Current and future projections of glacier contribution to streamflow in the upper Athabasca River Basin

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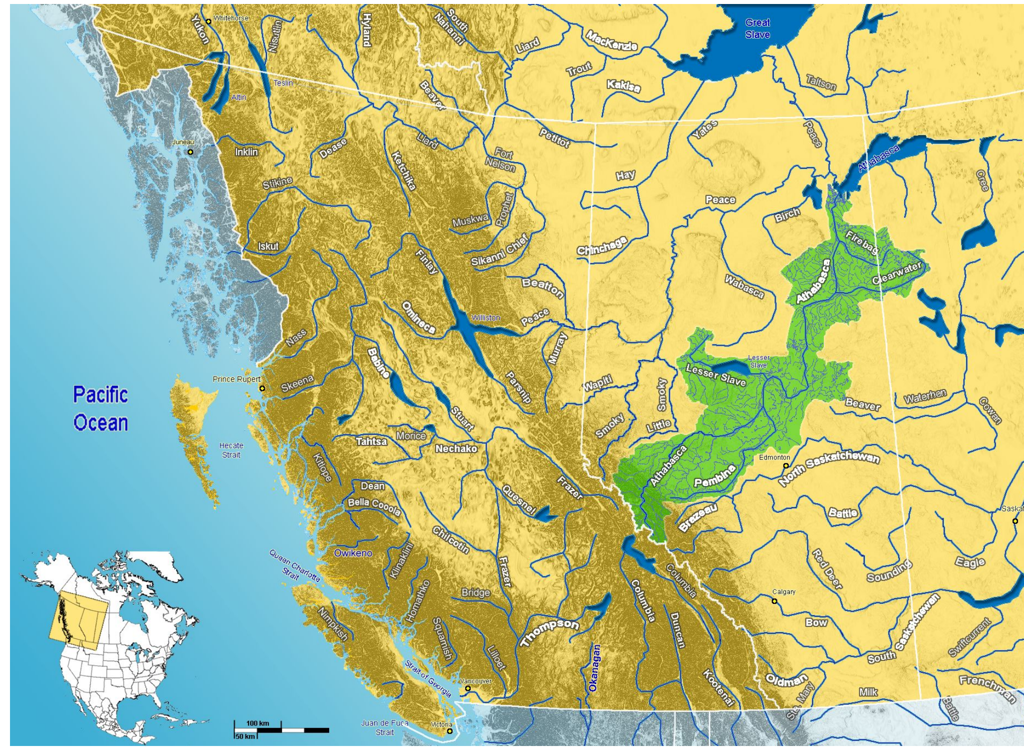
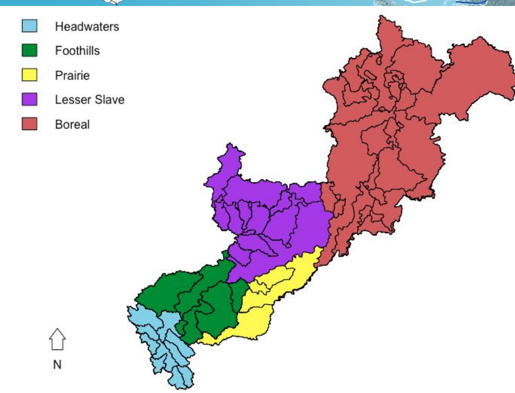
Athabasca River Basin

- Drains ~168,000 km^2
- Flows ~1,250 km from the Columbia Icefield (Jasper National Park) to Lake Athabasca
- One of the longest free-flowing (undammed) rivers in the world
- Contains a variety of land use:
  - Jasper NP, Peace-Athabasca Delta UNESCO World Heritage Site
  - Heavily forested foothills
  - Agricultural plains
  - Boreal forest
  - Oil and Gas
- Entire basin modelled as part of the Athabasca River Basin Initiative

