CSHS Operational Forecasting Workshop

THE ENSEMBLE RIVER FORECAST SYSTEM

Towards gaining certainty in uncertainty

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Frank Weber, Forecaster
Dimeji Omikunle, System Developer, Accenture Business Services
Scott Weston, Senior Hydrologist, Lead, Runoff Forecasting
Adam Gobena, Statistical Hydrologist

BC hydro
FOR GENERATIONS

hydrology & technical services

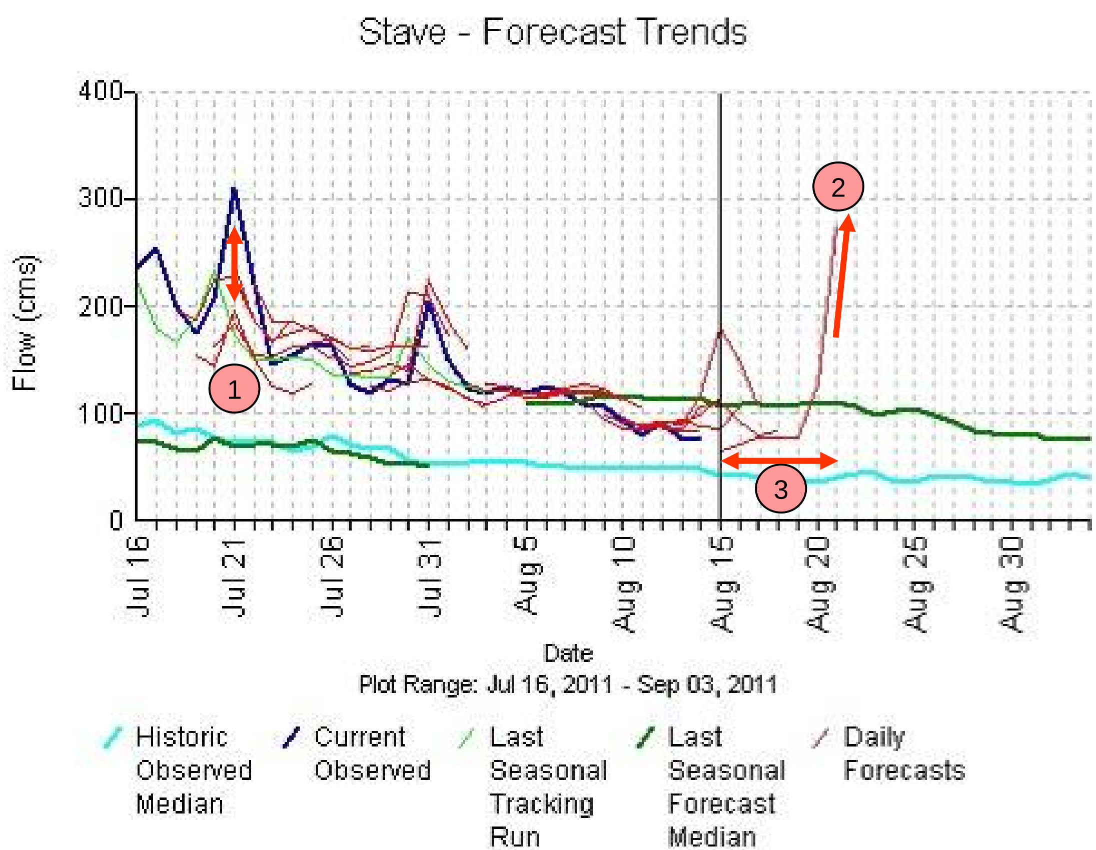
CONTENT

THE ENSEMBLE RIVER FORECAST SYSTEM

- Current issues with short- and long-range inflow forecasts
- A path to recovery
  - Hydrologic model calibration
  - Characterization of forecast uncertainty within the ensemble streamflow prediction framework
    - Weather forcings
    - Model parameters
    - Challenges with short- and long-range ensemble forecasting
- Summary and next steps

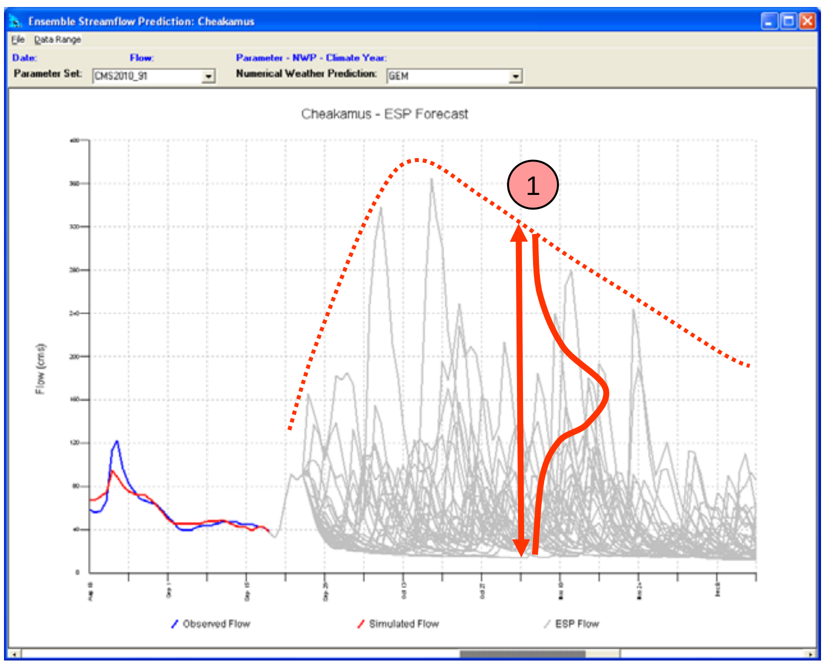
ISSUES WITH CURRENT SHORT-RANGE FORECASTS

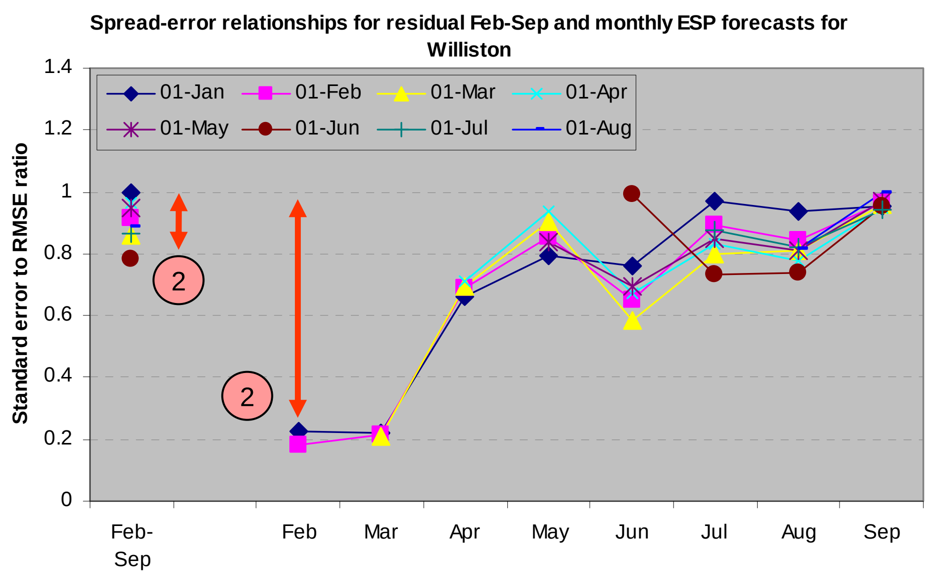
1. Accuracy leaves room for improvement ☺
2. Under-dispersion (i.e., deterministic product)
3. Relatively short lead-time; break the 5-day barrier



ISSUES WITH CURRENT LONG-RANGE FORECASTS

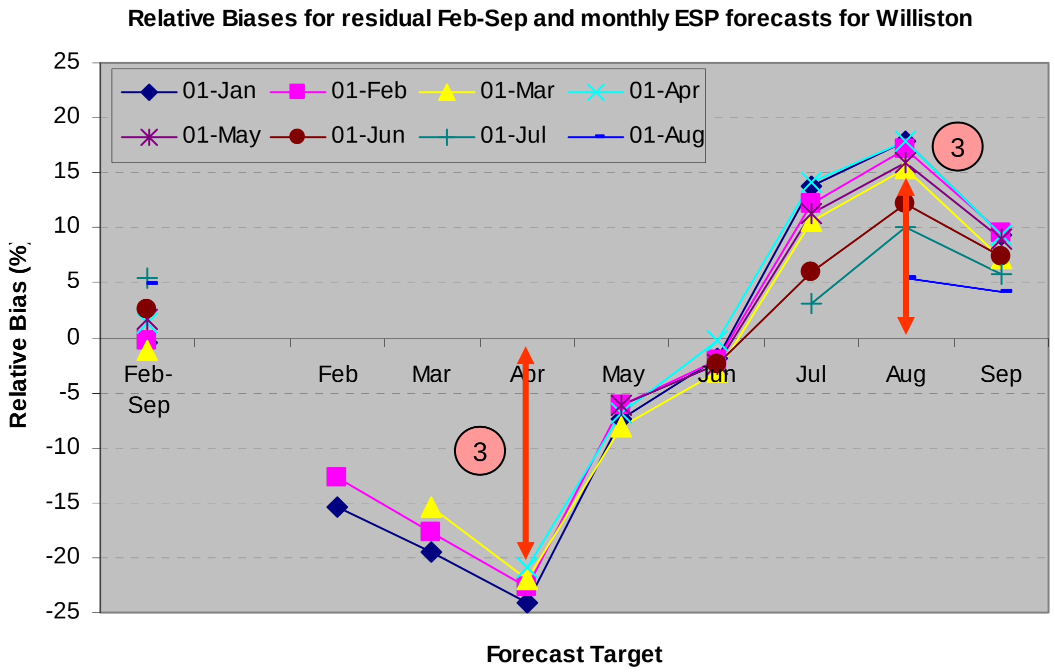
1. Under-dispersion of mid-range forecasts (e.g., for risk-of-spill assessments)
2. General under-dispersion of forecasted water supply
   - Spread of the ensemble is too small
   - Simulation of the error sources is incomplete





