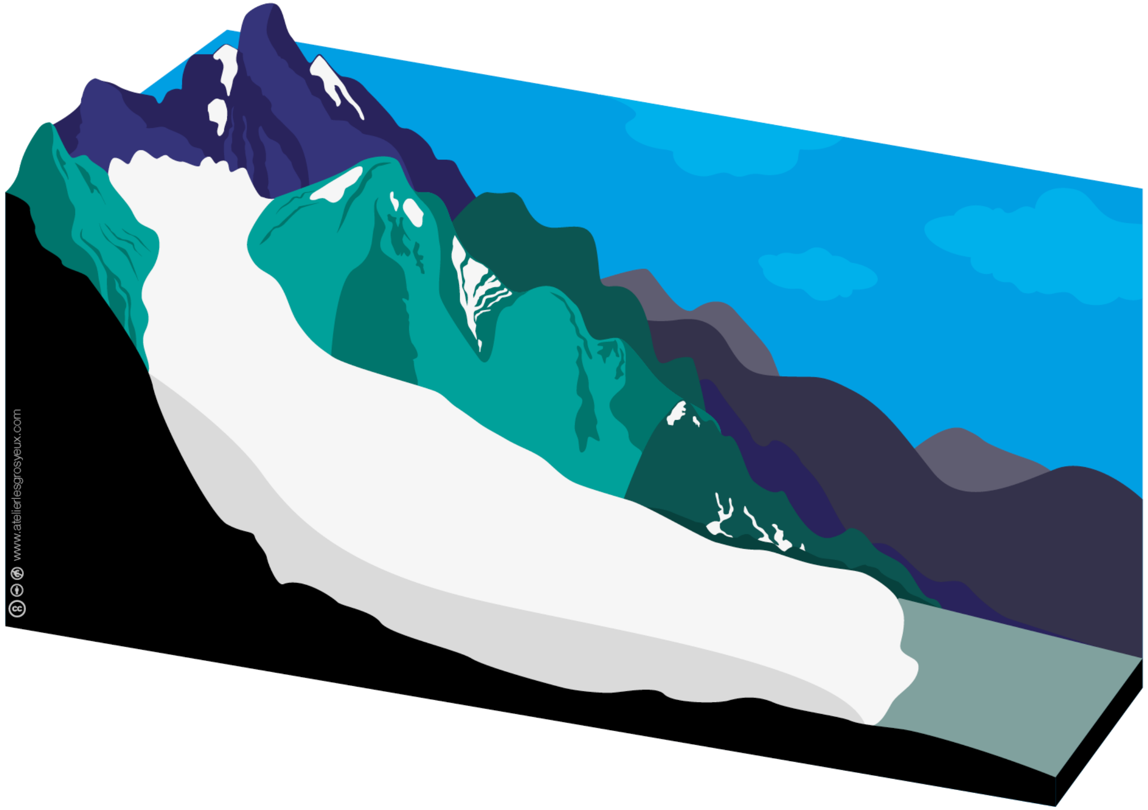
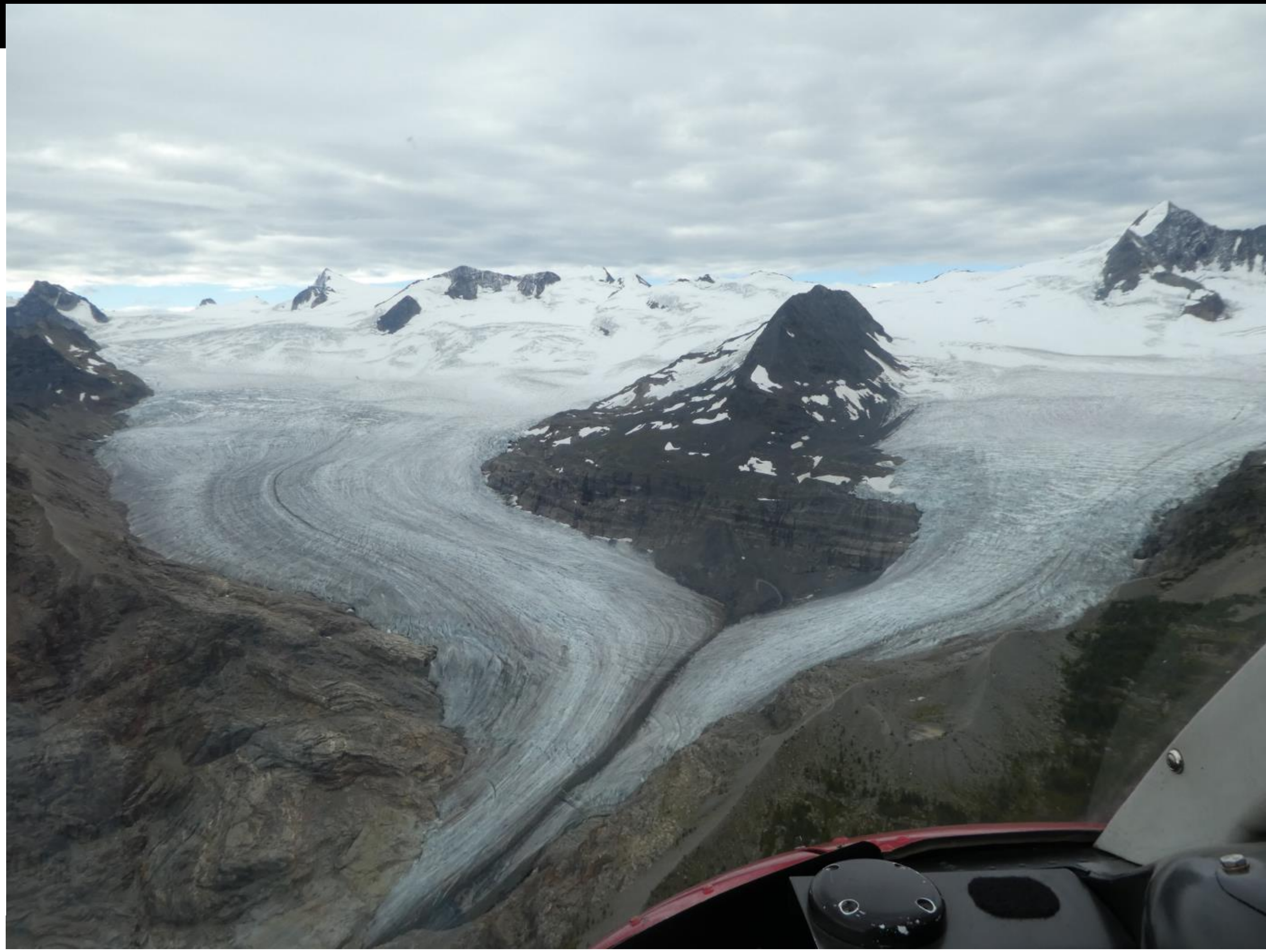
Glacier mass balance

