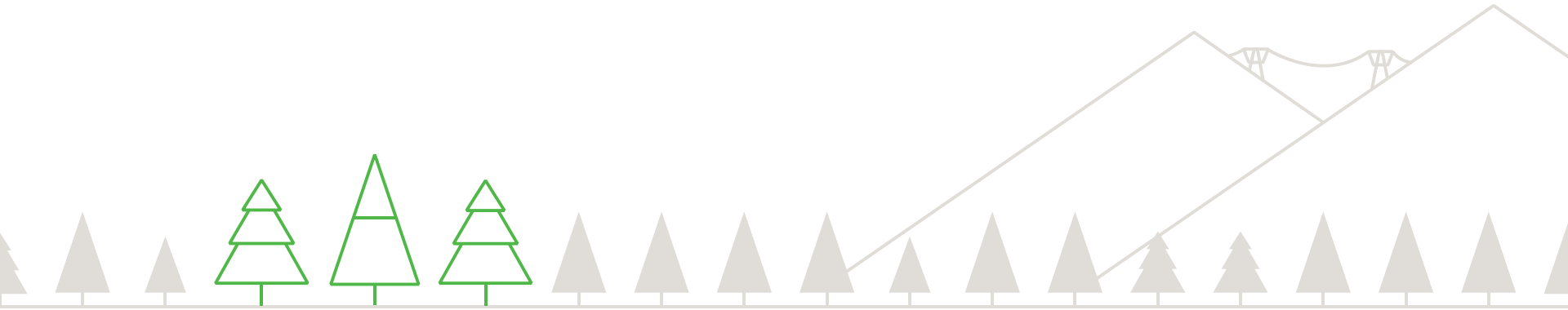
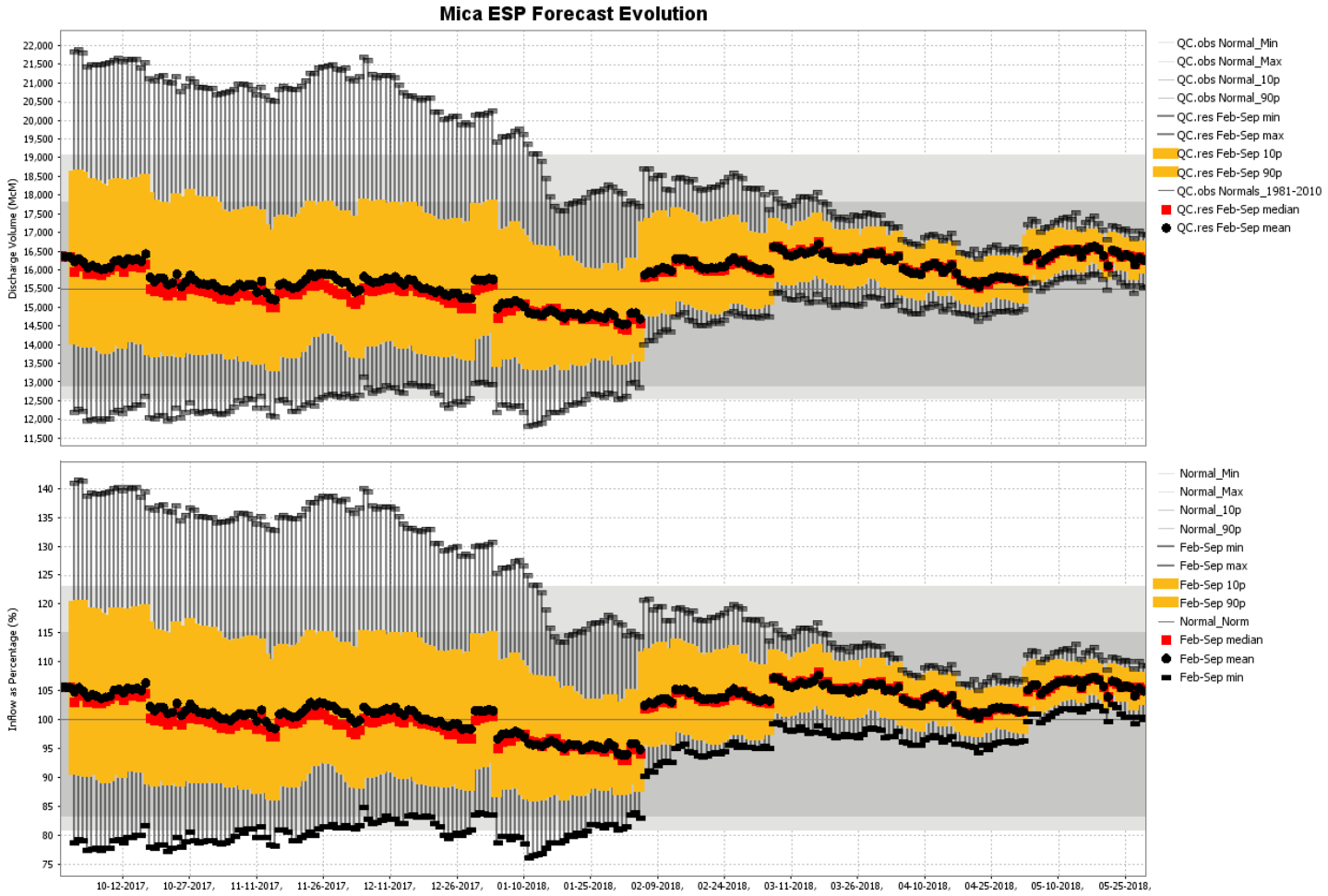
INFLOW FORECASTING AT BC HYDRO

Georg Jost, BC Hydro



BC Hydro
Power smart

LONG RANGE FORECAST EVOLUTION WY 2018



BC Hydro
Power smart

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

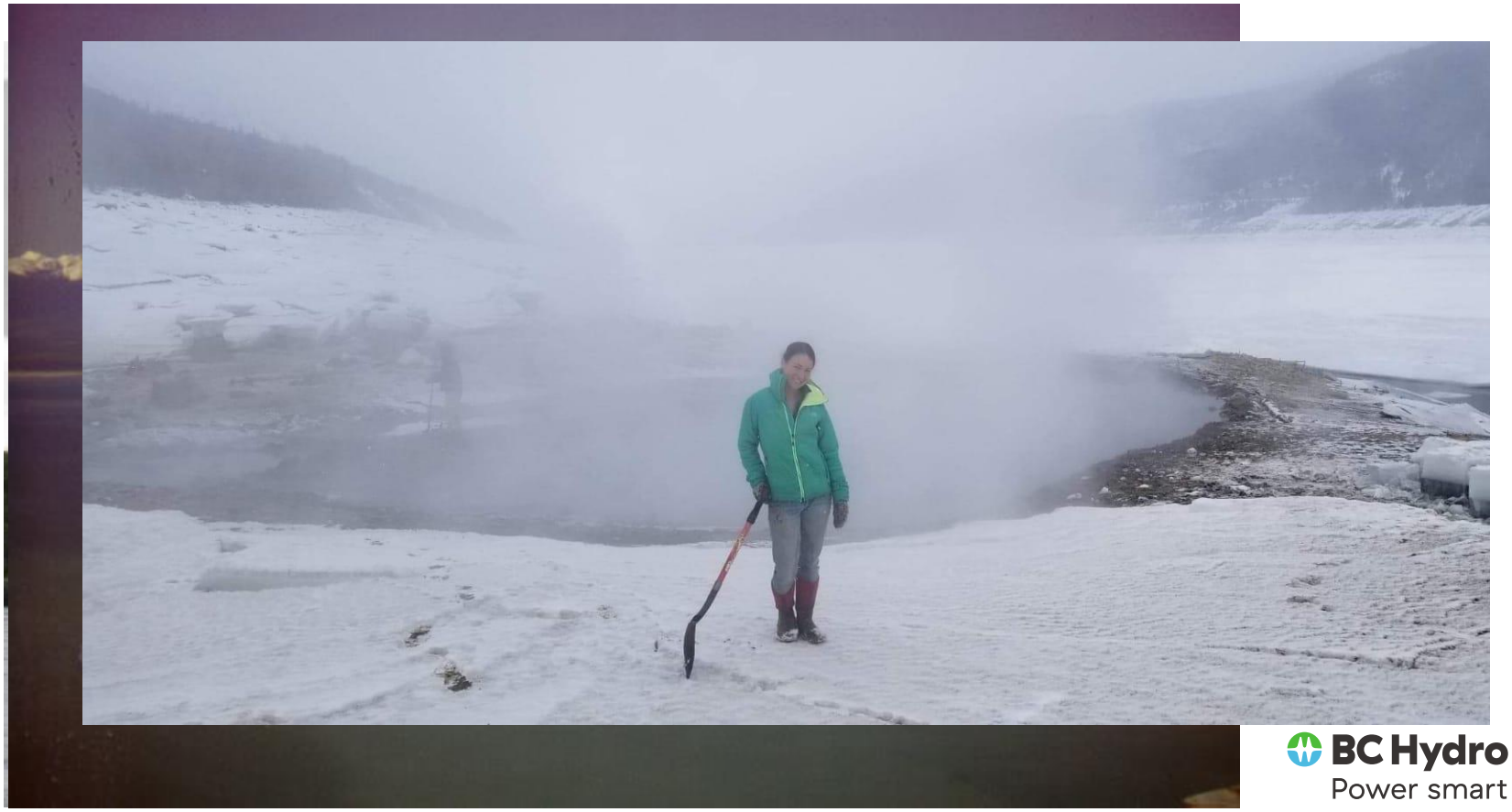
3

OUTLINE

- Forecasting system
- Hydrograph separation
- Super Ensemble Forecast
- Climate change studies
- Ensemble verification

WHY DO WE FORECAST?

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.

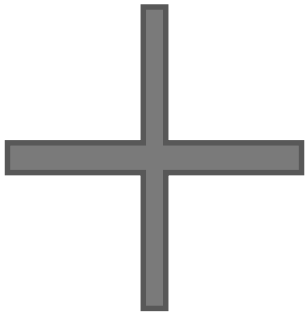


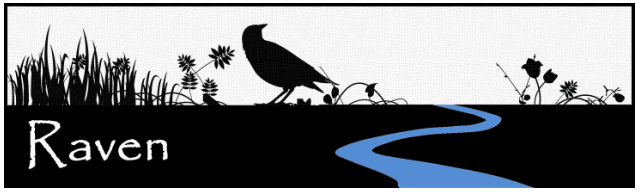
BC Hydro
Power smart

FORECASTING SYSTEM

FEWS

Deltares USA

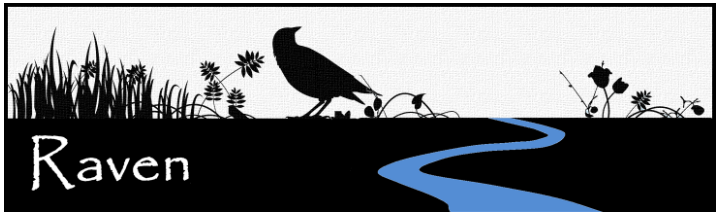




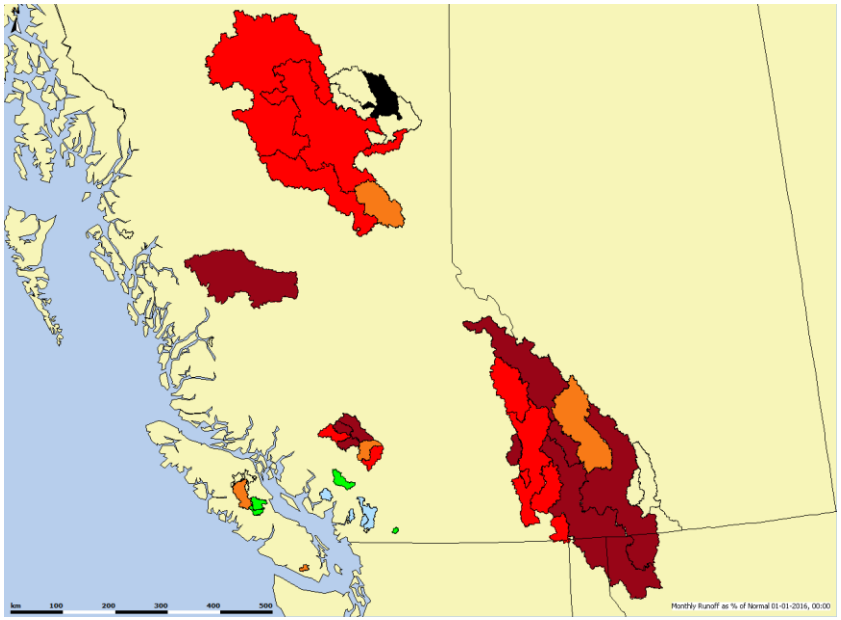
BC Hydro
Power smart

THE RAVEN MODEL

- Modelling platform
  - extensive library of process algorithms
  - Flexible spatial discretization
  - powerful & intuitive I/O
  - Netcdf support (new FEWS adaptor)
- 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