ISSUES WITH CURRENT LONG-RANGE FORECASTS

3. Sub-annual (monthly) forecast biases



A PATH TO RECOVERY

Improve forecast accuracy through better hydrologic models

- Improve UBC Watershed Model calibrations

Better characterize forecast uncertainty

- Add hydrologic modeling uncertainty through the use of UBC Watershed Model parameter set ensembles
- Add estimates of short-range numerical weather prediction uncertainty through the use of North American Ensemble Forecast System weather forecasts
- Improve estimates of long-range climate forcings through stochastically-generated historical weather data

Remove/minimize forecast biases

- Explicitly optimize/limit monthly UBC Watershed Model biases during model calibration
- Post-process long-range forecasts for residual UBC Watershed Model simulation biases

Extend the forecast horizon of short-range forecasts

- Use ensemble weather forecasts

UBC WATERSHED MODEL CALIBRATION

CALIBRATION OBJECTIVES

- Take advantage of new data
  - Longer and better quality datasets
  - More up-to-date (adjust for non-stationary catchment properties, e.g., glaciers)
- Reduce known problems (specifically, monthly biases, incorrect parameter values)
  - Weighted monthly bias is generally < 6%
  - Absolute maximum monthly bias is generally <10%
  - Yearly bias is <1% (calibration period)
- Obtain estimates of parameter sensitivity & uncertainty
  - Obtain hydrograph ensembles reflecting this uncertainty which can be used operationally
  - GLUE generates different sets of model parameters that are equally likely as simulators of real systems; here 100 such parameter sets were generated
  - To provide continuity for BC Hydro forecast product users, the equifinality assumption was violated on purpose and a single ‘best’ parameter set determined
  - Further, due to Forecast System run-time constraints, only up to 20 model parameter sets are used operationally

ENSEMBLE RIVER FORECAST SYSTEM - PROJECT CONSTRAINTS

- Limited funds & quick turn around time

- **Existing infrastructure** of the River Forecast System (RFS)
  - Originally design by E. Weiss and Accenture Business Services (ABS) in 2002
  - FAT client desktop application (business logic on local computer, databases on the server side)
  - VB6 application is unsupported by Microsoft
  - Availability of 3rd party components (e.g., for plotting) are waning
  - Hardware was not designed for super-ensemble forecasting
  - Databases are Oracle and WISKI (Oracle)
  - Contractor (ABS) resource availability

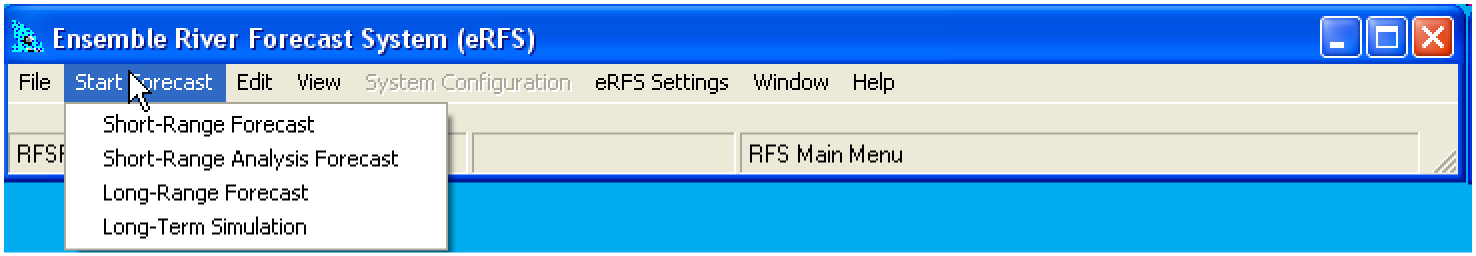
- **UBC Watershed Model is embedded into the forecast system**
- Model is currently run in a **24 hour time step**

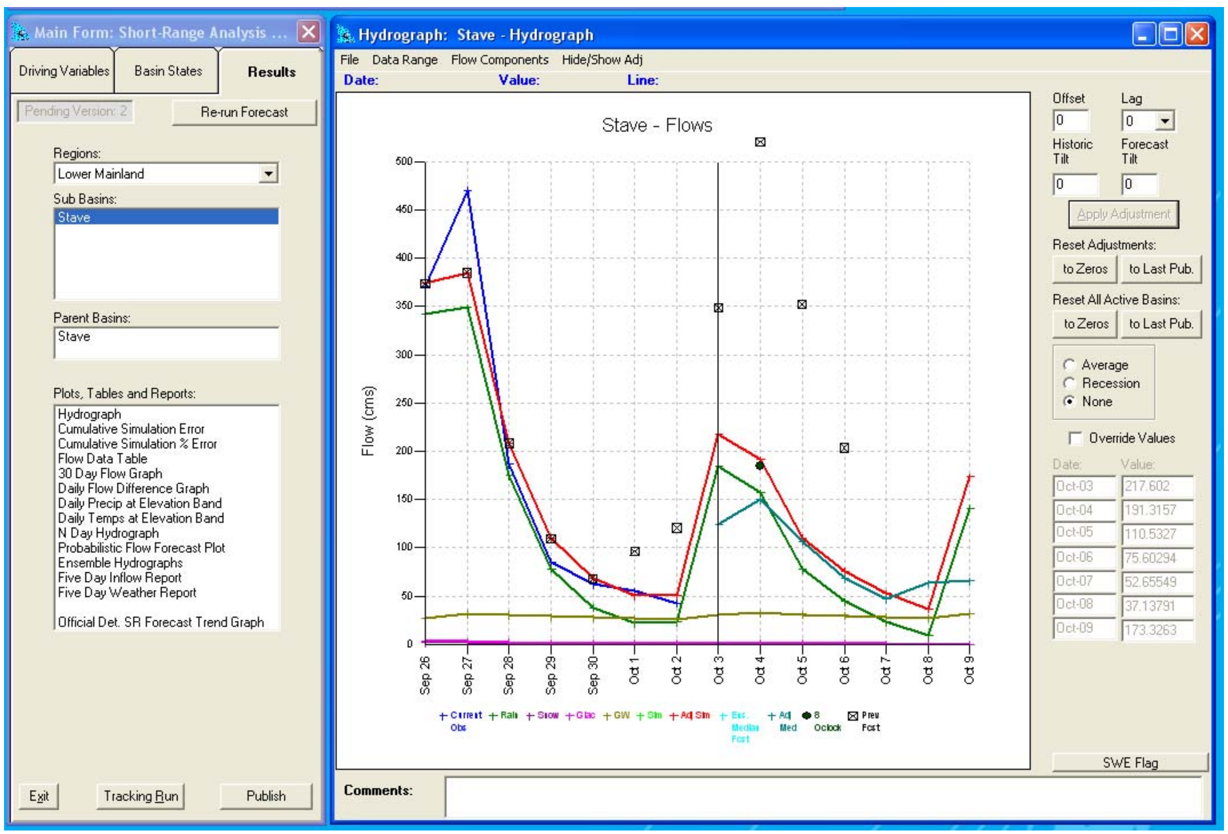
ENSEMBLE RIVER FORECAST SYSTEM - PROJECT CONSTRAINTS

- **Forecasting process**: manual-interactive
- **Initial basin state conditions**: deterministic, but assimilation of snow data is intended to reduce the uncertainty in snow storage estimates
- **Forecast system setup**: separate short- and long-range forecast modes
- **Forecast horizons**: 5 days and 12 months, respectively
- **Numerical weather predictions** for BC Hydro point locations: GEM Reg/Glb, GFS, NAEFS, nested short-term mesoscale NWPs

- BC Hydro Generation Resource Management users
  - Planning, Scheduling and Operations (e.g., forebay forecaster model)
  - Operation Planning Engineers (e.g., reservoir operations models, decision analysis framework for extreme flow events)
  - System Optimization (e.g., marginal cost model, spill risk analysis)
  - Hydrology & Technical Srvs.: Columbia River Treaty (e.g., coordination of storage regulation)

eRFS look & feel





CHARACTERIZE UNCERTAINTY

THE ENSEMBLE RIVER FORECAST SYSTEM

TECHNIQUE

- Ensemble Streamflow Prediction

  UBCWM is run forward repeatedly from currently observed initial conditions with

  (i) An ensemble of model parameter sets

  Future atmospheric forcings in each run drawn from

  (ii) An ensemble of weather forecasts (NWPs)

