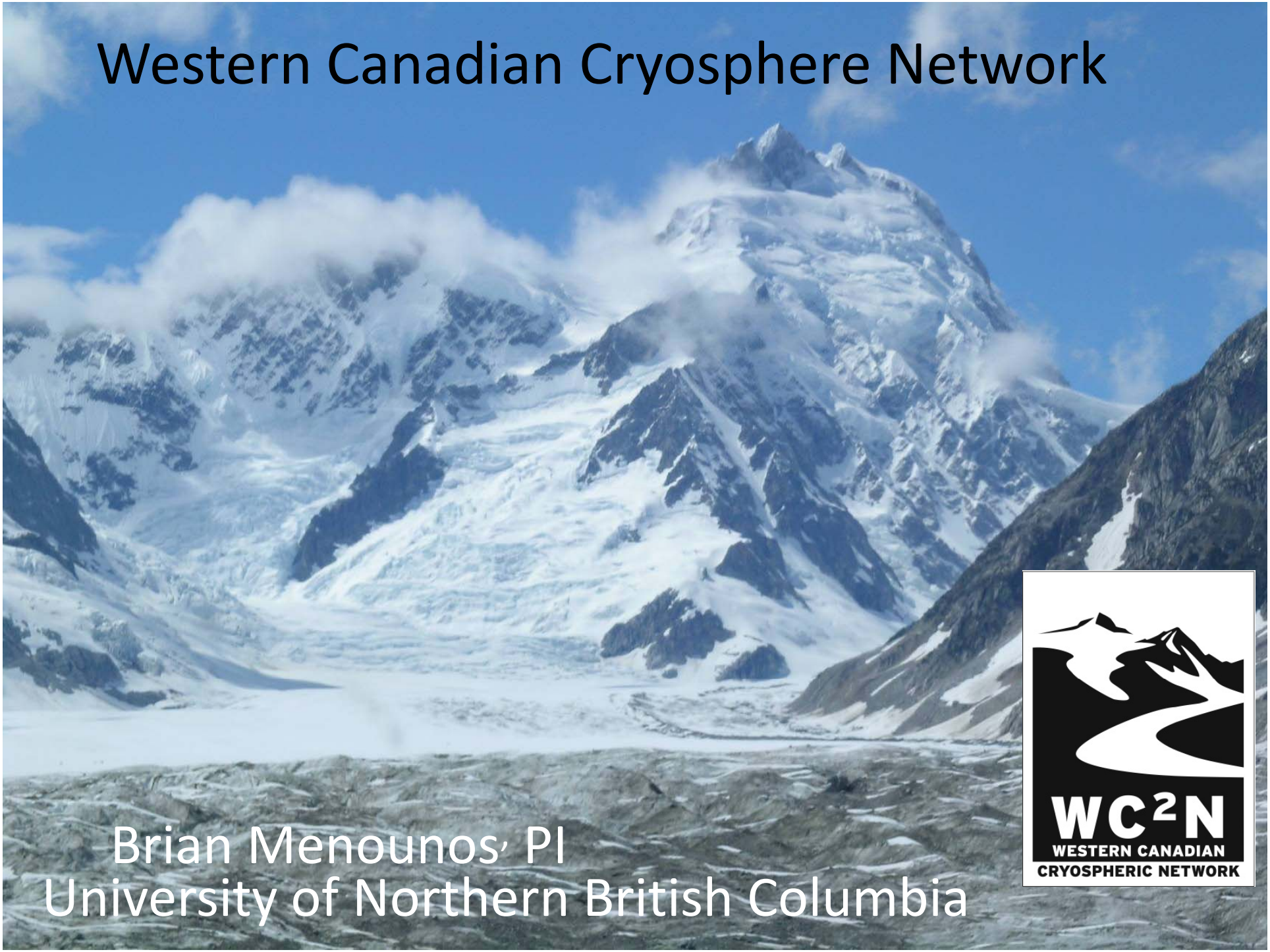
Western Canadian Cryosphere Network



Brian Menounos, PI
University of Northern British Columbia

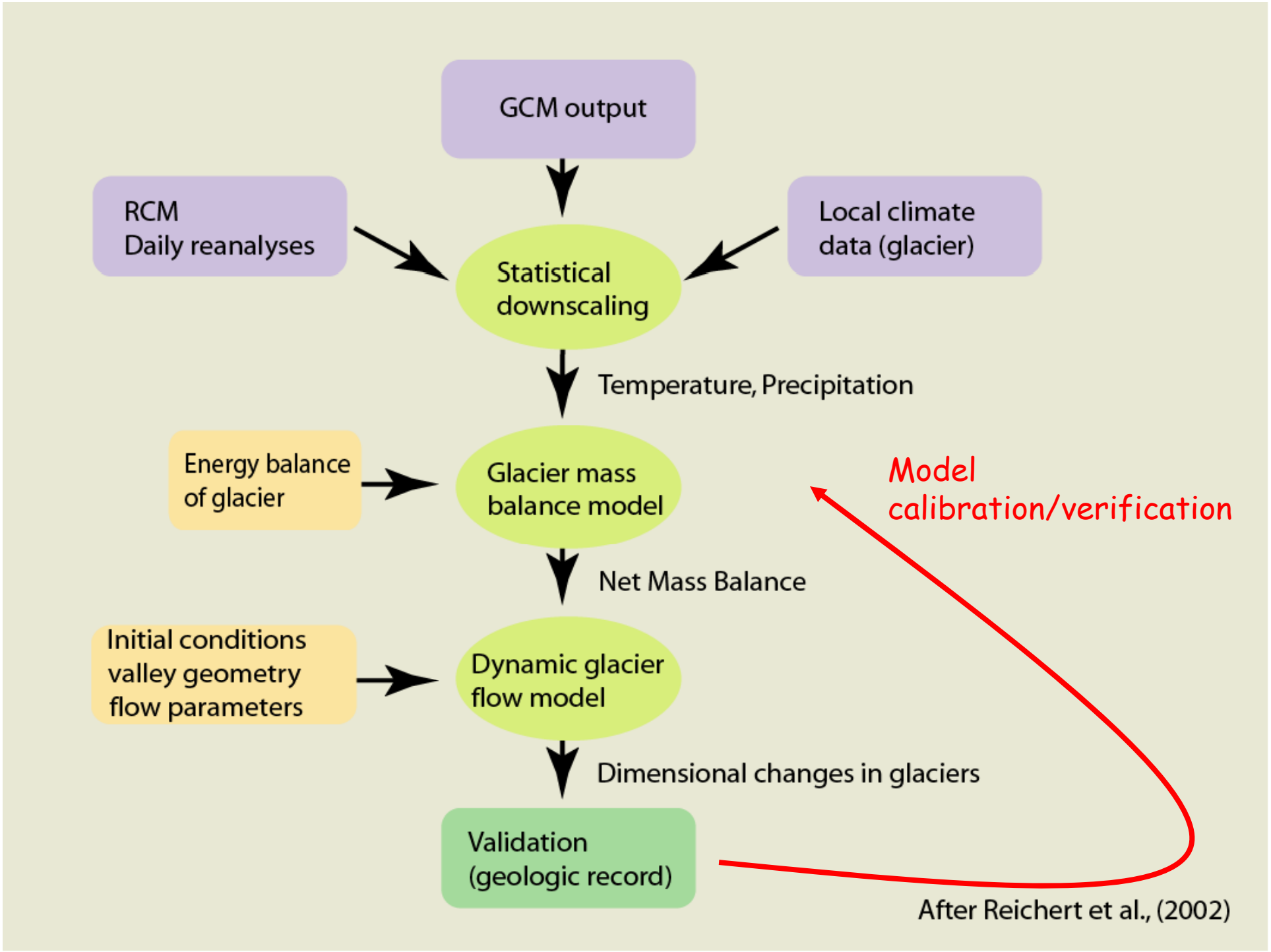
WC²N
WESTERN CANADIAN
CRYOSPHERIC NETWORK

WC2N: Research Objectives

1) Document N. Pacific climate variability and glacier extent (400 yrs ago to present)

2) Detail meteorological processes and their links to glacier nourishment (glacier mass balance)

3) Predict how glaciers will respond to projected climate change over the next 50-150 years


GCM output
RCM
Daily reanalyses
Local climate
data (glacier)
Statistical
downscaling
Temperature, Precipitation
Energy balance
of glacier
Glacier mass
balance model
Model
calibration/verification
Net Mass Balance
Initial conditions
valley geometry
flow parameters
Dynamic glacier
flow model
Dimensional changes in glaciers
Validation
(geologic record)
After Reichert et al., (2002)

Western Canadian Cryosphere Network

Investigators: Andrew Bush (**U. Alberta**); John Clague (**SFU**); Garry Clarke (**UBC**); Stephen Déry (**UNBC**); Peter Jackson (**UNBC**); Shawn Marshall (**U. Calgary**); Brian Menounos (**UNBC**); Dan Moore (**UBC**); Dan Smith (**U. Vic**); Eric Steig (**U. Washington**); Roger Wheate (**UNBC**)

<u>Research Collaborators</u>: Doug Clark (**Western Washington University**); Mike Demuth (**Natural Resources Canada**); Howard Conway (**U. Washington**); Kenichi Matsuoka (**U. Washington**); Joseph McConnell (**Desert Research Institute** – U. Nevada); Al Rasmussen (**U Washington**); Sonia Talwar (**Natural Resources Canada**); Paul Whitfield (**Env. Canada**)

Western Canadian Cryospheric Network

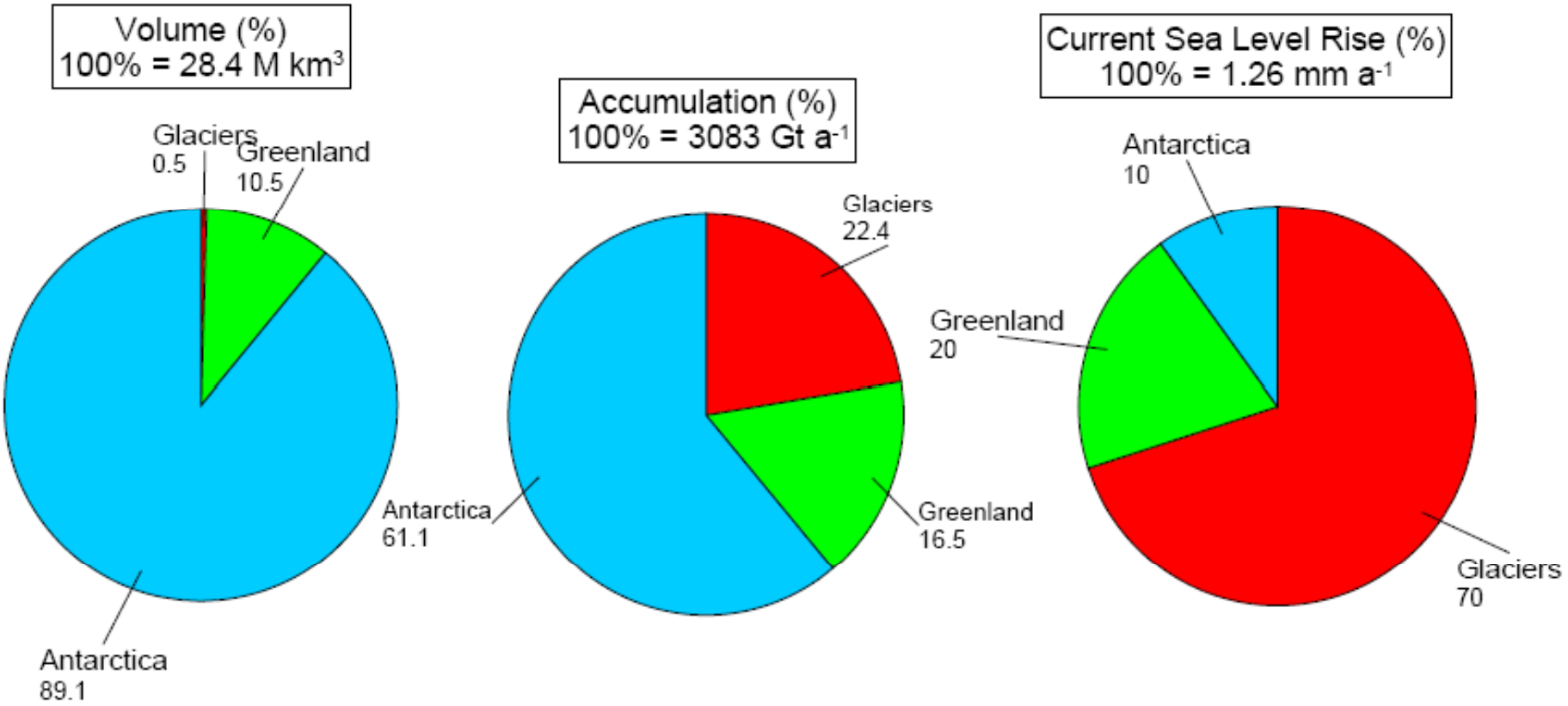
Research Partners: BC Hydro; BC Ministry of Sustainable Resources Management; BC Parks; BC Ministry of Environment (MoE); Columbia Basin Trust (CBT); Fisheries and Oceans Canada (DFO); Environment Canada - Cryosphere System in Canada (CRYSYS); Environment Canada - Meteorological Service of Canada (MSC); Global Land Ice Measurement from Space (GLIMS); Natural Resources Canada - National Glaciology Programme (NGP); Natural Resources Canada - Terrain Sciences Division National Snow and Ice Data Center (NSIDC); Parks Canada

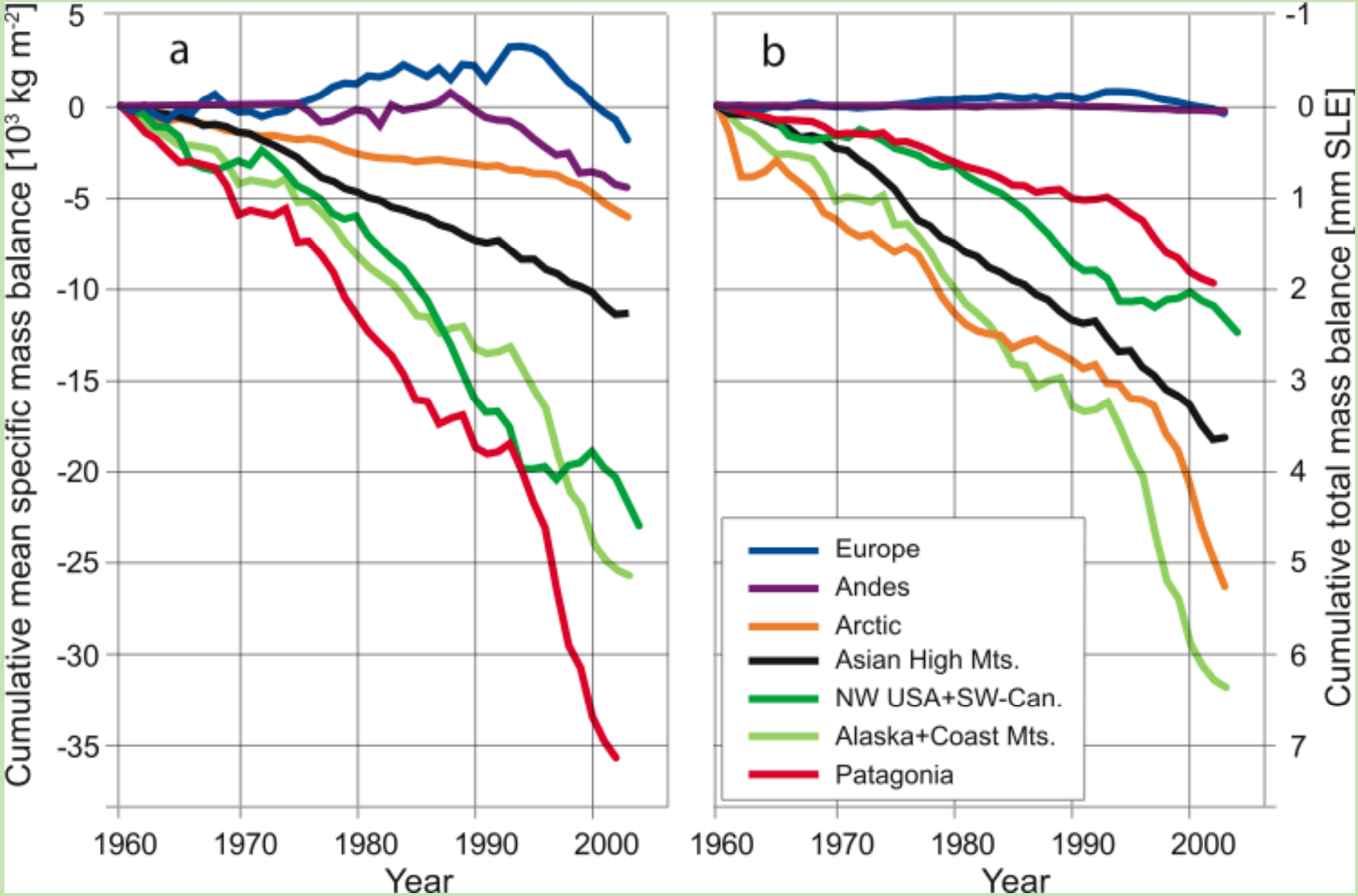
Mountain glaciers in the cryosphere

	Area (10^6 km^2)	Volume (10^6 km^3)	Sea Level (m)
Antarctica	12.1	29	68
Greenland	1.71	2.95	7.4
Mountain Glaciers	0.68	0.18	0.5
Sea Ice	16 to 25		0
Permafrost	22.7	?	?
Continental Snow	1 to 50	x	x

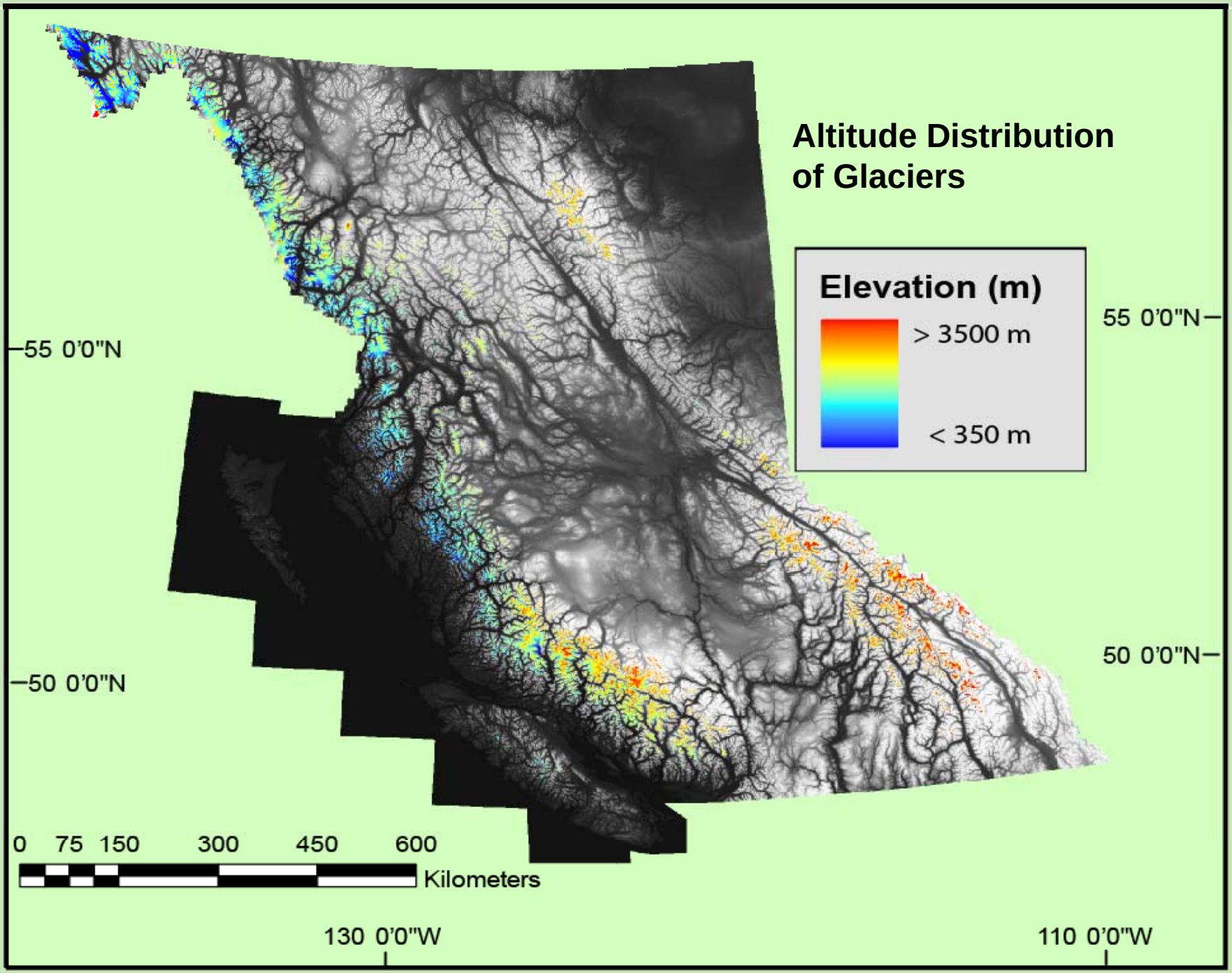
(IPCC 2001)

Global glaciers and ice sheets





IPCC – AR4 (2007)


Altitude Distribution of Glaciers
Elevation (m)
> 3500 m
< 350 m
55 0'0"N
50 0'0"N
0 75 150 300 450 600
Kilometers
130 0'0"W
110 0'0"W

Western Canadian glaciers

- **Natural climate stations**

  - Winter ppt; summer temp.