FORECASTING AT BC HYDRO



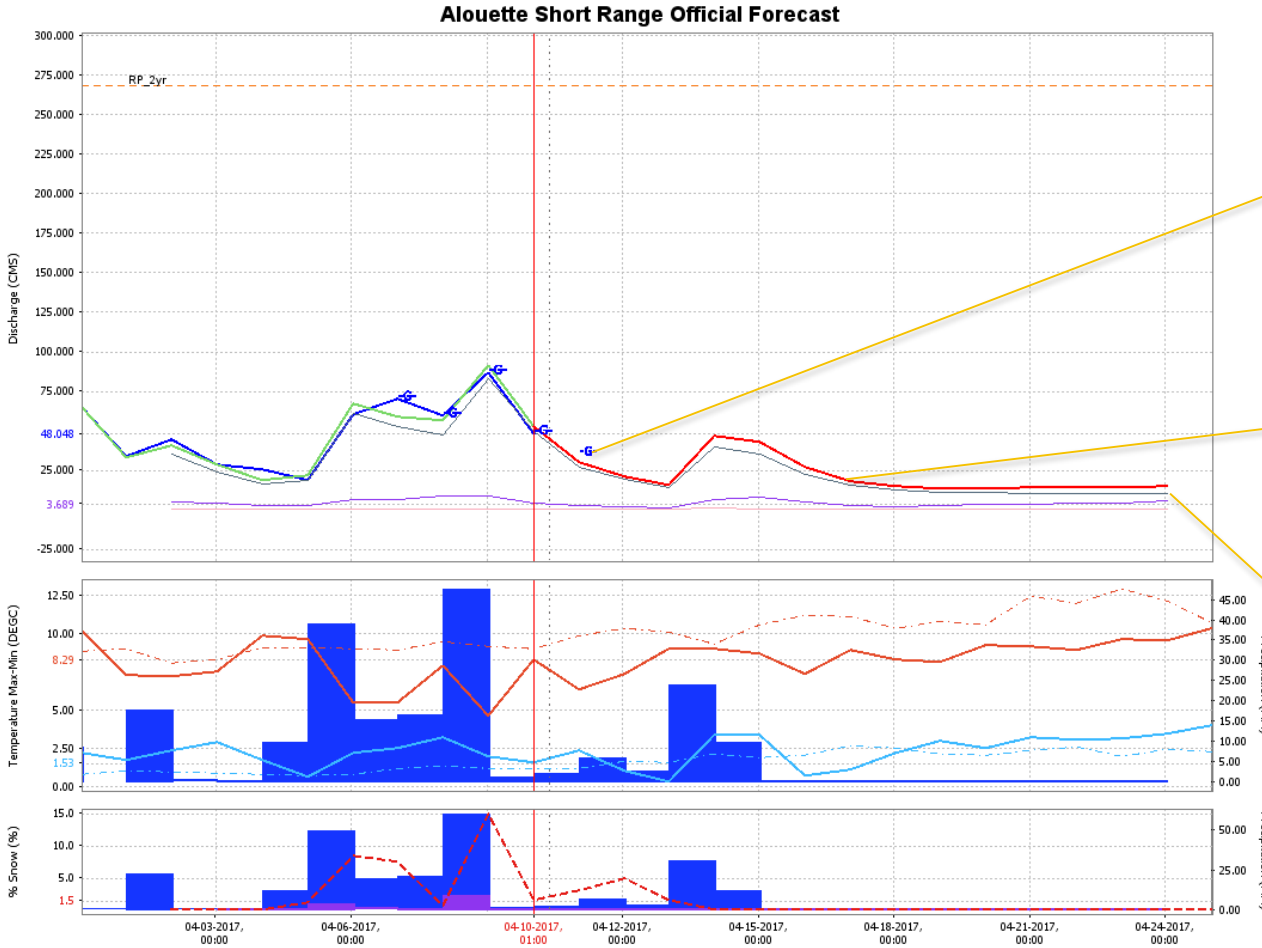
25 watersheds over a range of hydroclimates

- Short range deterministic forecasts
- Short range probabilistic forecasts
- Long range ensemble forecasts
- Long range statistical forecast
- Forecasts during construction work (e.g. Site C)
- Climate change projections

BC Hydro
Power smart

DETERMINISTIC FORECAST

Predicting exactly what the inflows will be - will always be wrong!



RDPS up to day 2; Medium range ensembles to day 30

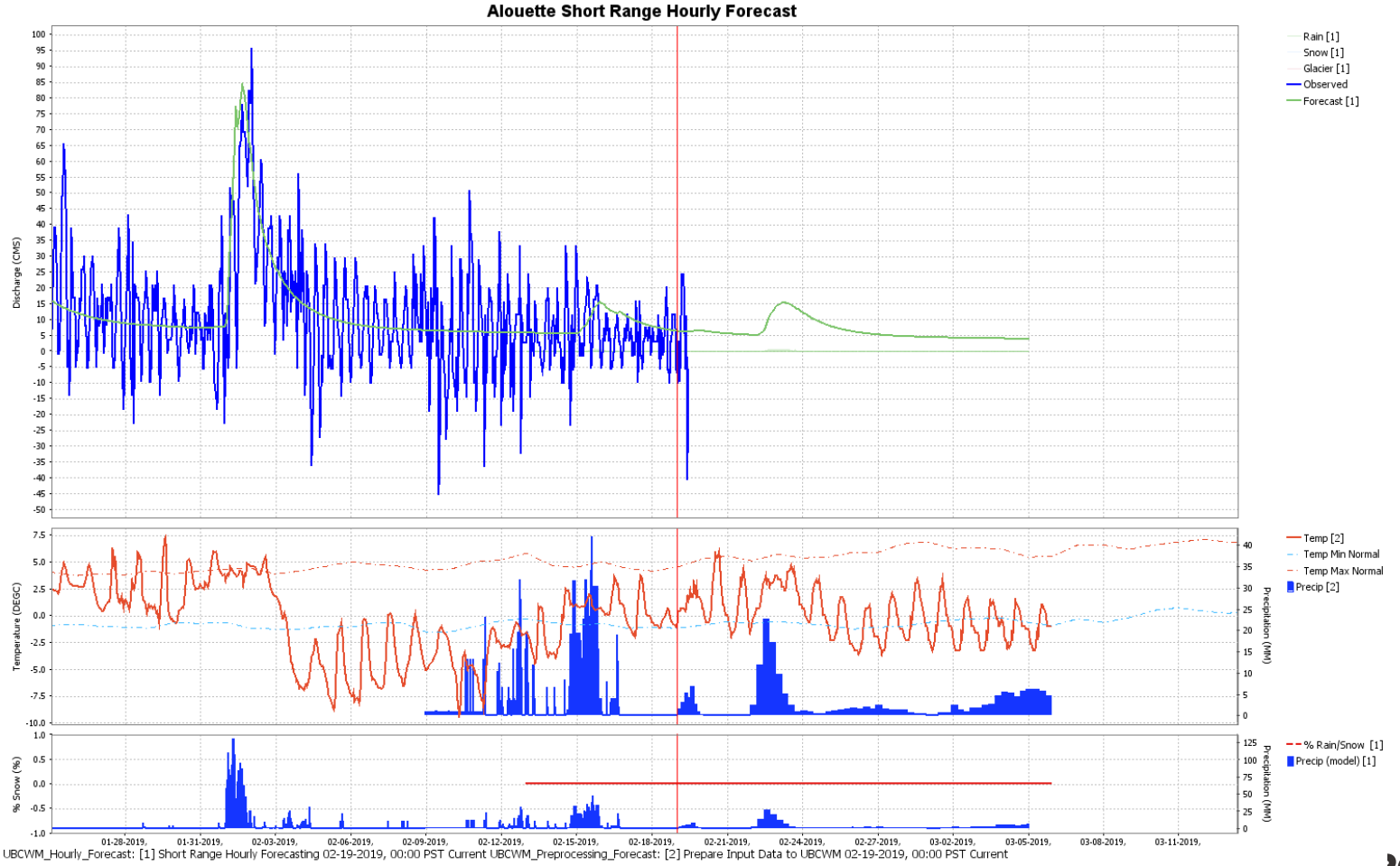
NAEFS median from day 3 to 15

Medium range ensembles plus climatology from day 15 to 30

BC Hydro
Power smart

DETERMINISTIC FORECAST

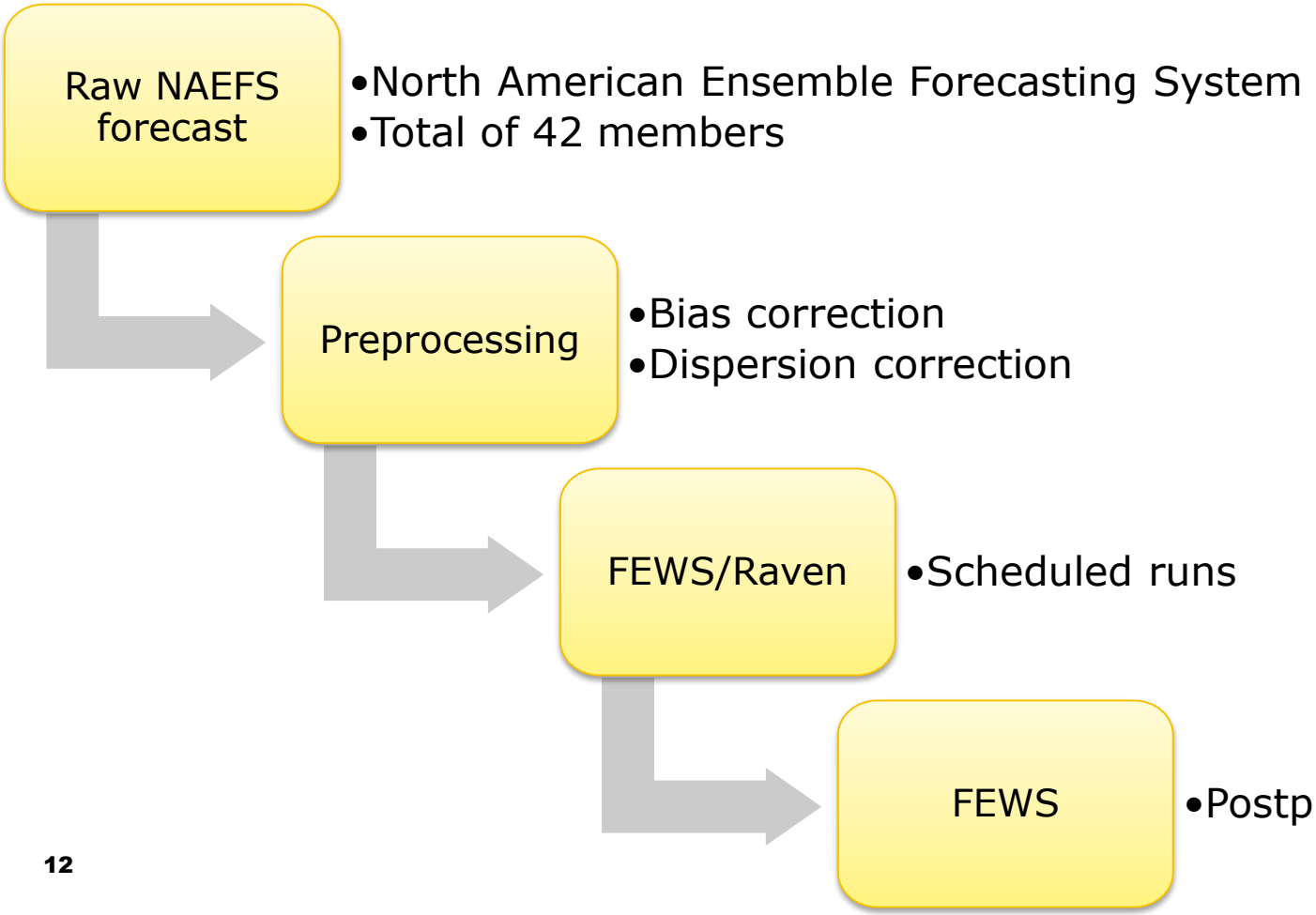
Hourly forecasting for all Coastal watersheds



BC Hydro
Power smart

PROBABILISTIC FORECAST: WEATHER

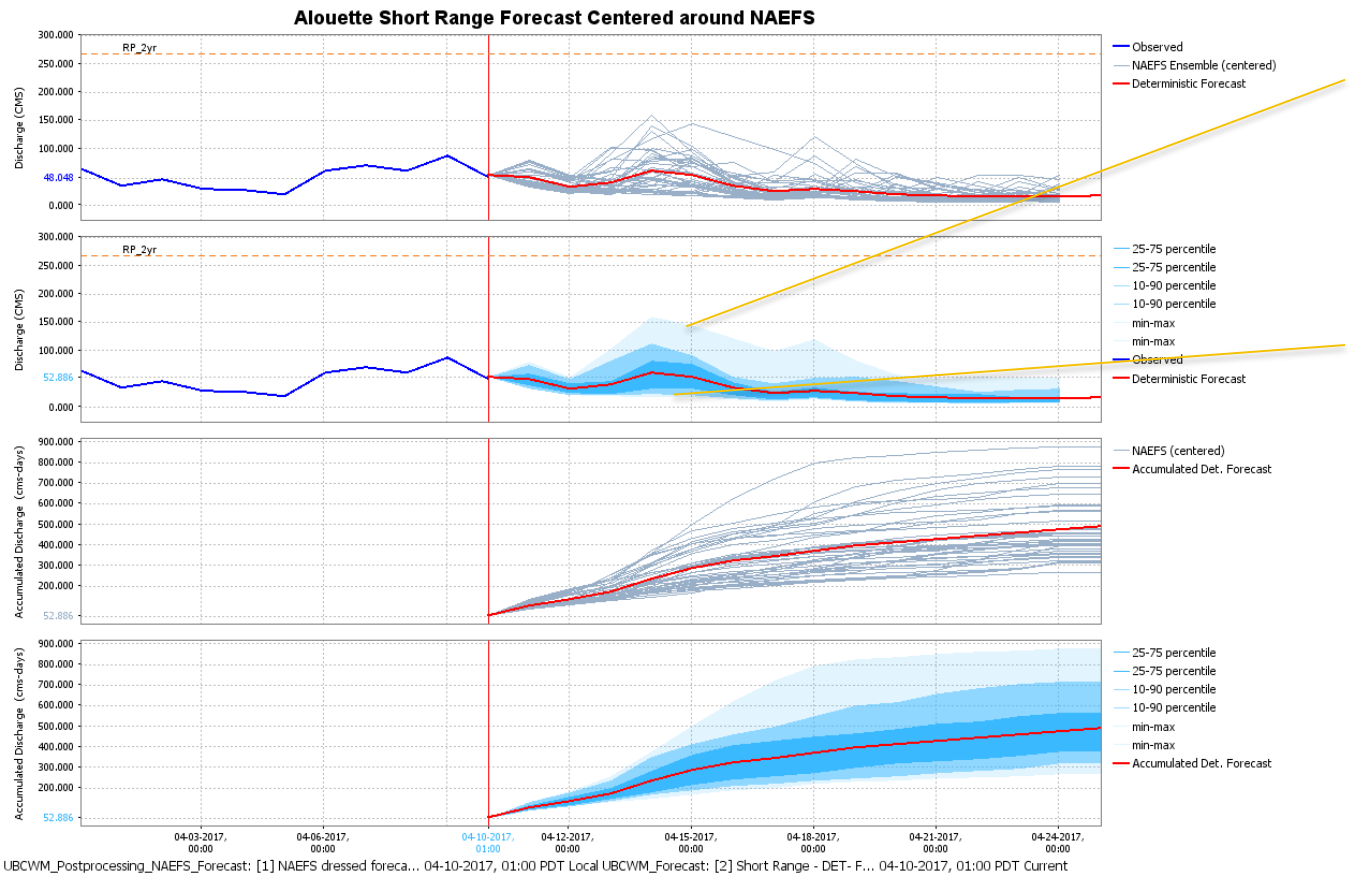
All forecasts 50% off – get them today!



