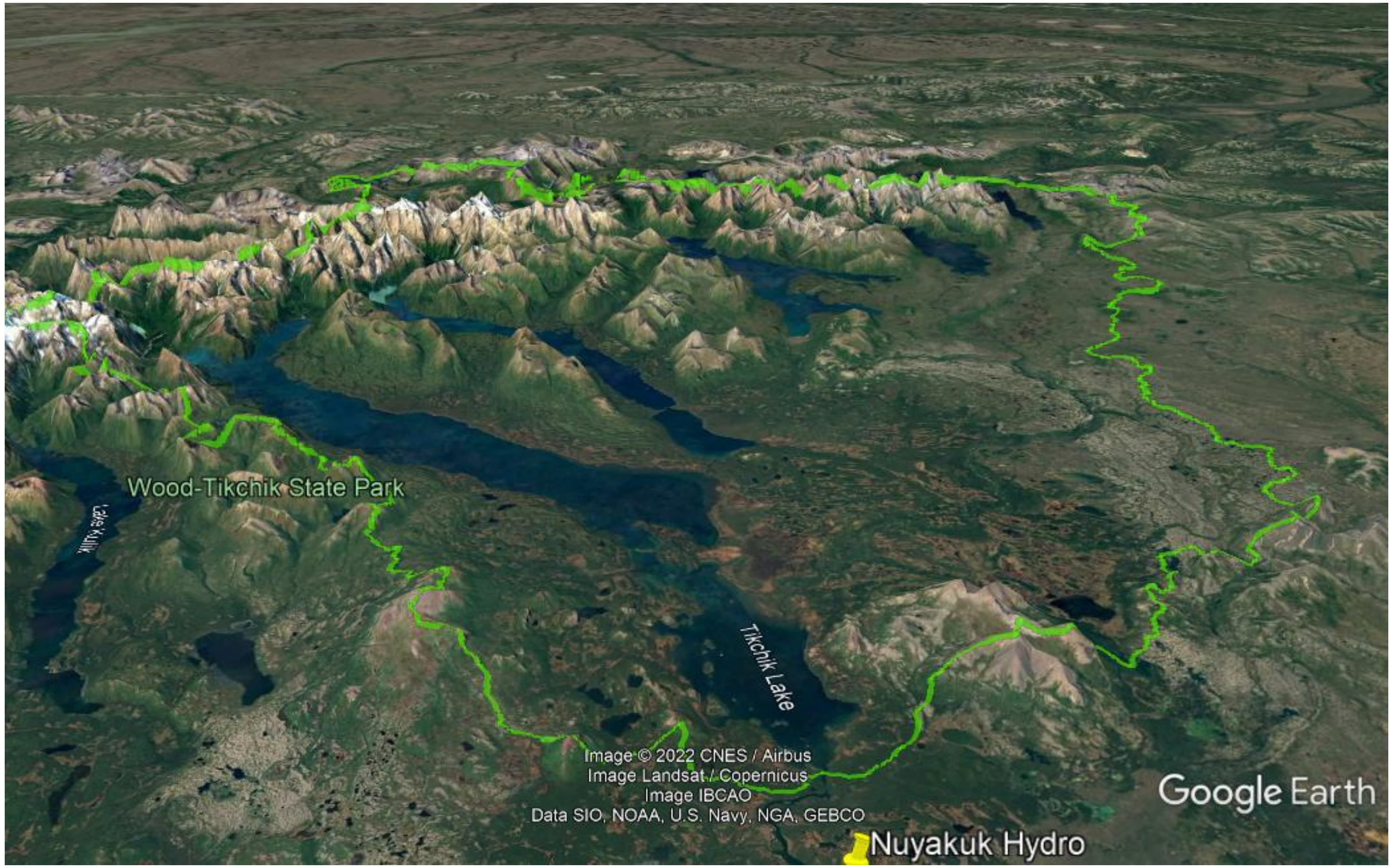
Nuyakuk Hydro
Hydrologic Model and Assessment

Robert Prucha, PhD – Integrated Hydro Systems LLC
Cameron Wobus, PhD - CK Blueshift LLC
Peter Bieniek, PhD – University of Alaska Fairbanks

Overview

- Motivation
- Model History
  - Full Nushagak model
  - Nuyakuk submodel
- Model Refinements
  - Nuyakuk model calibration
  - Sensitivity analysis
- Climate change simulations
  - Time periods, scenarios
  - Model implementation
- Results
  - Changes in hydrographs
  - Implications for hydropower resource



Motivation

- Proposed run-of-river hydropower project on Nuyakuk River. Need to understand:
  - How water diversions might affect downstream habitat, fish passage, etc
  - How climate change could affect the hydropower resource

These needs require an integrated, physically-based hydrologic model of the system

PROPOSED STUDY PLAN

NUYAKUK RIVER HYDROELECTRIC PROJECT
FERC NO. 14873

Submitted by:

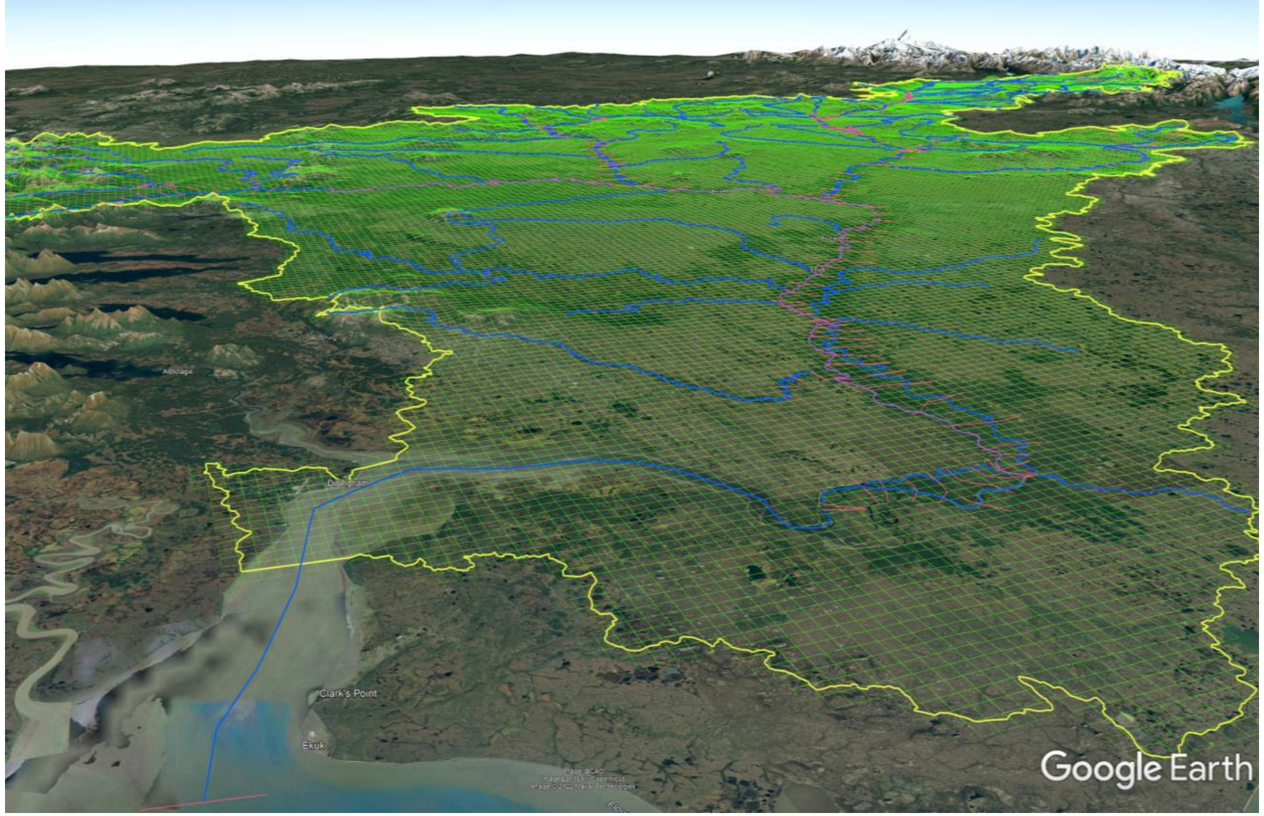
Nushagak COOPERATIVE

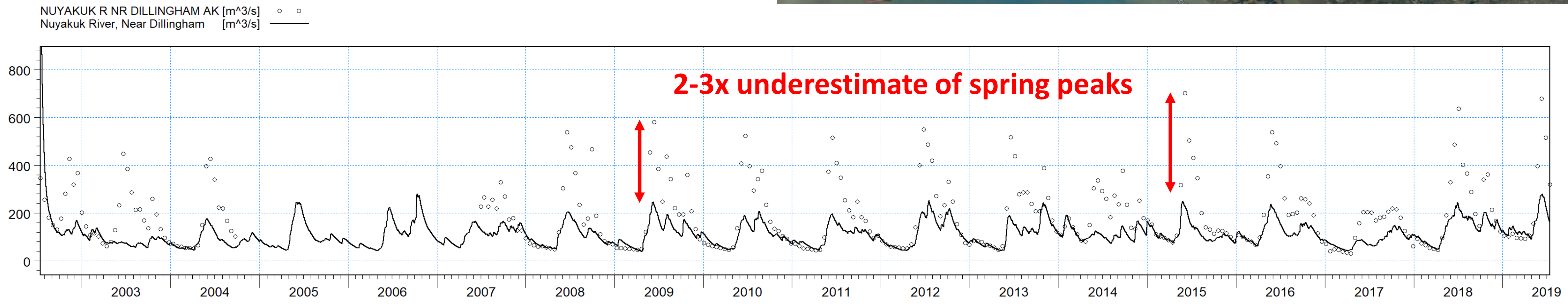
Nushagak Electric & Telephone Cooperative, Inc.
P.O. Box 350
Dillingham, AK 99576