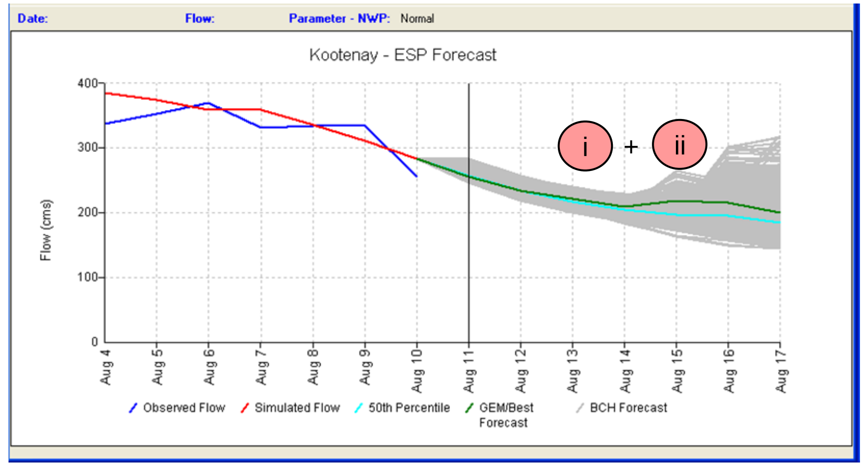
  (iii) An ensemble of historical observed climate

  (iv) An ensemble of historical synthetic climate

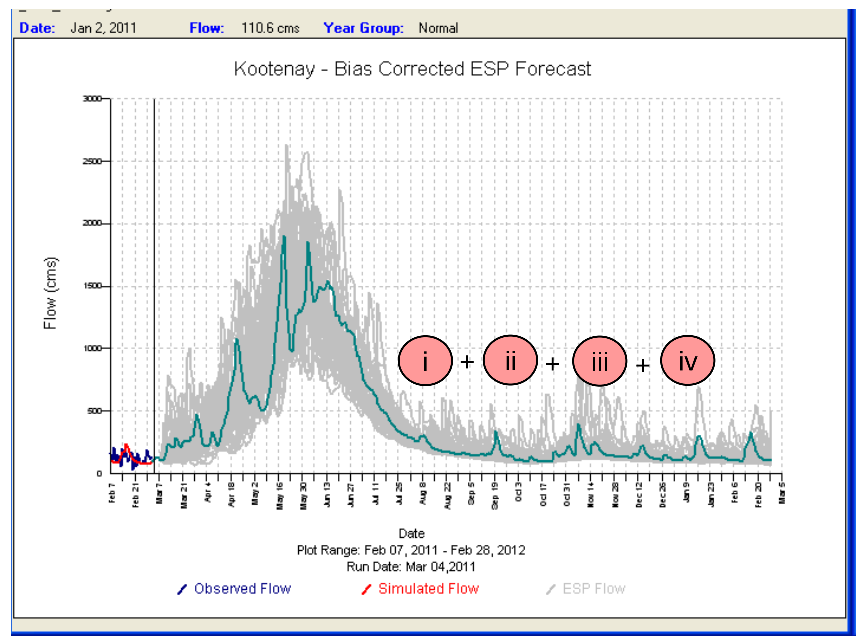
- Practical limitations due to old IT infrastructure
  - Ensemble forecasts only on a per-request basis
  - Ensemble size is flexible (1 → 250,000)

  Forecaster must select forecast variables!

SHORT-RANGE FORECAST



LONG-RANGE FORECAST



SHORT-RANGE FORECAST WEATHER FORCINGS

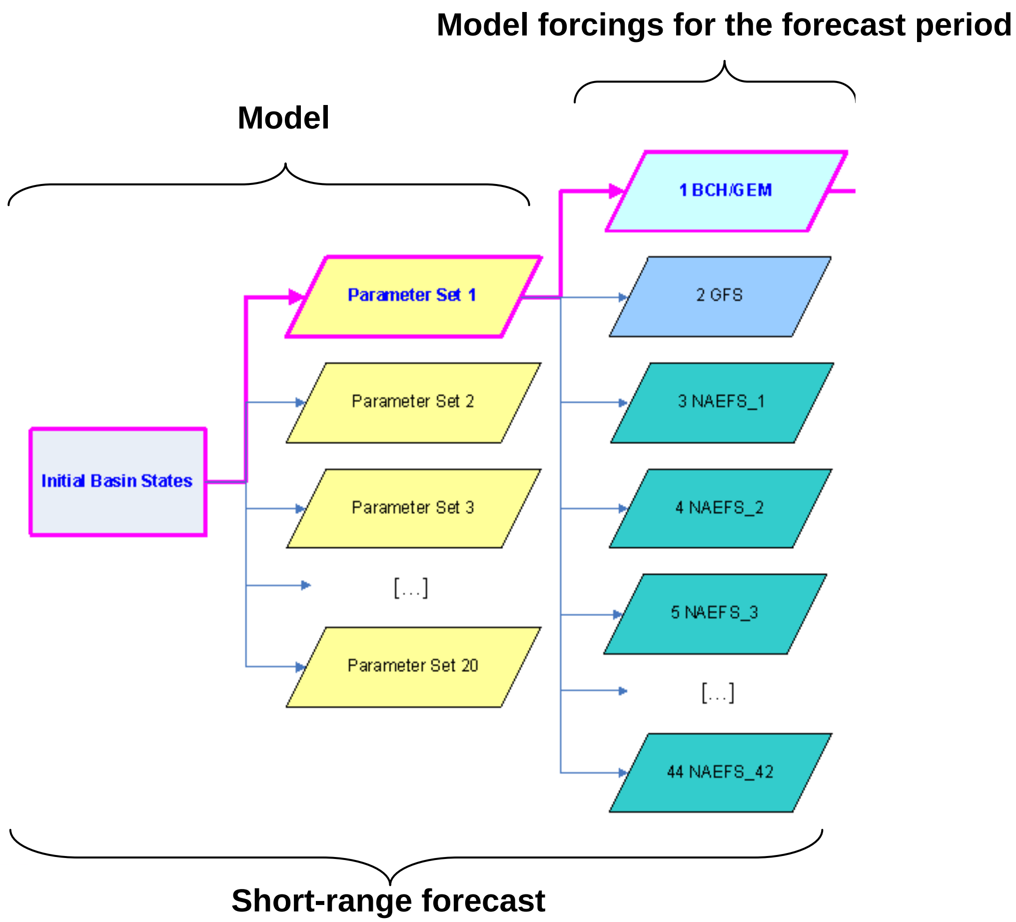
WEATHER FORECAST UNCERTAINTY

NWP forcings coupled to the UBC Watershed Model in the Ensemble River Forecast System:

- Canadian Meteorological Center – Global Environmental Model (GEM Reg/Glb; resolution: ~15 km for Regional) / ~40 km for Global)
- National Oceanic and Atmospheric Administration – Global Forecast System (GFS; resolution: ~15 km - ~40 km dynamical)
- North American Ensemble Forecast System (NAEFS; resolution: 1 degree, ~ 80-100 km), 42 member ensemble, lead time up to 15 days

- Gridded NWP data are downscaled to point locations using a cubic-spline interpolation
- Point NWP data are numerically bias-correction using a 21-day moving average for temperatures and a 60-day degree-of-mass-balance for precipitation.