BC Hydro
Power smart

PROBABILISTIC FORECAST: WEATHER

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



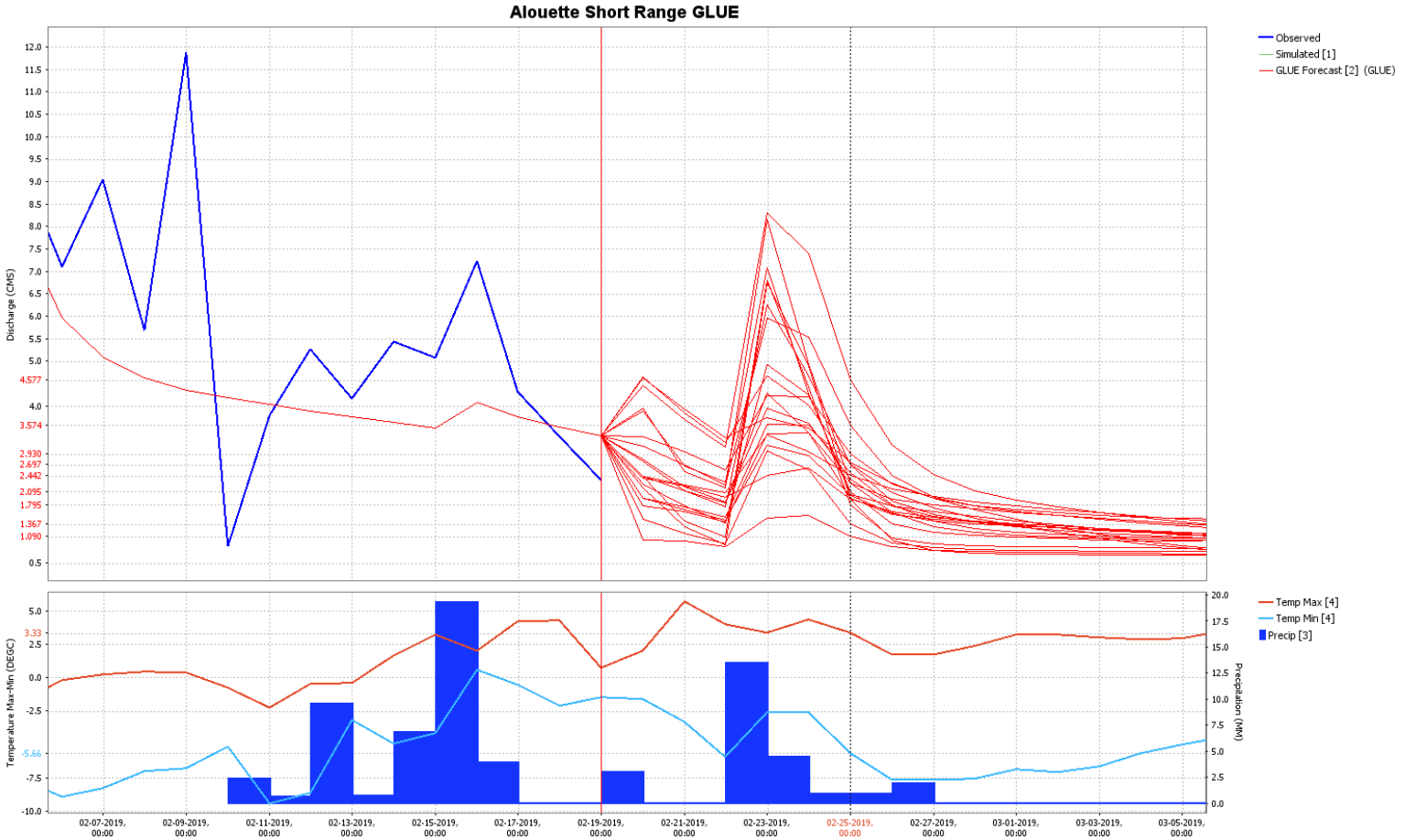
High scenario

Low scenario

BC Hydro
Power smart

PROBABILISTIC FORECAST: GLUE

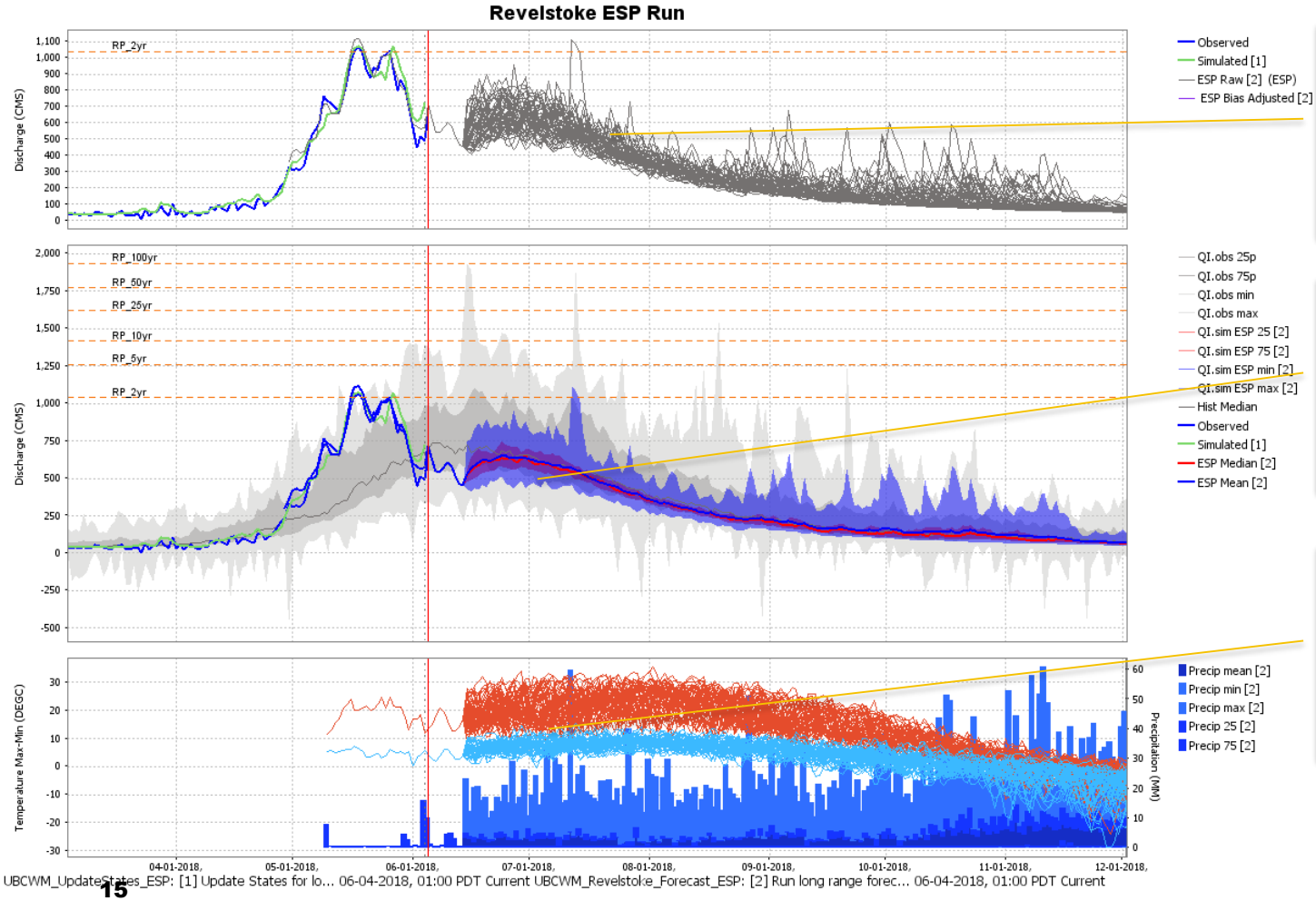
Generalized likelihood uncertainty estimation (GLUE)



BC Hydro
Power smart

LONG RANGE FORECASTS

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



Historical years (1968-2018)

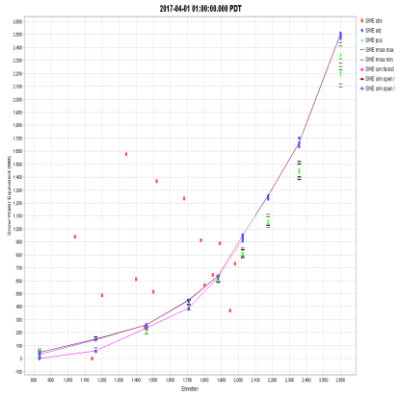
Probabilities of exceedance

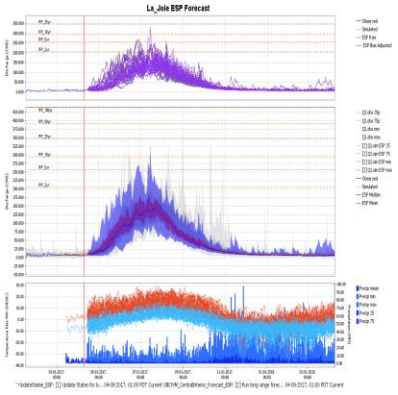
Historical precipitation and temperature

BC Hydro
Power smart

SNOW DATA ASSIMILATION

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





Measure snow

- surveys
- pillows

Update model

Forecast

- Weather forecast
- Historical weather sequence

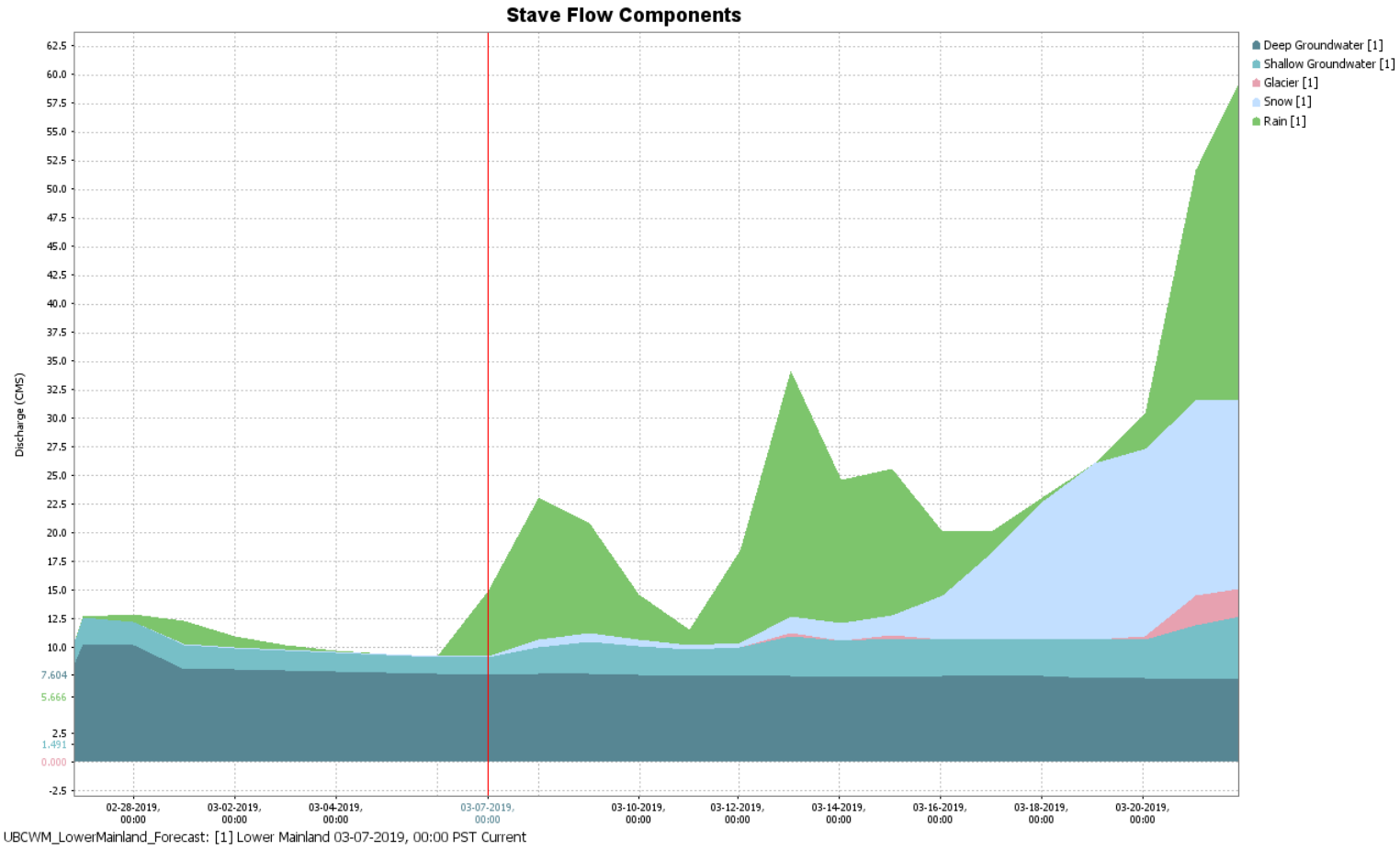
HYDROGRAPH SEPARATION

BC Hydro
Power smart

MOTIVATION

- We spend more and more time with communicating our forecasts (e.g., Internally, First Nations, Public Relations)
- How much do glaciers contribute to runoff?
- How good is our forecast?
- How much does snowmelt contribute to runoff?
- Coded transport model into Raven

