Forecasting to protect the construction site during Site C river diversion

> Georg Jost Hydrology, BC Hydro

Topics

- A brief history of Raven at BC Hydro
- Forecasting at BC Hydro
- Site C River diversion

A brief history of Raven at BC Hydro

- 2012-2013: Porting UBCWM code onto Raven (James Craig)
- 2013-2016: FEWS integration using python Raven model adaptor
- 2016: Switch from deterministic to probabilistic forecasting (NAEFS)
- 2019: Switch from daily to hourly forecasting for all Coastal watersheds
- 2020: WEF ensemble forecast replaces NAEFS ensembles
- 2021: Raven direct integration into FEWS (no intermediate code)
- 2025: Raven model revamp (testing various spatial discretizations, process algorithms, forcing etc).

Forecasting at BC Hydro

Why do we forecast reservoir inflows?

Water is the fuel for our plants. We don't want to spill water – but we also don't want to run out of water.



Forecasting at BC Hydro

- Short range forecasting (two weeks)
- Long range forecasting (one year)
- Climate change projections (till 2100)
 - Water use plans
 - Water license renewals
- Forecasts during construction work



• Columbia River Treaty forecasting and coordination

Short range forecasting

WEATHER FORECASTS



- 2-step postprocessing
- Copula mapping
- Current version:
 - Input: 148 members
 - Output: 128 members
 - Hourly time step
 - 15 day forecast



DETERMINISTIC FORECAST

Hourly forecasting for all Coastal watersheds... and Site C





PROBABILISTIC INFLOW FORECAST

Impossible to give accurate forecasts – we can only try to address and minimize the uncertainty in our forecasts. Ensemble forecasts with 148 members



Long range forecasting

WATER SUPPLY FORECASTING: ENSEMBLE PREDICTION OF INFLOWS

We use snow observations, weather forecasts, and historical weather to predict inflows over the next few months



UBCWM_Peace_Forecast_ESP: [2] Run long range forecast for Peace Region 01-18-2021, 00:00 PST Current

SNOW DATA ASSIMILATION

We use snow observations, weather forecasts, and historical weather to predict inflows over the next few months







HYDROGRAPH SEPARATION

Using Ravens built in transport model..... Communication of uncertainties



Williston ESP Flow Components

UBCWM_UpdateStates_ESP: [2] Long range Update states to bring mods into states 01-18-2021, 00:00 PST Current

Site C Supersensemble Forecasting

To develop a Storage Reservation Curve (SRC) for Williston reservoir with a probability of exceedance of ~ 1:200 to 1: 500

Site C River diversion (September 2020)



Site C River diversion



Tunnel intakes February 2020



Tunnel outlets February 2020



Powerhouse in February 2020



Cant estimate 1: 500 probability of exceedance of from conventional ESPs



03-14-2020, 03-29-2020, 04-13-2020, 04-28-2020, 05-13-2020, 05-28-2020, 06-12-2020, 06-27-2020, 07-12-2020, 07-27-2020, 08-11-2020, 08-26-2020, 09-10-2020, 09-25-2020, 09-10-2020, 09-25-2020, 09-10-2020, 09-25-2020, 09-10-2020, 09-25-2020, 09-10-2020, 09-25-2

SUPER ENSEMBLE FORECASTS (E.G. SITE C RIVER DIVERSION)

Uses historical weather plus Synthetic weather sequences as input to predict inflows over the next few months. $\sim 3 \times 1048$ traces





Synthetic Weather generator

Computers & Geosciences 41 (2012) 126-135



Neural networks for probabilistic environmental prediction: **C**ondition**a**l **D**ensity Estimation Network Creation and Evaluation (CaDENCE) in R

Alex J. Cannon

Environmental Sciences Research & Development Unit, Science Section, Meteorological Service of Canada, Environment Canada—Pacific & Yukon Region, 201-401 Burrard Street, Vancouver, BC, Canada V6C 355

