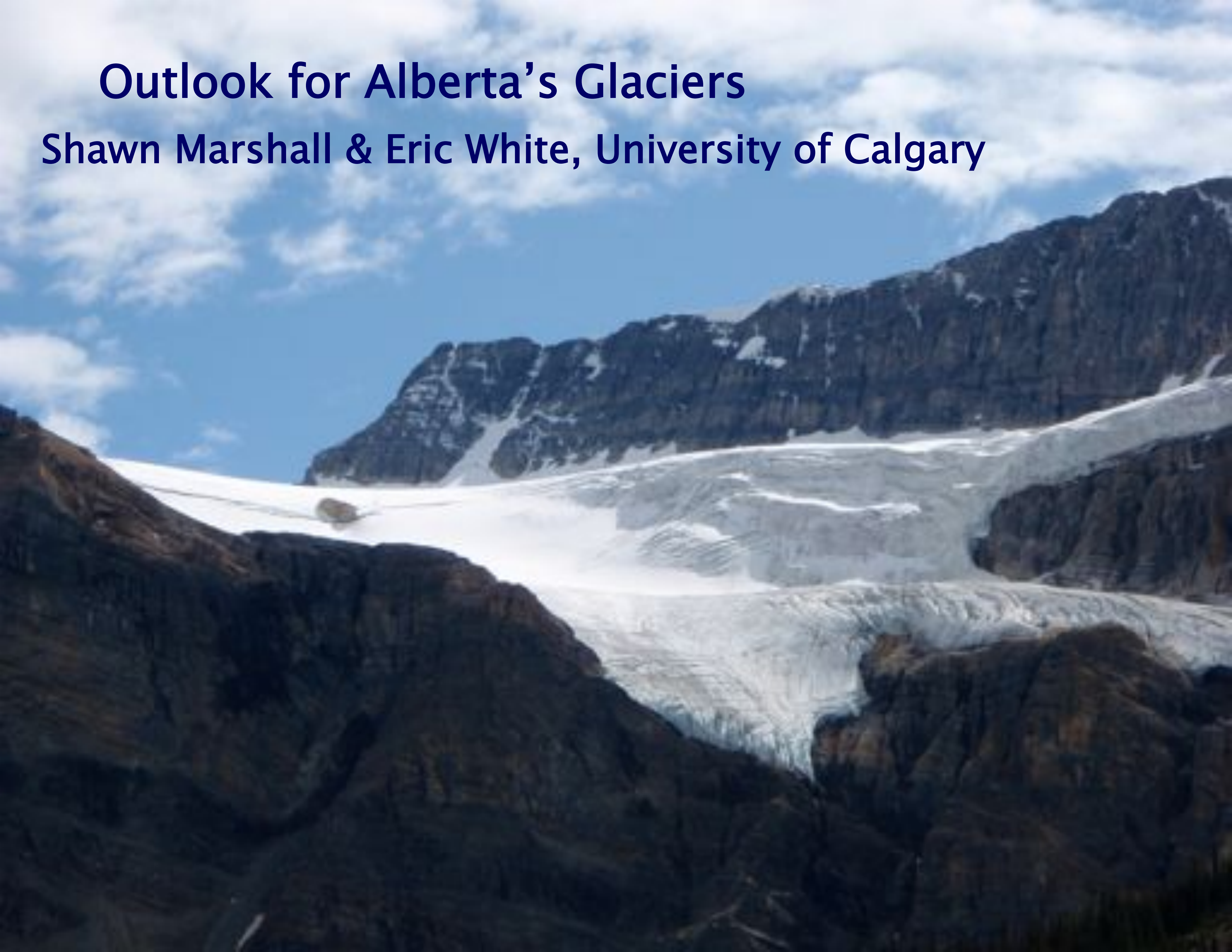
Outlook for Alberta’s Glaciers

Shawn Marshall & Eric White, University of Calgary

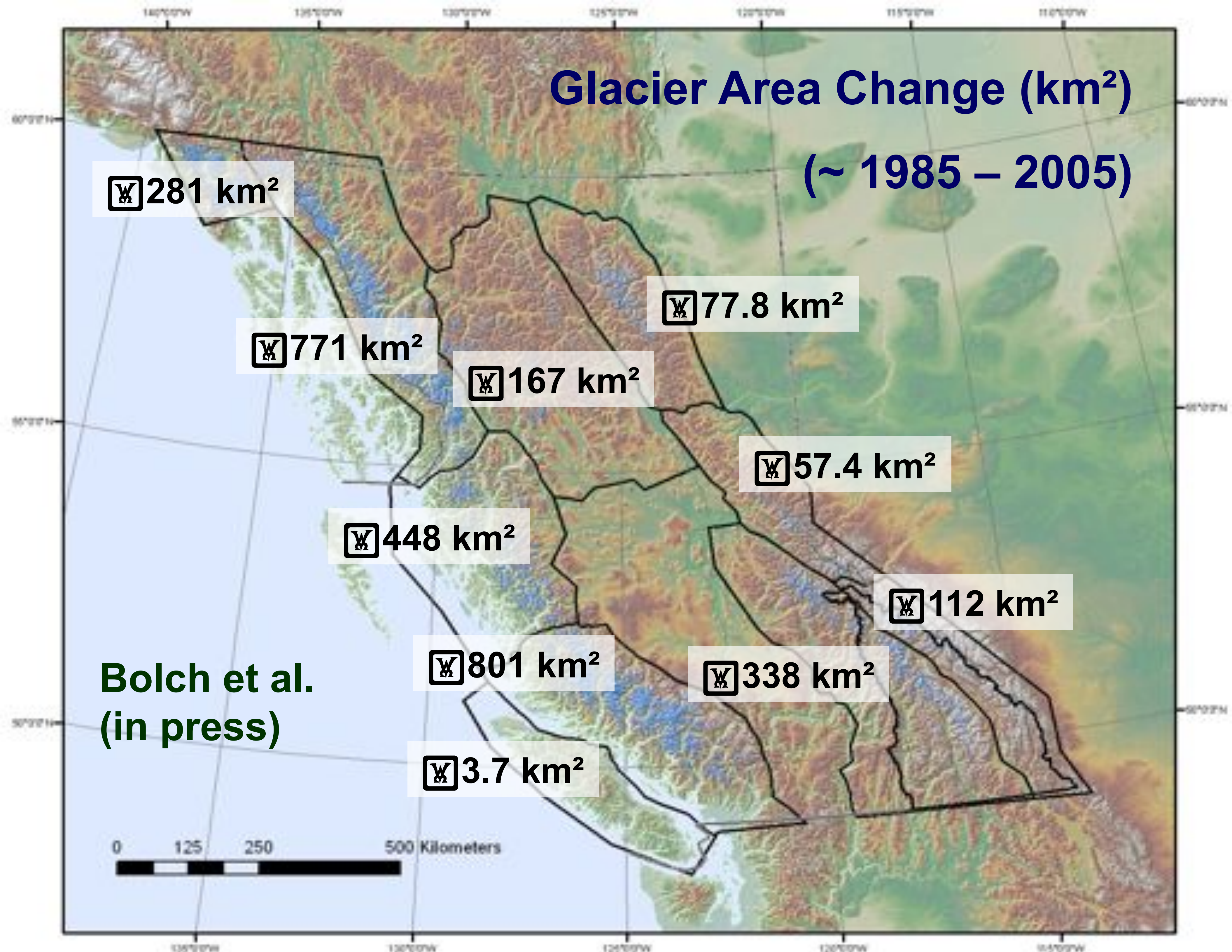


Really a synthesis drawing from the data and ideas of:

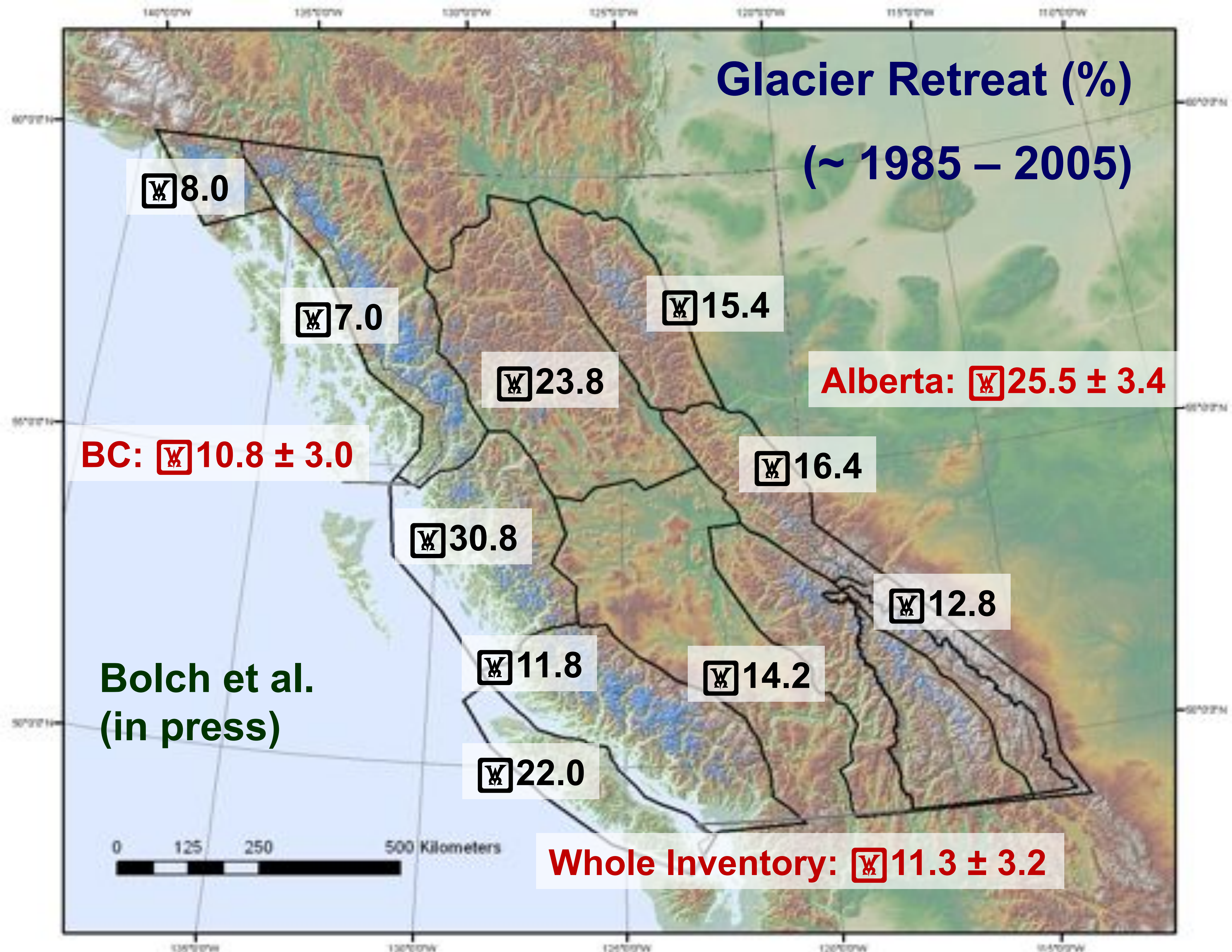
Tobias Bolch, Roger Wheate, Brian Menounos, UNBC

Mike Demuth, NGP-GSC; Joe Shea, Garry Clarke,

WC2N
WESTERN CANADIAN
CRYOSPHERIC NETWORK



Glacier Area Change (km²)
(~ 1985 – 2005)
281 km²
771 km²
167 km²
77.8 km²
57.4 km²
448 km²
112 km²
801 km²
338 km²
3.7 km²
Bolch et al.
(in press)
0
125
250
500 Kilometers



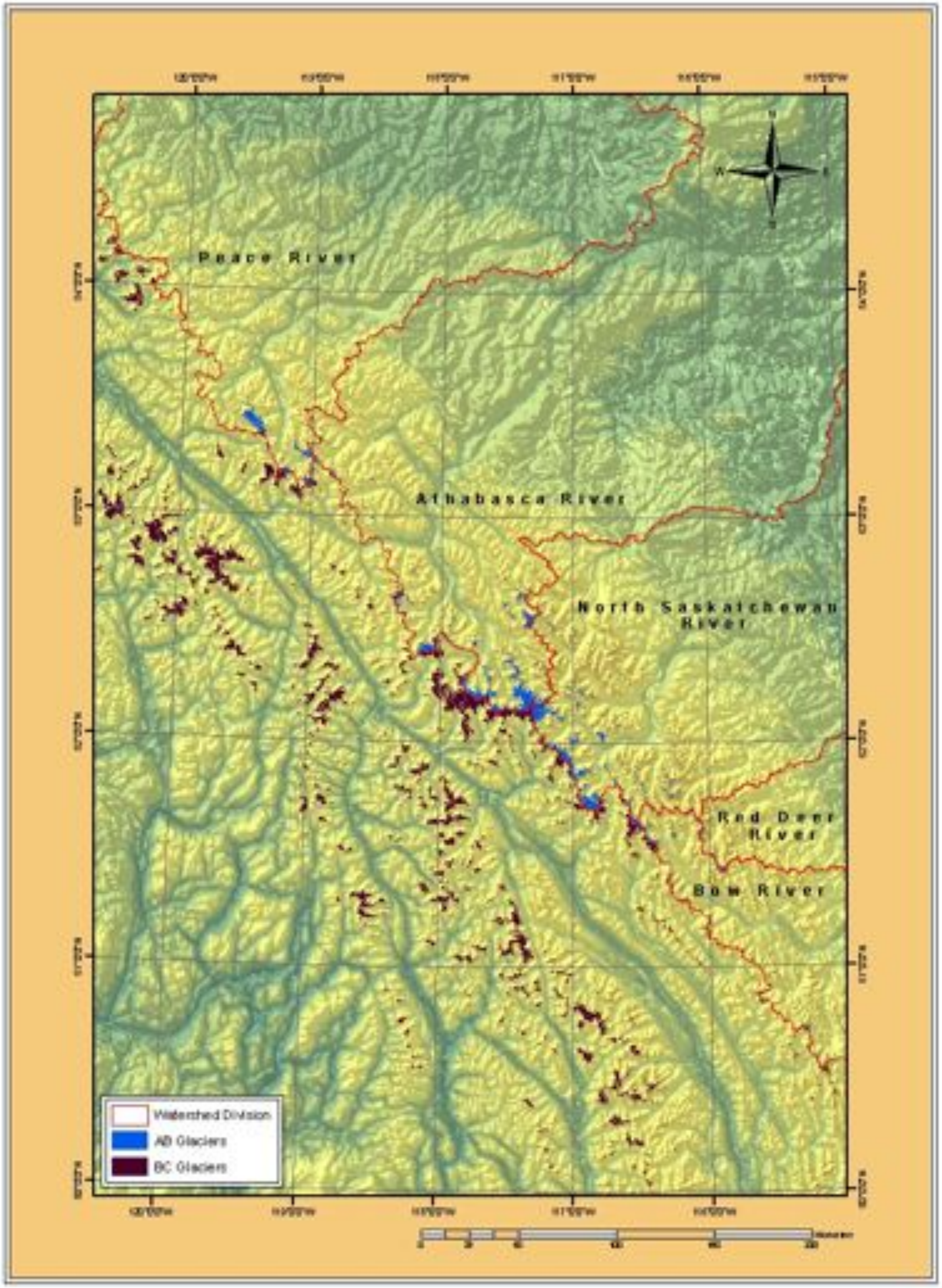
Glacier Retreat (%)
(~ 1985 – 2005)
8.0
7.0
15.4
23.8
Alberta: 25.5 ± 3.4
BC: 10.8 ± 3.0
16.4
30.8
12.8
11.8
14.2
Bolch et al.
(in press)
22.0
0 125 250 500 Kilometers
Whole Inventory: 11.3 ± 3.2