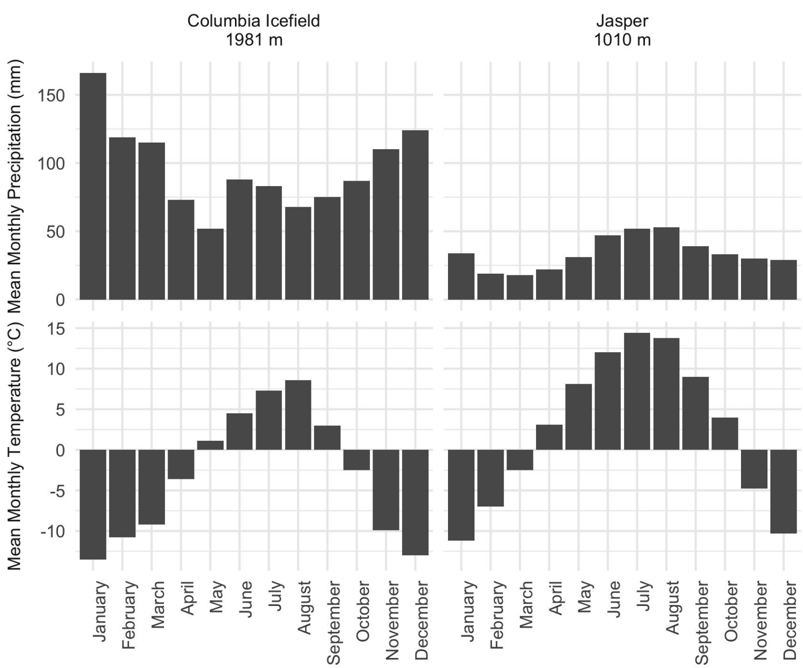


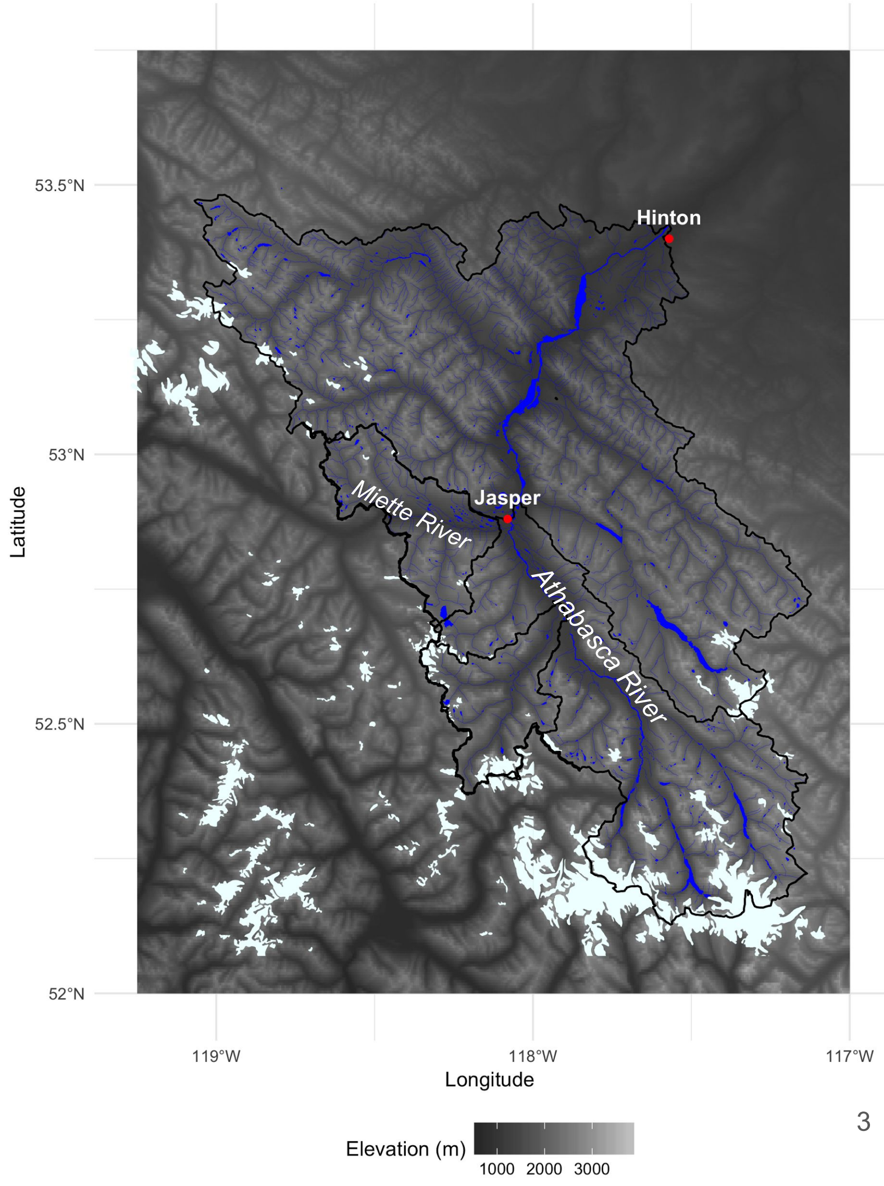
Wikipedia Commons



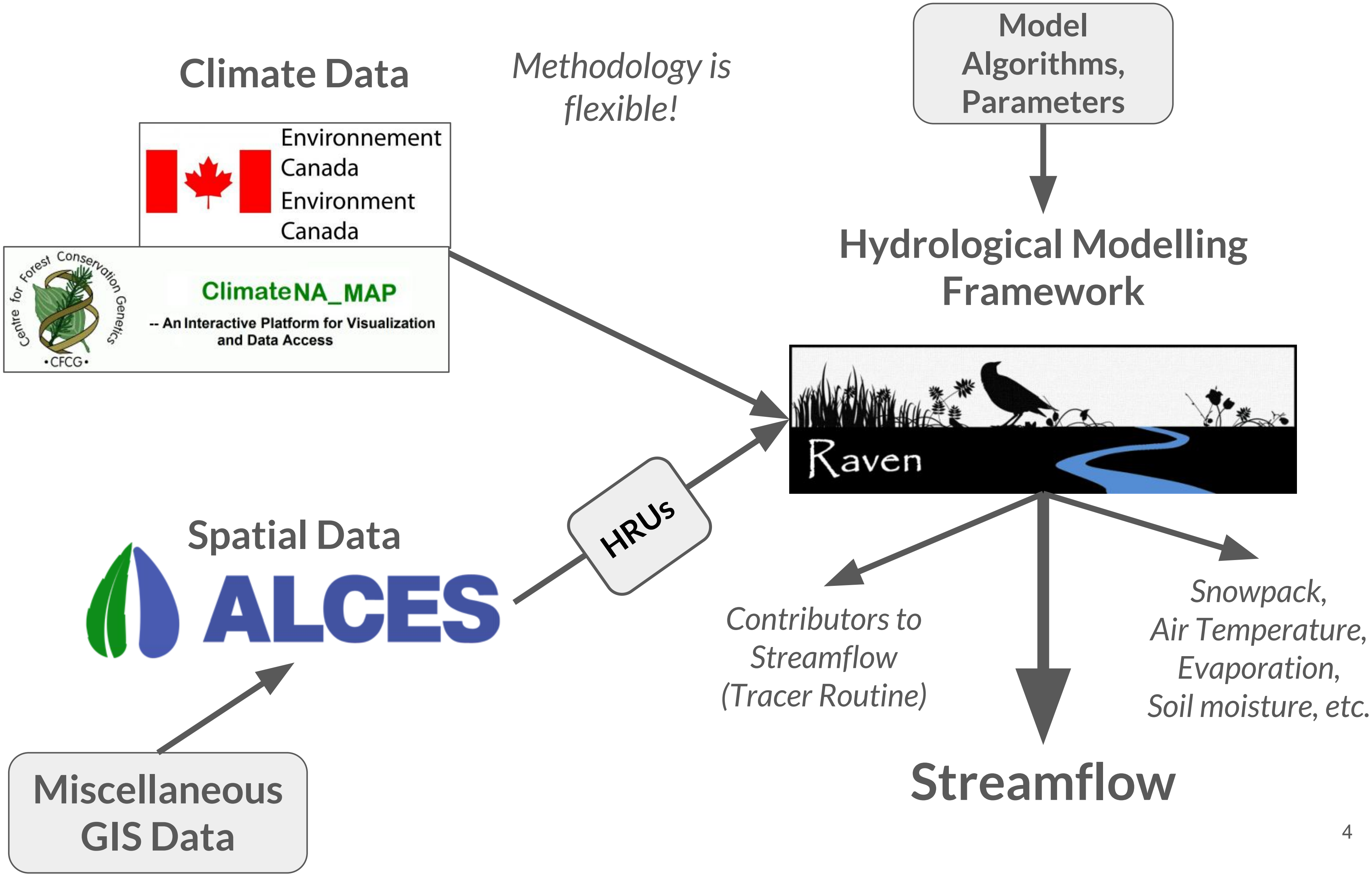
Athabasca River Headwaters

- Upstream of Hinton, AB (9,720 km^2)
- Primarily forest and alpine cover
- Glaciation primarily along southwest margins of watershed; currently covers
    - 2.8% of area upstream of Hinton,
    - 5.8% of area upstream of Jasper

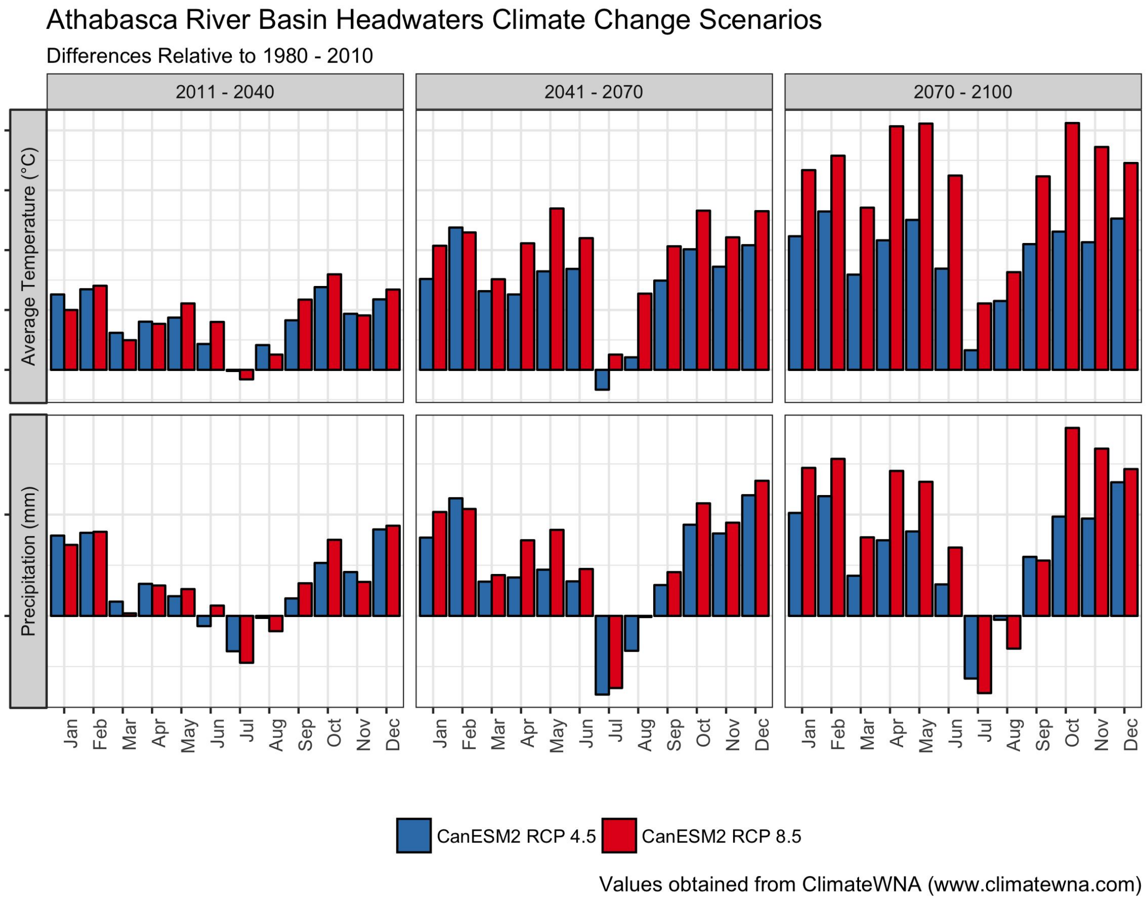




Modelling Methods



Climate Change Projections



- CanESM2 RCP 4.5 and RCP 8.5 Scenarios from ClimateWNA
  - Three thirty year periods
- Observed records scaled against differences between scenario and 1980 - 2010 normals