- **Critical resource**

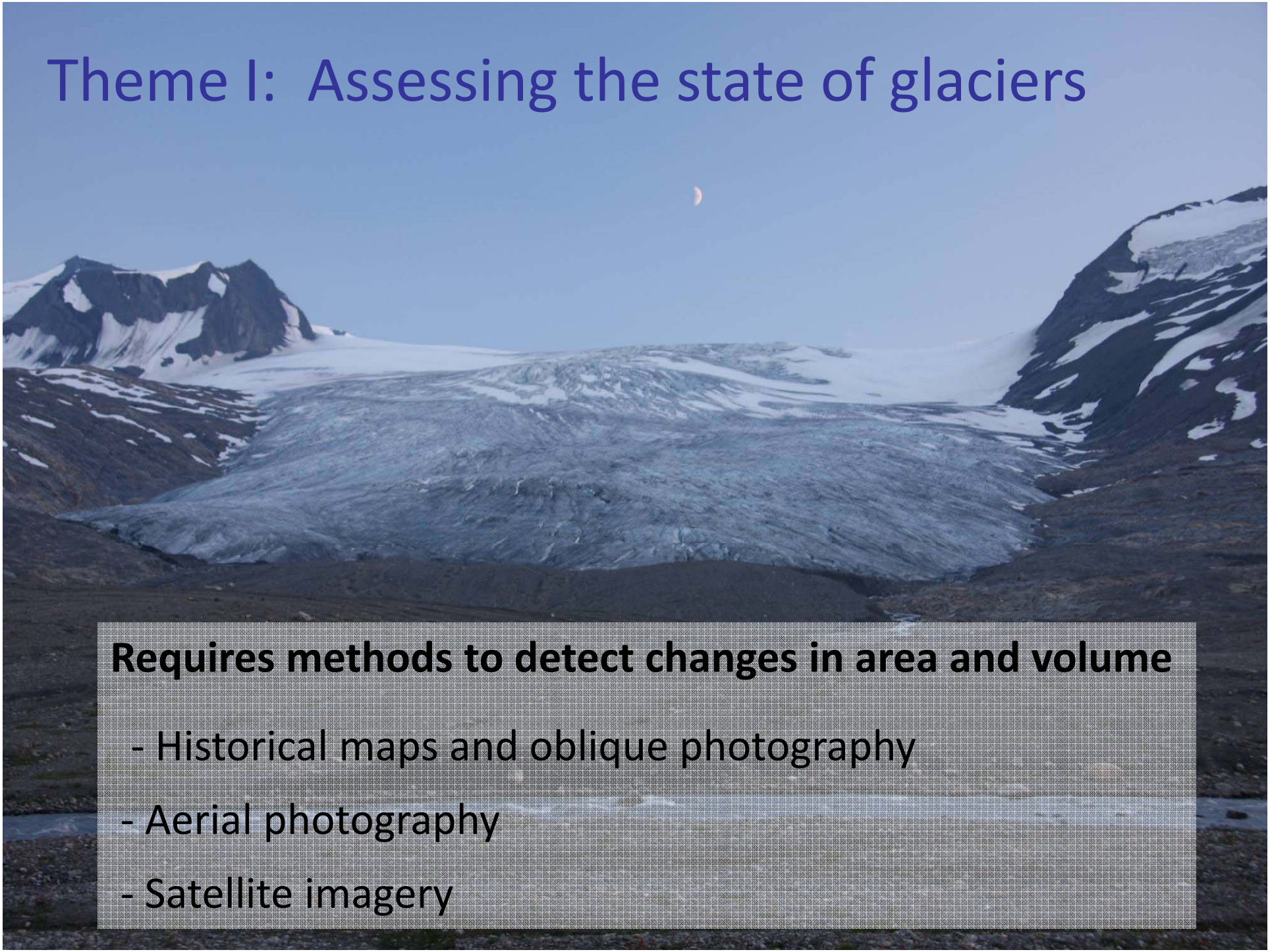
  - 30, 000 km^2 in BC (~ 3% landmass)

  - Freshwater (Canada and US)

  - Serve as flow regulators & thermostats

  - Hydro power from surface runoff (90% BC; 17% AB)

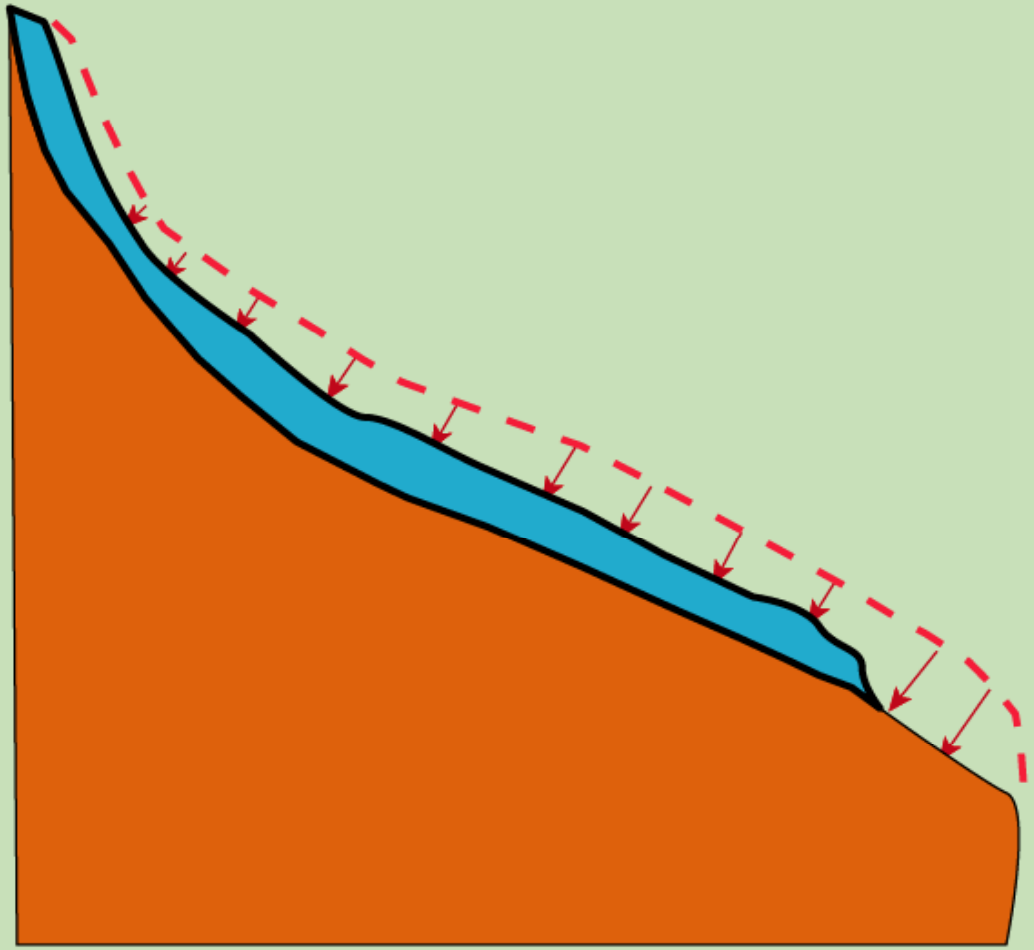
Theme I: Assessing the state of glaciers



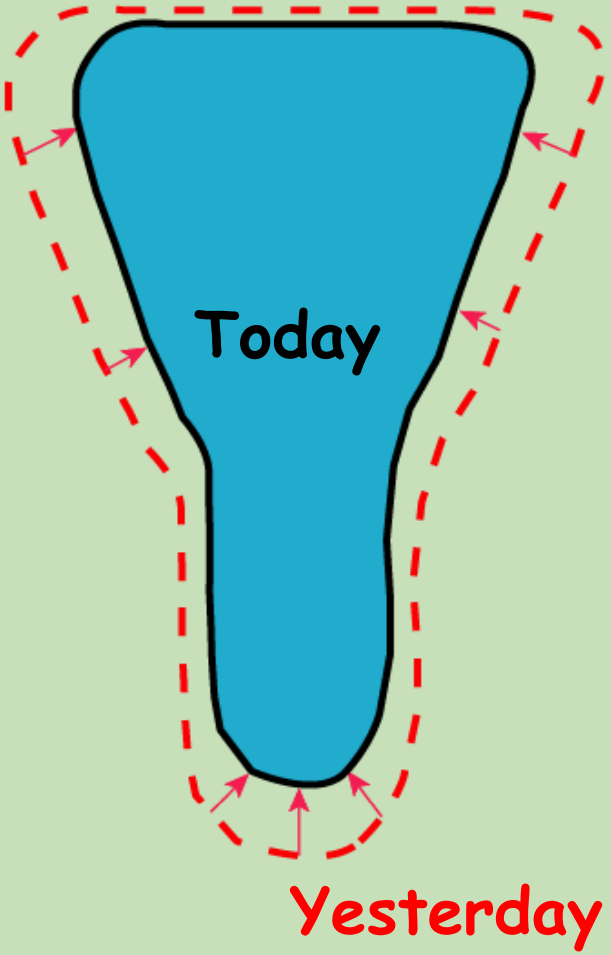
Requires methods to detect changes in area and volume

- Historical maps and oblique photography
- Aerial photography
- Satellite imagery

Changes in Glacier Thickness

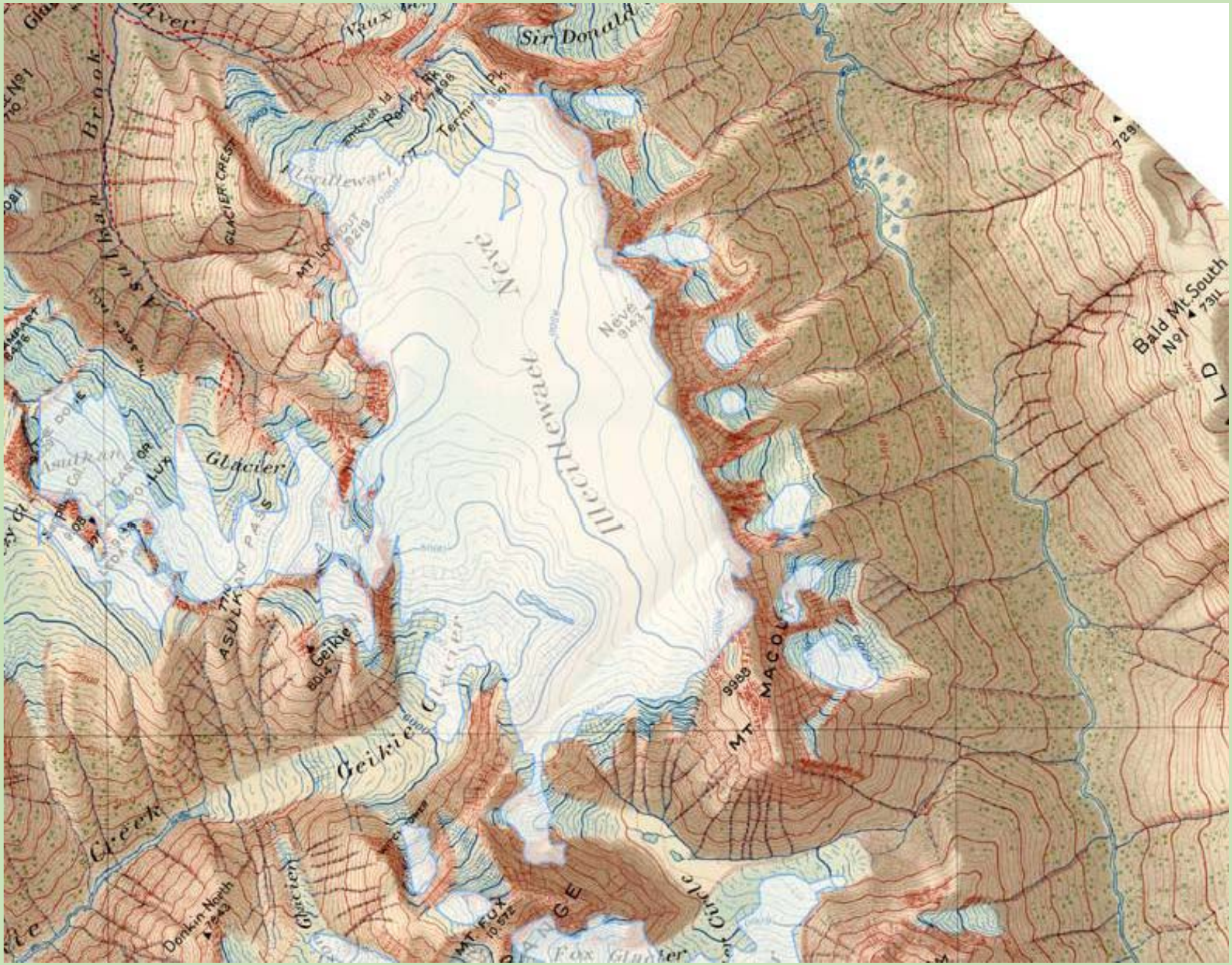


Changes in Glacier Area

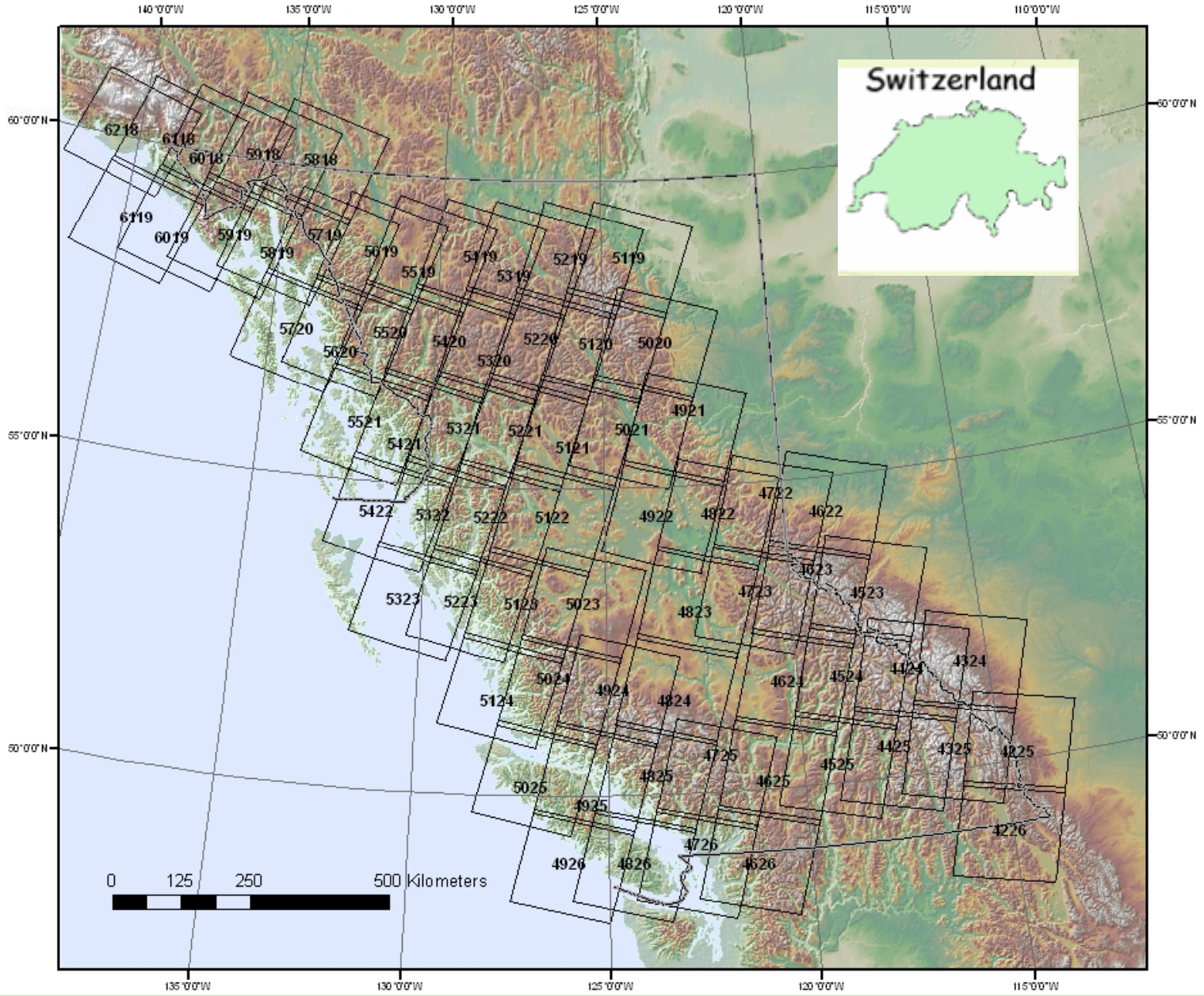


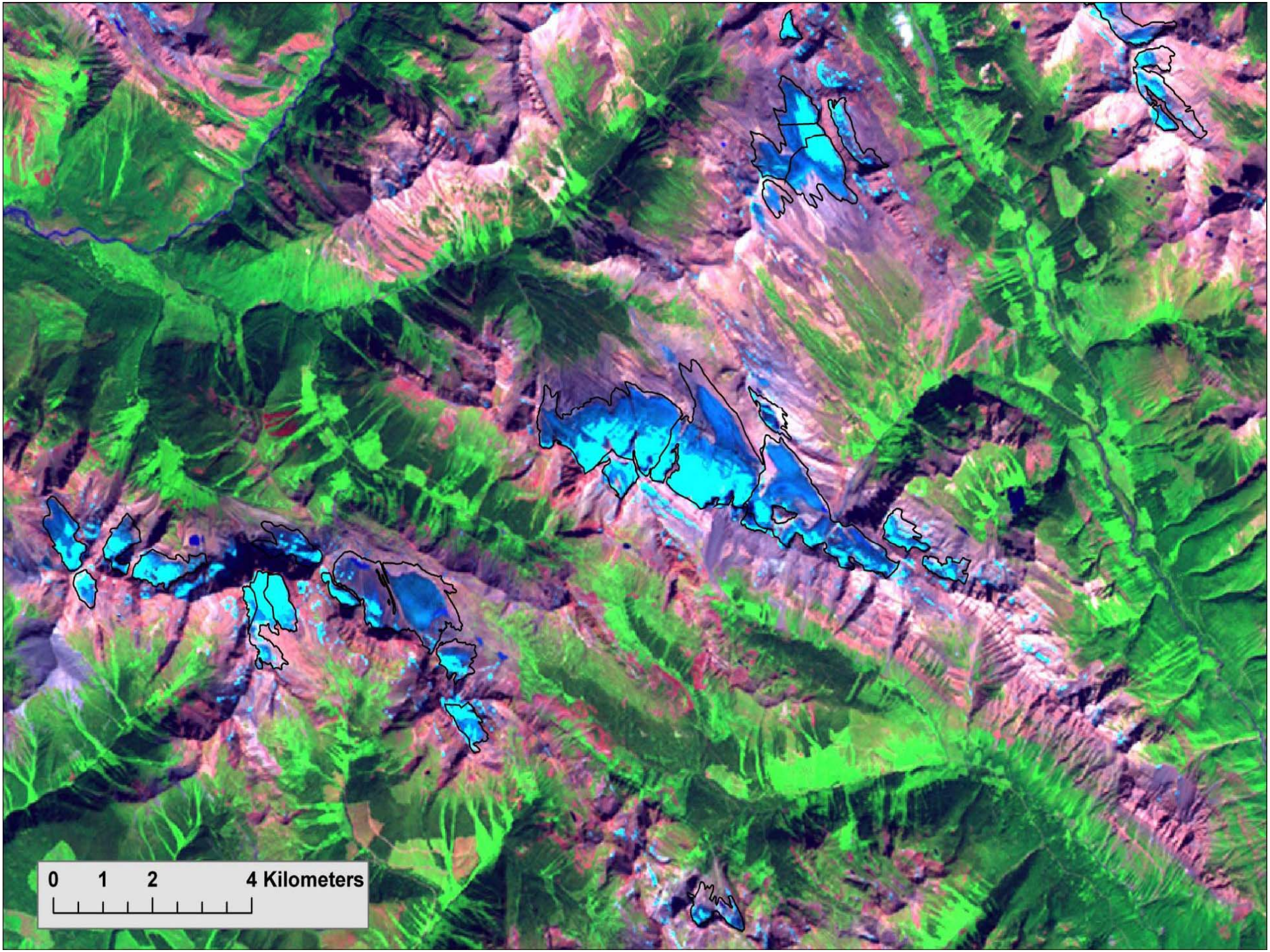
Robson Glacier (1908 – 2004)