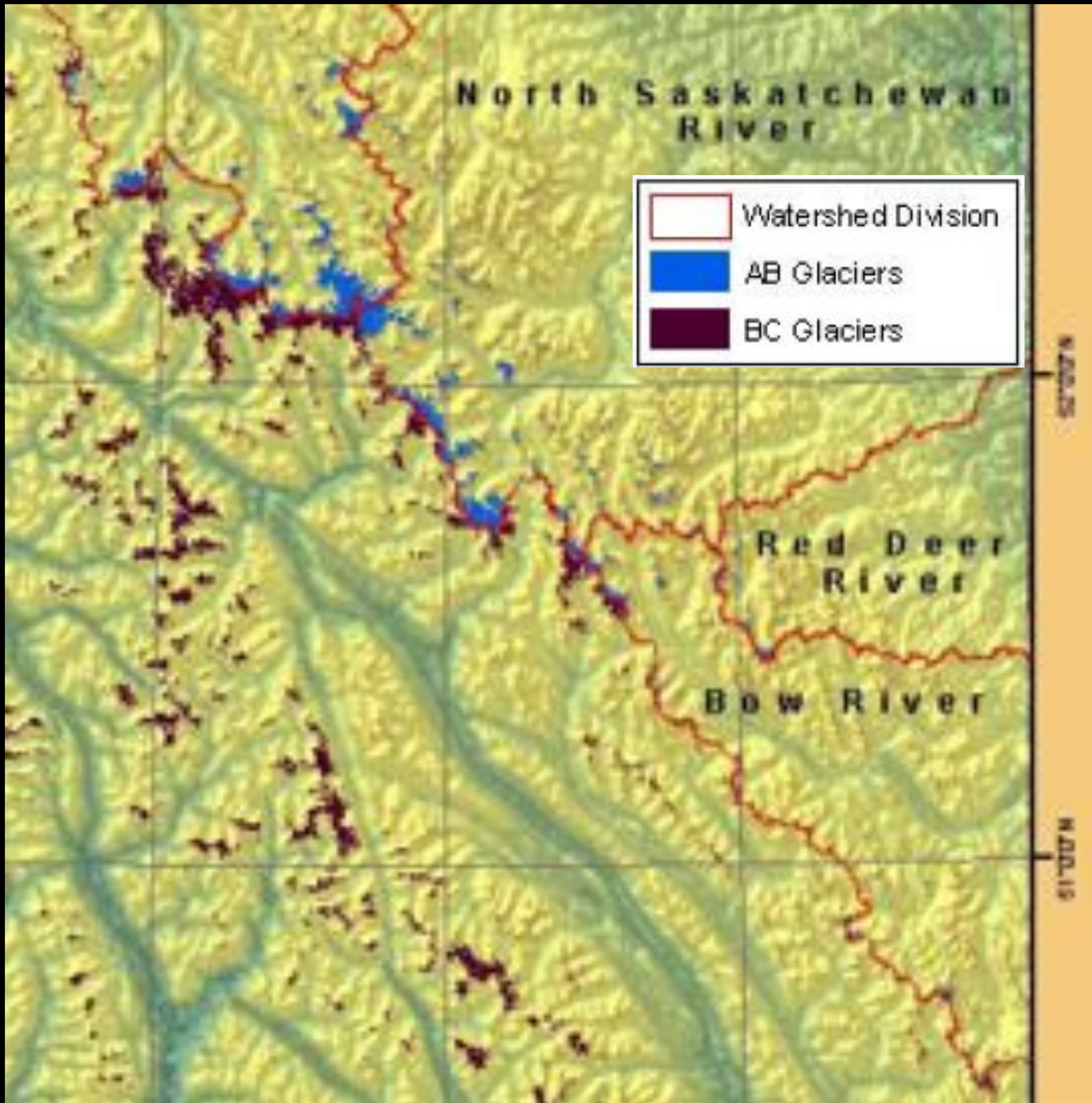
Glaciers of Alberta (2005)

	Glacier Count		Glacier Area	
Size Range (km^2)	Number	%	(km^2)	%
0.05 – 0.1	109	14.7	8.0	1.0
0.1 – 0.5	378	51.0	90.6	11.4
0.5 – 1.0	116	15.7	83.3	10.5
1 – 10	124	16.7	334.9	42.3
10 – 40	14	1.9	274.6	34.7
Total	741		791.4	

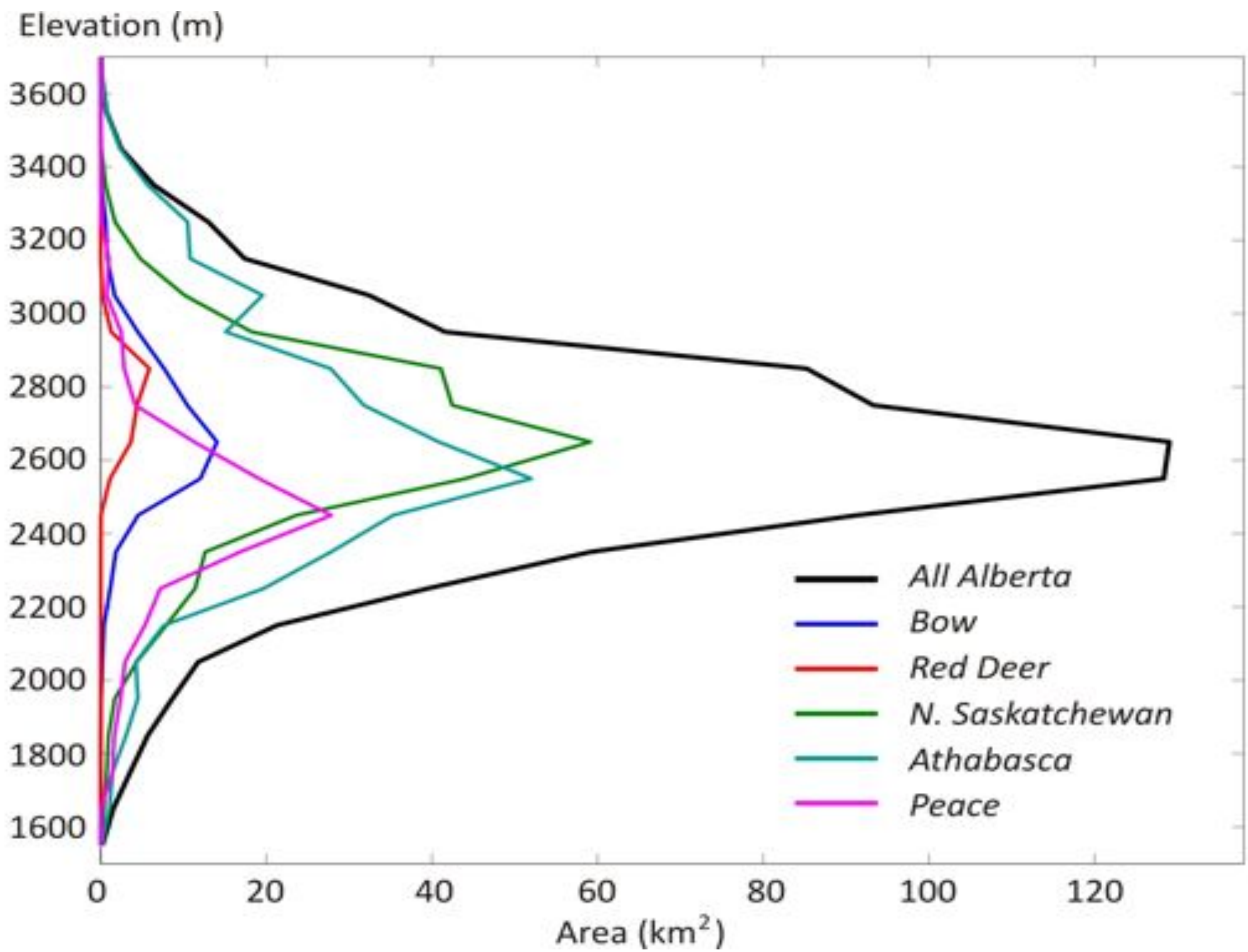
1985: **1053 km^2**

2005: **791 km^2**


Peace River
Athabasca River
North Saskatchewan River
Red Deer River
Bow River
Watershed Division
AB Glaciers
BC Glaciers


North Saskatchewan River
Watershed Division
AB Glaciers
BC Glaciers
Red Deer River
Bow River

Hypsometry of AB Glaciers



Estimating Glacier Volume

Most commonly: Volume-Area scaling

$$V = cA^b$$

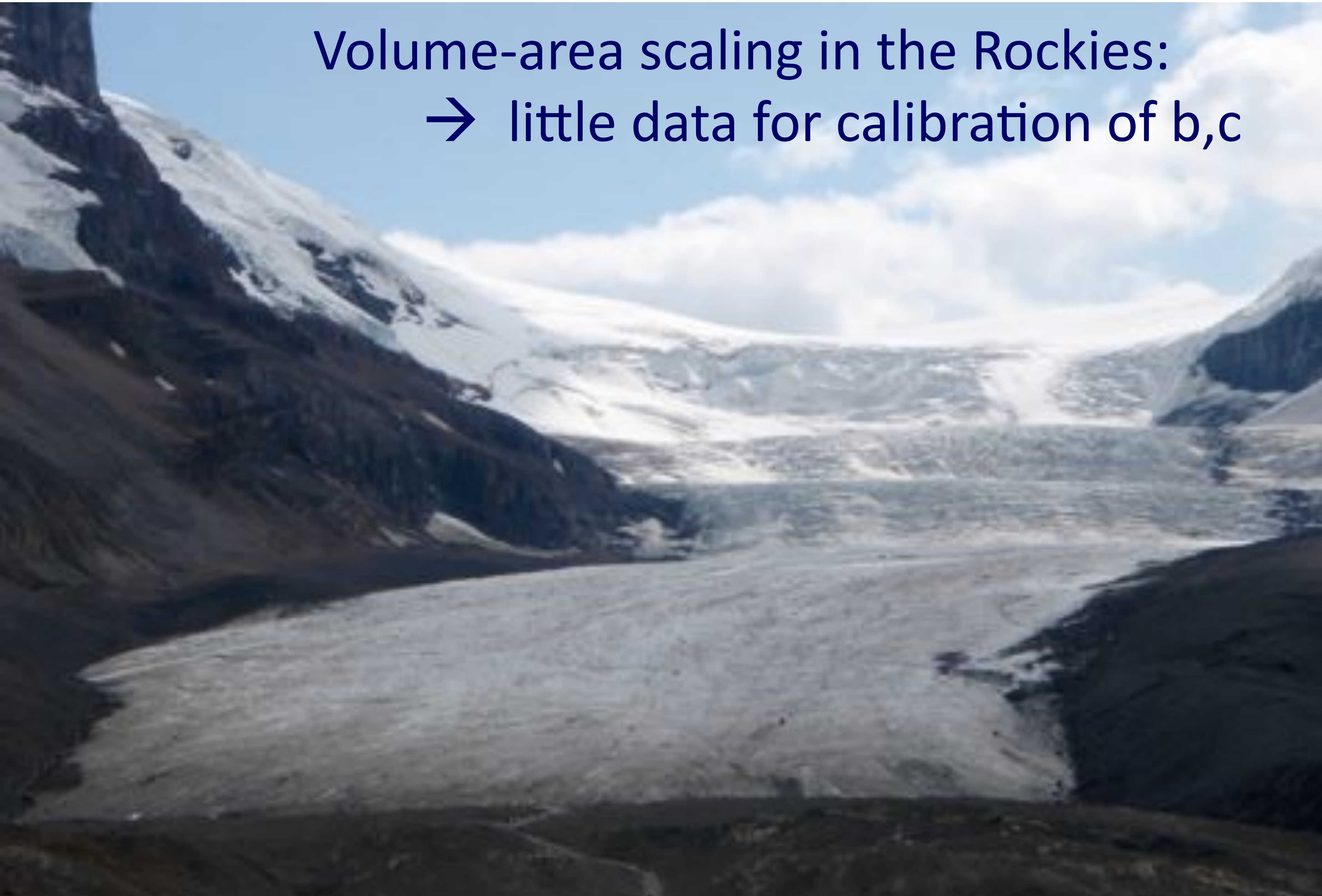
But see Clarke et al. (2009) for some alternative methods. One first-order approach is estimation of local ice thickness from local surface slope:

$$H = \frac{\tau_d}{\rho g \nabla s}$$

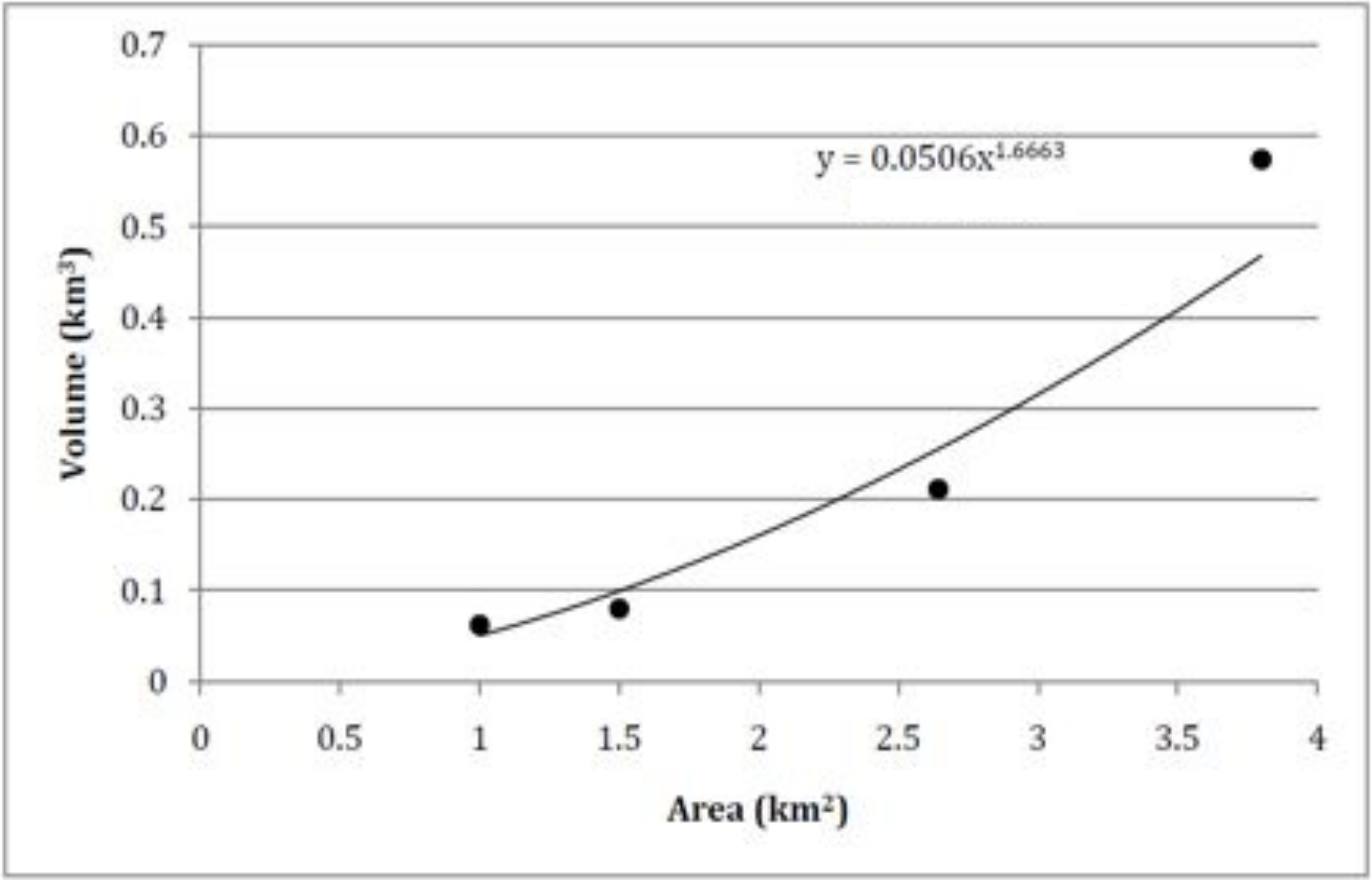
Glaciers of Alberta: Estimated Volume

Volume-area scaling in the Rockies:

→ little data for calibration of b,c



Volume-area scaling in the Rockies



Glaciers of Alberta: Estimated Volume

Modified volume-area scaling that separates valley glaciers and icefields

Method	*c*	*b*	Volume (km^3)
Global aggregate scaling parameters	0.0285	1.357	42
North American scaling parameters	0.0308	1.405	51
Rockies-specific scaling parameters	0.0506	1.6663	156
Rockies scaling with separate icefields	0.0506	1.6663/1.25	116
Local slope-thickness estimate			55
Glacier-averaged slope-thickness estimate			35

So conclusion: ca. 45 km^3 but really, ~30-115 km^3

Outline

1. Glaciers of Alberta: area, hypsometry, volume

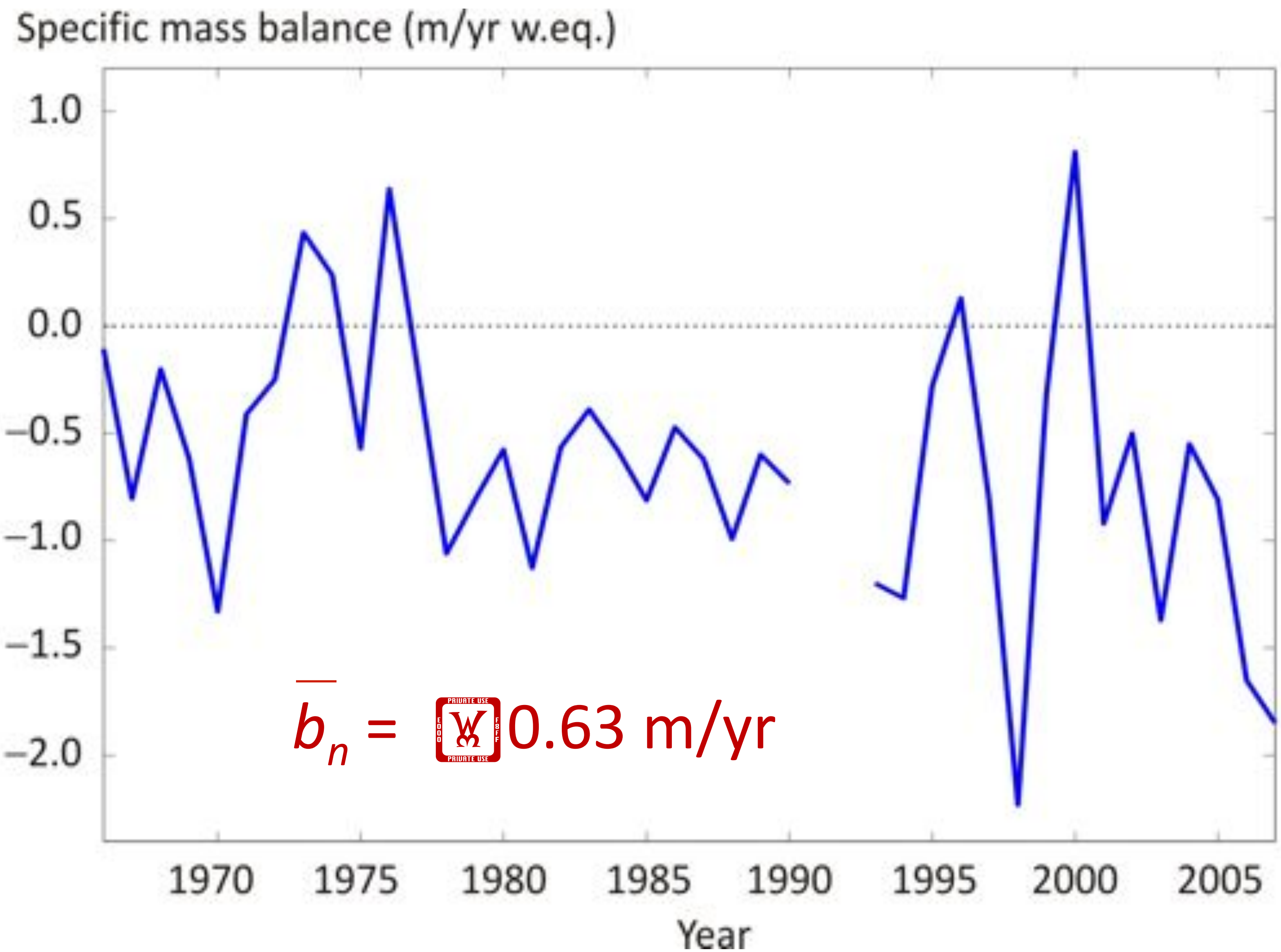
2. Estimating rates of future glacier retreat