March 2022

Model History

- We built a MikeSHE model of the entire Nushagak watershed in 2021
- This large-scale model underestimated peak runoff in the Nuyakuk
- Underscored need for refinements to Nuyakuk sub-model domain





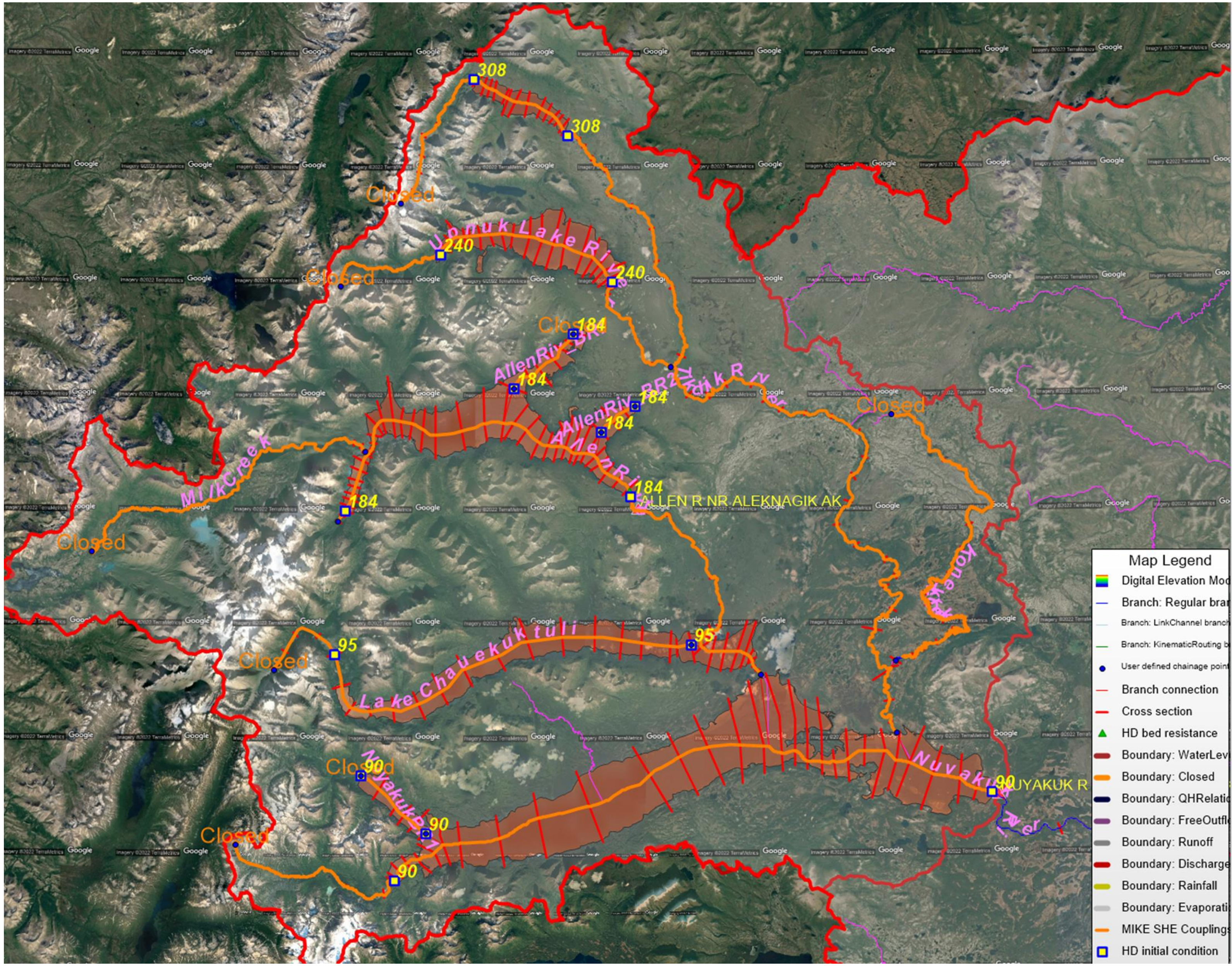
ME=76.7694 MAE=86.8419 RMSE=135.098
STDres=111.166 R(Correlation)=0.603268 R2(Nash_Sutcliffe)=0.0374732

Model Development

- The full Nushagak watershed is ~13,000 mi^2 – larger than the state of Massachusetts.
- We refined our Nushagak model to develop a more detailed model of the Nuyakuk sub-watershed (~1,500 mi^2)
- We focused on the following parameters to improve calibration at the Nuyakuk stream gage
  - Precipitation lapse rates
  - Spatial resolution/detail of drainage network
  - Distributed surface water storage parameters
  - Subsurface hydraulic parameters
  - River-aquifer exchange parameters

Surface Water Hydraulic Network

- Refined lake extent and bathymetry
- Improved definition of wetland areas
- These changes significantly improved numerical simulation

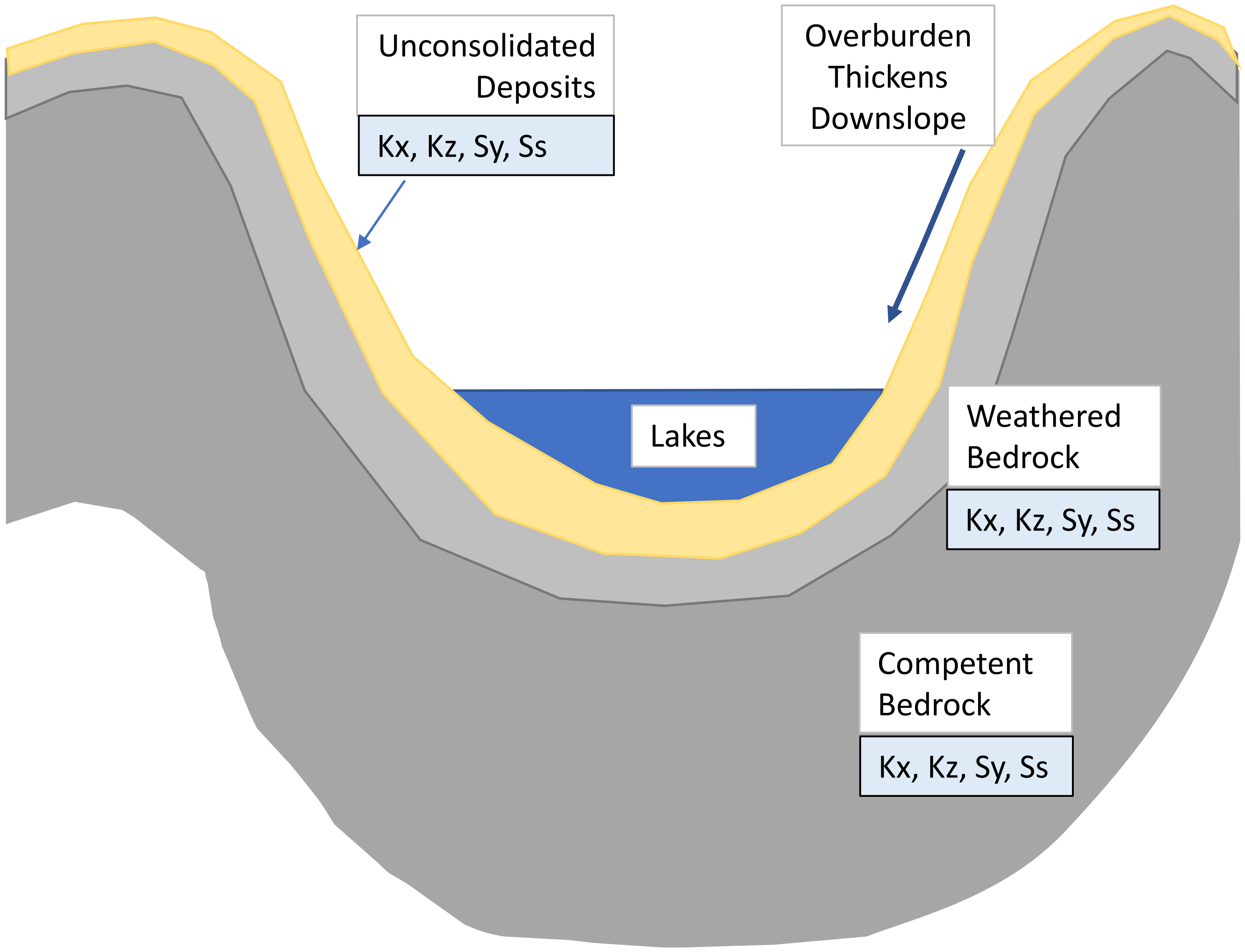


Model Calibration

- First calibrated sub-model area above Allen River @Aleknagik gage
- Assessed discharge sensitivity to a range of parameters
- Calibrated Full Nuyakuk model against discharge:
  - Allen River –Aleknagik gage
  - Nuyakuk River gage
- Also calibrated qualitatively against:
  - Seasonal ponding – USGS Dynamic Surface Water Extent data
  - Seasonal groundwater depths – Aerial imagery
  - Actual Evapotranspiration (EEFLUX-Metric)
  - Snow Cover Extent - MODIS

Calibration Parameters

Hydrologic Process	Parameter	Constraints
Surface Resistance	Manning's N	Distributed based on Land Cover Types
Overland Ponding	DetStor	Distributed based on ponded extents.
Saturated GW Flow	Hydraulic Conductivity	Distributed based on surficial geology
	Storage Term (Ss)	Uniform, adjusted
	Stream-Aquifer Leakage	Varies with Kh. Reduced beneath lakes
	Overburden thickness	Distributed based on topography, lake extent
Unsaturated GW Flow	Hydraulic Conductivity (Kx, Kz)	Distributed based on SSURGO survey
	Saturation Points	Distributed as above
Precipitation	ERA5 Station Elevations	Adjusted to match calibration
Precipitation	Lapse rate	Uniform value - increased.