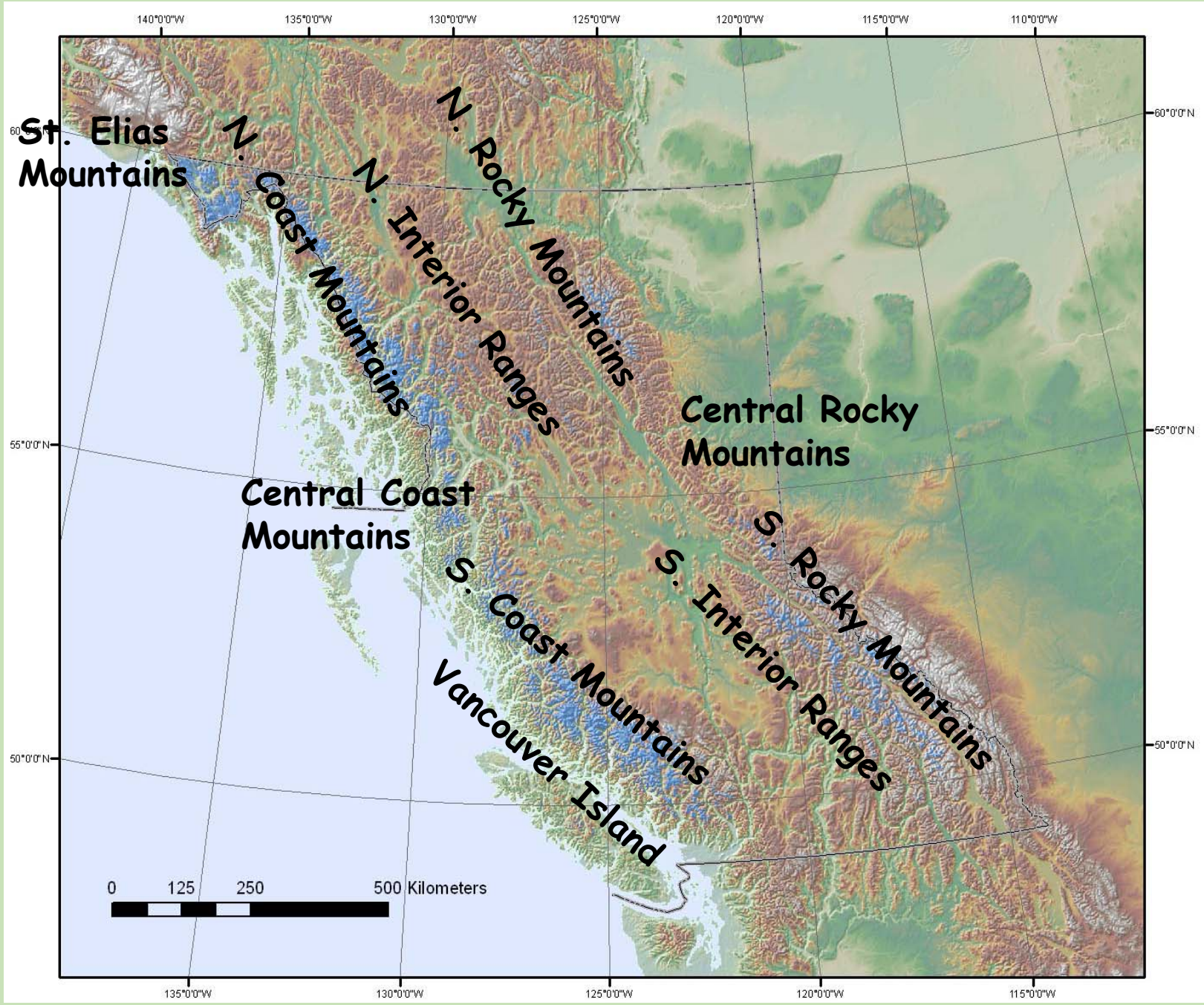
Glacier loss 1906 -1989 (TRIM – superimposed ice in white)

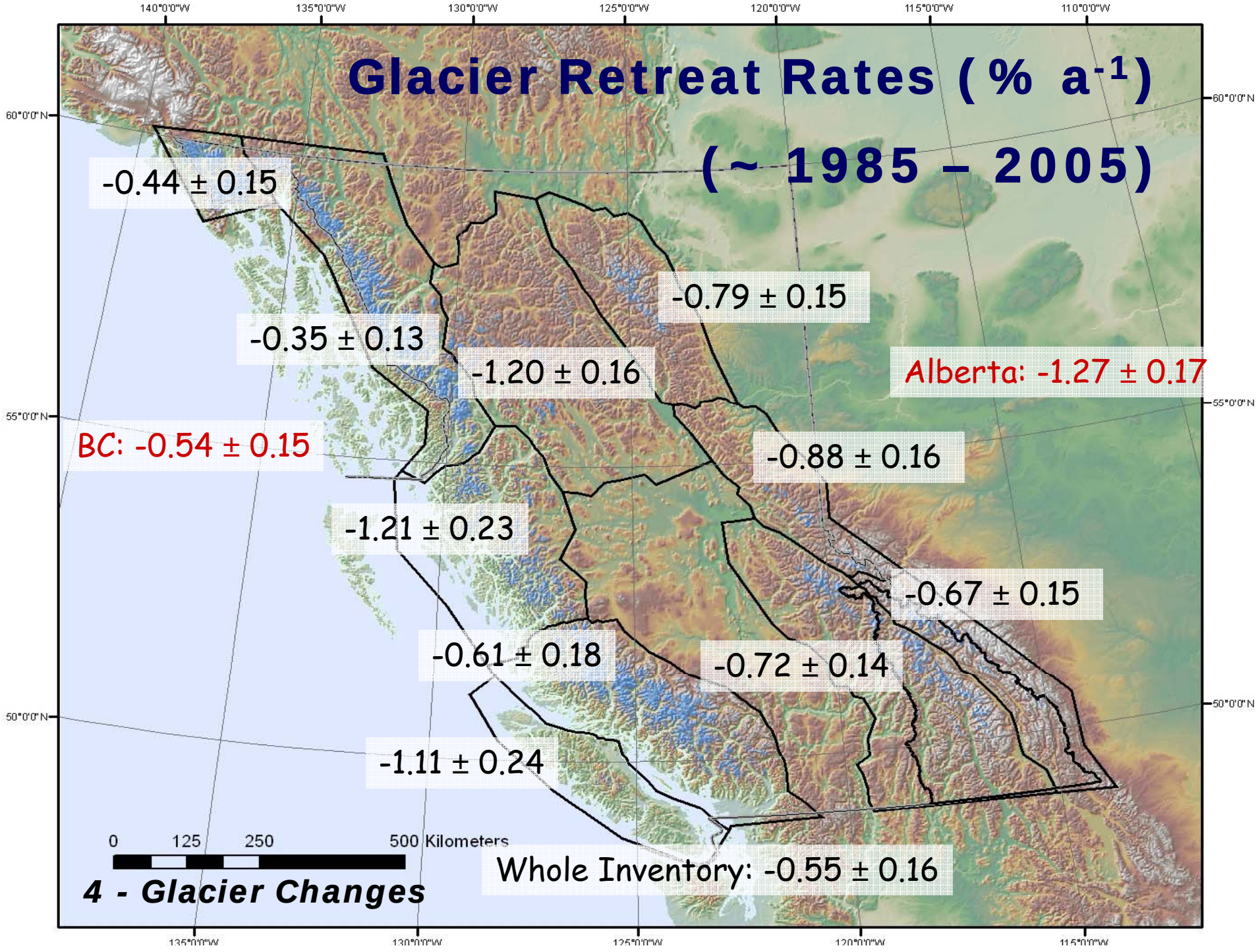


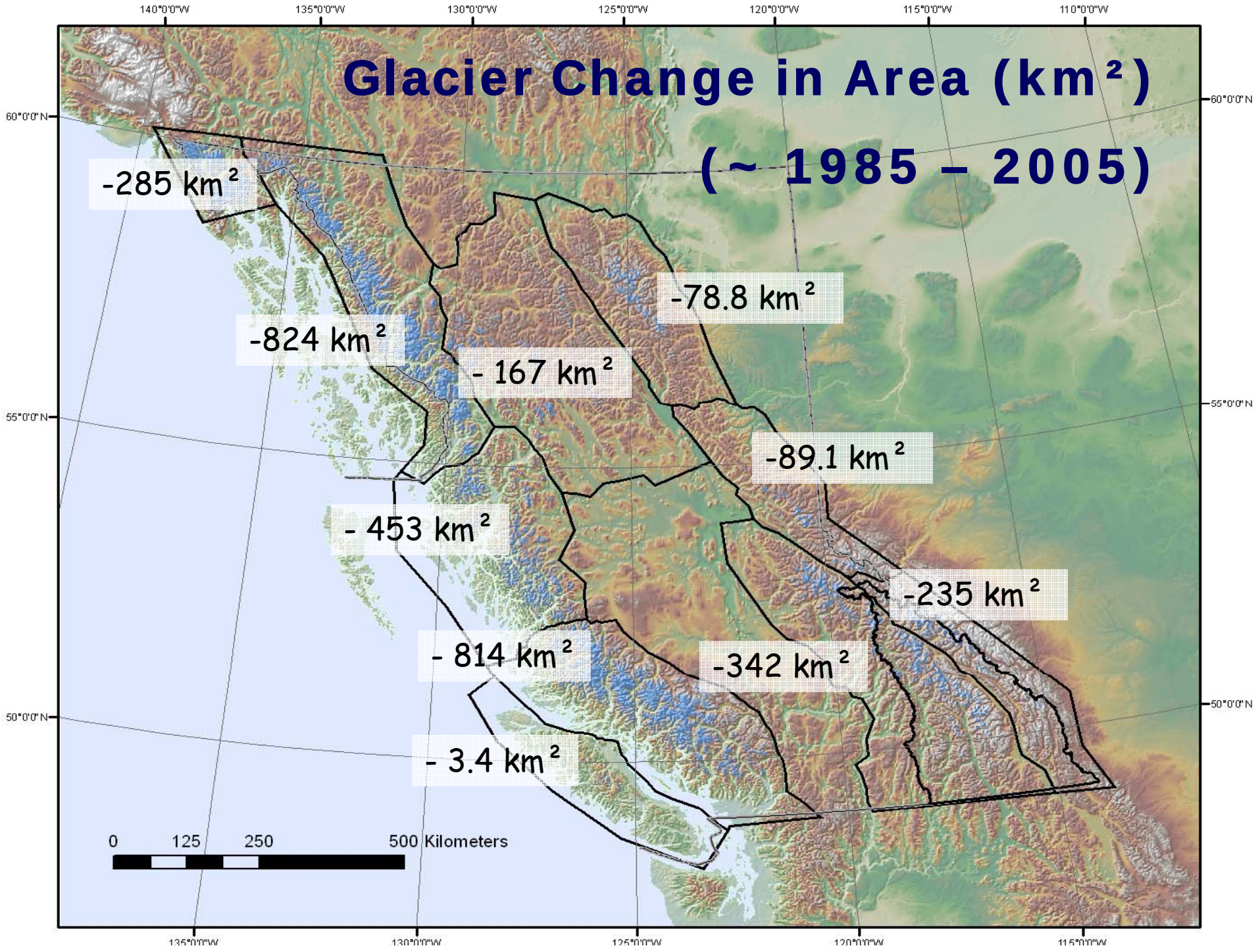
British Columbia: Landsat Path and Row

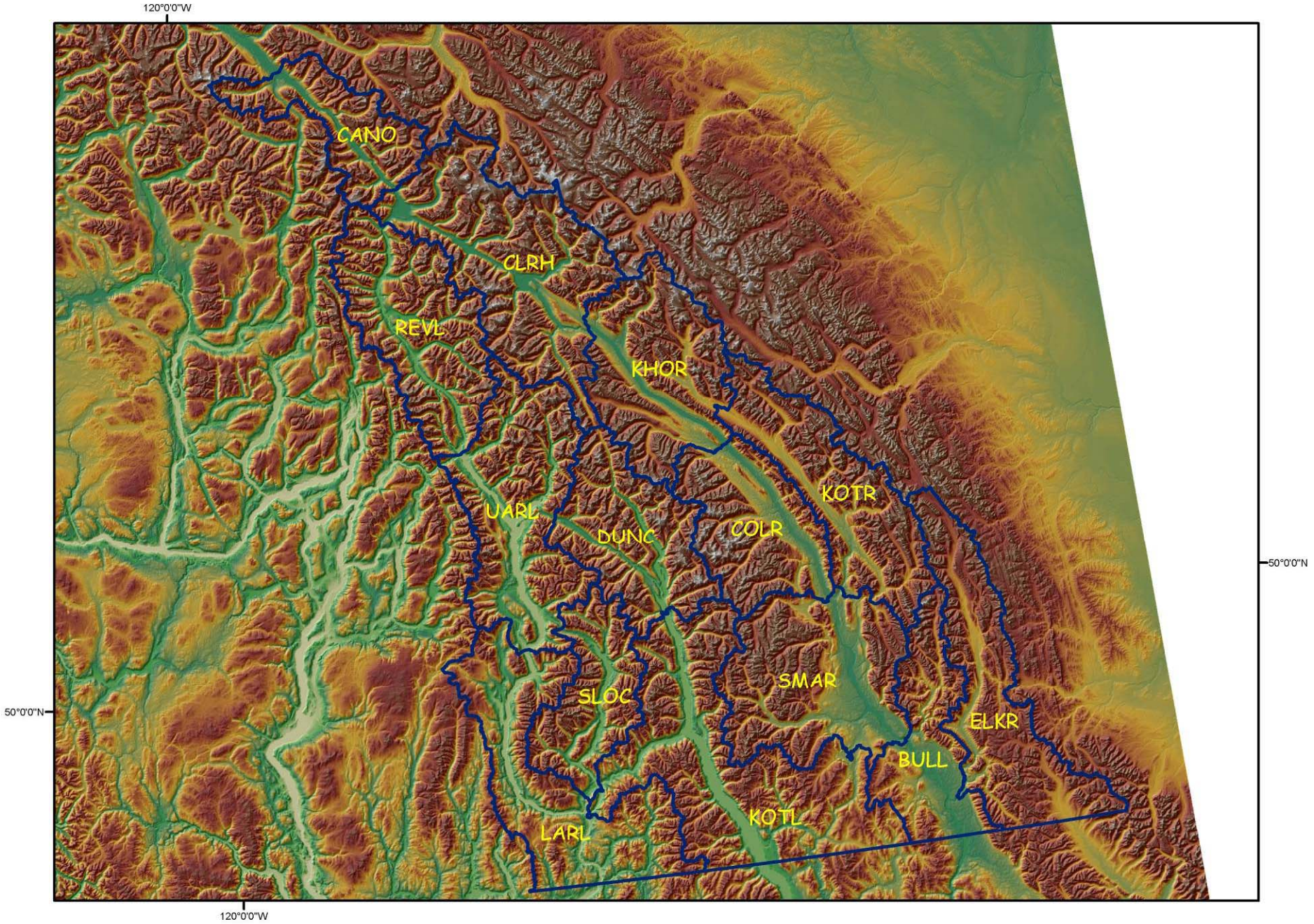


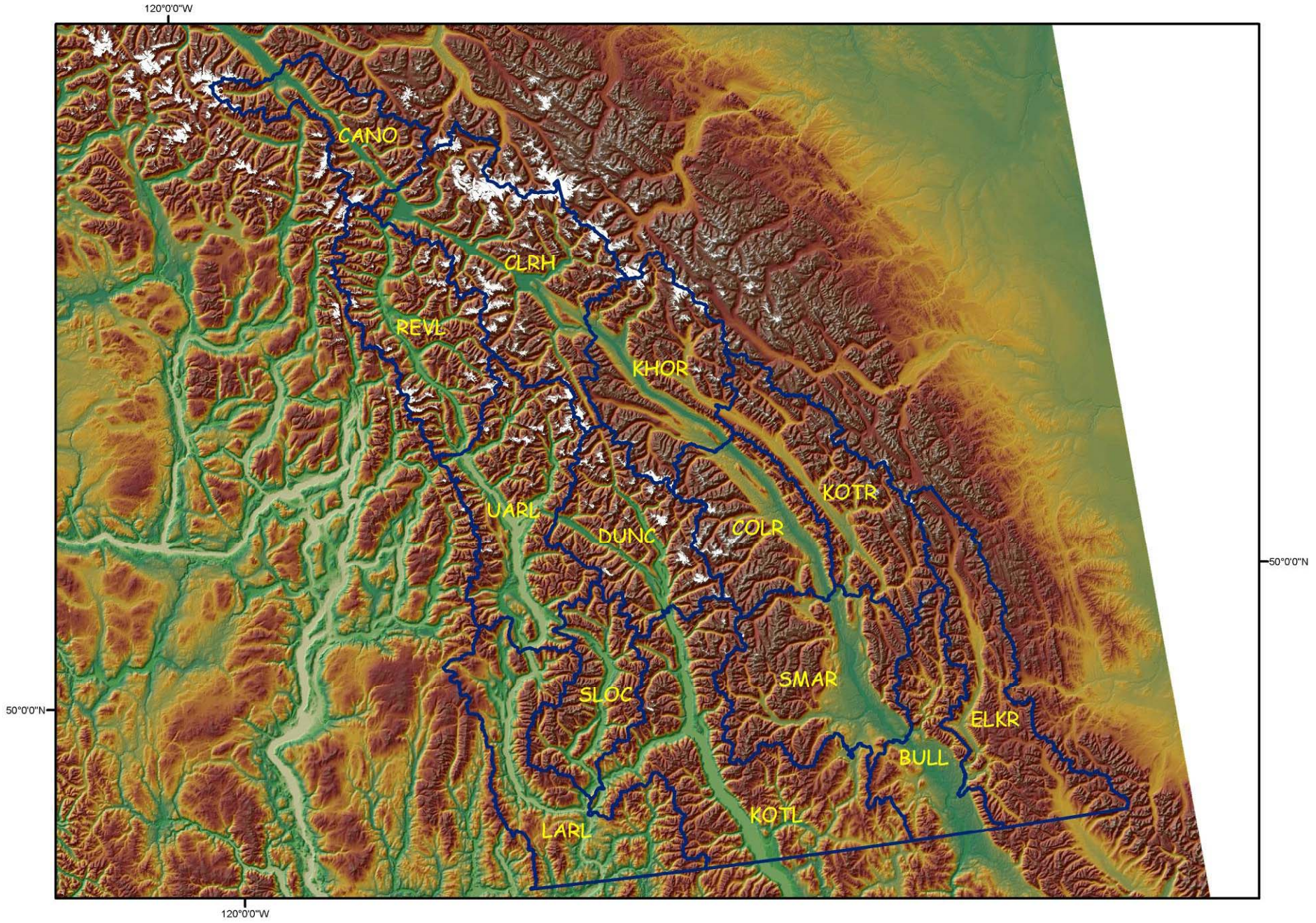

0 1 2 4 Kilometers


140°0'0"W
135°0'0"W
130°0'0"W
125°0'0"W
120°0'0"W
115°0'0"W
110°0'0"W
60°0'0"N
55°0'0"N
50°0'0"N
St. Elias Mountains
N. Coast Mountains
N. Interior Ranges
N. Rocky Mountains
Central Rocky Mountains
Central Coast Mountains
S. Rocky Mountains
S. Interior Ranges
S. Coast Mountains
Vancouver Island
0 125 250 500 Kilometers