    - mass balance rates, gradients

    - mass balance vs. local, synoptic climatology

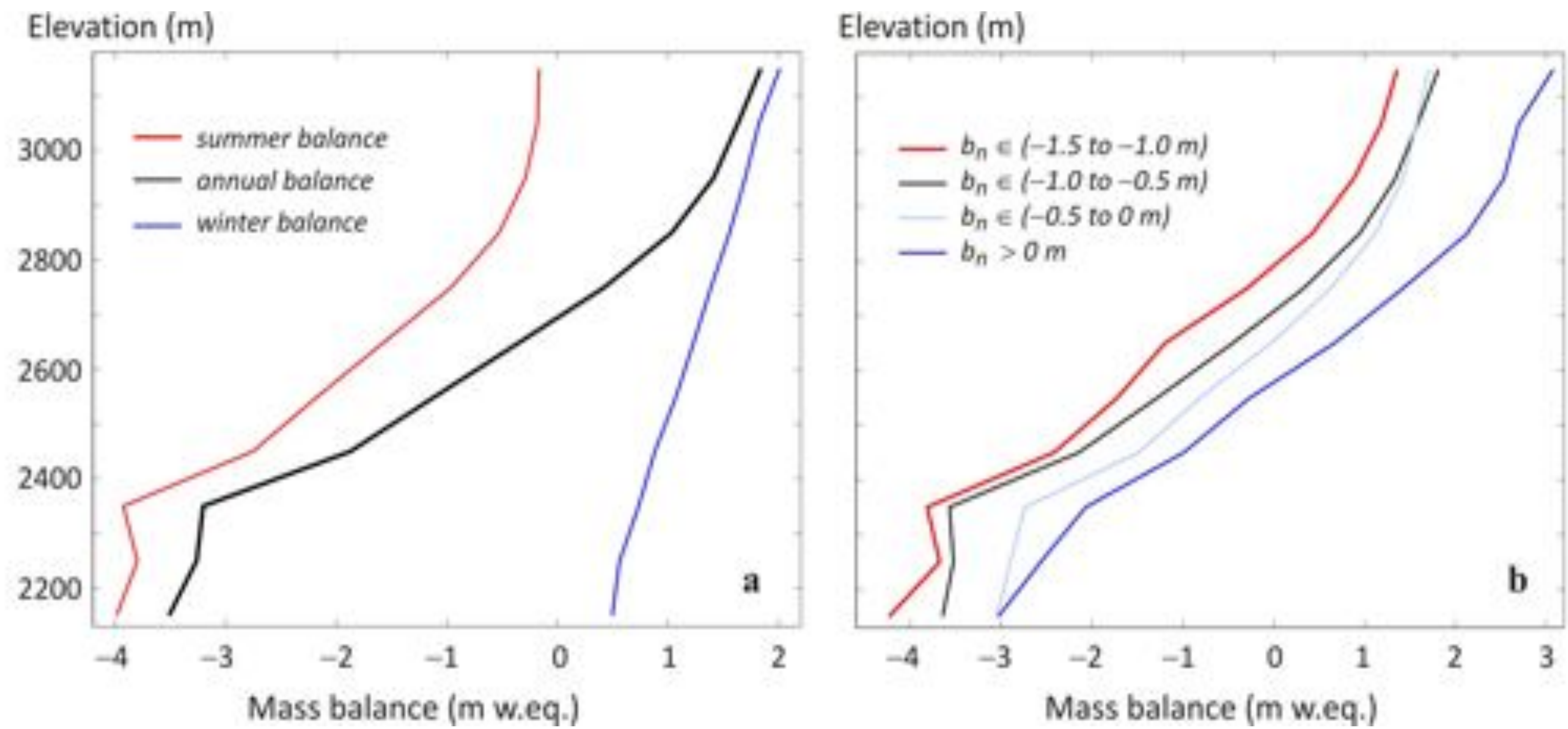
    - CGCM scenarios to drive future mass balance, with simplified glacier dynamics

Annual Mass Balance, Peyto Glacier, 1966-2007



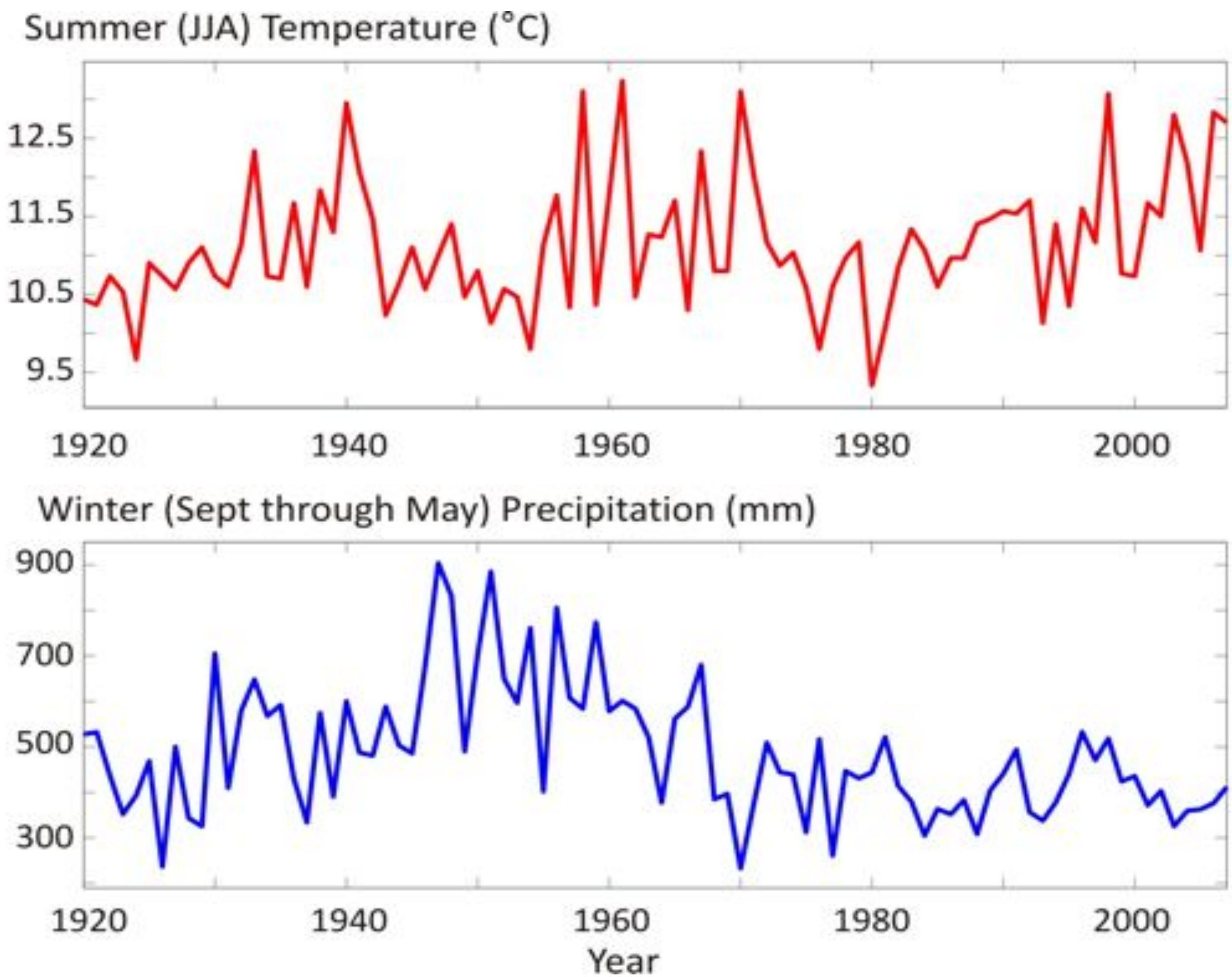
$\bar{b}_n = -0.63$ m/yr

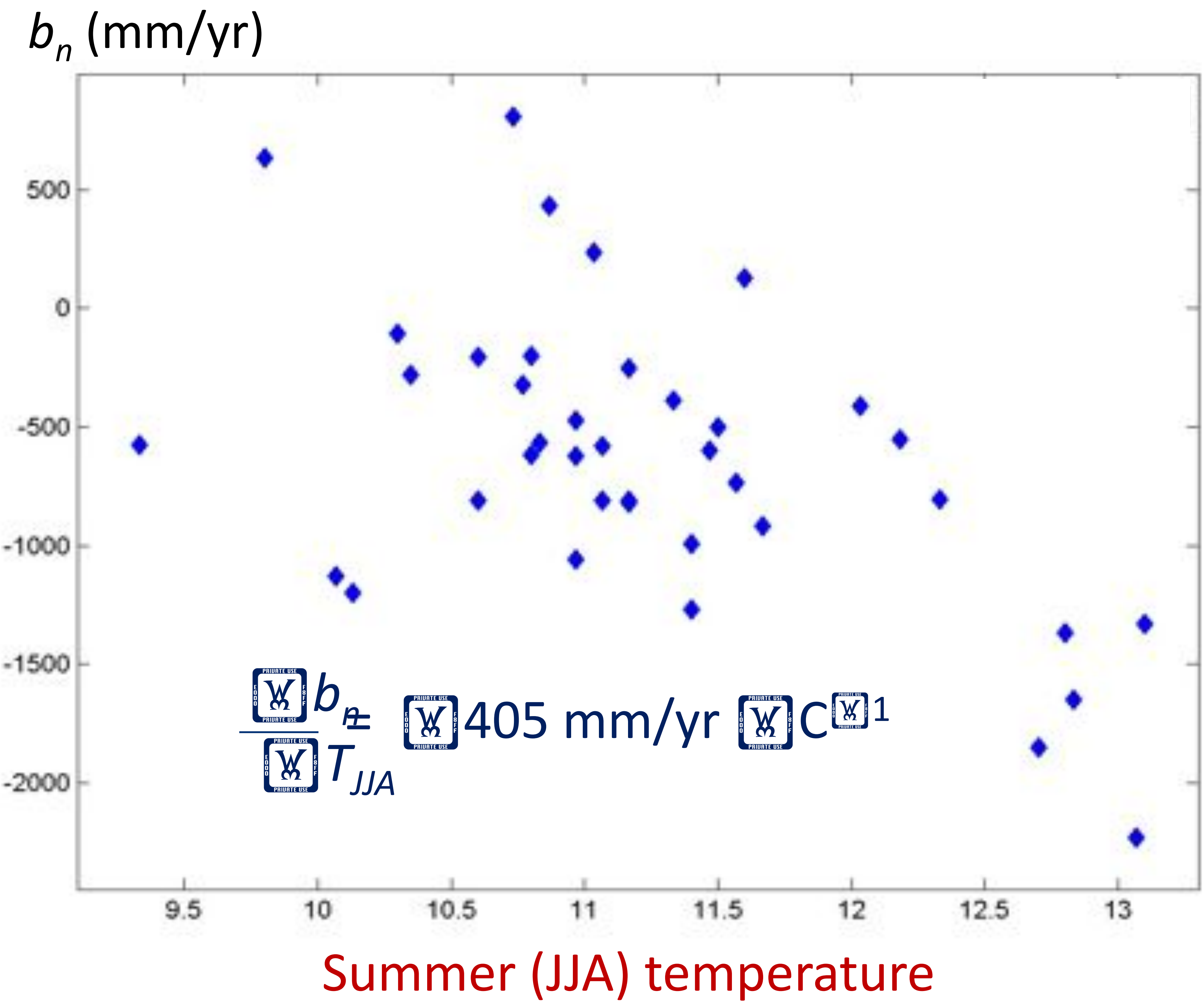
Peyto Glacier mass balance gradients, 1966-1995