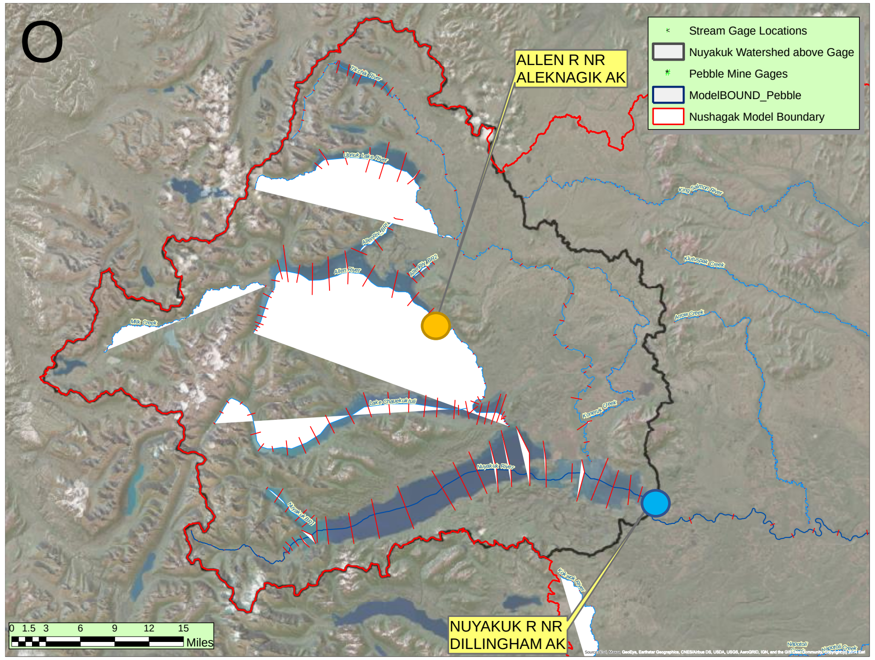


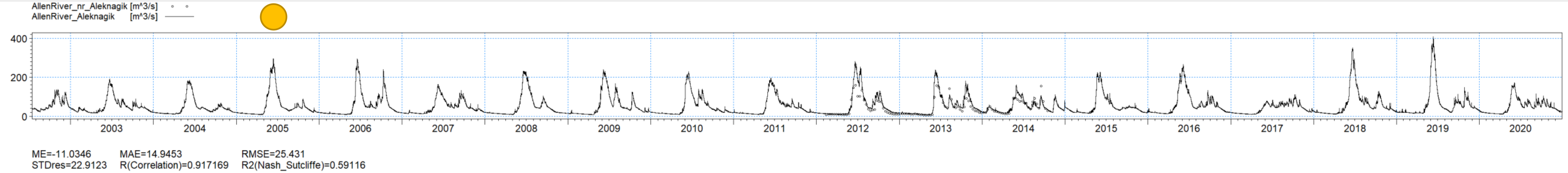
Re-calibrated Discharge Response

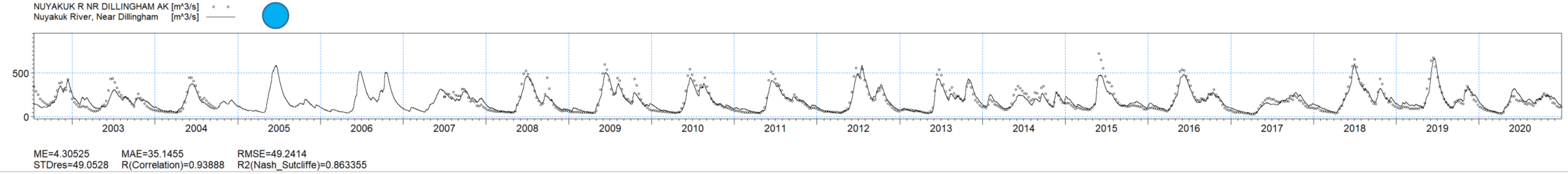
Calibration significantly improved

- Nuyakuk gage → ~94% Correlation
- Aleknagik gage → ~92 % Correlation

Peak Flows, Seasonal Volumes and Ascension/Recession Curves reproduced well.

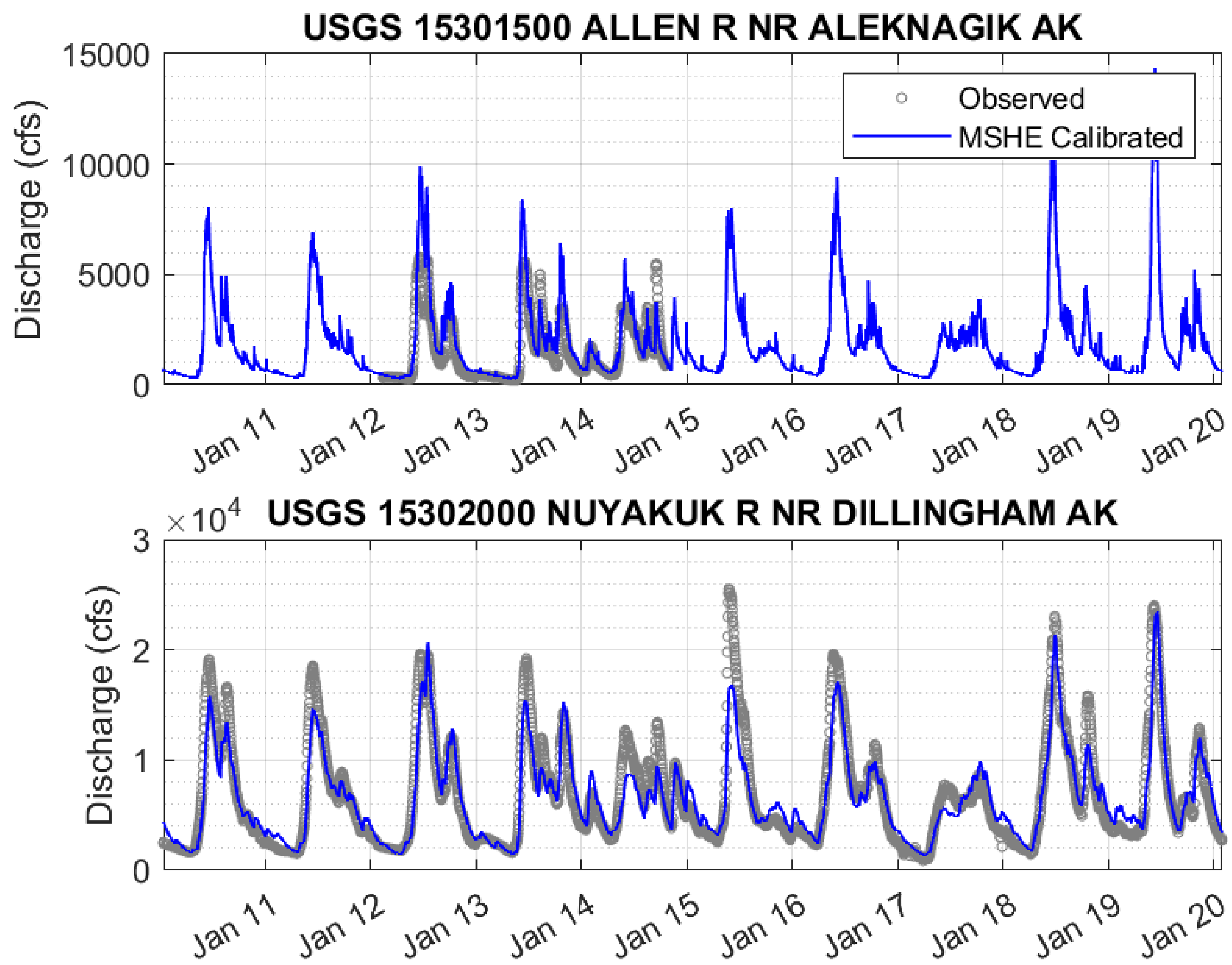






Discharge Response - Detail

- Baseflow replicated well at both USGS gage sites
- Peak flow timing matched for both spring and fall peaks
- Peak flow magnitudes matched well across multiple seasons of varying precipitation

