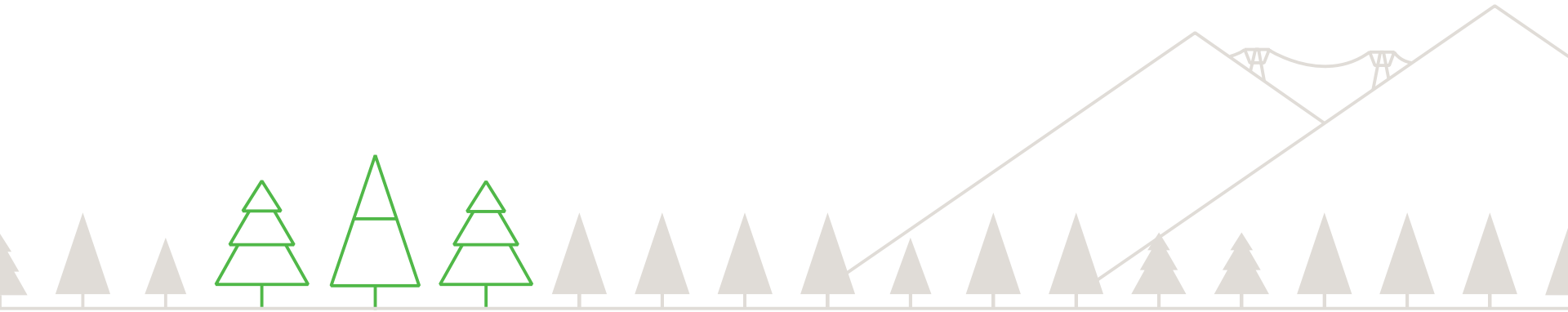
INFLOW FORECASTING AT BC HYDRO

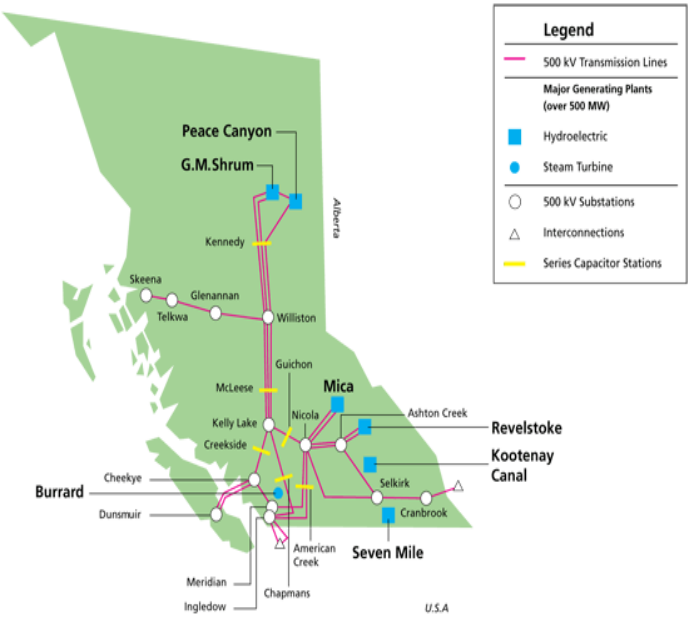
Georg Jost, BC Hydro



BC Hydro
Power smart

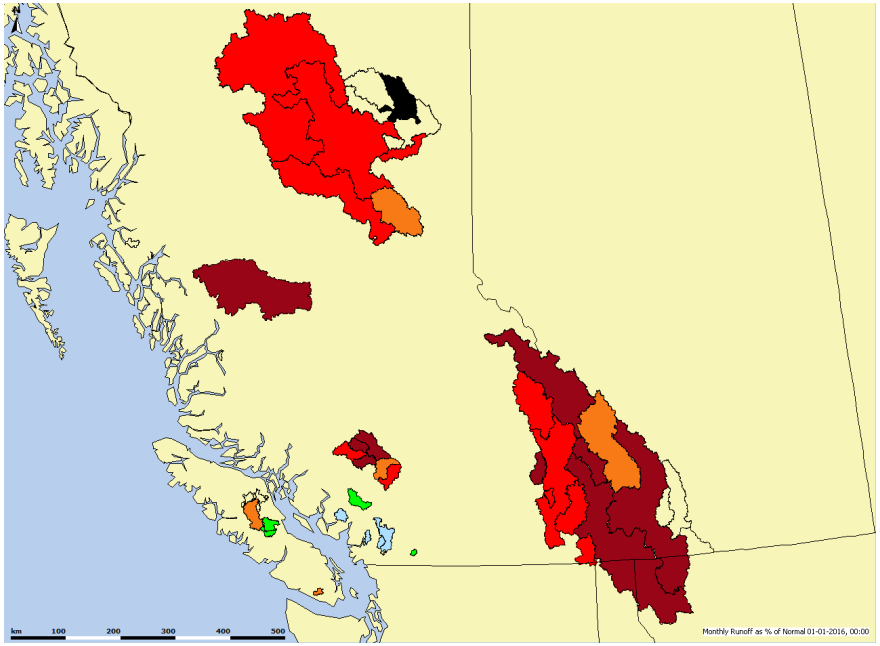
BC HYDRO - QUICK FACTS

- Provincial crown corporation
- Serves 95% of BC (1.8 million customers)
- 12,000 MW capacity (3rd largest in Canada)
- 99% hydroelectric and 1% thermal
- 85% of generation from Peace and Columbia



2

BC HYDRO SYSTEM - WATERSHEDS



23 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

BC Hydro
Power smart

Deltares USA

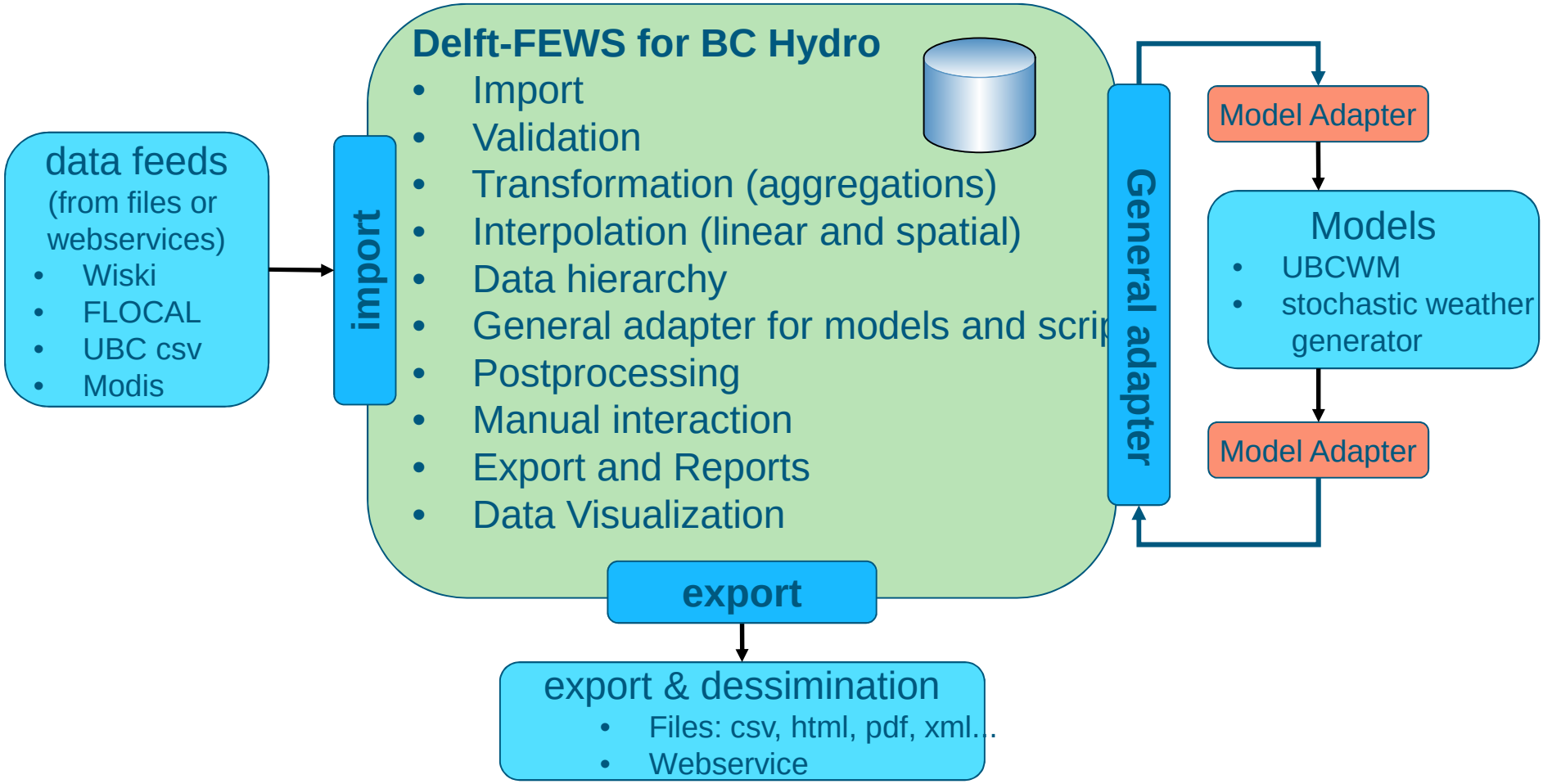
FEWS





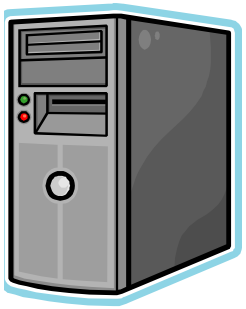
FORECASTING SYSTEM

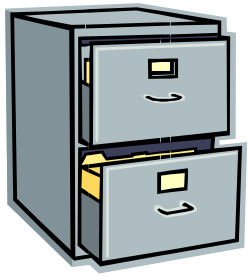
FEWS - CONCEPT



FEWS - SYSTEM







Forecaster

Conducts interactive forecast jobs at client application

Submits (modified) forecasts for approved run at server

Receives approved forecasts from server

Master Controller

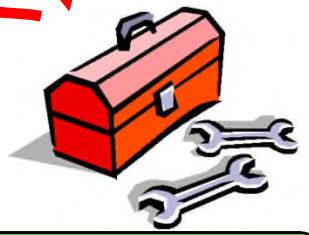
Schedules and dispatches forecast requests

Synchronizes approved forecasts back to central database and clients

Central Database

Storage of all (approved) data handled by server

(Postgress)



Shell servers

Executes approved forecasts

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

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

EACH PLANNING HORIZON HAS ITS OWN MODELLING STRATEGY

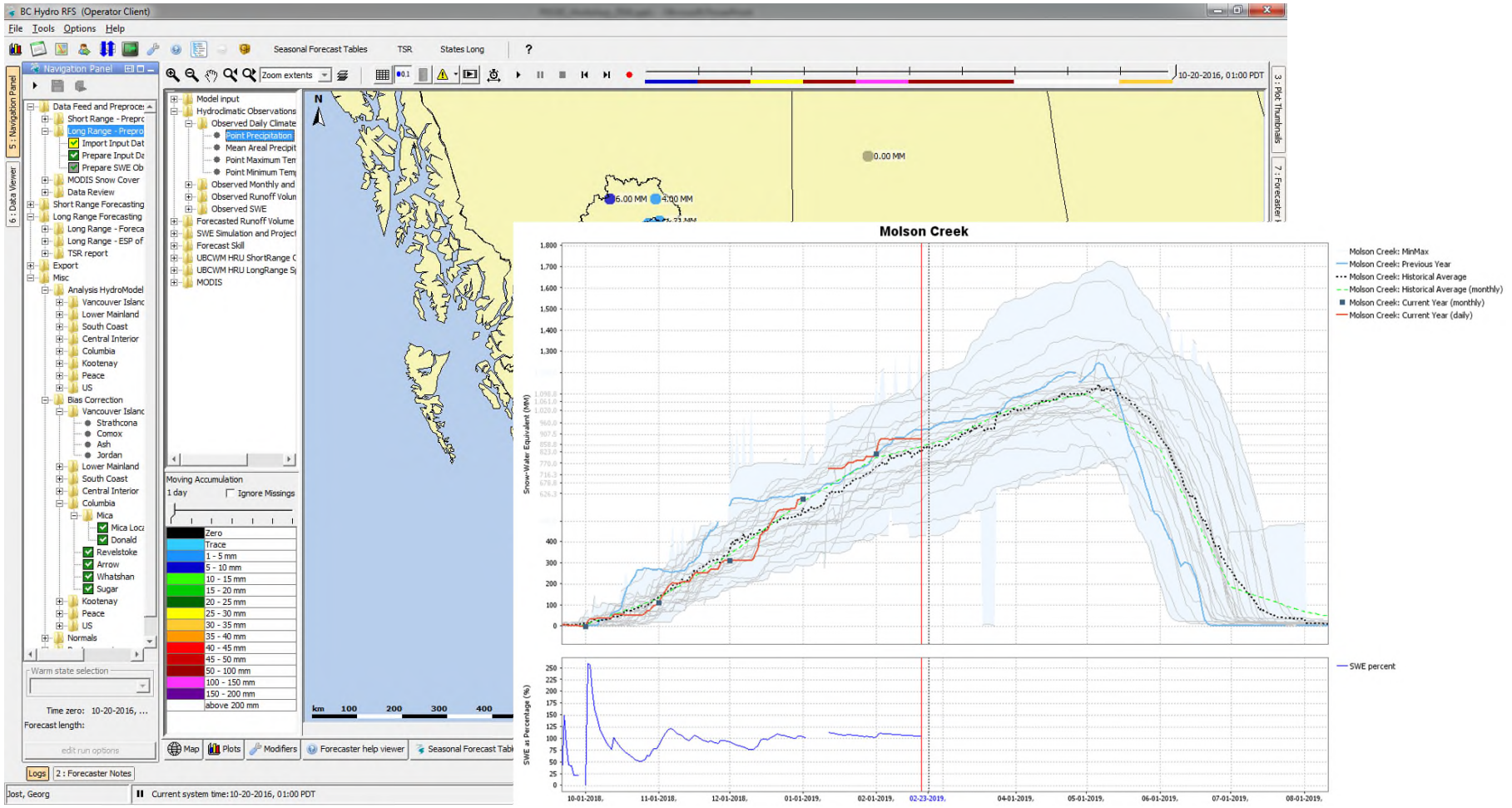
We run the same model but focus on different things

- Short range forecasting
  - What will happen in the next few hours to days?
- Long range forecasting
  - What will happened in the next year?
- Climate change impact assessments
  - What will happen in the next decades?