$$\frac{\partial b_n}{\partial z} = 6.14 \text{ mm/yr m}^{-1}$$

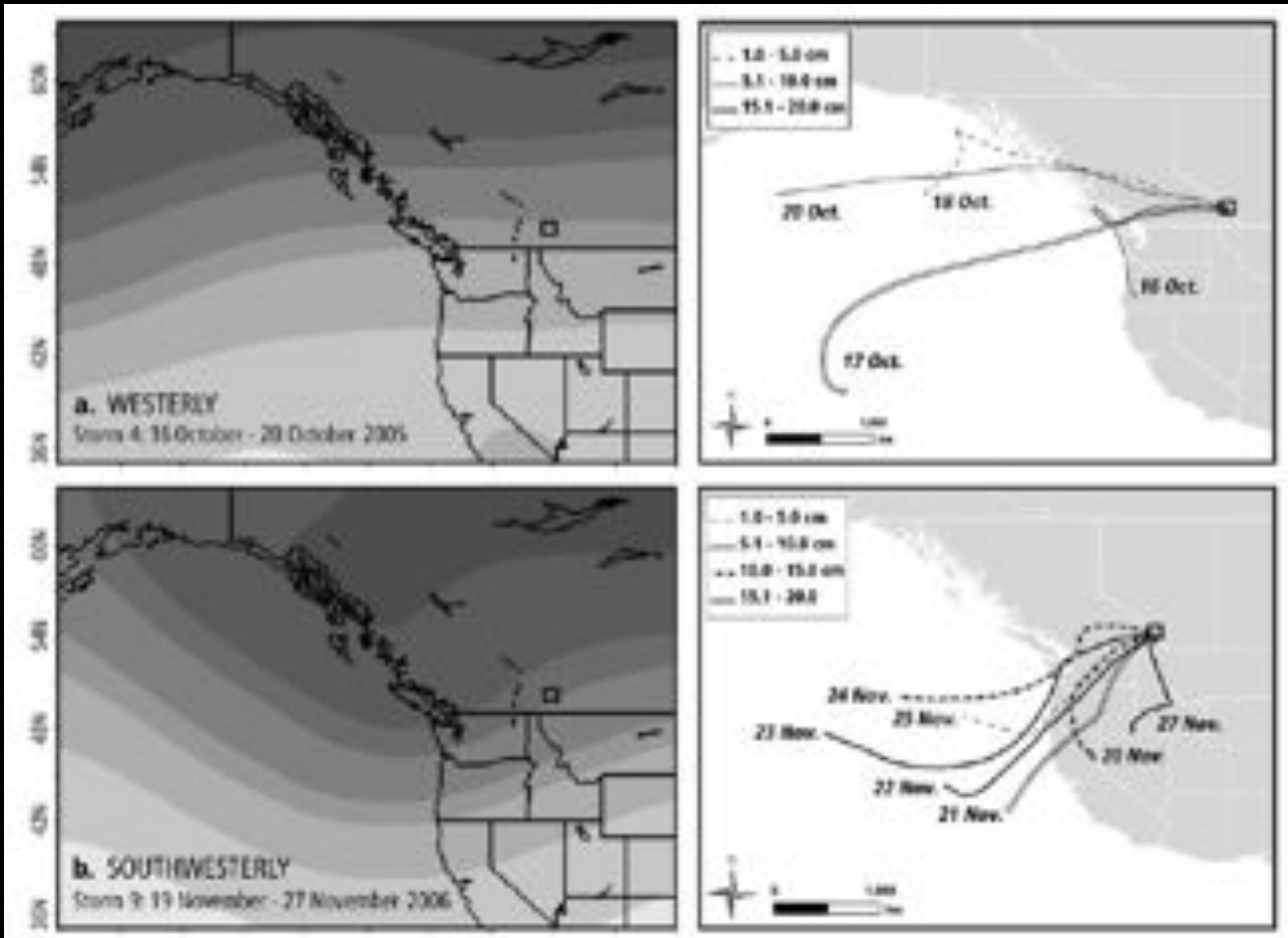
Lake Louise climatology



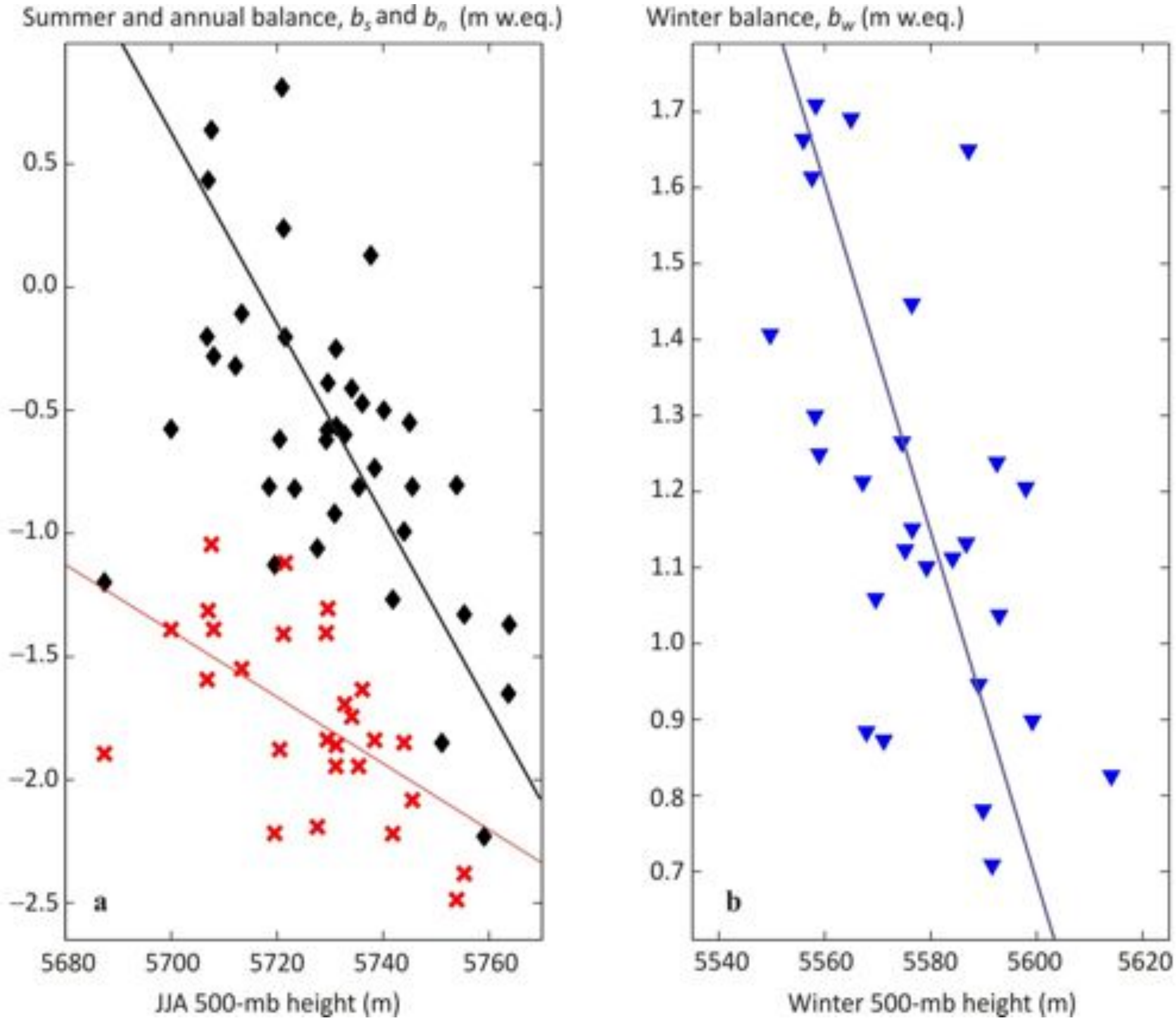


b_n (mm/yr)
500
0
-500
-1000
-1500
-2000
9.5
10
10.5
11
11.5
12
12.5
13
$\frac{\partial b_n}{\partial T_{JJA}} = -405$ mm/yr °C^{-1}
Summer (JJA) temperature

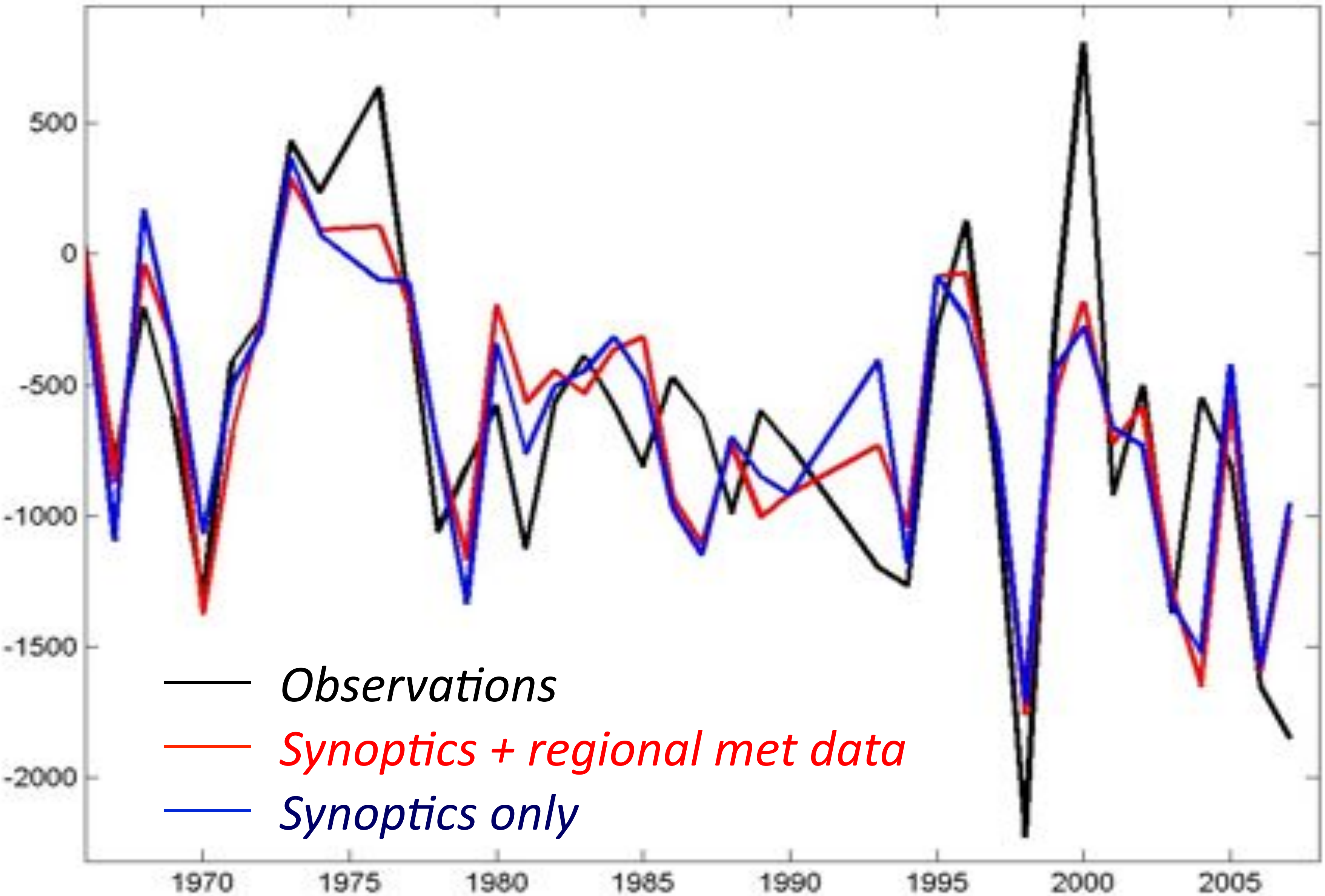
Connections: Glacier mass balance and synoptic patterns



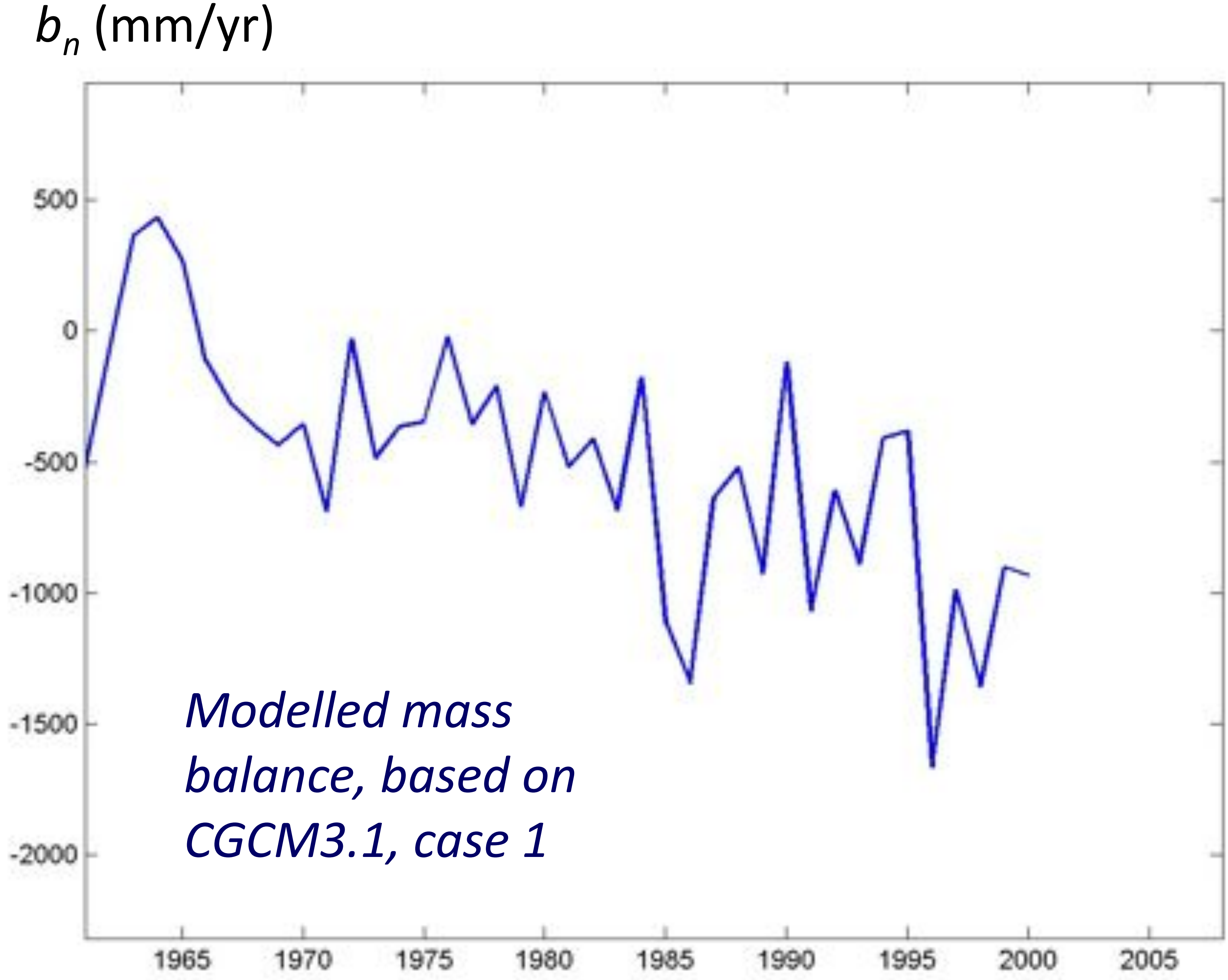
Sinclair & Marshall, Journal of Glaciology (2009)


Summer and annual balance, b_s and b_n (m w.eq.)
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
a
5680
5700
5720
5740
5760
JJA 500-mb height (m)
Winter balance, b_w (m w.eq.)
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
b
5540
5560
5580
5600
5620
Winter 500-mb height (m)

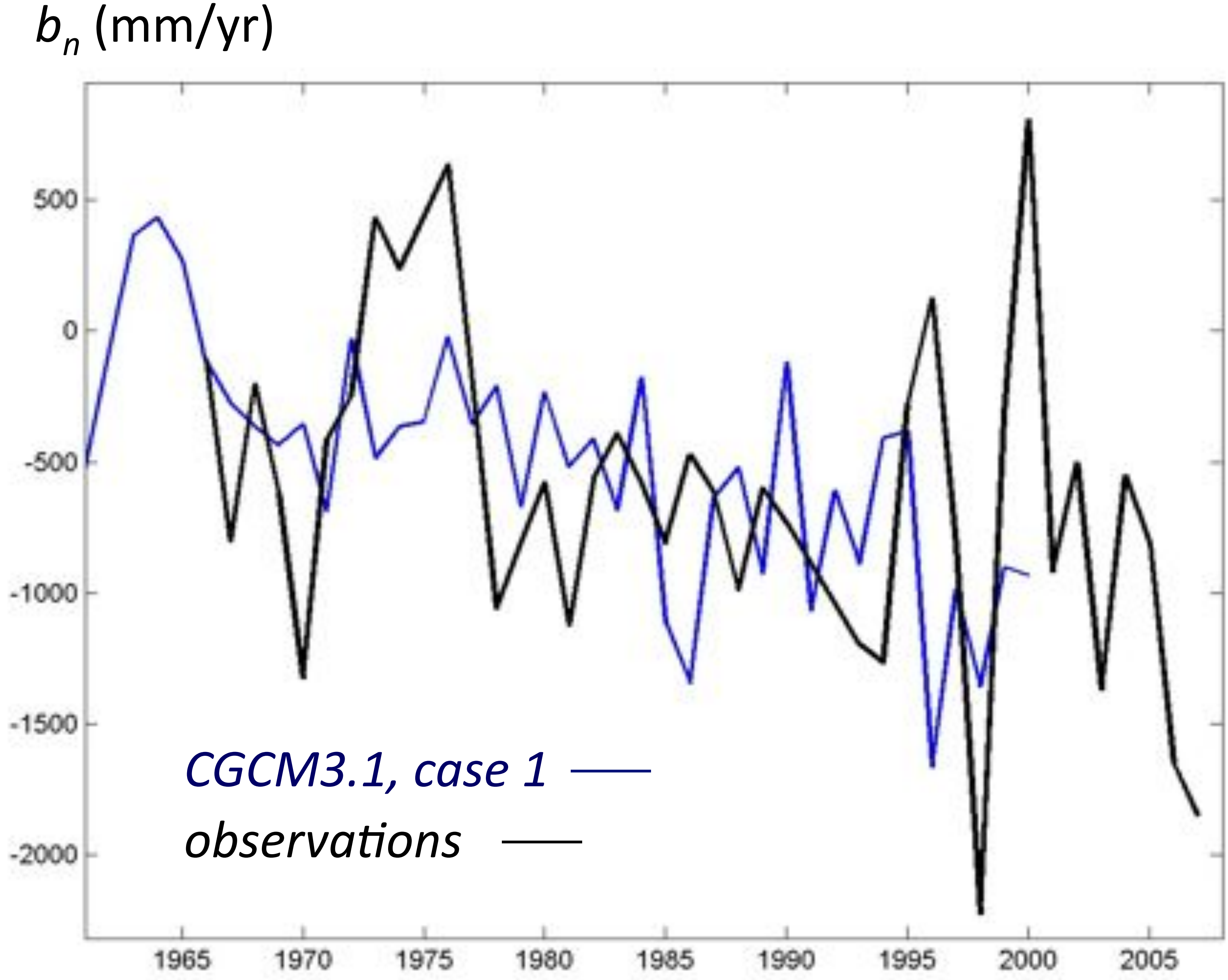
b_n (mm/yr) *MV Model vs. Observed Mass Balance*



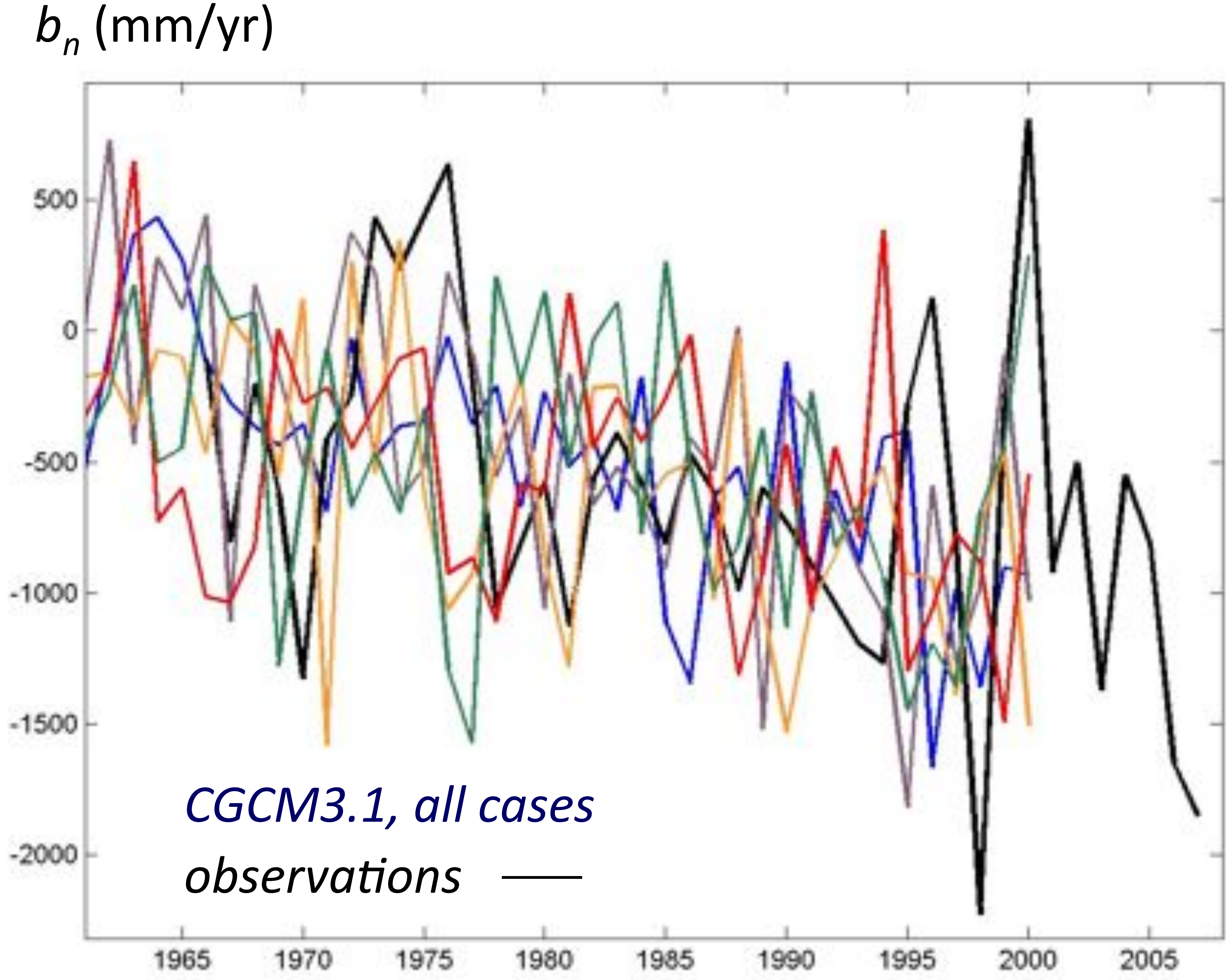
See Shea and Marshall, *IJC* (2007)



b_n (mm/yr)
500
0
-500
-1000
-1500
-2000
1965
1970
1975
1980
1985
1990
1995
2000
2005
Modelled mass balance, based on CGCM3.1, case 1



b_n (mm/yr)
500
0
-500
-1000
-1500
-2000
1965
1970
1975
1980
1985
1990
1995
2000
2005
CGCM3.1, case 1
observations



b_n (mm/yr)
500
0
-500
-1000
-1500
-2000
1965
1970
1975
1980
1985
1990
1995
2000
2005
CGCM3.1, all cases
observations