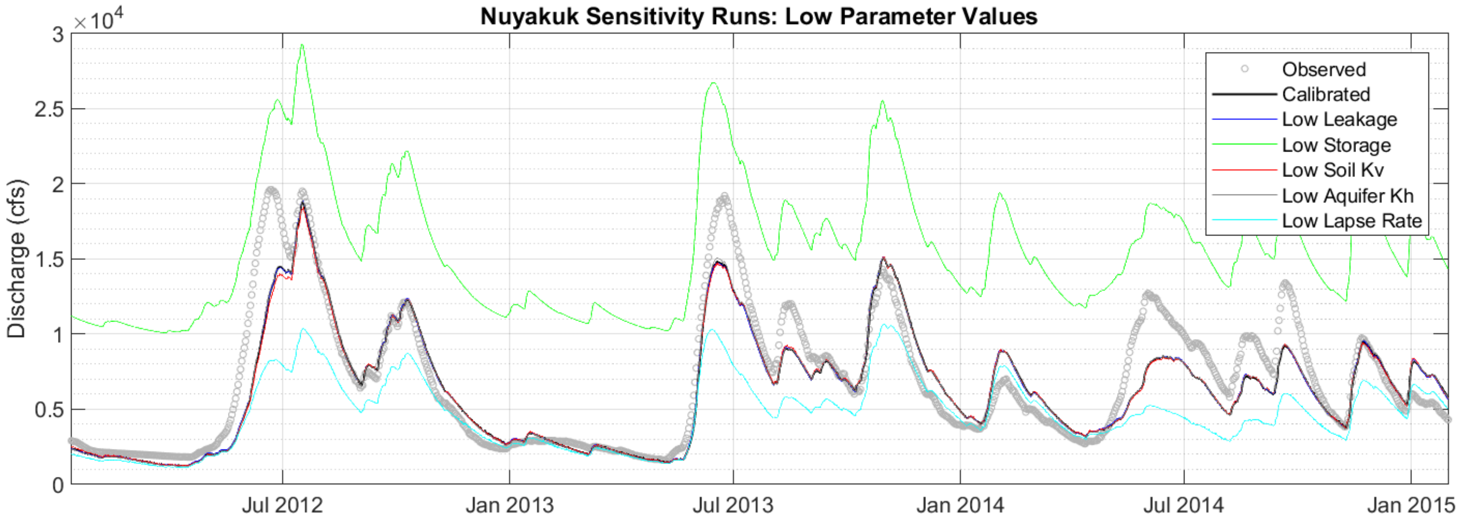


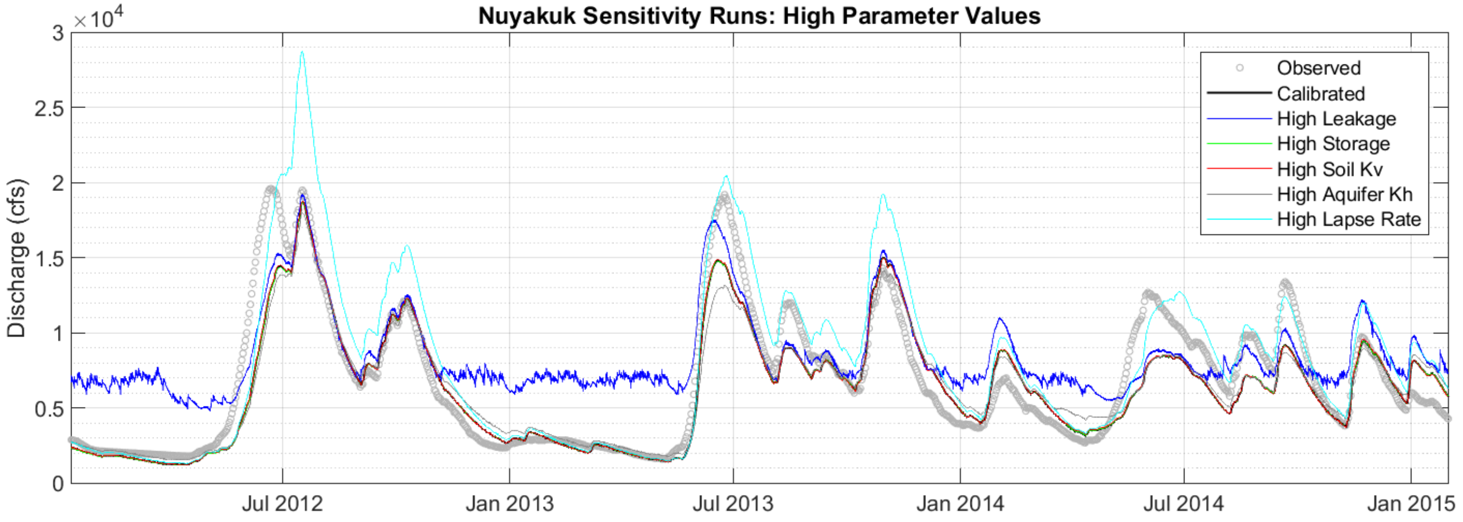
Sensitivity Runs - Summary

Sensitivity Run	Parameter Change	SENS name	Sens change	Allen River nr Aleknagik Gage	Nuyakuk River Gage	Allen River nr Aleknagik Gage2	Nuyakuk River Gage3	Column4
				MeanError	MeanError	R-Corr	R-Corr	Assumptions
		Baseline		-8.4	27.6	0.913	0.899	
Sens1	Riverbed Leakage	lowleak	1/10	-8.39	27.98	0.913	0.897	Only Lake Areas changed
Sens2	Riverbed Leakage	highleak	10x	-8.4	-36.2	0.912	0.85	Only Lake Areas changed
Sens3	Surface Water Storage	lowDETSTOR	1/2x baseline	-8.97	-229.9	0.914	0.861	Baseline has variable detention storage
Sens4	Surface Water Storage	highDETSTOR	2x baseline	-8.32	27.98	0.913	0.897	Baseline has variable detention storage
Sens5	Soil Kv	HighSoilKv	10x	-8.4	-36.2	0.912	0.851	Baseline has single soil type
Sens6	Soil Kv	LowSoilKv	1/10	-8.38	27.66	0.915	0.898	Baseline has single soil type
Sens7	SoilProp	Variable	SSURGO	-8.07	27.598	0.911	0.894	Baseline has single soil type
Sens8	Aquifer Kh	HighKh_L1	10x	-8.53	23.5	0.91	0.879	Baseline has variable K values
Sens9	Aquifer Kh	LowKh_L1	1/10	-8.37	27.74	0.913	0.9	Baseline has variable K values
Sens10	Aquifer Kv	HighKv_L1	10x	-9.7	20	0.89	0.86	Baseline has variable K values
Sens11	Aquifer Kv	LowKv_L1	1/10	-9.25	25.7	0.915	0.9	Baseline has variable K values
Sens12	Aquifer K	UniformKh Kv	Kh = Kv	-8.3	27.8	0.91	0.9	Variable K values
Sens13	PrcpLapse	High	25 %/100 m	-26.8	-16.7	0.91	0.9	Baseline is 17% /100m
Sens14	PrcpLapse	Low	5 %/100 m	9.96	71	0.87	0.85	Baseline is 17% /100m
Sens15	Bedrock	None		-8.5	27	0.92	0.9	Lower 2 layers inactive. Baseline has 3 layers.
Sens16	AlluvThick	Alluv_3m	3m thick	-8.5	27.5	0.92	0.9	Baseline is variable (TWI ver2)

Sensitivity Results

- Nuyakuk flow is relatively **sensitive** to:
  - Stream-aquifer leakage
  - Detention storage
  - Precipitation lapse rate
- Nuyakuk flow is relatively **less sensitive** to:
  - Soil hydraulic properties
  - Aquifer hydraulic properties



