Centre for Hydrology Coldwater Laboratory, Canmore, Canada

UAV-borne LiDAR Observations at the Canadian Rockies Hydrological Observatory

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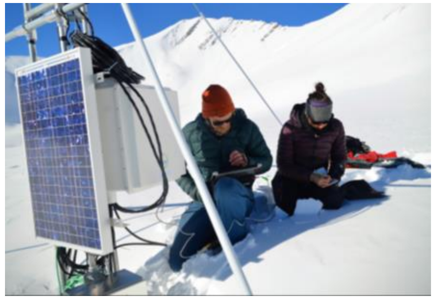
CENTRE FOR HYDROLOGY

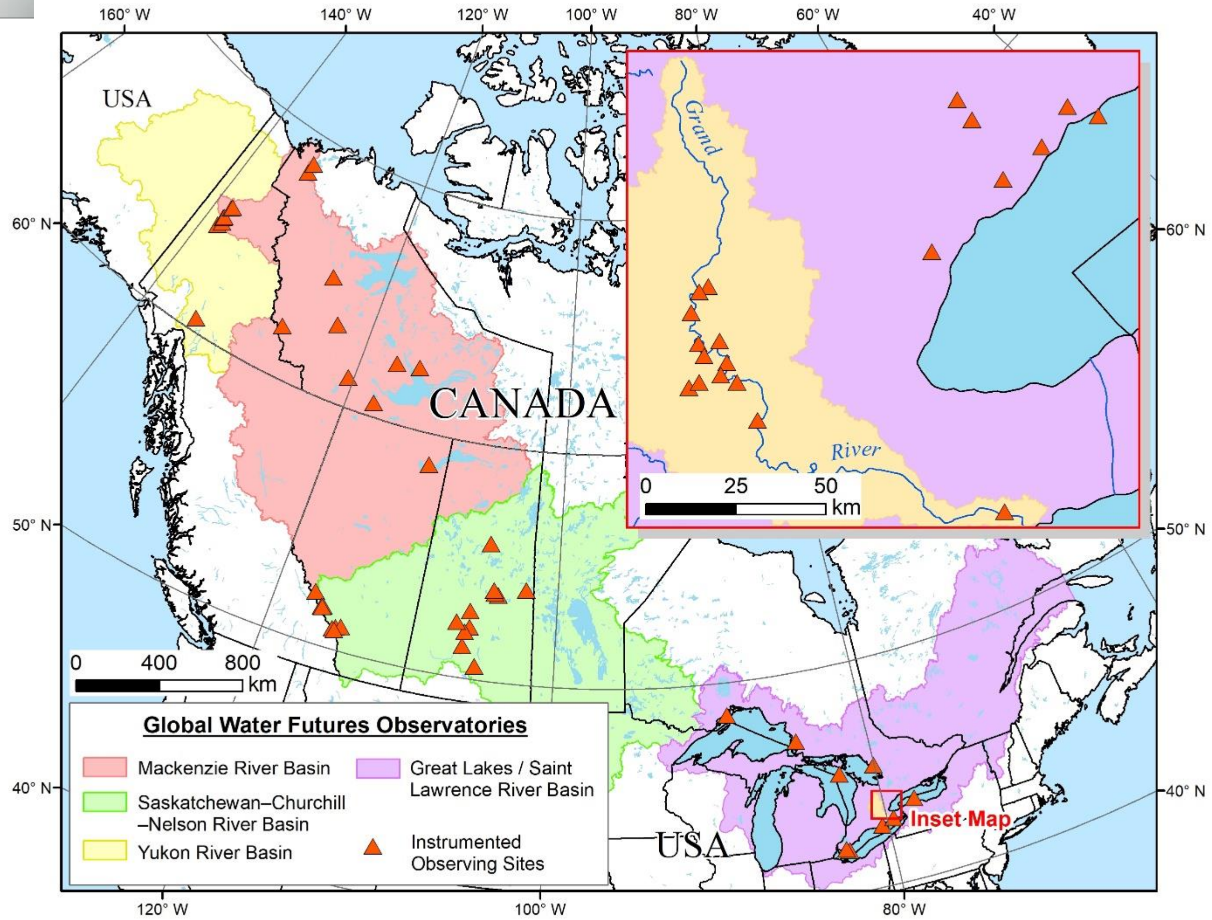
Canada’s freshwater early warning system