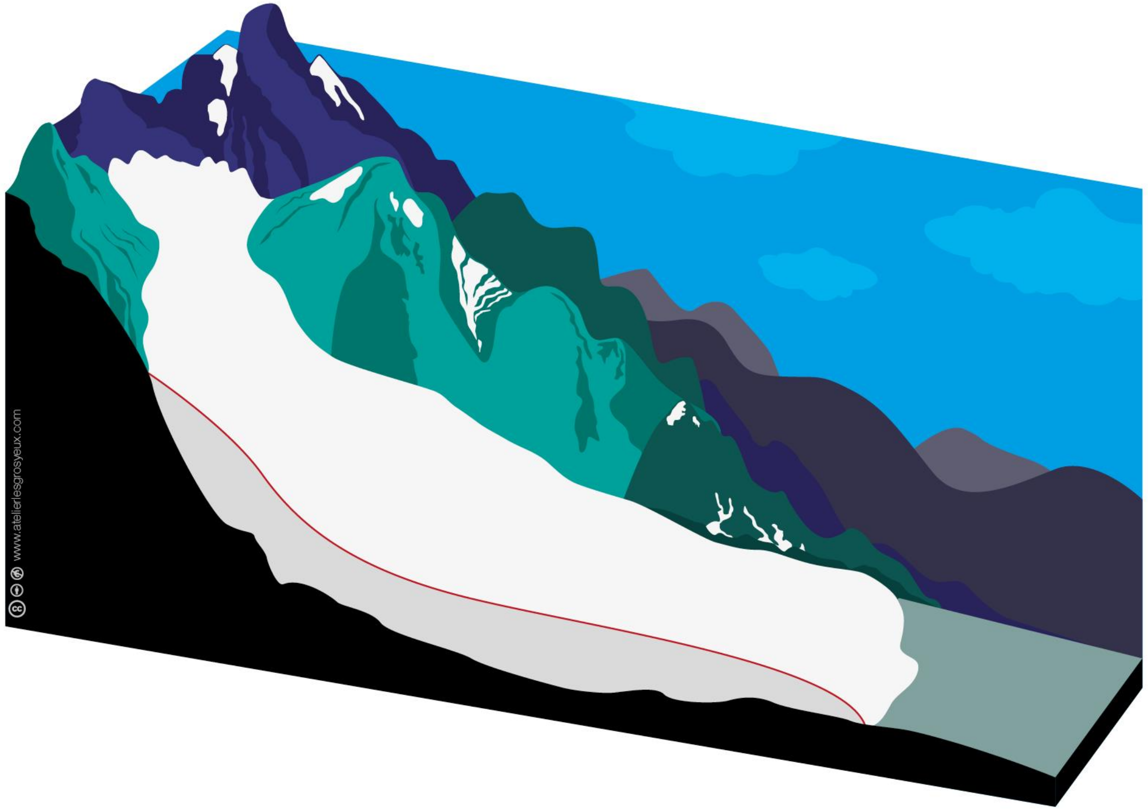
Ben M. Pelto

Mountain Glaciers

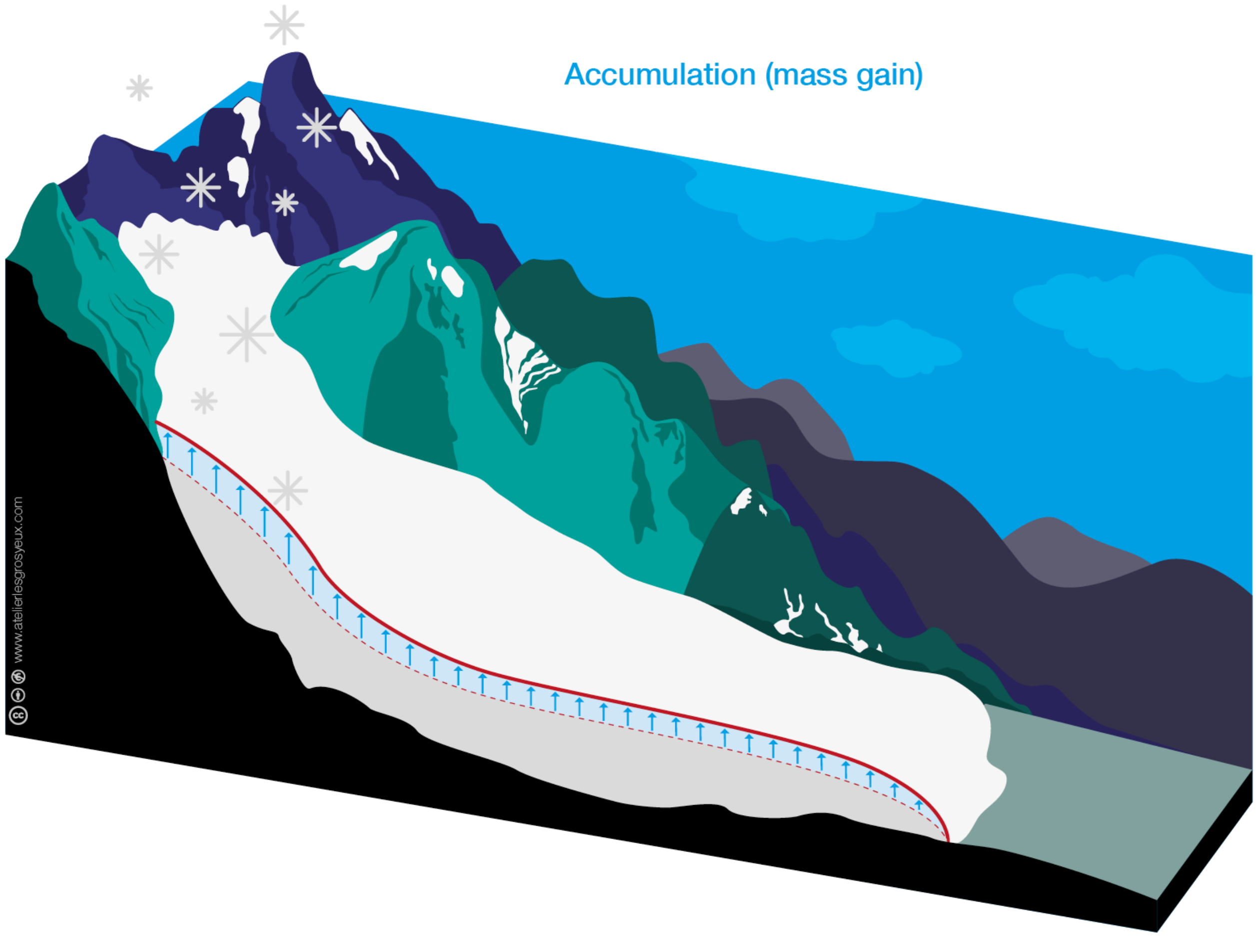




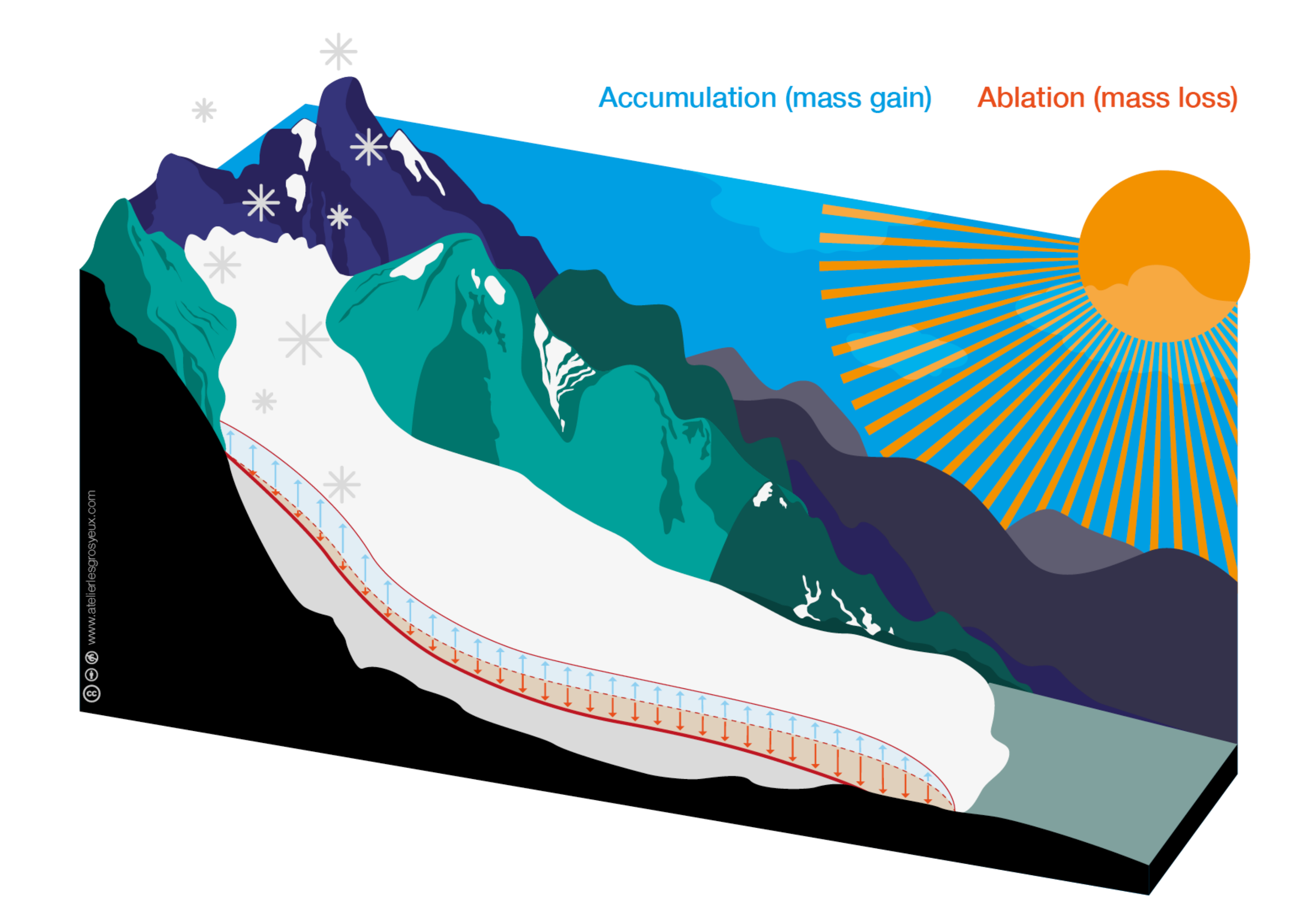
Glacier surface

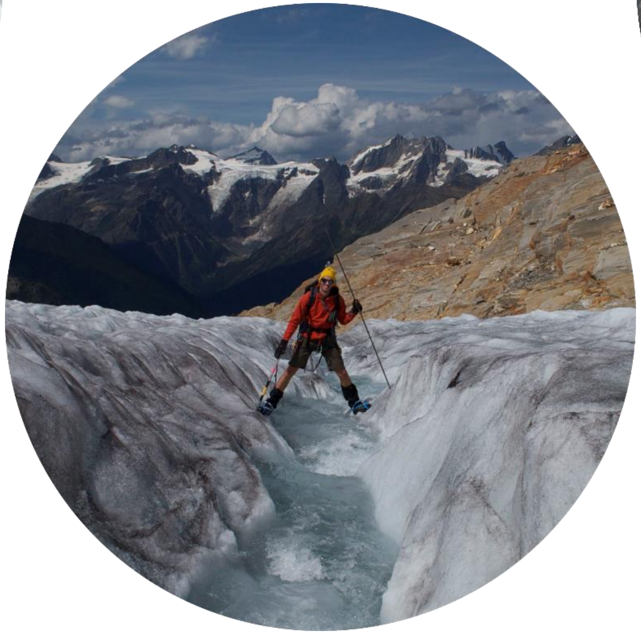


Accumulation

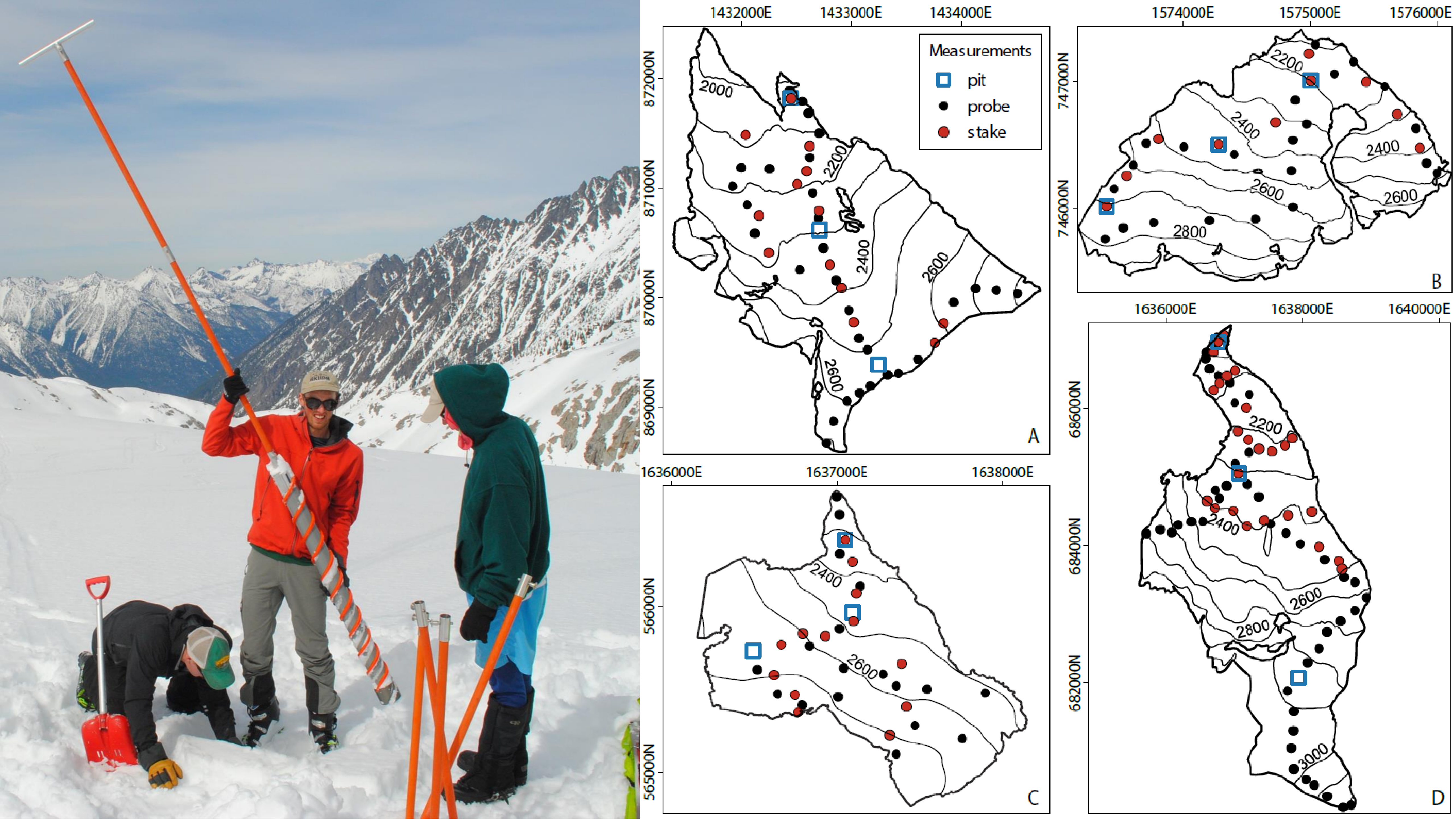


Ablation

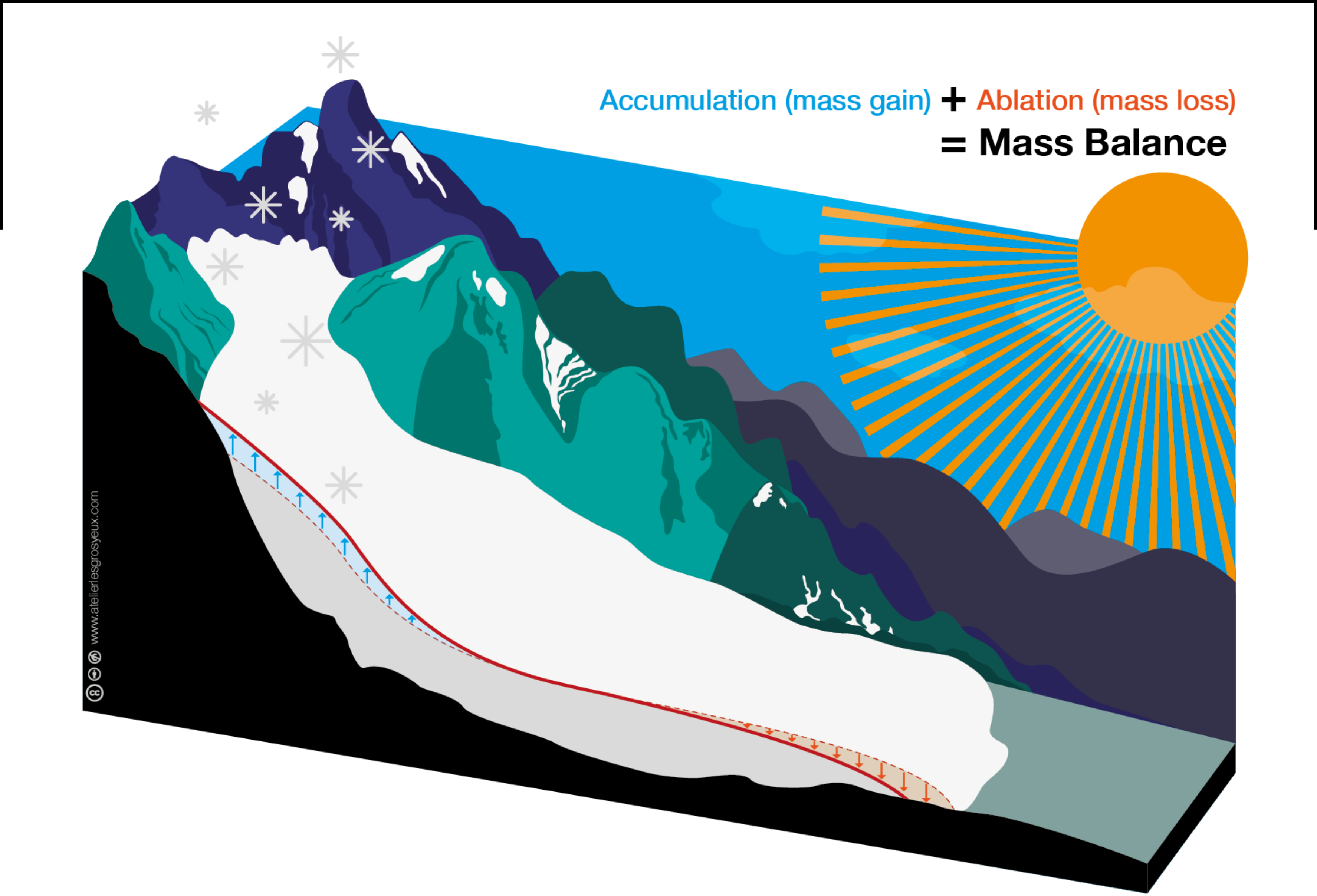

Accumulation (mass gain)
Ablation (mass loss)
www.atelierlesgrosyeux.com



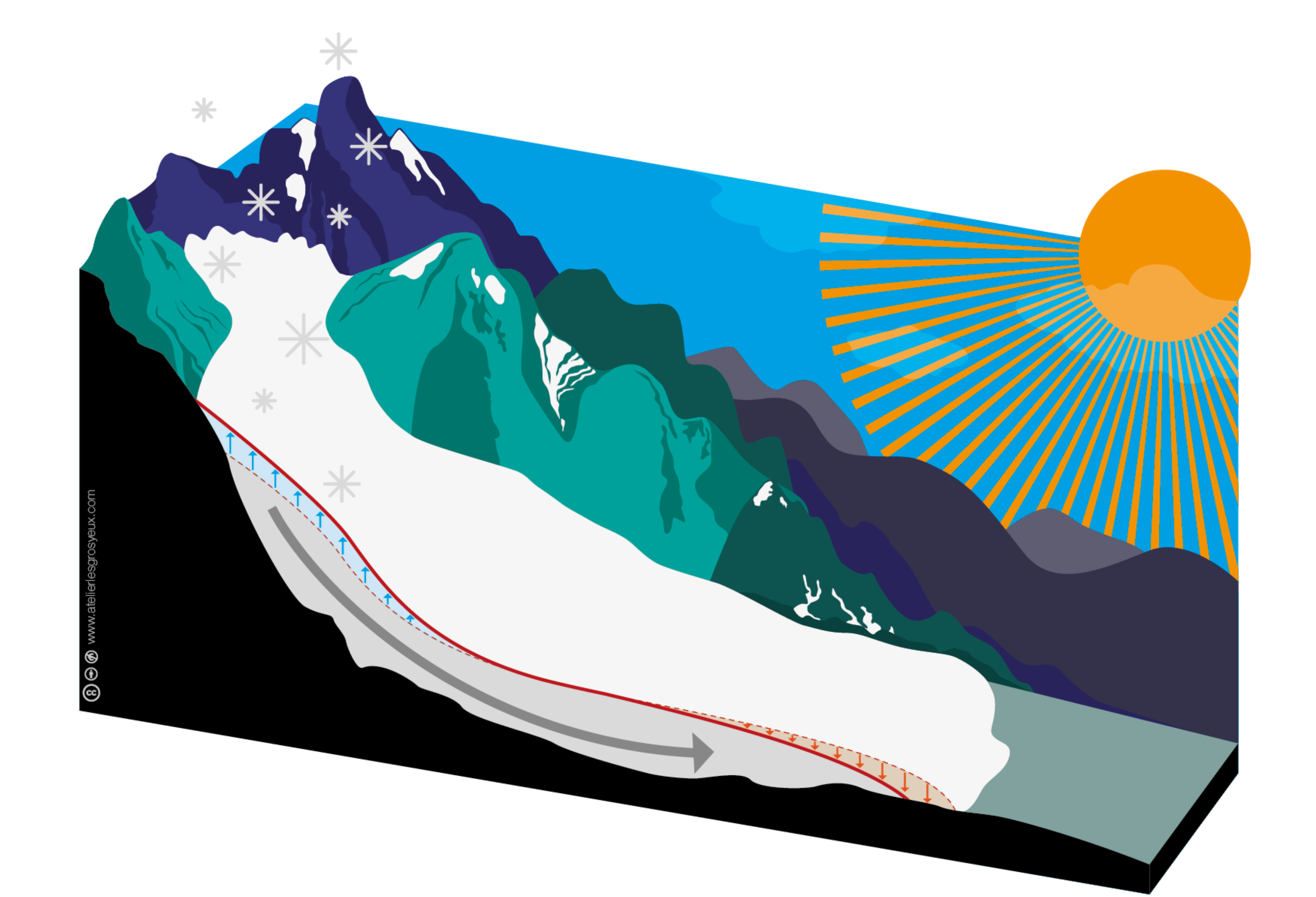
Accumulation + **Melt** = **Mass Balance**


Measurements
pit
probe
stake
1432000E
1433000E
1434000E
872000N
871000N
870000N
869000N
2000
2200
2400
2600
A
1574000E
1575000E
1576000E
747000N
746000N
2200
2400
2400
2600
2600
2800
B
1636000E
1637000E
1638000E
566000N
565000N
2400
2600
C
1636000E
1638000E
1640000E
686000N
684000N
682000N
2200
2400
2600
2800
3000
D

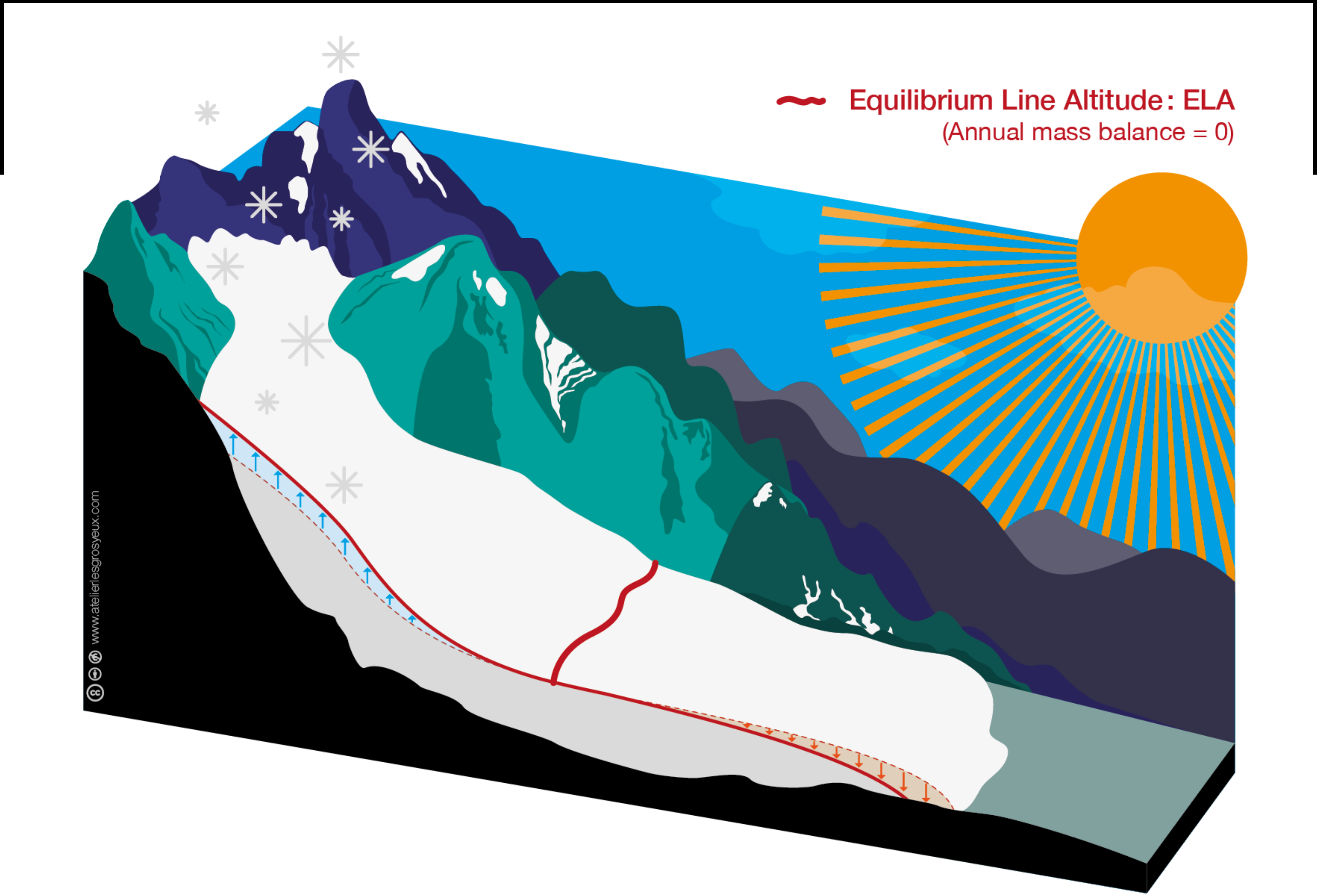
Glacier Mass Balance



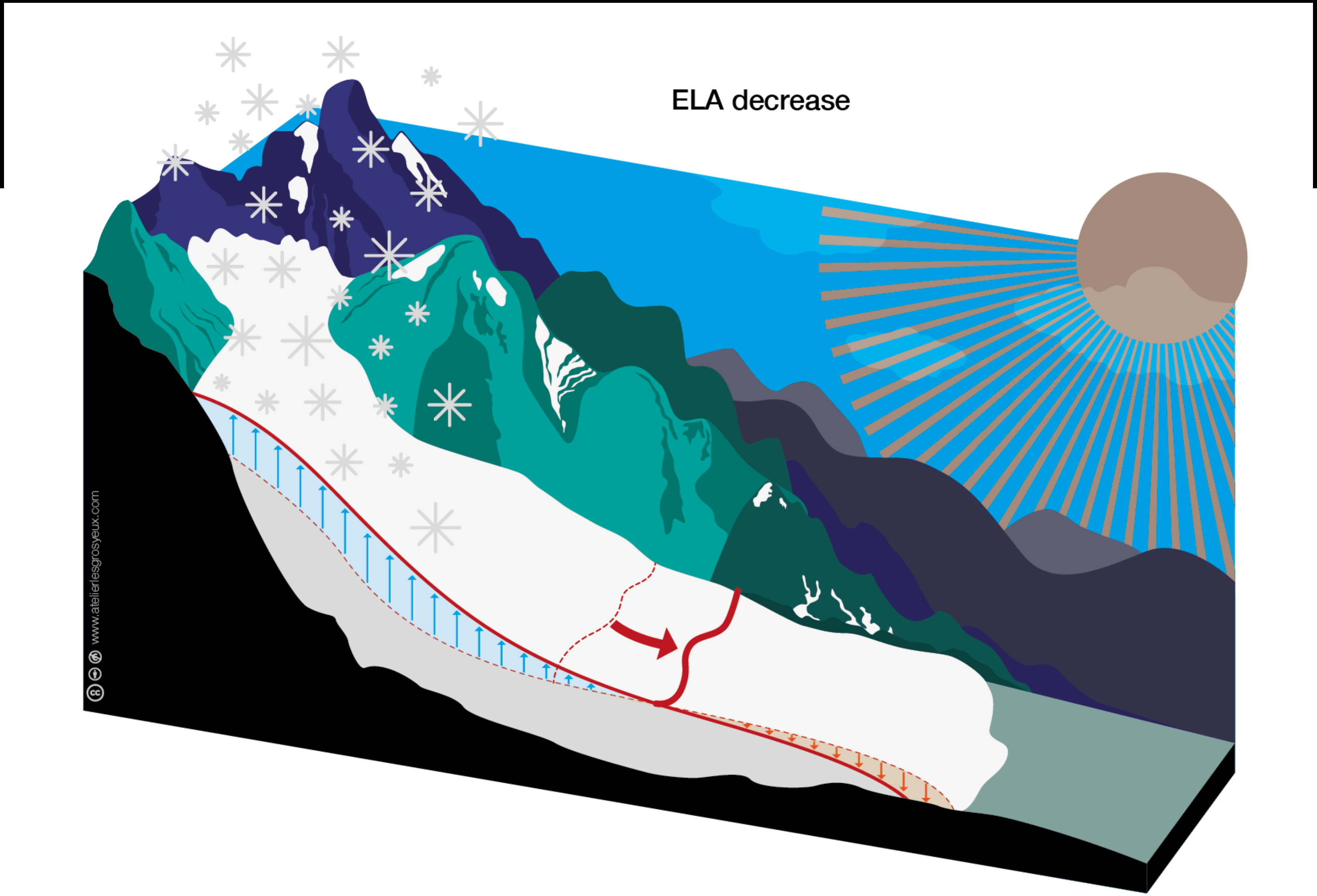
Ice velocity (flux)