SHORT RANGE FORECASTING (DAILY AND HOURLY)

OBSERVATIONS (PRECIPITATION, TEMPERATURE, INFLOWS)

Every forecast begins with analyzing observations

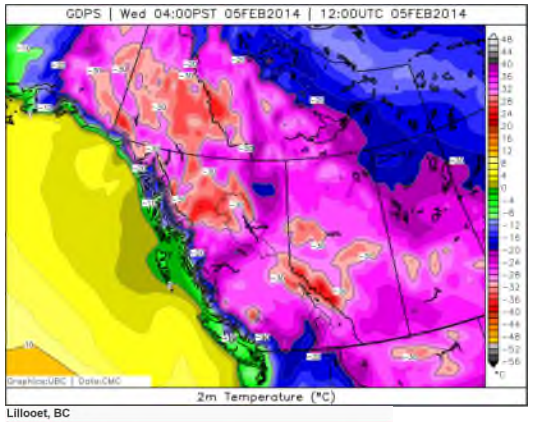


SHORT RANGE FORECASTING PROCESS

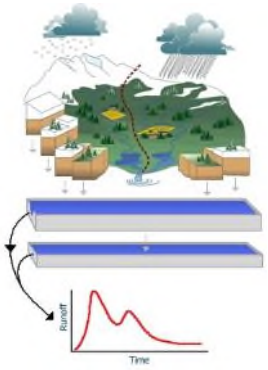
Hydroclimatic Data



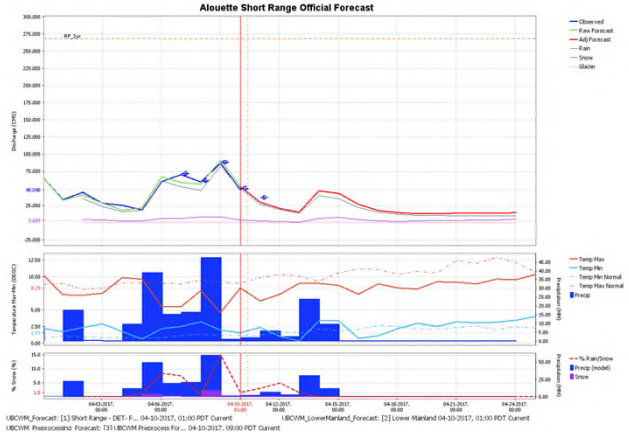
Numerical Weather Prediction Model, Weather forecast