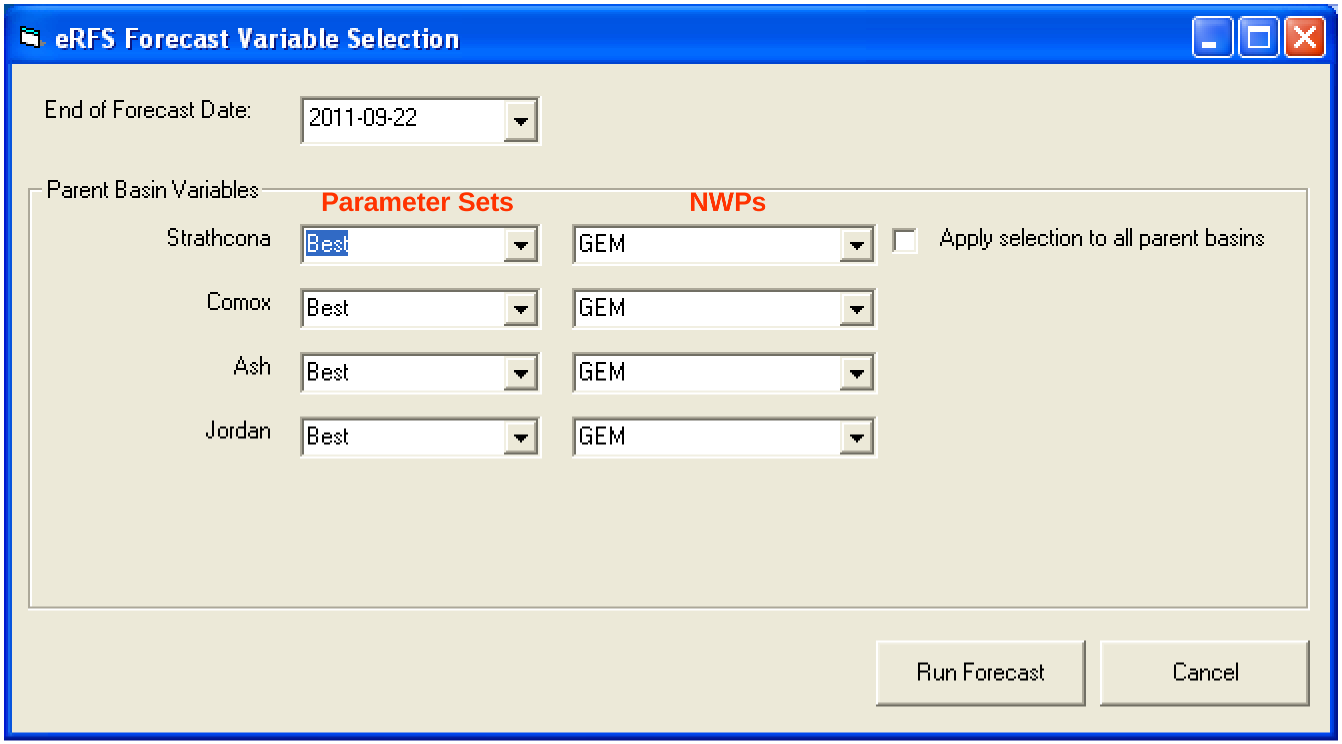
ENSEMBLE MEMBERS & COMBINATIONS



Largest ensemble:
880 members

SHORT-RANGE ENSEMBLE FORECASTING

FORECAST VARIABLE SELECTION



SHORT-RANGE ENSEMBLE FORECASTING

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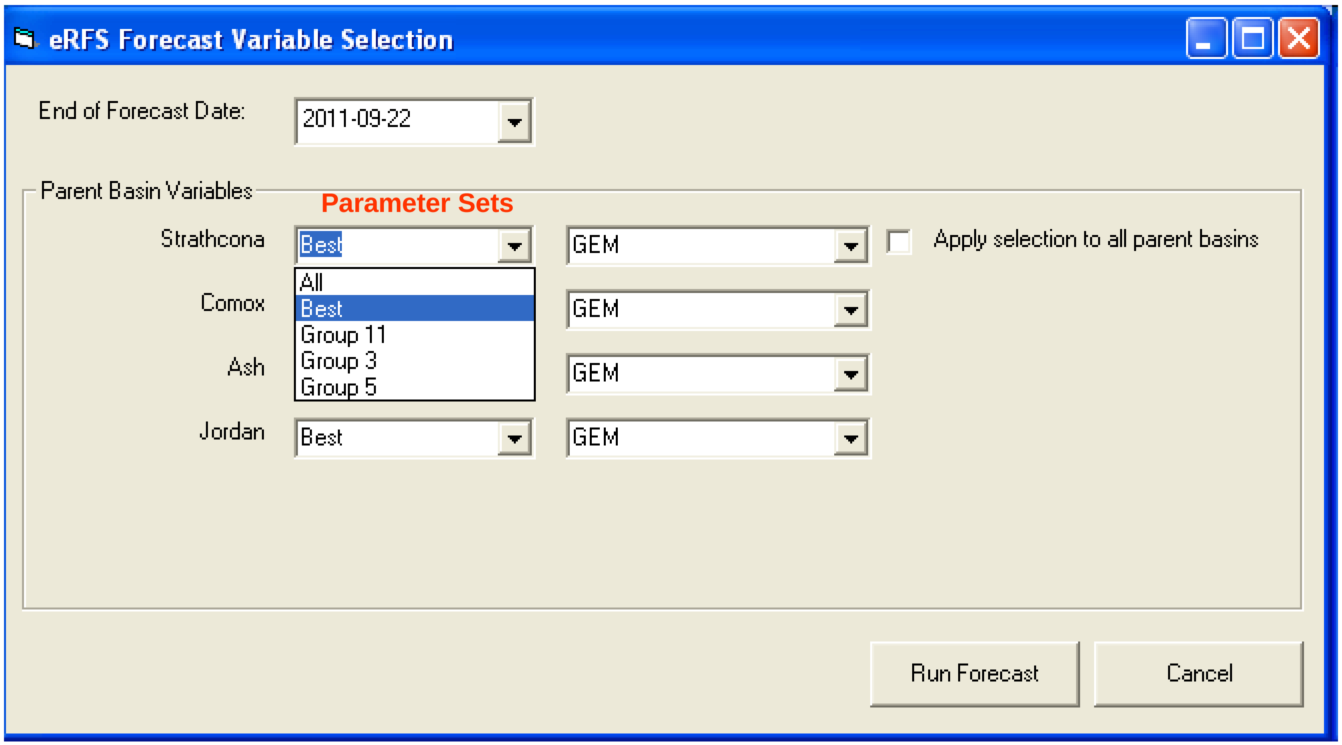
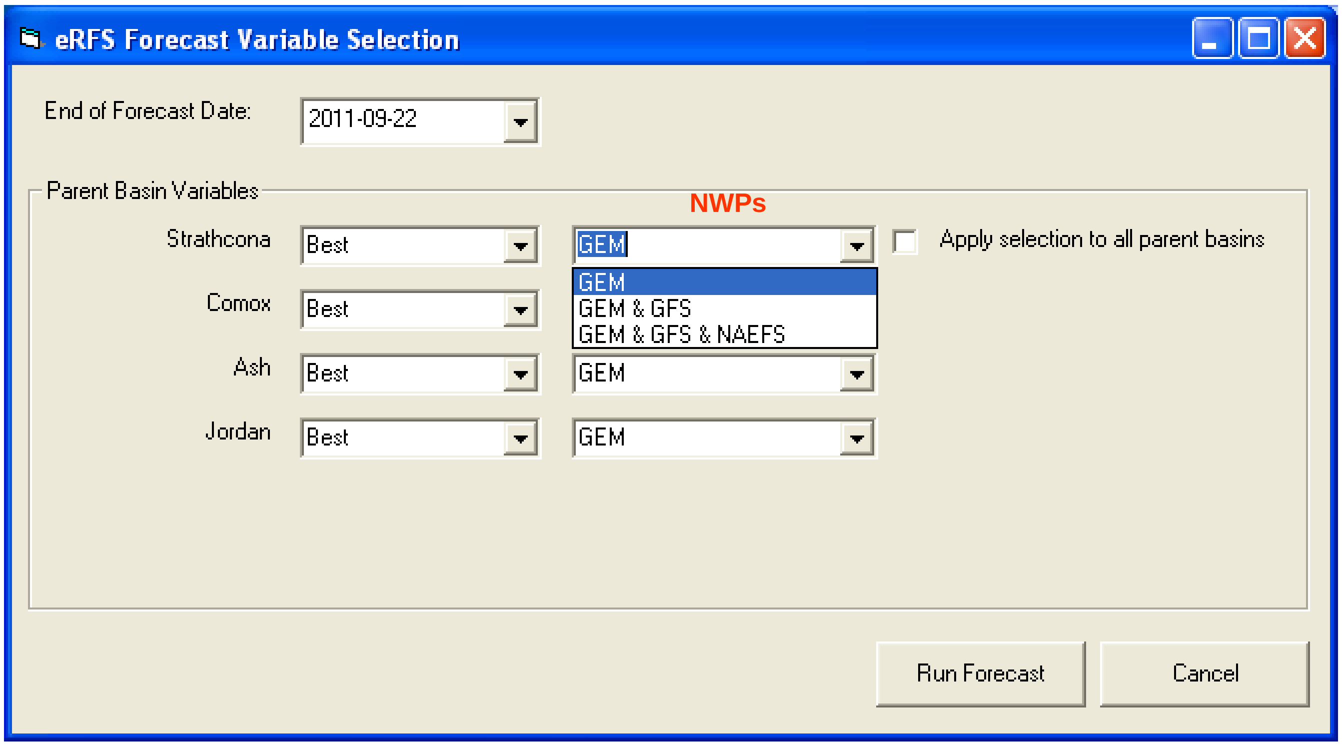
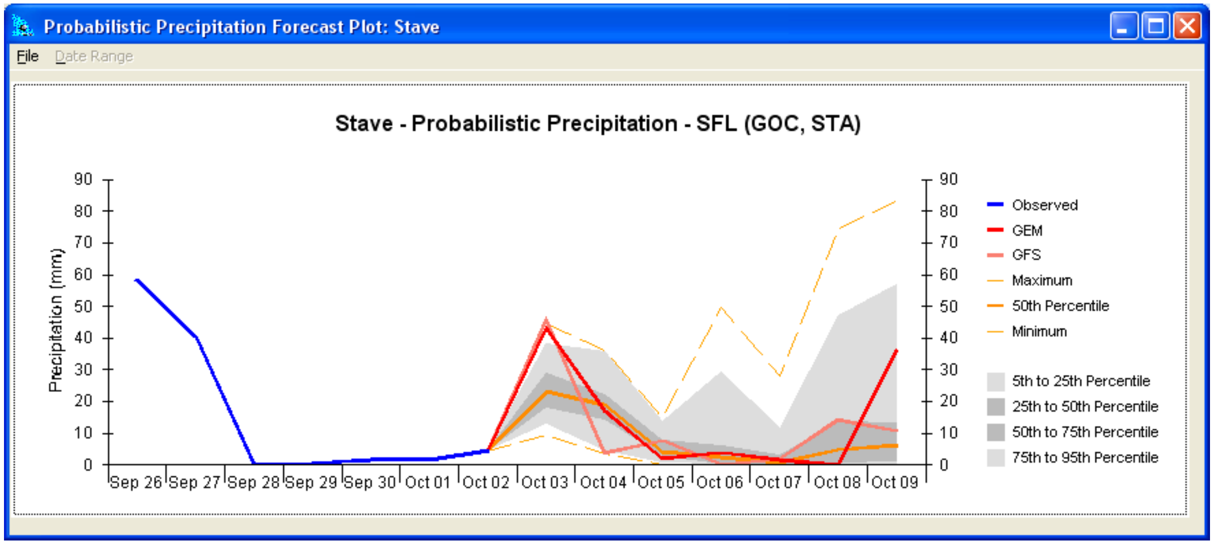