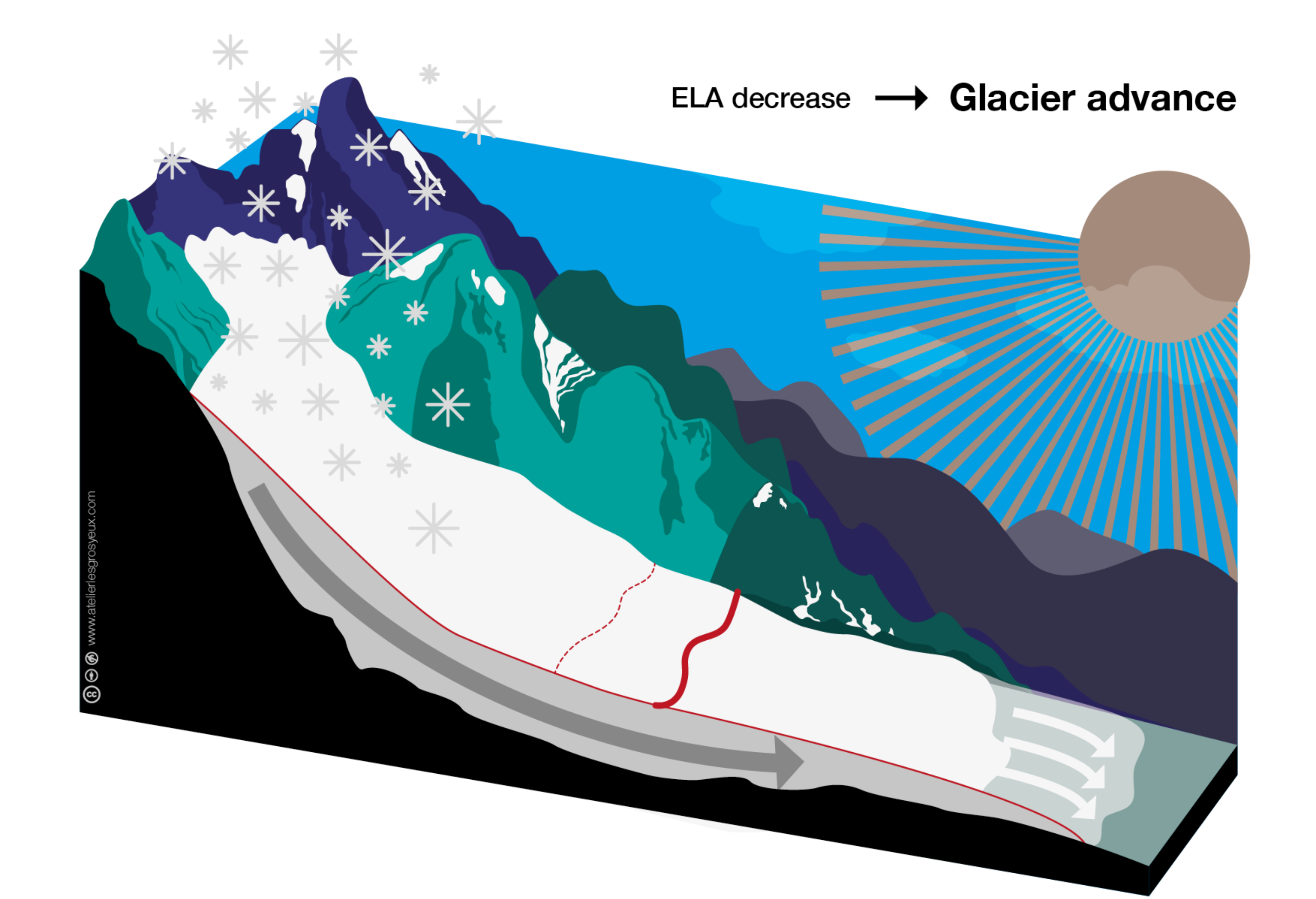
Equilibrium Line Altitude (ELA)