Hydrologic Model, Inflow forecast

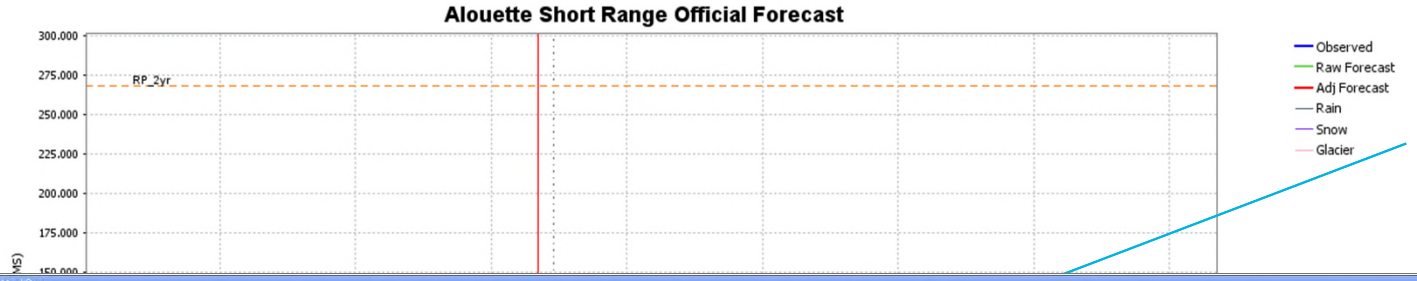


Max / Min Daily temperature

BC Hydro
Power smart

DETERMINISTIC FORECAST

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



RDPS for first two days

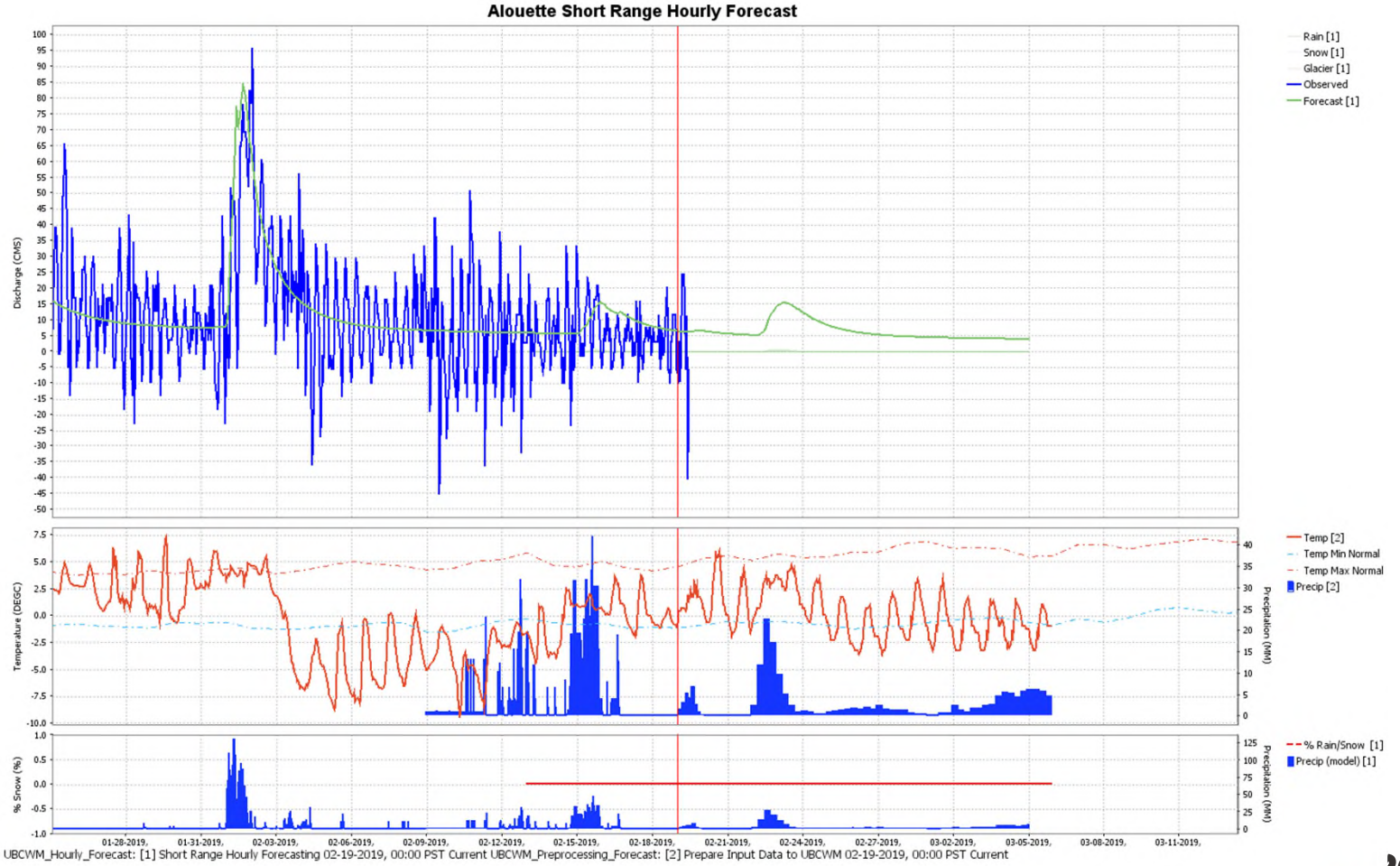
Modifiers

Mod type	Name	Summary	Locations	Start	End	Valid Time	User	Creation time	Active	Delete	Copy
Adjust Long Range Spi...	TN.index_Mica_Local	TN.index Mica_Local : Time series	Mica_Local	06-19-2017, 01:00	06-19-2017, 01:00	--	Jost, Georg	06-20-2017, 11:44	☑	☒	
Adjust Long Range Spi...	TX.index_Donald	TX.index Donald : Time series	Donald	06-19-2017, 01:00	06-20-2017, 01:00	--	Jost, Georg	06-20-2017, 11:43	☑	☒	
Adjust Long Range Spi...	TN.index_Donald	TN.index Donald : Time series	Donald	06-19-2017, 01:00	06-20-2017, 01:00	--	Jost, Georg	06-20-2017, 11:43	☑	☒	
Adjust Long Range Spi...	TN.index_Mica_Local_1	TN.index Mica_Local : Time series	Mica_Local	06-20-2017, 01:00	06-20-2017, 01:00	--	Jost, Georg	06-20-2017, 11:42	☑	☒	
Adjust Long Range Spi...	TN.index_Mica_Local_0	TN.index Mica_Local : Time series	Mica_Local	06-17-2017, 01:00	06-18-2017, 01:00	--	Jost, Georg	06-20-2017, 11:42	☑	☒	
Adjust Long Range Spi...	TX.index_Donald	TX.index Donald : Time series	Donald	06-18-2017, 01:00	06-20-2017, 01:00	--	Jost, Georg	06-20-2017, 11:42	☑	☒	
Adjust Long Range Spi...	TX.index_Mica_Local	TX.index Mica_Local : Time series	Mica_Local	06-18-2017, 01:00	06-20-2017, 01:00	--	Jost, Georg	06-20-2017, 11:41	☑	☒	
Adjust Long Range Spi...	TX.index_Mica_Local	TX.index Mica_Local : Time series	Mica_Local	06-14-2017, 01:00	06-14-2017, 01:00	--	Jost, Georg	06-20-2017, 11:41	☑	☒	
Adjust Long Range Spi...	TN.index_Donald_1	TN.index Donald : Time series	Donald	06-15-2017, 01:00	06-15-2017, 01:00	--	Jost, Georg	06-15-2017, 11:10	☑	☒	
Adjust Long Range Spi...	TN.index_Donald_0	TN.index Donald : Time series	Donald	06-09-2017, 01:00	06-10-2017, 01:00	--	Jost, Georg	06-15-2017, 11:10	☑	☒	
Adjust Long Range Spi...	TX.index_Mica_Local	TX.index Mica_Local : Time series	Mica_Local	06-13-2017, 01:00	06-13-2017, 01:00	--	Jost, Georg	06-15-2017, 11:10	☑	☒	
Adjust Long Range Spi...	TX.index_Donald	TX.index Donald : Time series	Donald	06-13-2017, 01:00	06-14-2017, 01:00	--	Jost, Georg	06-15-2017, 11:09	☑	☒	
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Adjust Long Range Spi...	PP.index_Mica_Local	PP.index Mica_Local : Time series	Mica_Local	06-10-2017, 01:00	06-10-2017, 01:00	--	Jost, Georg	06-12-2017, 11:27	☑	☒	
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Adjust Long Range Spi...	TX.index_Mica_Local	TX.index Mica_Local : Time series	Mica_Local	06-12-2017, 01:00	06-12-2017, 01:00	--	Jost, Georg	06-12-2017, 11:27	☑	☒	
Adjust Long Range Spi...	TX.index_Mica_Local	TX.index Mica_Local : Time series	Mica_Local	06-09-2017, 01:00	06-09-2017, 01:00	--	Jost, Georg	06-12-2017, 11:26	☑	☒	
LongRange_ShortRang...	ESP_Output_MergeWeighted			--	--	--	Jost, Georg	06-05-2017, 14:50	☑	☒	
LongRange_ShortRang...	ESP_MergeWeighted			--	--	--	Jost, Georg	06-05-2017, 14:50	☑	☒	
Adjust Long Range Spi...	TN.index_Donald	TN.index Donald : Subtract 2.0	Donald	05-17-2017, 01:00	06-05-2017, 01:00	--	Jost, Georg	06-05-2017, 11:32	☑	☒	
Adjust Long Range Spi...	TN.index_Mica_Local	TN.index Mica_Local : Time series	Mica_Local	06-02-2017, 01:00	06-05-2017, 01:00	--	Jost, Georg	06-05-2017, 11:27	☑	☒	
Adjust Long Range Spi...	TN.index_Mica_Local	TN.index Mica_Local : Time series	Mica_Local	05-30-2017, 01:00	05-31-2017, 01:00	--	Jost, Georg	06-05-2017, 11:26	☑	☒	
LongRange_ShortRang...	ESP_MergeWeighted			--	--	--	Jost, Georg	05-24-2017, 10:56	☐	☒	
LongRange_ShortRang...	ESP_Output_MergeWeighted			--	--	--	Jost, Georg	05-24-2017, 10:56	☐	☒	
Adjust Long Range Spi...	TX.index_Mica_Local	TX.index Mica_Local : Time series	Mica_Local	05-17-2017, 01:00	05-18-2017, 01:00	--	Jost, Georg	05-19-2017, 10:34	☑	☒	
Adjust Long Range Spi...	PP.index_Mica_Local	PP.index Mica_Local : Time series	Mica_Local	05-18-2017, 01:00	05-18-2017, 01:00	--	Jost, Georg	05-19-2017, 10:34	☑	☒	
Adjust Long Range Spi...	TX.index_Donald	TX.index Donald : Time series	Donald	05-13-2017, 01:00	05-15-2017, 01:00	--	Jost, Georg	05-15-2017, 13:50	☑	☒	
Adjust Long Range Spi...	TN.index_Donald	TN.index Donald : Time series	Donald	05-14-2017, 01:00	05-15-2017, 01:00	--	Jost, Georg	05-15-2017, 13:50	☑	☒	
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Adjust Long Range Spi...	TX.index_Donald	TX.index Donald : Time series	Donald	05-06-2017, 01:00	05-08-2017, 01:00	--	Jost, Georg	05-15-2017, 13:49	☑	☒	
Adjust Longe Range E...	ADJUST_FORCINGS_ESP_FORECAST...	Subtract 1.5	Donald,Mica_Local	05-03-2017, 01:00	05-11-2017, 01:00	05-10-2017, 01:00	Jost, Georg	05-05-2017, 13:15	☑	☒	
LongRange_ShortRang...	LONGRANGE_SHORTRANGE_MERGE_...			--	--	--	Jost, Georg	05-03-2017, 11:42	☑	☒	
Adjust Long Range Spi...	TN.index_Donald	TN.index Donald : Subtract 2.0	Donald	04-02-2017, 01:00	05-03-2017, 01:00	--	Jost, Georg	05-03-2017, 11:35	☑	☒	
Adjust Long Range Spi...	TN.index_Mica_Local	TN.index Mica_Local : Subtract 2.0	Mica_Local	04-02-2017, 01:00	05-03-2017, 01:00	--	Jost, Georg	05-03-2017, 11:33	☑	☒	
Adjust Longe Range E...	TN.index_Mica_Local_Donald	Subtract 1.0	Donald,Mica_Local	04-20-2017, 01:00	04-25-2017, 01:00	04-20-2017, 01:00	Jost, Georg	04-20-2017, 10:40	☑	☒	
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Adjust Long Range Spi...	TN.index_Mica_Local	TN.index Mica_Local : Subtract 2.0	Mica_Local	03-07-2017, 00:00	04-05-2017, 01:00	--	Jost, Georg	04-05-2017, 09:43	☑	☒	
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HRU_All	DEEP_GW_HRU_OPEN_North_EB1 82...	Multiply 1.3	OPEN_North_EB9 3025.3m,OPEN_So...	03-01-2017, 00:00	03-01-2017, 00:00	--	Weston, Scott	03-21-2017, 08:04	☑	☒	
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HRU_All	SHALLOW_GW_HRU_OPEN_North_E...	Multiply 1.5	OPEN_North_EB9 3025.3m,OPEN_So...	11-18-2016, 00:00	11-18-2016, 00:00	--	Jost, Georg	12-01-2016, 13:25	☑	☒	
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Adjust Long Range Spi...	TN.index_Donald_1	TN.index Donald : Time series	Donald	11-16-2016, 00:00	11-16-2016, 00:00	--	Jost, Georg	11-16-2016, 11:32	☑	☒	
Adjust Long Range Spi...	TN.index_Donald_0	TN.index Donald : Time series	Donald	11-14-2016, 00:00	11-14-2016, 00:00	--	Jost, Georg	11-16-2016, 11:32	☑	☒	
HRU_All	DEEP_GW_HRU_OPEN_North_EB1_O...	Multiply 0.8	OPEN_North_EB9 3025.3m,OPEN_So...	10-01-2016, 01:00	10-01-2016, 01:00	--	Jost, Georg	11-07-2016, 14:25	☑	☒	

Create mod | HRU_All | HRU_Forest | HRU_Open_North | HRU_Open_South | HRU_EB1 | HRU_EB2 | HRU_EB3 | HRU_EB4 | HRU_EB5 | HRU_EB6 | HRU_EB7 | HRU_EB8 | HRU_EB9 | Import | Export | Reorder

DETERMINISTIC FORECAST

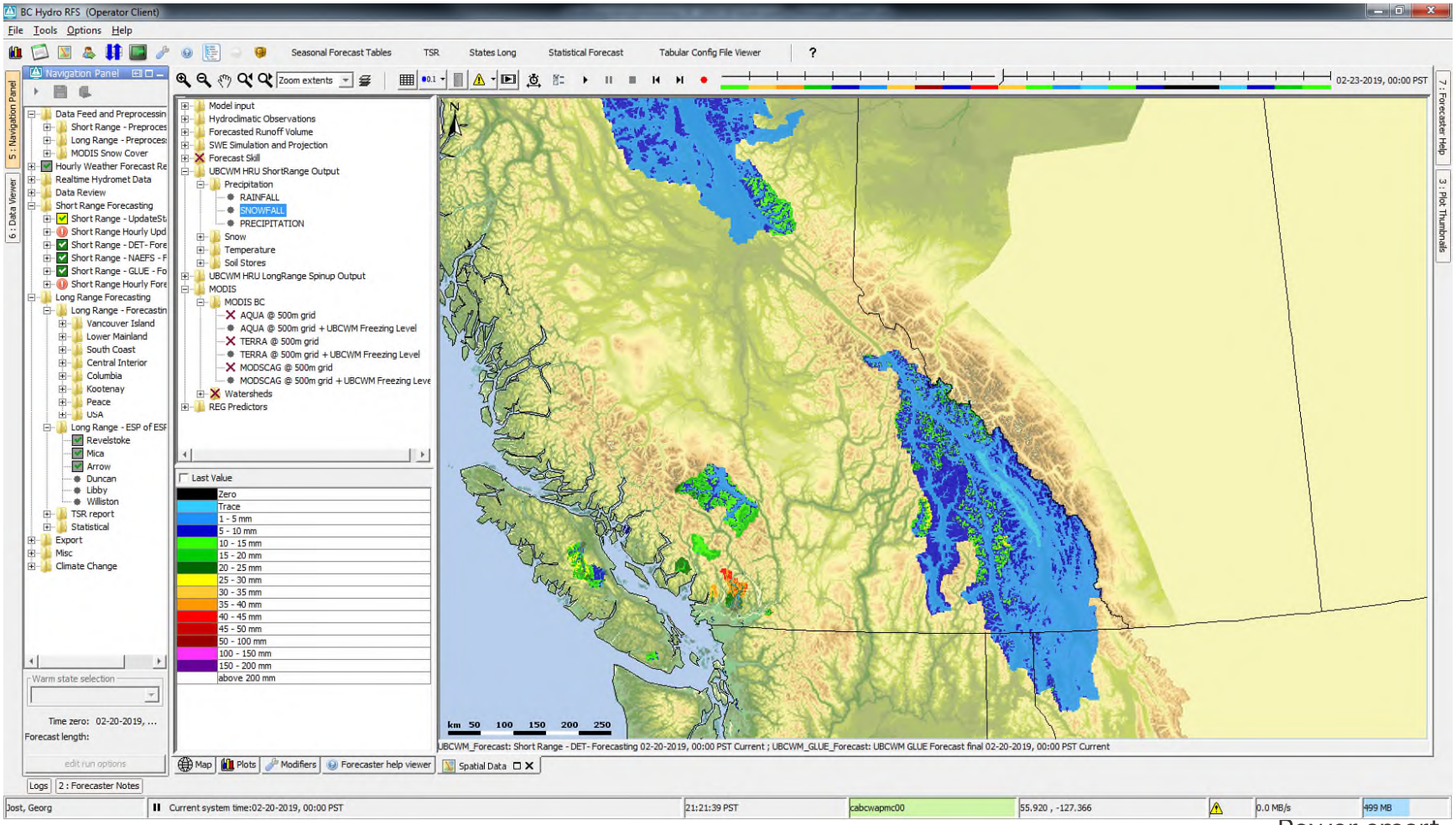
Hourly forecasting for all Coastal watersheds