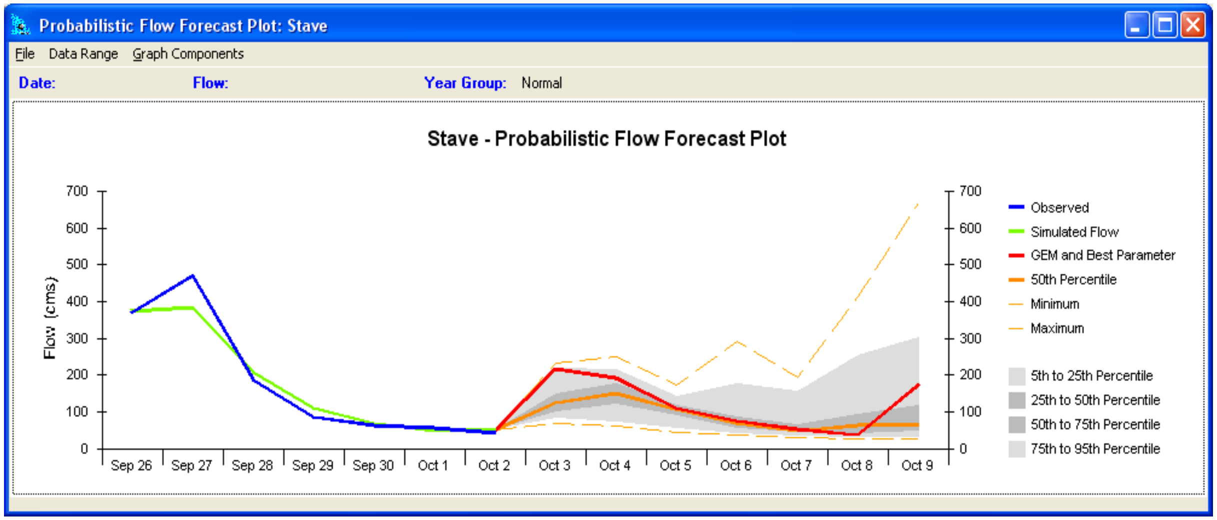
SHORT-RANGE ENSEMBLE FORECASTING

FORECAST VARIABLE SELECTION



eRFS - SOME PLOTS & PRODUCTS





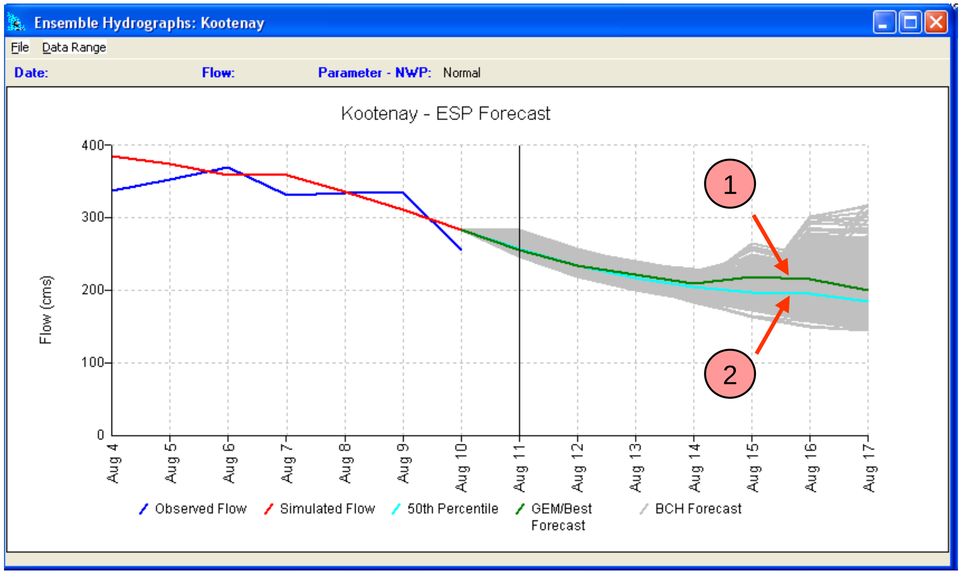
SHORT-RANGE ENSEMBLE FORECASTING - CHALLENGE no. 1

NUMERICAL WEATHER PREDICTIONS

The ultimate goal is to issue an ensemble forecast

All other sources of forecasting uncertainty aside, what is the most probable estimate of future weather and resulting flows?

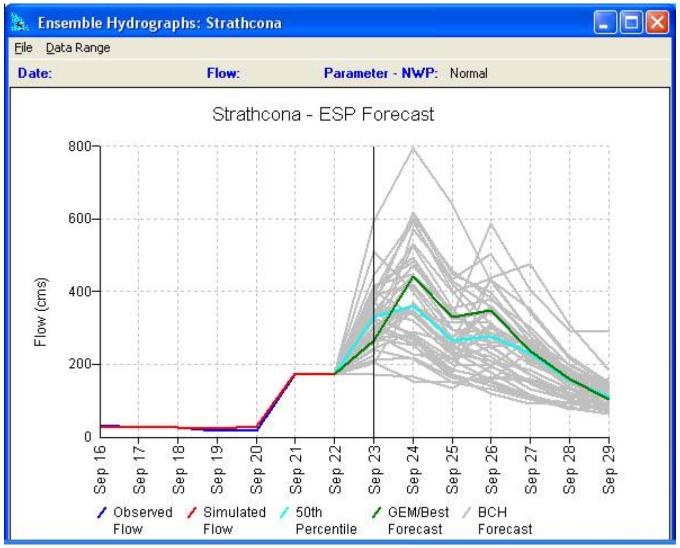
1. A forecast issued with a high-resolution, manually-adjusted NWP (such as the operational version of GEM, adjusted by BC Hydro meteorologists)
2. A statistical combination of low-resolution NWP ensembles (such as the NAEFS ensemble median or mean)



SHORT-RANGE ENSEMBLE FORECASTING - CHALLENGE no. 1

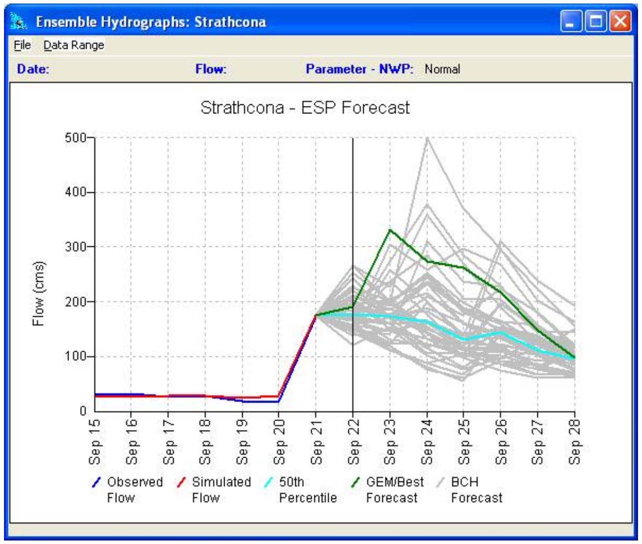
The ideal case

NAEFS ensembles provide uncertainty estimates for the deterministic, high-resolution, manually-adjusted GEM forecast, in which case the ensemble median is similar to the deterministic high-resolution forecast



The real case

The deterministic high-resolution GEM forecast is an extreme scenario



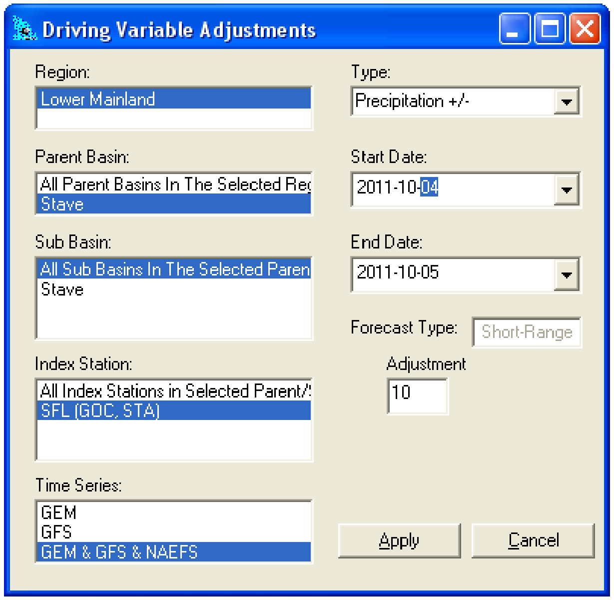
Which forecast is more likely: a high-resolution, manually-adjusted GEM-based forecast or the median NAEFS forecast?