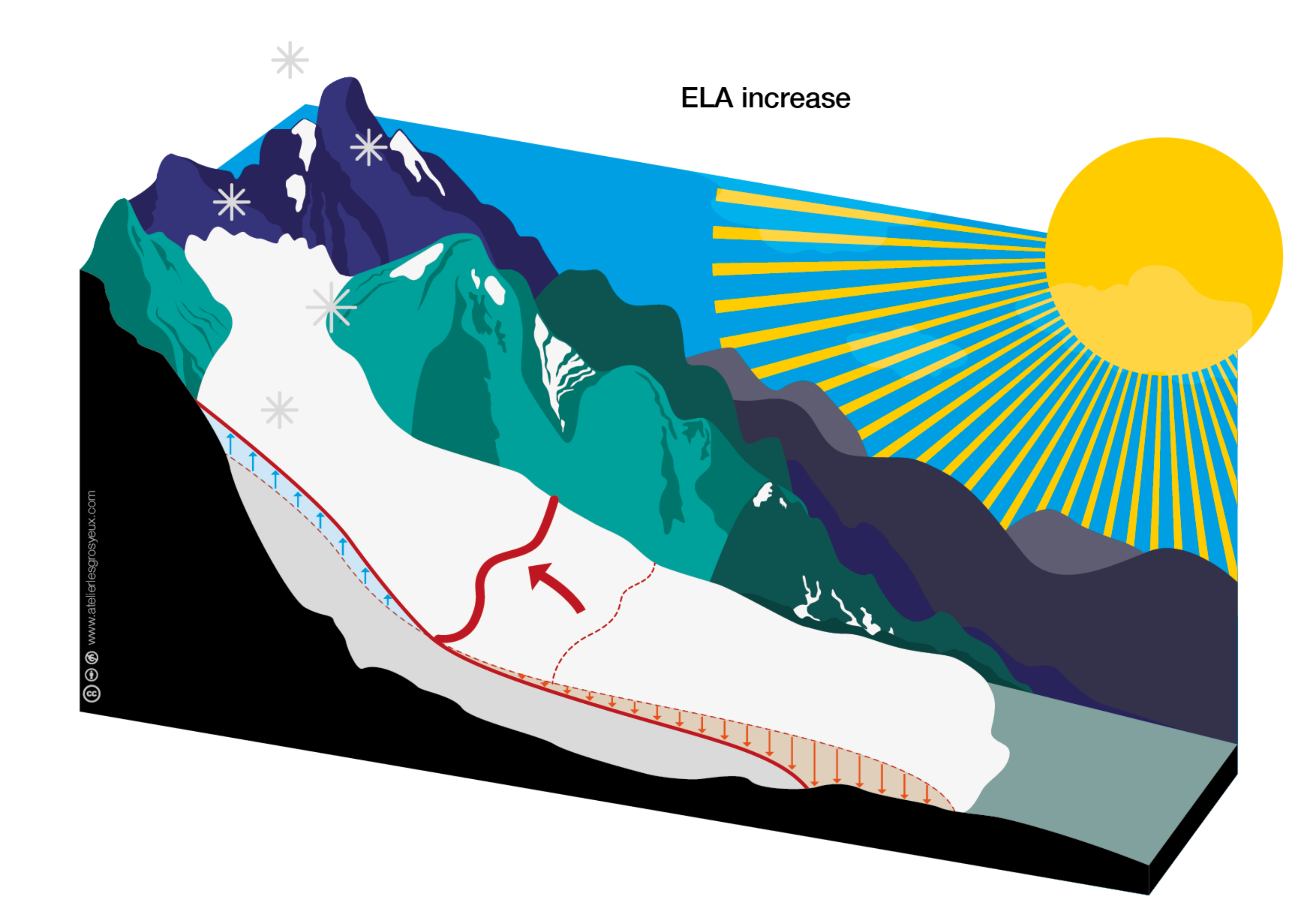
ELA decrease



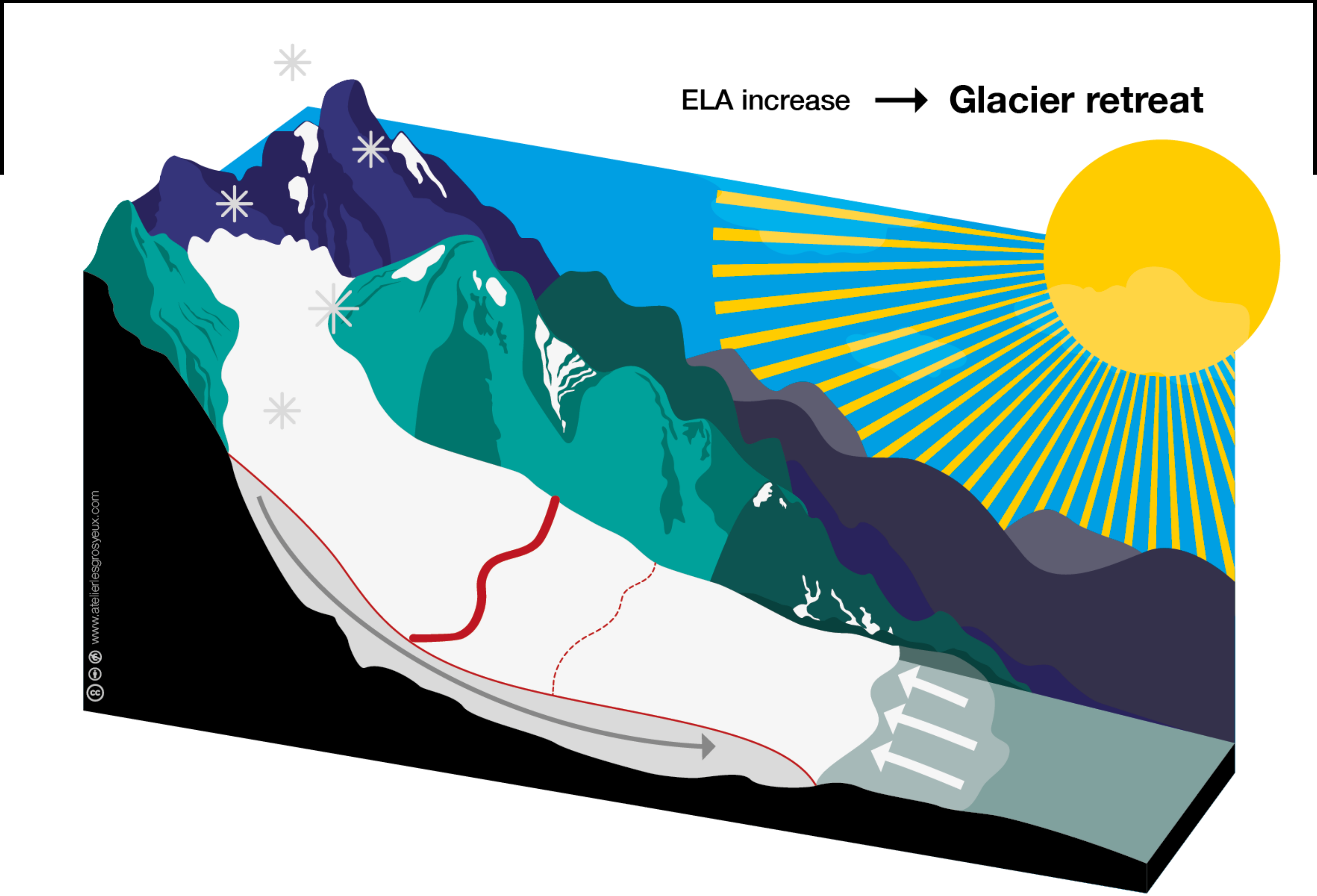
Glacier Advance



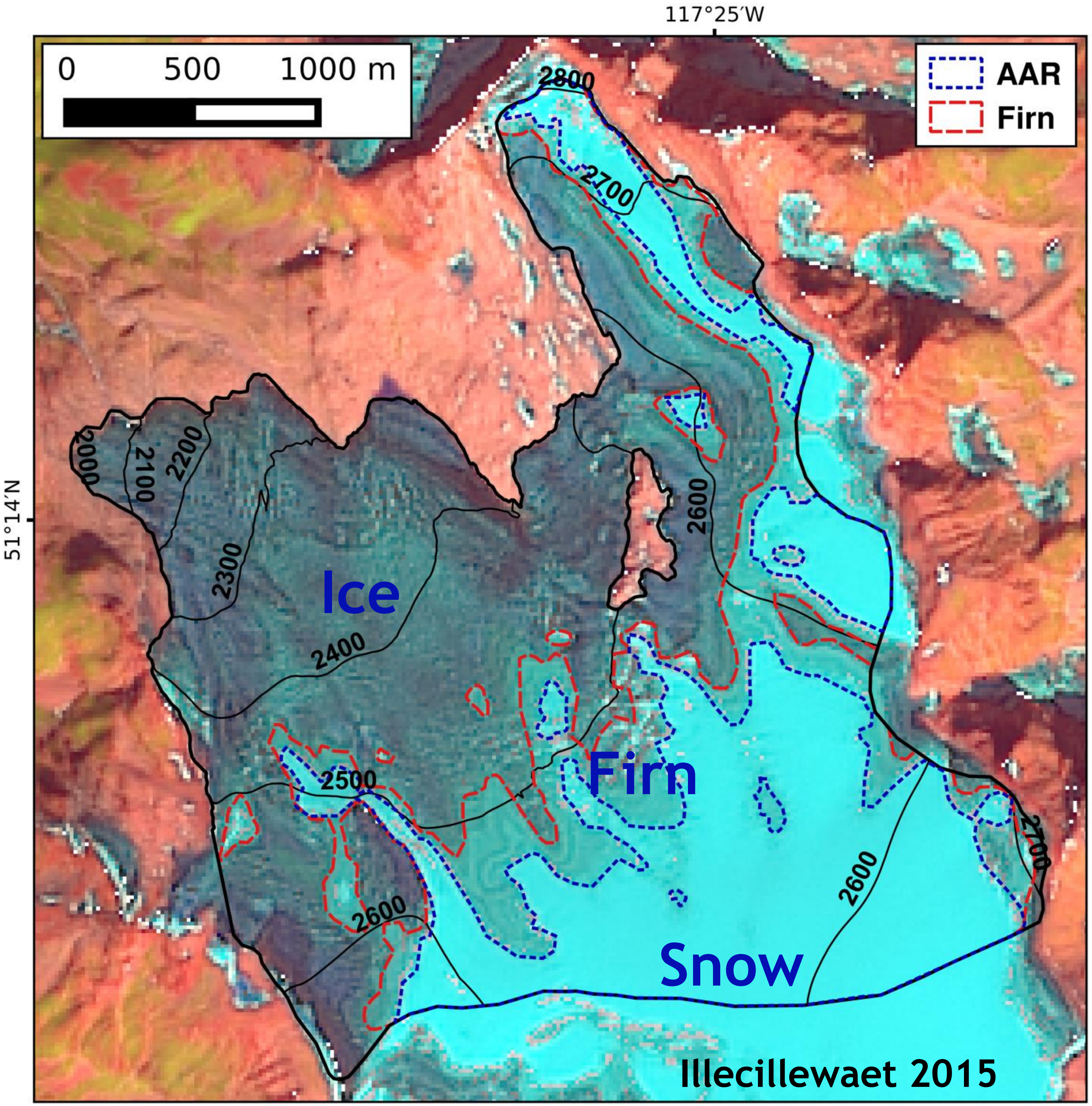
ELA increase – today's scenario

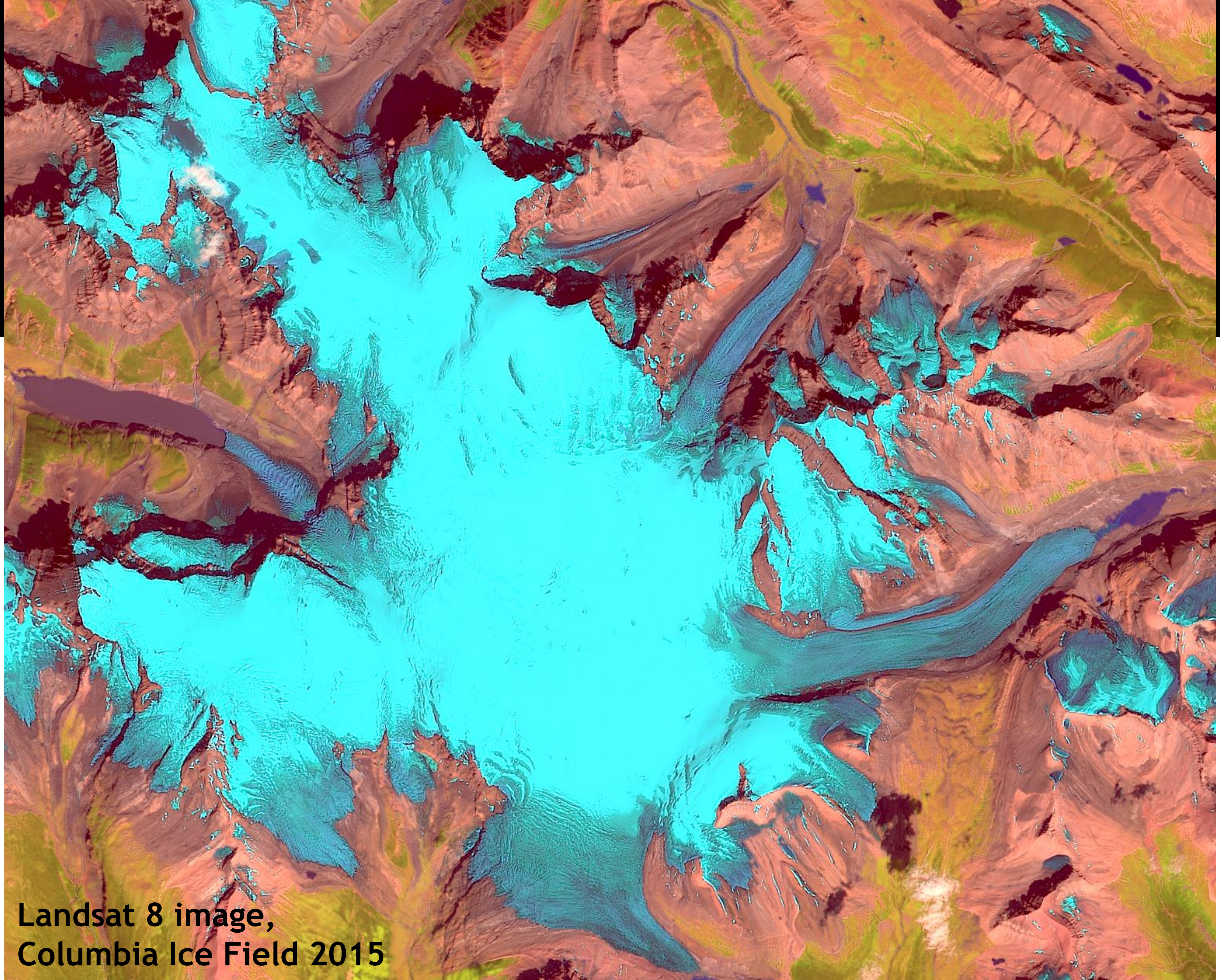


Glacier retreat



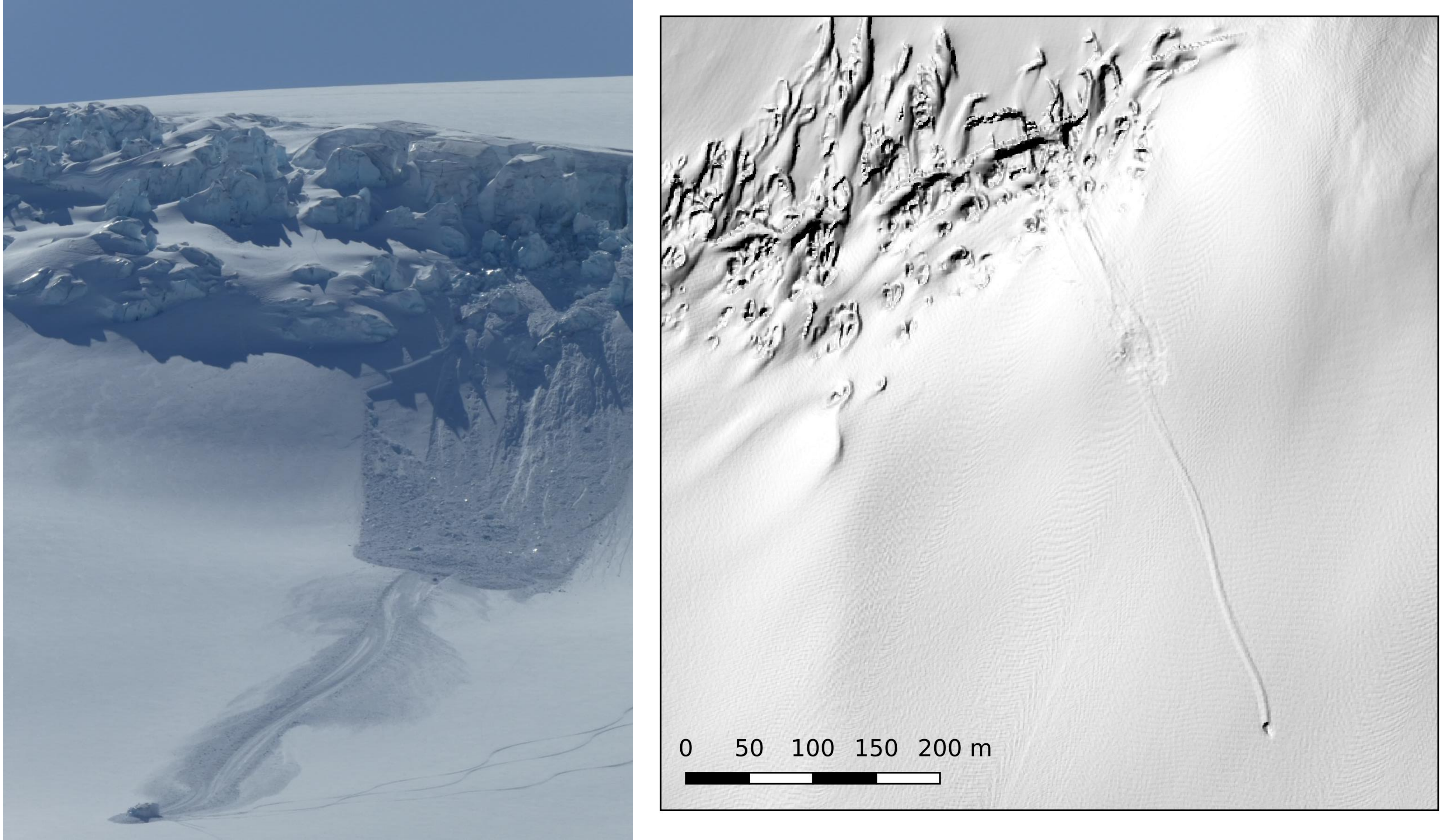
Satellite detection

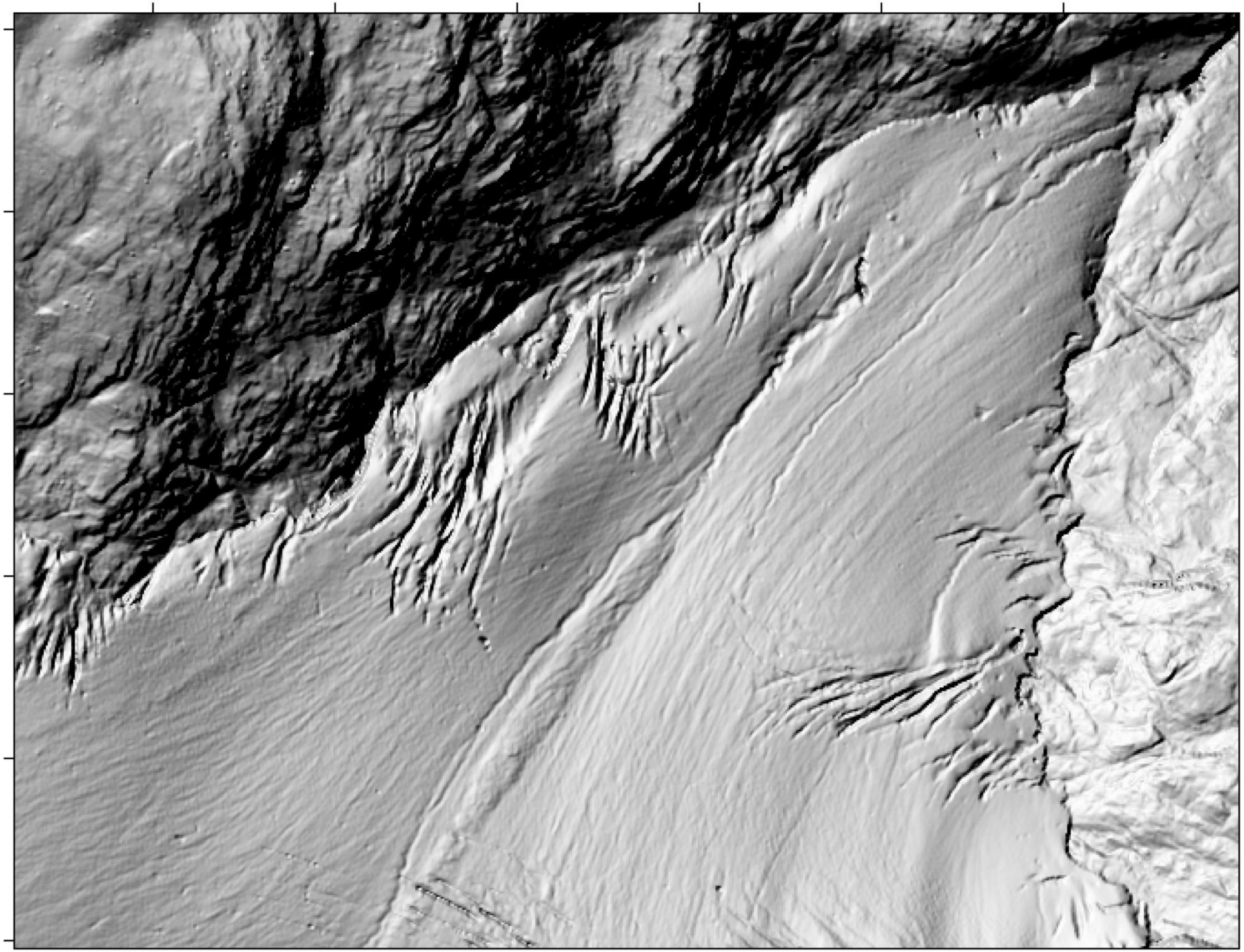


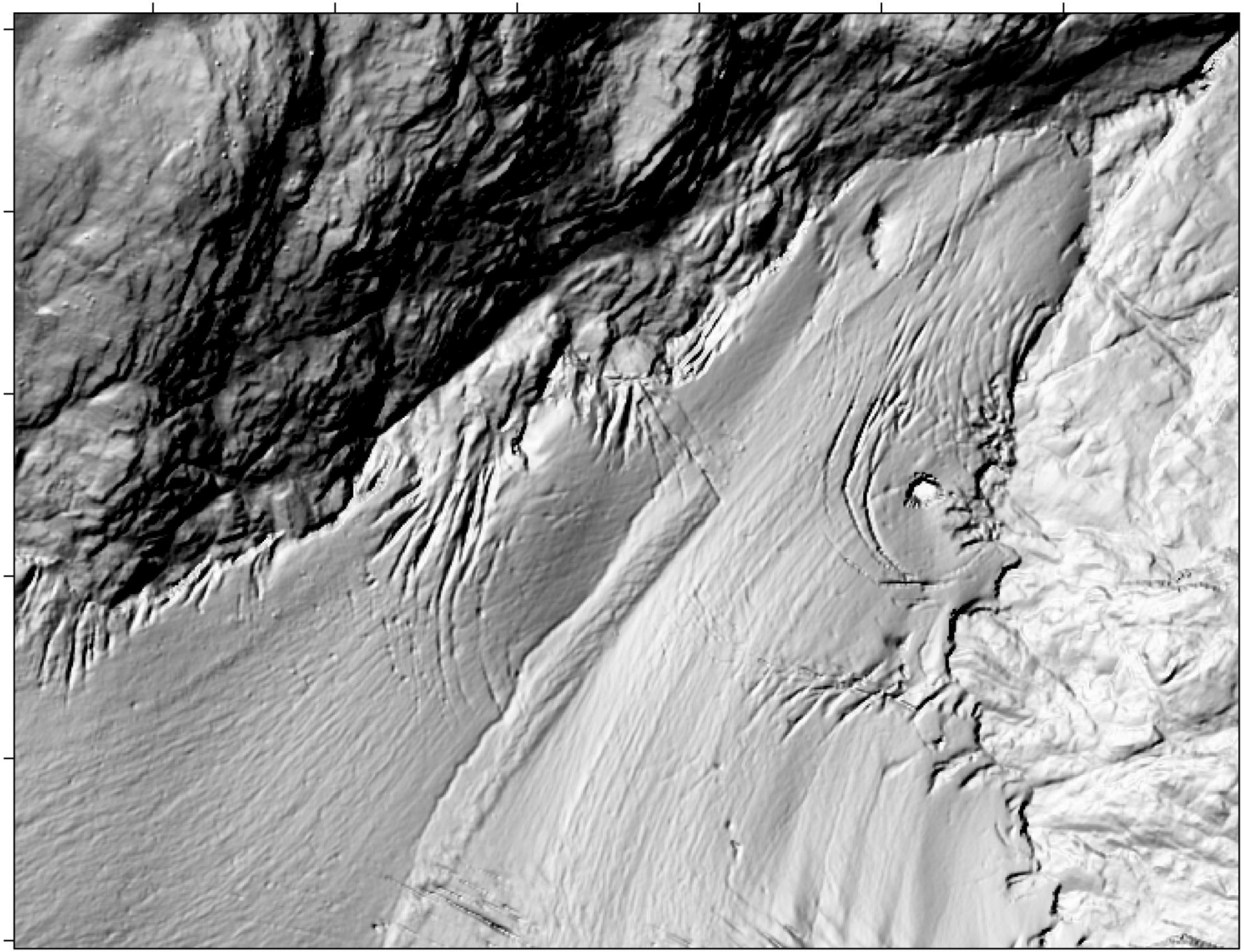

Landsat 8 image,
Columbia Ice Field 2015

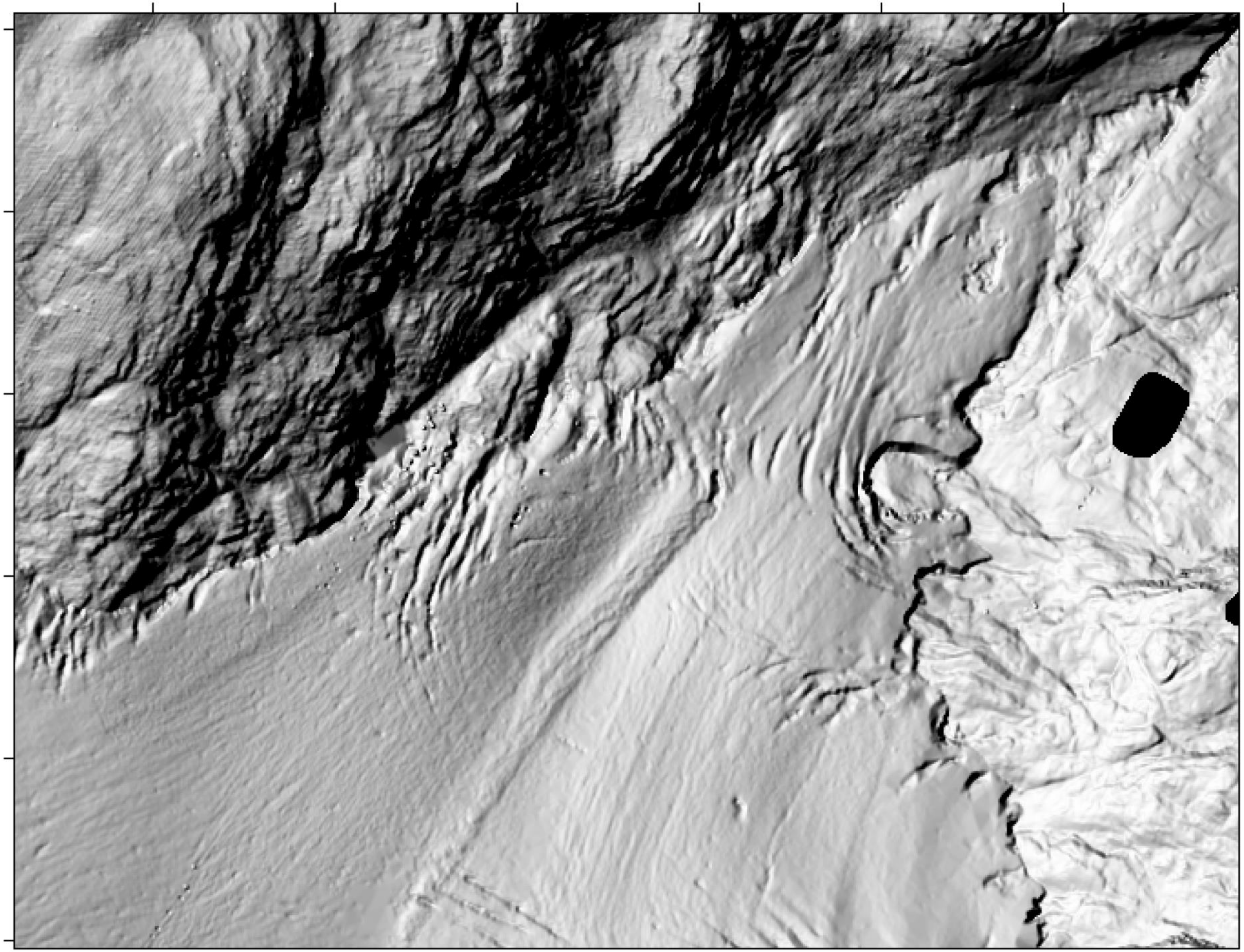
Airborne Laser Scanning (ALS or LiDAR)