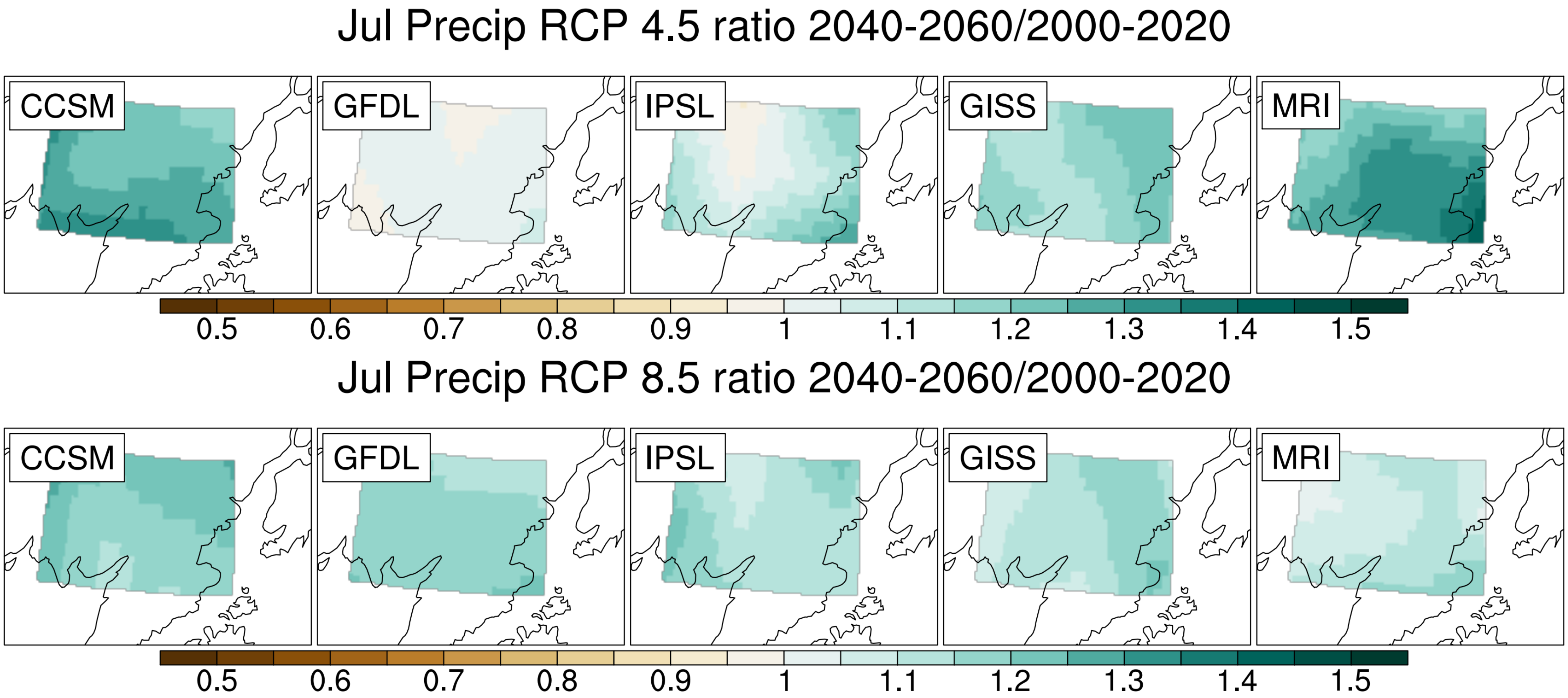


Climate Change Methods

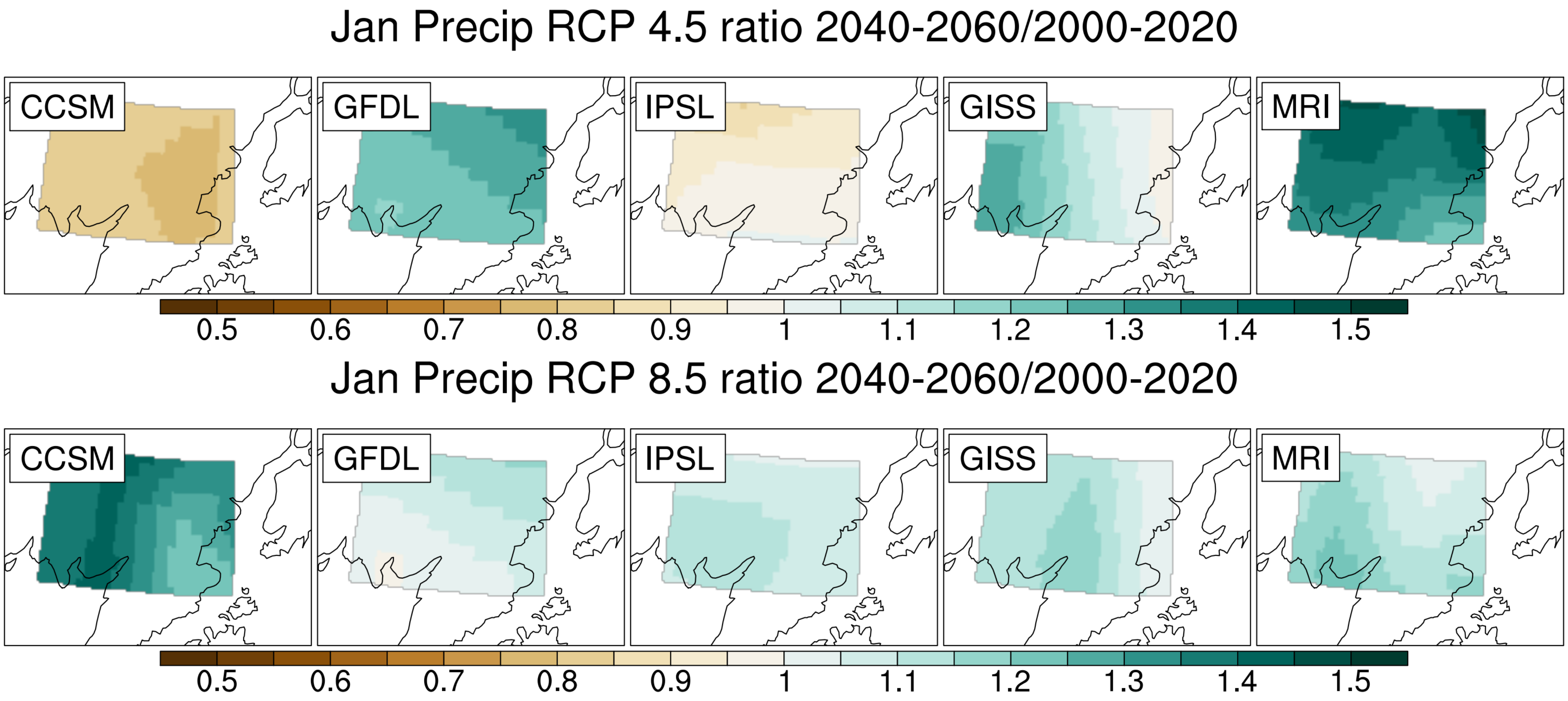
- Delta method: Applied GCM-derived change factors to baseline ERA5 climate data
- Extracted monthly data for mid-century (2040-2060) and compared to baseline (2000-2020) to calculate GCM change factors
- Used five global climate models (GCMs) selected by Scenarios Network for Alaska + Arctic Planning (SNAP) program to represent Alaska climate:
    - CCSM, GFDL, IPSL, GISS, MRI
- Applied two greenhouse gas trajectories (RCP4.5 and RCP8.5) to bracket future impacts

Scenarios Network
FOR ALASKA + ARCTIC PLANNING

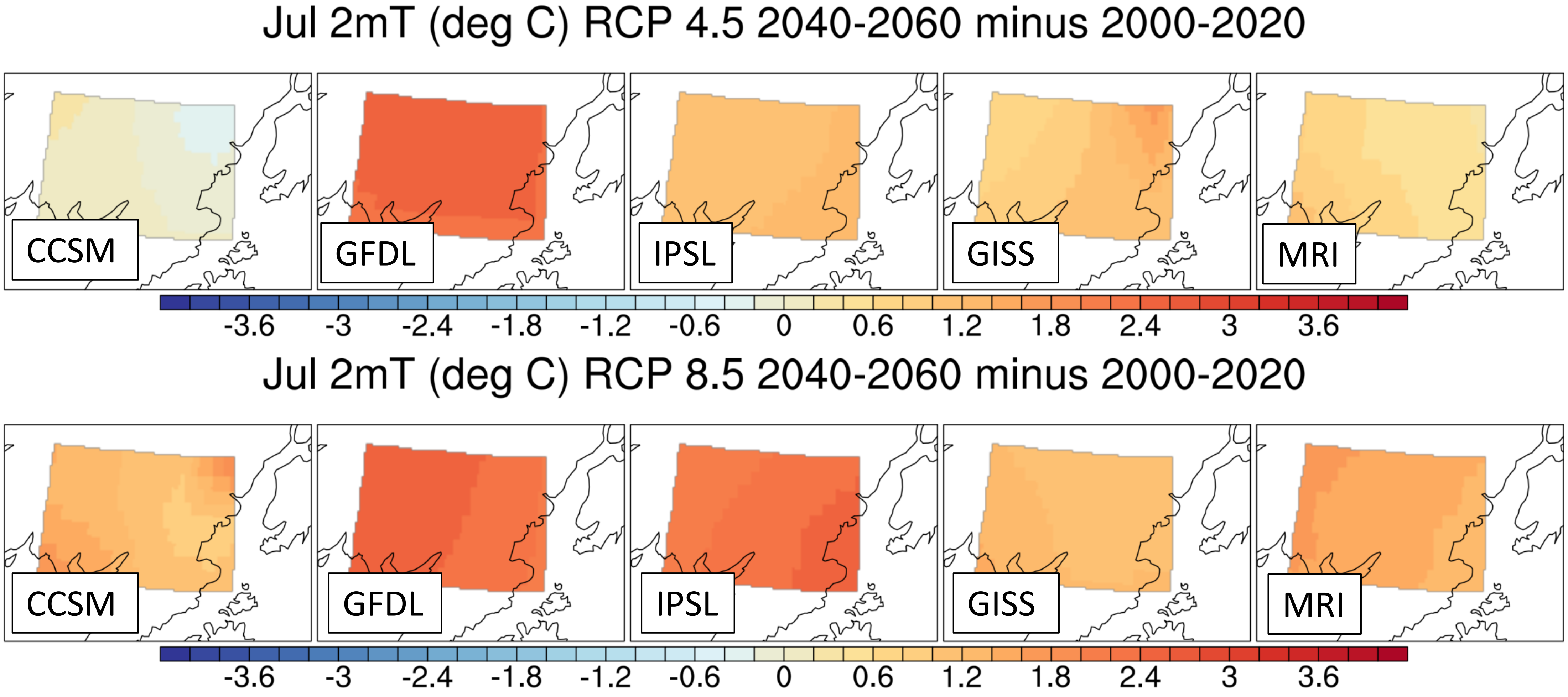
Precipitation Changes: mid-century summer