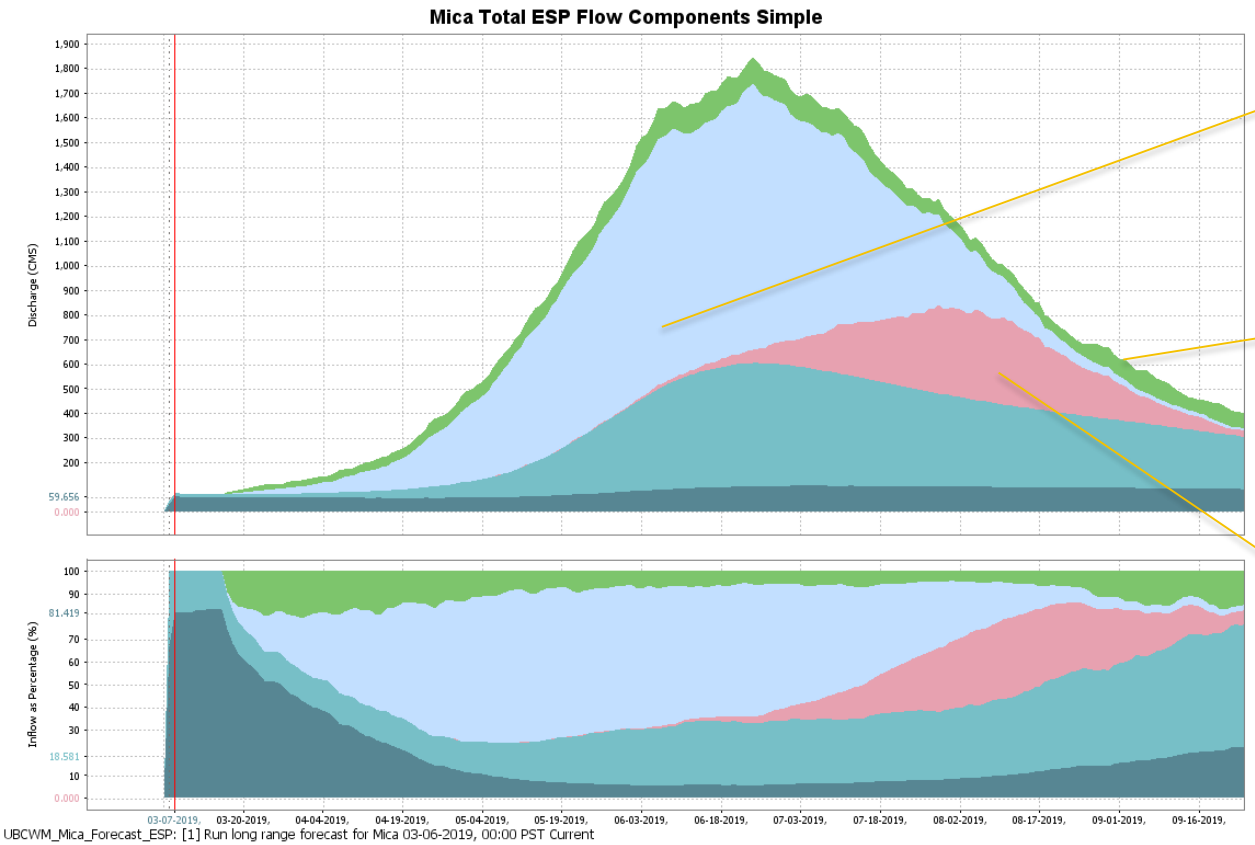
SHORT RANGE FORECAST



BC Hydro
Power smart

WHAT CAN WE AND WHAT CANT WE PREDICT?

Most of the skill in seasonal forecasting comes from knowing how much snow we have



Snow (blue) can be measured

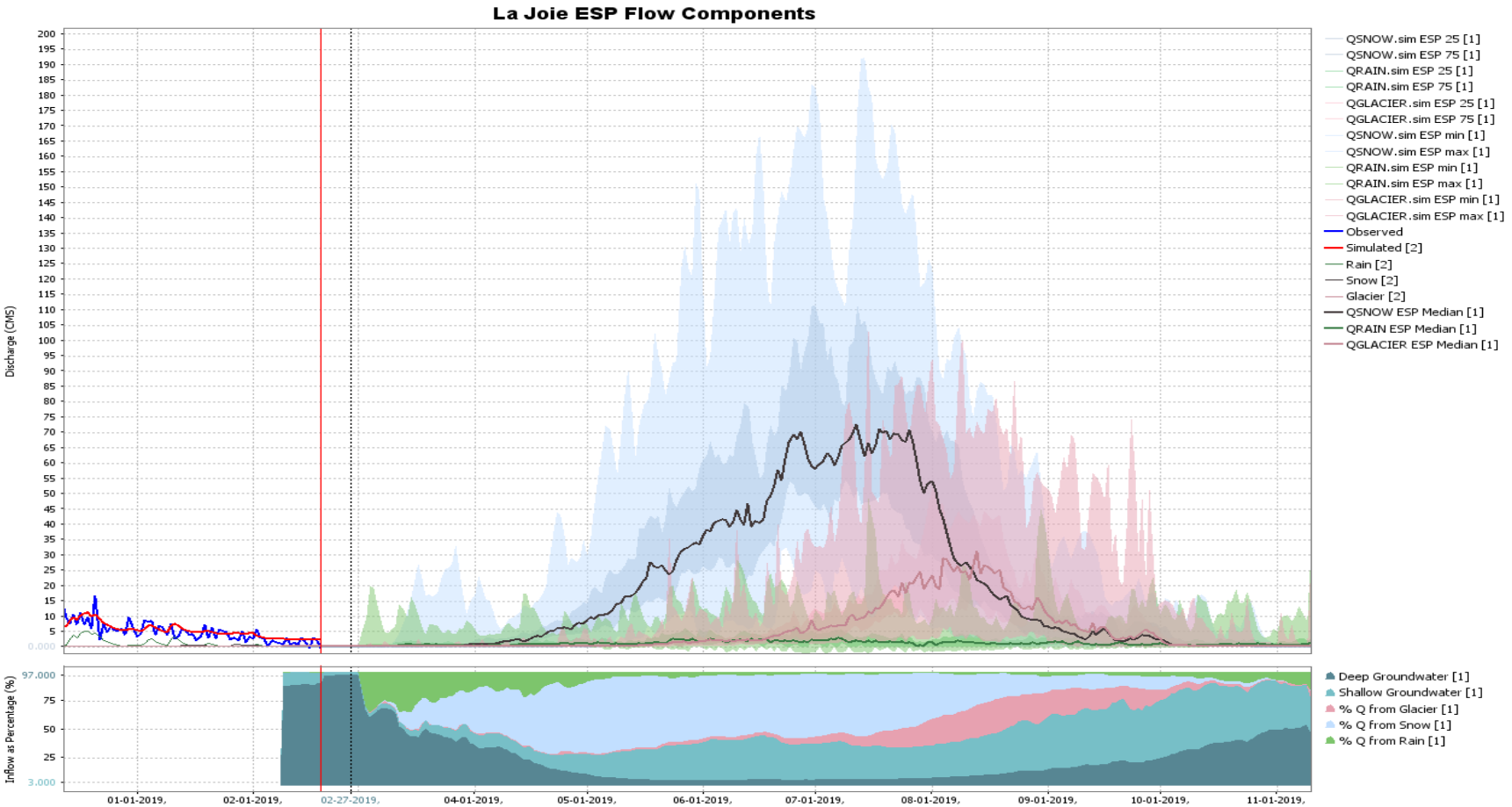
Rain (green) can be forecasted for about one week

Glacier melt (pink)

BC Hydro
Power smart

PROBABILISTIC VERSION

Most of the skill in seasonal forecasting comes from knowing how much snow we have



SUPER ENSEMBLE FORECAST

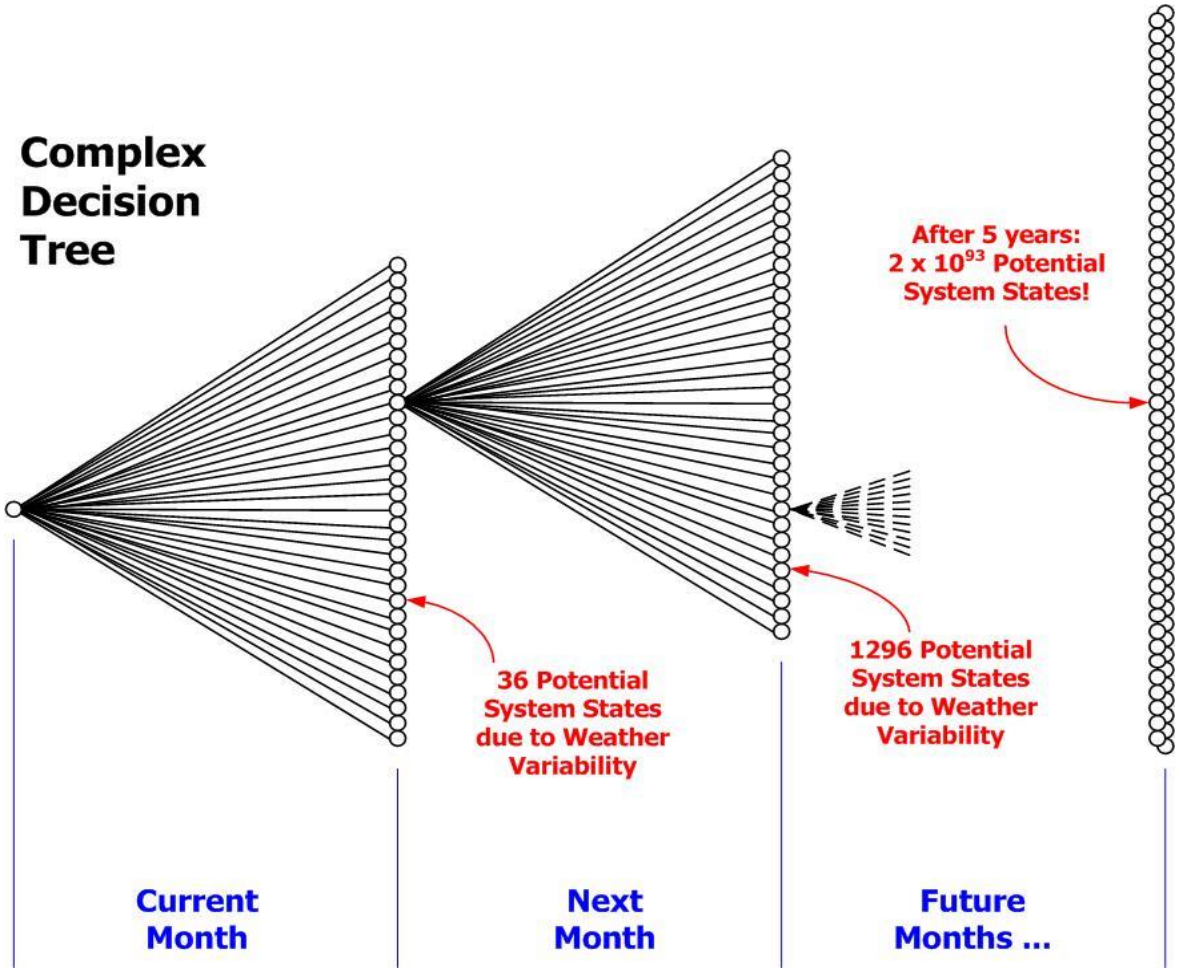
BC Hydro
Power smart

MOTIVATION

- Extreme scenarios for Energy Planning
- Constraint to use historical (i.e., observed) and not synthetic forcings
- Needed to relate other predictors to dates in the forecast

