PRECIP MULTIPLE
  - SoilEvaporation SOILEVAP_UBC MULTIPLE ATMOSPHERE
  - Infiltration INF_UBC PONDED_WATER MULTIPLE
  - Flush RAVEN_DEFAULT SURFACE_WATER INT_SOIL2 # from infiltration
  - GlacierInfiltration GINFIL_UBCWM PONDED_WATER MULTIPLE
  - Percolation PERC_LINEAR_ANALYTIC INT_SOIL INT_SOIL2 # comment out for fast runoff
  - Baseflow BASE_LINEAR_ANALYTIC INT_SOIL3 SURFACE_WATER
  - BASE_LINEAR_ANALYTIC DEEP_GW SURFACE_WATER
  - BASE_LINEAR_ANALYTIC SHALLOW_GW SURFACE_WATER
  - GlacierRelease GRELEASE_LINEAR GLACIER SURFACE_WATER

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### Process formulation

- EndHydrologicProcesses

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BC Hydro
Power smart
GR4J model

# Hydrologic process order for GR4J Emulation

:HydrologicProcesses

:Precipitation PRECIP_RAVEN ATMOS_PRECIP MULTIPLE
:SnowTempEvolve SNOTEMP_NEWTONS SNOW_TEMP
:SnowBalance SNOBAL_CEMA_NIEGE SNOW PONDED_WATER
:OpenWaterEvaporation OPEN_WATER_EVAP PONDED_WATER ATMOSPHERE #Pn
:Infiltration INF_GR4J PONDED_WATER MULTIPLE #Ps-
:SoilEvaporation SOILEVAP_GR4J PRODUCT_STORE ATMOSPHERE #Es
:Percolation PERC_GR4J PRODUCT_STORE TEMP_STORE #Perc
:Flush RAVEN_DEFAULT SURFACE_WATER TEMP_STORE #Pn-Ps
:Split RAVEN_DEFAULT TEMP_STORE CONVOLUTION[0] CONVOLUTION[1] 0.9 #Split Pr
:Convolve CONVOL_GR4J_1 CONVOLUTION[0] ROUTING_STORE #Q9
:Convolve CONVOL_GR4J_2 CONVOLUTION[1] TEMP_STORE #Q1
:Percolation PERC_GR4JEXCH ROUTING_STORE GW_STORE #F(x1)
:Percolation PERC_GR4JEXCH2 TEMP_STORE GW_STORE #F(x1)
:Flush RAVEN_DEFAULT TEMP_STORE SURFACE_WATER #Qd
:Baseflow BASE_GR4J ROUTING_STORE SURFACE_WATER #Qr

:EndHydrologicProcesses

# Hydrologic process order for GR4J Emulation

:hydrologicprocesses

:Precipitation PRECIP_RAVEN ATMOS_PRECIP MULTIPLE
:SnowTempEvolve SNOTEMP_NEWTONS SNOW_TEMP
:SnowBalance SNOBAL_CEMA_NIEGE SNOW PONDED_WATER
:OpenWaterEvaporation OPEN_WATER_EVAP PONDED_WATER ATMOSPHERE #Pn
:Infiltration INF_GR4J PONDED_WATER MULTIPLE #Ps-
:SoilEvaporation SOILEVAP_GR4J PRODUCT_STORE ATMOSPHERE #Es
:Percolation PERC_GR4J PRODUCT_STORE TEMP_STORE #Perc
:Flush RAVEN_DEFAULT SURFACE_WATER TEMP_STORE #Pn-Ps
:Split RAVEN_DEFAULT TEMP_STORE CONVOLUTION[0] CONVOLUTION[1] 0.9 #Split Pr
:Convolve CONVOL_GR4J_1 CONVOLUTION[0] ROUTING_STORE #Q9
:Convolve CONVOL_GR4J_2 CONVOLUTION[1] TEMP_STORE #Q1
:Percolation PERC_GR4JEXCH ROUTING_STORE GW_STORE #F(x1)
:Percolation PERC_GR4JEXCH2 TEMP_STORE GW_STORE #F(x1)
:Flush RAVEN_DEFAULT TEMP_STORE SURFACE_WATER #Qd
:Baseflow BASE_GR4J ROUTING_STORE SURFACE_WATER #Qr