Next steps:
- Compare deterministic, high-resolution, manually-adjusted GEM with median NAEFS forecasts
- Compare NWPs and provide recommendations
- Possibly update NEAFS ensemble forecasts with recent observations and forecaster knowledge

SHORT-RANGE ENSEMBLE FORECASTING - CHALLENGE no. 2

FORECAST UPDATING

- Differences between simulated and observed flow up to the time of the forecast are an issue, as they lead to incorrect initial conditions.
- Similarly, known imperfections in the models and/or the calibration should be accounted for in the forecast period



Updating of ensemble forcings

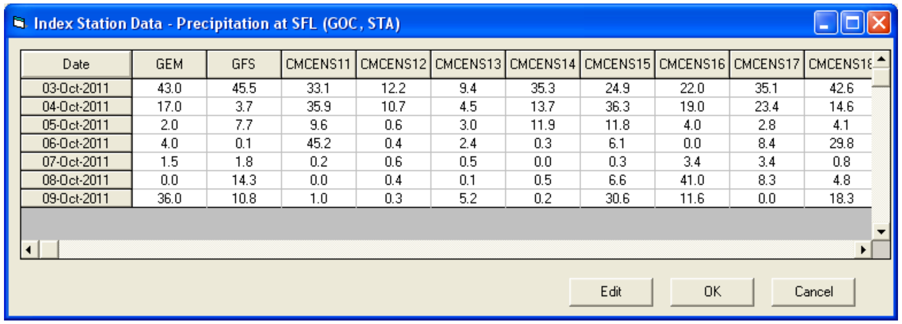
Option 1: Equally across all ensemble members

Option 2: Individually for each ensemble member

Extremely time consuming!

Next steps: - Minimize the necessity to update forecasts

- Modeling in an hourly time step



Date	GEM	GFS	CMCENS11	CMCENS12	CMCENS13	CMCENS14	CMCENS15	CMCENS16	CMCENS17	CMCENS18
03-Oct-2011	43.0	45.5	33.1	12.2	9.4	35.3	24.9	22.0	35.1	42.6
04-Oct-2011	17.0	3.7	35.9	10.7	4.5	13.7	36.3	19.0	23.4	14.6
05-Oct-2011	2.0	7.7	9.6	0.6	3.0	11.9	11.8	4.0	2.8	4.1
06-Oct-2011	4.0	0.1	45.2	0.4	2.4	0.3	6.1	0.0	8.4	29.8
07-Oct-2011	1.5	1.8	0.2	0.6	0.5	0.0	0.3	3.4	3.4	0.8
08-Oct-2011	0.0	14.3	0.0	0.4	0.1	0.5	6.6	41.0	8.3	4.8
09-Oct-2011	36.0	10.8	1.0	0.3	5.2	0.2	30.6	11.6	0.0	18.3

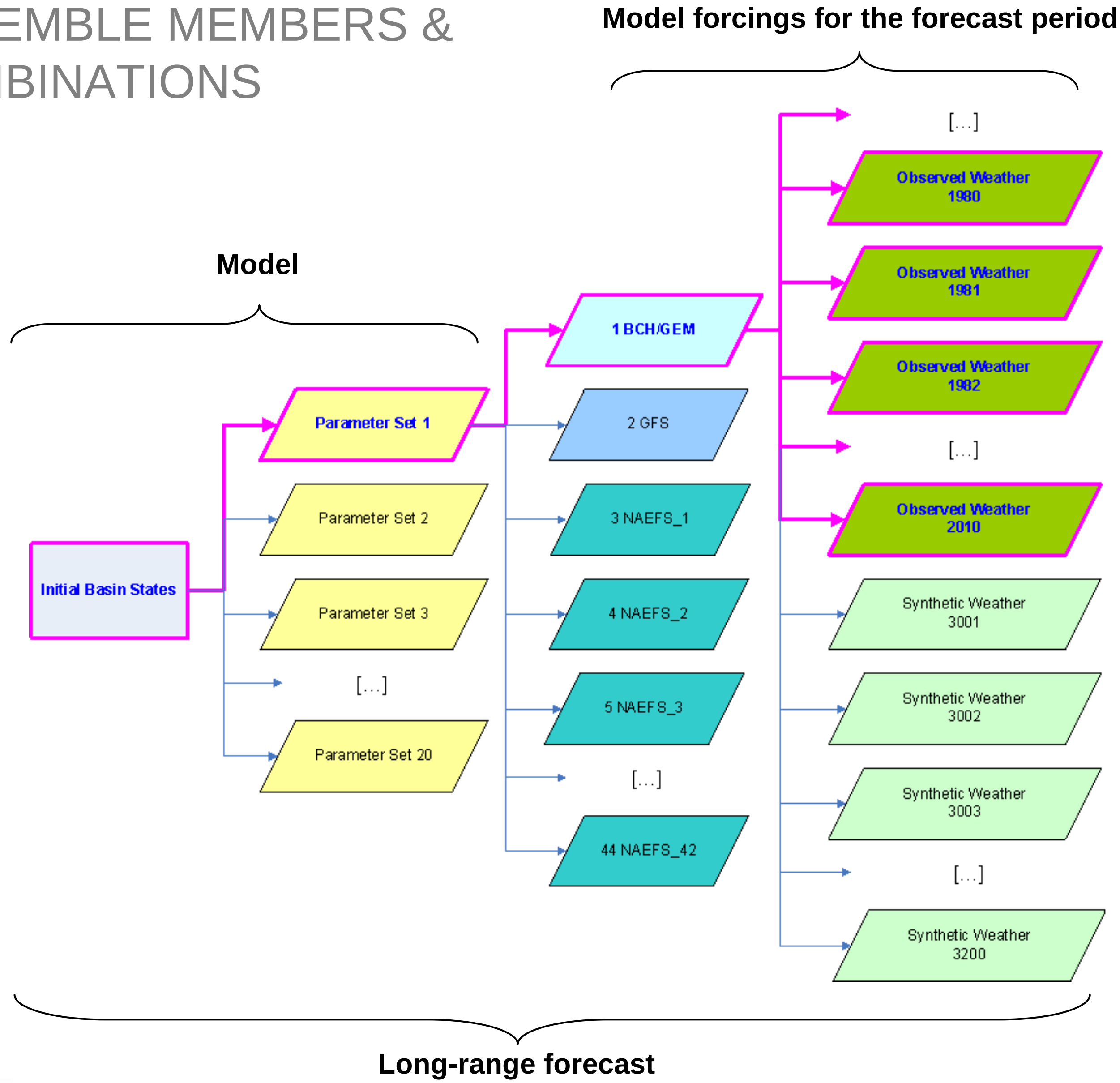
LONG-RANGE FORECAST WEATHER FORCINGS

Numerical weather forecasts are only accurate a few days out largely due to deterministic chaos

- Traditionally observed weather is used as model forcings
  - Relatively short records for south coast watersheds (~30 years)
  - Relatively long records for interior watersheds (~40 years)

- Now additionally available are stochastically-generated daily precipitation, and minimum and maximum daily temperature time series for a continuous 250 year period
  - More extreme weather sequences
  - Used here: a Conditional Density Estimation Network (CDEN, Cannon 2011 submitted), which is an extension of a multi-layer perceptron ANN and in which not only the mean but also the parameters of the distribution describing the predictand are conditioned on covariates
  - Spatial coherence among 3 variables and across 33 sites was preserved