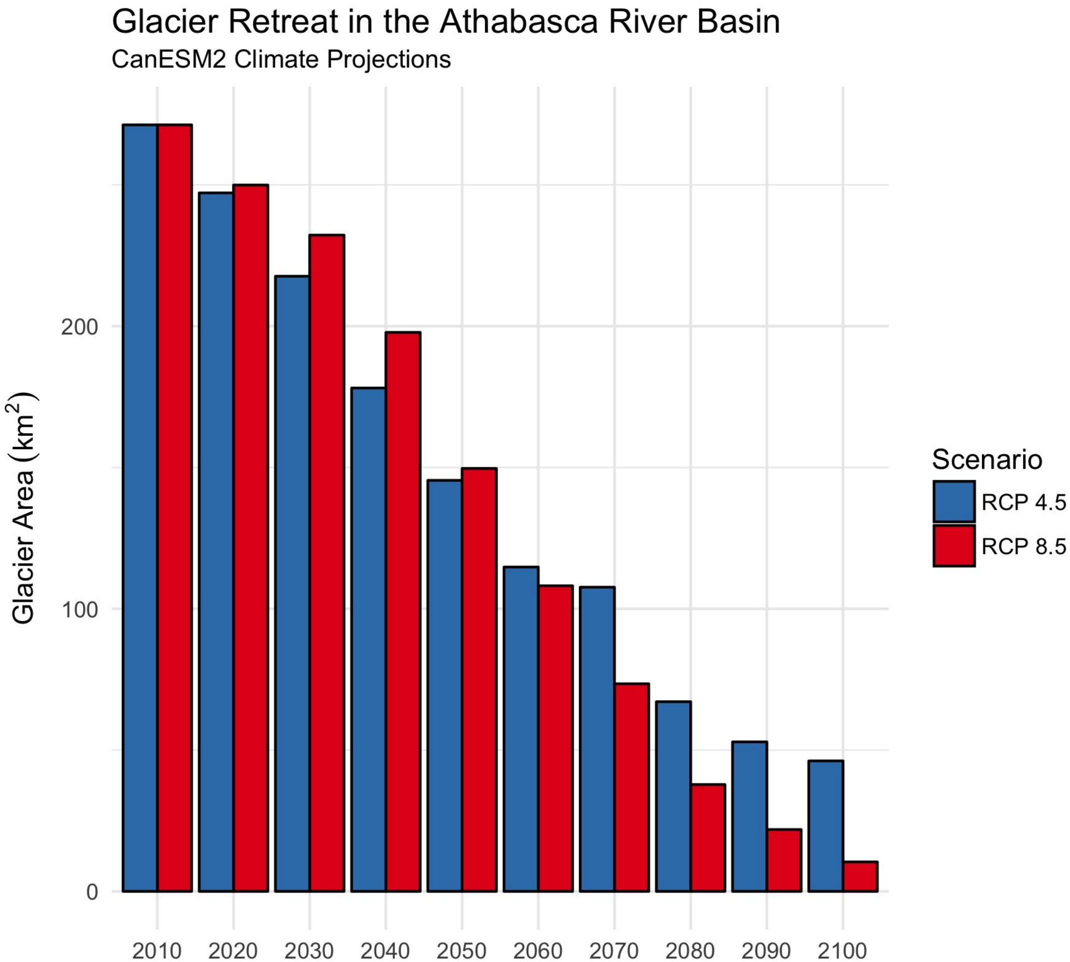
Warmer air temperatures, more precipitation

Climate Change Projections (cont.)

Glacier Area

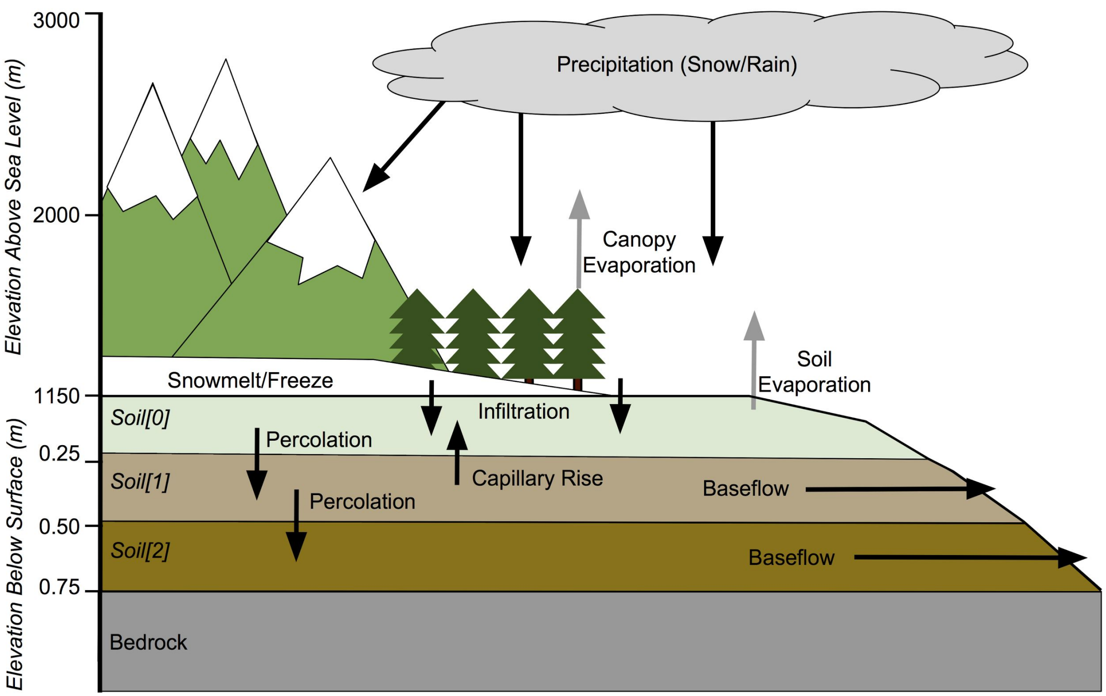
- CanESM2 RCP 4.5 and RCP 8.5 Scenarios
- Implemented decadal changes from 2010 - 2100 into Raven

ARB projected to lose half glacier coverage by ~2060



Data are obtained from Clarke, G. K., Jarosch, A. H., Anslow, F. S., Radić, V., & Menounos, B. (2015). Projected deglaciation of western Canada in the twenty-first century. Nature Geoscience, 8(5), 372-377.

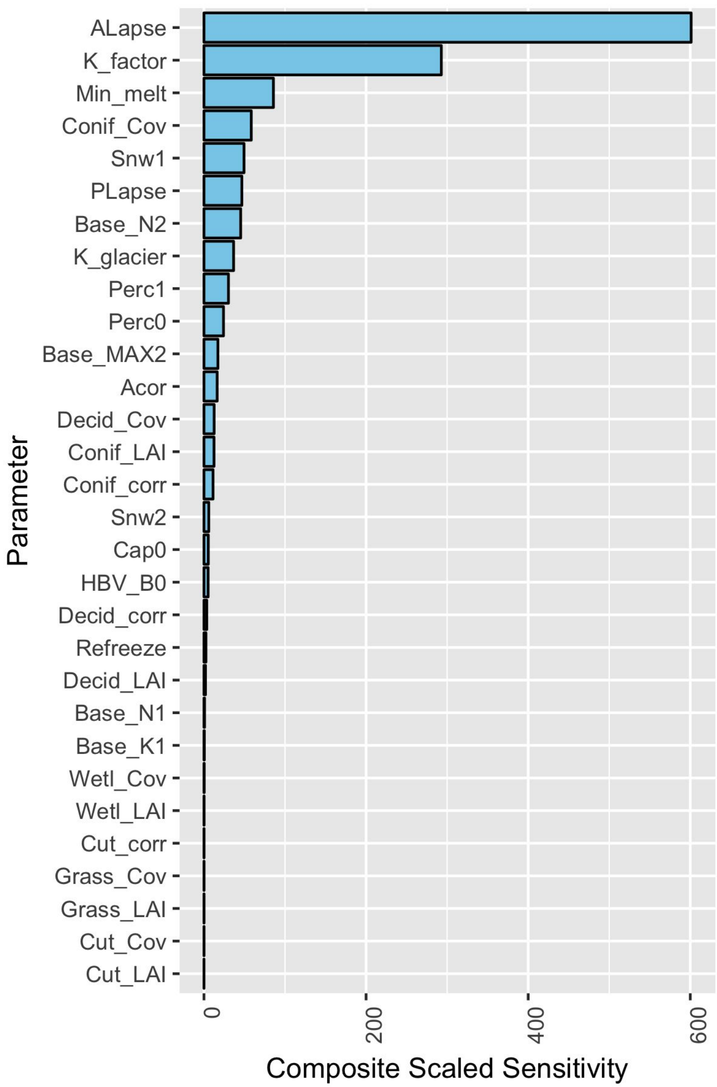
Modified HBV-EC



Emulated in Raven, following the HBV-EC model with a few notable points:

- ***Snow-melt***: spatially corrected Temperature Index Model that varies by day-length and is corrected by land cover type.
- ***Glacier melt***: exposed ice uses scaled melt factor (~x3.5 snow)
- ***Potential Evapotranspiration***: Priestley-Taylor equation
- ***Baseflow:*** (2-reservoir soil) lowest layer uses VIC algorithm