SUPER ENSEMBLE FORECAST

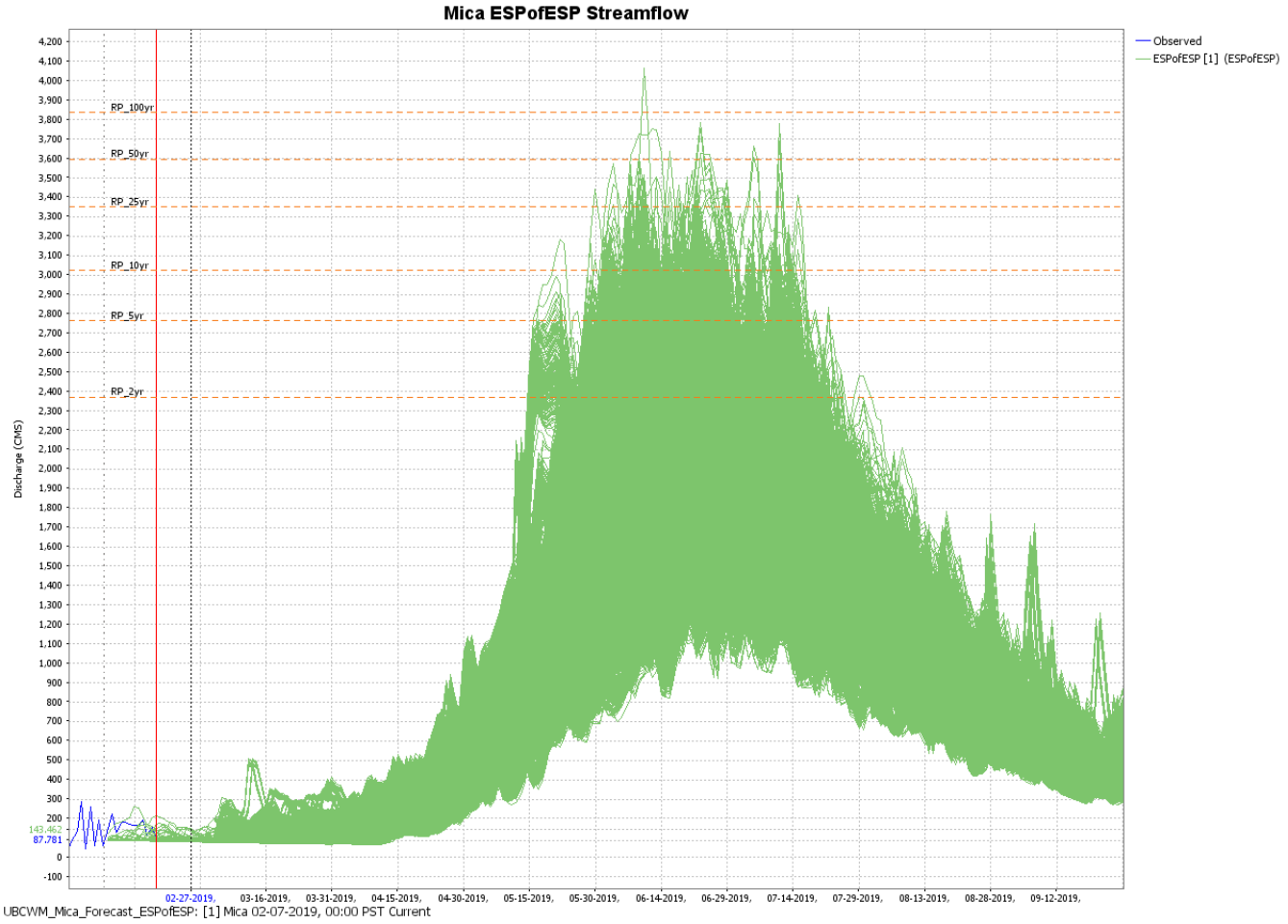
Seasonal forecasts usually (not always) underestimate the uncertainty



BC Hydro
Power smart

ESP OF ESP

Seasonal forecasts usually (not always) underestimate the uncertainty



BC Hydro
Power smart

ESP OF ESP

Seasonal forecasts usually (not always) underestimate the uncertainty

Seasonal forecast for Mica issued on 2019-0

Remainder of Feb - Sep Runoff Volume (Mil. Cu. M)

	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
MIN	14270	14034	13701	13023	10244	5861	2909	1010
10%	14727	14487	14276	13672	10790	6615	3107	1048
MEAN	15891	15650	15344	14650	12133	7656	3617	1245
50%	15839	15569	15347	14594	12120	7680	3557	1225
90%	17233	16996	16583	15862	13502	8569	4201	1473
MAX	18068	17837	17420	16899	14743	9879	4787	1874
STD	877	875	854	840	972	869	428	172
NORM	15495	15231	14909	14278	12115	8145	4115	1379

Remainder of Feb - Sep Runoff Volume (Percent of Normals)

	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
MIN	92	92	92	91	85	72	71	73
10%	95	95	96	96	89	81	76	76
MEAN	103	103	103	103	100	94	88	90
50%	102	102	103	102	100	94	86	89
90%	111	112	111	111	111	105	102	107
MAX	117	117	117	118	122	121	116	136
STD	6	6	6	6	8	11	10	12

Seasonal ESPofESP forecast for Mica issued on 2019-02-07

Remainder of Feb - Sep Runoff Volume (Mil. Cu. M)

	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
MIN	13375	13115	12798	12250	9553	5570	2707	941
10%	15111	14851	14539	13838	11272	6788	3176	1059
MEAN	16378	16125	15815	15112	12537	7890	3693	1240
50%	16271	16019	15728	15032	12466	7859	3655	1205
90%	17768	17522	17189	16447	13840	9023	4253	1470
MAX	21305	21074	20751	19923	17272	11982	5978	2147
STD	1076	1079	1067	1059	1036	873	424	167
NORM	15495	15231	14909	14278	12115	8145	4115	1379

Remainder of Feb - Sep Runoff Volume (Percent of Normals)

	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP
MIN	86	86	86	86	79	68	66	68
10%	98	98	98	97	93	83	77	77
MEAN	106	106	106	106	104	97	90	90
50%	105	105	106	105	103	96	89	87
90%	115	115	115	115	114	111	103	107
MAX	138	138	139	140	143	147	145	156
STD	7	7	7	7	9	11	10	12

CLIMATE CHANGE IMPACT ASSESSMENTS

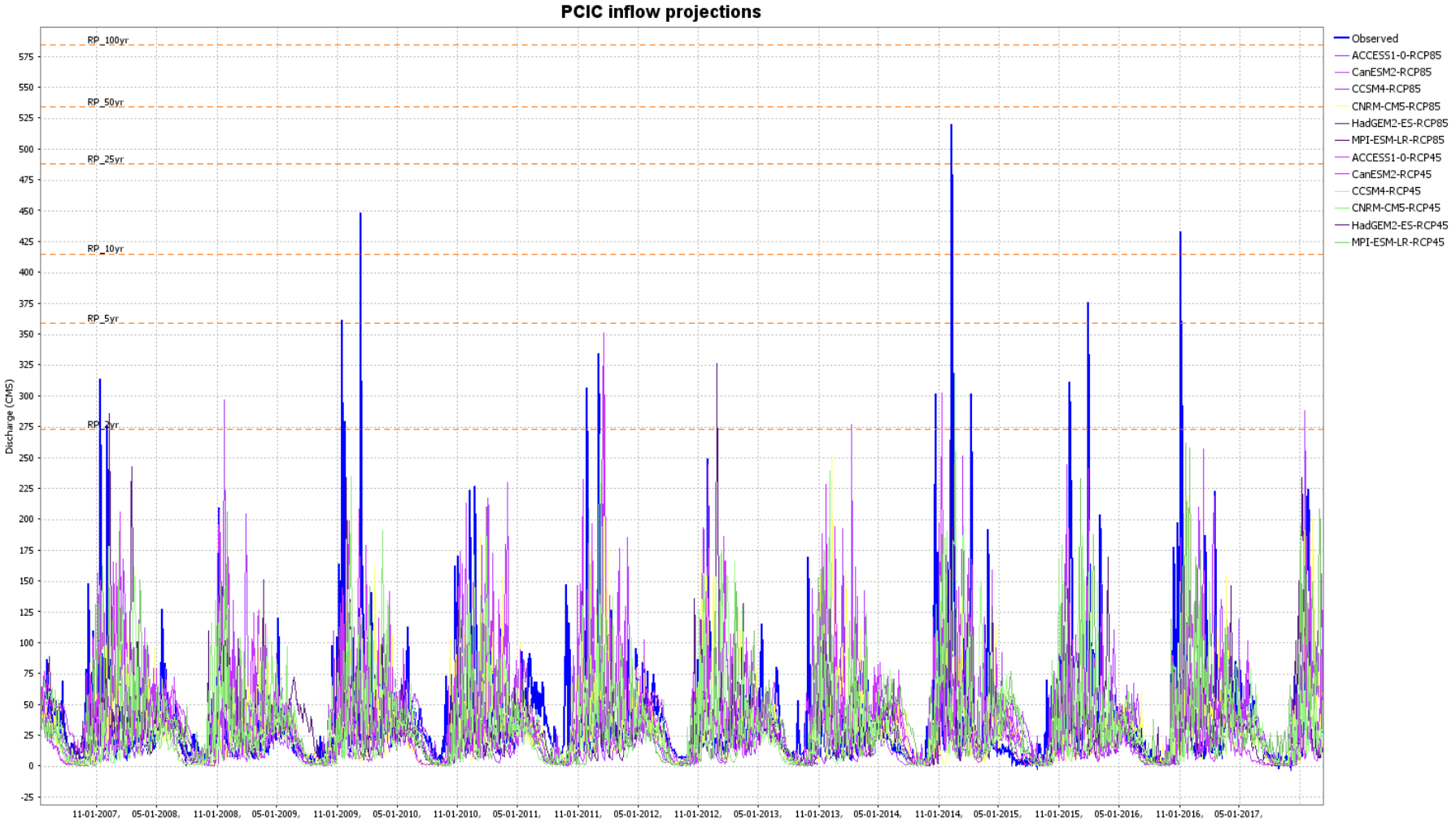
BC Hydro
Power smart

MOTIVATION

- Quality controlling third party climate change projections is not super
- Scientific community usually reports anomalies (i.e, changes)
- Operational models (Energy demand, Energy supply, Fish flow, etc) require absolute numbers.

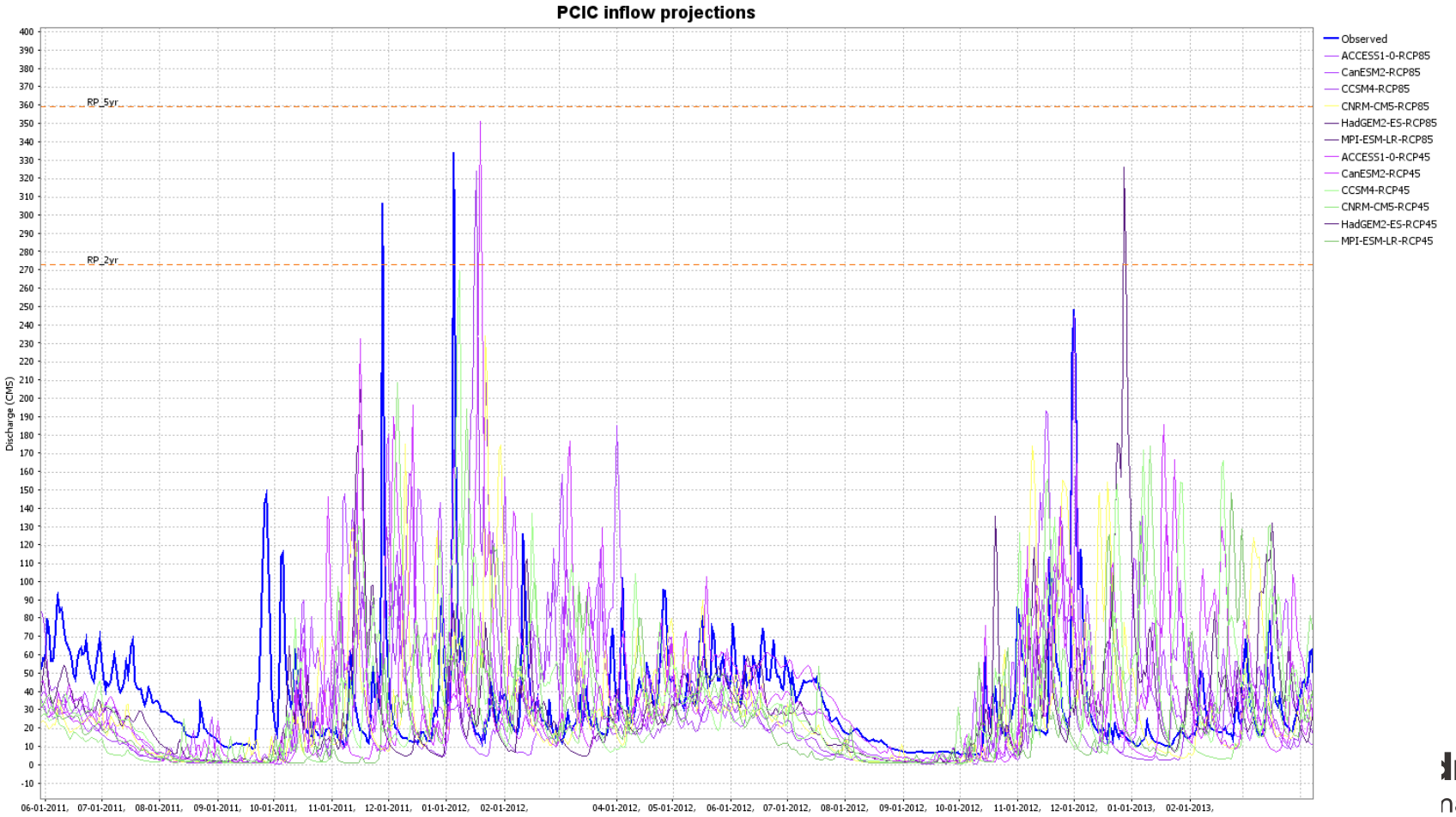
HOW ROBUST ARE PROJECTED CHANGES TO EXTREMES?

Direct model output vs observed (don't just look at GOF stats!)