BC Hydro
Power smart

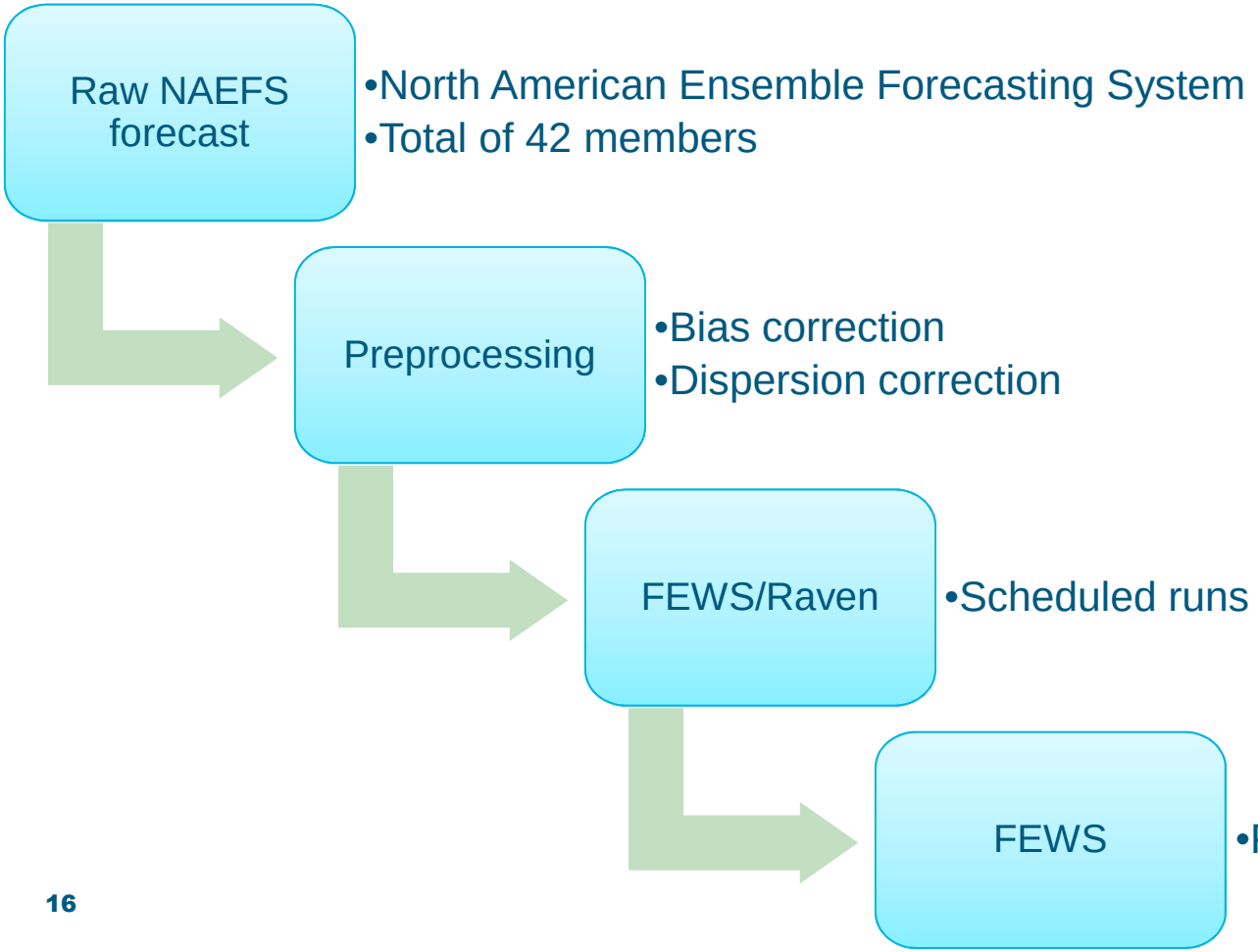
DETERMINISTIC FORECAST

Hourly forecasting for all Coastal watersheds



PROBABILISTIC FORECAST: WEATHER

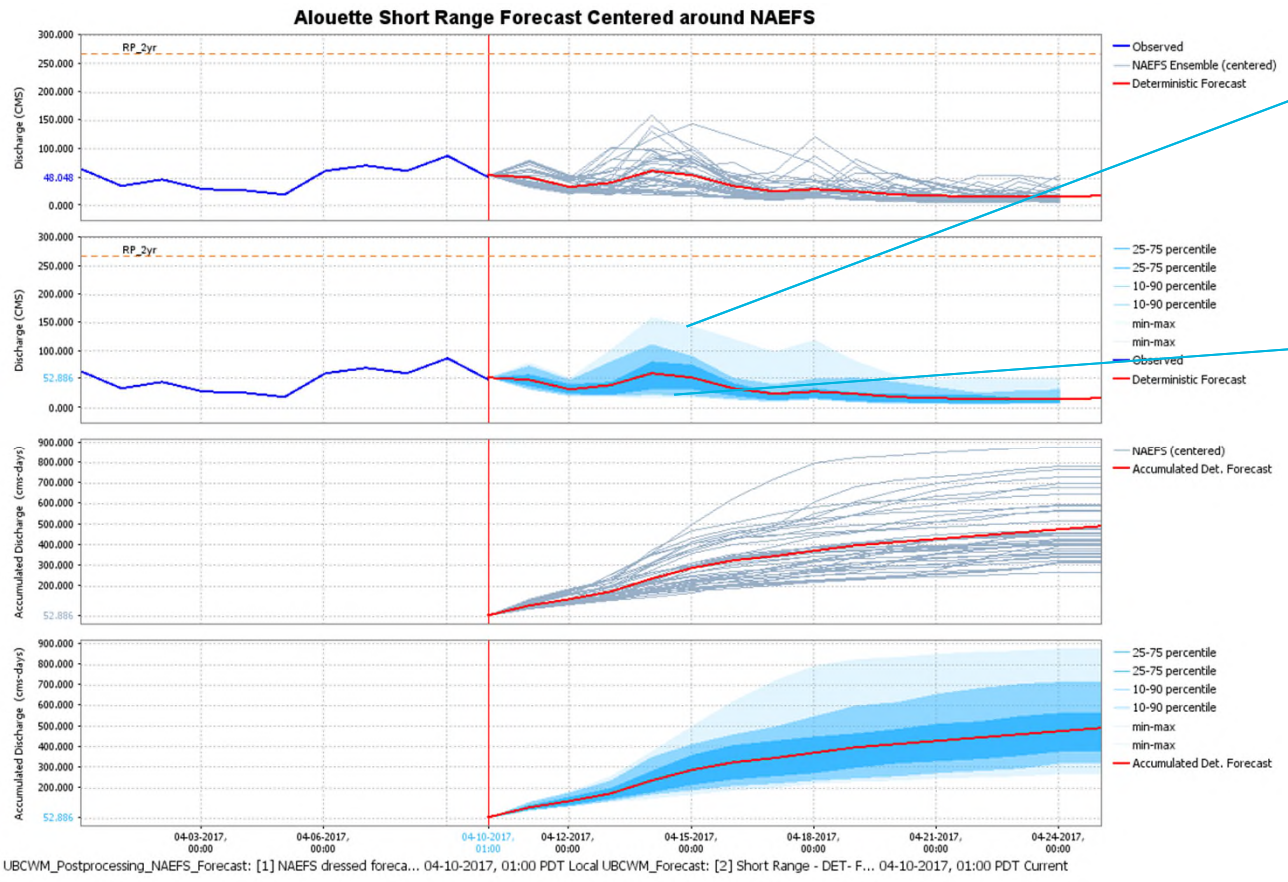
All forecasts 50% off – get them today!



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



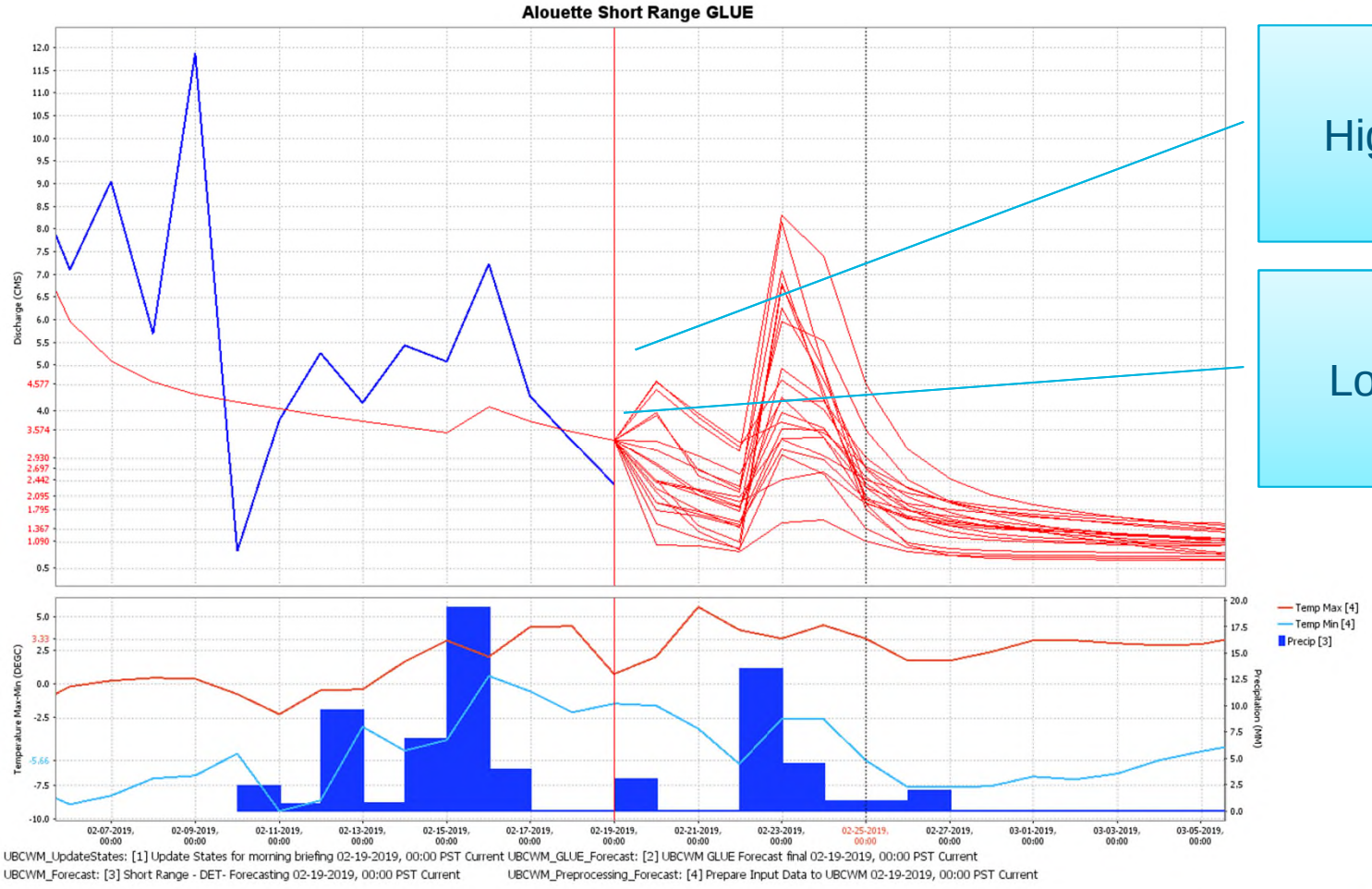
High scenario

Low scenario

BC Hydro
Power smart

PROBABILISTIC FORECAST: GLUE

Generalized likelihood uncertainty estimation (GLUE)



High scenario

Low scenario

BC Hydro
Power smart

LONG RANGE FORECASTING

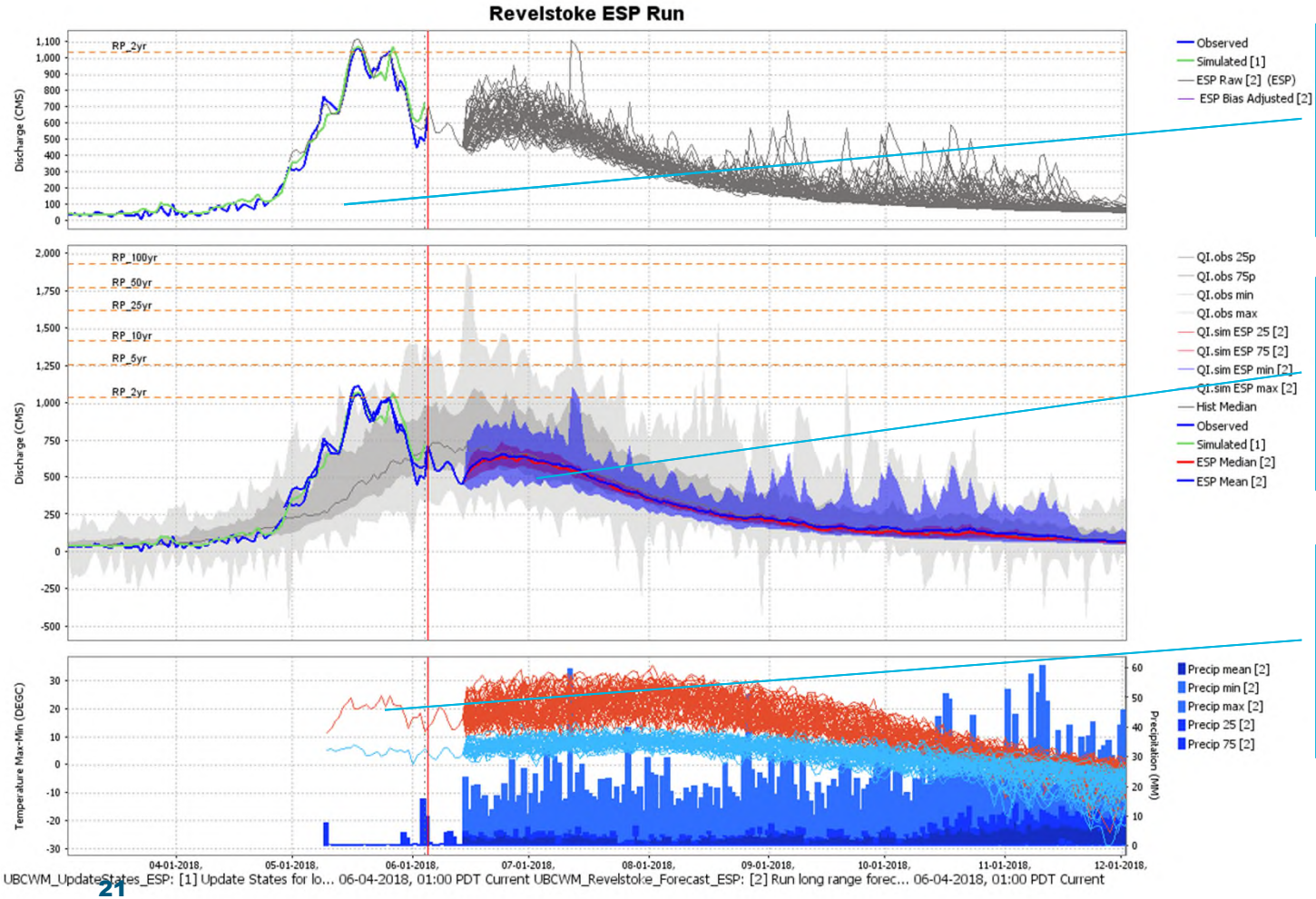
BC Hydro
Power smart

LONG RANGE FORECASTING

- Statistical forecasts based on PCA (mostly for Columbia River Treaty)
- Ensemble forecasts using Raven plus SWE PCA
  - Daily scheduled runs
  - Bi weekly Columbia River Treaty flow coordination
  - Monthly official water supply forecasts
  - On demand scenarios (spillway repairs, ENSO, summer flows etc.)