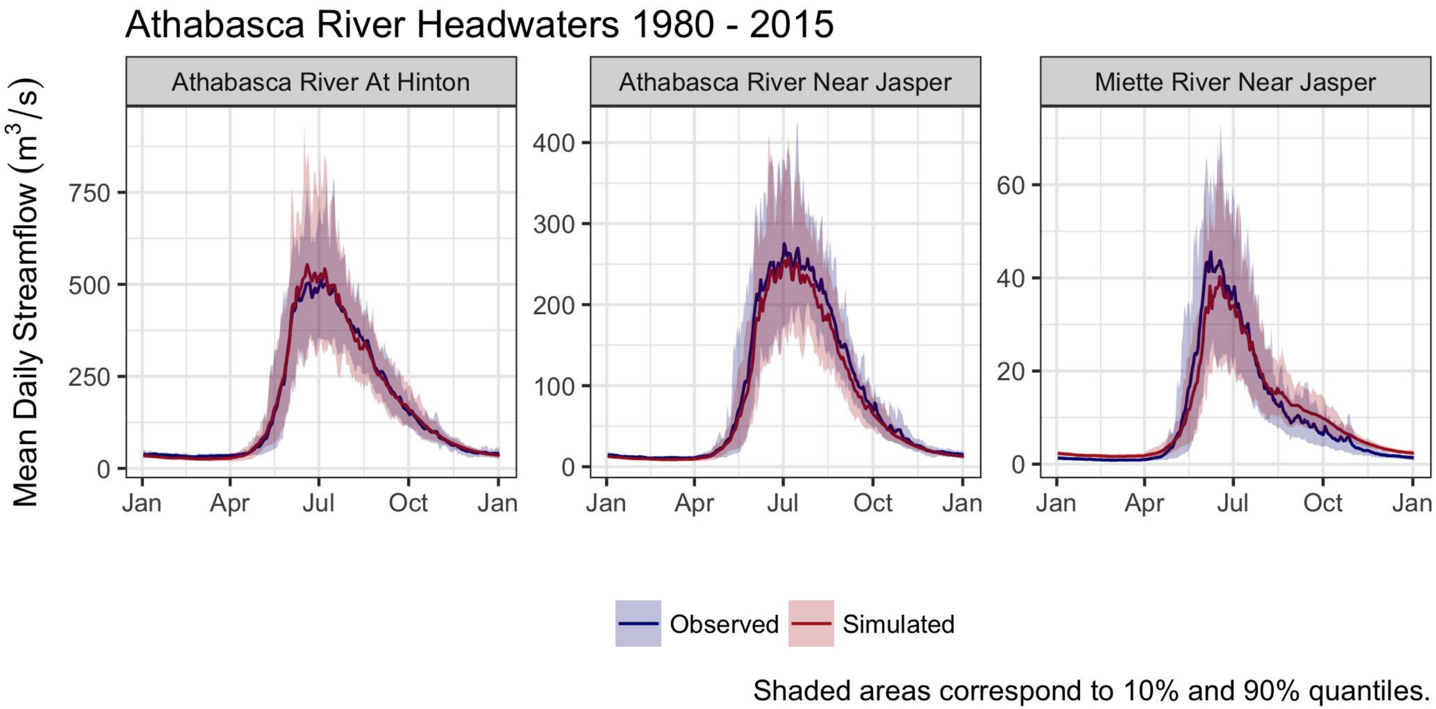
Model Performance



- Temperature/Precipitation Lapse Rates, Snowmelt parameters (and coniferous forest coverage) are most sensitive parameters
- Air Temperature and Snow Water Equivalent are well simulated at independent verification sites

Site	**Network**	**Elevation (m)**	***r^2***		
			T	***P***	***SWE***
Sunwapta	EC, AB_EP	1416	0.87	-	0.63
Marmot Basin	EC, AB_EP	1800	0.93	0.71	0.63
Southesk	AB_EP	2045	-	-	0.82
Yellowhead	EC, BC_RFC	1847	0.89	-	0.92

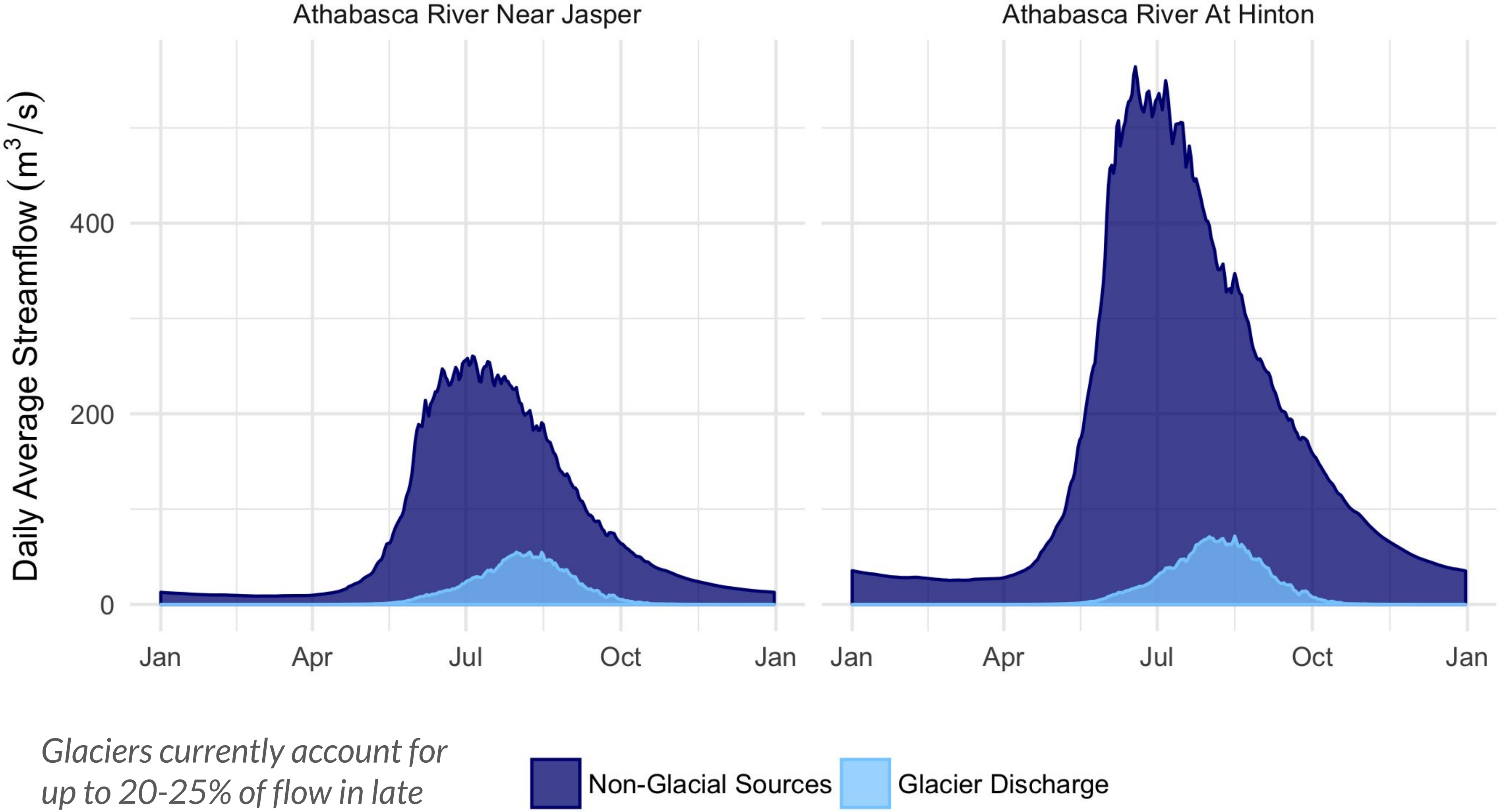
Model Performance



Site	Calibration		Verification	
	NSE	*PBIAS*	*NSE*	*PBIAS*
Athabasca River At Hinton	0.90	1%	0.91	1%
Athabasca River Near Jasper	-	-	0.93	-5%
Miette River Near Jasper	0.87	5%	0.86	2%