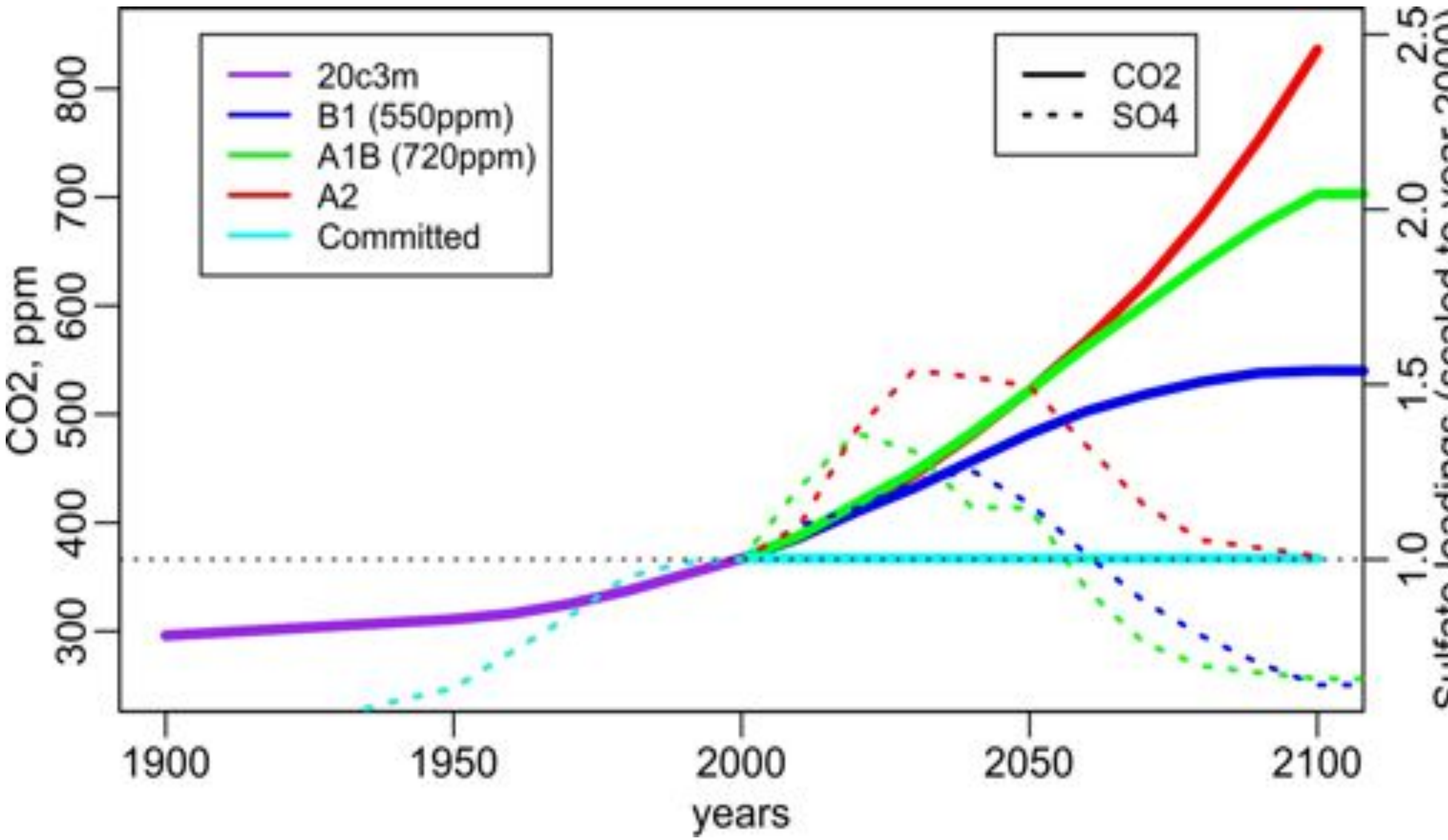
AB Glacier Discharge, 2006-2007: *1.2 km³/yr*

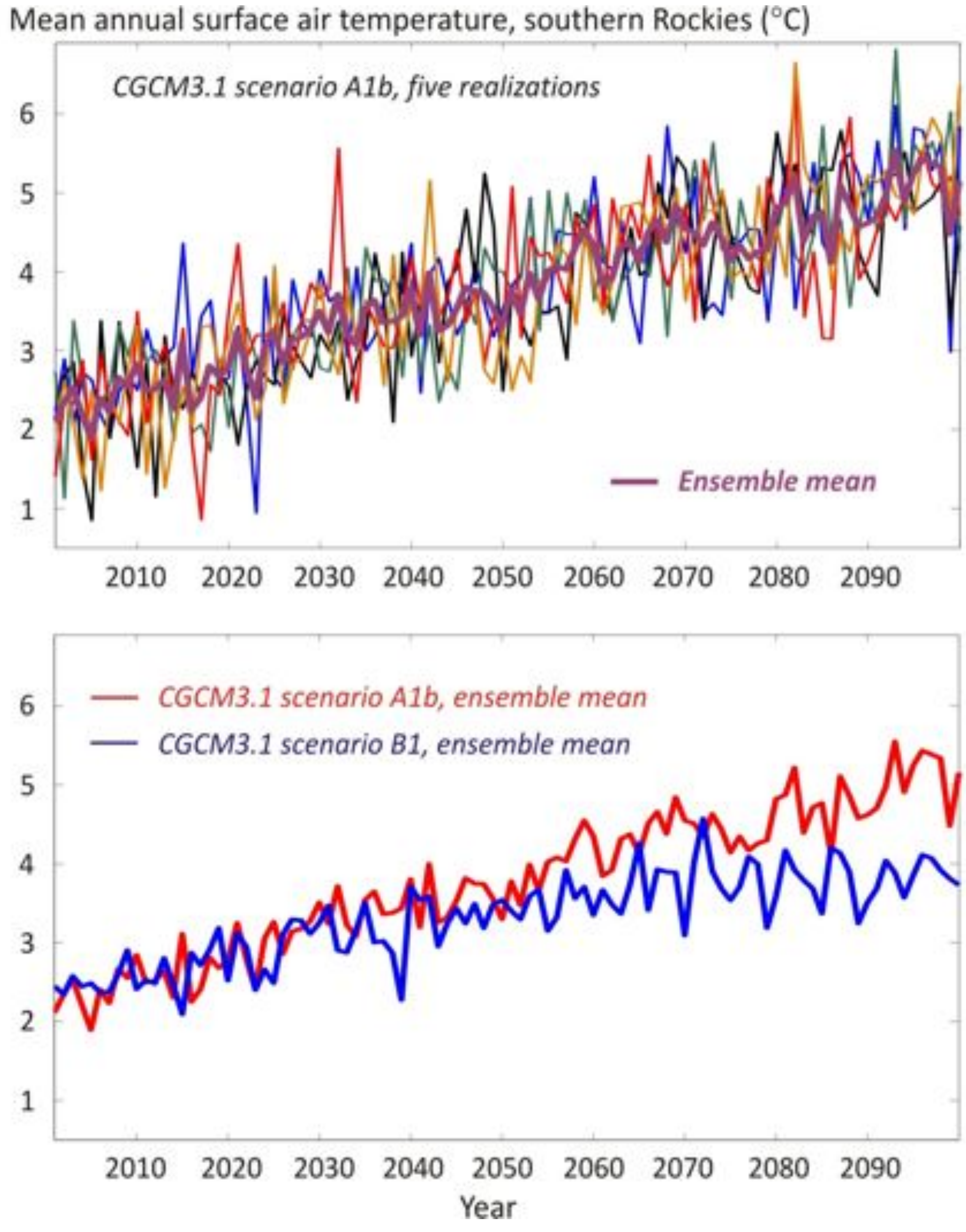
Average discharge, 2000s: *0.66 km³/yr*

One could extrapolate simple-mindedly, based on recent rates of loss and reservoir volume in each basin. The results, for 45 km^3 of initial ice:

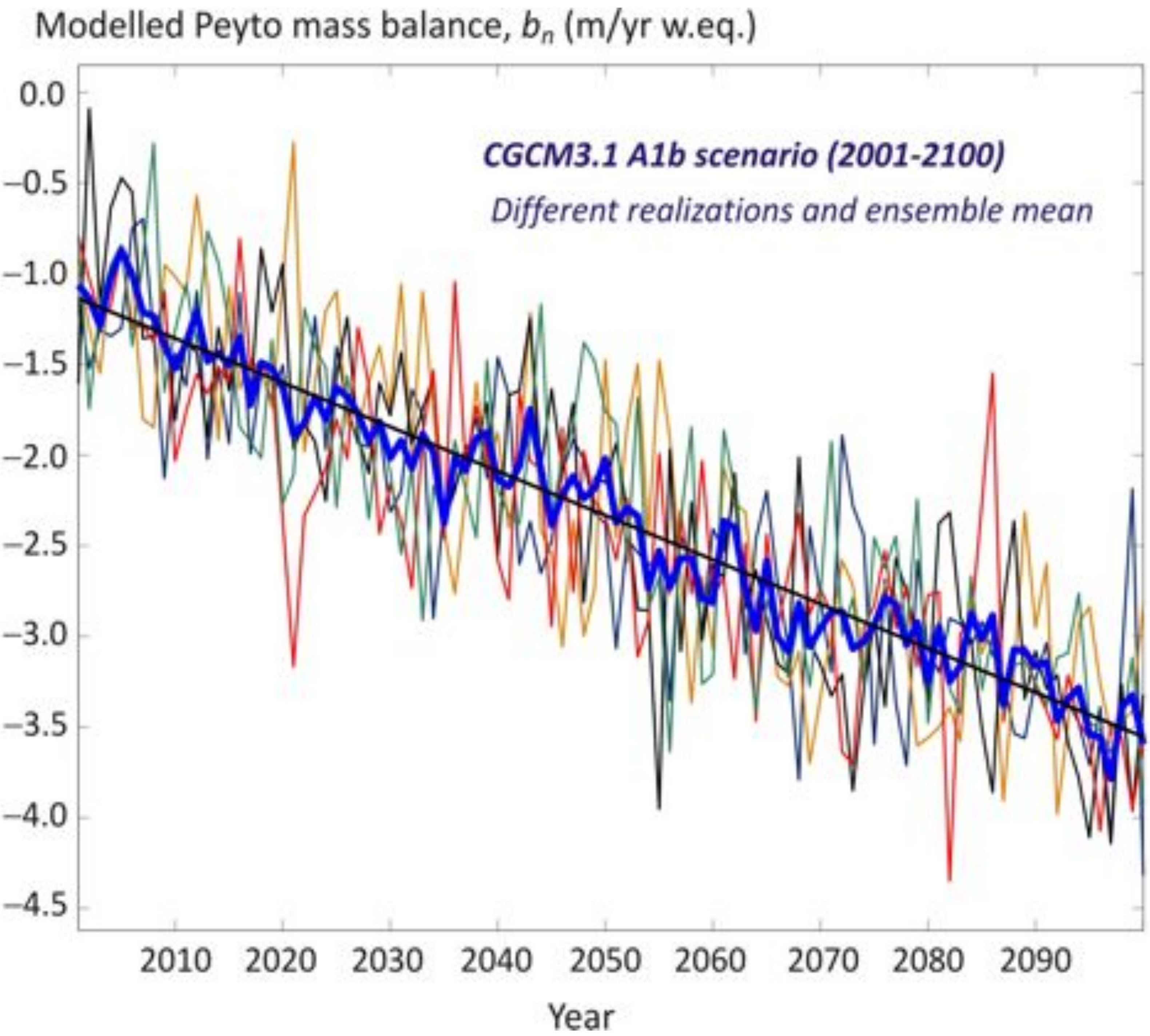
Bow:	53 yr
Red Deer:	132 yr
North Sask:	72 yr
Athabasca:	83 yr
Peace:	97 yr

IPCC SRES Climate Forcing Scenarios

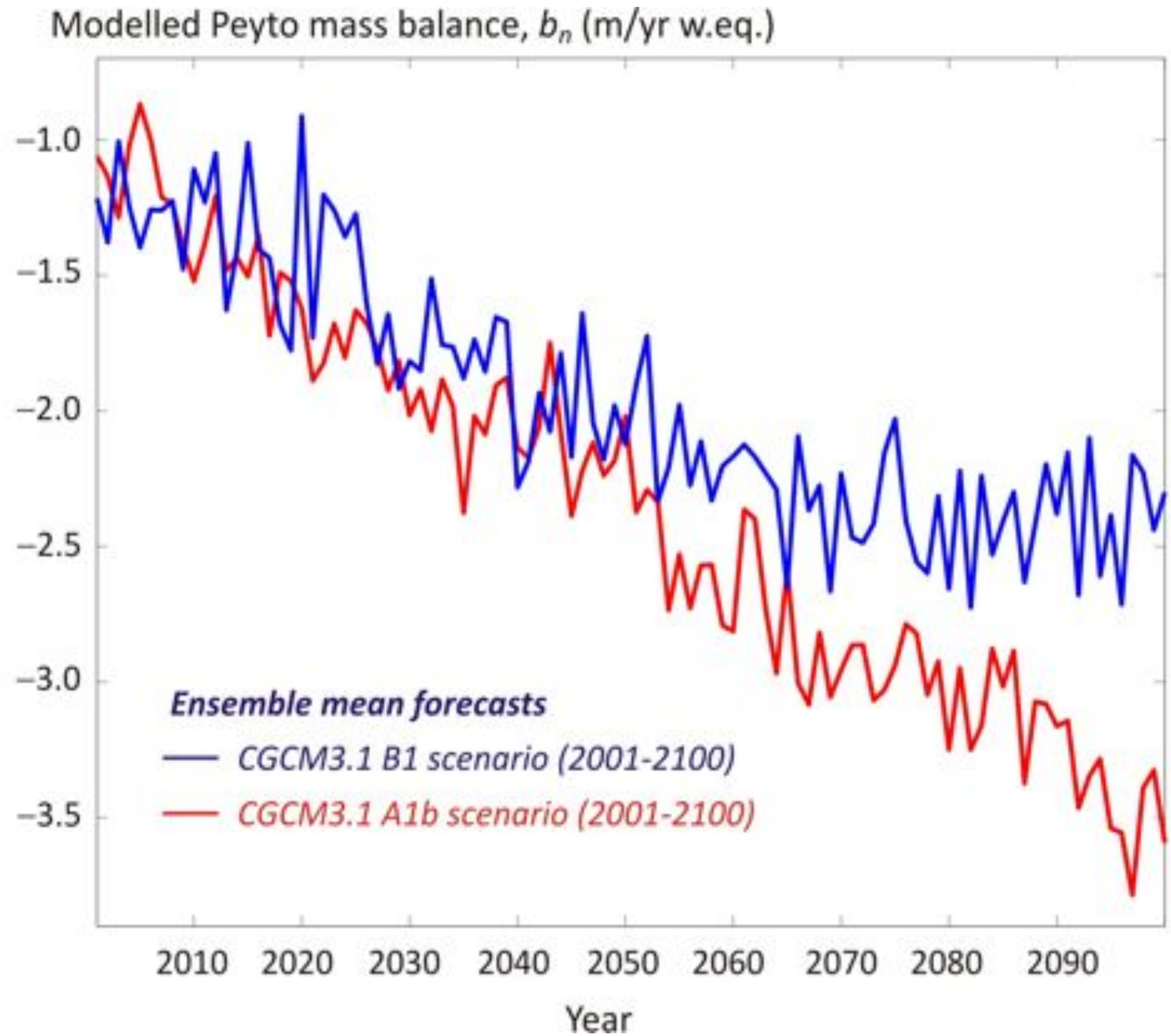




Mean annual surface air temperature, southern Rockies (°C)
CGCM3.1 scenario A1b, five realizations
Ensemble mean
CGCM3.1 scenario A1b, ensemble mean
CGCM3.1 scenario B1, ensemble mean
6
5
4
3
2
1
2010
2020
2030
2040
2050
2060
2070
2080
2090
Year