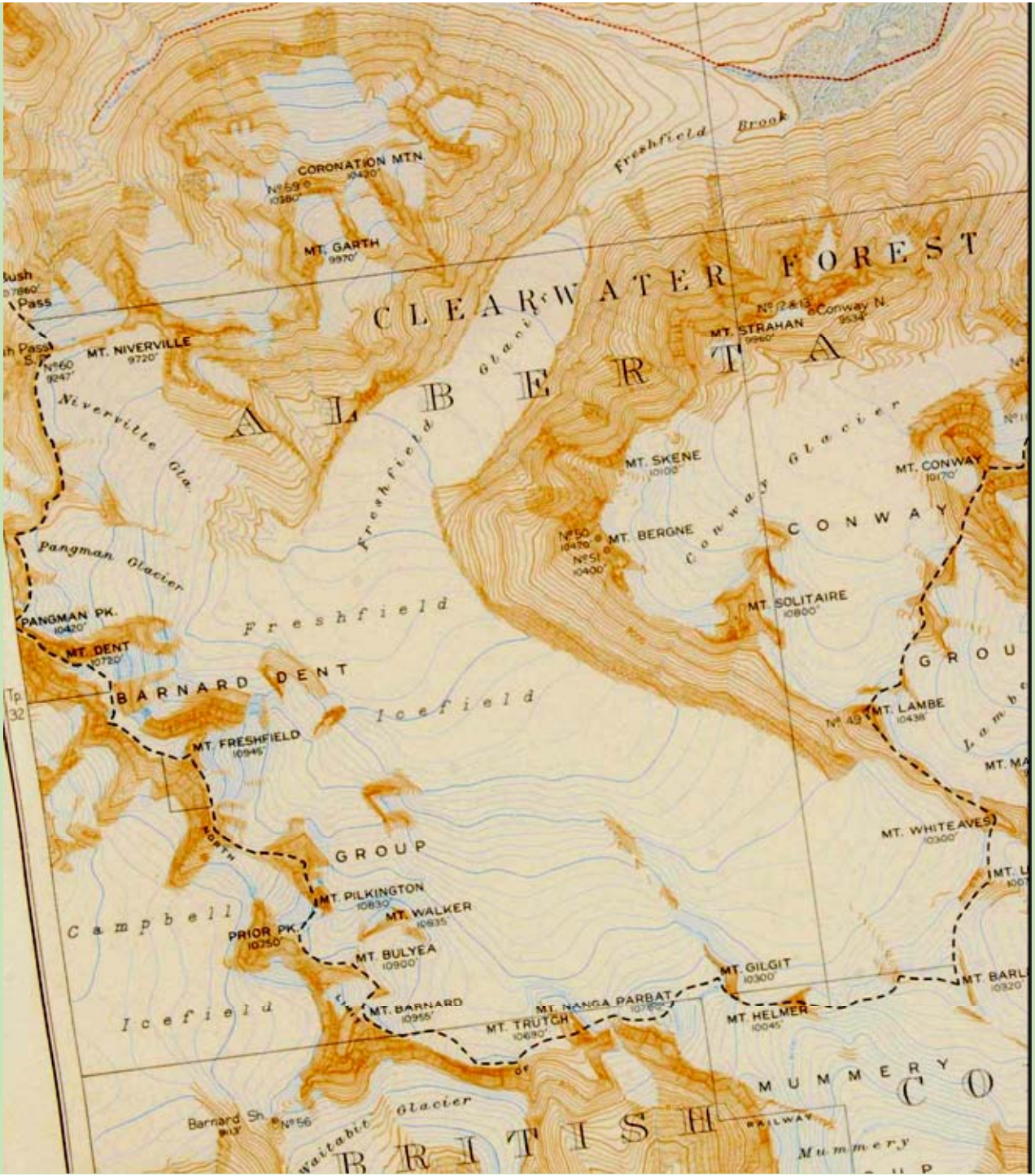

Glacier Retreat Rates (% a-1)
(~ 1985 – 2005)
-0.44 ± 0.15
-0.35 ± 0.13
-0.79 ± 0.15
-1.20 ± 0.16
Alberta: -1.27 ± 0.17
BC: -0.54 ± 0.15
-0.88 ± 0.16
-1.21 ± 0.23
-0.67 ± 0.15
-0.61 ± 0.18
-0.72 ± 0.14
-1.11 ± 0.24
0 125 250 500 Kilometers
Whole Inventory: -0.55 ± 0.16
4 - Glacier Changes


Glacier Change in Area (km²)
(~ 1985 – 2005)
-285 km²
-824 km²
- 167 km²
-78.8 km²
-89.1 km²
- 453 km²
-235 km²
- 814 km²
-342 km²
- 3.4 km²
0 125 250 500 Kilometers
140°0'0"W
135°0'0"W
130°0'0"W
125°0'0"W
120°0'0"W
115°0'0"W
110°0'0"W
60°0'0"N
55°0'0"N
50°0'0"N

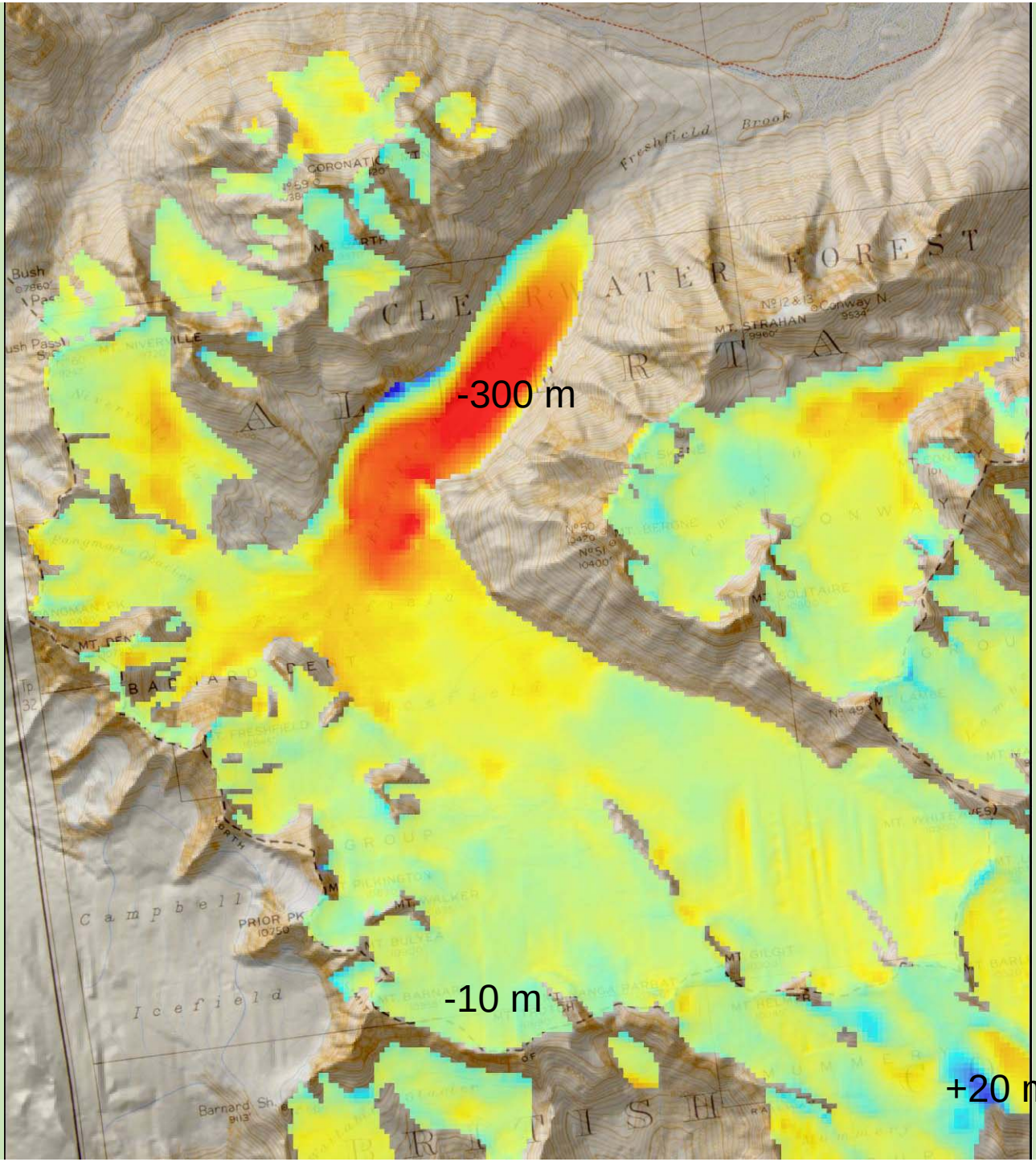

120°0'0"W
CANO
CLRH
REVL
KHOR
KOTR
UARL
DUNC
COLR
SLOC
SMAR
ELKR
BULL
KOTL
LARL
50°0'0"N
50°0'0"N
120°0'0"W


120°0'0"W
CANO
CLRH
REVL
KHOR
KOTR
UARL
DUNC
COLR
SMAR
SLOC
ELKR
BULL
KOTL
LARL
50°0'0"N
50°0'0"N
120°0'0"W

BASIN	Glaciers (1985)	Glacier Area (km^2) (1985)	Glaciers (2005)	Glacier Area (km^2) (2005)
BULL	1	0.45	2	0.35
CANO	160	287	193	256
CLRH	605	1,273	703	1,056
COLR	107	118	131	90
DUNC	267	307	310	251
ELKR	20	13	22	12
KHOR	199	331	203	265
KOTL	26	31	58	27
KOTR	52	32	67	26
REVL	344	440	414	359
SLOC	12	7.32	25	6.48
SMAR	4	5.35	6	4.24
UARL	250	274	284	236
		3119 km^2		2590 km^2


CLEARWATER FOREST
ALBERTA
CORONATION MTN.
10420'
No 59
10380'
MT. GARTH
9970'
Freshfield Brook
MT. NIVERVILLE
9720'
No 60
9247'
Niverville Gla.
Freshfield Glacier
No 12 & 13
Conway N.
9534'
MT. STRAHAN
9960'
MT. SKENE
10100'
Conway Glacier
MT. CONWAY
10170'
CONWAY
No 50
10470'
No 51
10400'
MT. BERGNE
Pangman Glacier
PANGMAN PK.
10420'
MT. SOLITAIRE
10800'
Freshfield
MT. DENT
10720'
BARNARD DENT
Icefield
MT. FRESHFIELD
10945'
No 49
MT. LAMBE
10438'
MT. WHITE AVES
10300'
NORTH
GROUP
MT. PILKINGTON
10830'
MT. WALKER
10835'
Campbell
PRIOR PK.
10250'
MT. BULYEA
10900'
MT. GILGIT
10300'
MT. BARNARD
10955'
MT. NANGA PARBAT
MT. TRUTCH
10690'
MT. HELMER
10045'
Icefield
Barnard Sh.
No 56
Waitabit Glacier
MUMMERY
BRITISH
RAILWAY
Mummery

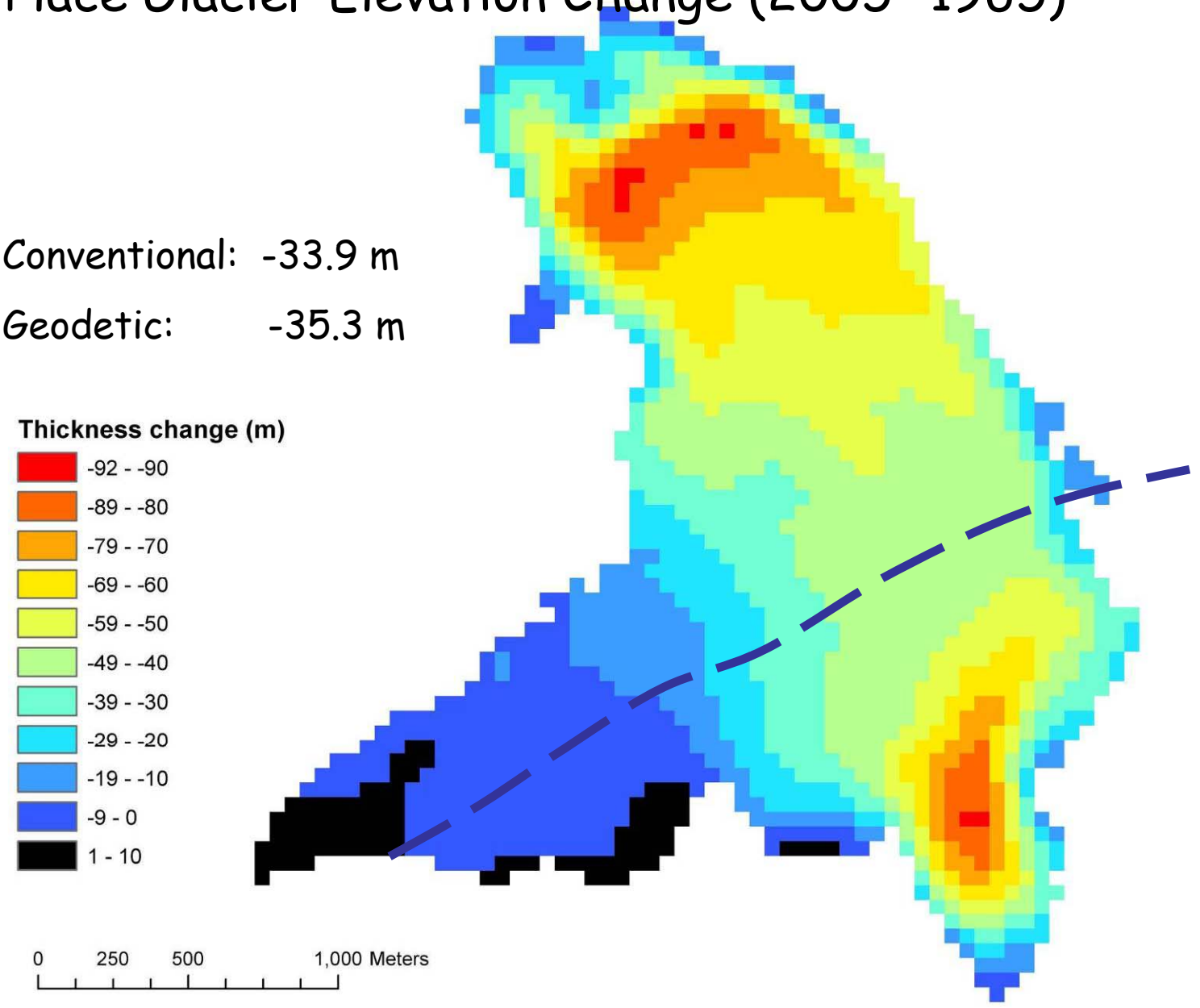

Freshfield Brook
CLEARWATER FOREST
ALBERTA
MT. NIVERVILLE
9720'
Bush
Pass
MT. STRAHAN
9960'
Conway N.
9534'
Freshfield
Icefield
MT. DENT
Campbell
Icefield
PRIOR
10750'
MT. BULYEA
MT. TRUTCH
Barnard
BRITISH

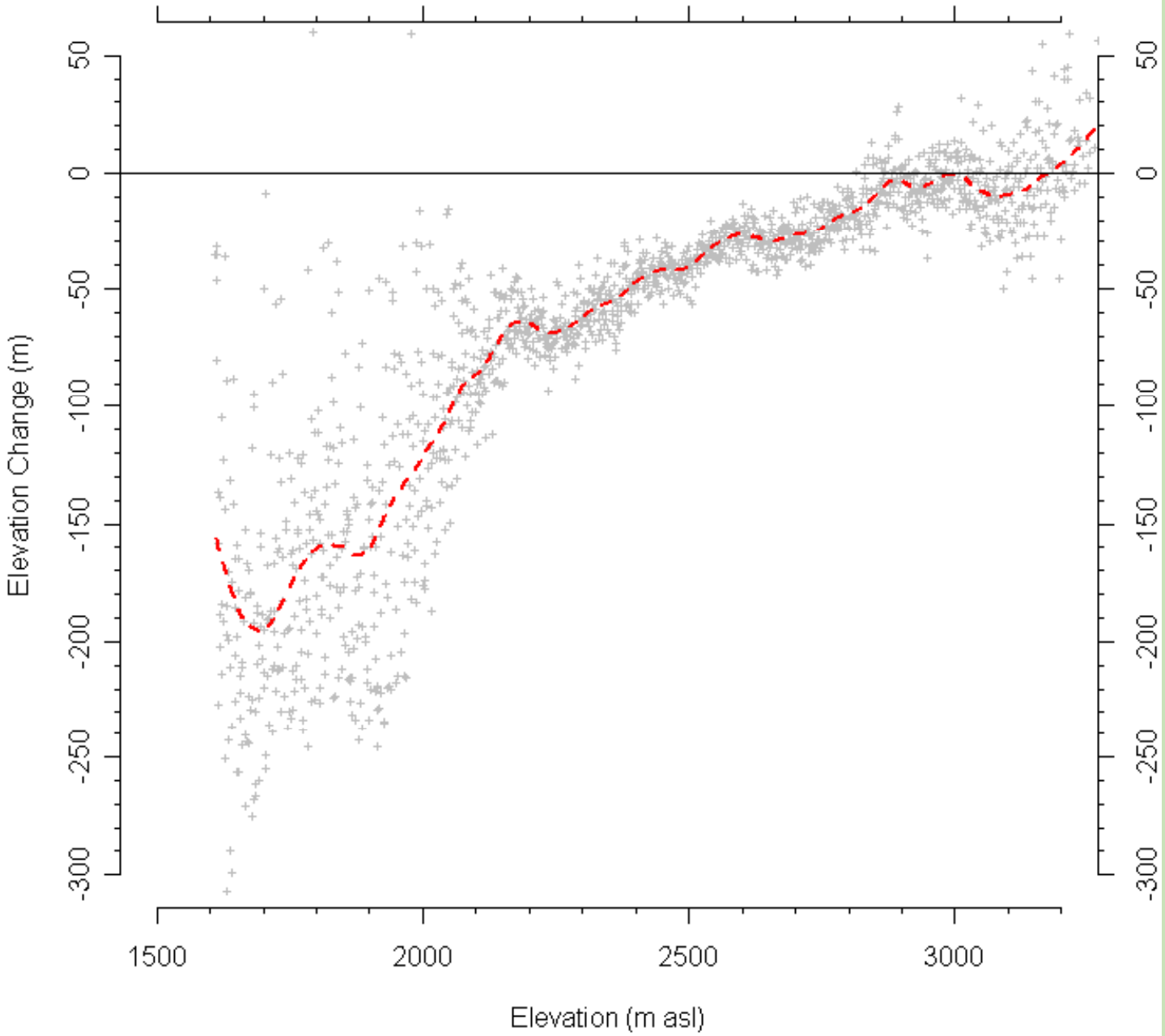

-300 m
-10 m
+20 m

Place Glacier Elevation Change (2005 -1965)

Conventional: -33.9 m

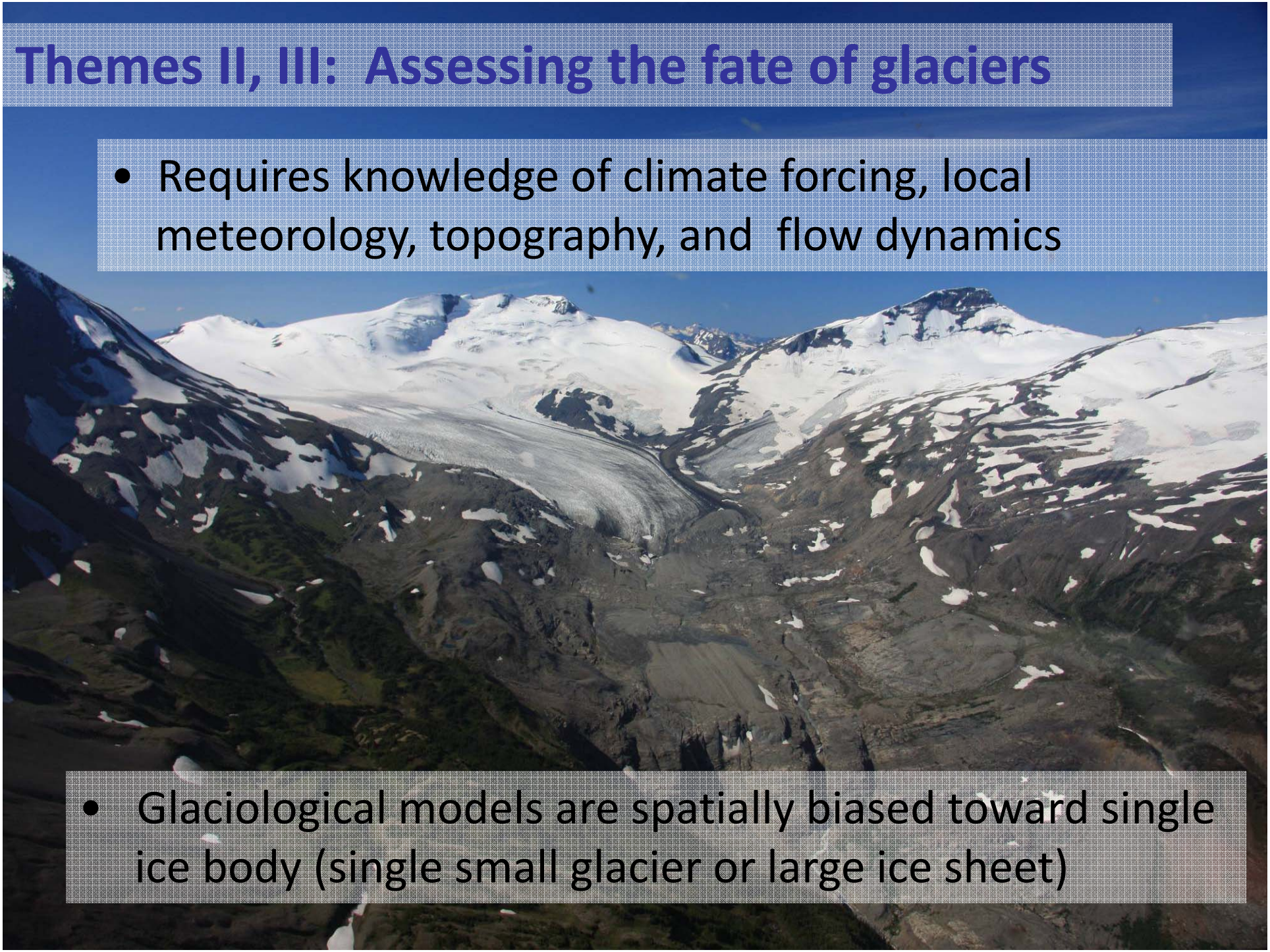
Geodetic: -35.3 m




Elevation Change (m)
50
0
-50
-100
-150
-200
-250
-300
1500
2000
2500
3000
Elevation (m asl)