Current Glacier Contributions to Streamflow

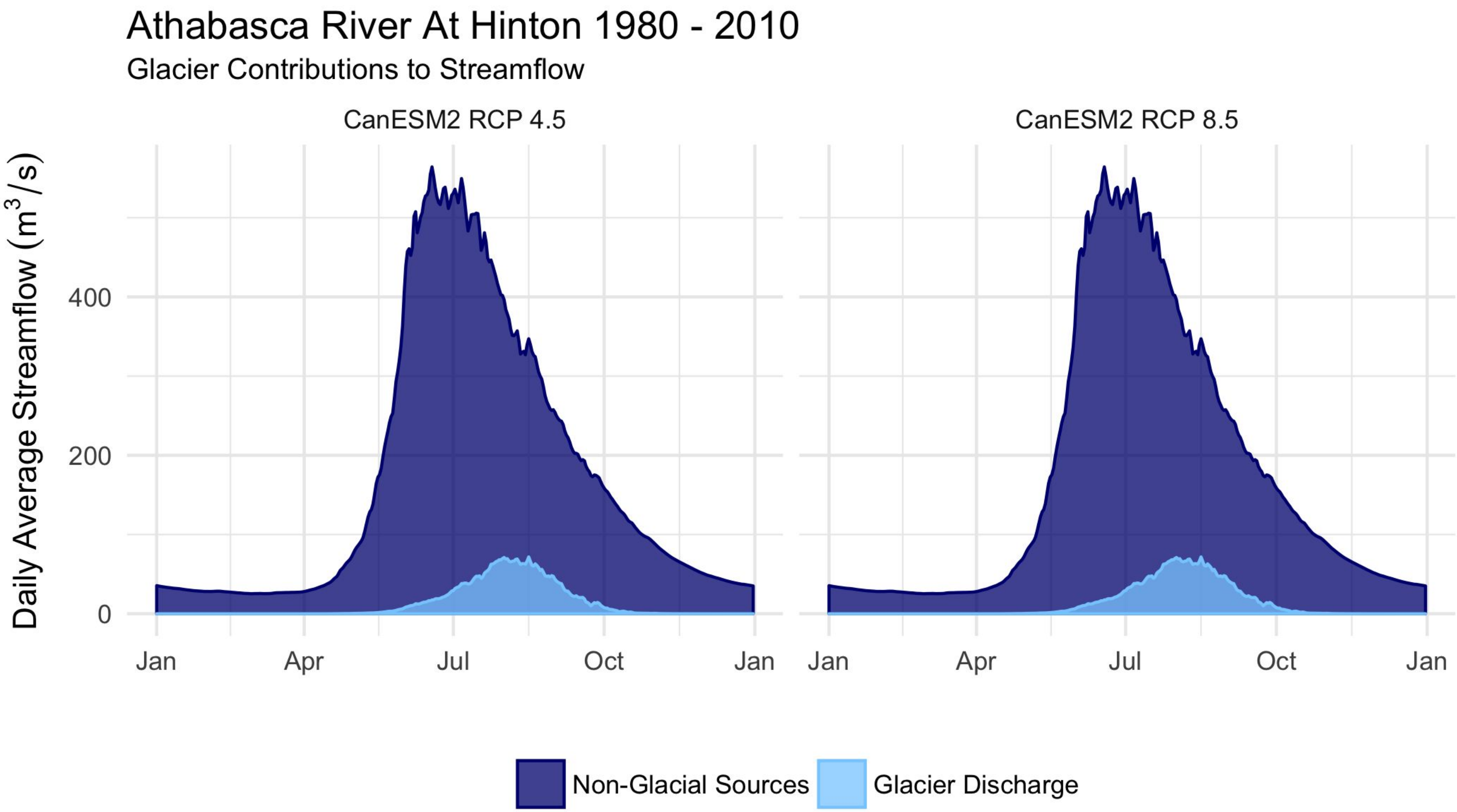
1980 - 2010



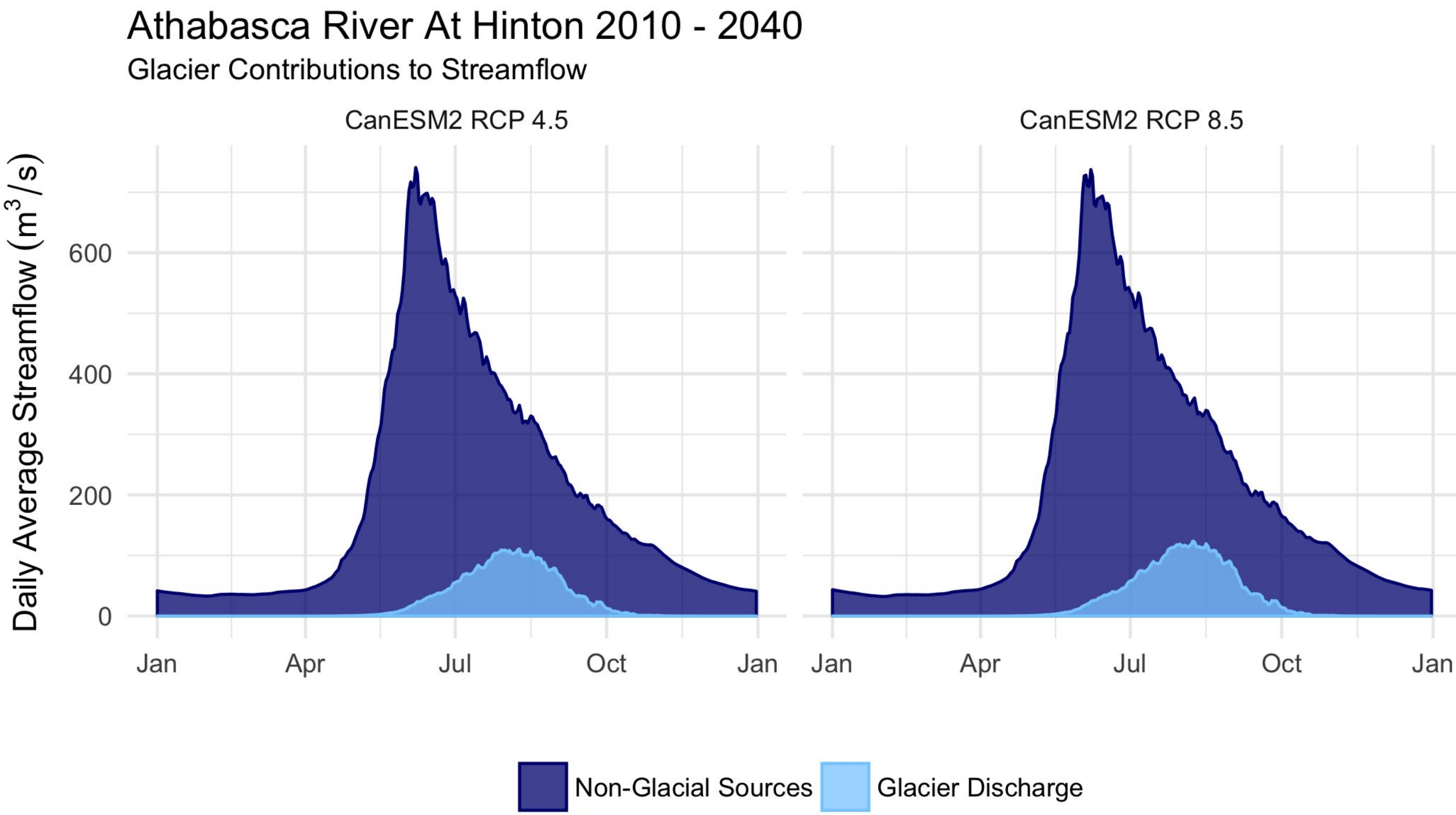
Glaciers currently account for up to 20-25% of flow in late summer