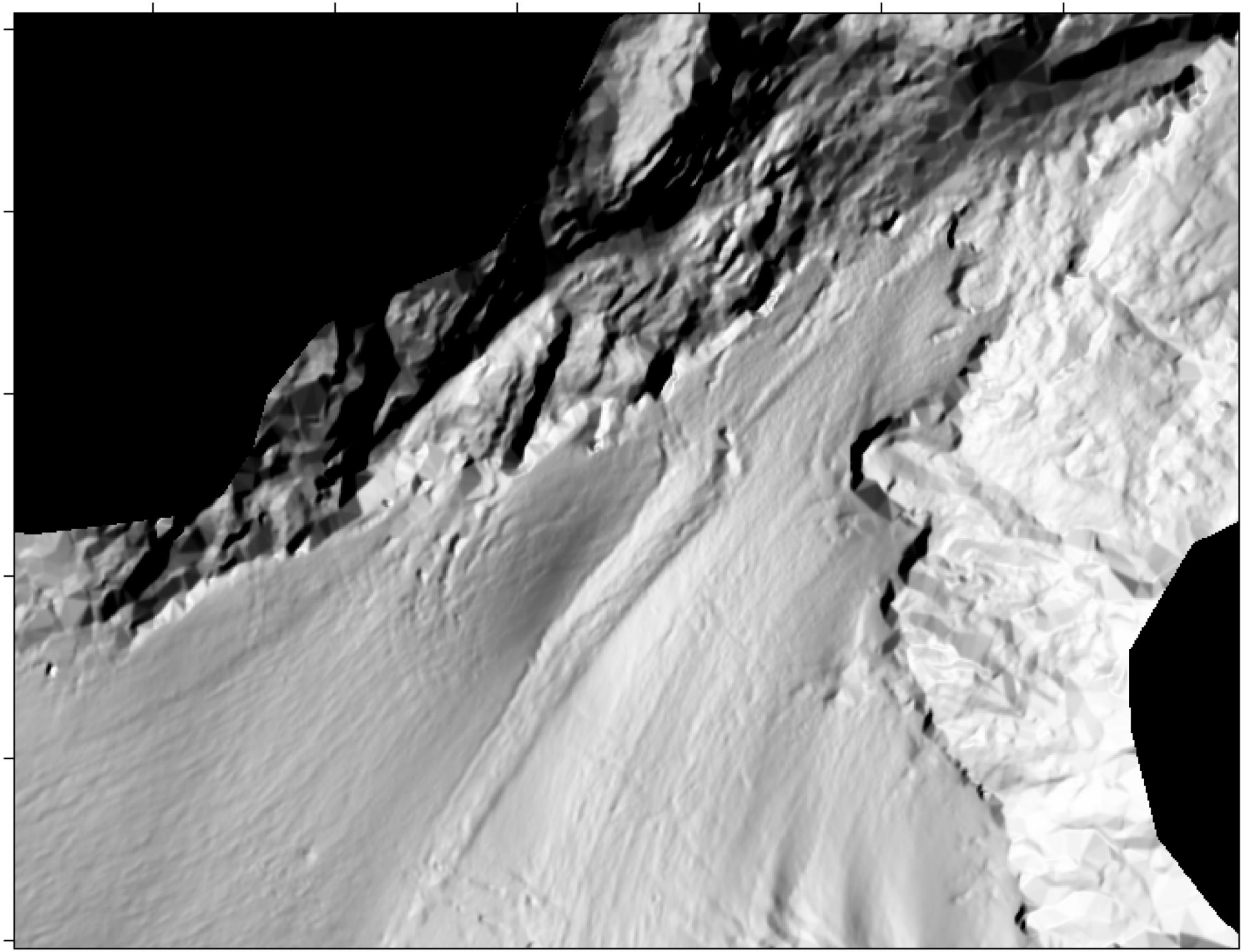
- LiDAR: Light detection and ranging
- Uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth
- Laser scanner (range) + GPS (location)
- Typically around 1-2 laser shots per m^2
- Produce a point cloud of samples (x,y,z)
- DEM is generated from the point cloud

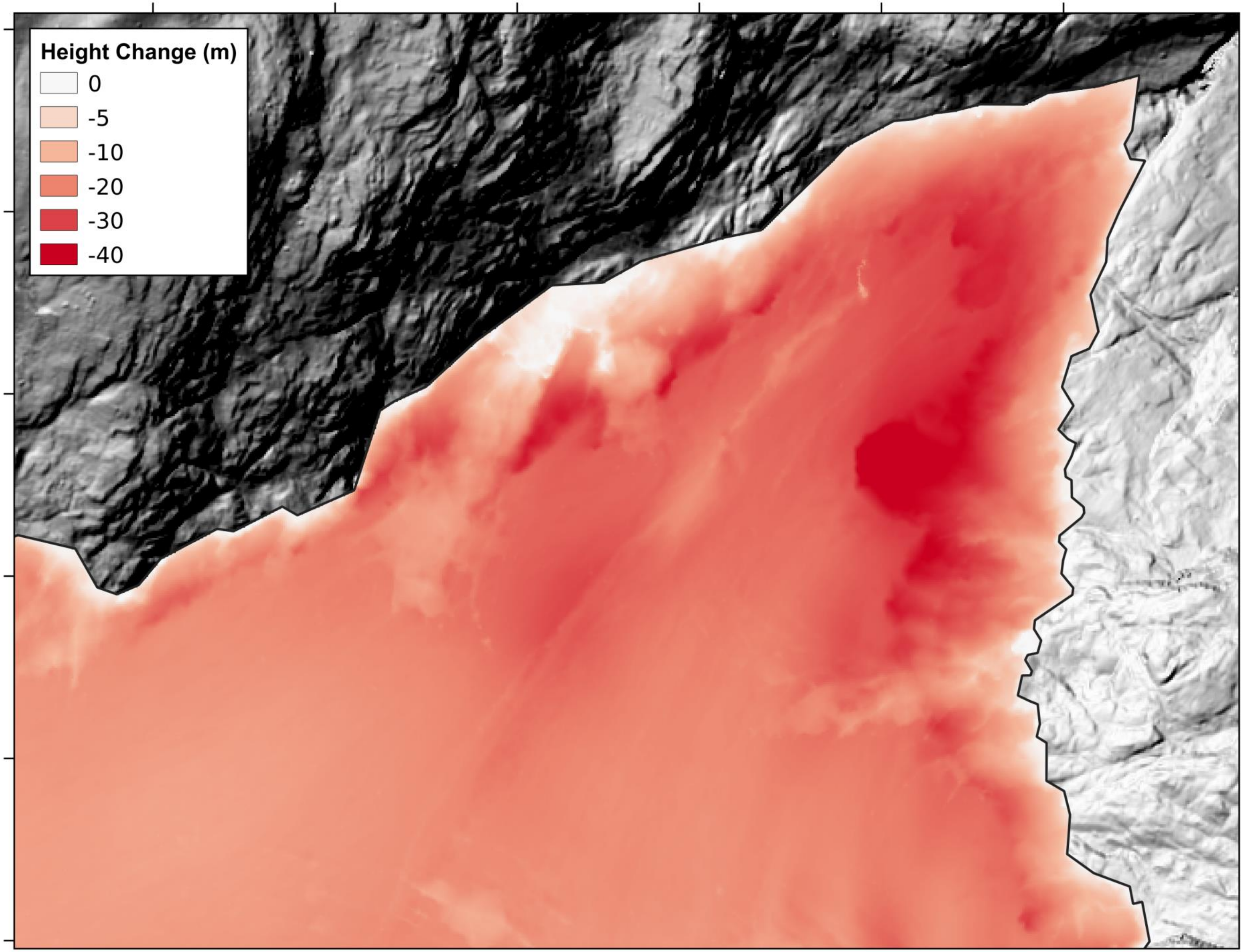

0 50 100 150 200 m

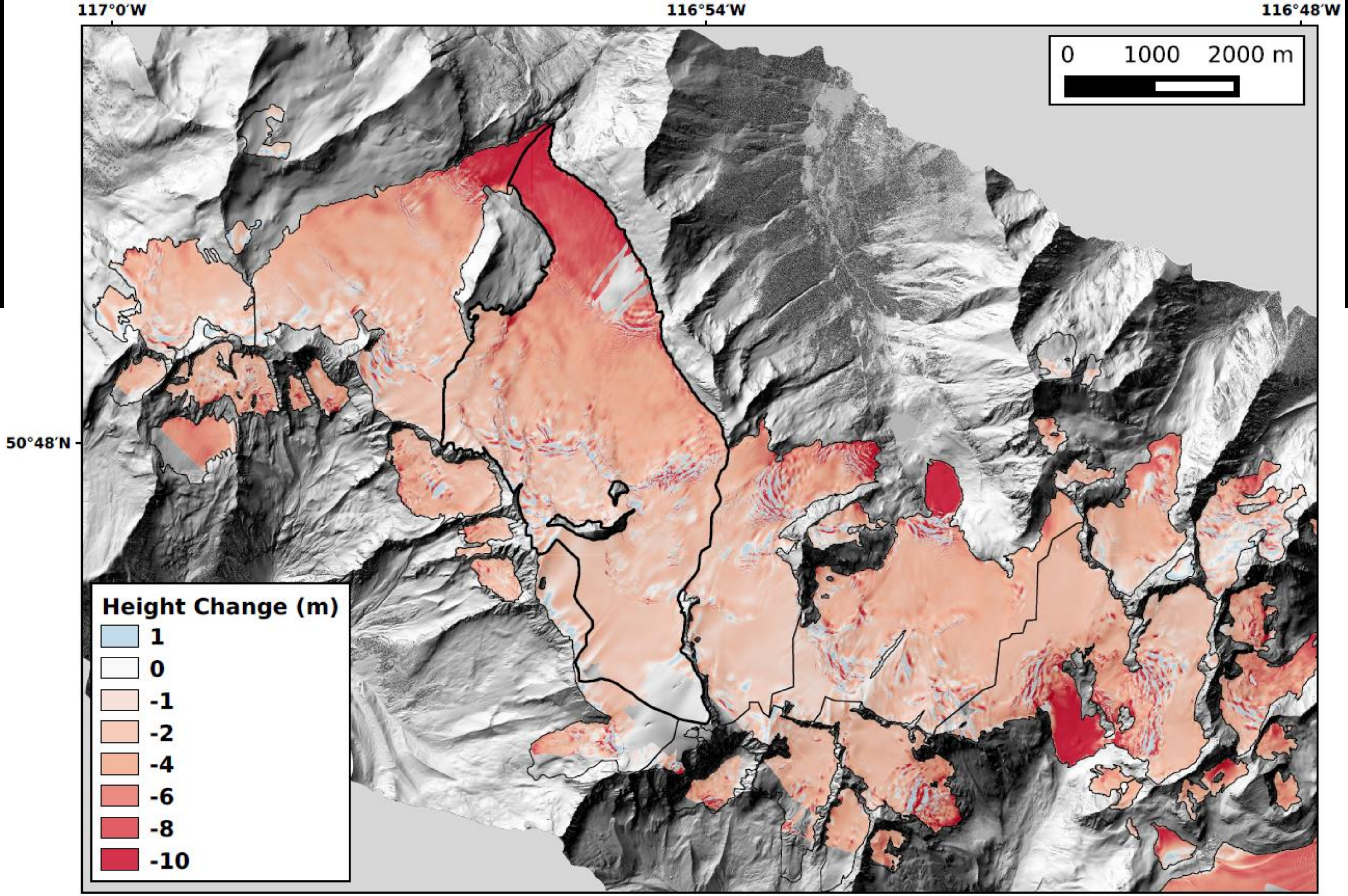




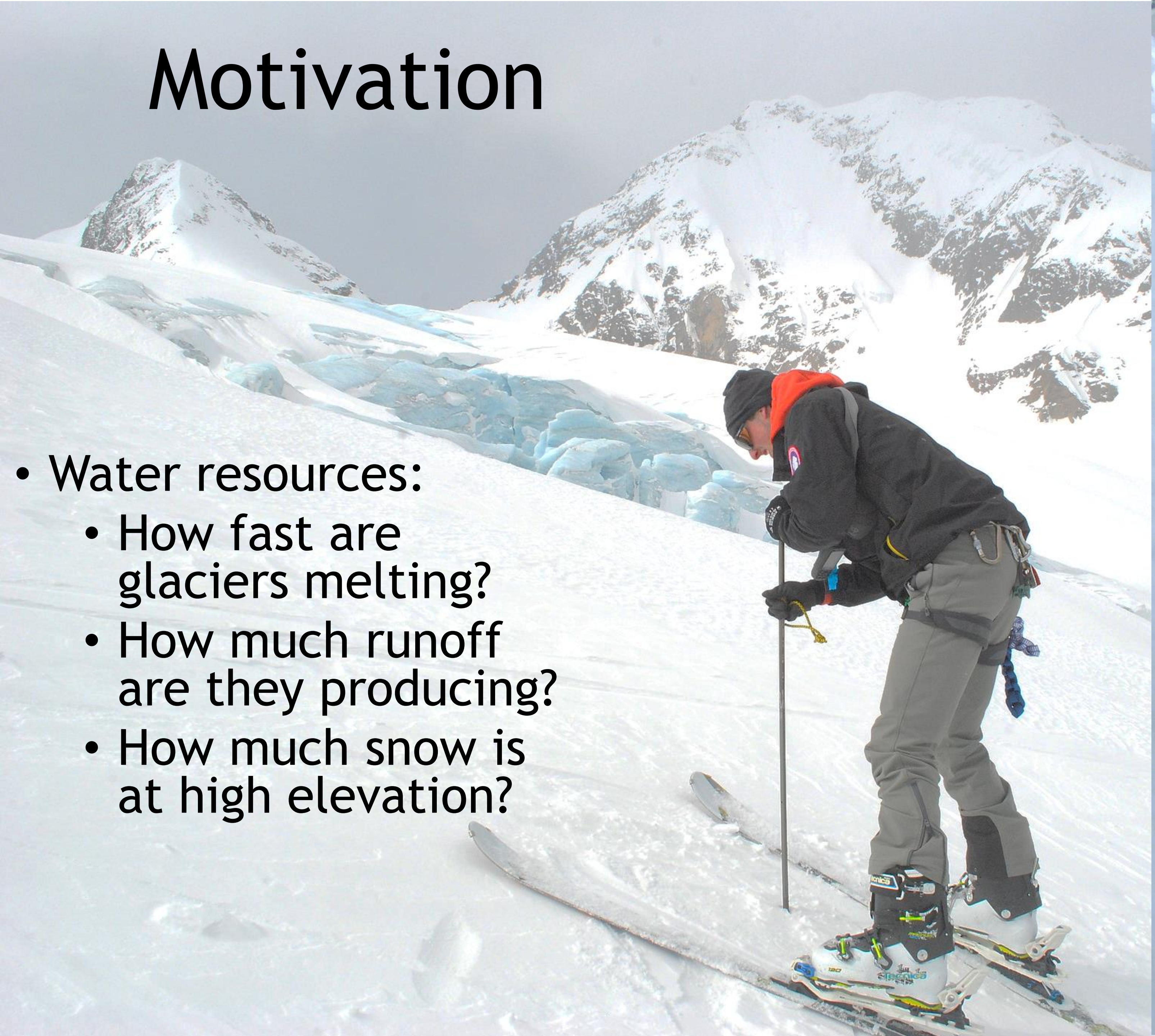





Height Change (m)
0
-5
-10
-20
-30
-40

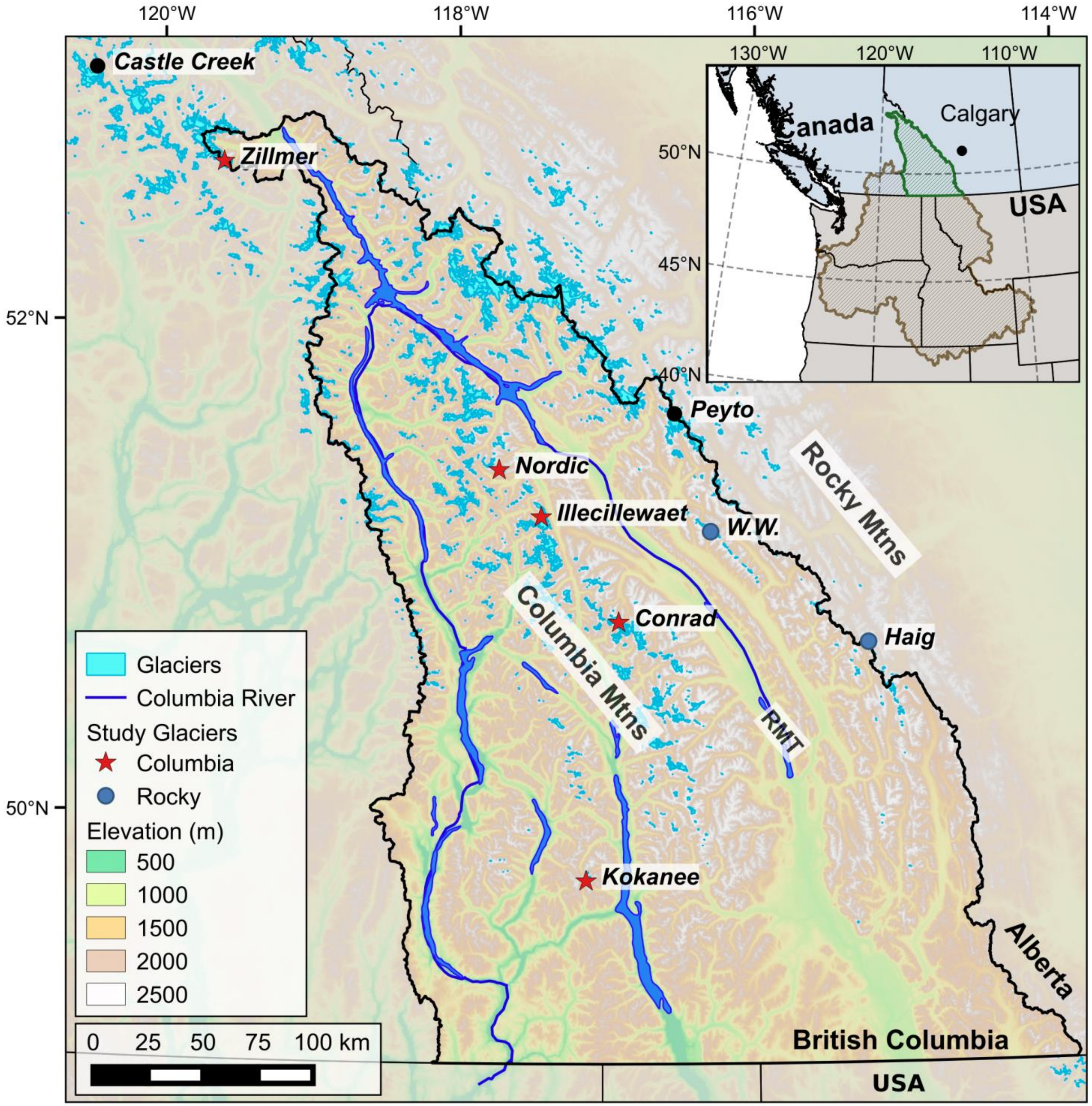

117°0′W
116°54′W
116°48′W
50°48′N
0
1000
2000 m
Height Change (m)
1
0
-1
-2
-4
-6
-8
-10