Modelled Peyto mass balance, b_n (m/yr w.eq.)
CGCM3.1 A1b scenario (2001-2100)
Different realizations and ensemble mean
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−3.0
−3.5
−4.0
−4.5
2010
2020
2030
2040
2050
2060
2070
2080
2090
Year



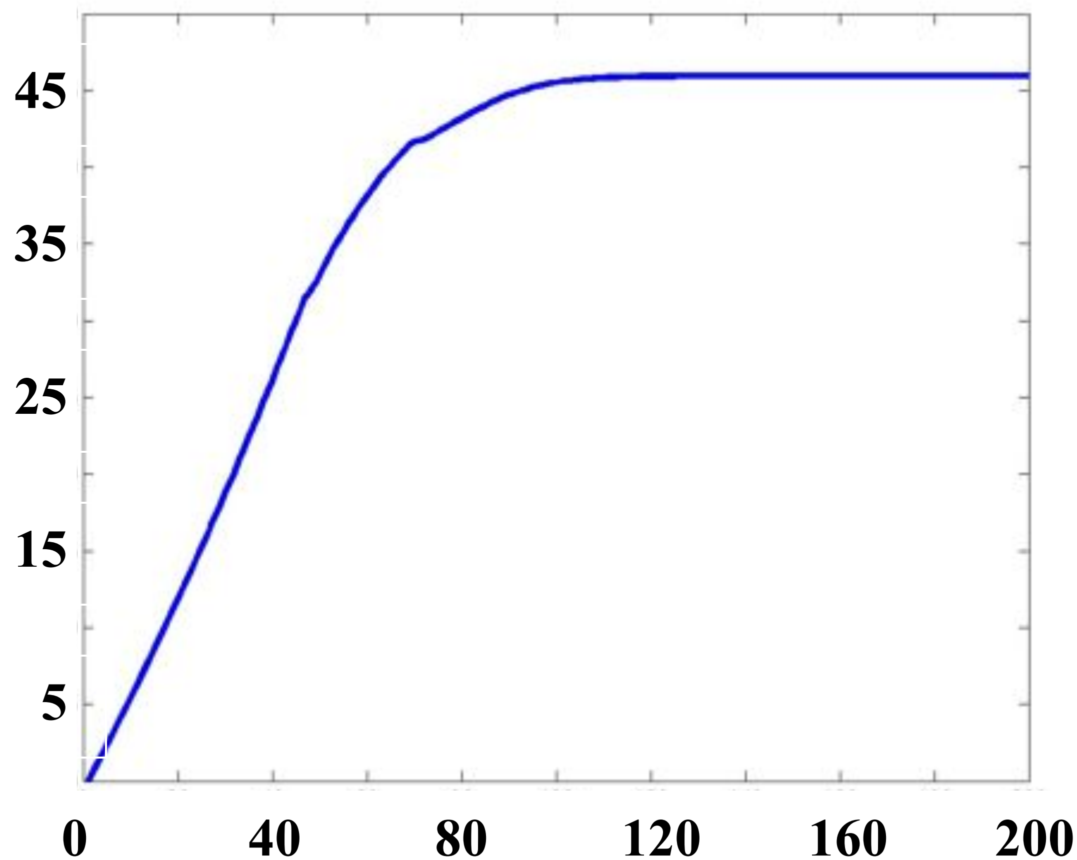
Modelled Peyto mass balance, b_n (m/yr w.eq.)
−1.0
−1.5
−2.0
−2.5
−3.0
−3.5
Ensemble mean forecasts
CGCM3.1 B1 scenario (2001-2100)
CGCM3.1 A1b scenario (2001-2100)
2010
2020
2030
2040
2050
2060
2070
2080
2090
Year

A simple model of glacier dynamics

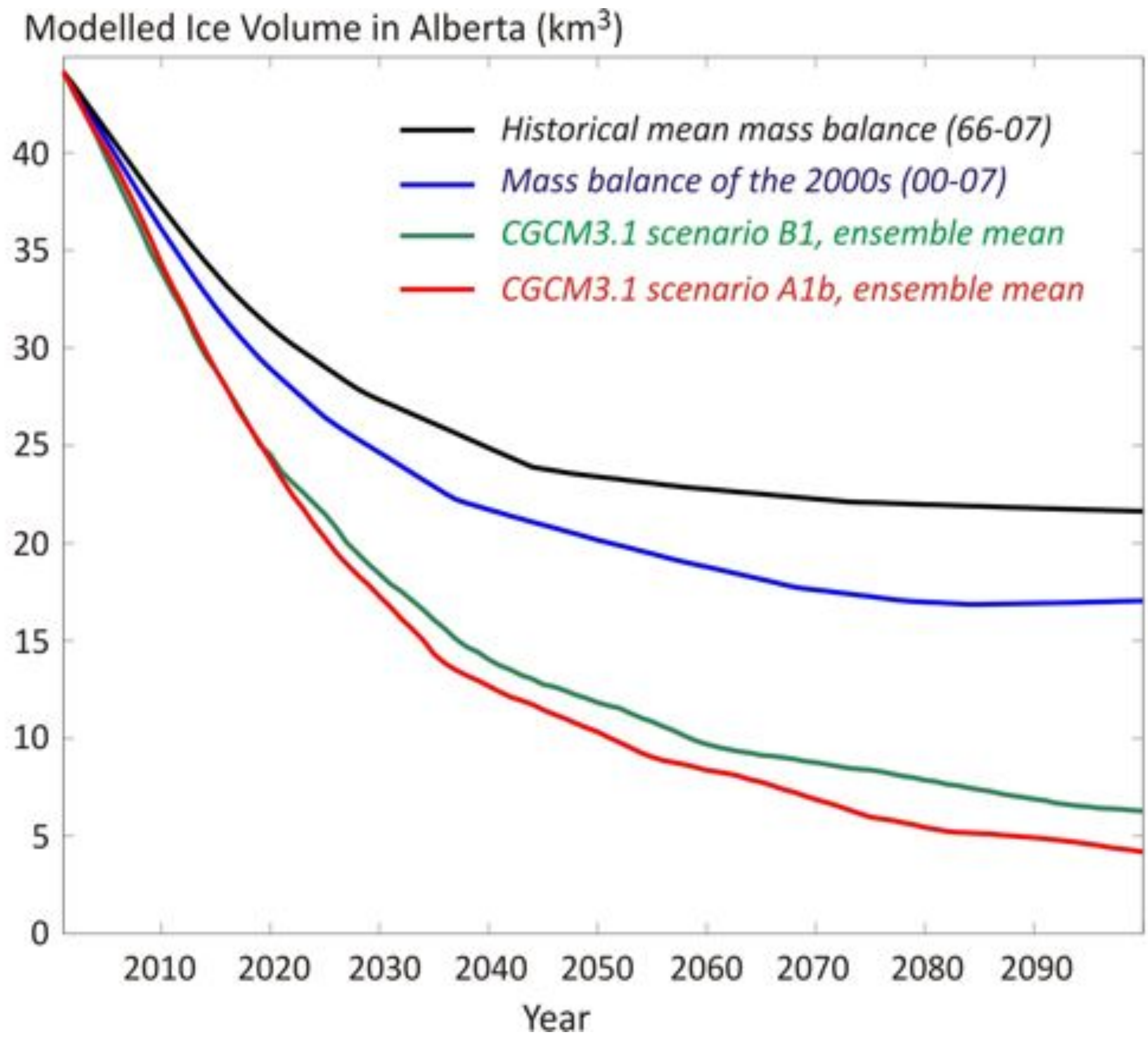
For each vertical level:

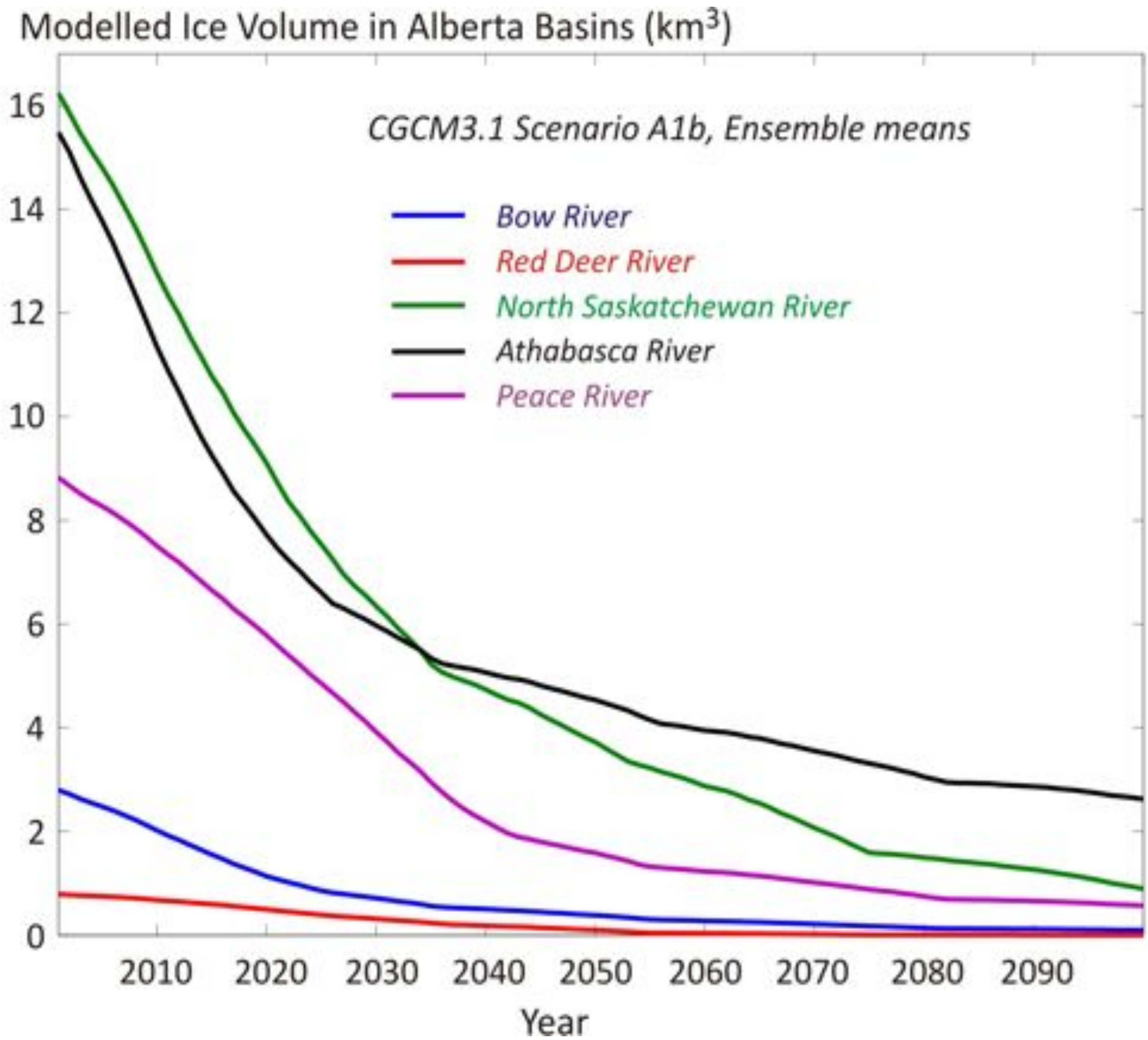
$$\frac{\square H}{\square t} = \square \square \square \, Q + b_n$$

$$Q = \square \, A \, H^5 \, \square s^3$$



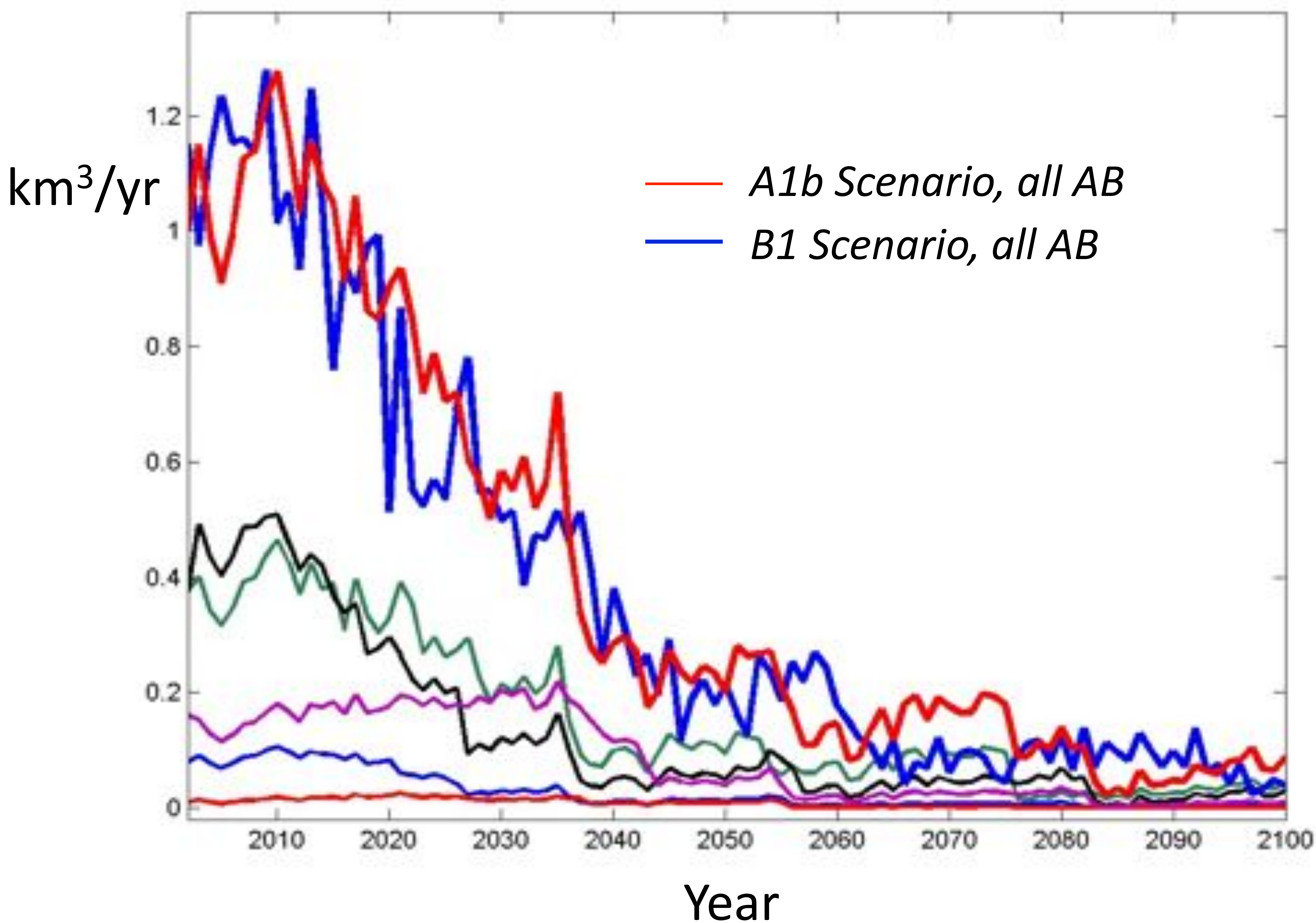
Model spinup

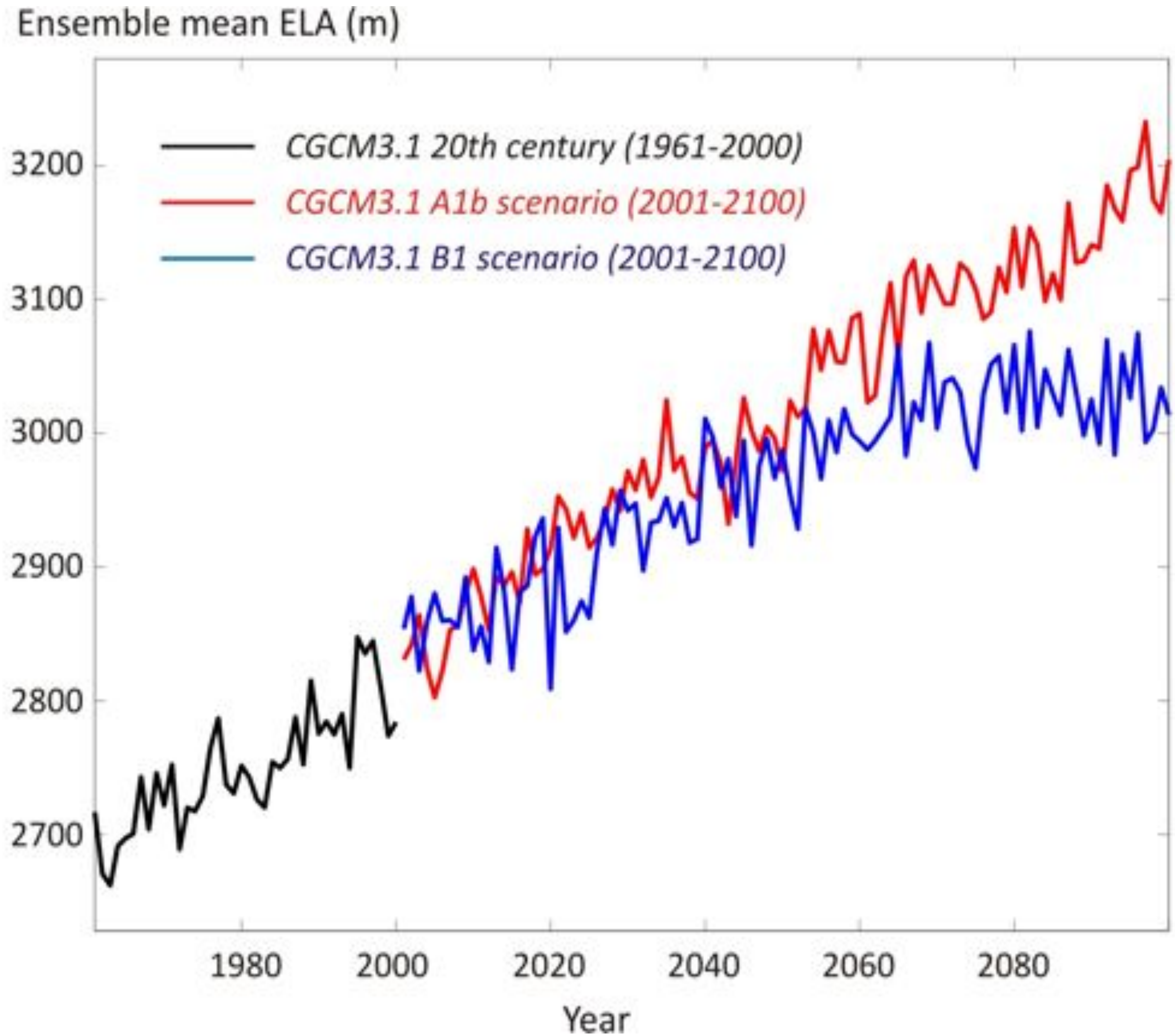

Modelled Ice Volume in Alberta (km3)
Historical mean mass balance (66-07)
Mass balance of the 2000s (00-07)
CGCM3.1 scenario B1, ensemble mean
CGCM3.1 scenario A1b, ensemble mean
0
5
10
15
20
25
30
35
40
2010
2020
2030
2040
2050
2060
2070
2080
2090
Year