ENSEMBLE PREDICTION OF INFLOWS

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



Historical years (1968-2018)

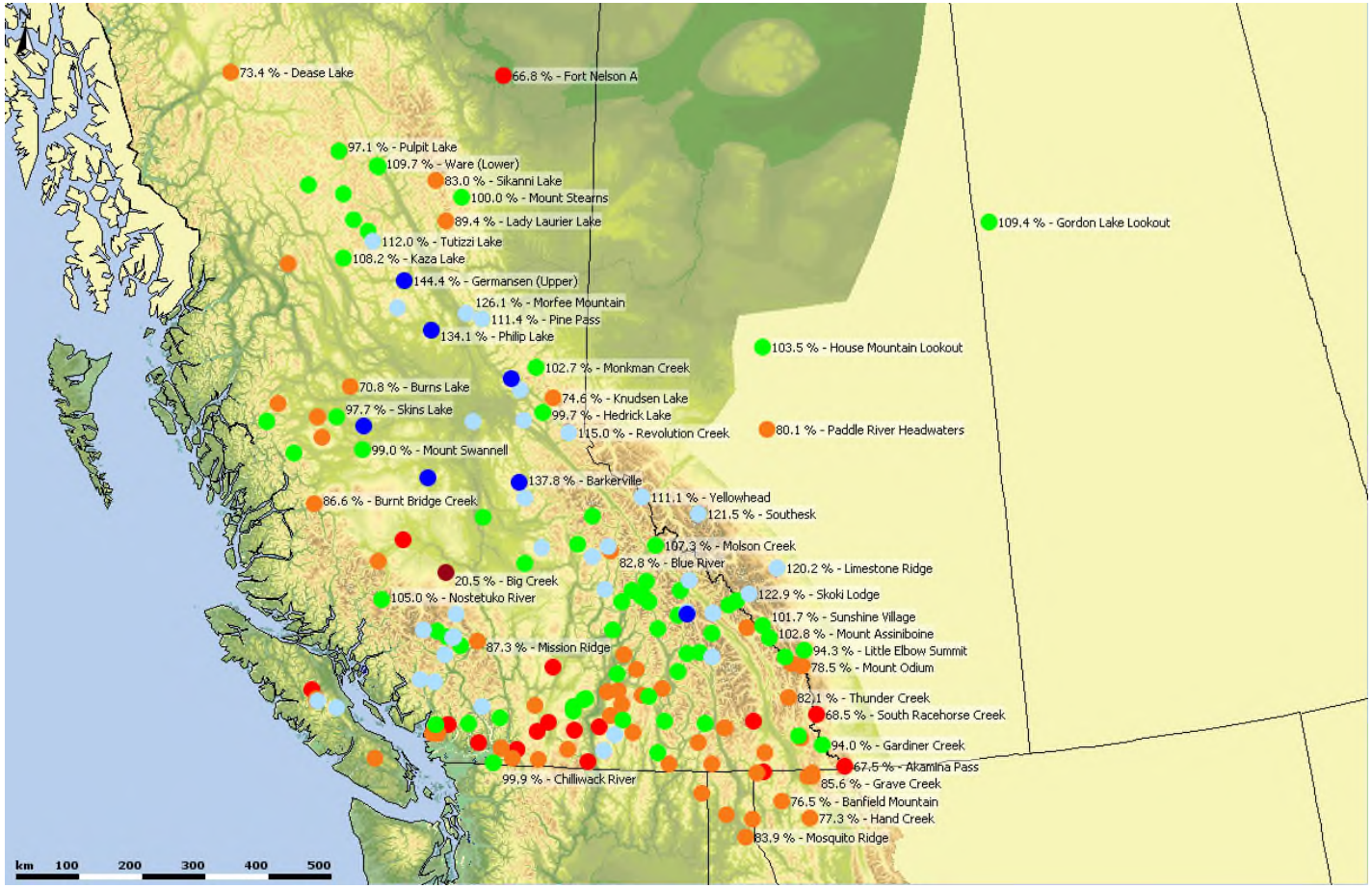
Probabilities of exceedance

Historical precipitation and temperature (1968-2018)