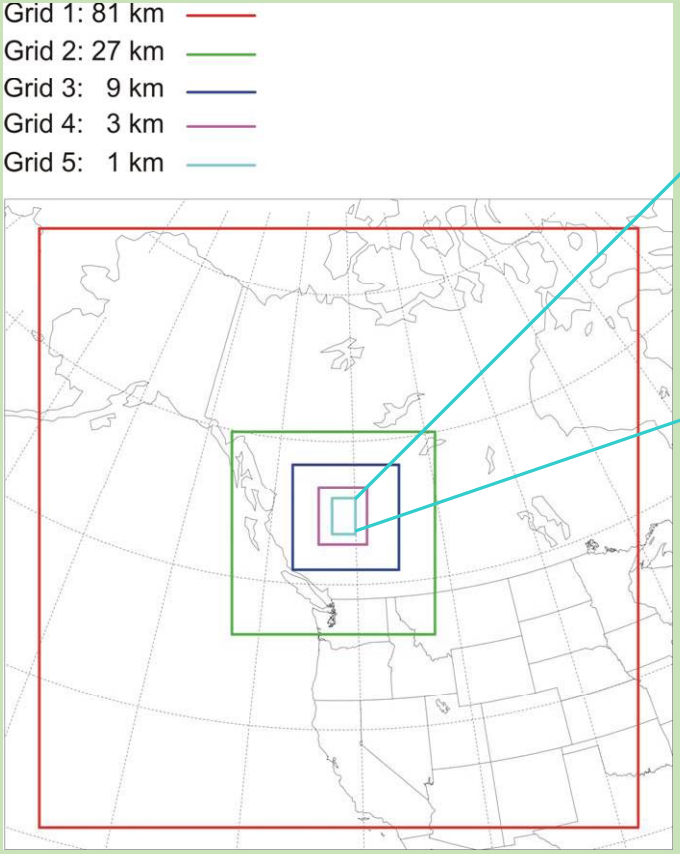
Themes II, III: Assessing the fate of glaciers

- Requires knowledge of climate forcing, local meteorology, topography, and flow dynamics



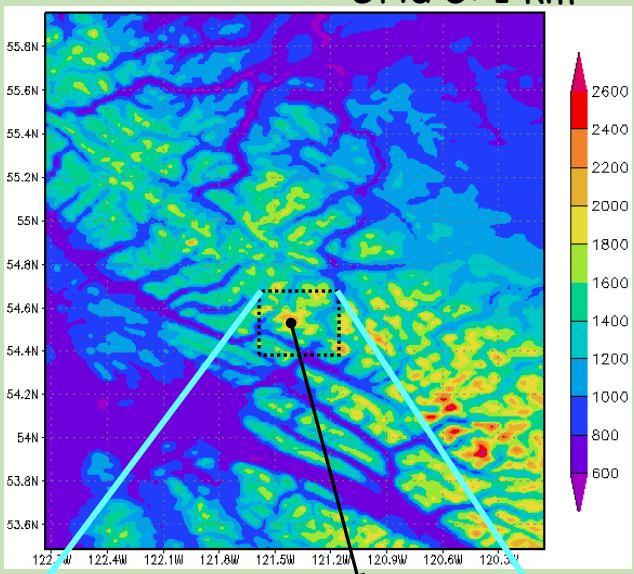
- Glaciological models are spatially biased toward single ice body (single small glacier or large ice sheet)

Variable scale atmospheric models

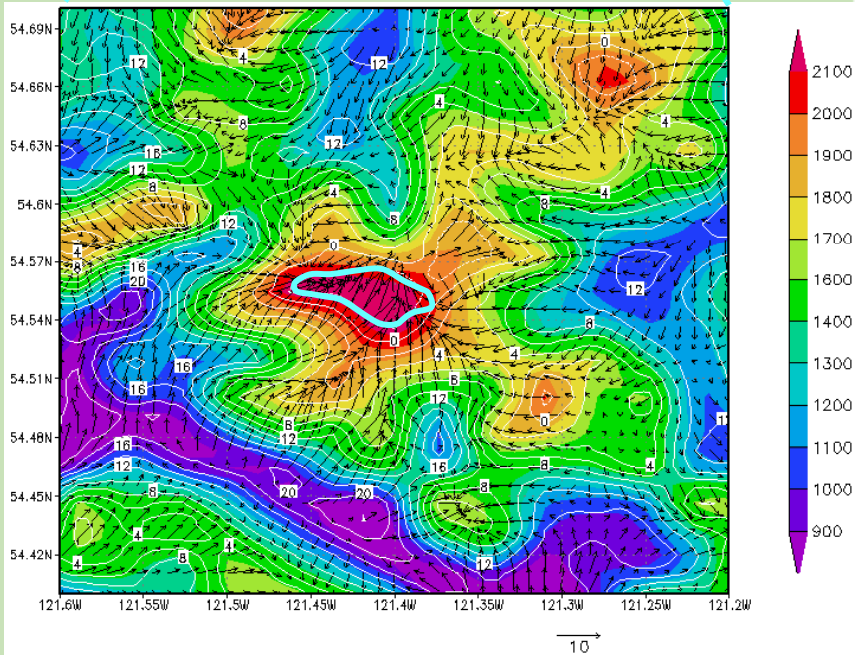


Monkman/Parsnip glaciers

Grid 5: 1 km



Near-surface winds & 2-metre temp. (21Z 22 JUL 2002)

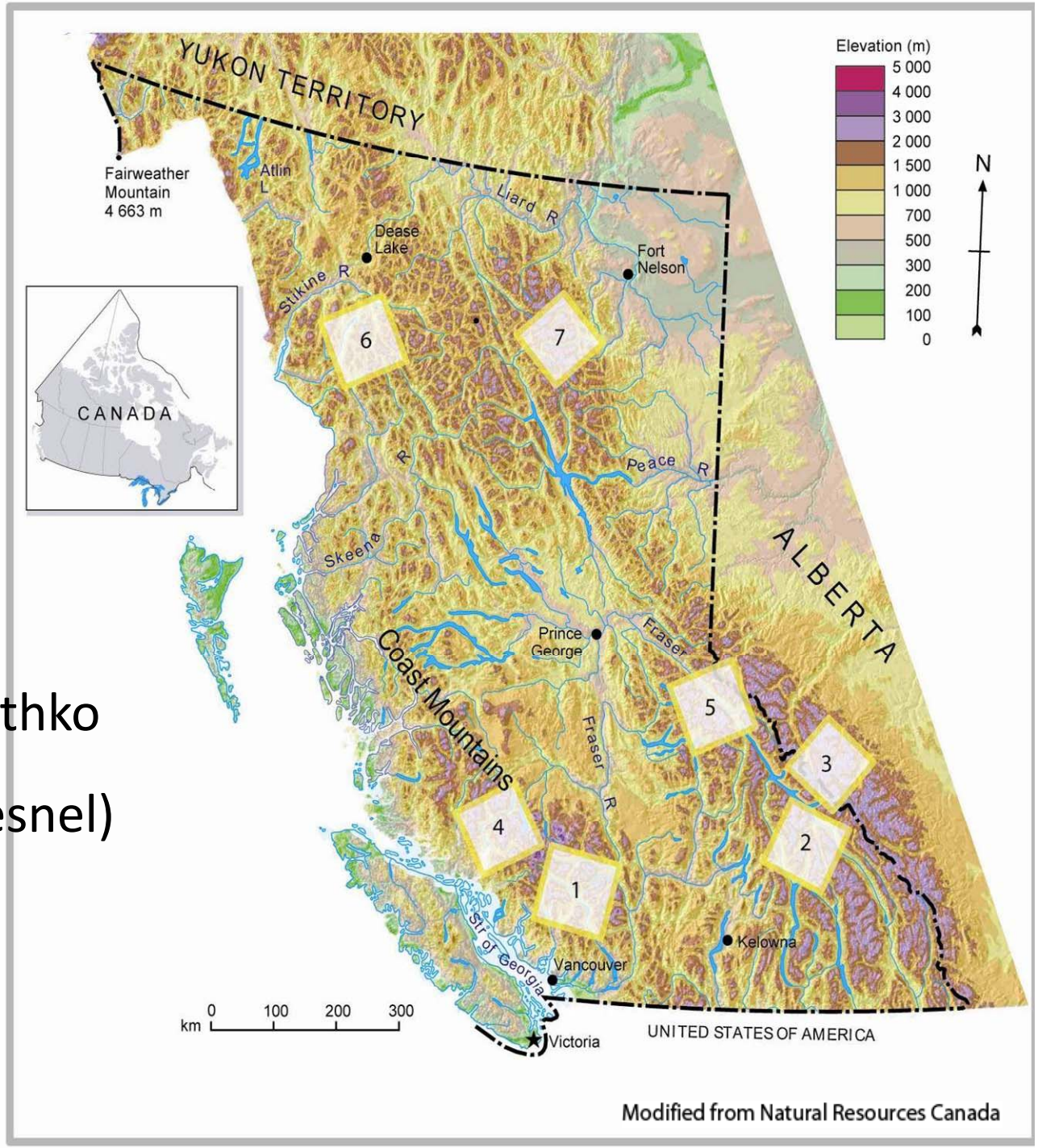


- Downscale GCM to regional/local scale
- Resolving topography is crucial

Peter Jackson (UNBC)

Targeted Regions

1) S. Coast Mountains (BC Hydro)
2) Columbia, Selkirks (BC Hydro; CBT)
3) Southern Rockies
4) Waddington, Homathko
5) Cariboo Mtns. (Quesnel)
6) Central-N. Coast
7) N. Rockies



Ice Dynamics

Governing equation
(conservation of mass):

$$\frac{\partial H_{i,j}}{\partial t} = - \frac{\partial}{\partial x_j} (H \bar{u}_{i,j}) + \dot{b}$$

Ice velocity is calculated based on a constitutive law (e.g., Glen's flow law) and the momentum (stress) balance

3D Ice Thermodynamics

Governing equation
(conservation of energy):

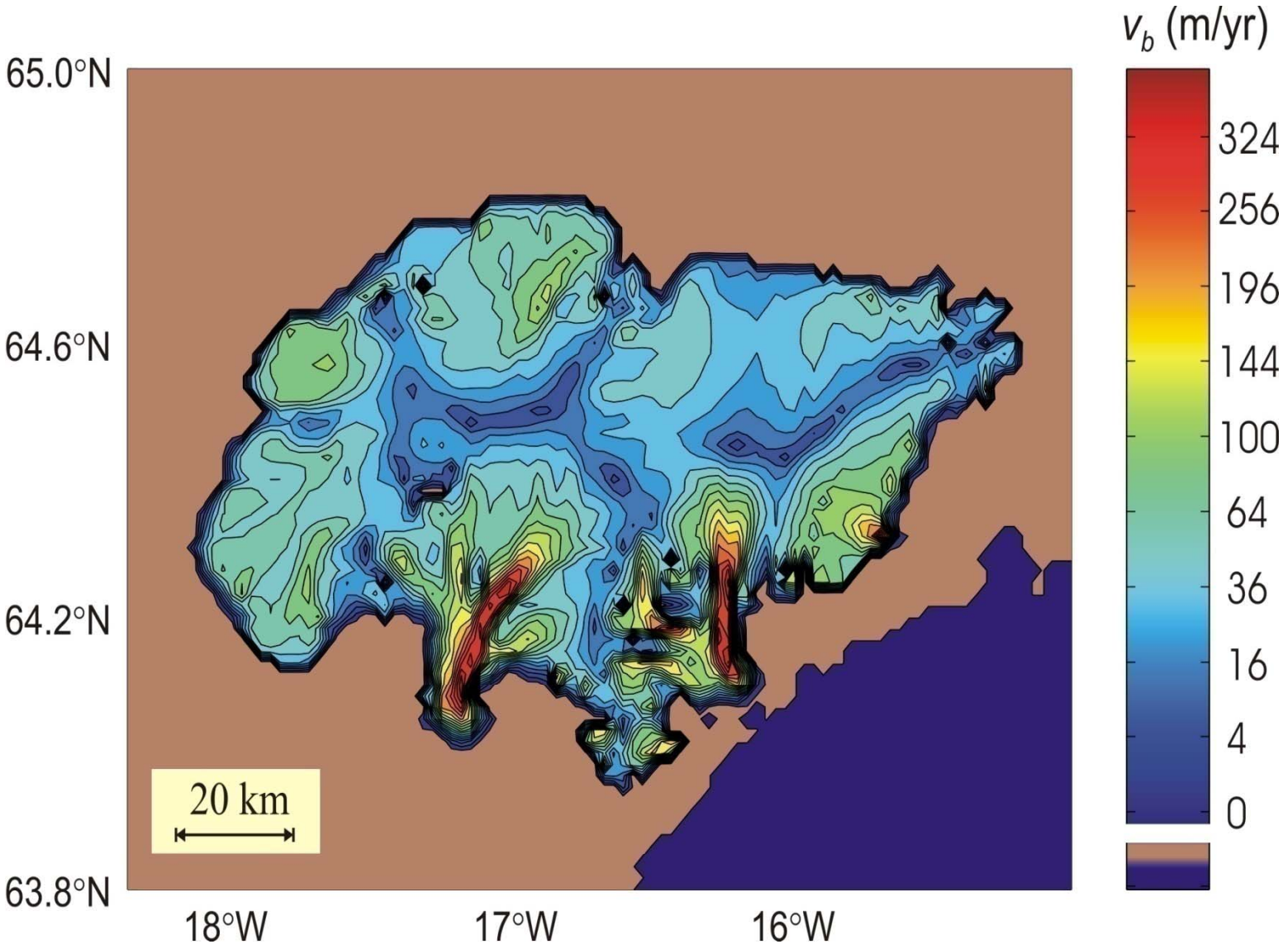
$$\frac{\partial T}{\partial t} = -\frac{\partial}{\partial x_k}(v_k T) + \kappa \frac{\partial^2 T}{\partial z^2} + \frac{\Phi}{\rho c}$$