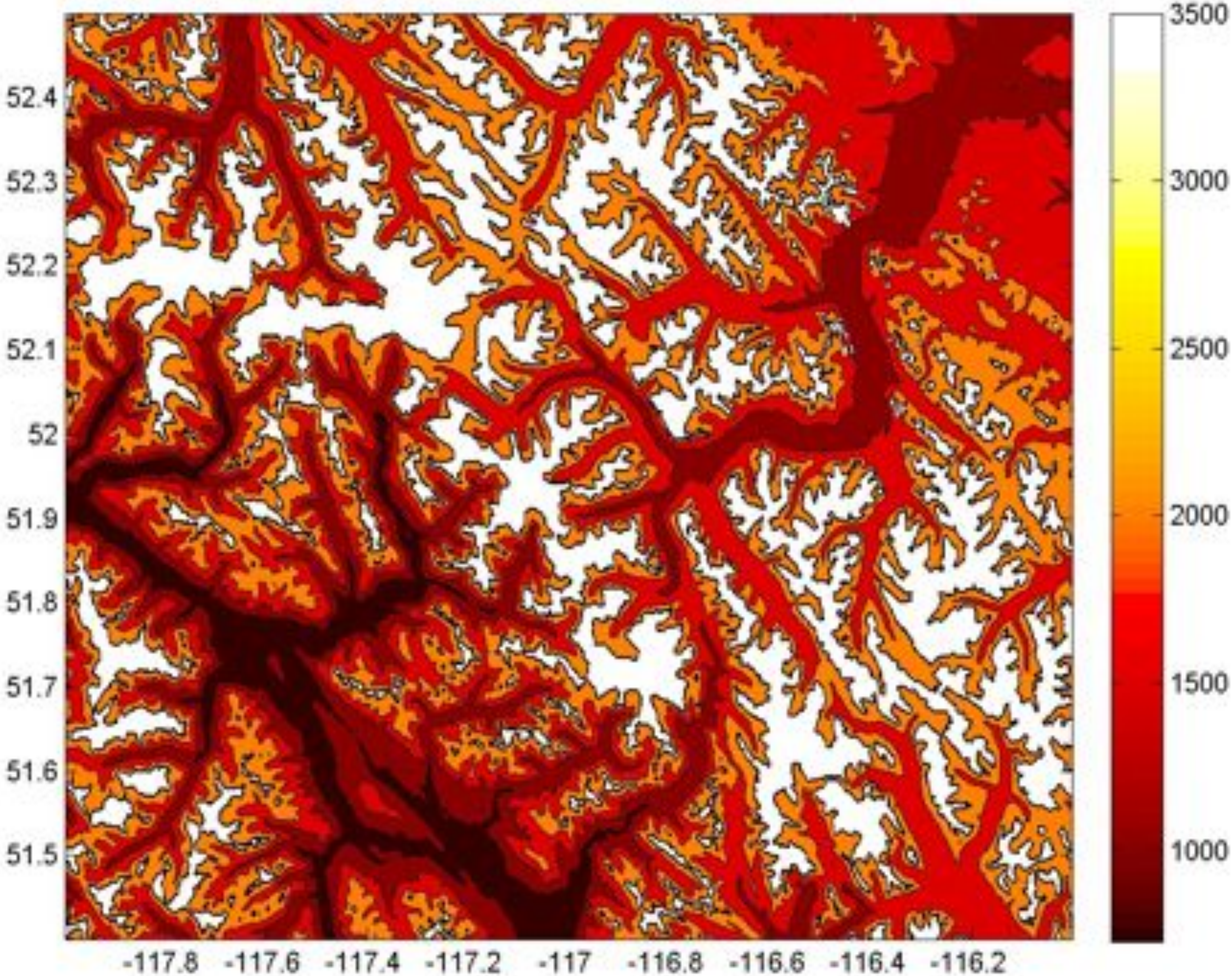
Modelled Ice Volume in Alberta Basins (km3)
CGCM3.1 Scenario A1b, Ensemble means
Bow River
Red Deer River
North Saskatchewan River
Athabasca River
Peace River
16
14
12
10
8
6
4
2
0
2010
2020
2030
2040
2050
2060
2070
2080
2090
Year

Modelled 21st century glacier discharge, AB



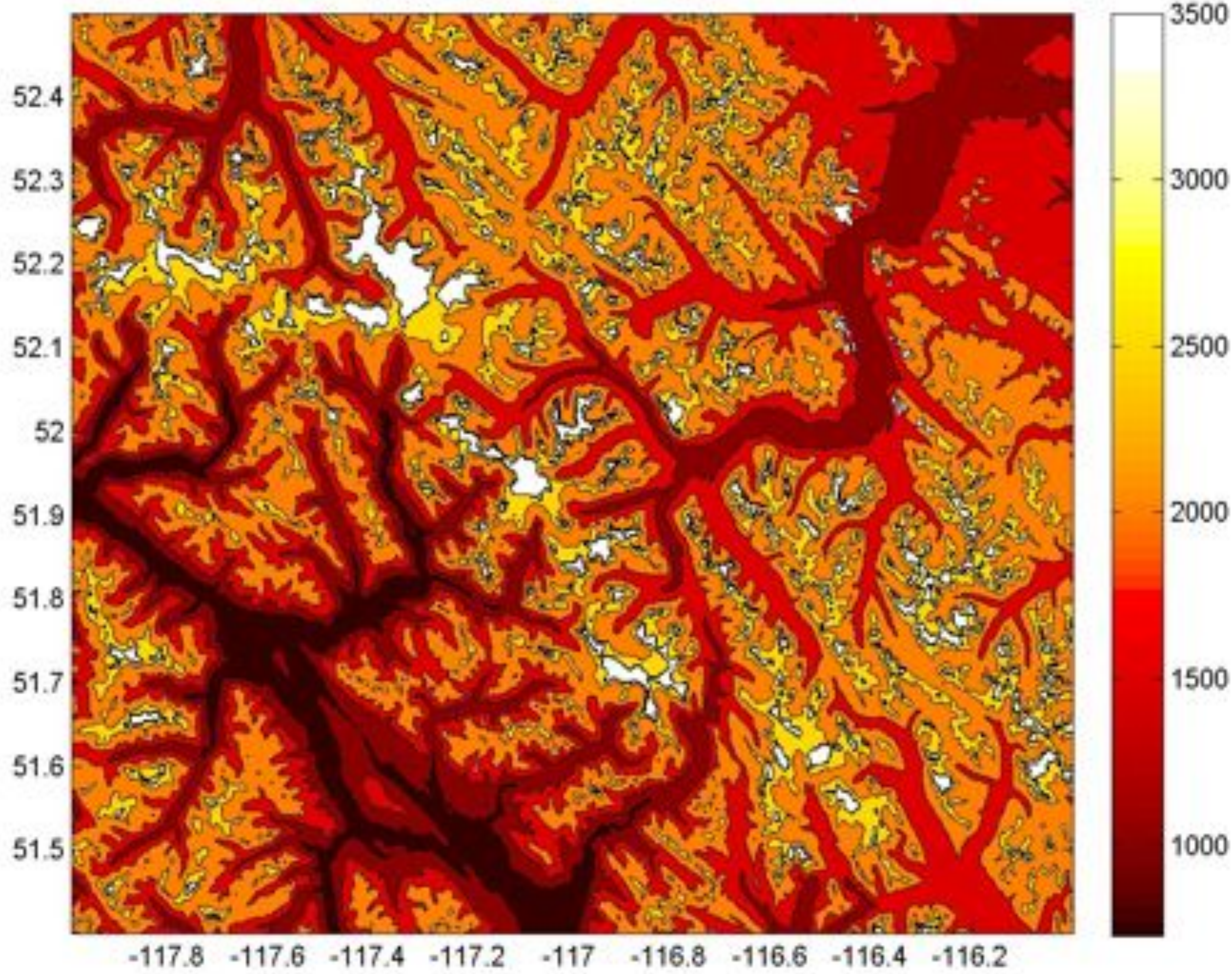


Ensemble mean ELA (m)
CGCM3.1 20th century (1961-2000)
CGCM3.1 A1b scenario (2001-2100)
CGCM3.1 B1 scenario (2001-2100)
3200
3100
3000
2900
2800
2700
1980
2000
2020
2040
2060
2080
Year



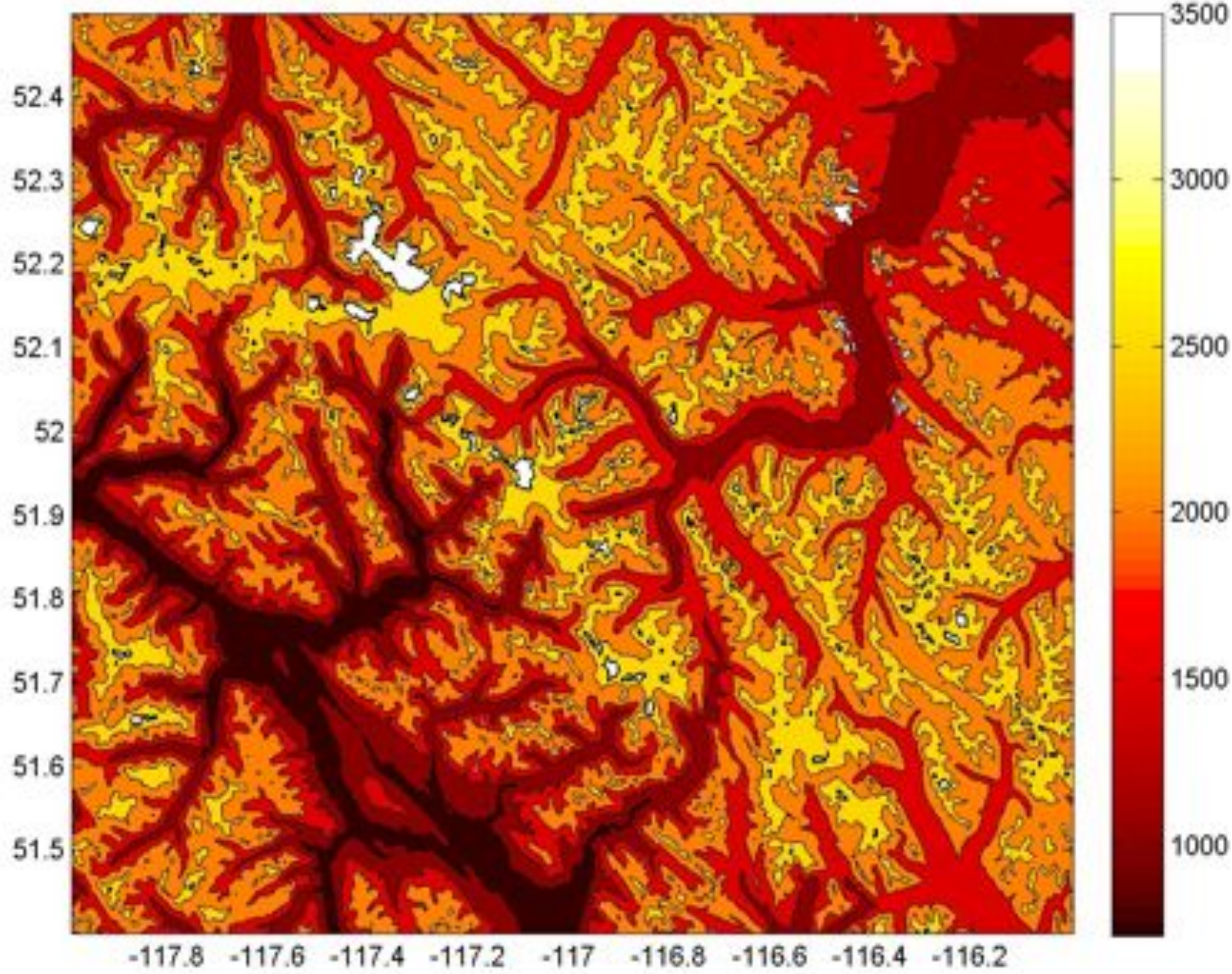
52.4
52.3
52.2
52.1
52
51.9
51.8
51.7
51.6
51.5
-117.8
-117.6
-117.4
-117.2
-117
-116.8
-116.6
-116.4
-116.2
3500
3000
2500
2000
1500
1000

ELA = 2600 m



52.4
52.3
52.2
52.1
52
51.9
51.8
51.7
51.6
51.5
-117.8
-117.6
-117.4
-117.2
-117
-116.8
-116.6
-116.4
-116.2
3500
3000
2500
2000
1500
1000

ELA = 2800 m



52.4
52.3
52.2
52.1
52
51.9
51.8
51.7
51.6
51.5
-117.8
-117.6
-117.4
-117.2
-117
-116.8
-116.6
-116.4
-116.2
3500
3000
2500
2000
1500
1000

ELA = 3000 m

Summary

First-order estimate of the glacier volume, future mass balance, and meltwater discharge for Alberta's glaciated catchments.

By far the greatest uncertainty is the present-day ice volume. We estimate 30-110 km^3, more likely to be near the low end. If 40-50 km^3 at present, we forecast reductions to 5-10 km^3 by 2100.

This is over-simplified and is no substitute for physics-based models of mass balance and ice flow

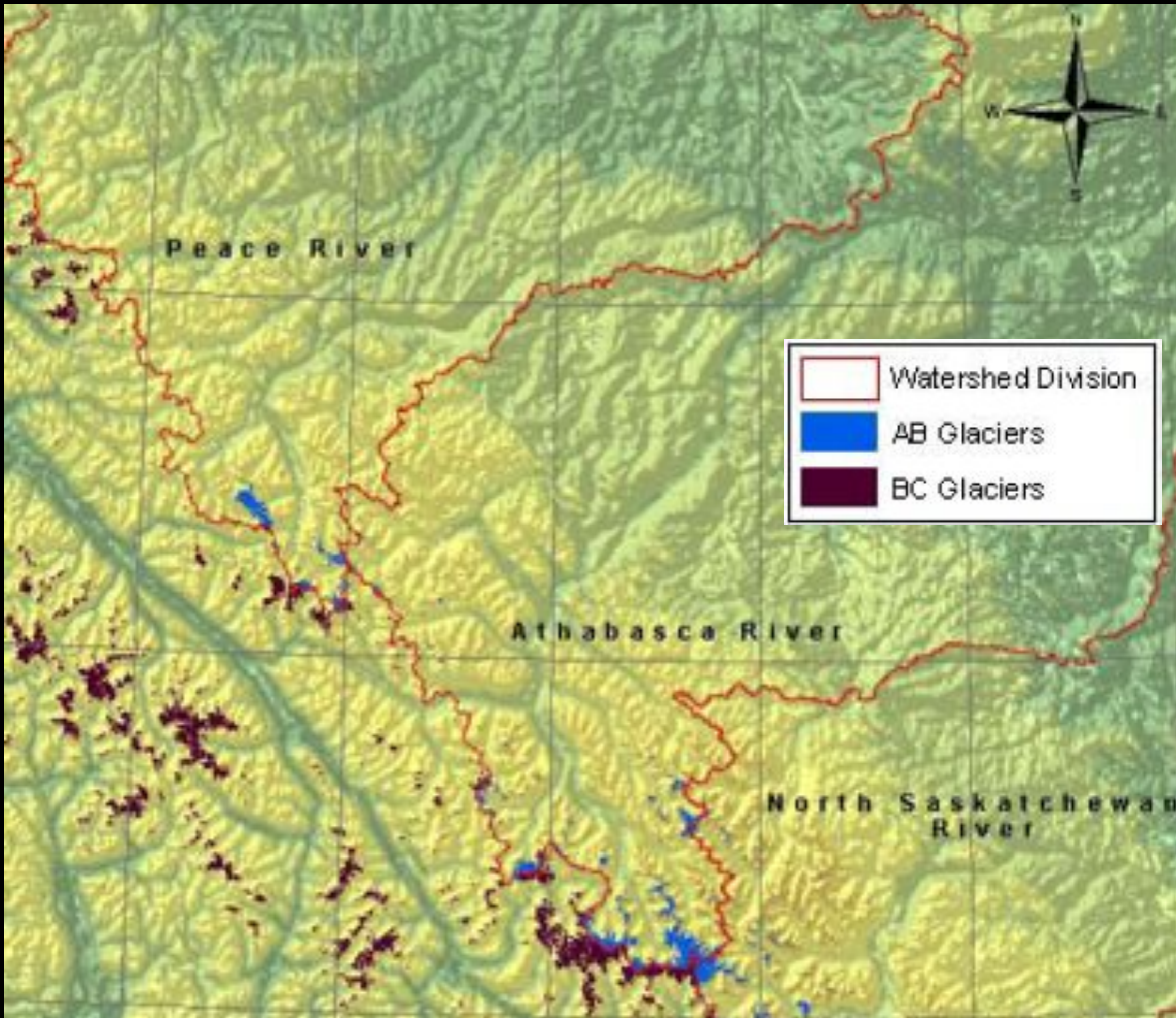

Questions?