BC Hydro
Power smart

SNOW DATA ASSIMILATION

Pillows, scales, ultrasonic…but mostly manual snow courses

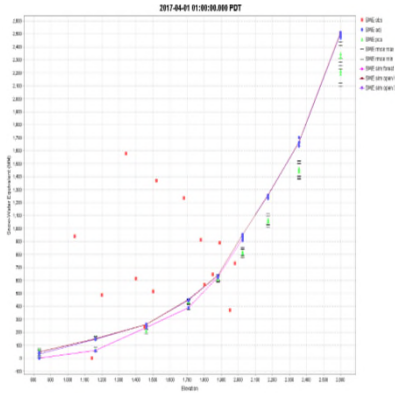


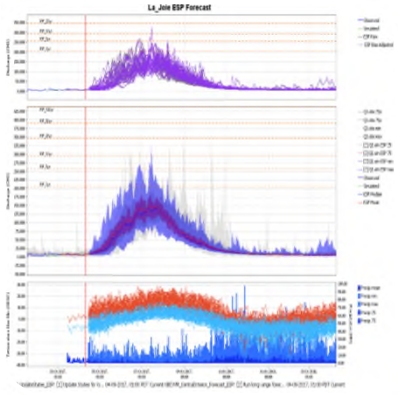
BC Hydro
Power smart

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

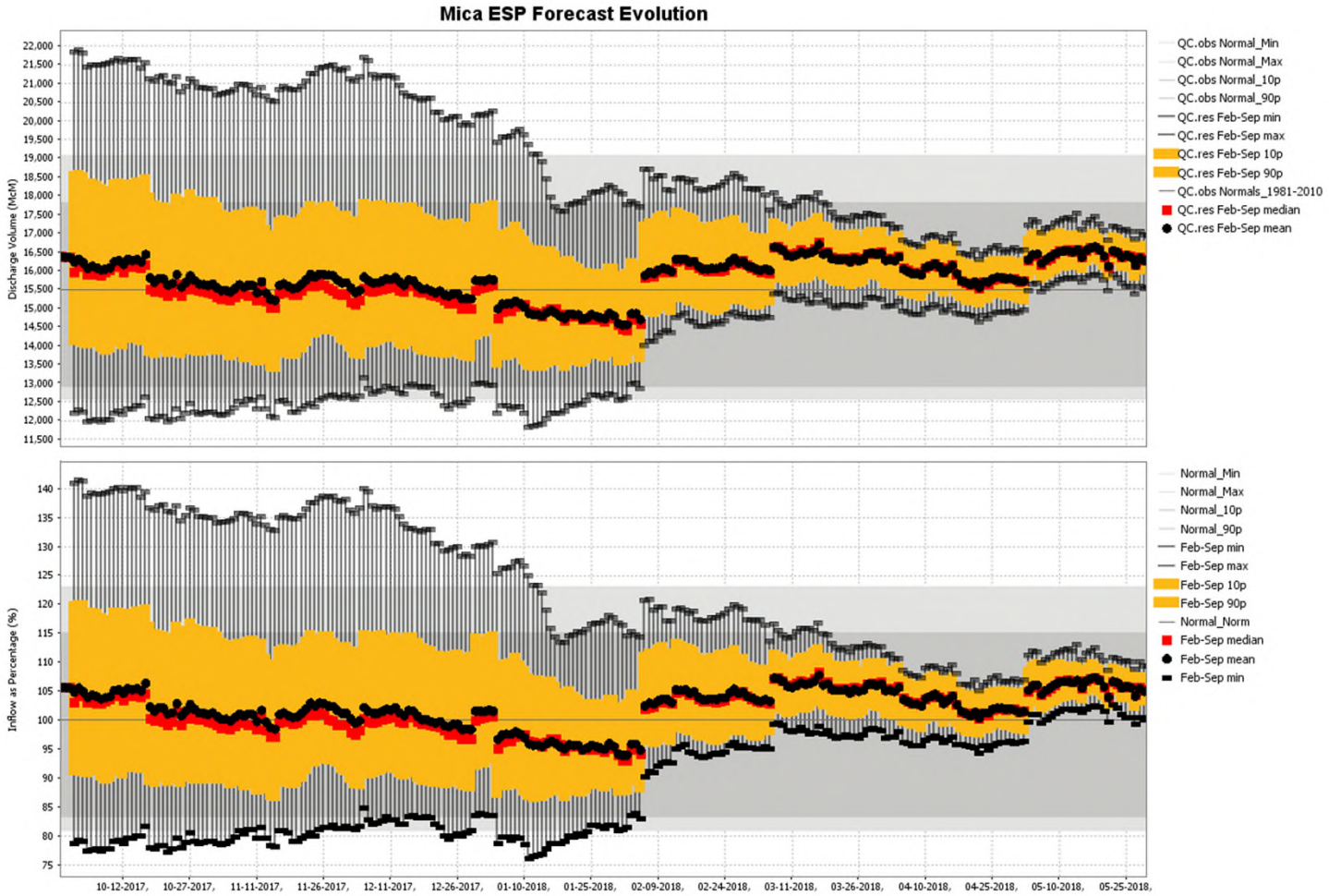
Forecast

- Weather forecast
- Historical weather sequence

Power smart

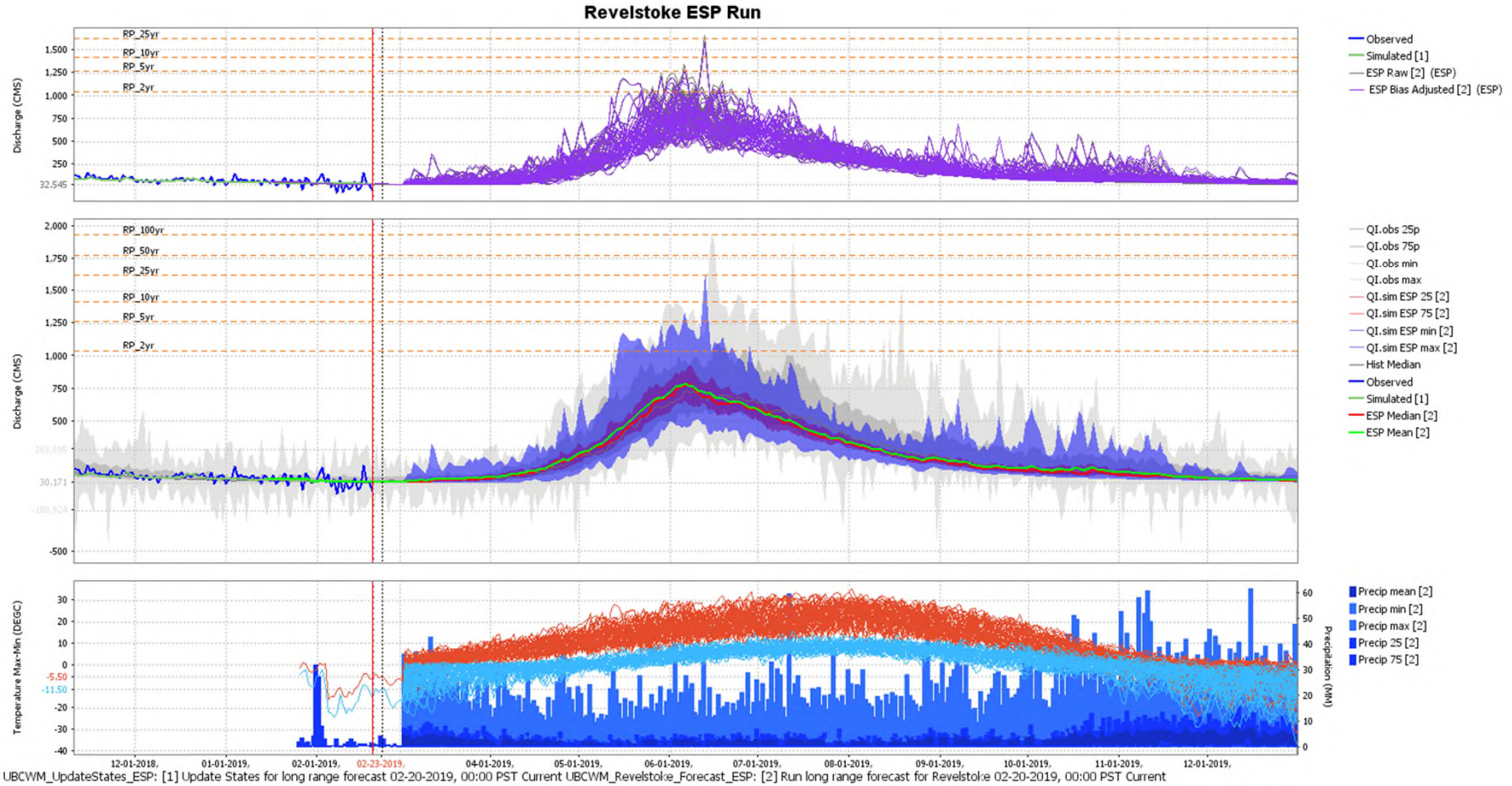
LONG RANGE FORECAST EVOLUTION

WY 2018



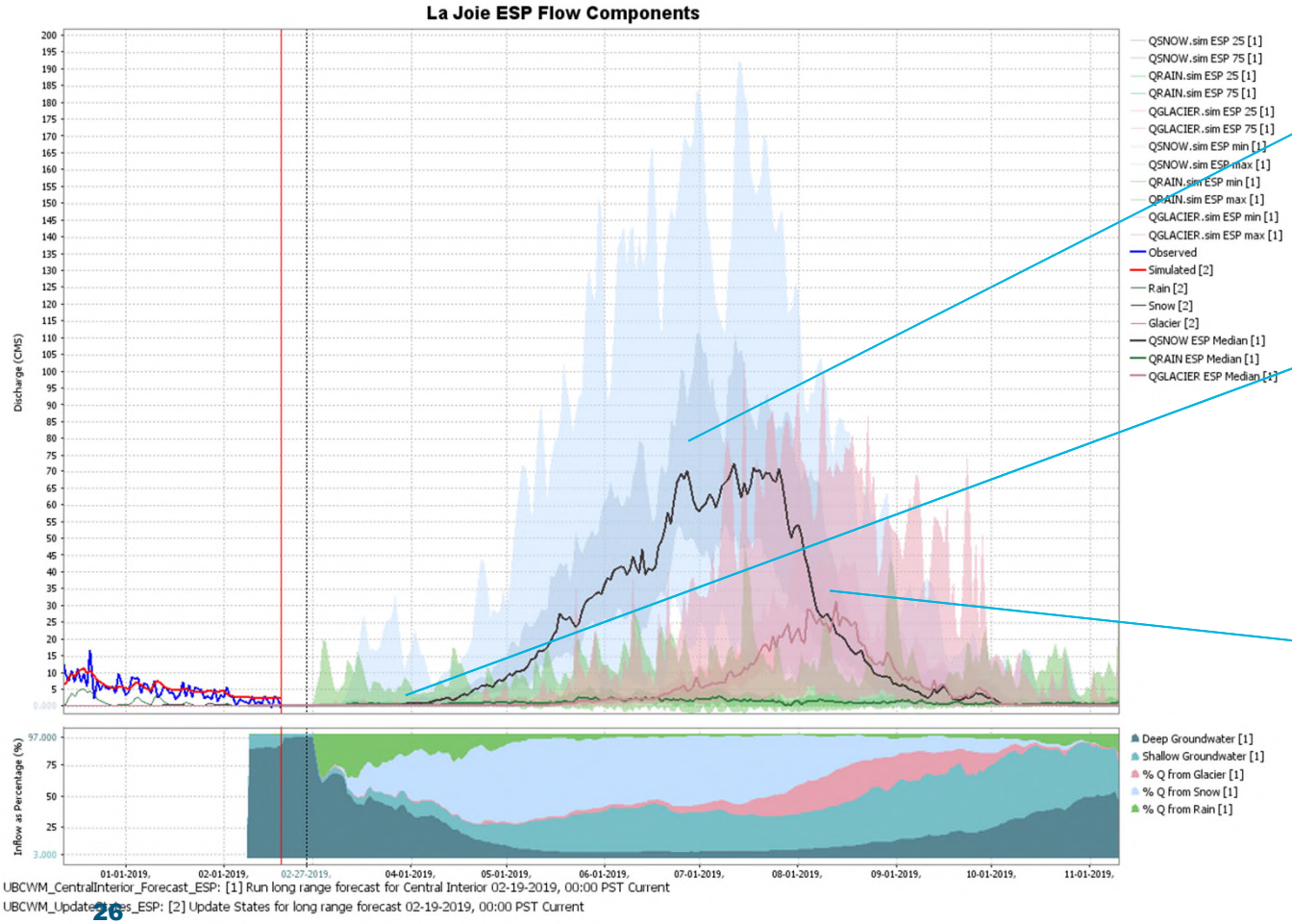
BC Hydro
Power smart

Long range forecast



WHAT WE CAN AND WHAT WE CANT PREDICT

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



Snow (blue) can be measured

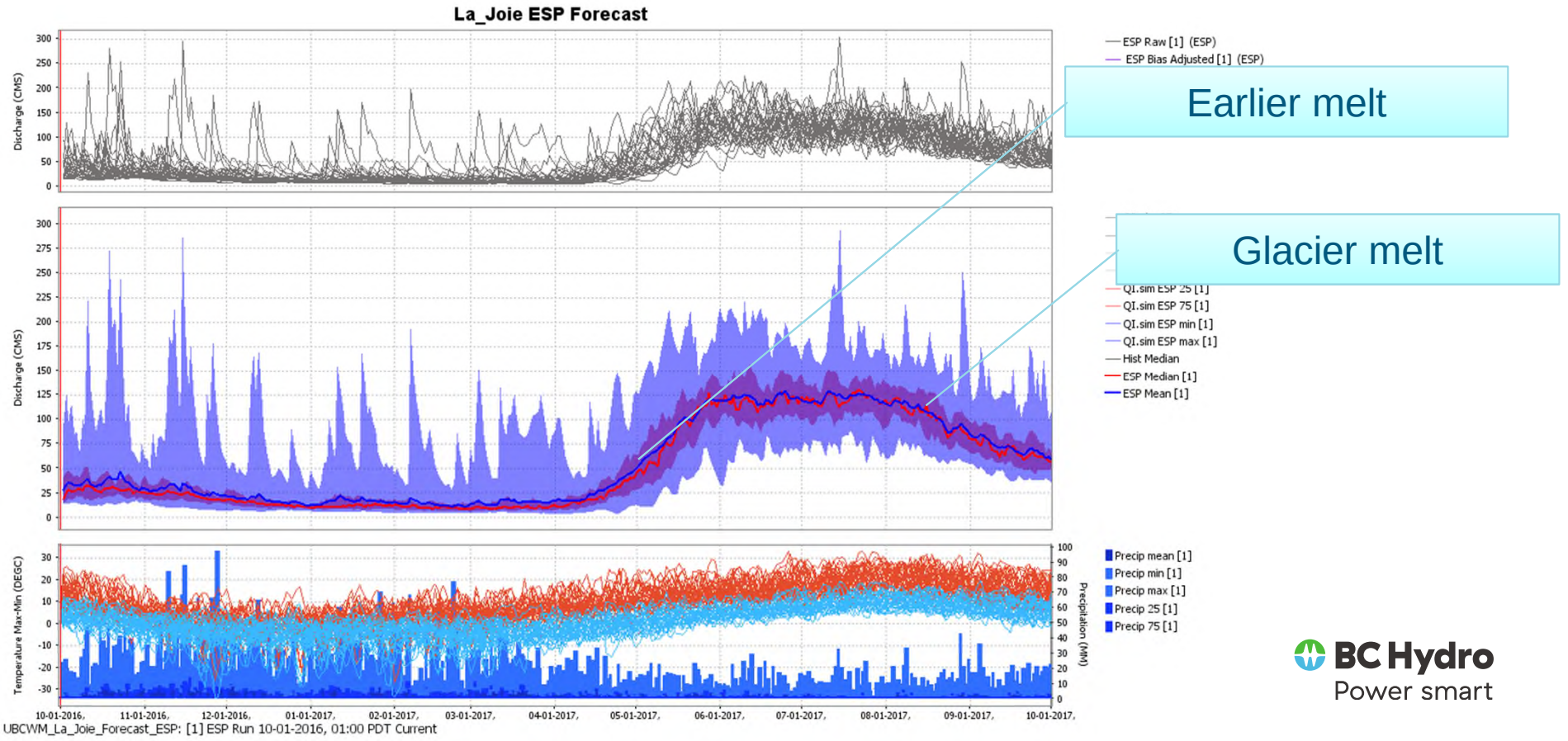
Rain (green) can be forecasted for about one week

Glacier melt (pink)

BC Hydro
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Effect of +2 dC T for Downton Lake

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



BC Hydro
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ESP OF ESP

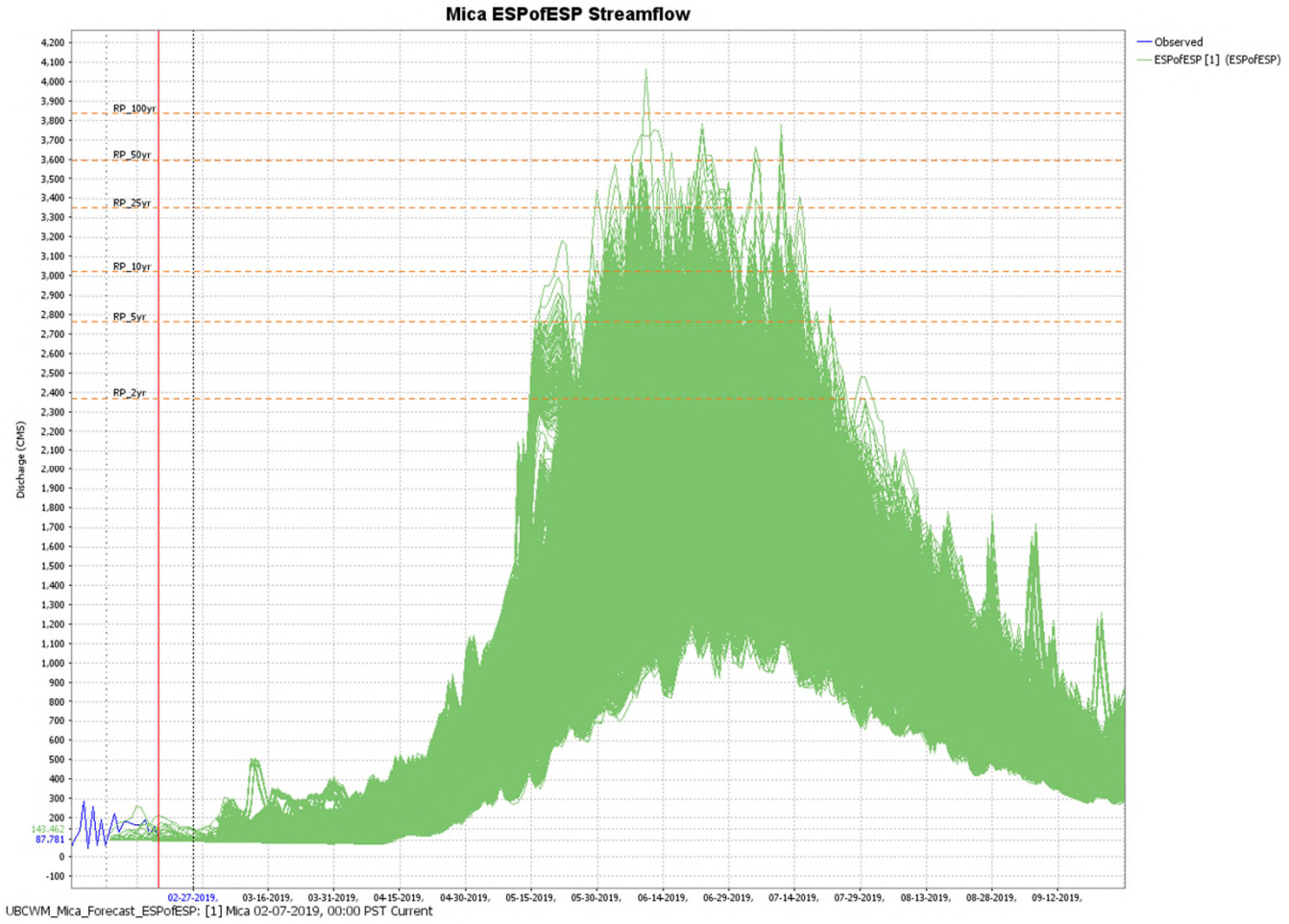
Seasonal forecasts usually (not always) underestimate the uncertainty