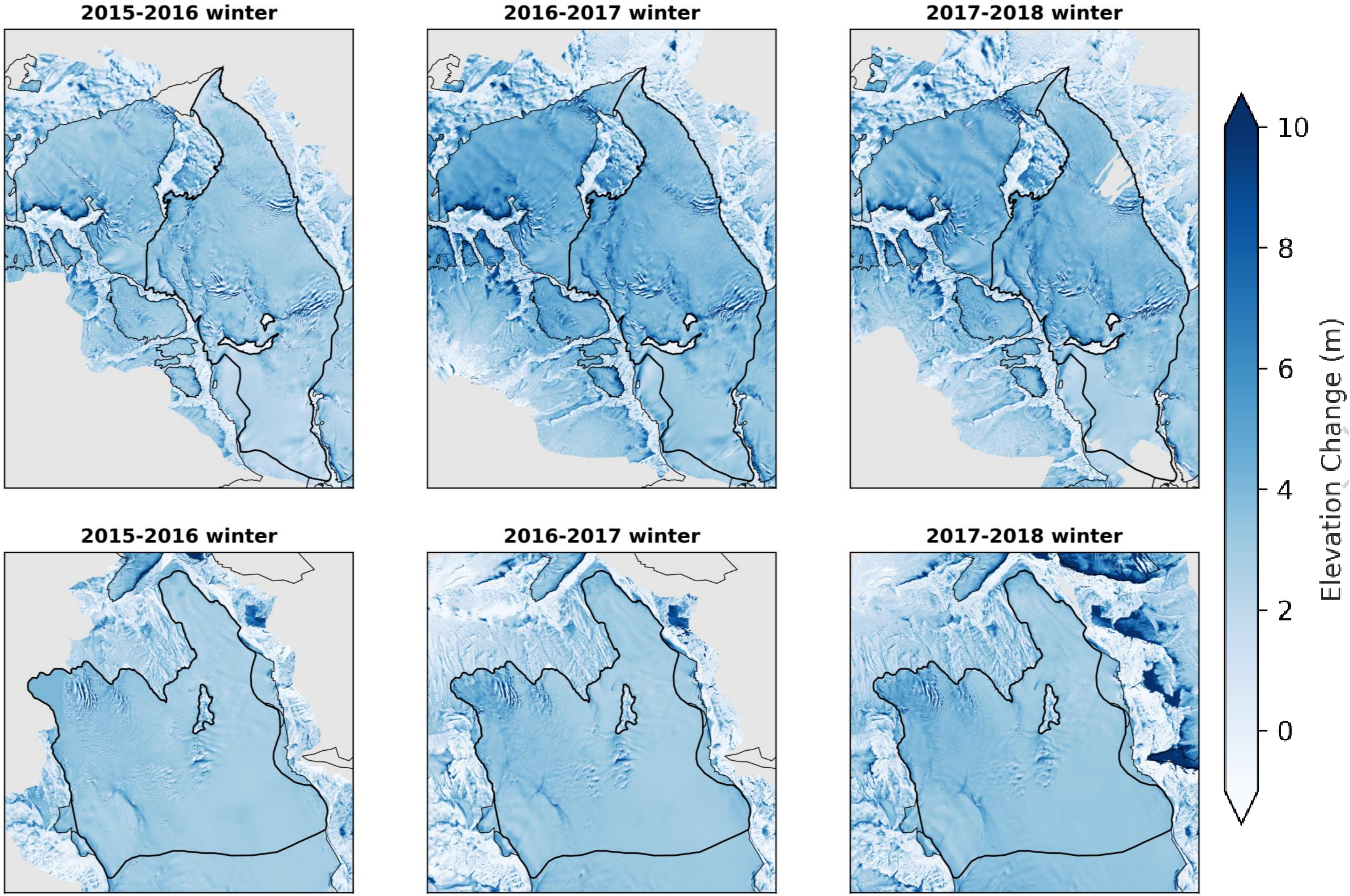
Motivation



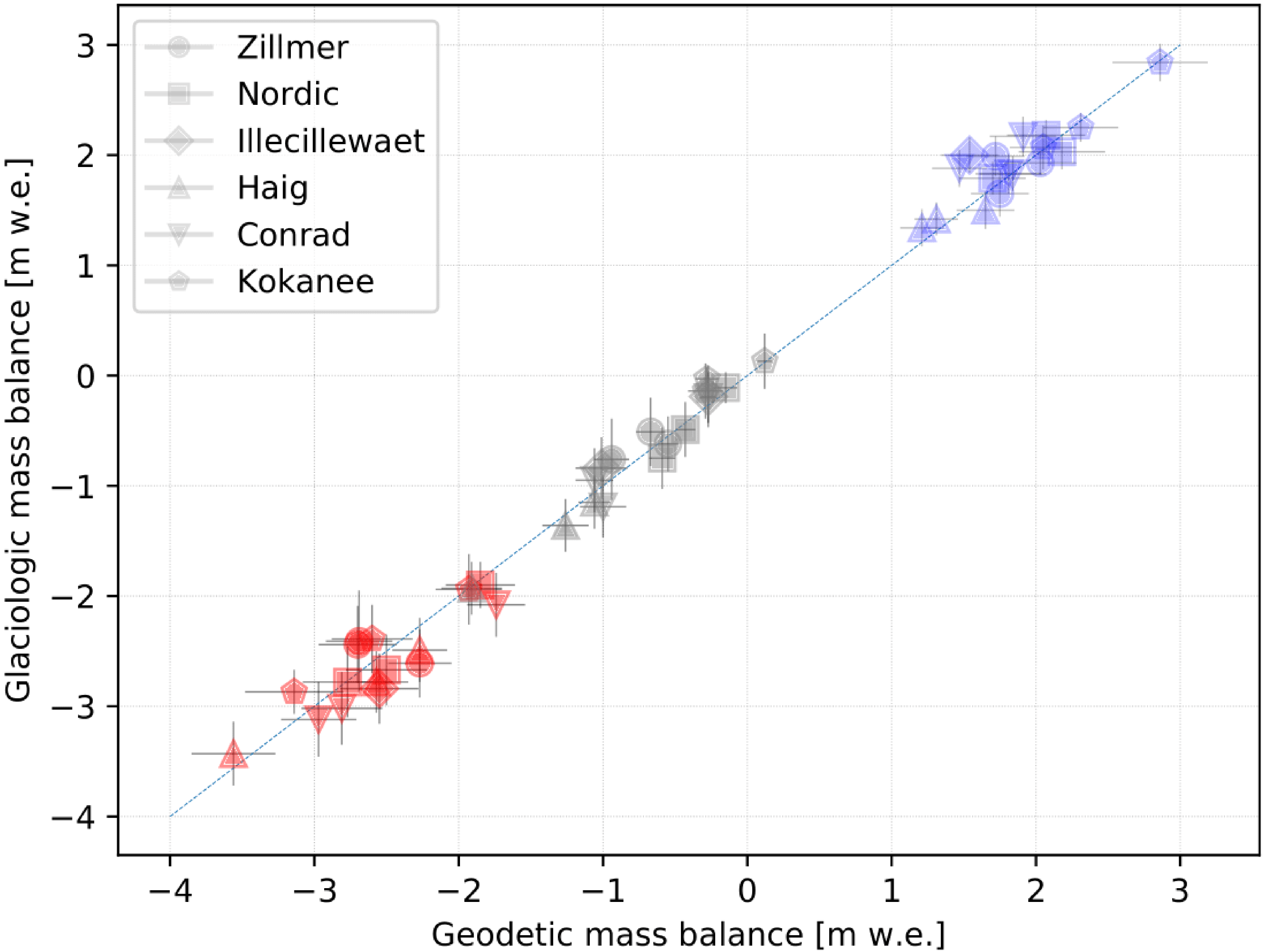
- Water resources:
  - How fast are glaciers melting?
  - How much runoff are they producing?
  - How much snow is at high elevation?

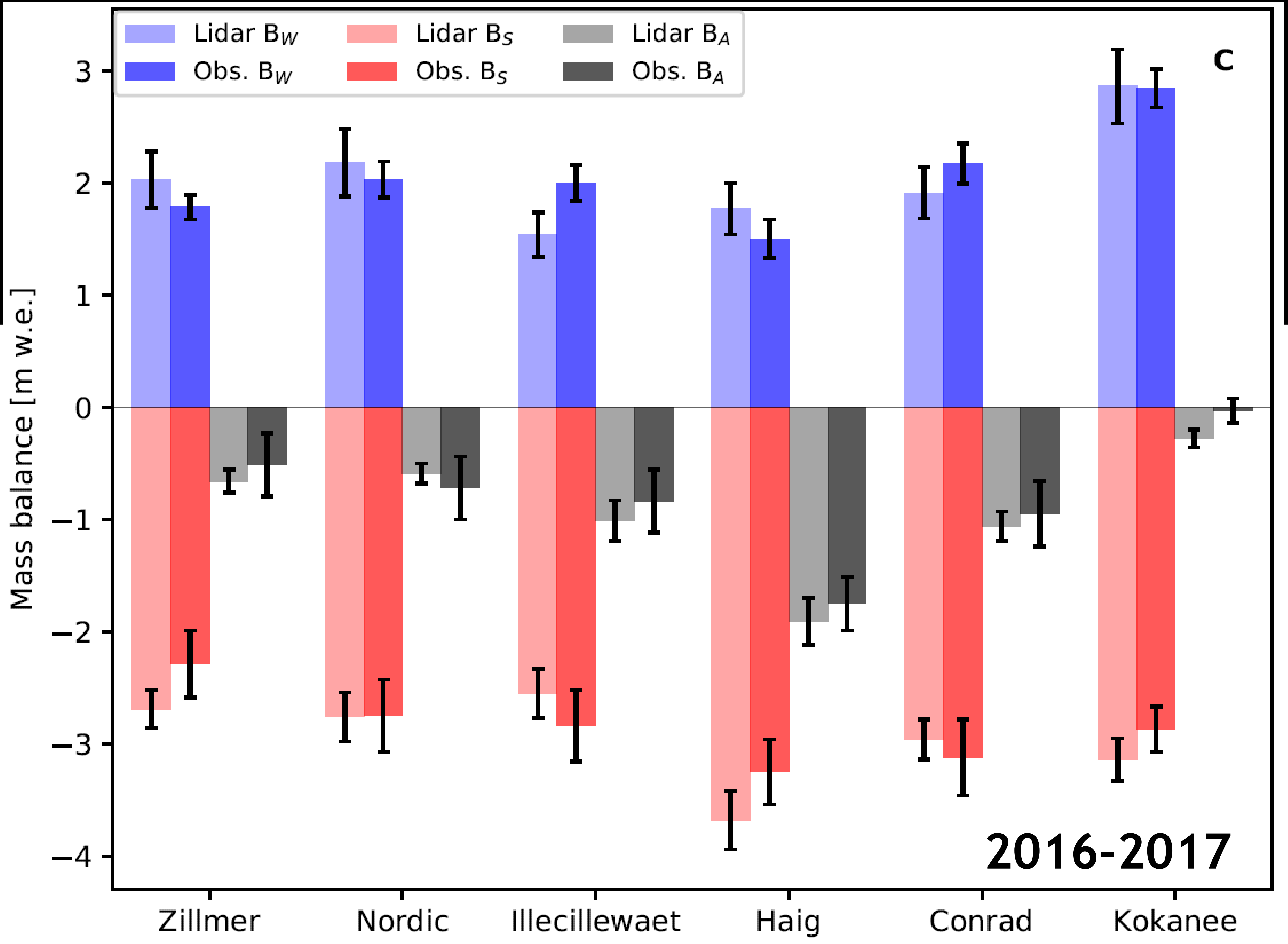
Canadian Columbia River Basin





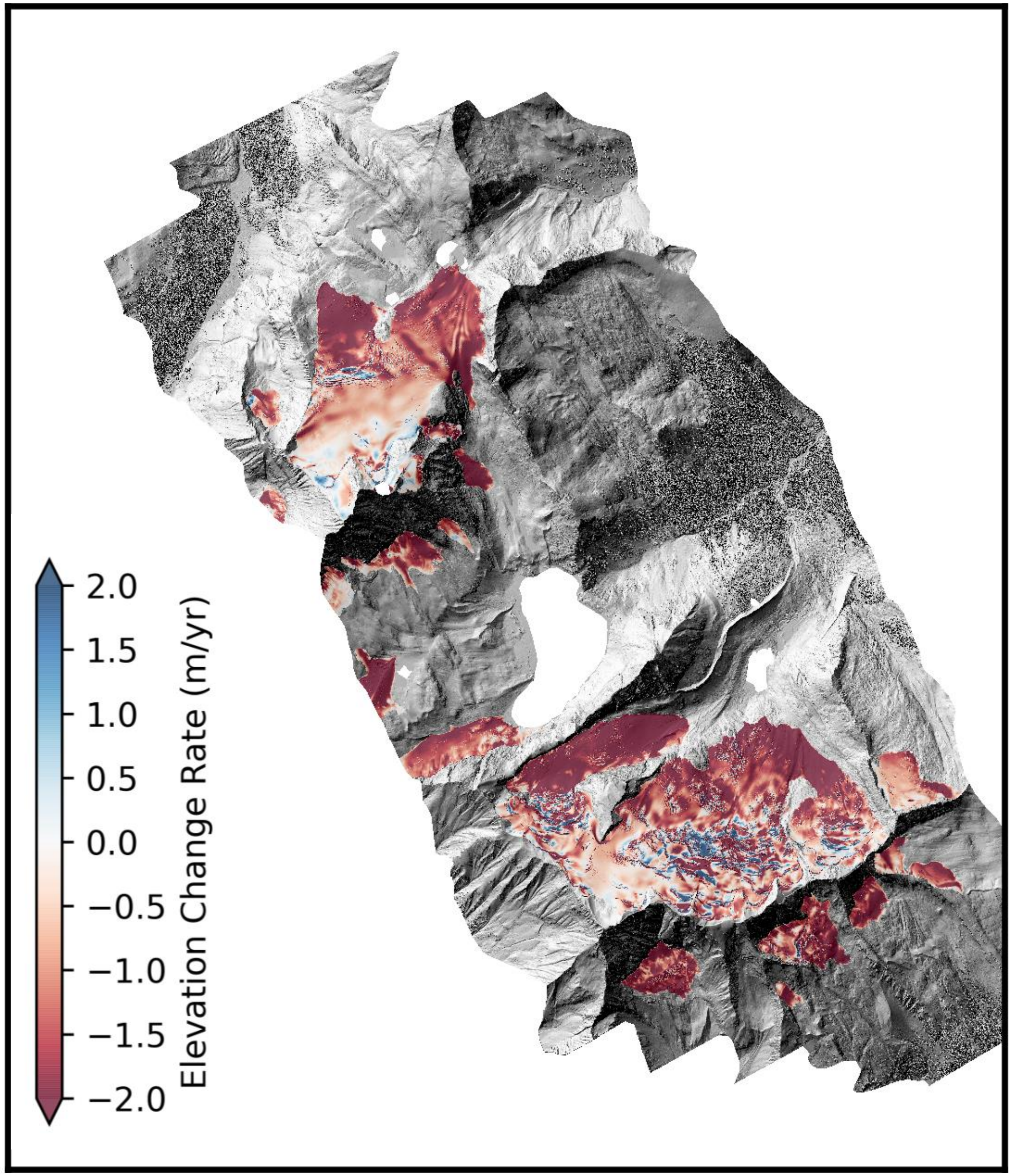
2015-2016 winter
2016-2017 winter
2017-2018 winter
2015-2016 winter
2016-2017 winter
2017-2018 winter
Elevation Change (m)
10
8
6
4
2
0


Zillmer
Nordic
Illecillewaet
Haig
Conrad
Kokanee
Glaciologic mass balance [m w.e.]
Geodetic mass balance [m w.e.]
3
2
1
0
−1
−2
−3
−4
−4
−3
−2
−1
0
1
2
3