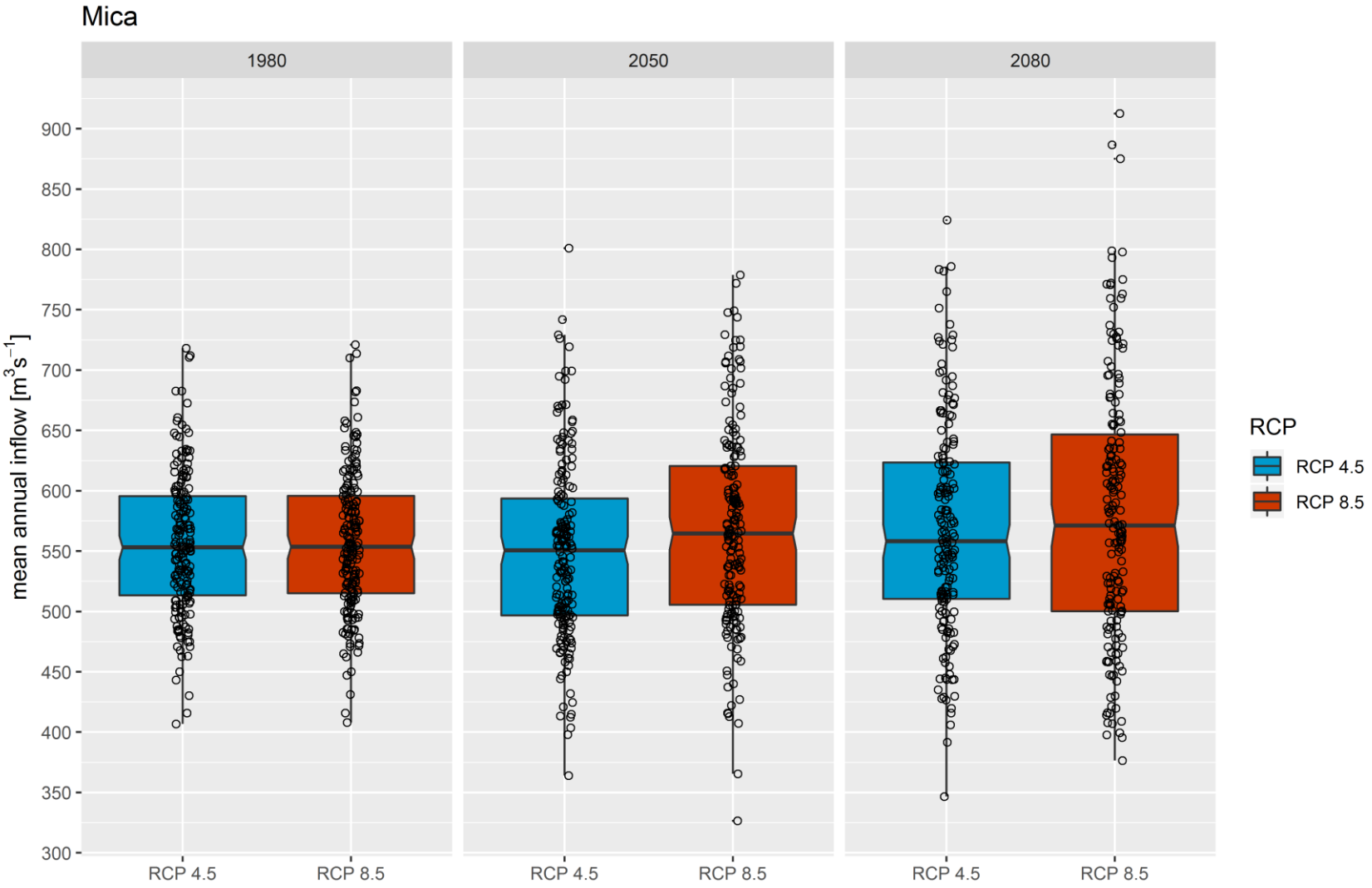


TIMING OF FRESHET?

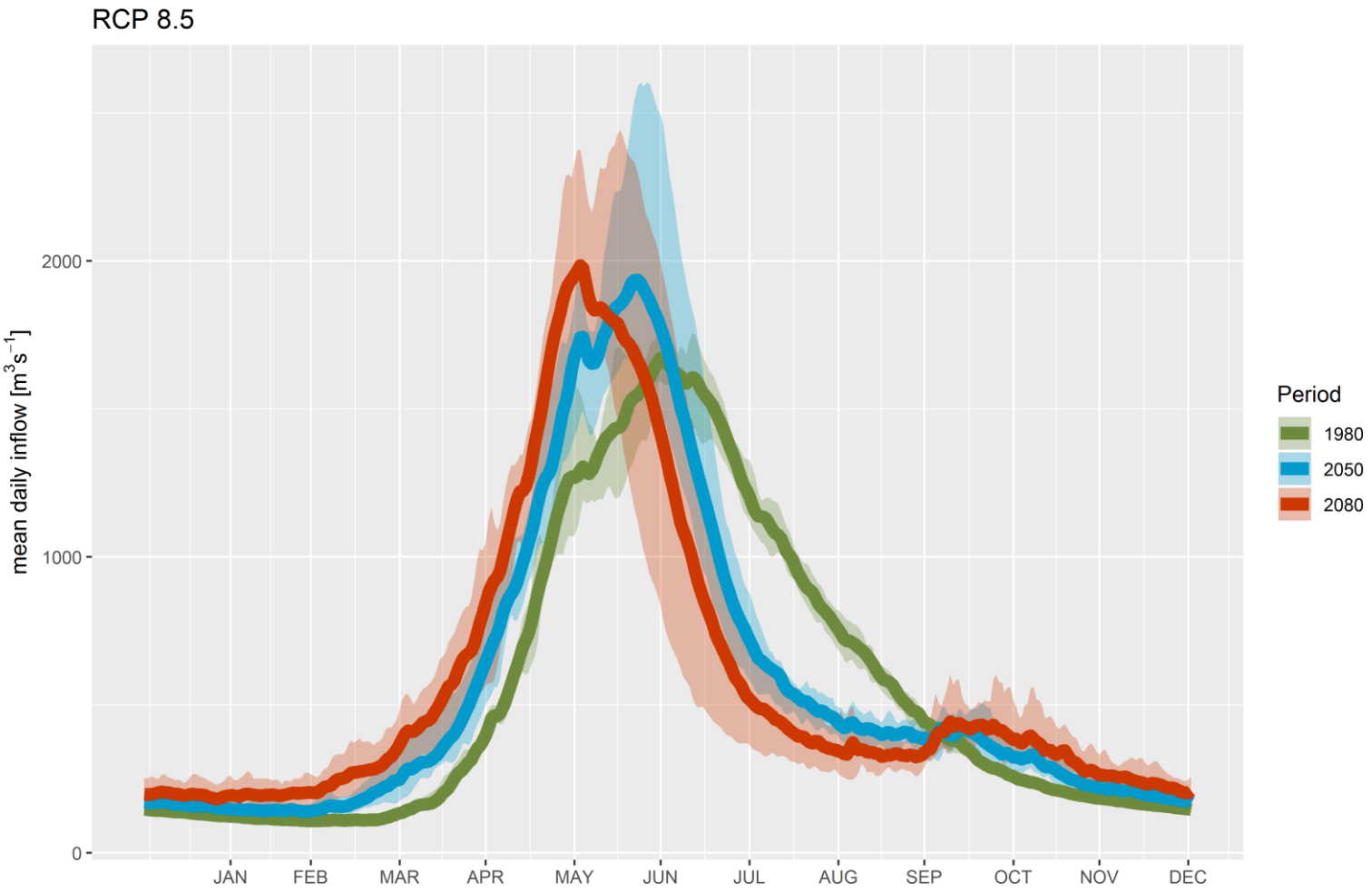
Direct model output vs observed (don't just look at GOF stats!)



ANNUAL INFLOW PROJECTIONS



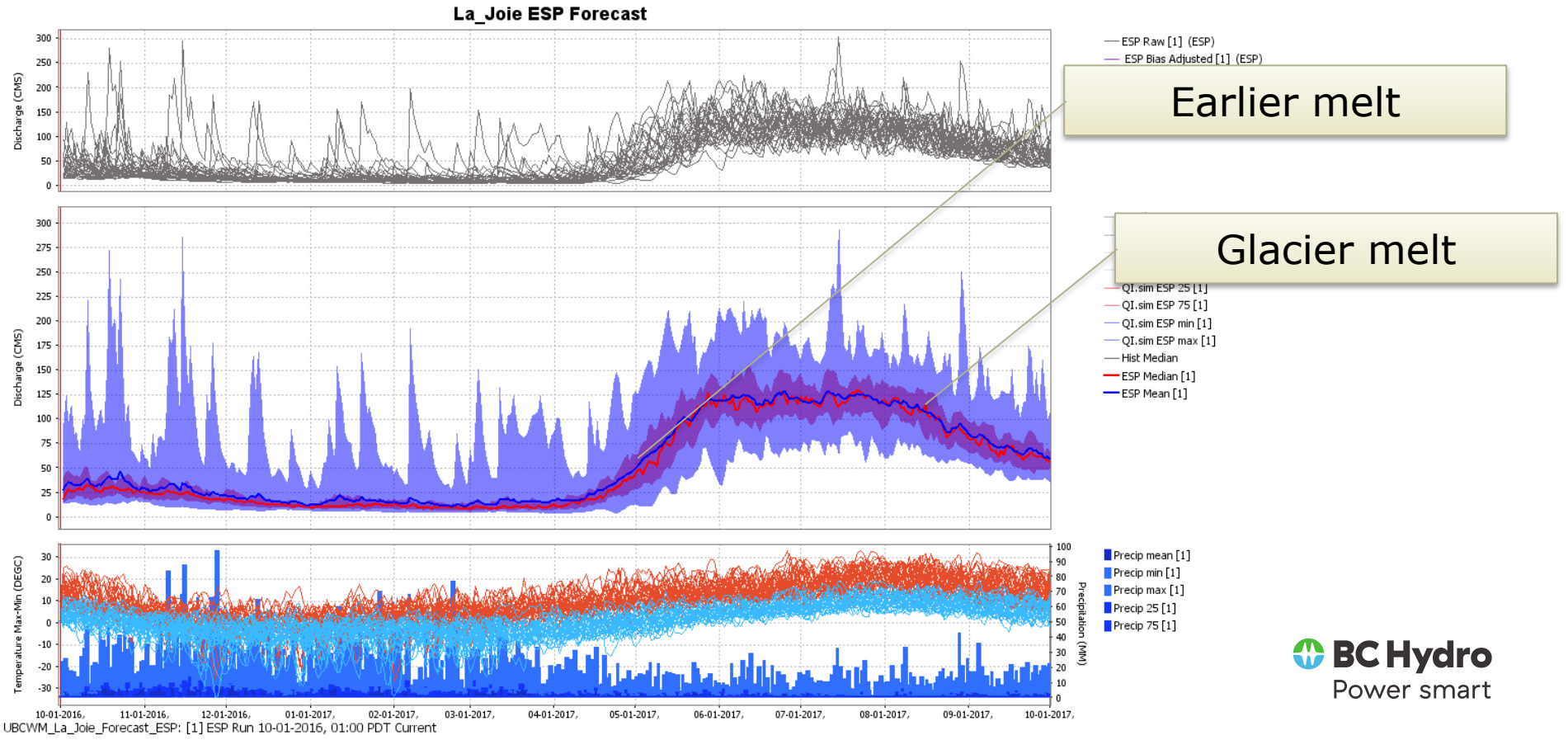
SEASONAL INFLOW PROJECTIONS



BC Hydro
Power smart

EFFECT OF +2 DC T FOR DOWNTON LAKE

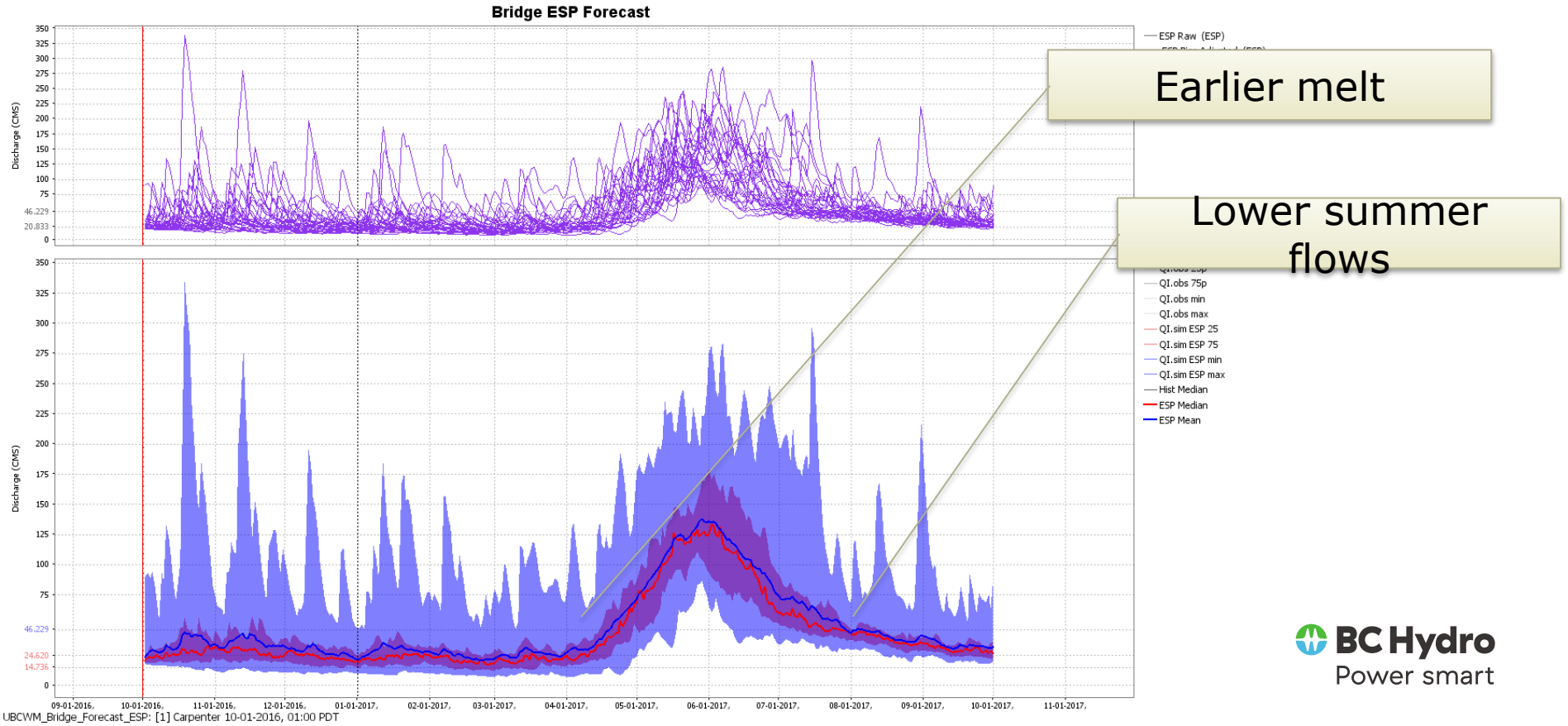
Glaciers fill in the gap from early snow melt. But for how long?