ESP	subtyp	jan	feb	mar	may	jun	jul
ESP orig		1970	1970	1970	1970	1970	1970
		1971	1971	1971	1971	1971	1971
		1972	1972	1972	1972	1972	1972
ESP feb	M(ember)1	1970	1970	1970	1970	1970	1970
	M2	1970	1971	1971	1971	1971	1971
	M3	1970	1972	1972	1972	1972	1972
	M1	1971	1970	1970	1970	1970	1970
	M2	1971	1971	1971	1971	1971	1971
	M3	1971	1972	1972	1972	1972	1972
	M1	1972	1970	1970	1970	1970	1970
	M2	1972	1971	1971	1971	1971	1971
	M3	1972	1972	1972	1972	1972	1972
ESP mar	M1	1970	1970	1970	1970	1970	1970
	M2	1970	1970	1971	1971	1971	1971
	M3	1970	1970	1972	1972	1972	1972
	M1	1971	1971	1970	1970	1970	1970
	M2	1971	1971	1971	1971	1971	1971
	M3	1971	1971	1972	1972	1972	1972
	M1	1972	1972	1970	1970	1970	1970
	M2	1972	1972	1971	1971	1971	1971
	M3	1972	1972	1972	1972	1972	1972
ESP apr	M1	1970	1970	1970	1970	1970	1970
	M2	1970	1970	1970	1971	1971	1971
	M3	1970	1970	1970	1972	1972	1972
	M1	1971	1971	1971	1970	1970	1970
	M2	1971	1971	1971	1971	1971	1971
	M3	1971	1971	1971	1972	1972	1972
	M1	1972	1972	1972	1970	1970	1970
	M2	1972	1972	1972	1971	1971	1971
	M3	1972	1972	1972	1972	1972	1972
ESP may	M1	1970	1970	1970	1970	1970	1970
	M2	1970	1970	1970	1970	1971	1971
	M3	1970	1970	1970	1970	1972	1972
	M1	1971	1971	1971	1971	1970	1970
	M2	1971	1971	1971	1971	1971	1971
	M3	1971	1971	1971	1971	1972	1972
	M1	1972	1972	1972	1972	1970	1970
	M2	1972	1972	1972	1972	1971	1971
	M3	1972	1972	1972	1972	1972	1972
ESP jun	M1	1970	1970	1970	1970	1970	1970
	M2	1970	1970	1970	1970	1970	1971
	M3	1970	1970	1970	1970	1970	1972
	M1	1971	1971	1971	1971	1971	1970
	M2	1971	1971	1971	1971	1971	1971
	M3	1971	1971	1971	1971	1971	1972
	M1	1972	1972	1972	1972	1972	1970
	M2	1972	1972	1972	1972	1972	1971
	M3	1972	1972	1972	1972	1972	1972

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Seasonal forecasts usually (not always) underestimate the uncertainty



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ESP OF ESP

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

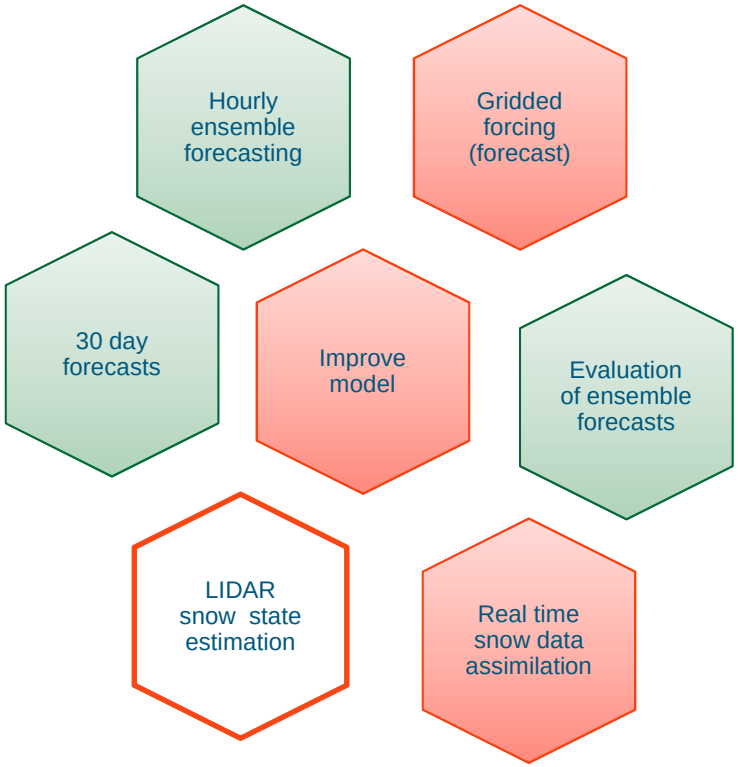
Remainder of Feb - Sep Runoff Volume (Mil. Cu. M)

	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

WHAT ARE WE WORKING ON?



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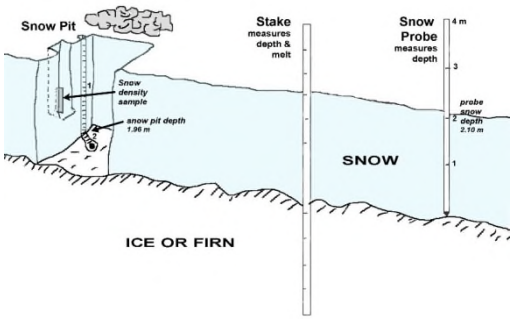
MODEL SNOW STATES UPDATING FROM LIDAR

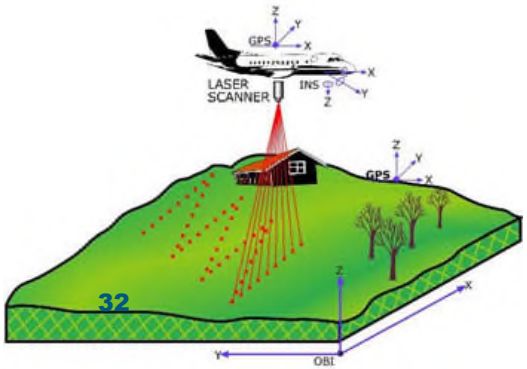
Bridge Glacier monitoring

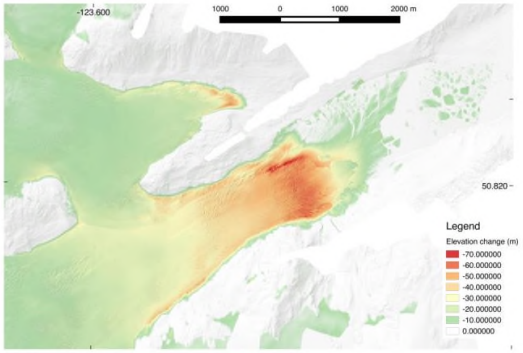


Mass Balance Monitoring

- 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.












10
5

CLIMATE CHANGE IMPACT ASSESSMENTS

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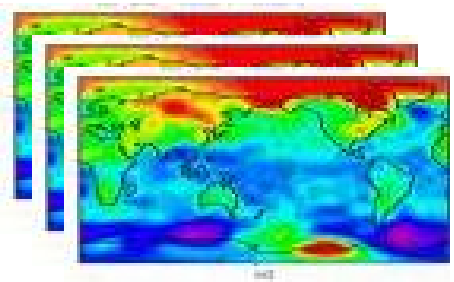
THE GOAL OF WORKING WITH SCENARIOS IS NOT TO PREDICT THE FUTURE, BUT TO BETTER UNDERSTAND UNCERTAINTIES
IN ORDER TO REACH DECISIONS THAT ARE ROBUST UNDER A WIDE RANGE OF POSSIBLE FUTURES

Climate change Impact Assessment Process

EMISSION SCENARIOS
Global emissions and land use change based on future socio-economic development

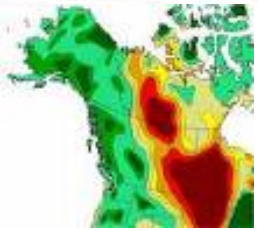
GLOBAL CLIMATE MODELS (GCMS)
Global climate responses to emission scenarios (temperature, precipitation, etc.)

Resolution
~ 200 km grids



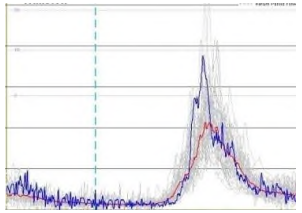
STATISTICAL DOWNSCALING
Regional climate responses (orographic and coastal effects, extremes, etc.)

Resolution for model requirements
~ 6 km grids



HYDROLOGICAL MODEL
Changes to the hydrological cycle (snow, glaciers, evaporation, runoff, etc.)

Flow Scenarios



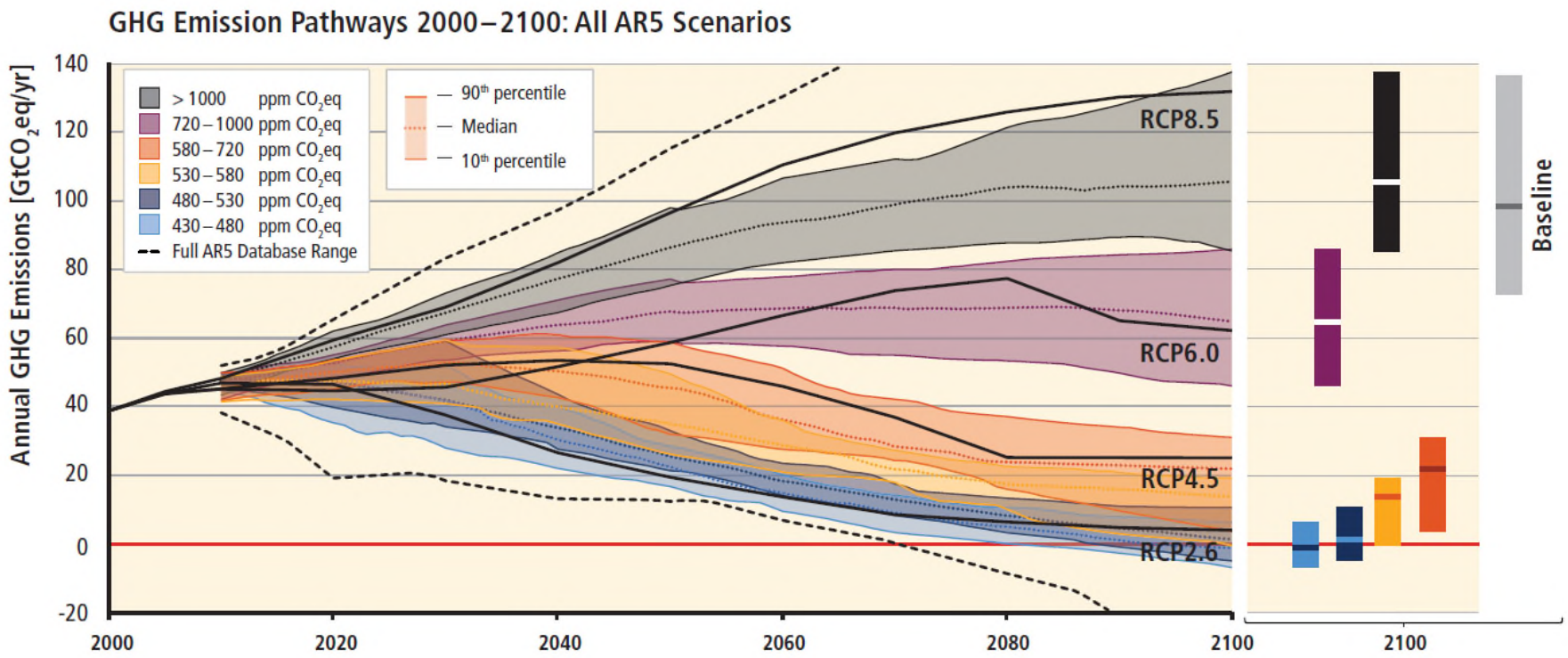
HYDROLOGICAL IMPACTS
Water supply to: reservoirs, hydropower generation, operation of reservoirs, fish and their habitat, etc.

Adaptation (e.g., Reservoir Operations)

PACIFIC CLIMATE IMPACTS CONSORTIUM

Representative Concentration Pathways (RCPs)

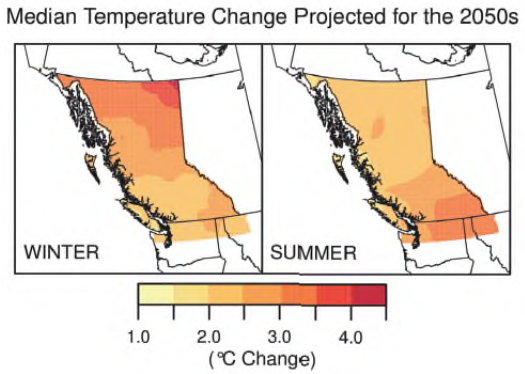
Emission scenarios based on different future worlds

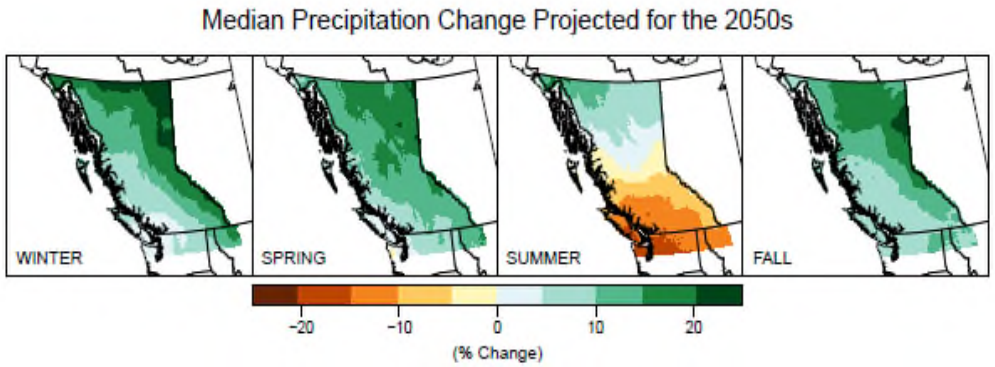


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PRECIPITATION AND TEMPERATURE PROJECTIONS

Good confidence in Temperature projections. Lower confidence in precipitation projections.