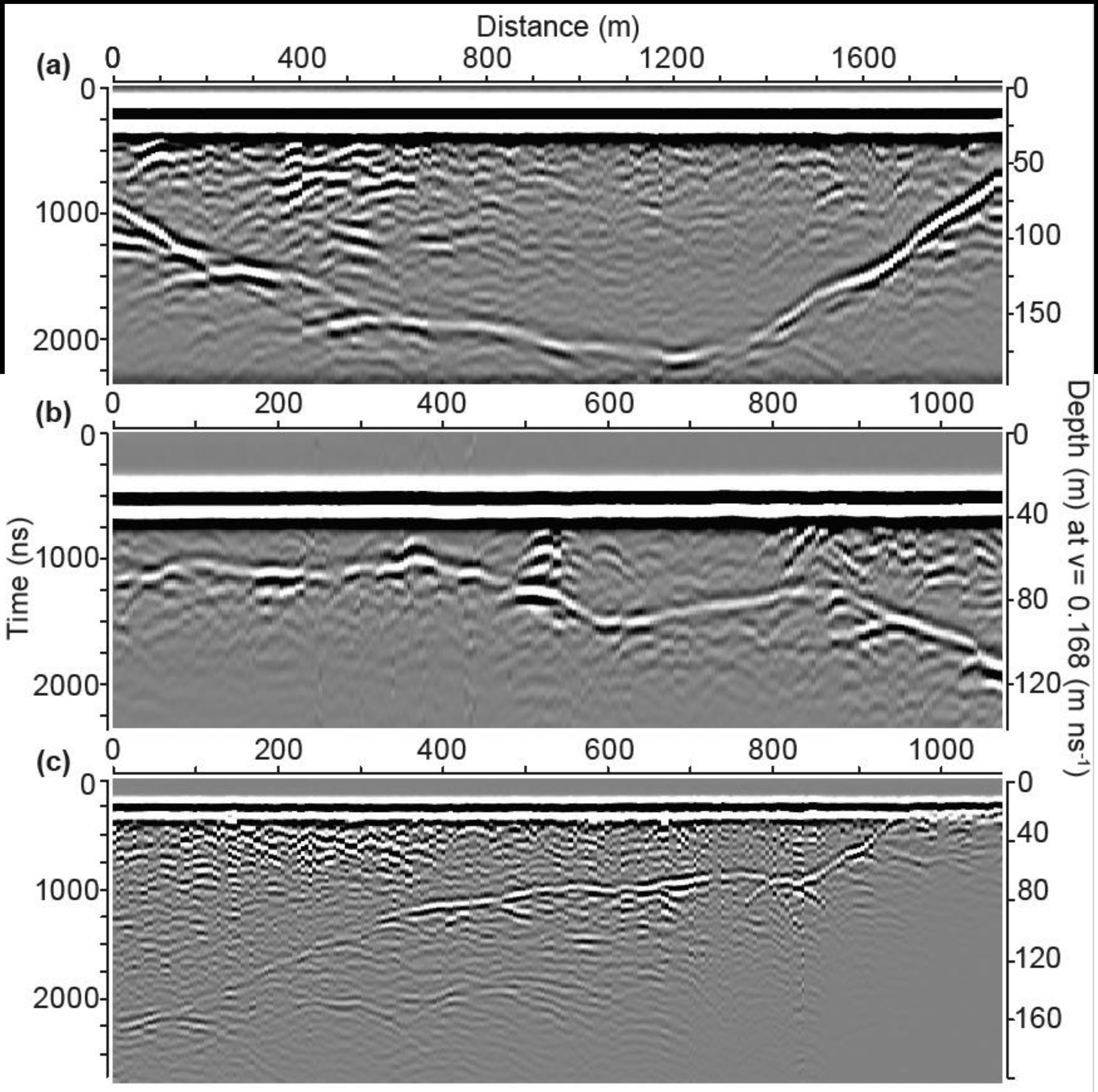


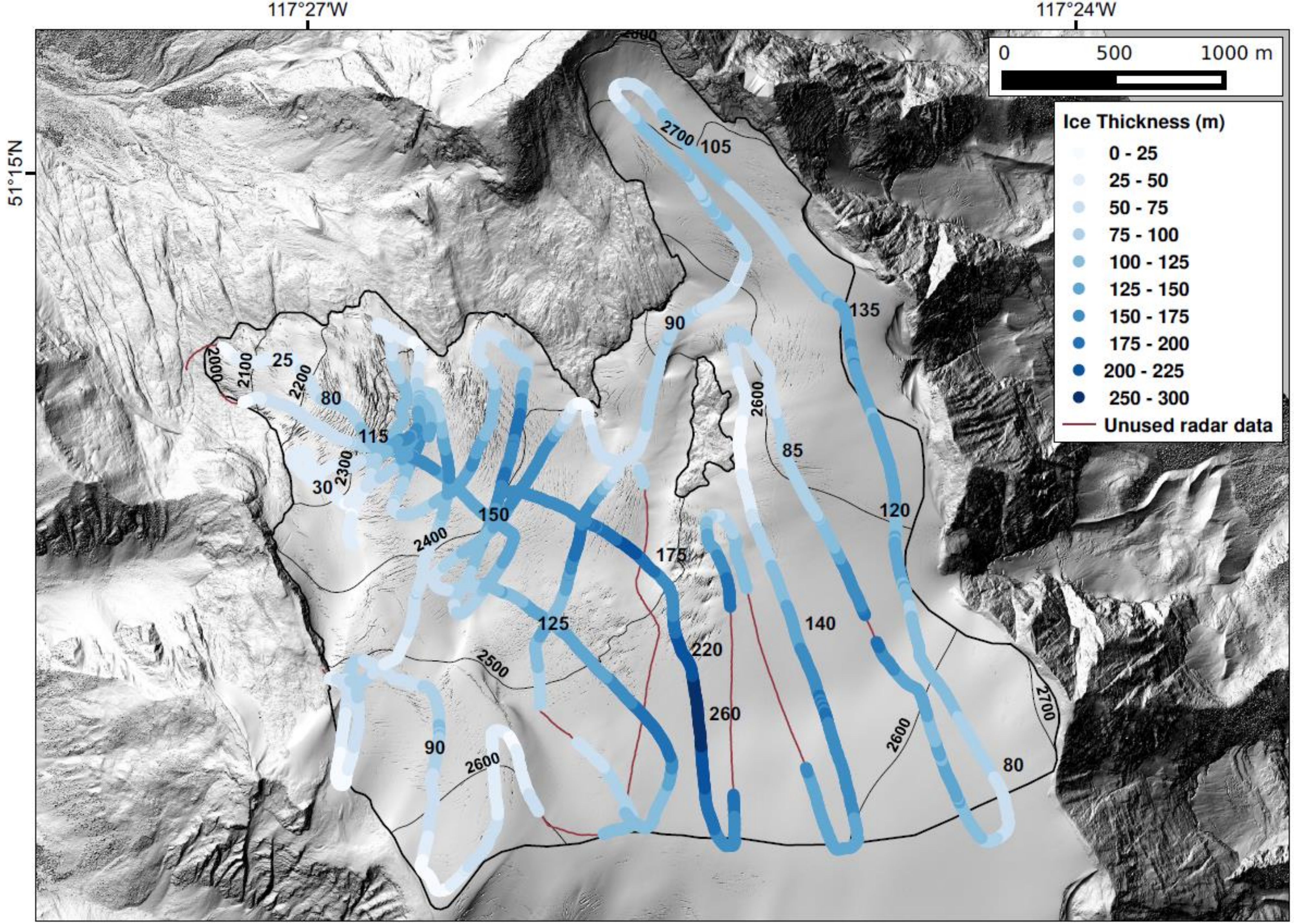
Lidar B_W
Obs. B_W
Lidar B_S
Obs. B_S
Lidar B_A
Obs. B_A
c
Mass balance [m w.e.]
3
2
1
0
−1
−2
−3
−4
2016-2017
Zillmer
Nordic
Illecillewaet
Haig
Conrad
Kokanee

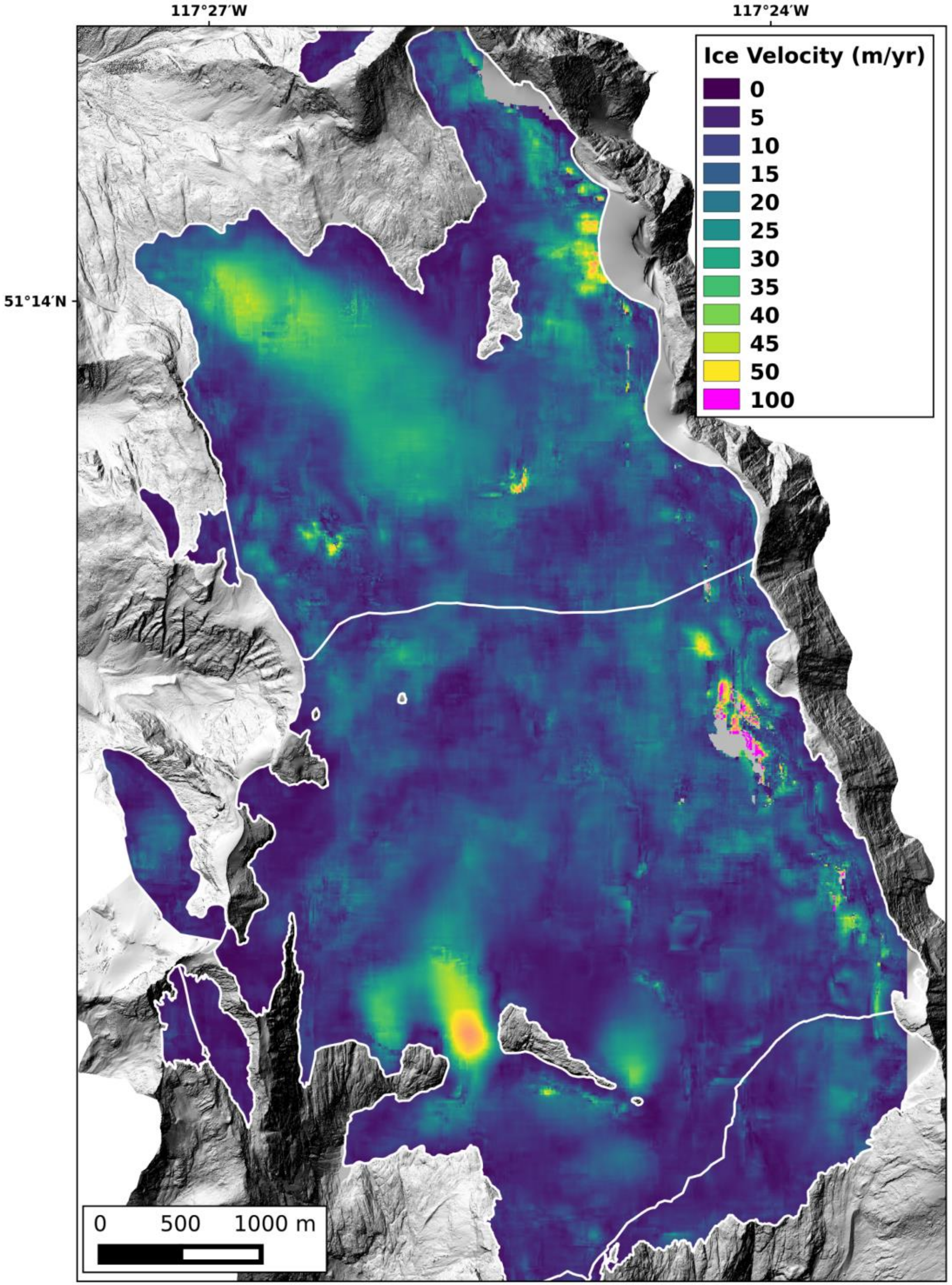
2014 to 2017

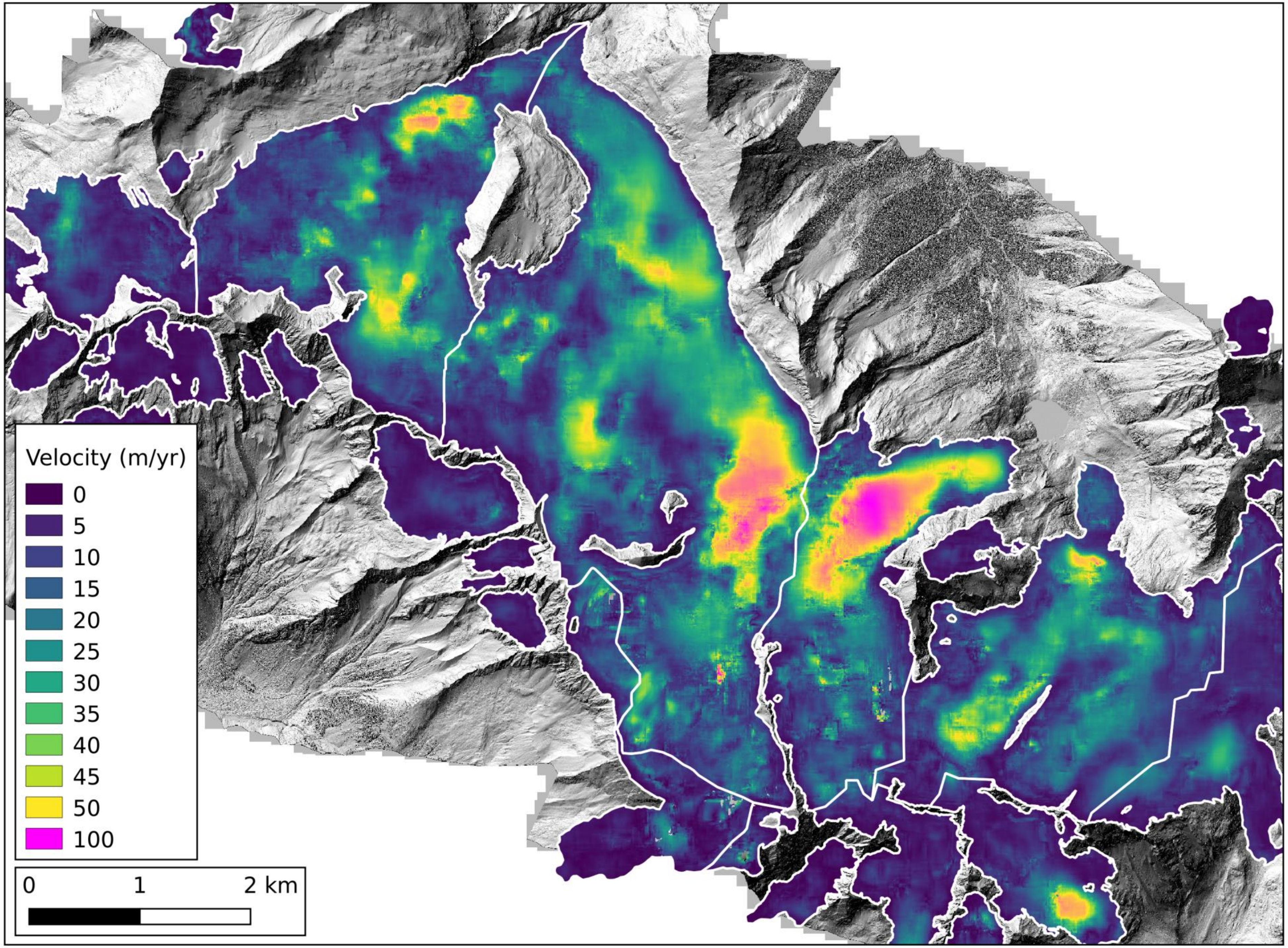


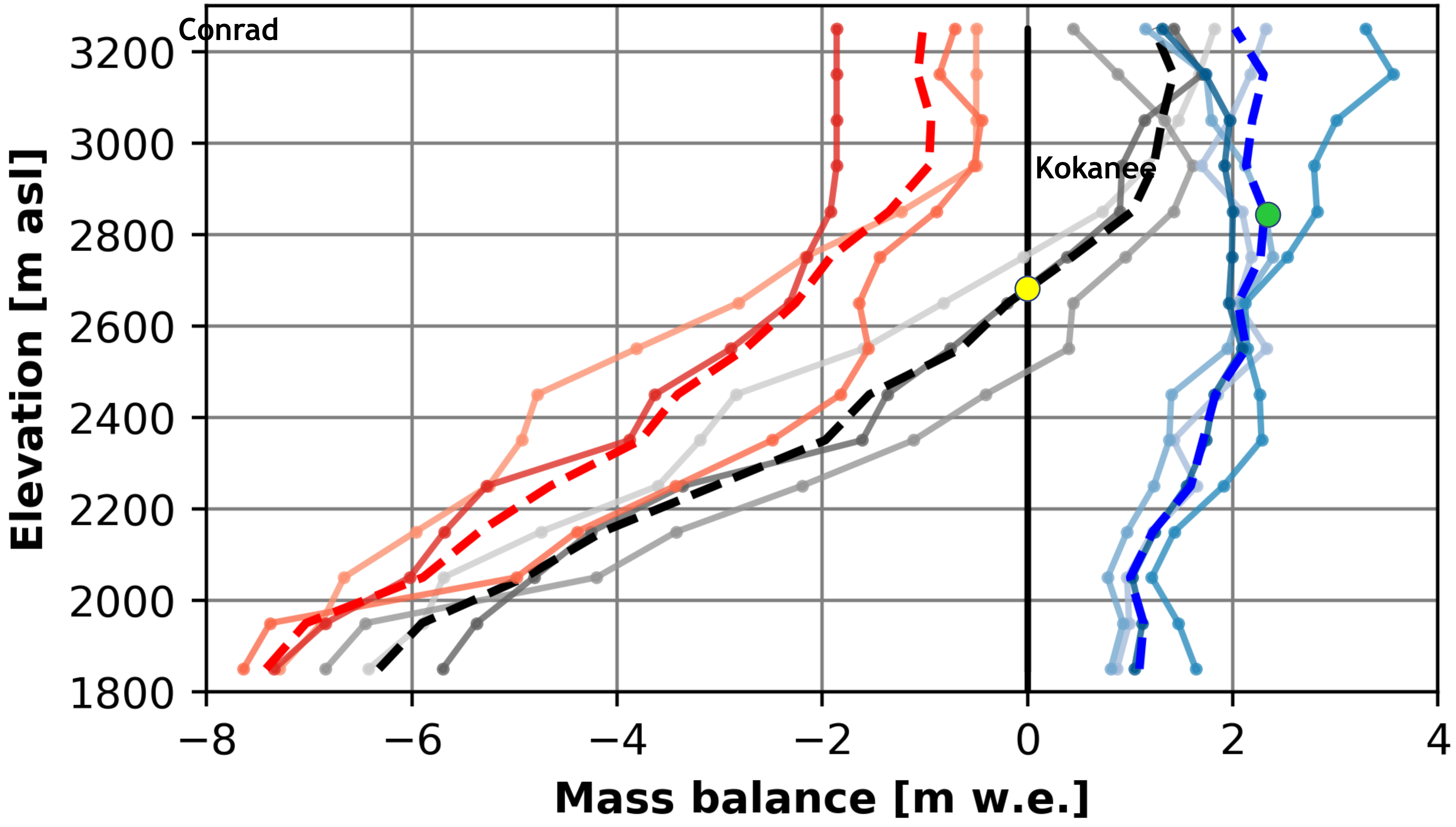
Ice Thickness




117°27'W
117°24'W
51°15'N
0
500
1000 m
Ice Thickness (m)
0 - 25
25 - 50
50 - 75
75 - 100
100 - 125
125 - 150
150 - 175
175 - 200
200 - 225
250 - 300
Unused radar data
2000
2100
2200
2300
2400
2500
2600
2700
25
80
115
30
150
90
105
135
85
120
175
125
220
260
140
80
90