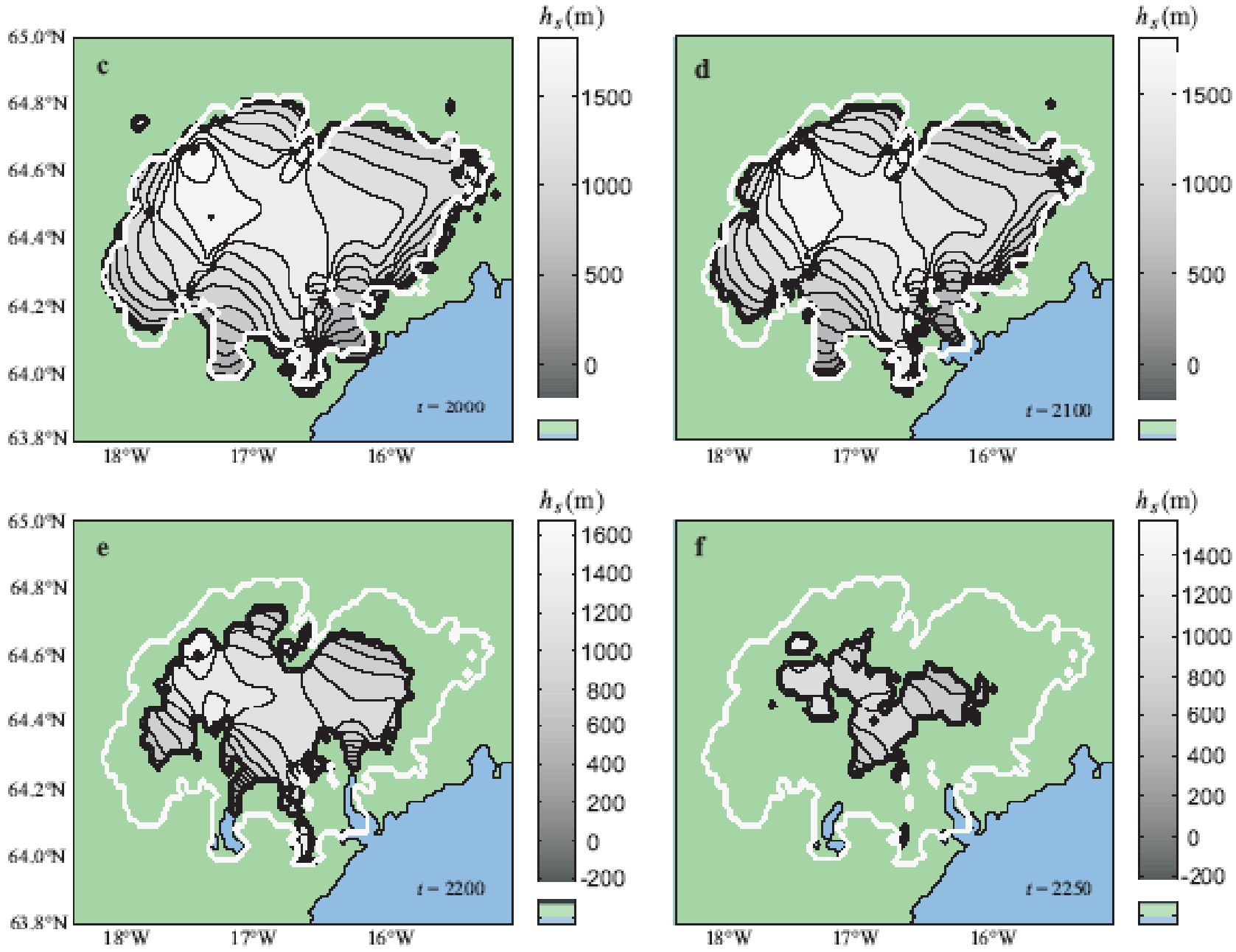
3D heat advection

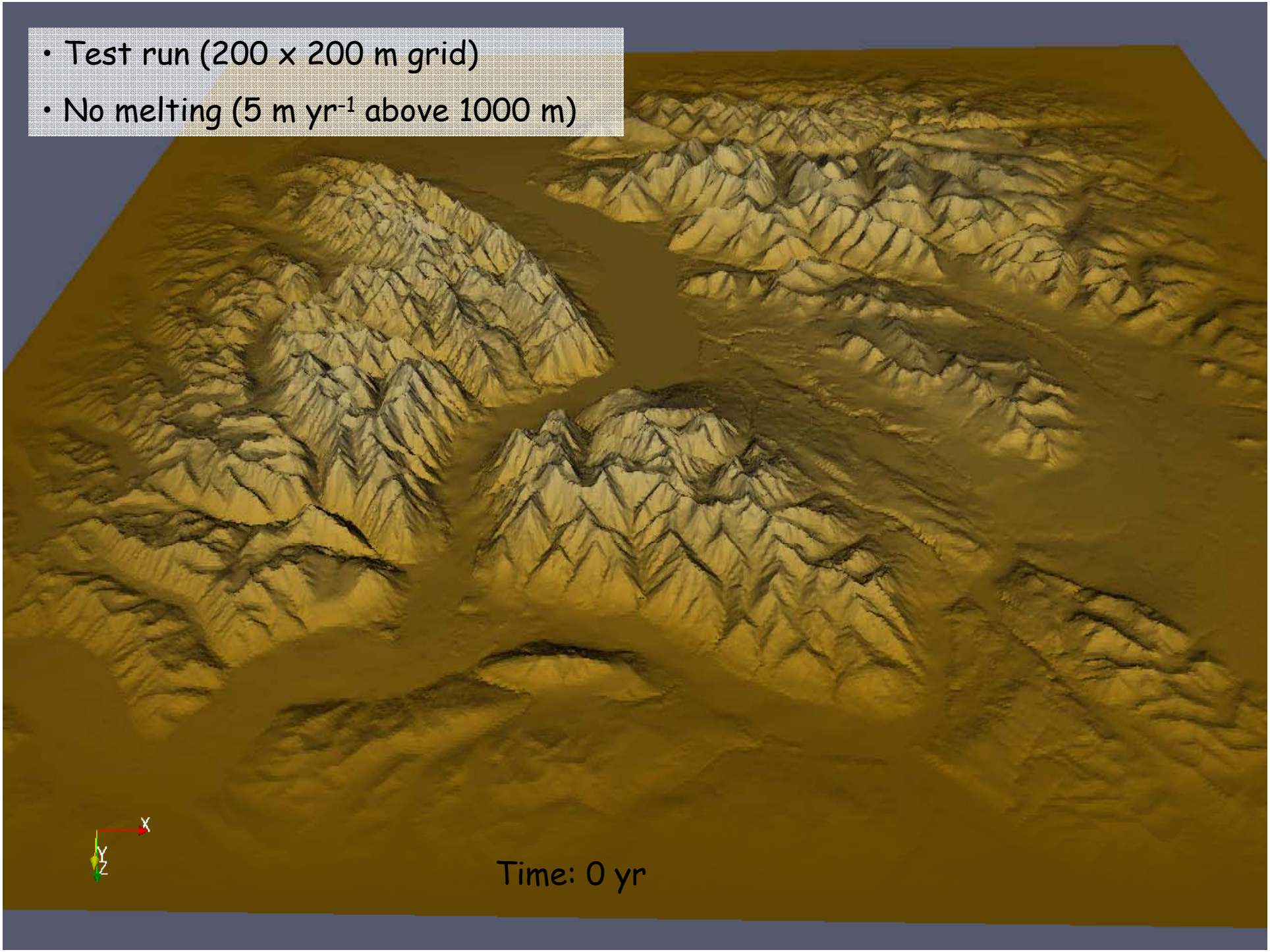
vertical diffusion

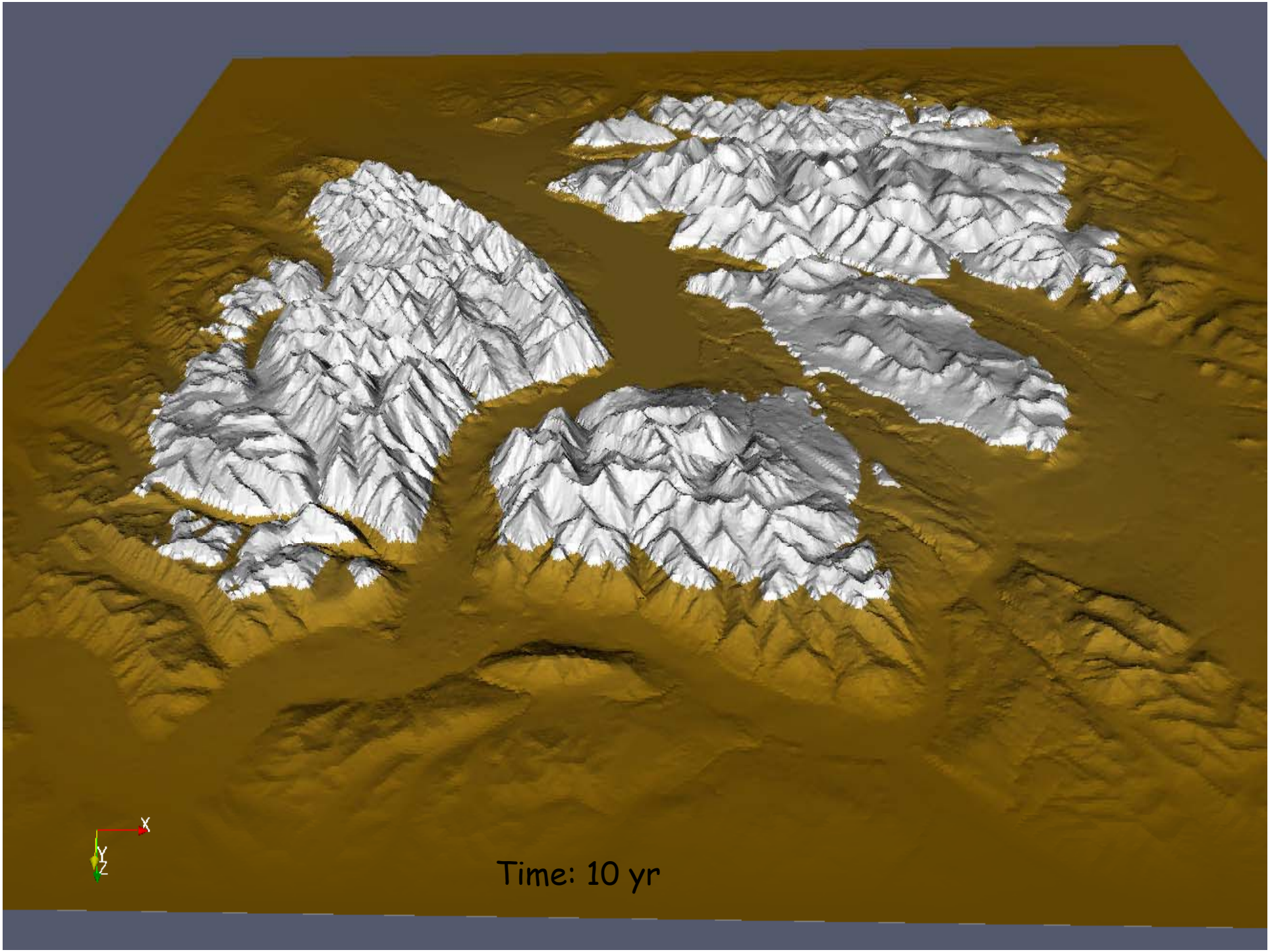
strain heating

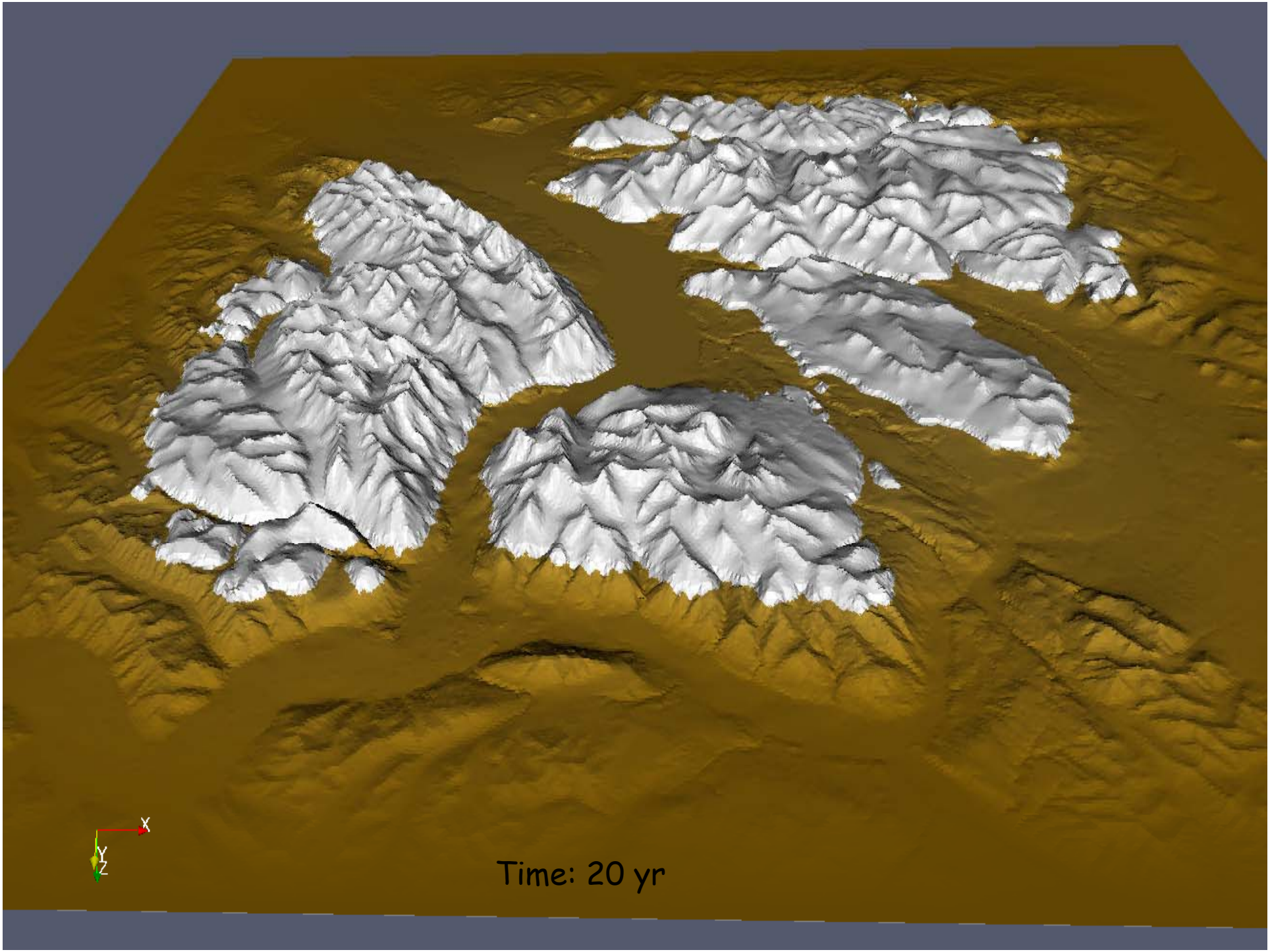
Surface velocity (basal flow + deformation)

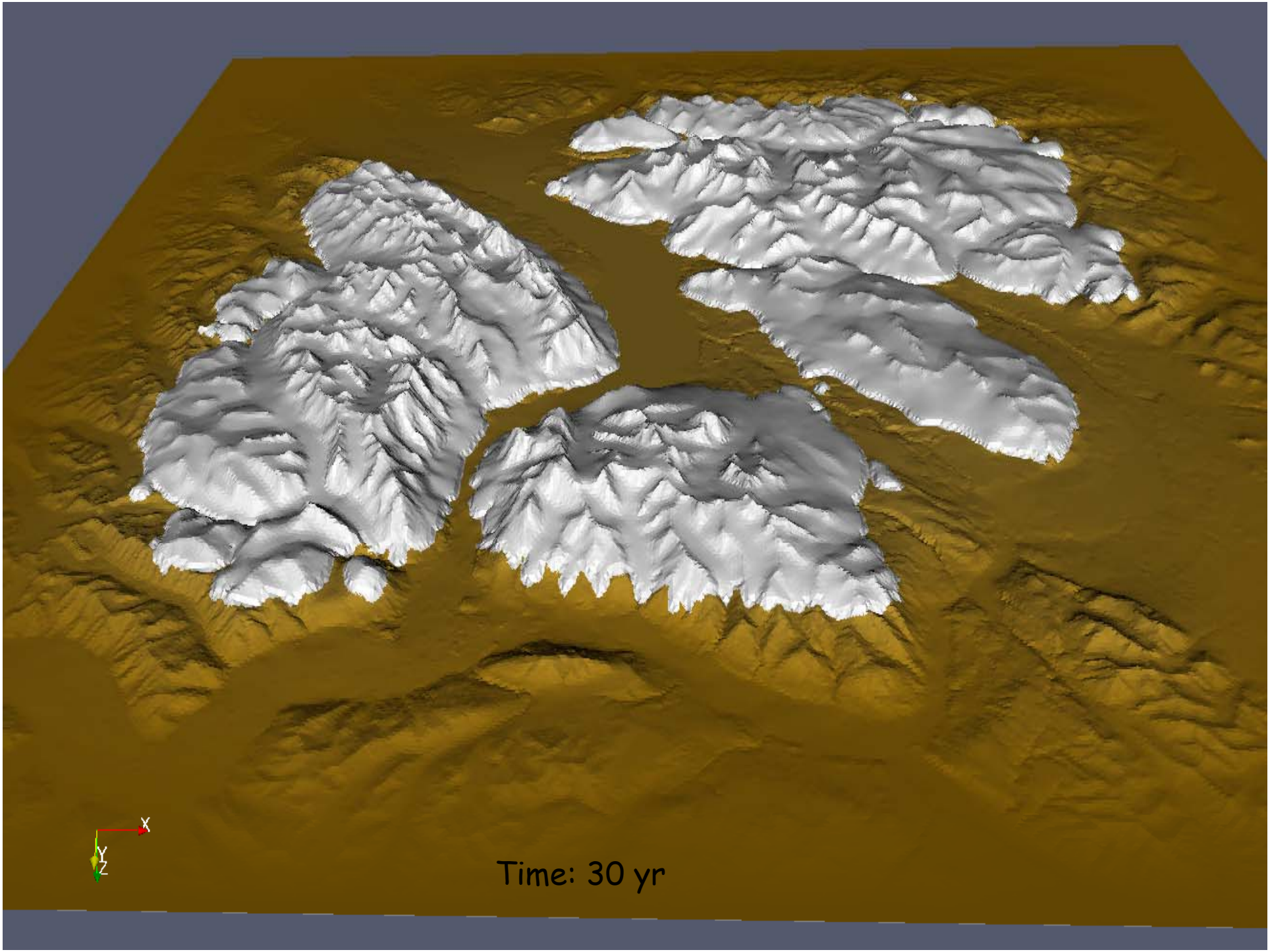


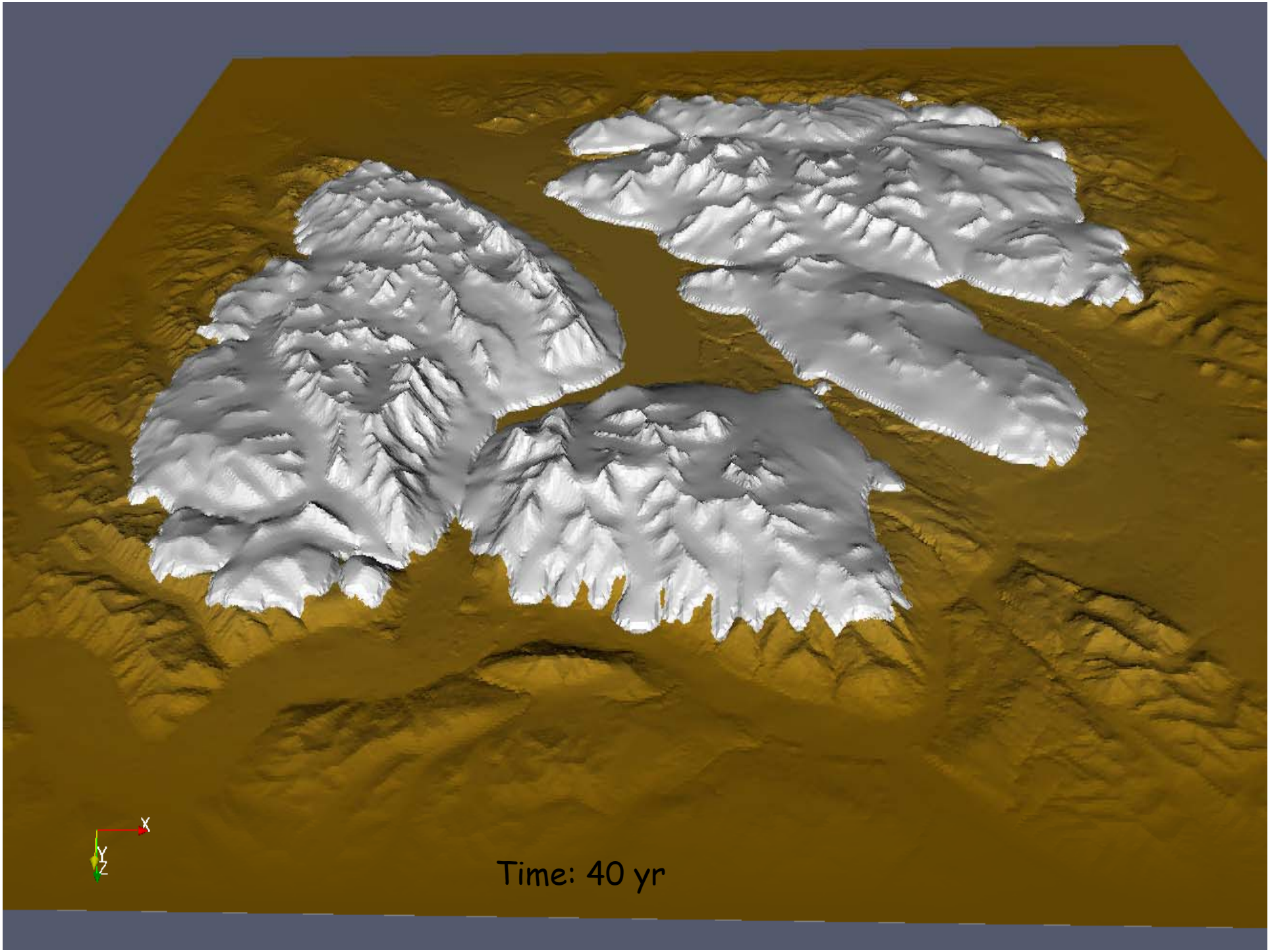

c
d
e
f
h_s(m)
1500
1000
500
0
1600
1400
1200
800
600
400
200
-200
t = 2000
t = 2100
t = 2200
t = 2250
65.0°N
64.8°N
64.6°N
64.4°N
64.2°N
64.0°N
63.8°N
18°W
17°W
16°W

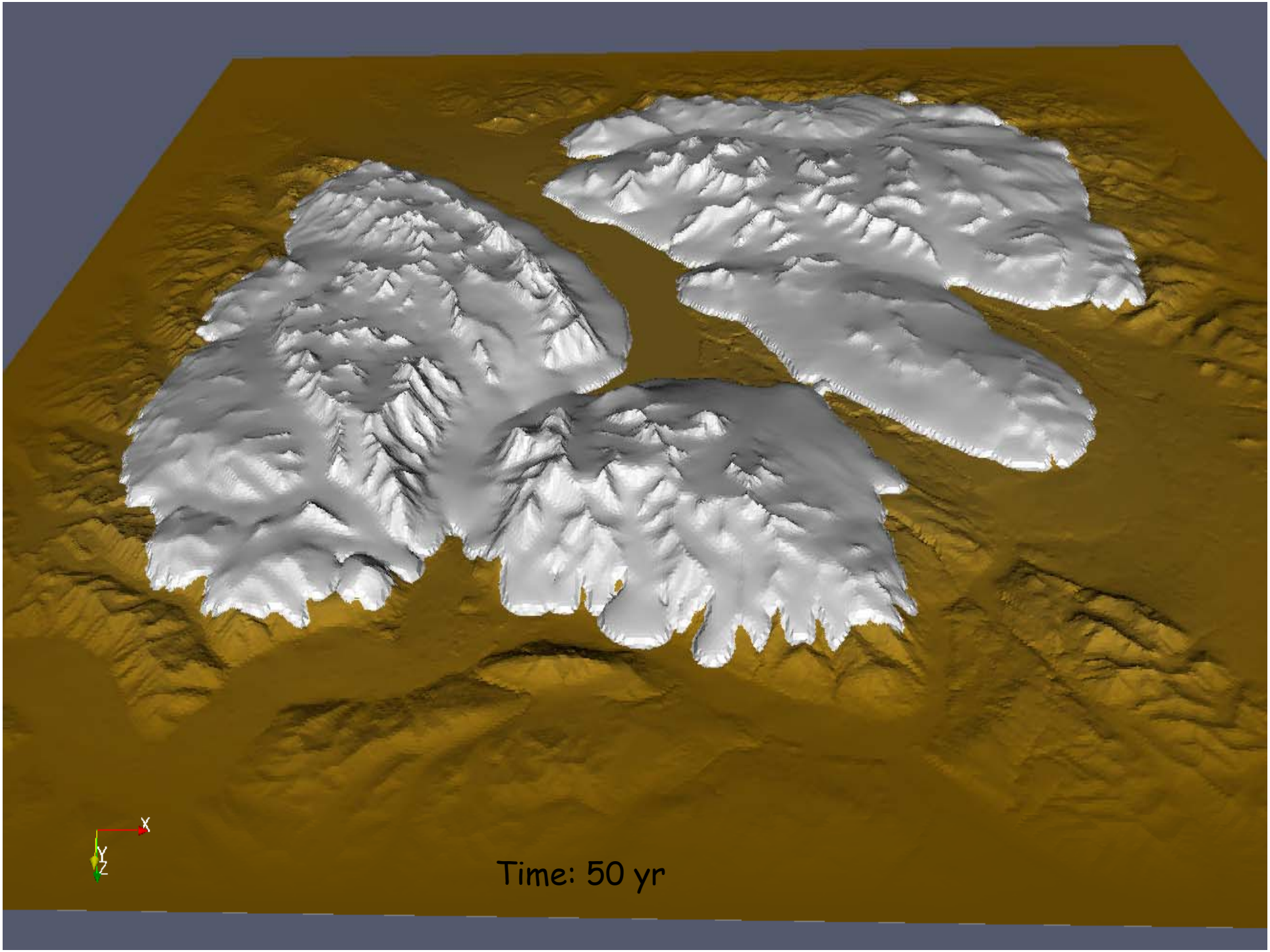

• Test run (200 x 200 m grid)
• No melting (5 m yr^{-1} above 1000 m)
X
Y
Z
Time: 0 yr