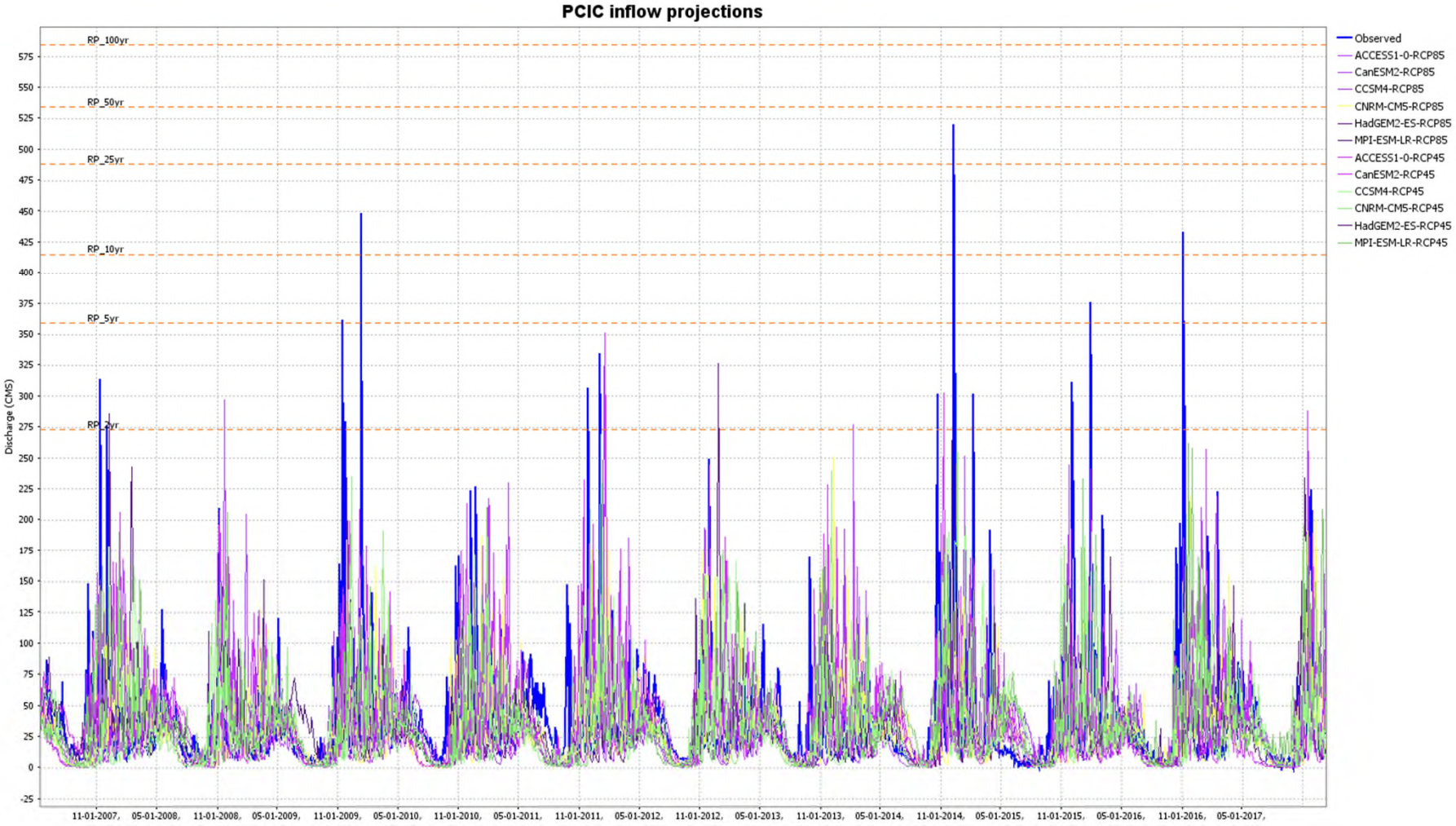




- By 2050:
  - 1.4 – 3.7 °C increase in mean temperature
  - 0 – 18% increase in annual precipitation
  - Modest increase in annual water supply
  - Significant change in timing of runoff

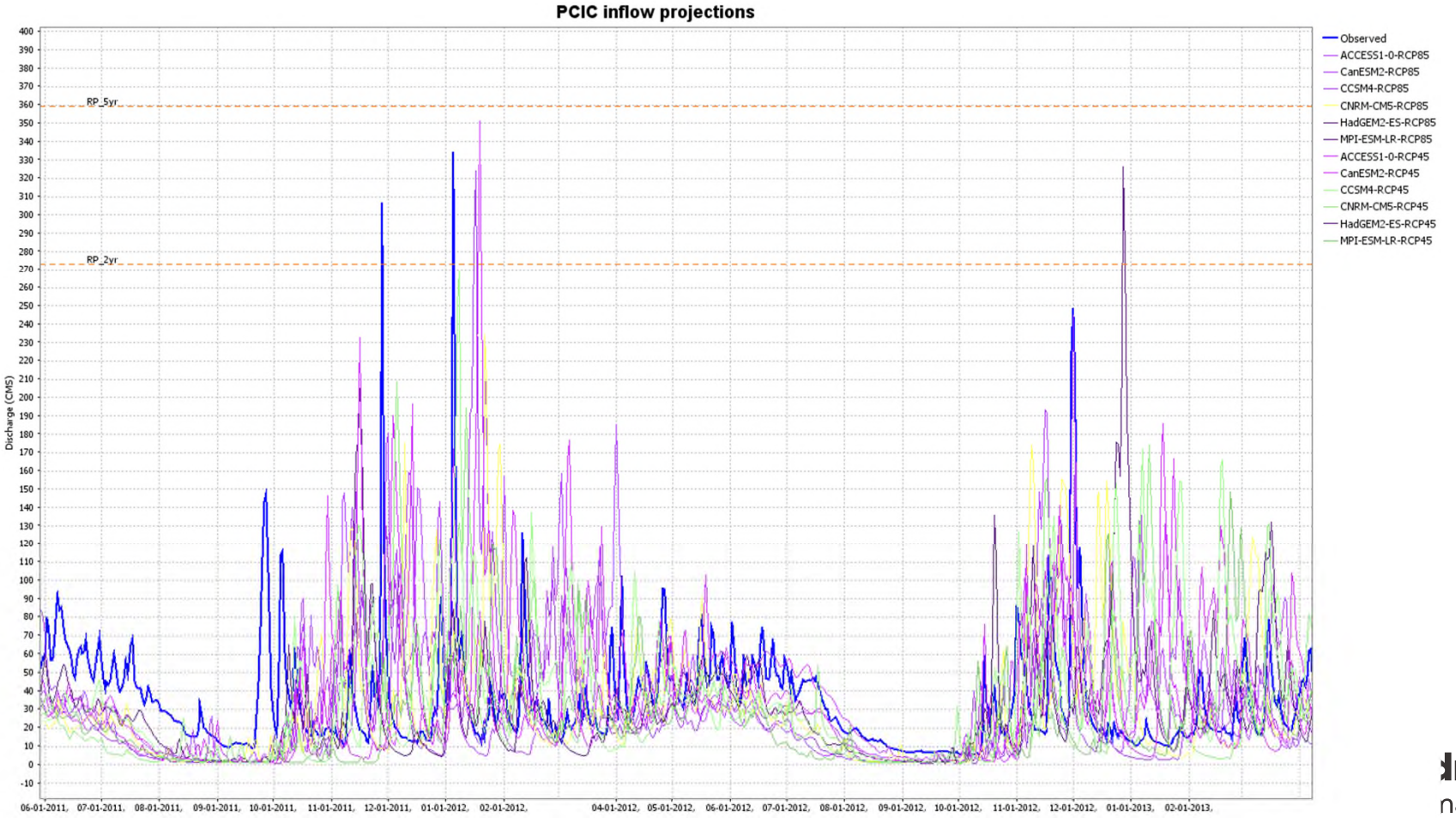
CHALLENGES WITH OPERATIONAL USE OF CLIMATE CHANGE PROJECTIONS

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



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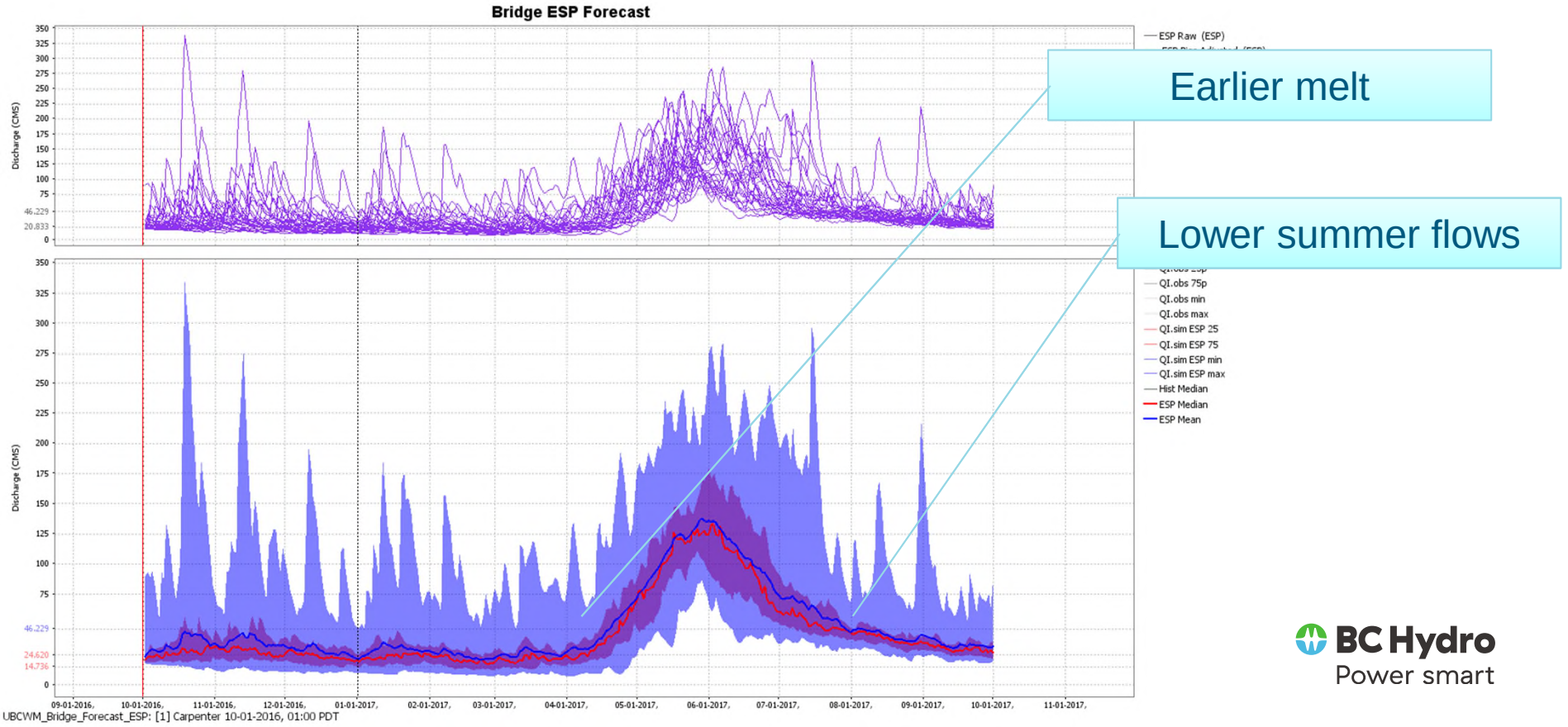


OPERATIONAL USE OF CLIMATE CHANGE PROJECTIONS

- Scientific community usually reports anomalies (i.e, changes)
- Operational models (Energy demand, Energy supply, Fish flow, etc) require absolute numbers.
- Ideally the direct model output should be used
- Delta approach as an alternative and quantile mapping as a last resort.

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

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