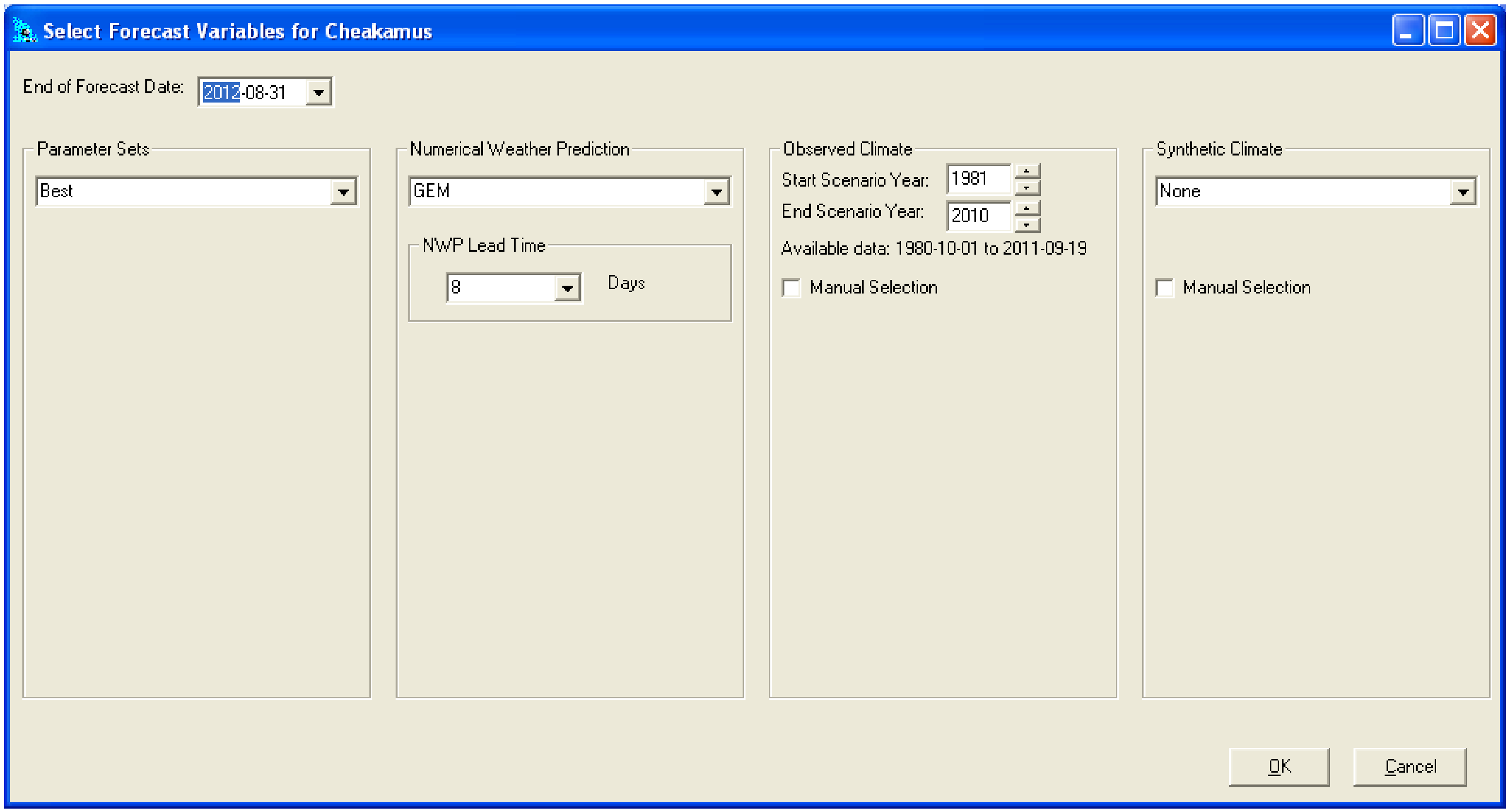
ENSEMBLE MEMBERS & COMBINATIONS



Largest ensemble:
~250,000 members

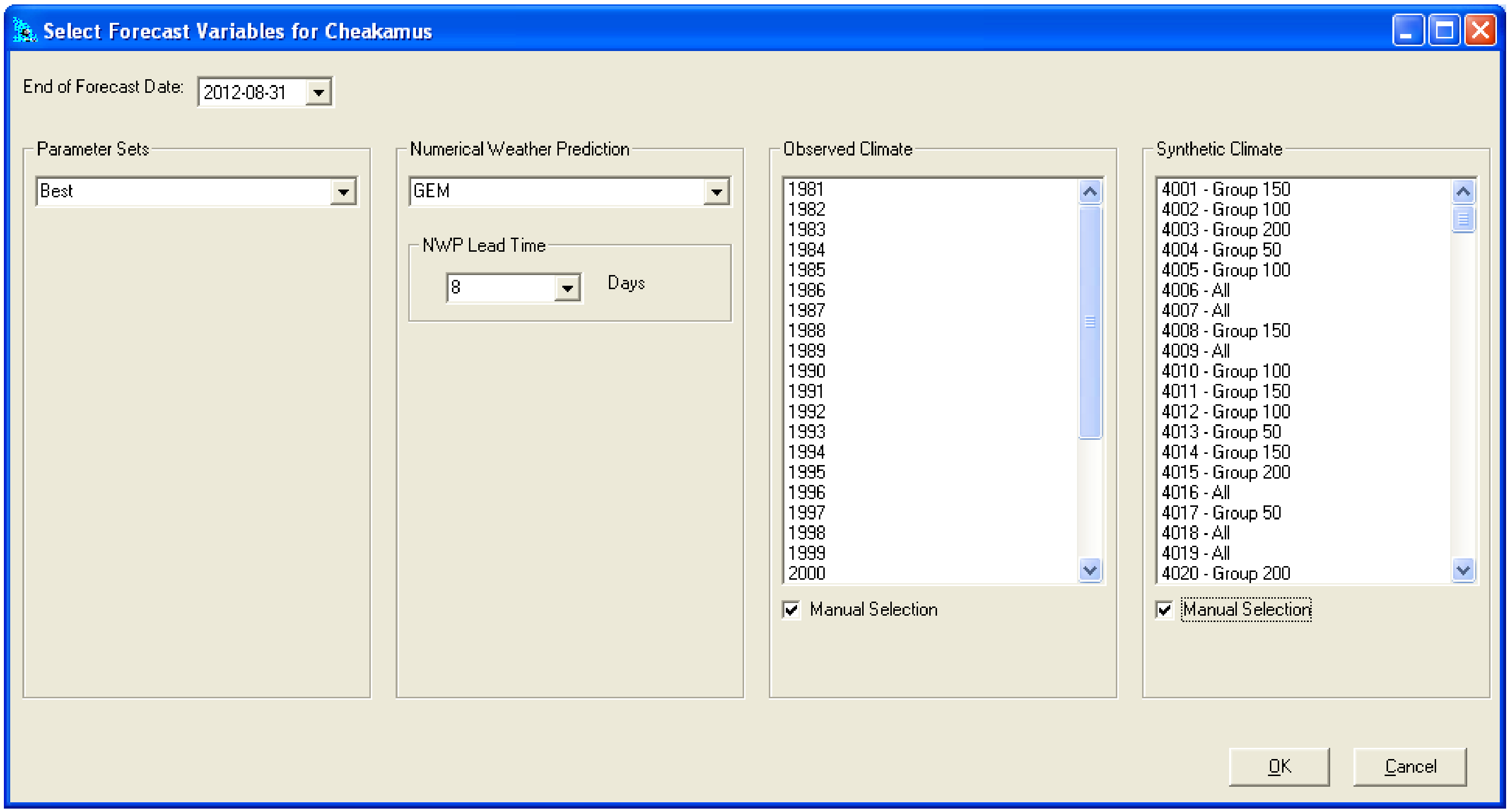
LONG-RANGE ENSEMBLE FORECASTING

FORECAST VARIABLE SELECTION



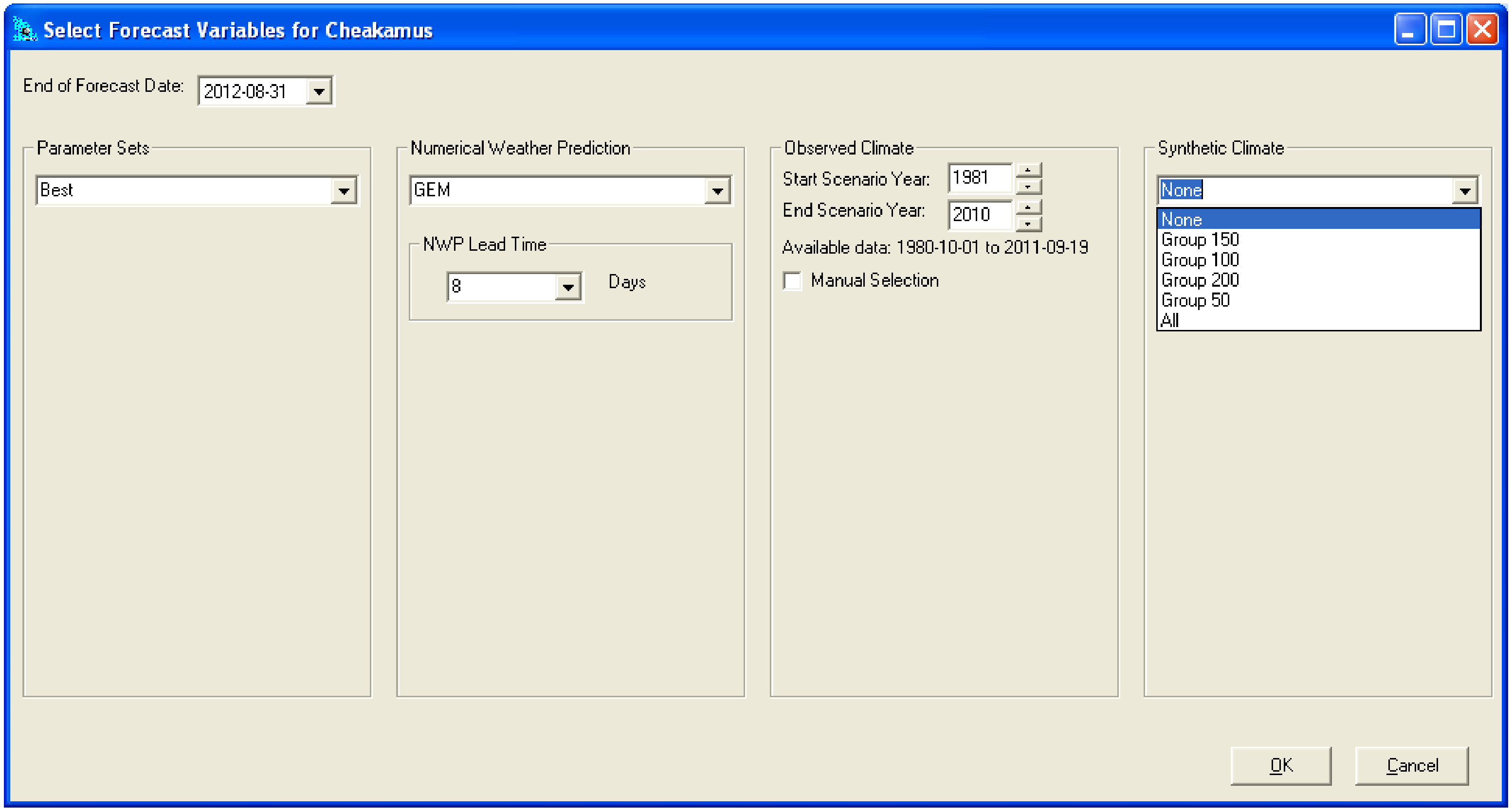
LONG-RANGE ENSEMBLE FORECASTING

FORECAST VARIABLE SELECTION



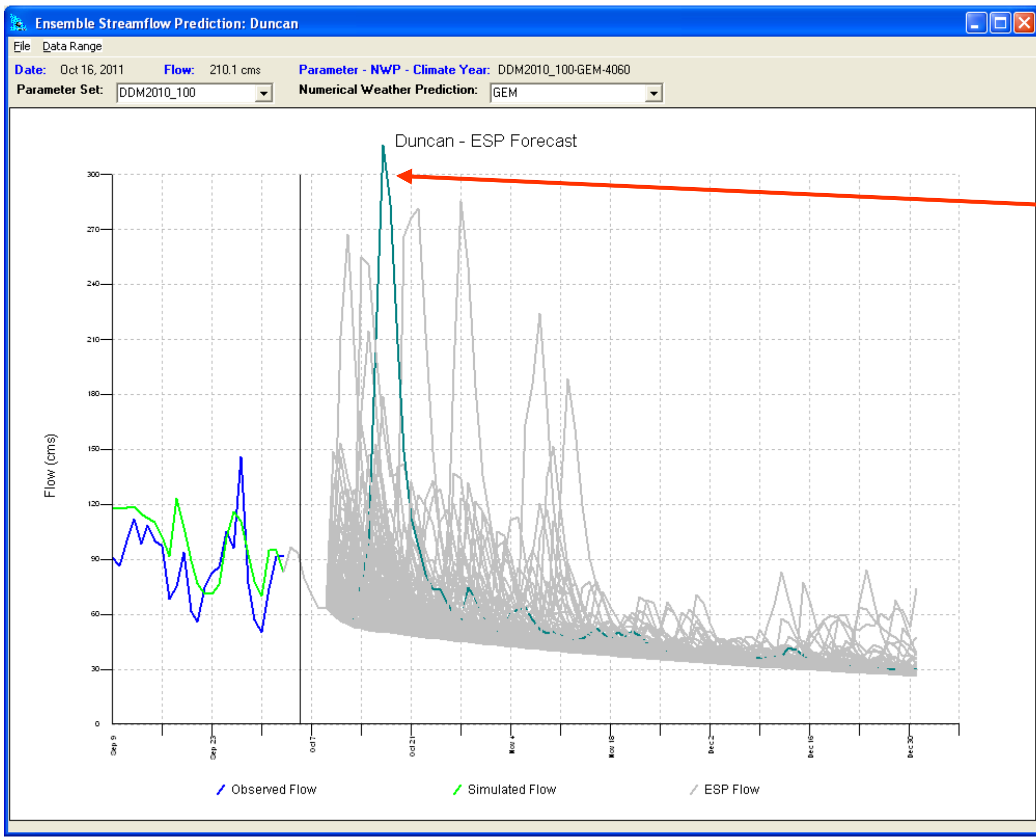
eRFS - ENSEMBLE FORECASTING

LONG-RANGE ENSEMBLE FORECAST



SYNTHETIC WEATHER EFFCTS

For example, a combination of a 5-day deterministic NWP forecast, of 40 years of observed and 100 synthetic weather sequences



Scenarios forced with synthetic weather:

- Plausible flow sequences
- Fill the gaps between ‘historic’ events
- Help better define the tails of the forecast distribution

LONG-RANGE ENSEMBLE FORECASTING - CHALLENGE no. 3

OBTAIN RELIABLE ENSEMBLE FORECASTS

Previous models generated forecast distributions which ranged from poor to good and under-dispersed to over-dispersed, depending on (i) forecast issue date, (ii) target period and (iii) model

For example, spread-skill relationship for Mica forecasts (Standard Error/RMSE)

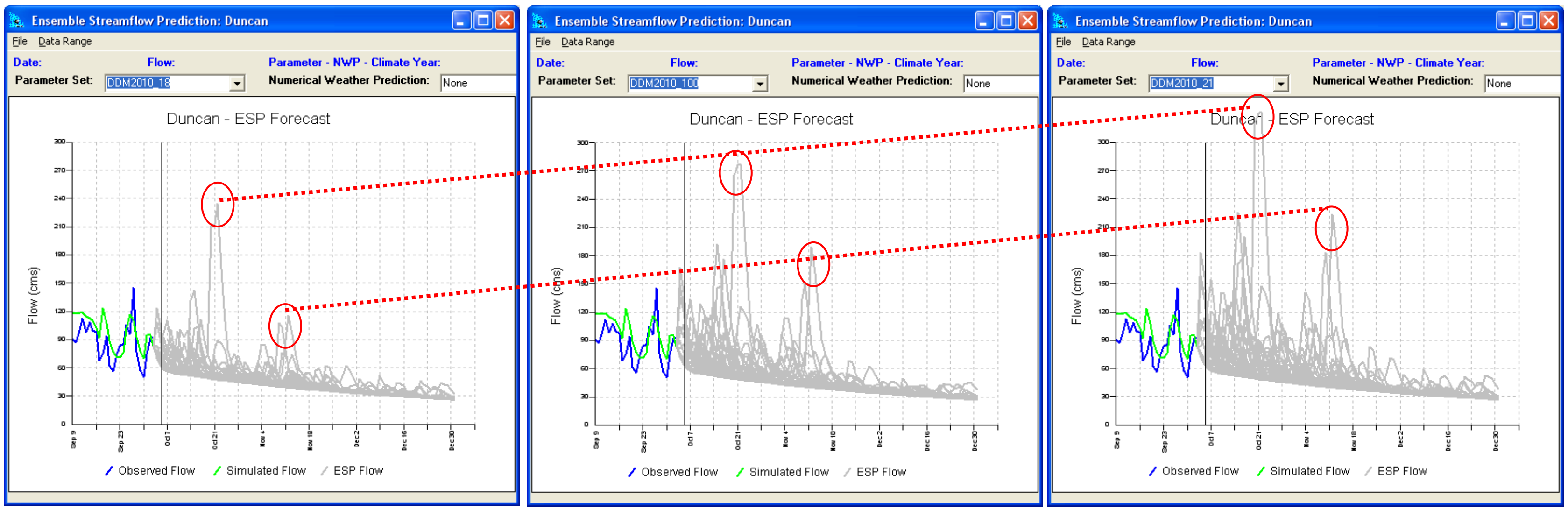
Forecast Issue Date	Residual Feb-Sep	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
January 1	1.01	0.25	0.41	0.76	0.84	1.00	1.10	0.94	1.31
February 1	0.86	0.19	0.42	0.75	0.79	0.97	1.02	0.79	1.28
March 1	0.76		0.37	0.73	0.81	0.96	0.98	0.75	1.28
April 1	0.78			0.68	0.79	1.04	1.08	0.76	1.28

Next steps:

- Perform hindcasting experiments with the new models and update verification statistics