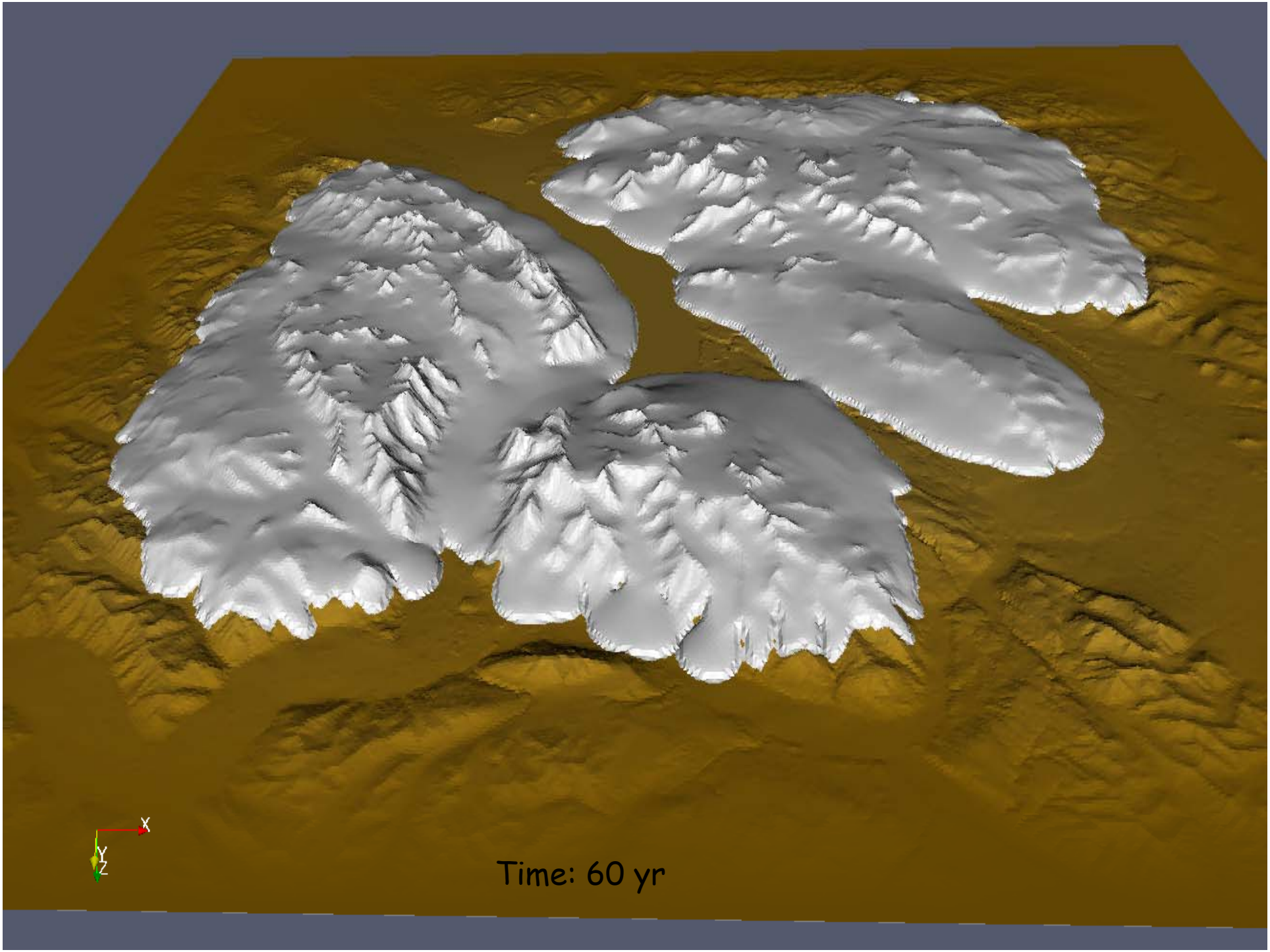

X
Y
Z
Time: 10 yr

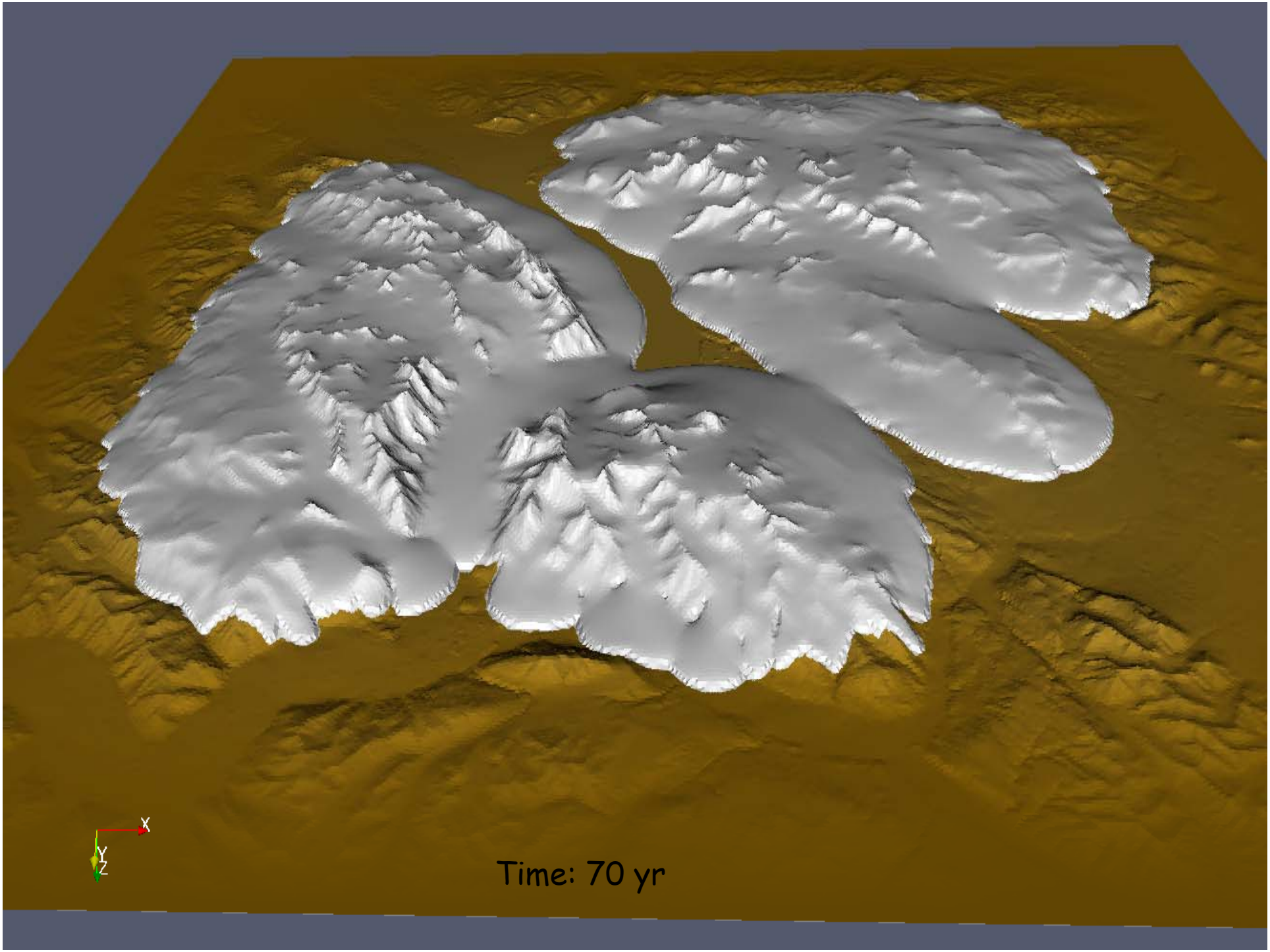

X
Y
Z
Time: 20 yr

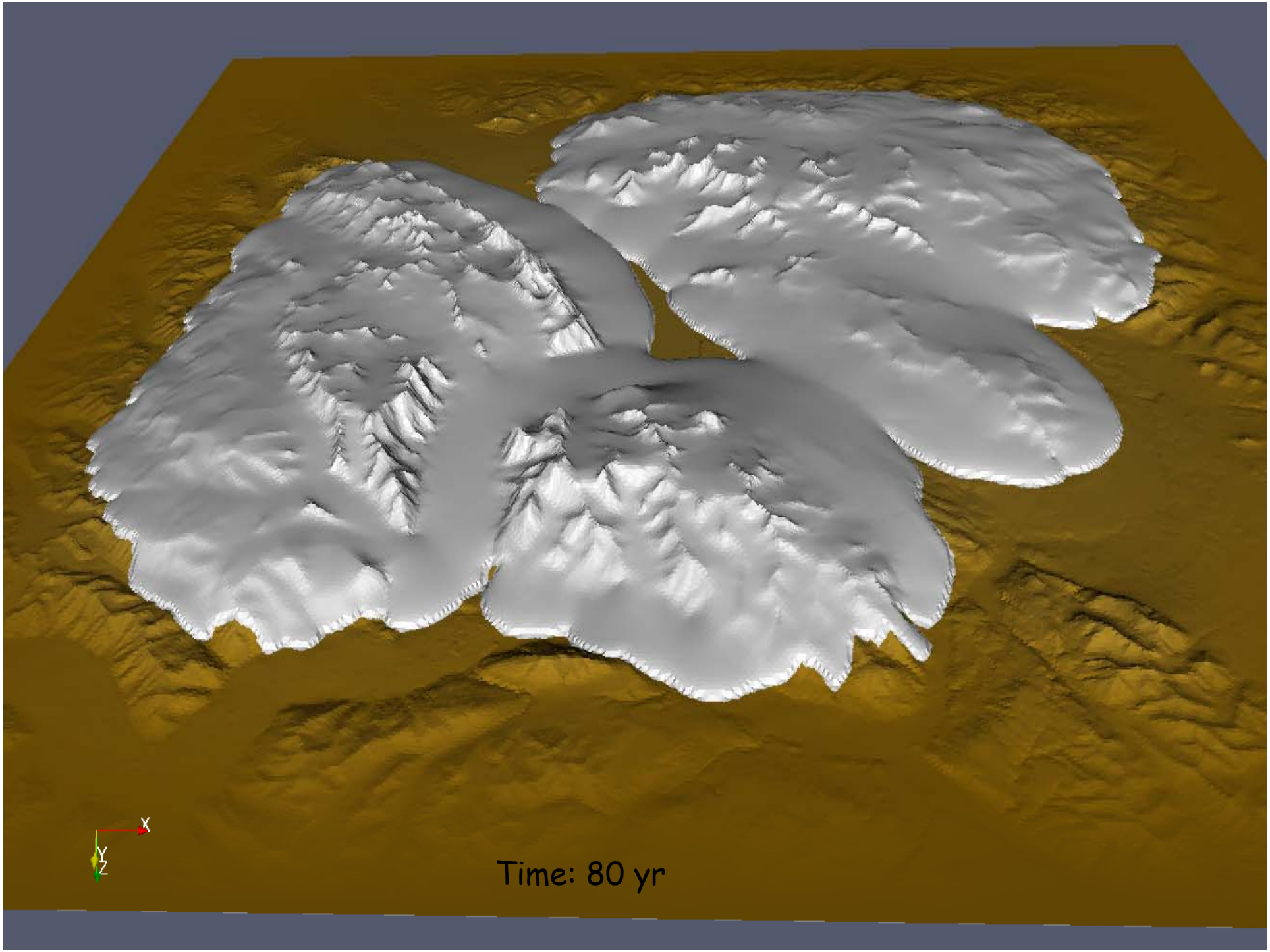

X
Y
Z
Time: 30 yr

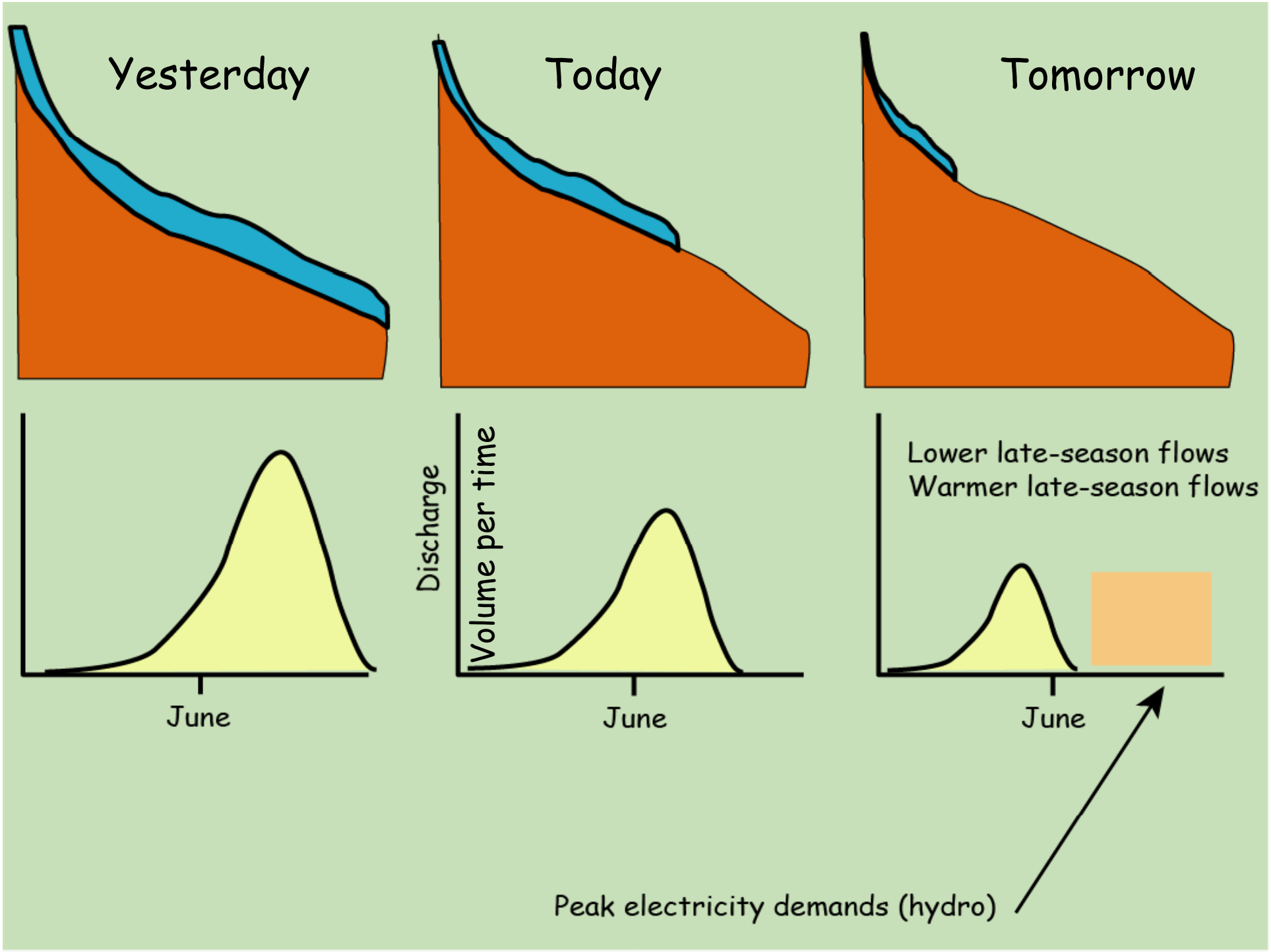

X
Y
Z
Time: 40 yr


X
Y
Z
Time: 50 yr

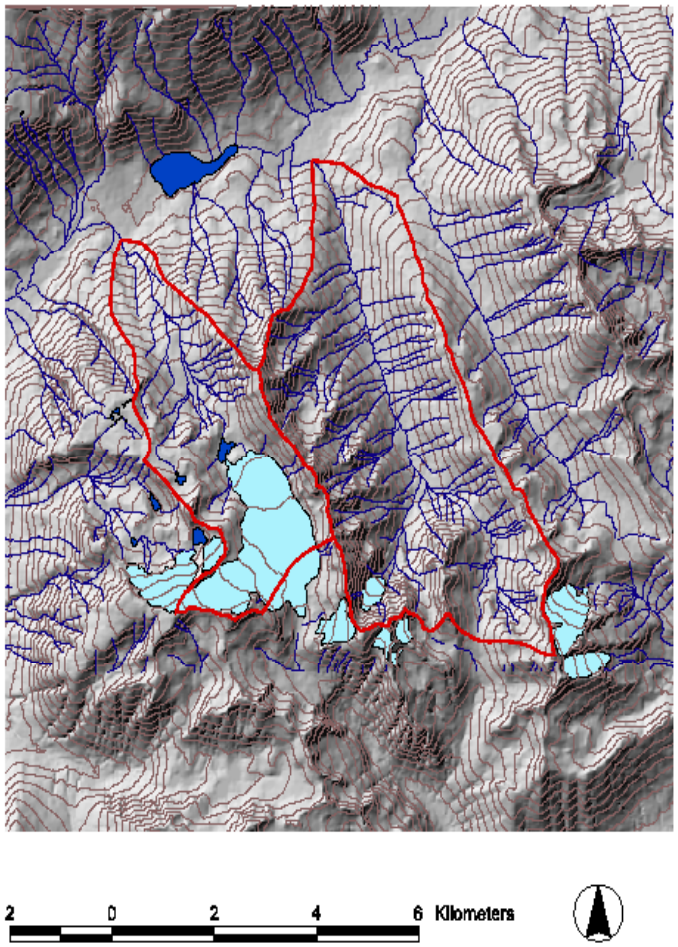

X
Y
Z
Time: 60 yr

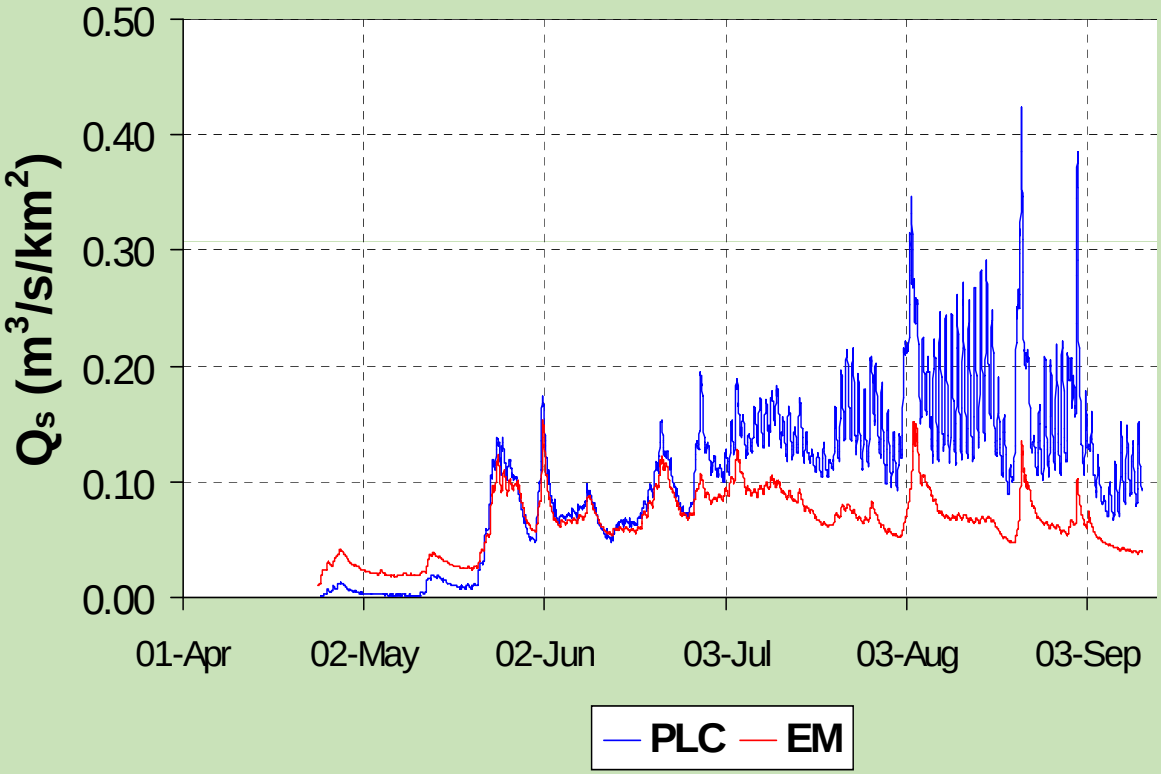

X
Y
Z
Time: 70 yr


X
Y
Z
Time: 80 yr

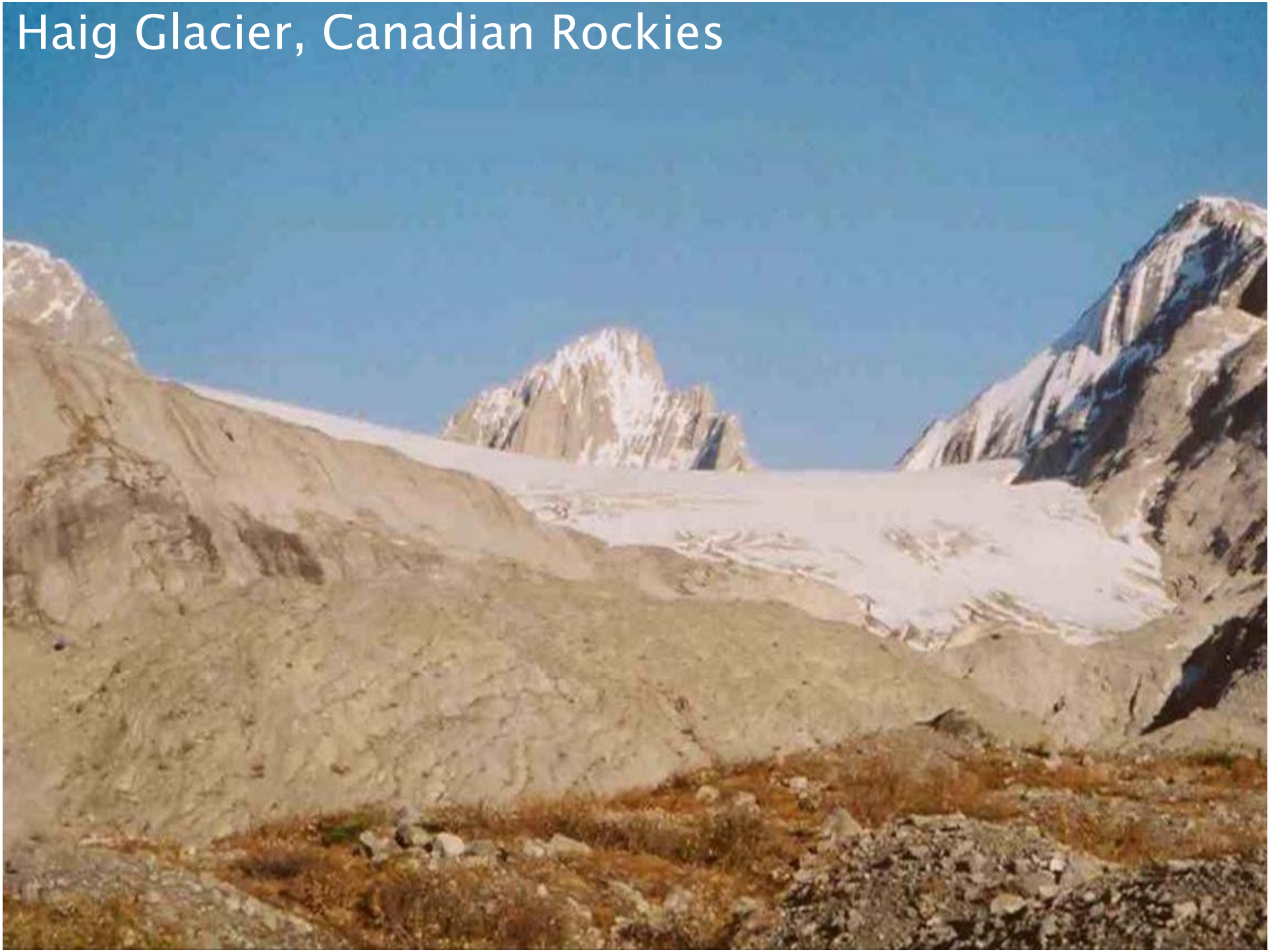

Yesterday
Today
Tomorrow
Discharge
Volume per time
June
June
June
Lower late-season flows
Warmer late-season flows
Peak electricity demands (hydro)