BC Hydro
Power smart

EFFECT OF +2 DC T FOR CARPENTER

No glaciers to fill the gap from early snow melt ->lower summer flows



Earlier melt

Lower summer flows

BC Hydro
Power smart

ESP HINDCASTING (LONG RANGE)

BC Hydro
Power smart

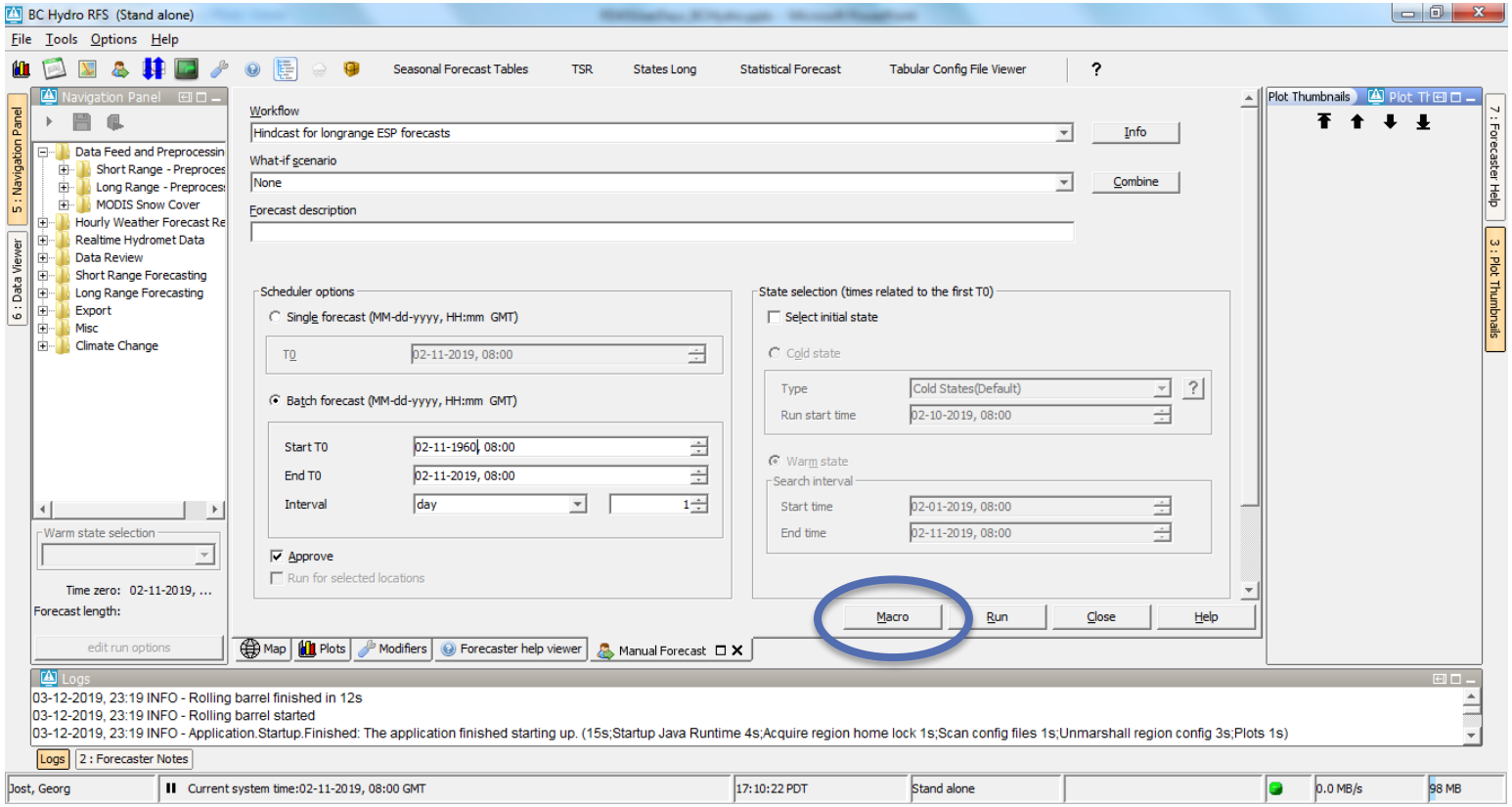
MOTIVATION

- Columbia River Treaty official seasonal forecasts are currently based on statistics
- Tasked to look into switching to ESPs
- Need to compare uncertainties between statistical and ESP forecasts

HOW TO DO HINDCASTS IN FEWS

- In the standalone
- Empty local datastore
- Separate update states workflow
- Separate snow data assimilation in batch mode
- Calculate bias correction factors
- ESP runs in batch mode with added export to archive and xml.