- Quantify the relative contributions from the various sources of forecasting uncertainty
- Assess how combinations of added modeling and weather forecasting uncertainty affect the spread skill relationship

MODELING UNCERTAINTY

For example, forecasts produced with 3 behavioral parameter sets, representing low, middle and high responses (peak flow is 235, 278 and 332 m^3/s, respectively)



SUMMARY

The Ensemble River Forecast System was specifically designed to address forecast bias and the incomplete handling of sources of uncertainty by

- Minimizing monthly and yearly modeling biases in the UBC Watershed Model
- Obtaining different physical parameterizations of the UBC Watershed Model
- Producing flow forecasts with an ensemble of model parameter set
- Forcing hydrologic models with atmospheric models of different structure (GEM & GFS) and perturbed initial states and model physics (NAEFS ensemble)
- Forcing hydrologic models with stochastically extended weather sequences

NEXT STEPS

- Compare NWP performance and provide recommendations
- Specifically, compare deterministic, high-resolution, manually-adjusted GEM and median NAEFS forecasts
- Possibly update NAEFS ensemble forecasts in real-time with recent observations and forecaster knowledge
- Reduce the hydrologic modeling time step to hourly
- Perform hindcasting experiments with the current modeling system
- Assess how combinations of added modeling and weather forecasting uncertainty affect the spread-skill relationship
- Assess the impact of ensemble forecasting on staffing resources

THANKS FOR LISTENING