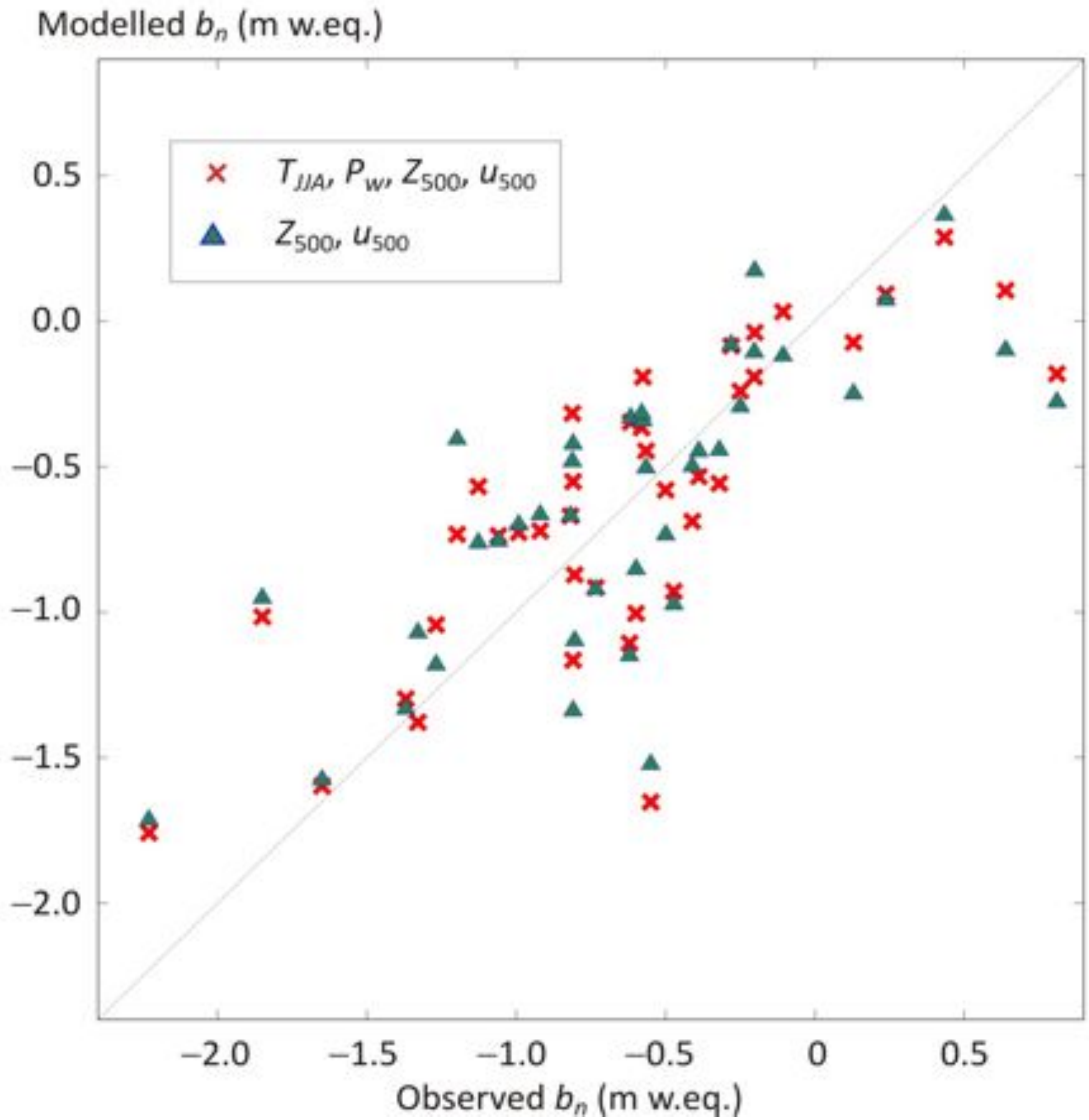

Haig Glacier, Sept 2006

Forecasts for the World's Glaciers

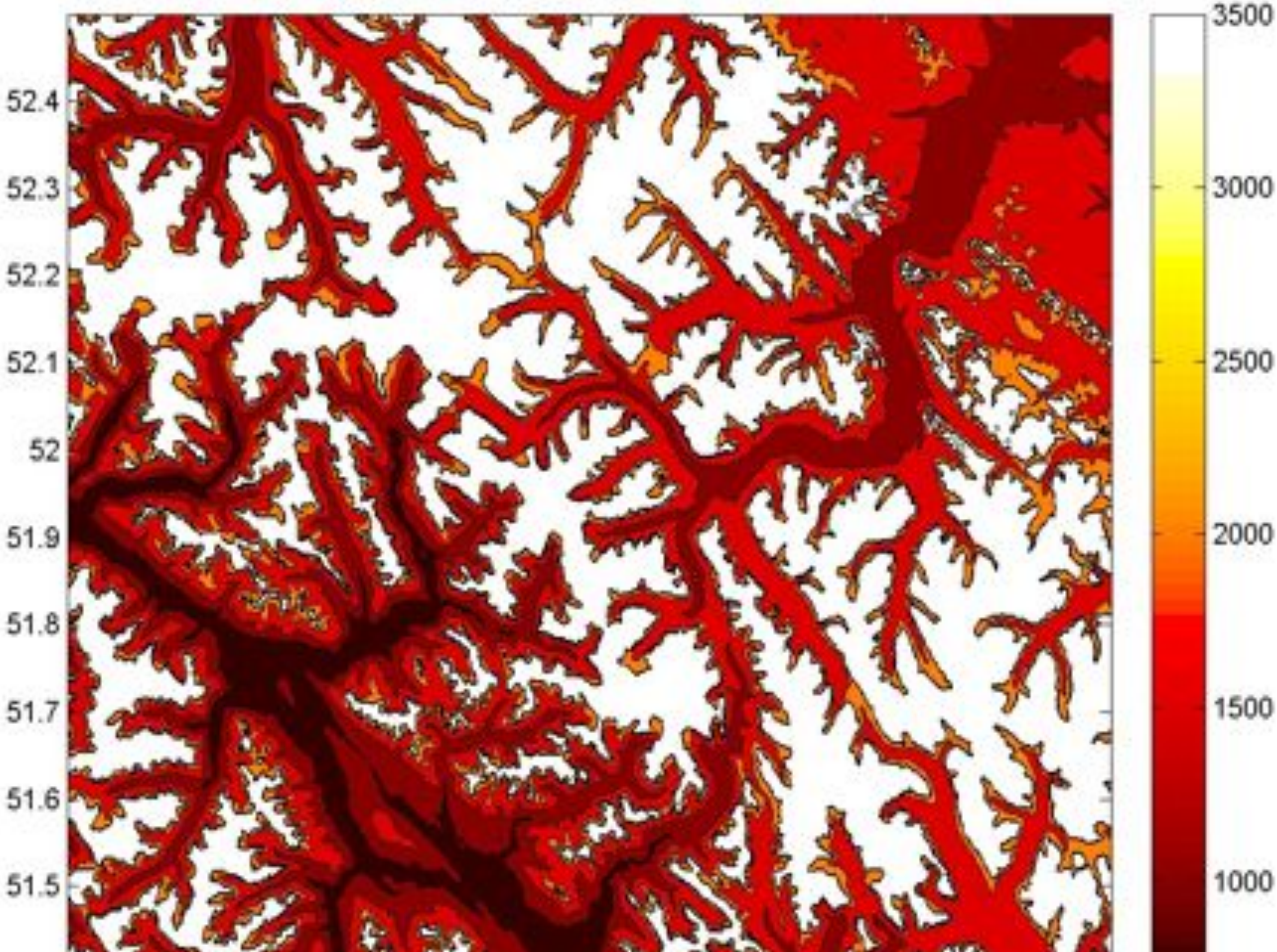
There are a few aspects to this:

- glacier dynamics
  - subglacial topography
  - basal sliding → role of meltwater
- **high-resolution climate scenarios**
- **translating climate scenarios to glacier mass balance**

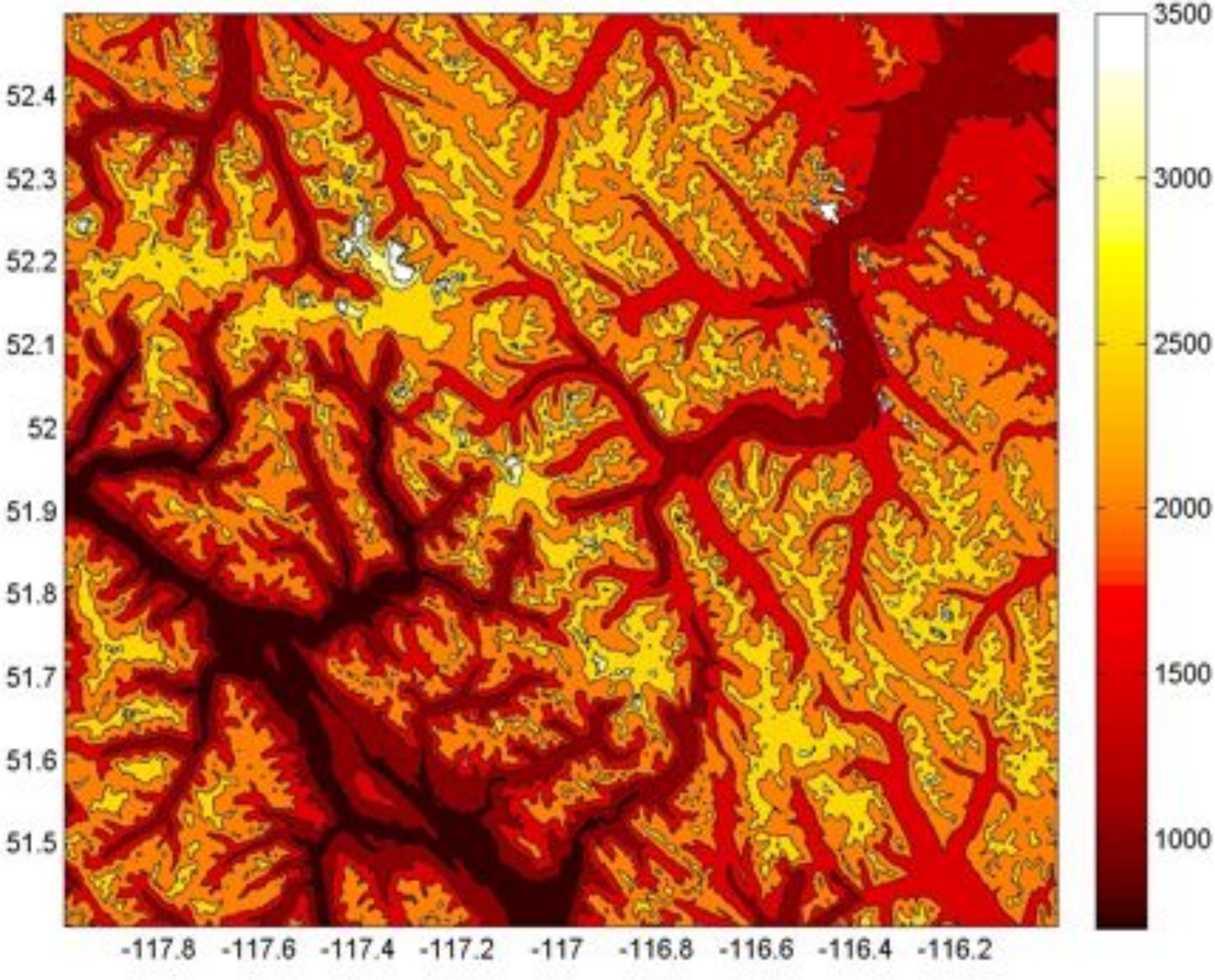

N
W
E
S
Peace River
Athabasca River
North Saskatchewan River
Watershed Division
AB Glaciers
BC Glaciers



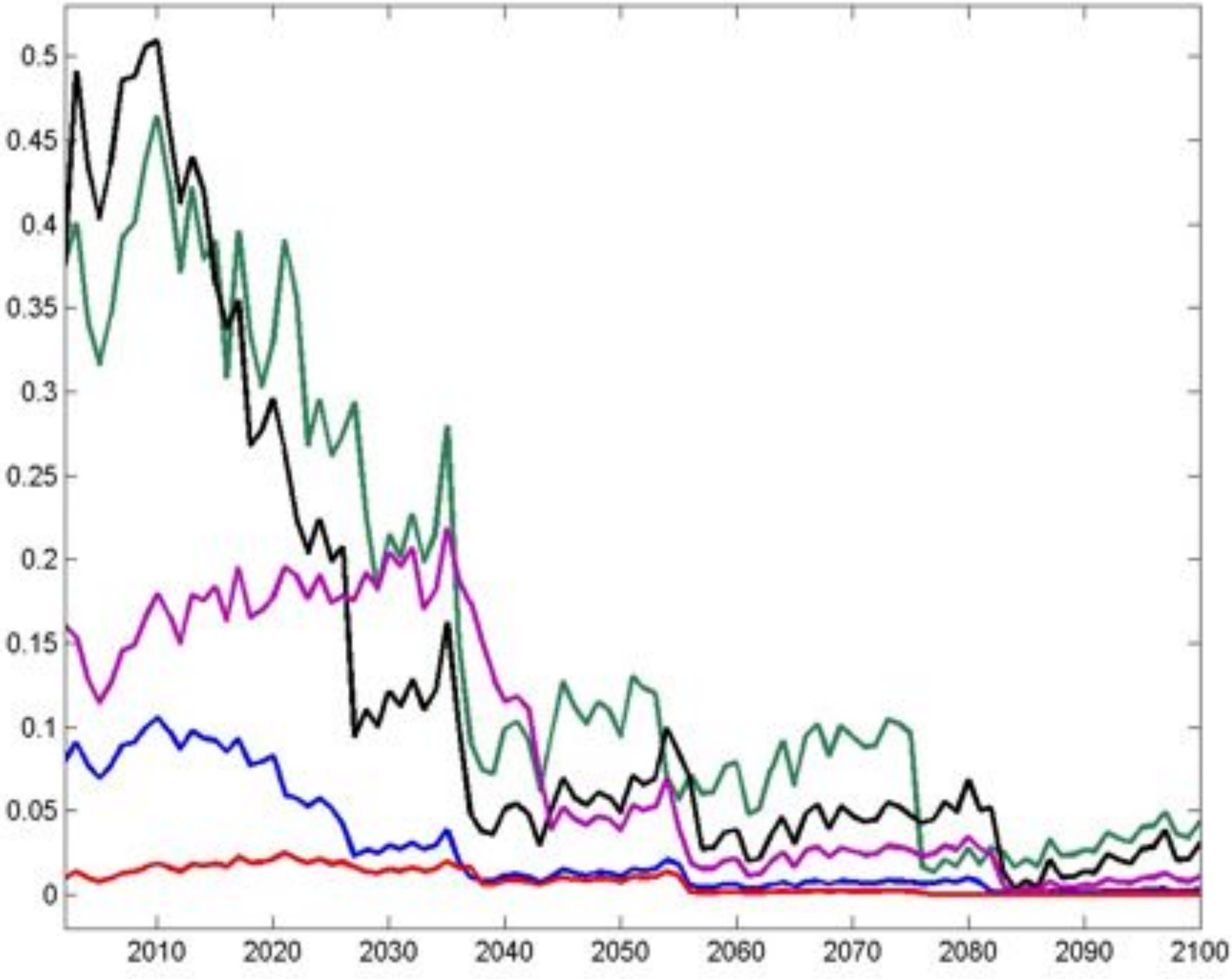
Modelled b_n (m w.eq.)
T_{JJA}, P_w, Z_{500}, u_{500}
Z_{500}, u_{500}
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.0
−1.5
−1.0
−0.5
0
0.5
Observed b_n (m w.eq.)



3500
3000
2500
2000
1500
1000
52.4
52.3
52.2
52.1
52
51.9
51.8
51.7
51.6
51.5
-117.8
-117.6
-117.4
-117.2
-117
-116.8
-116.6
-116.4
-116.2


52.4
52.3
52.2
52.1
52
51.9
51.8
51.7
51.6
51.5
-117.8
-117.6
-117.4
-117.2
-117
-116.8
-116.6
-116.4
-116.2
3500
3000
2500
2000
1500
1000

ELA = 3100 m



0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100