Obtained from Raven tracer routine

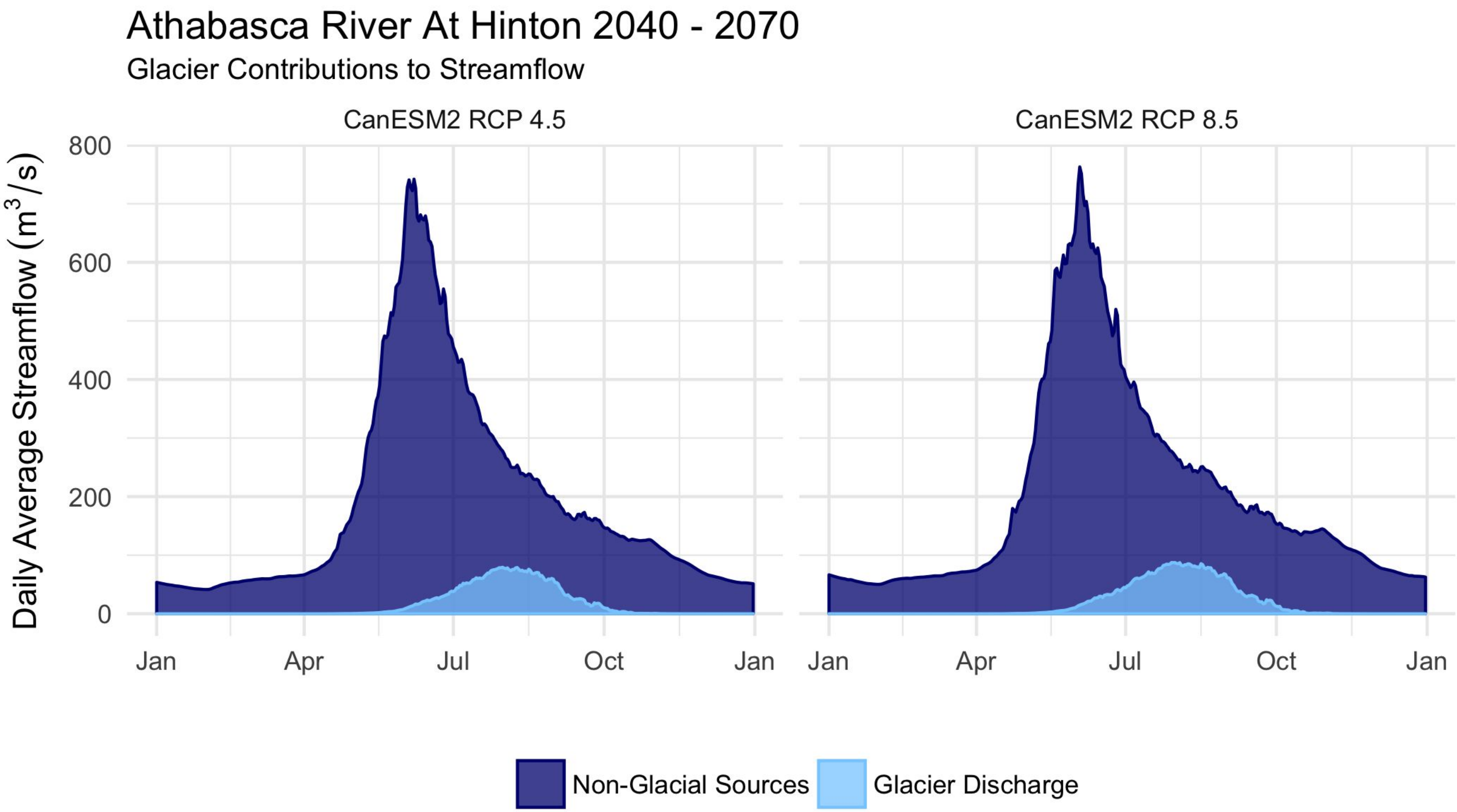
Glacier Contributions to Streamflow



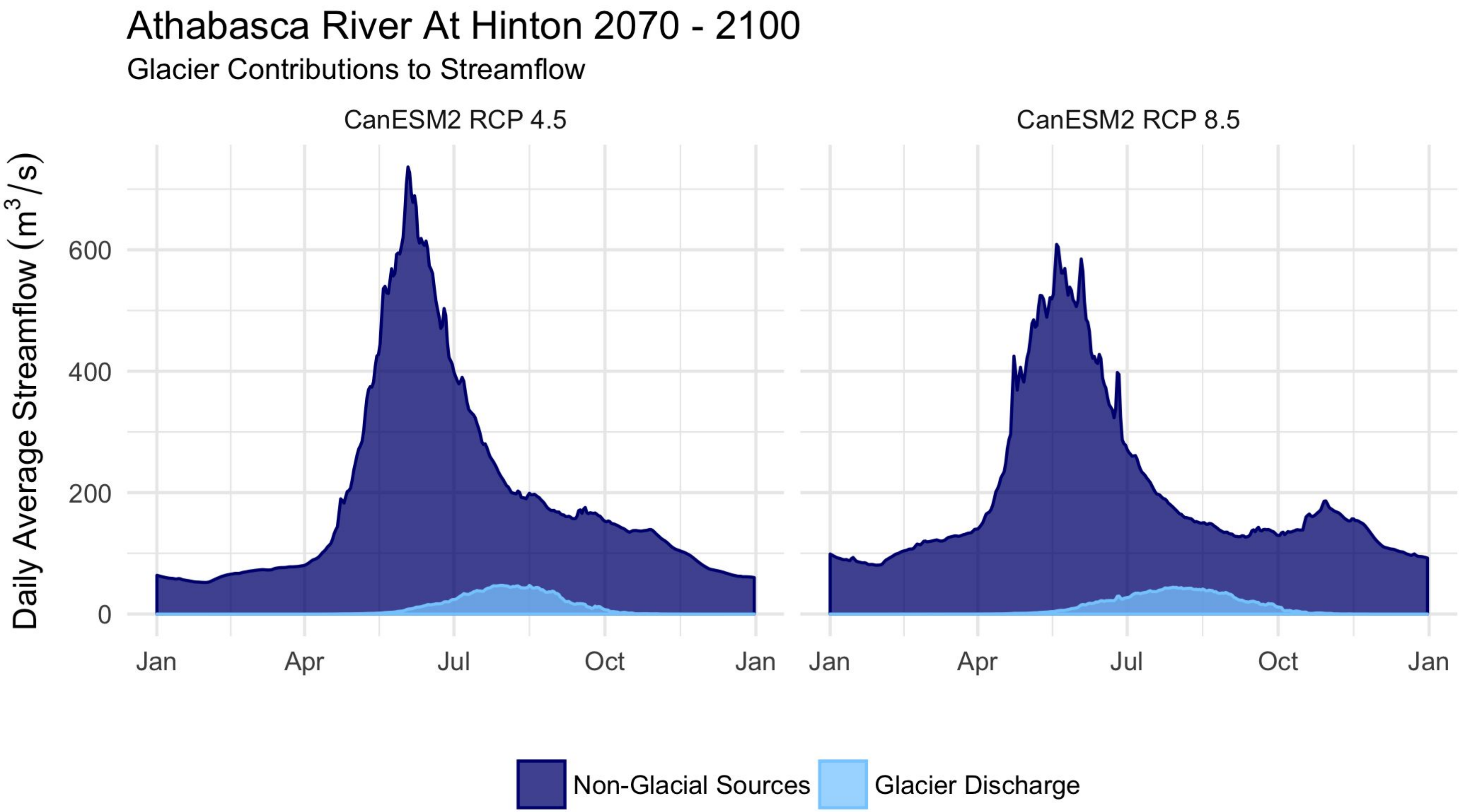
Glacier Contributions to Streamflow



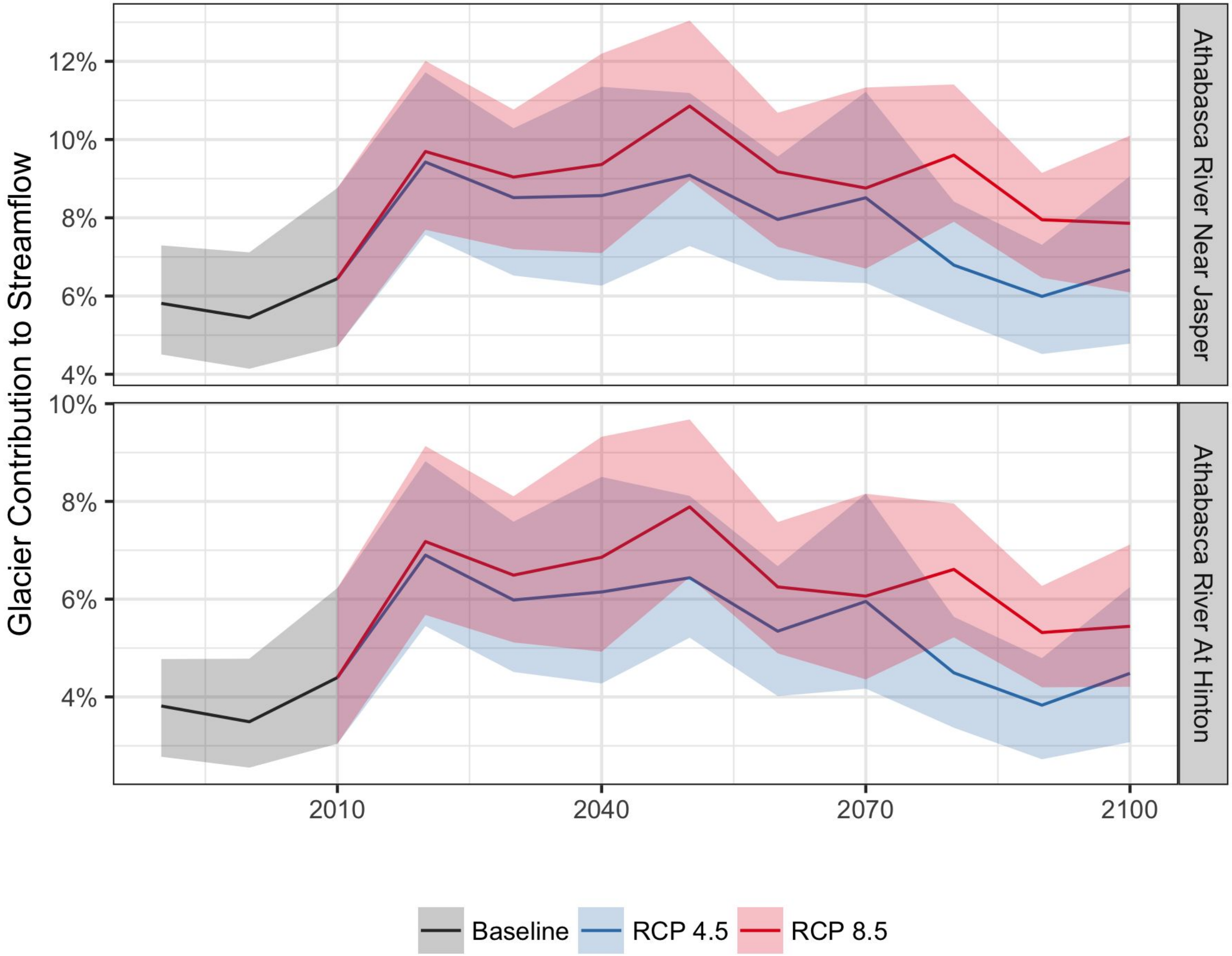
Glacier Contributions to Streamflow



Glacier Contributions to Streamflow

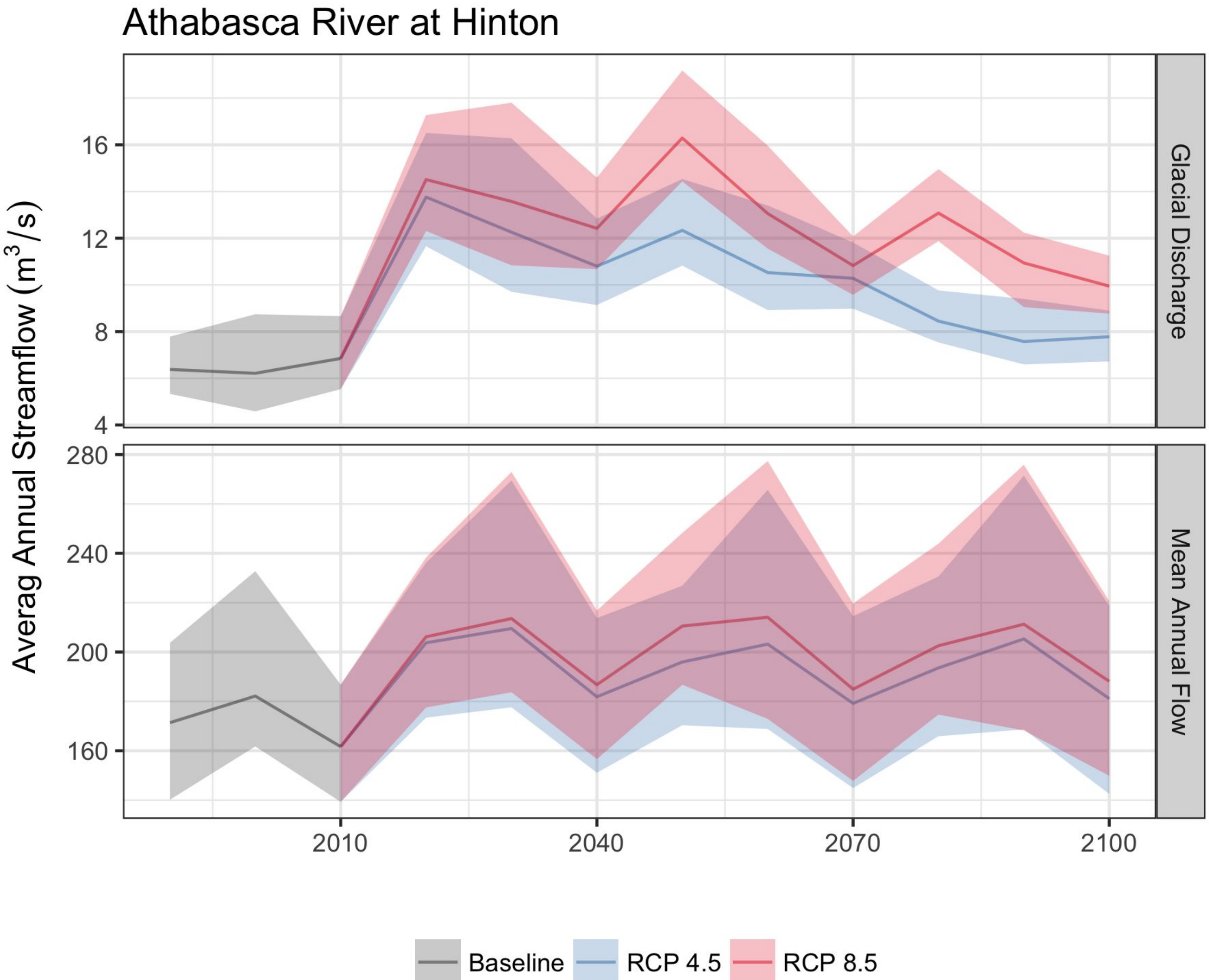


Glacier Contributions to Streamflow

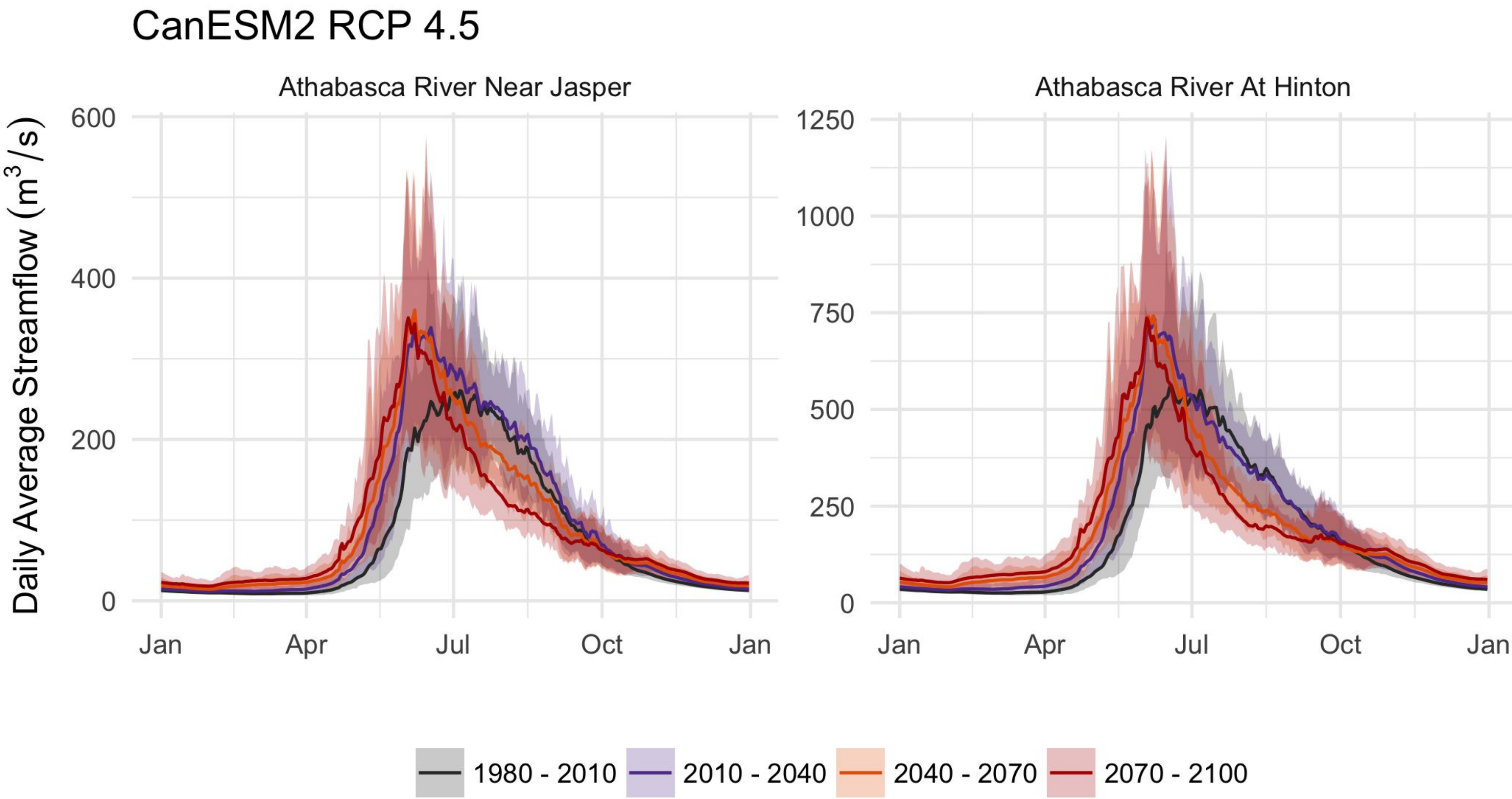


Shaded areas represent 10% and 90% quantiles.

Peak Water?


Athabasca River at Hinton
Averag Annual Streamflow (m^3/s)
16
12
8
4
280
240
200
160
2010
2040
2070
2100
Glacial Discharge
Mean Annual Flow
Baseline
RCP 4.5
RCP 8.5

Streamflow Under Future Conditions



Shaded areas correspond to 90th and 10th quantiles.

Implications and what (if anything) we do about it

Implications of less glacier area in the ARB

- Less July-September streamflow; typically a period where water shortages already occur downstream
  - Agricultural Demand
  - Industrial Licences
  - Municipal Use
  - Aboriginal Navigation

What can we do to offset reduced late-summer streamflow?

- Timing more critical than annual water yields
- Precautionary Withdrawal Limits/Reduce demands?
  - Demands expected to increase with more population, agriculture
- Build water storage (off-stream storage, dams)
- "Switzerland Attempts to Conserve a Glacier by Covering It in Blankets"
- "Artificial glacier could help Ladakh villagers adapt to climate change"

Conclusions

- **Glaciers are important in the upper Athabasca River Basin**
  - (for streamflow, but also a host of things not mentioned here)
  - Provide up to 20% of streamflow at Hinton in August, very little during the rest of the year
  - Glacier contributions occur mostly after freshet -- coincide with lower streamflow
- **Glacier coverage is expected to decrease**
  - ARB expected to be lose about half it's current glacier coverage by 2070, and for it to halve again by 2100
  - Shrinking glaciers mean less late-summer/fall water
- **Glacier discharge expected to increase until 2050**
  - Double the contributions to streamflow by 2050, but expected to decrease after that
- **Future streamflow expected to increase in spring, decrease in summer/fall**
  - Higher, earlier freshet (warmer temperatures increase rate and timing of snowmelt)
  - Less streamflow in August-September, larger changes further into future

Timing of flow is key:

Less streamflow during periods when water deficits are already common is likely to stress the system, will require adaptation or engineering solutions (or a combination of the two).

Acknowledgements

ARB Working Group

Where can I find out more about this project?