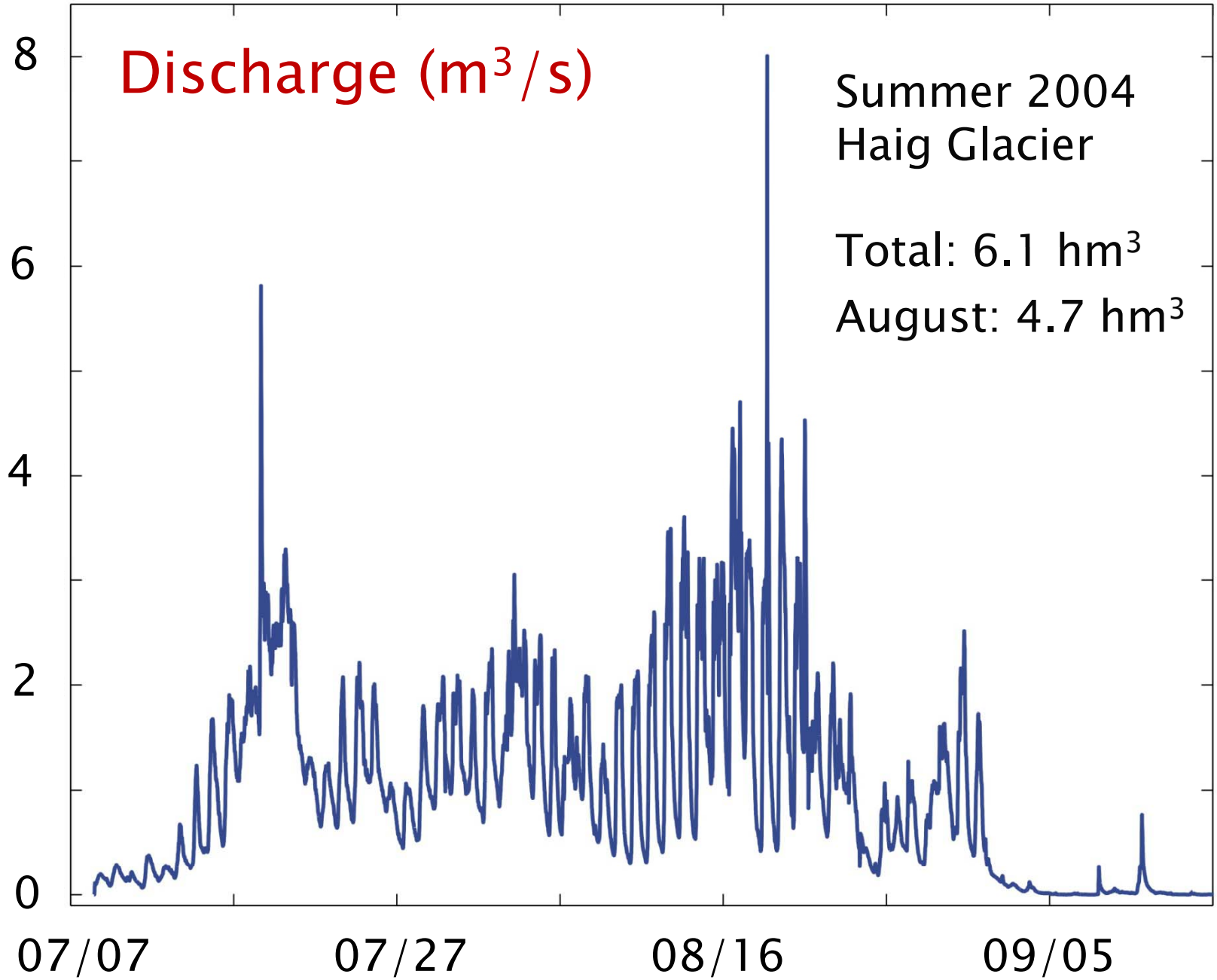
Characteristics of Glacier Runoff: Place and Eight Mile Creeks, Coast Mountains BC





Dan Moore (UBC)


Haig Glacier, Canadian Rockies

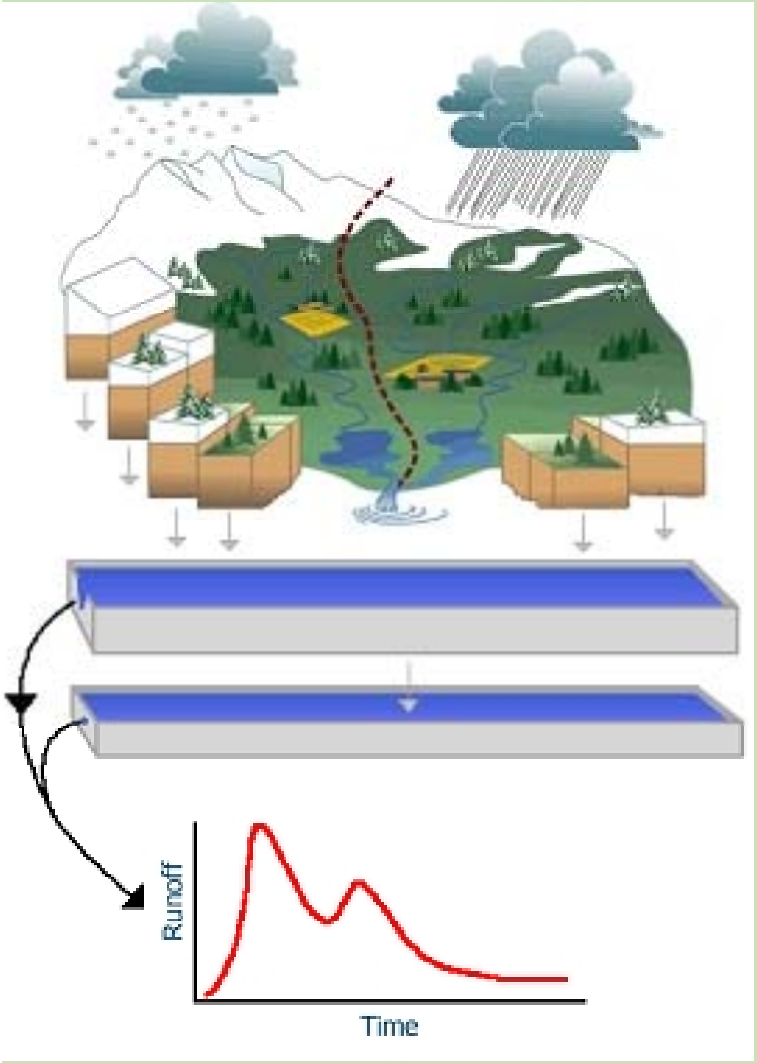

Discharge (m³/s)
Summer 2004
Haig Glacier
Total: 6.1 hm³
August: 4.7 hm³
8
6
4
2
0
07/07
07/27
08/16
09/05

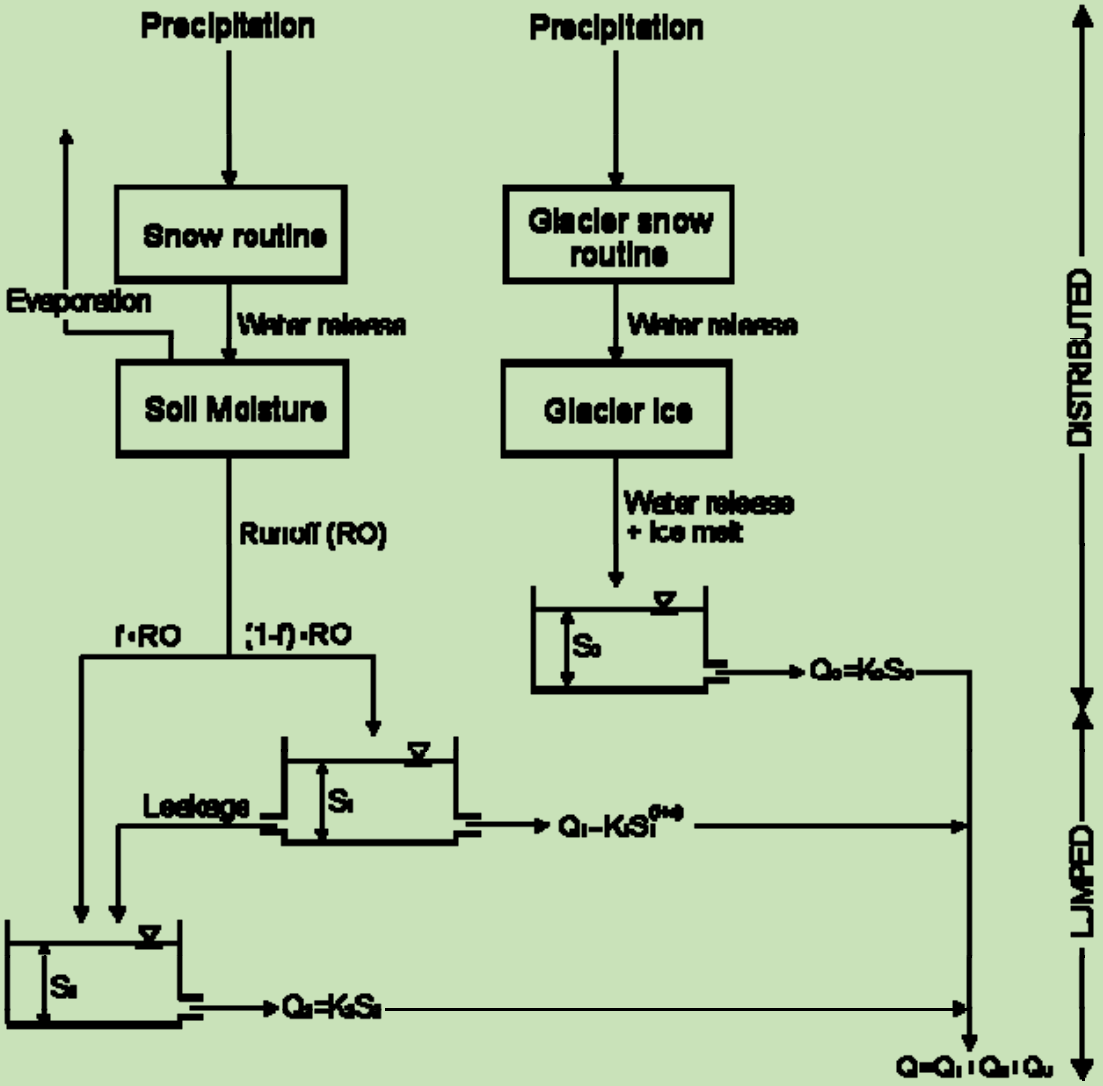
Haig Glacier runoff, 2001–2005

	Summer mass mass balance (m w.eq.)	*Runoff (JJAS) Total (m w.eq.)*	*Snow*	*Ice*	
2001–02	–2.13	2.30	1.44	0.86	(37% ice)
2002–03	–2.66	2.71	1.14	1.57	(58% ice)
2003–04	–1.83	2.14	1.26	0.88	(41% ice)
2004–05	–1.76	2.03	1.23	0.80	(40% ice)

Average runoff from seasonal snow: 56 %
glacier ice: 44 %

HBV-EC hydrological model





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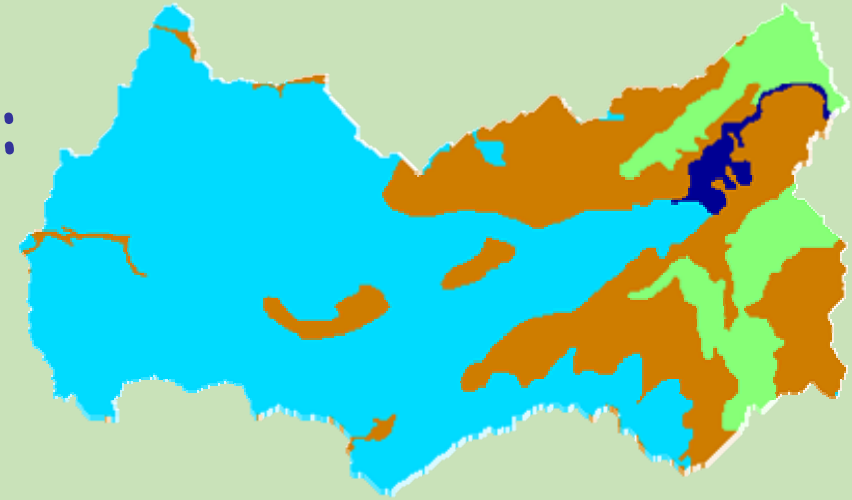
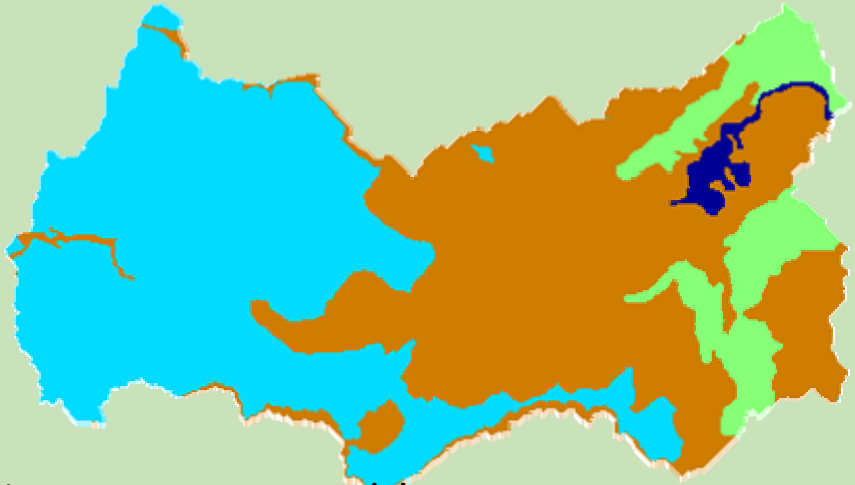
Glacier cover change: (1990 to 2095) Bridge Glacier Basin



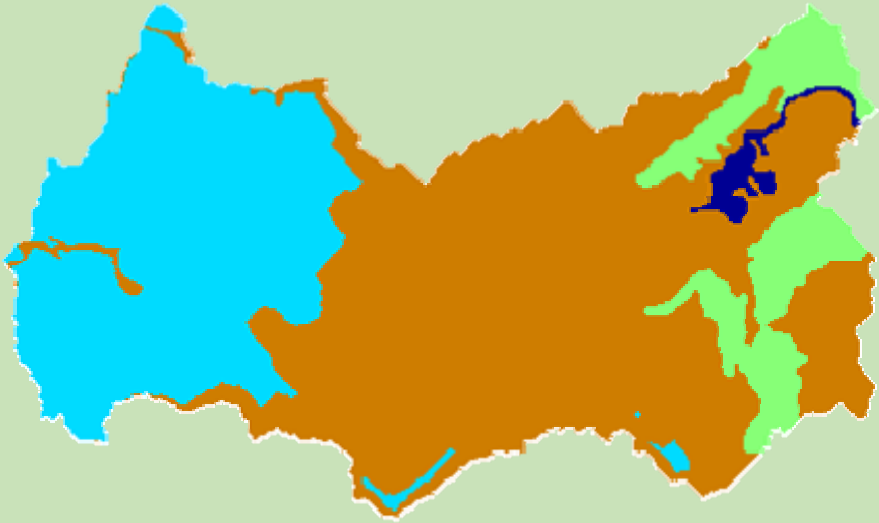
BTM Land Cover
(Landsat Image mid-1990s)

Glacier
Open
Forest
Lake

S0: "No change"



S2: SRES A2



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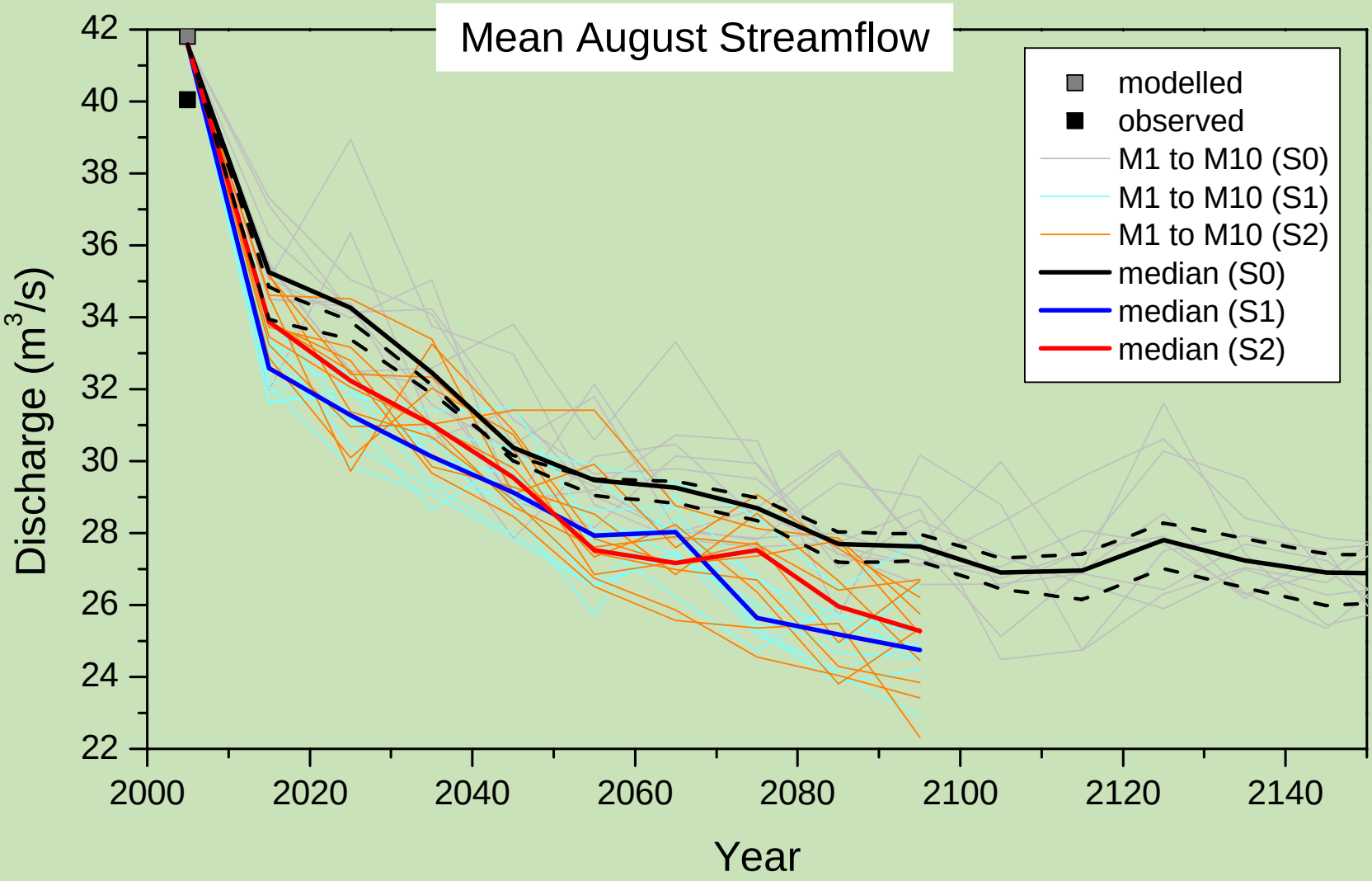
Changes to August streamflow



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GLIMS

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