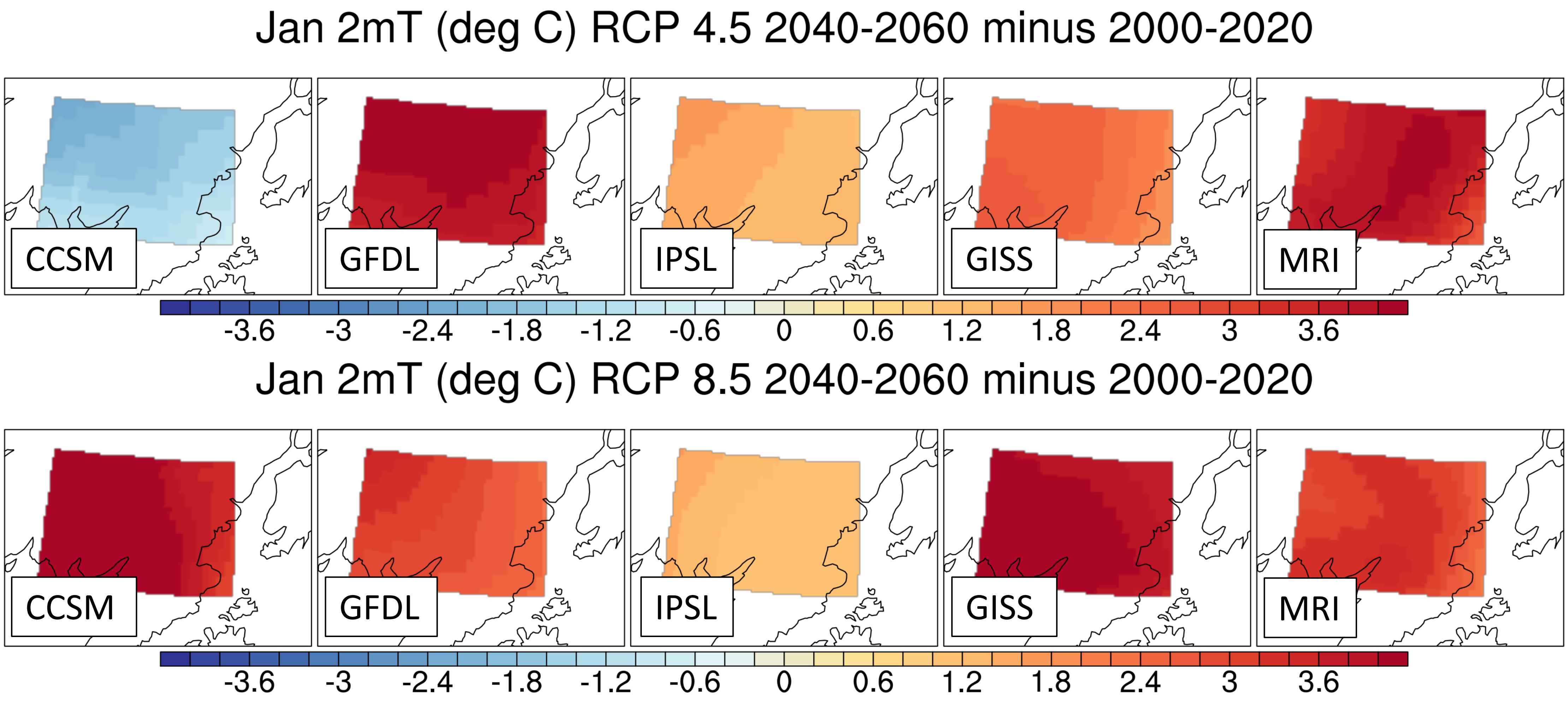
Precipitation Changes: mid-century winter



Temperature Changes: mid-century summer



Temperature Changes: mid-century winter

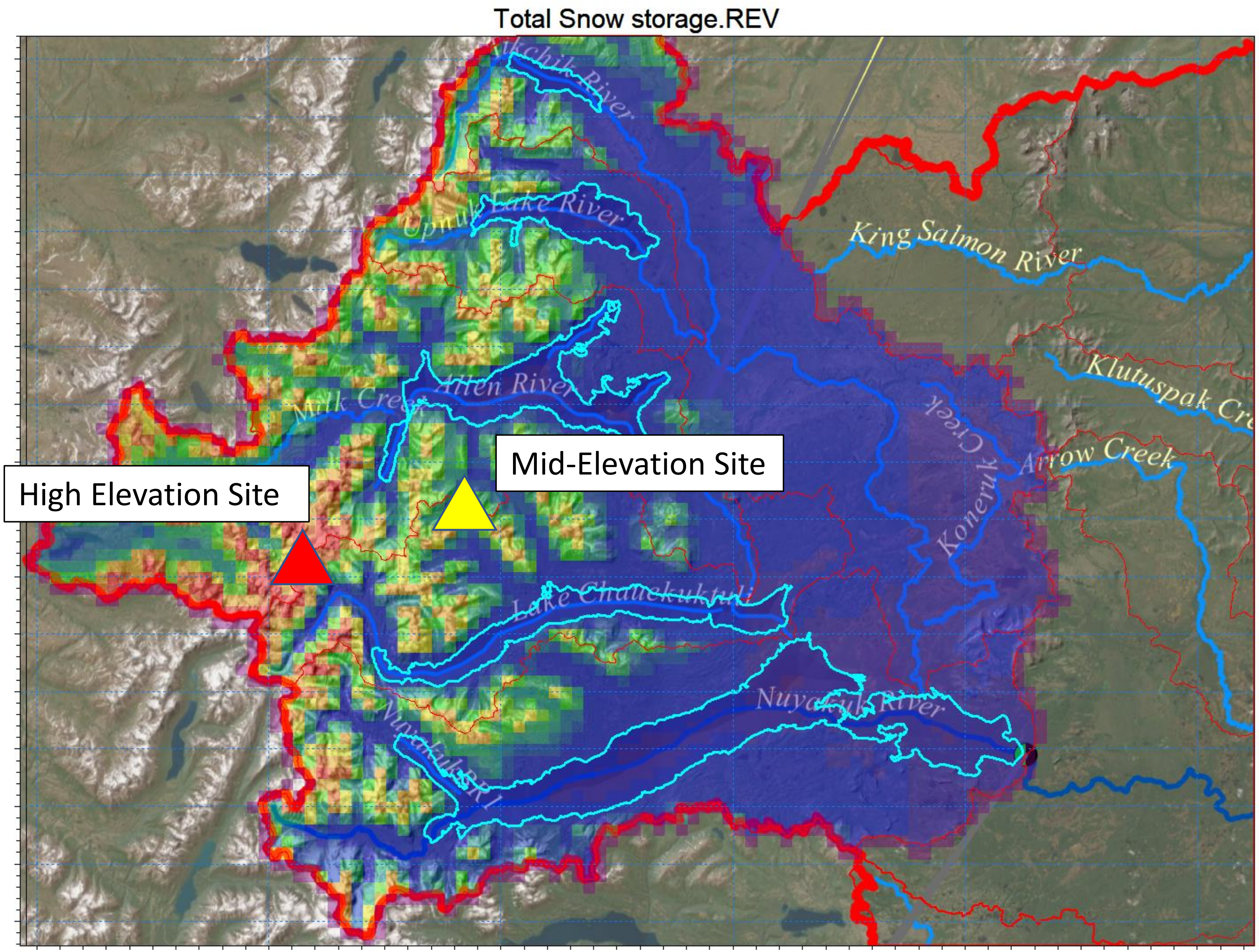


Climate Change Summary 2040-2060 vs 2000-2020

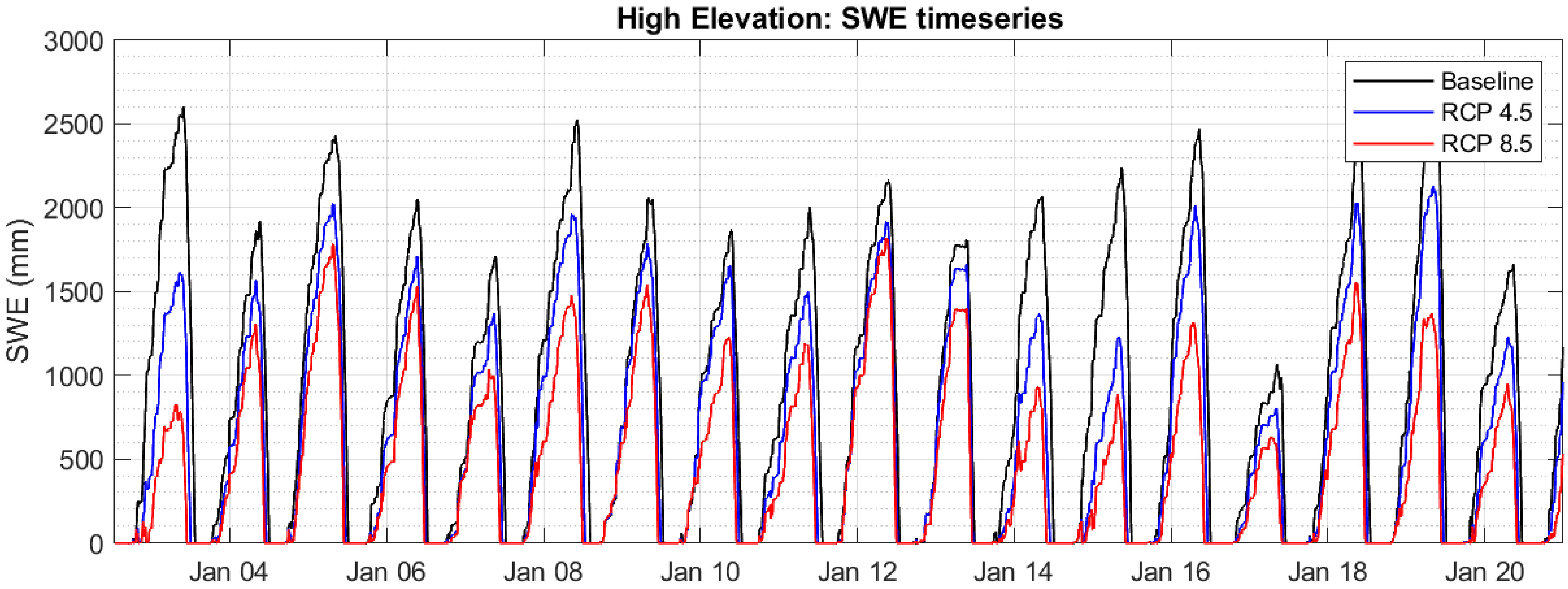
- Significantly warmer temperatures
  - RCP 4.5: 1°C (~2°F) warmer in summer, 2°C (~4°F) warmer in winter
  - RCP 8.5: 1.7°C (~3°F) warmer in summer, 3°C (~6°F) warmer in winter
  - CCSM is an outlier in all seasons under RCP 4.5
- Slightly higher precipitation
  - RCP 4.5: 5% increase in summer, 10% increase in winter
  - RCP 8.5: 15% increase in summer, 15% increase in winter