117°27′W
117°24′W
51°14′N
Ice Velocity (m/yr)
0
5
10
15
20
25
30
35
40
45
50
100
0
500
1000 m


Velocity (m/yr)
0
5
10
15
20
25
30
35
40
45
50
100
0
1
2 km



Conrad
Kokanee
Elevation [m asl]
Mass balance [m w.e.]
1800
2000
2200
2400
2600
2800
3000
3200
−8
−6
−4
−2
0
2
4

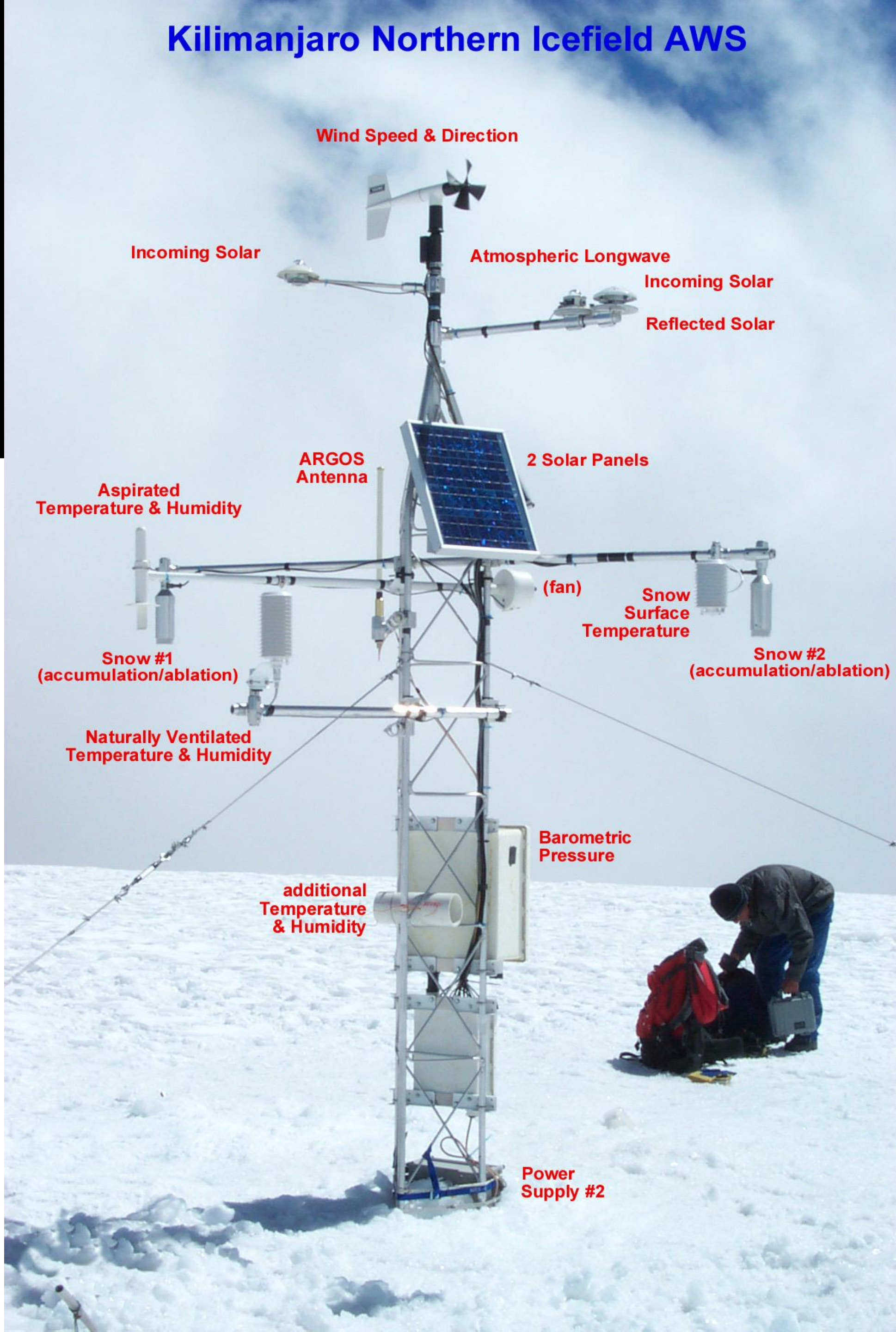
Surface energy balance

$$S_i + S_r + L_i + L_o + Q_H + Q_L + Q_R + Q_G = Q_M$$

- QM (energy available for melting)
- Incoming shortwave (Si)
- reflected shortwave (Sr)
- incoming longwave (Li)
- Outgoing longwave (Lo)
- Turbulent fluxes of sensible and latent heat (QH and QL)
- Rain heat flux (QR)
- Ground heat flux (QG).

Surface energy balance

$$S_i + S_r + L_i + L_o + Q_H + Q_L + Q_R + Q_G = Q_M$$



Degree day models

Melt is a function of temperature!

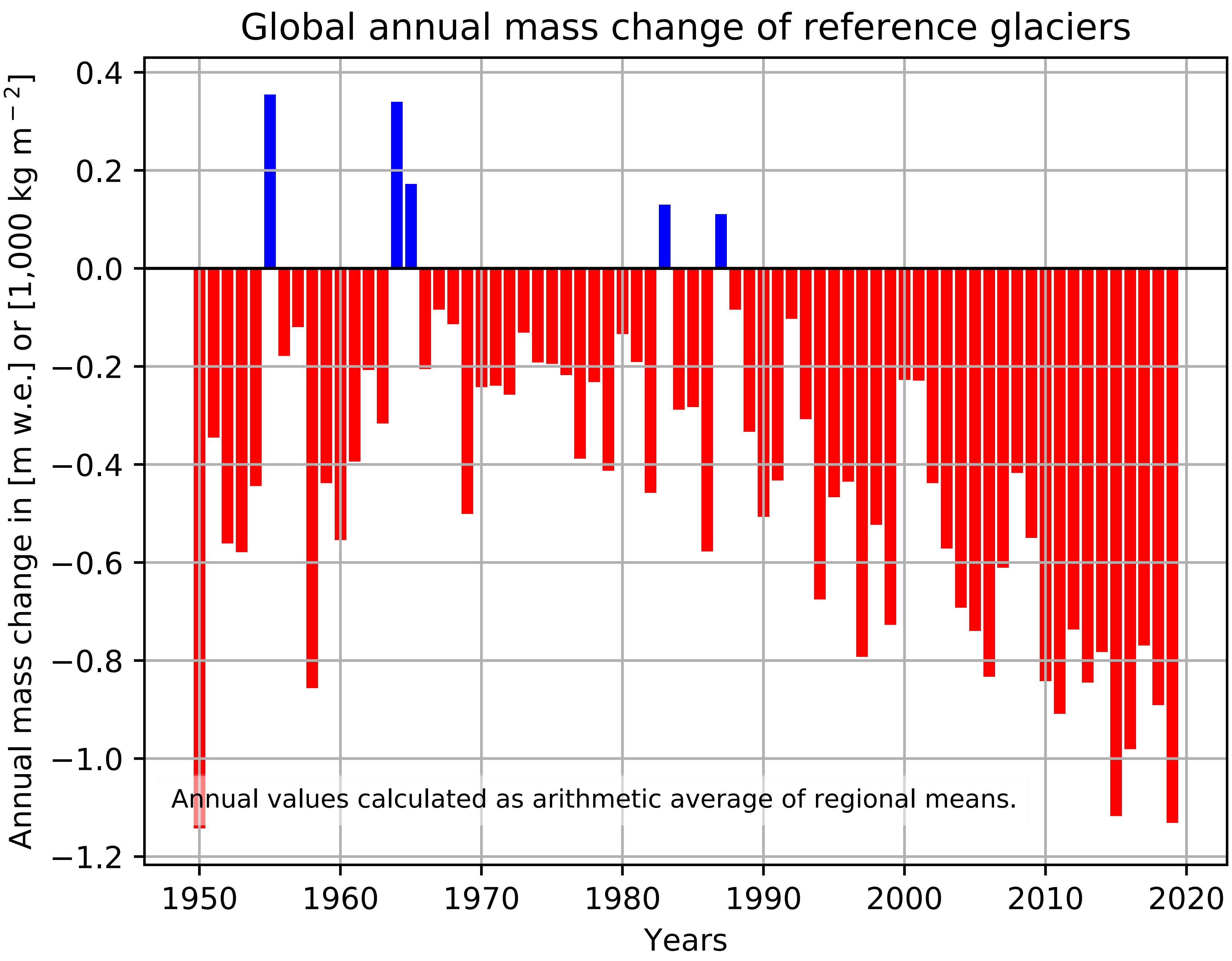
- Are a simple technique used to estimate the amount of melt on a glacier.
- Uses air temperature to predict the amount of melt on a glacier.
- Are important inputs to many numerical glacier models
- Assume an empirical relationship between melt rates and air temperatures (Positive Degree Days), and this empirical relationship (the Degree Day Factor) varies from glacier to glacier.
- Work well because air temperature data are readily available, and they perform well despite their simplicity.

Degree day models

Melt is a function of temperature!

$$M = K_I \, PDD + K_S \, PDD$$

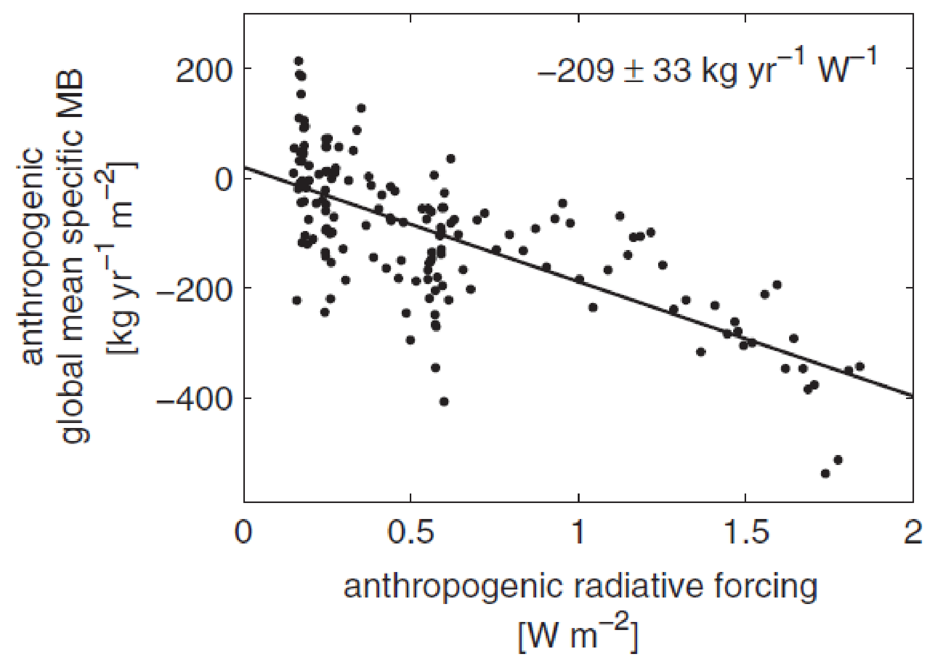
Parameter	Symbol	Units
Melt (depth of snow melted)	M	mm w.e.
Positive degree day sum per year	PDD	$^{\circ}C \, a^{-1}$
Degree day factor	K_I and K_S (for ice and snow)	mm w.e. $d^{-1} \, ^{\circ}C^{-1}$



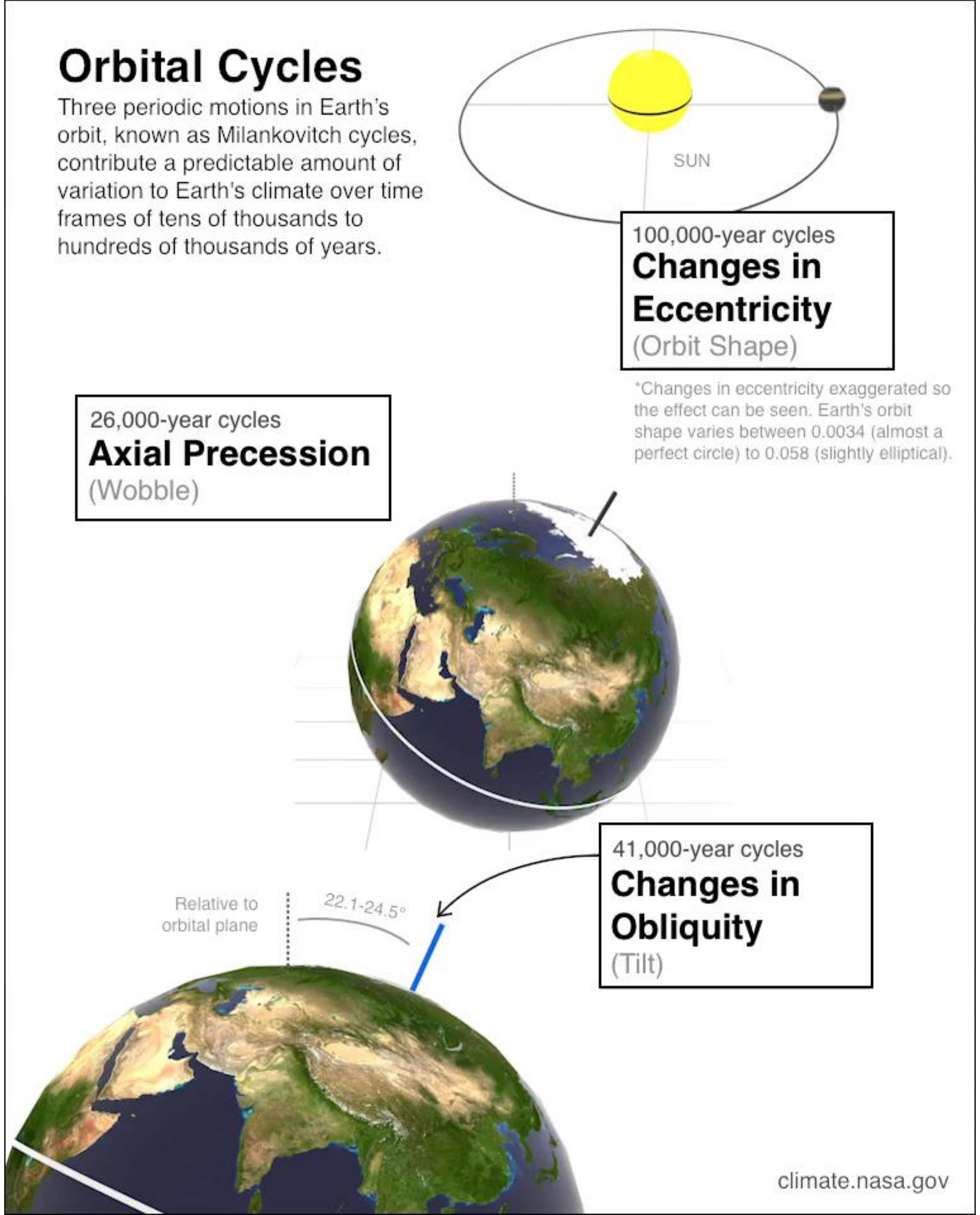
https://wgms.ch/

Anthropogenic glacier mass loss

- From **1851 to 2010**, only **25 ± 35%** of the global glacier mass loss during the period is attributable to anthropogenic causes.
- From **1991 to 2010**, the anthropogenic fraction increased to **69 ± 24%.**



Marzeion et al. (2014)



https://climate.nasa.gov/


What else would you like to know?

Hands on Glacier Modeling

https://edu.oggm.org/en/latest/

References

- Degree day models: http://www.antarcticglaciers.org/glaciers-and-climate/numerical-ice-sheet-models/modelling-glacier-melt/
- Marzeion, Ben, et al. "Attribution of global glacier mass loss to anthropogenic and natural causes." *Science* 345.6199 (2014): 919-921.
- Mass balance graphics: https://edu.oggm.org/en/latest/glacier_basics.html
- NASA Climate, https://climate.nasa.gov/blog/2949/why-milankovitch-orbital-cycles-cant-explain-earths-current-warming/
- Pelto, B. M., Menounos, B., and Marshall, S. J.: Multi-year evaluation of airborne geodetic surveys to estimate seasonal mass balance, Columbia and Rocky Mountains, Canada, The Cryosphere, 13, 1709–1727, https://doi.org/10.5194/tc-13-1709-2019, 2019.
- Surface energy balance: Fitzpatrick, Noel, Valentina Radić, and Brian Menounos. "Surface energy balance closure and turbulent flux parameterization on a mid-latitude mountain glacier, Purcell mountains, Canada." *Frontiers in Earth Science* 5 (2017): 67.
- World Glacier Monitoring Service, https://wgms.ch/