- Google arb initiative

Where can I get the slides for this?

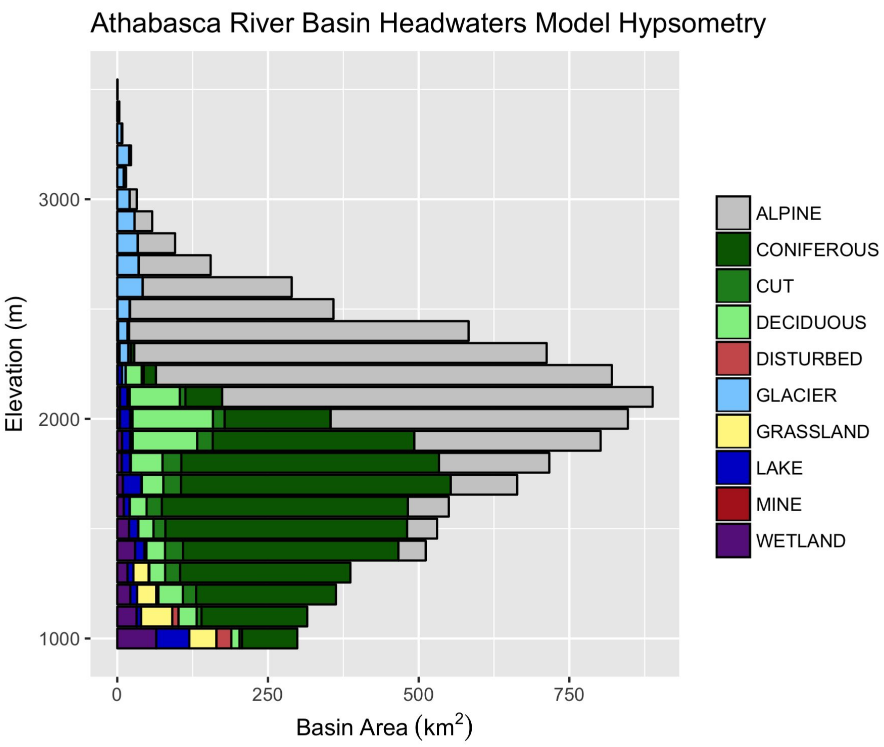
- https://github.com/mchernos/CGU2017

Outline

1. Introductions
   a. Athabasca River Basin and Project Scope
   b. Athabasca River Basin Headwaters
2. Hydrologic Modelling Methods
   a. Data (Meteorology and Land Use)
   b. Glacier Dataset
   c. Modified HBV-EC Model
   d. Model Calibration and Verification
   e. Climate Change Scenarios
3. Model Results
   a. Model Performance
   b. Current Glacier Contributions to Streamflow
   c. Future Glacier Contributions to Streamflow
   d. Streamflow Under Future Conditions
4. Implications and Future Considerations

Hydrologic Response Units (HRUs)

- In order to reduce computation time, complexity, the watershed is divided into HRUs.
- Within each sub-basin, proportion of each land cover type delineated by:
  - 100 m elevation bands (1000 - 3800 m)
  - Land cover type (Coniferous Forest, Deciduous Forest, Cut Forest, Grassland, Wetland, Mine, Disturbed (Urban), Alpine, and Glacier)
  - Aspect and Slope classes
- Glacier change: Decadal changes implemented within Raven
  - 'GLACIER' HRUs changed to 'ALPINE'
- Resulted in 18,234 HRUs



Data Sources

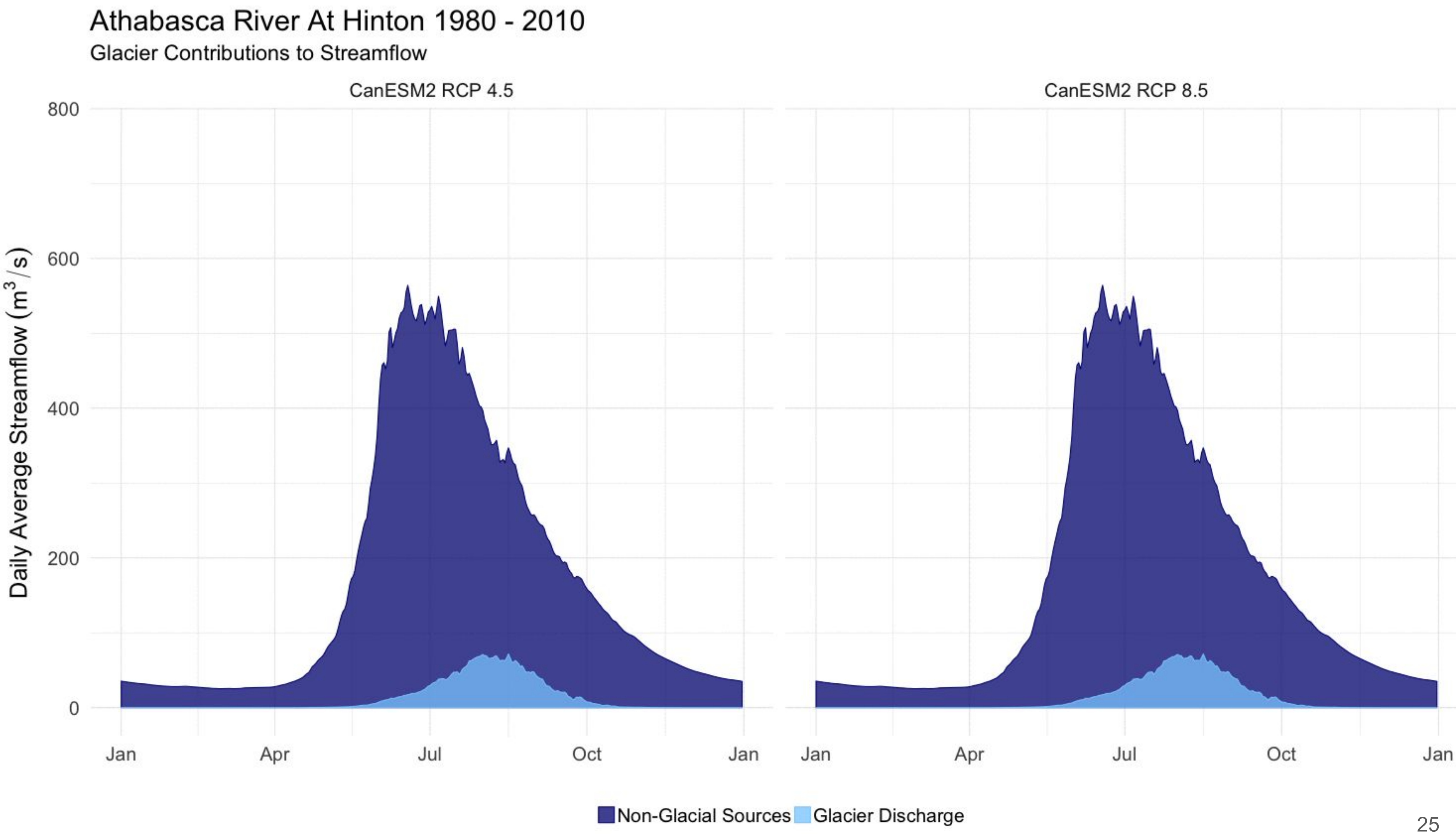
- **Streamflow**
  - 3 Water Survey of Canada Hydrometric Gauges
  - Athabasca River near Jasper, at Hinton, and one major tributary (Miette River)
- **Climate Data**
  - Four Environment Canada climate stations (Mica, Cariboo, Jasper, Hinton):
  - Seven synthetic climate stations:
    - Scaled nearest observed met station using PRISM climate normals 1961-1990.
- **Land Cover**
  - ABMI 2010 Land Cover dataset, derived from Landsat
  - Glacier coverage
    - From Clarke, G. K., Jarosch, A. H., Anslow, F. S., Radić, V., & Menounos, B. (2015). Projected deglaciation of western Canada in the twenty-first century. *Nature Geoscience*, *8*(5), 372-377.
    - http://couplet.unbc.ca/data/RGM_archive/

Model Calibration

- Calibrated using OSTRICH
  - Levenberg-Marquhart and DDS algorithms
  - Calibrated to Athabasca River Near Jasper and Miette River at Jasper from 2000 - 2010
  - Verified from 1990 - 2010
- Step-like process to leverage multiple data sets and (hopefully!) improve hydrological process-representation

Guiding Principle	Parameters	Criteria/Objective
1) Isolate and exclude insensitive parameters	All	*CSS* ≈ 0 ("not calculated")
2) Ensure correct volume of water in catchment	T, P lapse rates, Interception, glacier melt	Minimize PBIAS, maximize NSE
3) Ensure correct freshet timing	T lapse rate, melt factors	Maximize NSE, ensure SWE timing
4) Calibrate routing, sensitivity, and baseflow	Soil routing parameters	Maximize NSE
5) Approximate parameter uncertainty	All	Obtain parameter *SE*

Glacier Contributions to Streamflow



Water Balance Under Current and Future Conditions