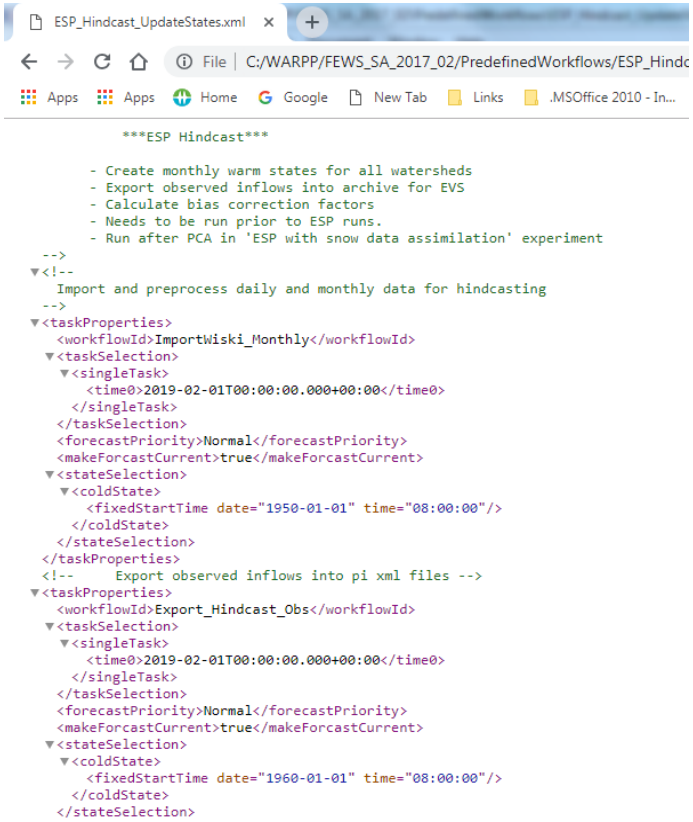
MANUAL OR WITH MACRO



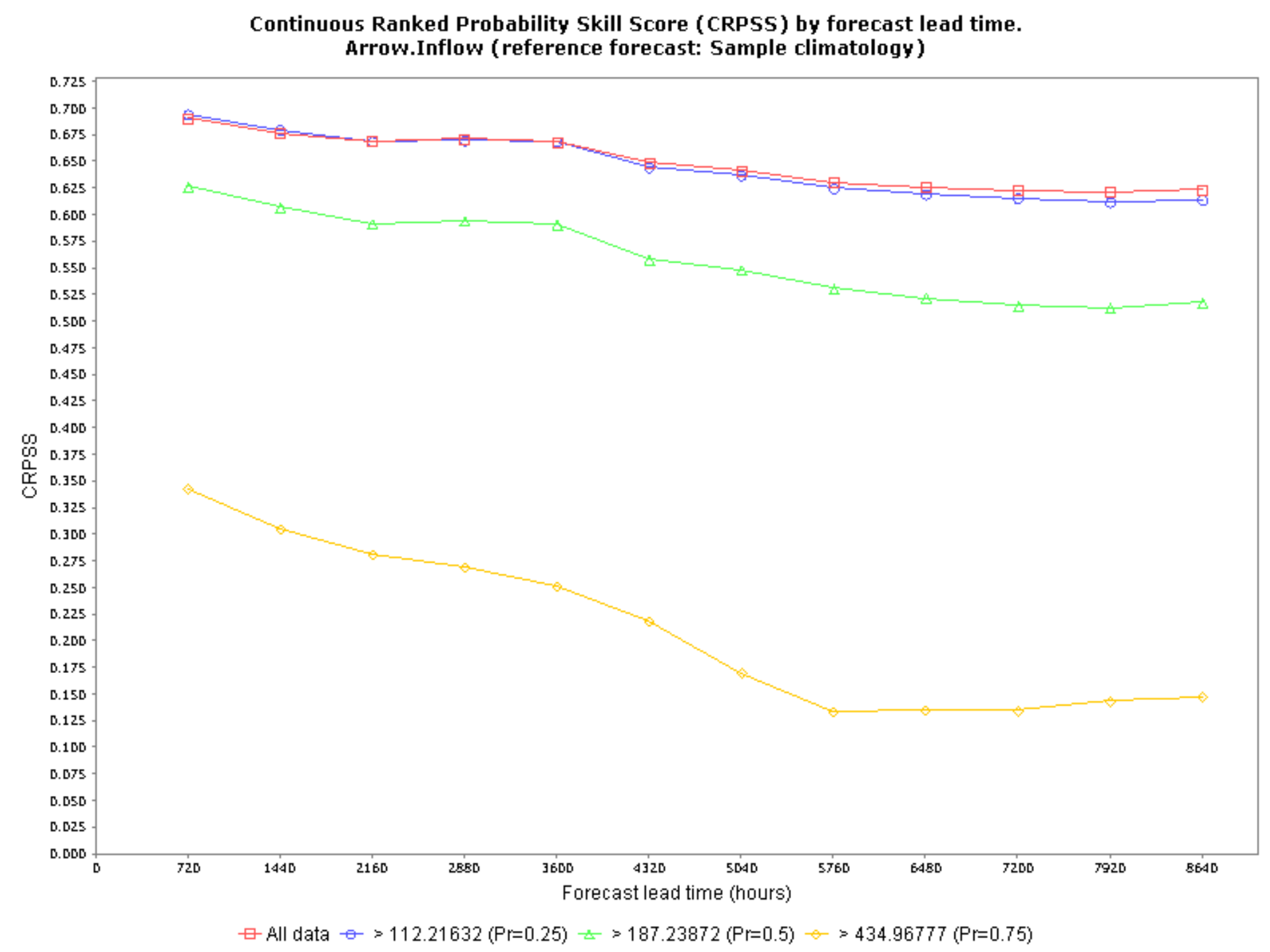
BC Hydro
Power smart

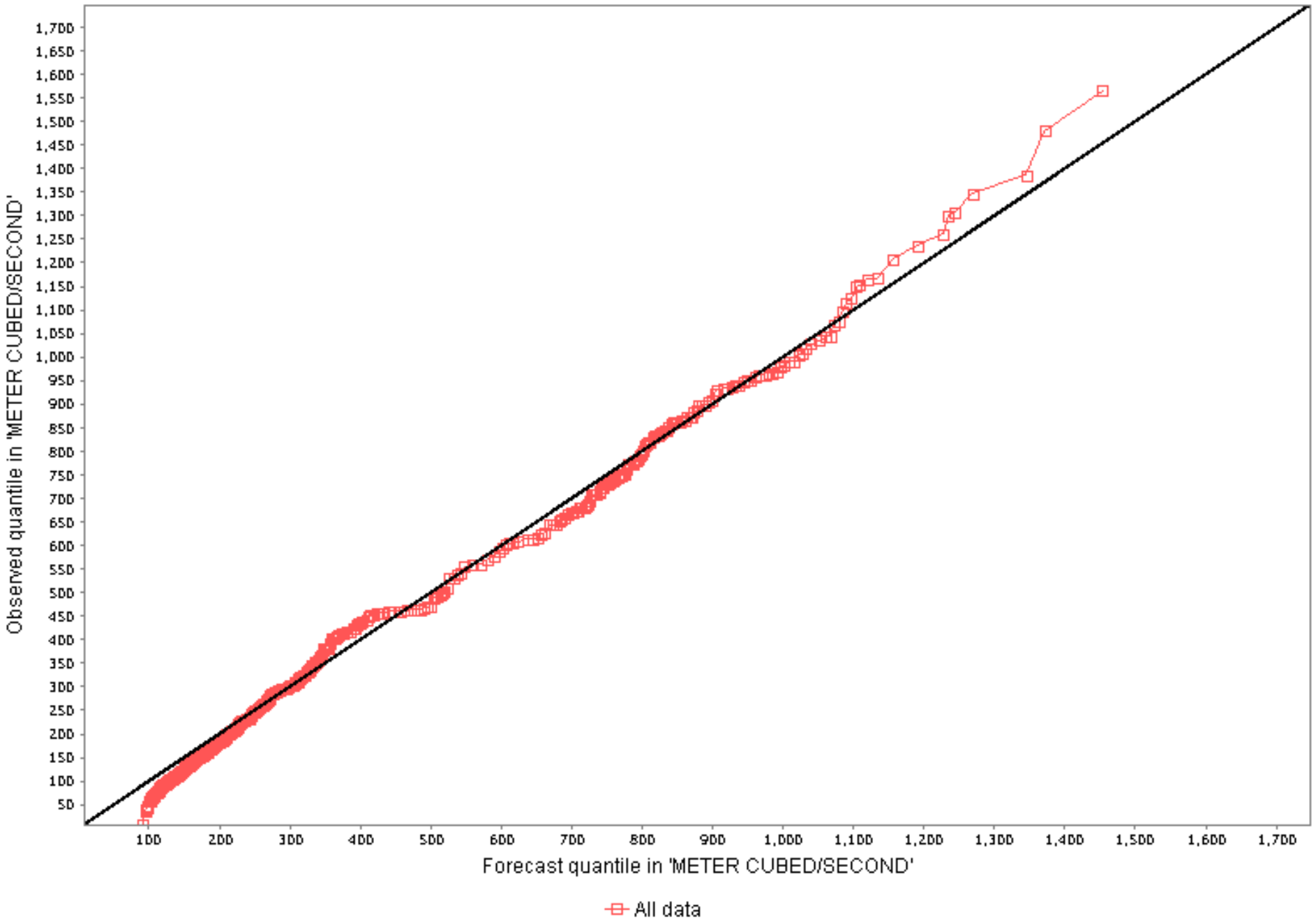
MACRO

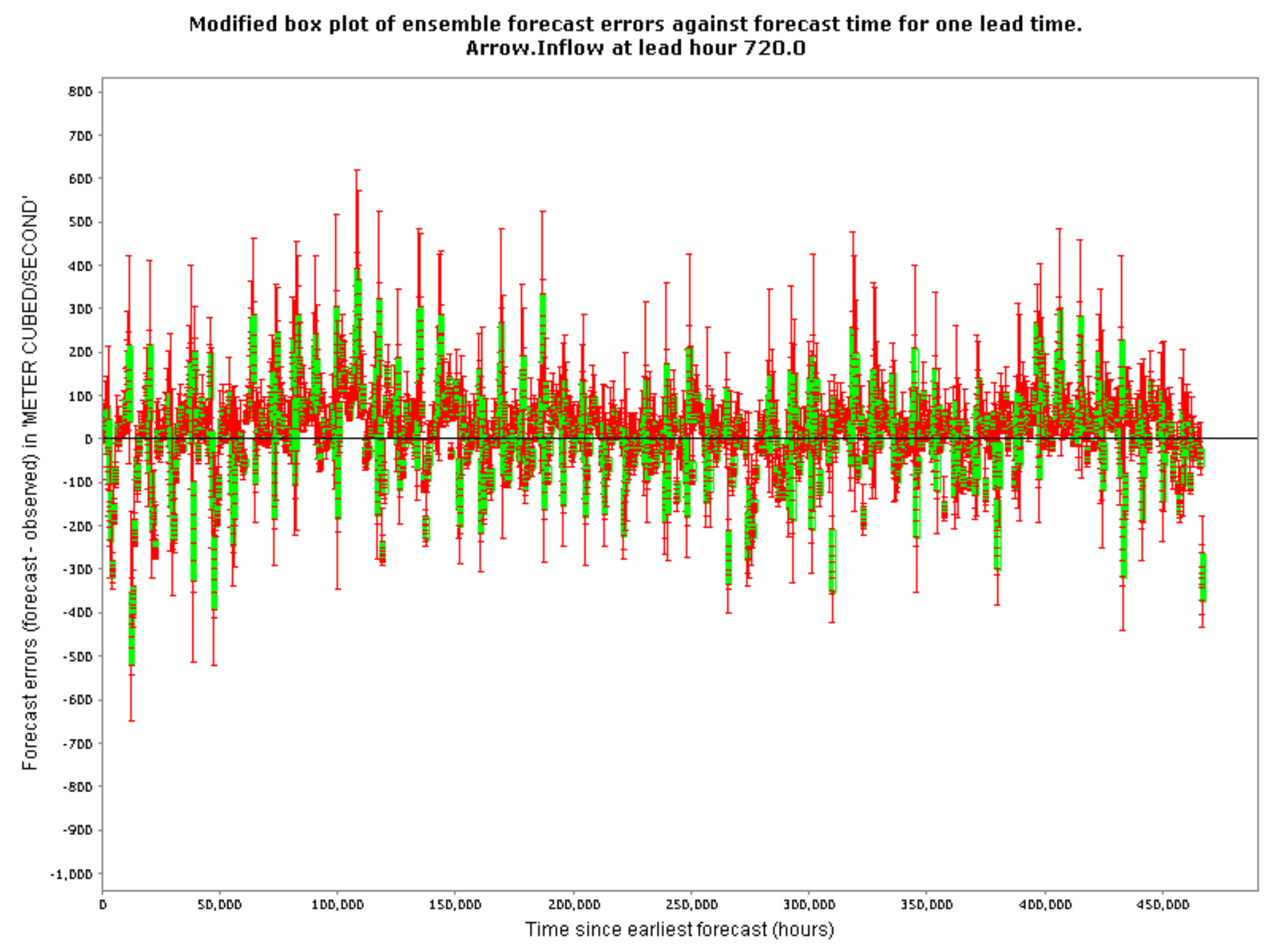
- From empty datastore to 'ready for ESP' batch runs
- Waiting for enhancement to run in monthly intervals. Will allow to create start to end scrips for each experiment

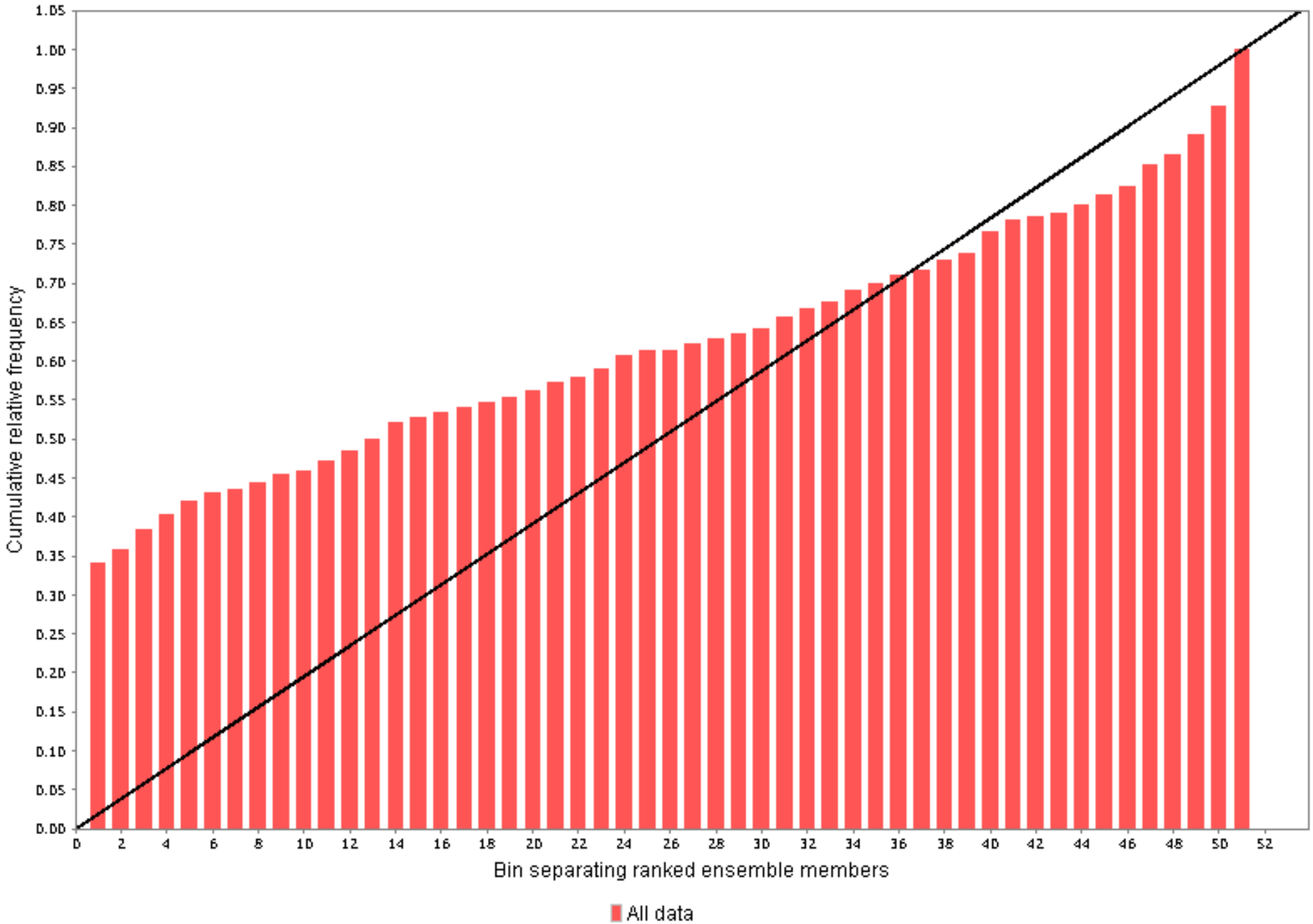


41

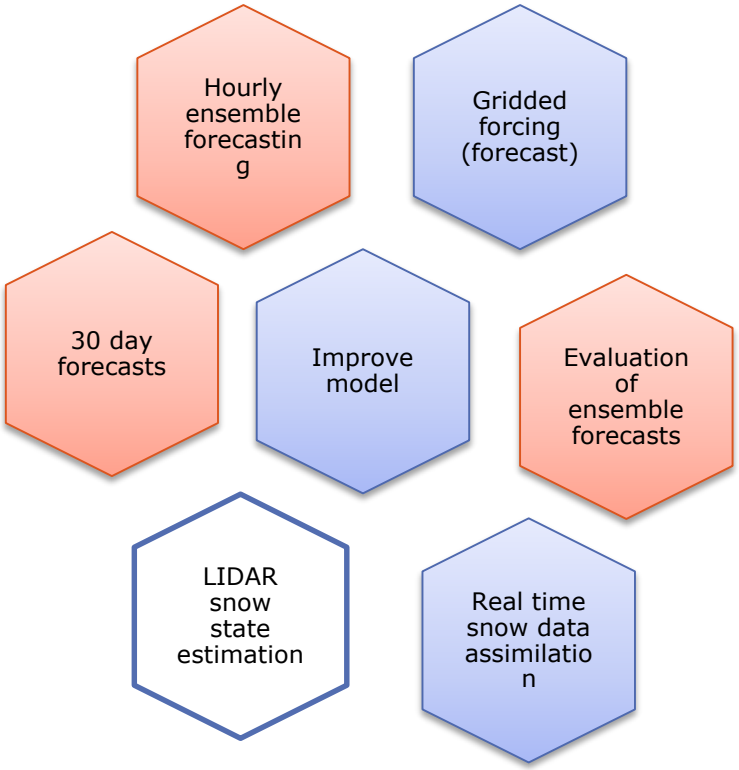

Continuous Ranked Probability Skill Score (CRPSS) by forecast lead time.
Arrow.Inflow (reference forecast: Sample climatology)
CRPSS
0.725
0.700
0.675
0.650
0.625
0.600
0.575
0.550
0.525
0.500
0.475
0.450
0.425
0.400
0.375
0.350
0.325
0.300
0.275
0.250
0.225
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
0
72D
144D
216D
288D
360D
432D
504D
576D
648D
720D
792D
864D
Forecast lead time (hours)
All data
> 112.21632 (Pr=0.25)
> 187.23872 (Pr=0.5)
> 434.96777 (Pr=0.75)


Ensemble quantile-quantile plot.
Arrow.Inflow at lead hour 720.0
Observed quantile in 'METER CUBED/SECOND'
Forecast quantile in 'METER CUBED/SECOND'
All data


Modified box plot of ensemble forecast errors against forecast time for one lead time.
Arrow.Inflow at lead hour 720.0
Forecast errors (forecast - observed) in 'METER CUBED/SECOND'
800
700
600
500
400
300
200
100
0
-100
-200
-300
-400
-500
-600
-700
-800
-900
-1,000
0
50,000
100,000
150,000
200,000
250,000
300,000
350,000
400,000
450,000
Time since earliest forecast (hours)


Rank histogram.
Arrow.Inflow at lead hour 720.0
Cumulative relative frequency
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52
Bin separating ranked ensemble members
All data

WHAT ARE WE WORKING ON?



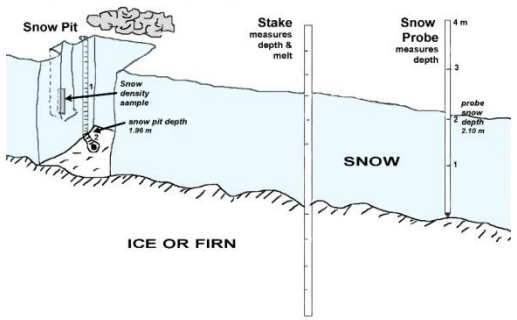
BC Hydro
Power smart

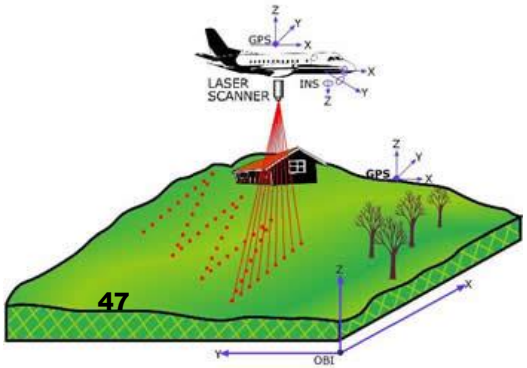
MODEL SNOW STATES UPDATING FROM LIDAR

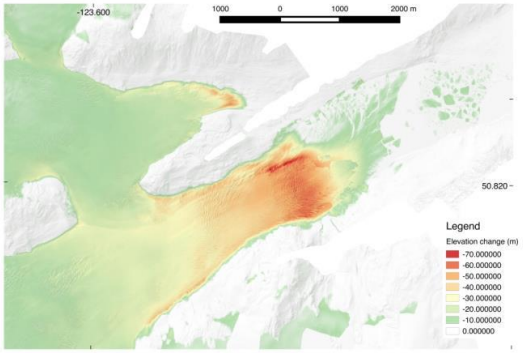
Bridge Glacier monitoring

Mass Balance Monitoring

- Stake method
- Lidar: LIDAR, which stands for Light Detection and Ranging, is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth.







THE GOAL OF WORKING WITH SCENARIOS IS NOT TO PREDICT THE FUTURE, BUT TO BETTER UNDERSTAND UNCERTAINTIES IN ORDER TO REACH DECISIONS THAT ARE ROBUST UNDER A WIDE RANGE OF POSSIBLE FUTURES