:EndHydrologicProcesses
HBV model

# Hydrologic process order for HBV-EC Emulation
#

:HydrologicProcesses

  :SnowRefreeze FREEZE_DEGREE_DAY SNOW_LIQ SNOW
  :Precipitation PRECIP_RAVEN ATMOS_PRECIP MULTIPLE
  :CanopyEvaporation CANEV_ALL CANOPY ATMOSPHERE
  :CanopySnowEvap CANEV_ALL CANOPY_SNOW ATMOSPHERE
  :SnowBalance SNOBAL_SIMPLE_MELT SNOW SNOW_LIQ
  :
  :Overflow RAVEN_DEFAULT SNOW_LIQ PONDED_WATER
  :Flush RAVEN_DEFAULT PONDED_WATER GLACIER
  :
  :GlacierMelt GMELT_HBV GLACIER_ICE GLACIER
  :GlacierRelease GRELEASE_HBV EC GLACIER SURFACE_WATER
  :
  :Infiltration INF_HBV PONDED_WATER MULTIPLE
  :Flush RAVEN_DEFAULT SURFACE_WATER FAST_RESERVOIR
  :
  :SoilEvaporation SOILEVAP_HBV SOIL[0] ATMOSPHERE
  :CapillaryRise RISE_HBV FAST_RESERVOIR SOIL[0]
  :LakeEvaporation LAKE_EVAP_BASIC SLOW_RESERVOIR ATMOSPHERE
  :
  :Percolation PERC_CONSTANT FAST_RESERVOIR SLOW_RESERVOIR
  :Baseflow BASE_POWER_LAW FAST_RESERVOIR SURFACE_WATER
  :Baseflow BASE_LINEAR SLOW_RESERVOIR SURFACE_WATER

:EndHydrologicProcesses

# Additional hydrologic processes

:Snowmelt SNOWMELT SNOWMELT SNOW_00 SNOW_LIQ SNOW
:FixedConcentration FIXED_CONC SNOWMELT SNOW_00 SNOW_LIQ SNOW
:Transport SNOWMELT SNOWMELT SNOW_00 SNOW_LIQ SNOW

# Transport calculations for estimation of snowmelt and glacier
# contributions to runoff
Raven – Raven and FEWS
Raven - FEWS interface

Model decoupled from forecasting system.

- Relative loose connection between FEWS and Raven
- Easy to plug in another model given no changes to I/O
- A bit more work if model uses different inputs and different discretization
- Plan to move python adapter to C++ (dll)
Raven – FEWS spatial data

High spatial resolution from 1:n relationship between Raven output and HRU shapes
Raven – FEWS spatial data

Spatial visualization of Freezing

- Rain on snow events (overlay with MODIS images)
- Snow melt
Raven – FEWS snow data assimilation

SWE vs Elevation for major land cover types (Forest, Open South, Open North)
Raven – FEWS interface

Raven has a build in transport model

Kootenay Lake Short Range Official Forecast

hydrograph separation into rain, snow and glacier runoff
Long Range ensemble forecast

Revelstoke ESP Run

[Graph showing discharge and temperature over time]
Probabilistic short range forecasting
Why use probabilistic forecasting?

Impossible to give accurate forecasts – we can only try to address and minimize the uncertainty in our forecasts.
Uncertainty in weather forecasts

Raw NAEFS forecast
- North American Ensemble Forecasting System
- Total of 42 members

Preprocessing
- Bias correction
- Dispersion correction

FEWS/Raven
- Scheduled runs

FEWS
- Postprocessing
Direct model output (Raven)

NAEFS ~ 50 k resolution

RDPS ~ 10k resolution but only runs 2 day forecast

Very little skill in forecasts beyond day 8

Probabilistic inflow forecast has highest value between day 3 and day 8
‘Dressed’ NAEFS forecast

Sledge hammer: Center NAEFS spread around official deterministic forecast

The hammer:

$$E_D = FC_{det} \times \frac{E_{NAEFS}}{E_{NAEFS}}$$

NAEFS Uncertainty centered around deterministic forecast
Uncertainty in hydrological model

Generalized Likelihood Uncertainty Estimation (GLUE) Beven and Binley (1992)

- Equifinality
- Monte Carlo simulations
- 20 ‘behavioural’ parameter sets/basin
- Uncertainty depends on:
  - time of the year
  - Rain, snow or rain and snow
  - Initial conditions
Uncertainty in hydrological model

Generalized Likelihood Uncertainty Estimation (GLUE) Beven and Binley (1992)
Points for discussion

- Raven
  - Lots of options that can’t all be tested. How to approach this?
- Raven and FEWS
  - Would be nice if FEWS to work with native model files (not only PI-xml and netcdf)
- Probabilistic short range forecasting
  - How do we deal with coarse resolution NAEFS vs high res regional model?
Whats next?

- Evaluation of short range ensembles
- Hourly forecasting
- Improve model
- Explicit routing
- Multi model prediction
- Gridded forcing (forecast)