Snowpack

- Seasonal changes in snow water equivalent (SWE)
- Changes vary by elevation

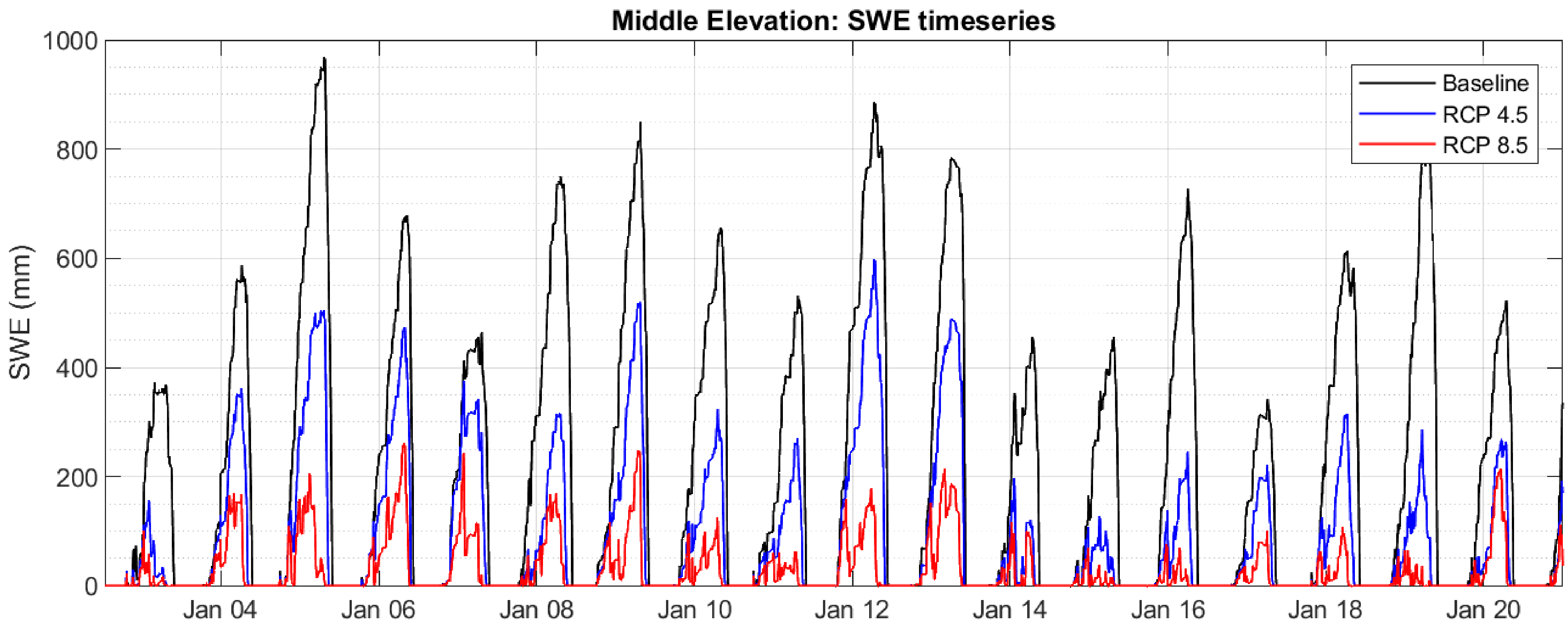


Climate Change Results – High Elevation Snow



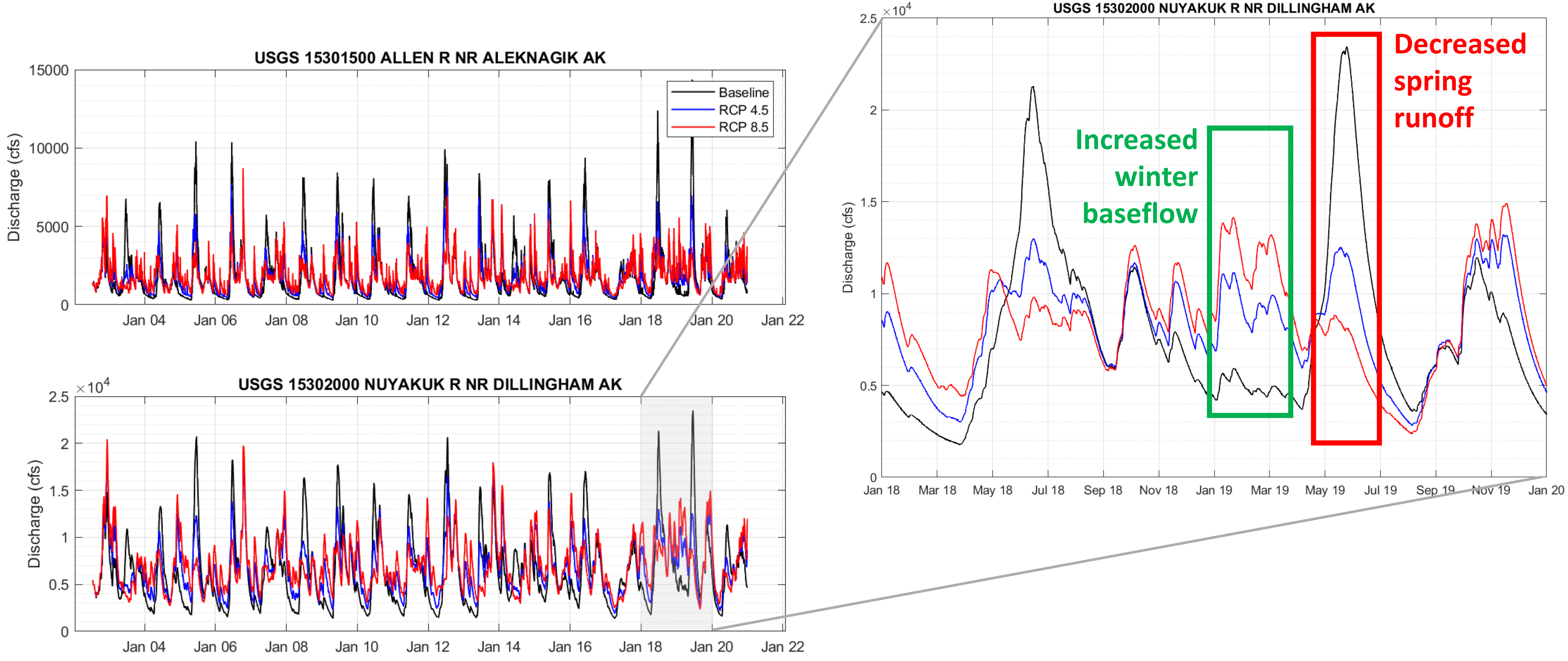
- Both RCP scenarios REDUCE snowpack (SWE).
- Lower elevation SWE is affected more than higher elevation SWE

Climate Change Results – Mid-Elevation Snow



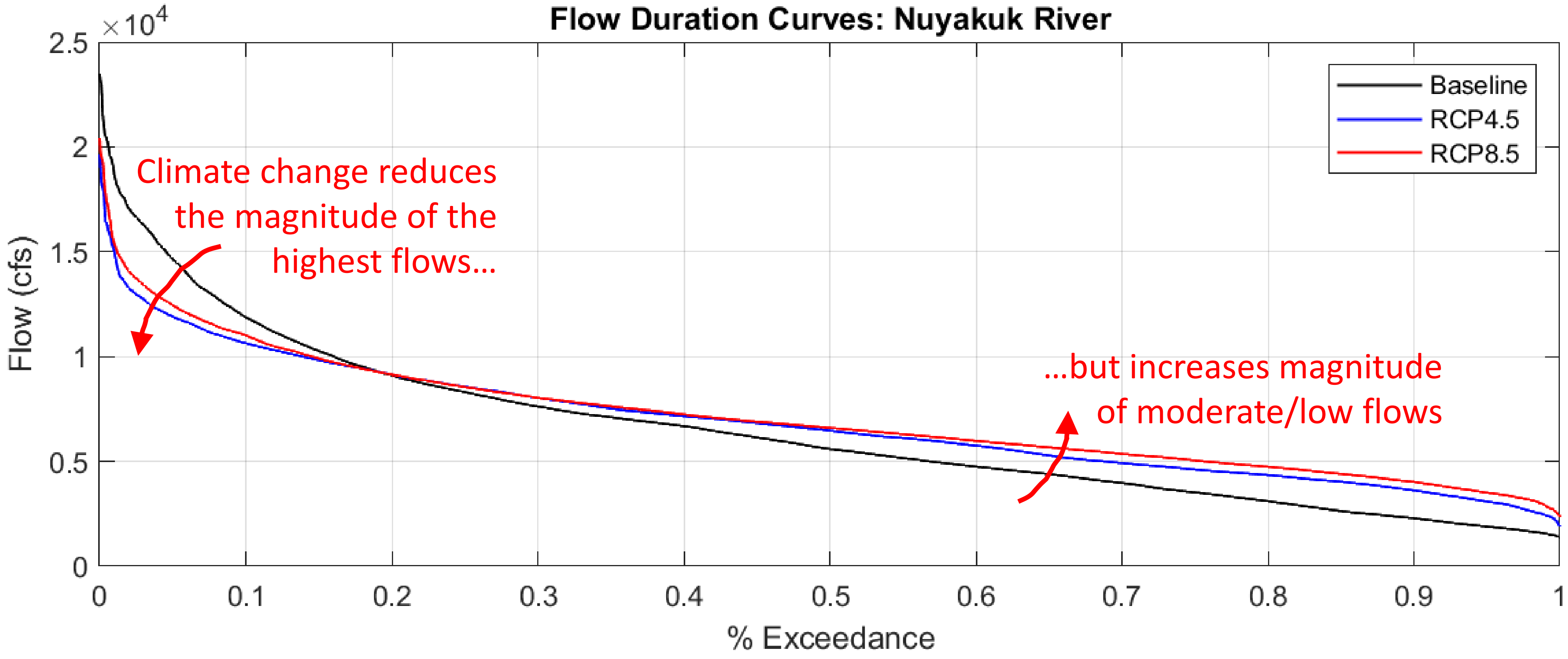
- Both RCP scenarios REDUCE snowpack (SWE).
- Lower elevation SWE is affected more than higher elevation SWE