ARTICLE INFO

ABSTRACT

Article history: Received 26 January 2011 Received in revised form 24 August 2011 Accepted 24 August 2011 Available online 12 September 2011

Keywords: Probabilistic Nonlinear Artificial neural network Interactions Prediction interval R programming language A conditional density estimation network (CDEN) is a probabilistic extension of the standard multilayer perceptron neural network (MLP). A CDEN model allows users to estimate parameters of a specified probability density function conditioned upon values of a set of predictors using the MLP architecture. The result is a flexible model for the mean, the variance, exceedance probabilities, prediction intervals, etc. from the specified conditional distribution. Because the CDEN is based on the MLP, nonlinear relationships, including those involving complicated interactions between predictors, can be described by the modeling framework. CDEN models have been applied to a wide range of environmental prediction tasks, such as precipitation downscaling, extreme value analysis in hydrology, wind retrievals from satellites, and air quality forecasting. This paper describes the CaDENCE (Conditional Density Estimation Network Creation and Evaluation) package, which provides routines for creating and evaluating CDEN models in the R programming language. CaDENCE routines are demonstrated on a dataset consisting of suspended sediment concentrations and discharge measurements from the Fraser River at Hope, British Columbia, Canada.

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SUPER ENSEMBLE FORECASTS

Superensemble forecasts (3000+ traces) extend both the dry and wet tail ends of probabilistic forecasts. Increases reliability in estimating low probabilities of exceedance (~1 in 200 to 1 in 500).



UBCWM_Williston_Forecast_Superensemble_ESP: [1] Williston 10-09-2019, 01:00 PDT Current ____UBCWM_Peace_Forecast_ESP: [2] Run long range forecast for Peace Region 10-09-2019, 01:00 PDT Current



SUPER ENSEMBLE FORECASTS

Uncertainty decreases with each forecast update



SUPER ENSEMBLE FORECASTS

Operate along a storage reservation course that leads to the desired reservoir level at river diversion



How did it work out?

Is the powerhouse is still there?



How did the 2020 water year leading to river diversion shape up?









FORECASTS EVOLUTION LEADING UP TO DIVERSION (SEPT. 2020)

Uncertainty decreases with each forecast update



Power smart

SITE C CONSTRUCTION SITE RIGHT BEFORE RIVER DIVERSION (SEPT. 2020)





UPSTREAM DIVERSION TUNNELS AND COFFER DAM





THE POWERHOUSE IS STILL HERE :)





PICTURES OF CONSTRUCTION WORK AFTER DIVERSION







And after all of that ... a glacier appeared...





Current status

- 4 units online (180 MW each)
- Unit 5 in process of getting commissioned
- Both unit 5 and 6 in service by end of 2025



Overview of Raven revamp

Raven

Watershed discretization

Three setups

- Lumped routing
- Routing at WSC gauges
- Routing at WSC gauges and subwatersheds
- Include lakes and reservoirs
- Climate station selection

Use expert knowledge to select 5-10 combinations of candidate equations to test

- Hourly rain/snow partitioning
- Dingman radiation
- Evaporation within the model
- Two-layer snowpack
- Cold content, etc.

Testing

Model generator creates test setups for all 30 watersheds

- Parameter sensitivity analysis
- Wrapper around Ostrich optimizes all 30 watersheds in one go.
- Calibrate to all data
- Calibrate to high inflow events only
- Calibrate for low flows only*

Notes:

This is essentially the equivalent of the model comparison that we did 15 year ago but a bit more targeted.

Our hourly model implementation was a simpler version of that work (e.g., without the watershed discretization part)

* These can be skipped

Overview of FEWS work

Implement new model(s)

- "go to" model for hourly forecasting
- "go to" model for daily forecasting and water supply forecasting
- Auxiliary model(s) for high inflow events
- Update spatial displays to new GRUs

Snow data assimilation

- Re-map Principal Component Analysis (PCA) to GRUs of new models
- Setup PCA to run between snow survey dates on auto stations alone