Climate Change Results - Discharge



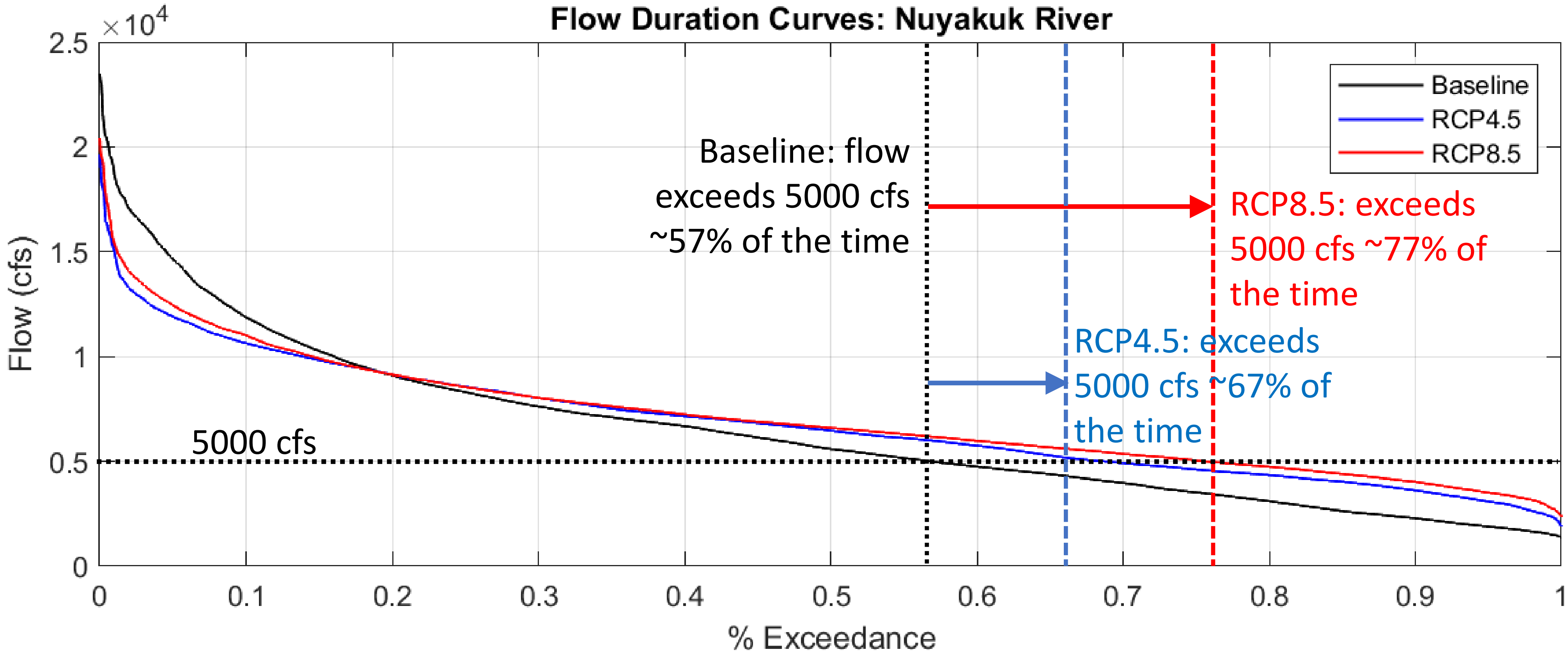
Climate Change Results – Flow duration curves

- Flow duration curves illustrate how often flows of certain magnitudes are exceeded.



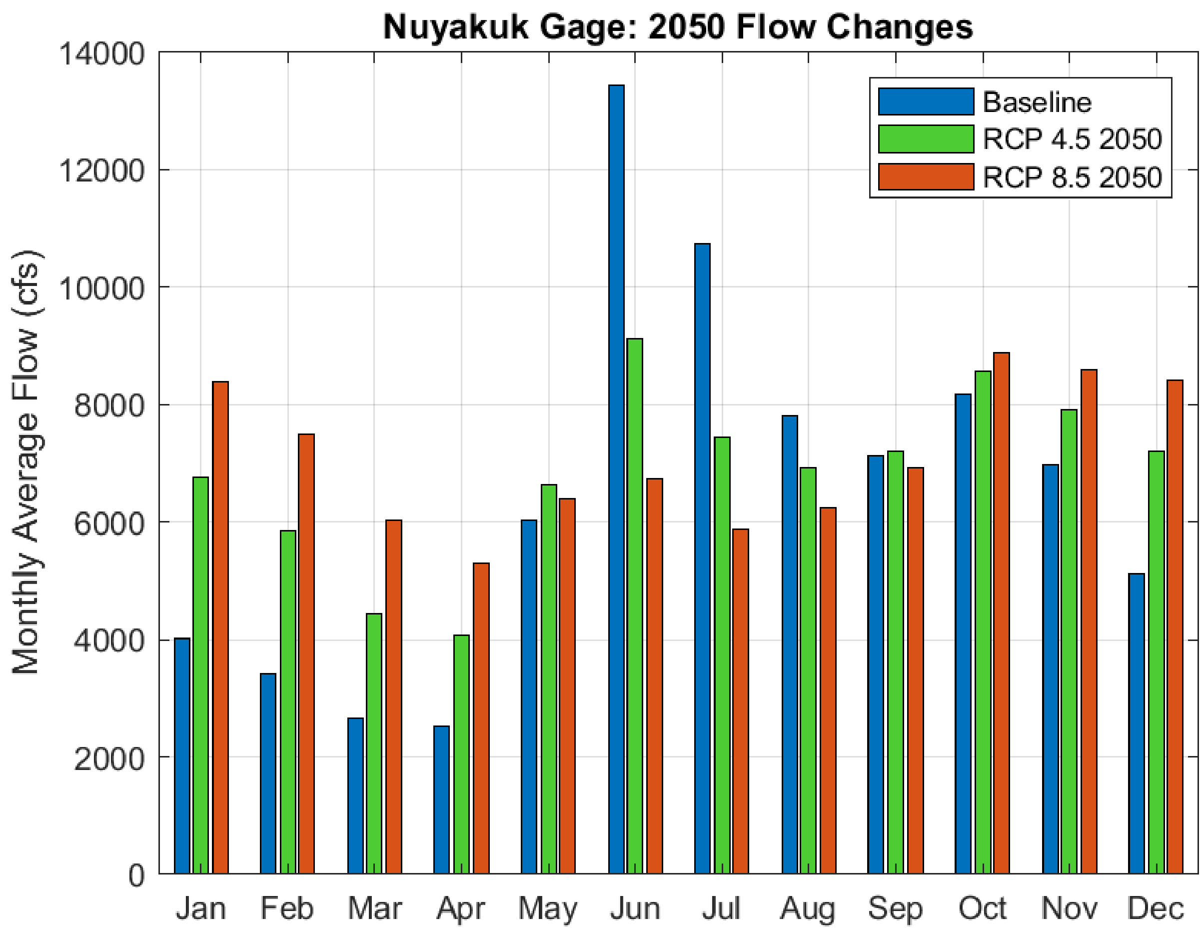
Implications for hydropower resource (1)

- Need a minimum flow to turn turbines: hydrograph changes could affect the fraction of time power can be generated
  - **Example** below: Change in frequency of flows >5000cfs



Implications for hydropower resource (2)

- Average monthly flows decrease substantially in June-July
- Average monthly flows increase substantially in December-March
- These changes should be evaluated in more detail in the context of:
  - Seasonal electricity demand (winter heating vs summer fisheries needs)
  - Salmon migration patterns



Additional Model Capabilities

- Coupled hydro-economic model of hydropower facility
- Habitat suitability modeling
  - Environmental flows
  - Stream depth, velocity
  - Stream temperature
- Climate change impacts to entire Nushagak system
- Other development impacts to full Nushagak system