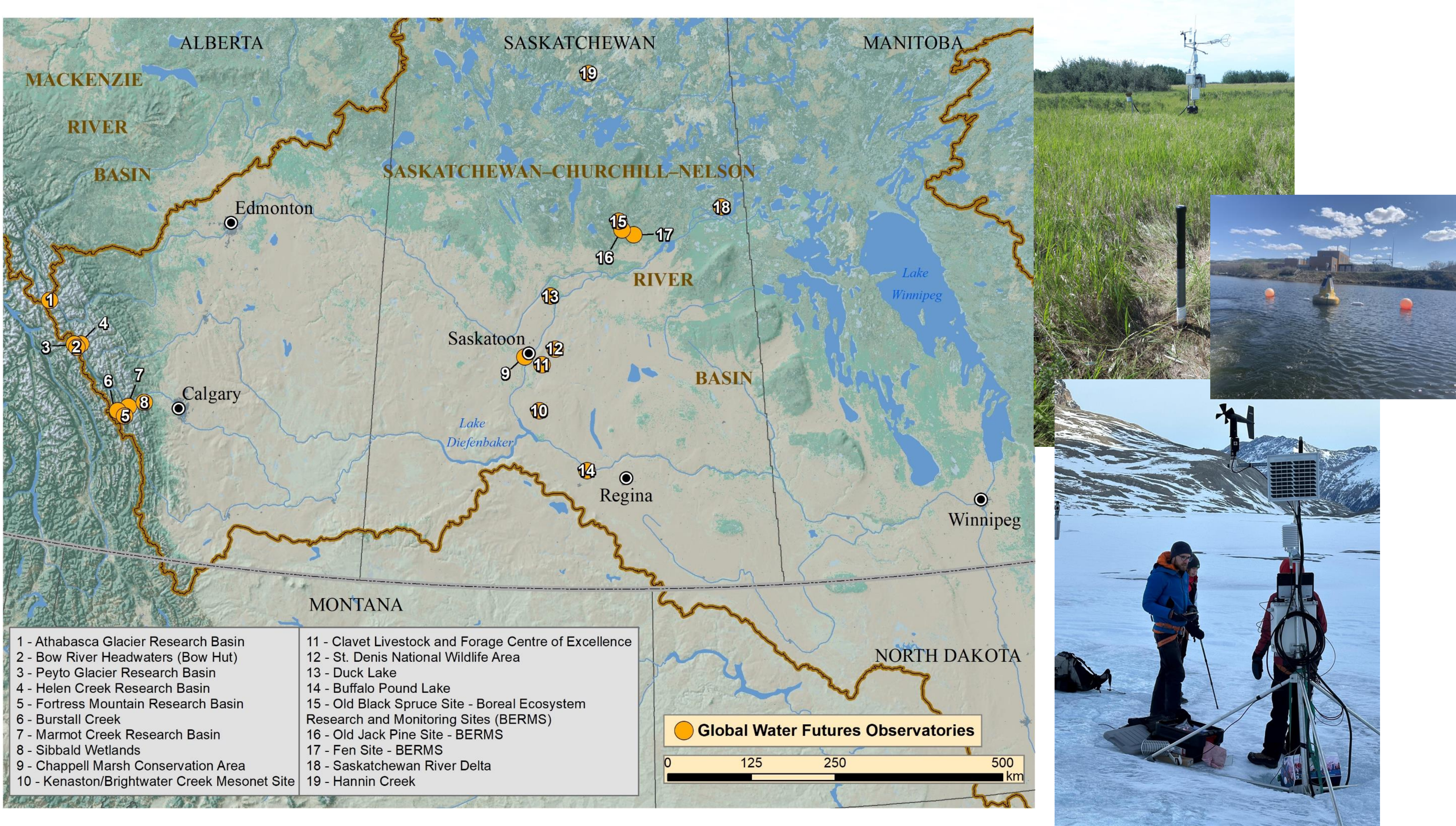



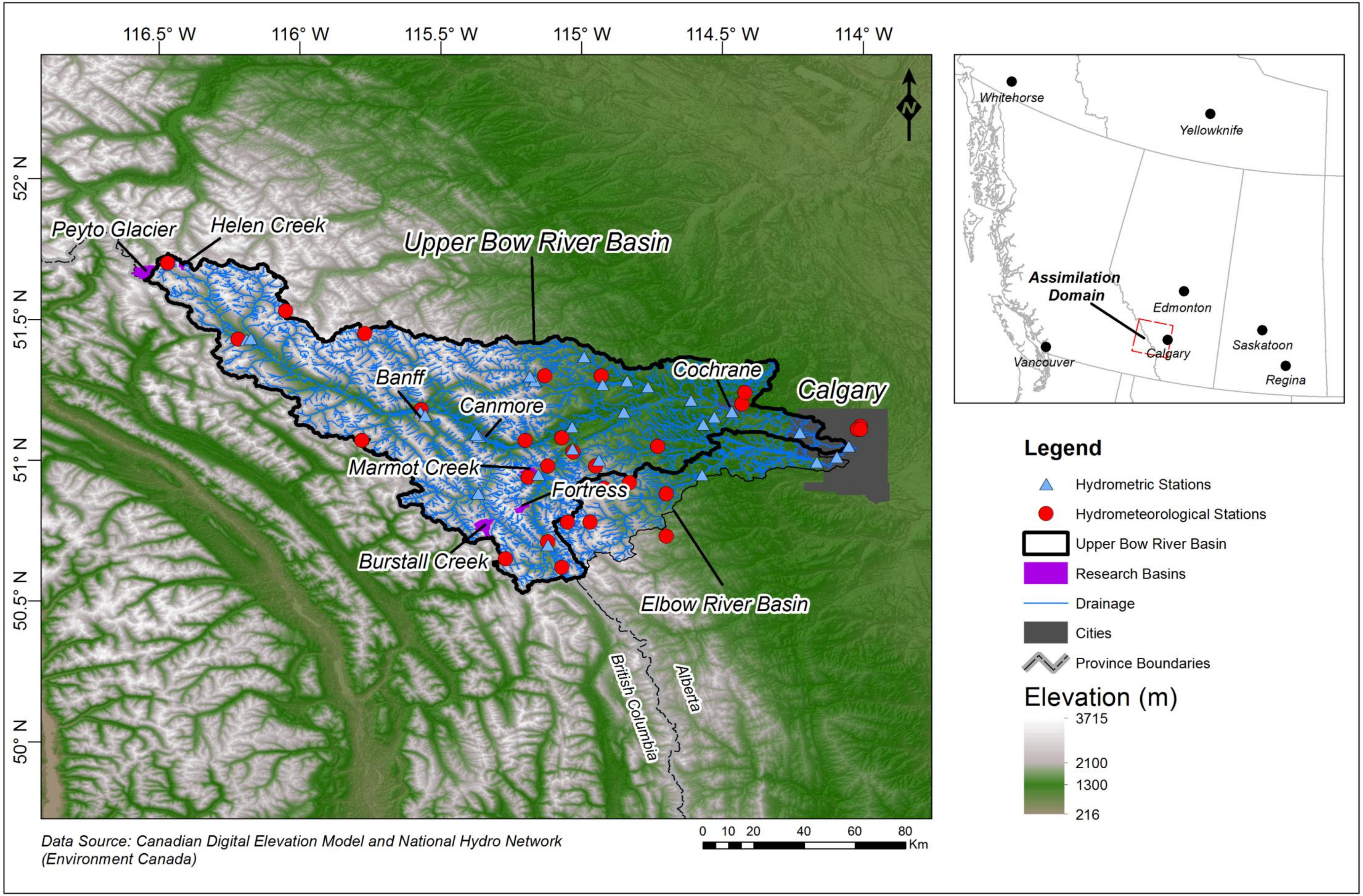




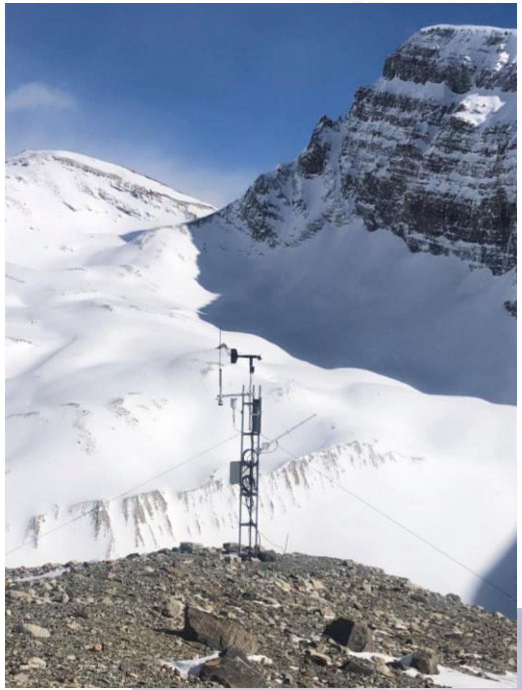


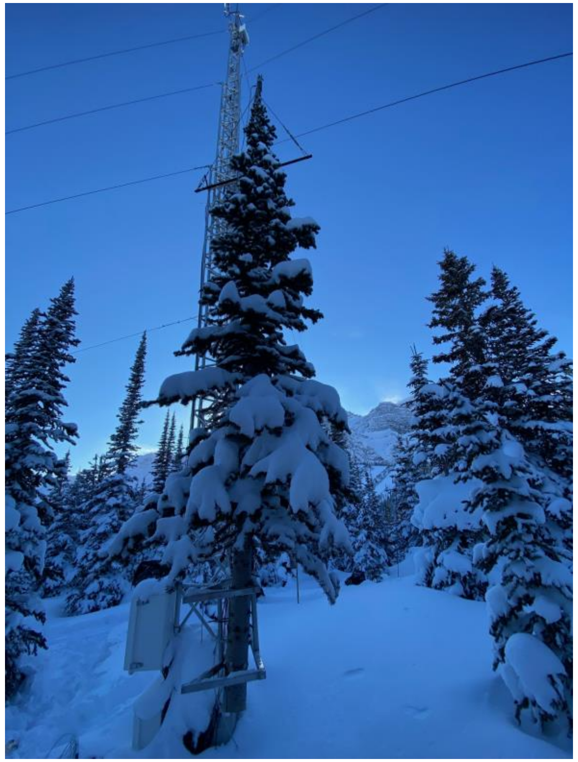




ALBERTA
SASKATCHEWAN
MANITOBA
MACKENZIE
RIVER
BASIN
SASKATCHEWAN–CHURCHILL–NELSON
RIVER
BASIN
Edmonton
Calgary
Saskatoon
Regina
Winnipeg
Lake Winnipeg
Lake Diefenbaker
MONTANA
NORTH DAKOTA
1 - Athabasca Glacier Research Basin
2 - Bow River Headwaters (Bow Hut)
3 - Peyto Glacier Research Basin
4 - Helen Creek Research Basin
5 - Fortress Mountain Research Basin
6 - Burstall Creek
7 - Marmot Creek Research Basin
8 - Sibbald Wetlands
9 - Chappell Marsh Conservation Area
10 - Kenaston/Brightwater Creek Mesonet Site
11 - Clavet Livestock and Forage Centre of Excellence
12 - St. Denis National Wildlife Area
13 - Duck Lake
14 - Buffalo Pound Lake
15 - Old Black Spruce Site - Boreal Ecosystem Research and Monitoring Sites (BERMS)
16 - Old Jack Pine Site - BERMS
17 - Fen Site - BERMS
18 - Saskatchewan River Delta
19 - Hannin Creek
Global Water Futures Observatories
0 125 250 500
km

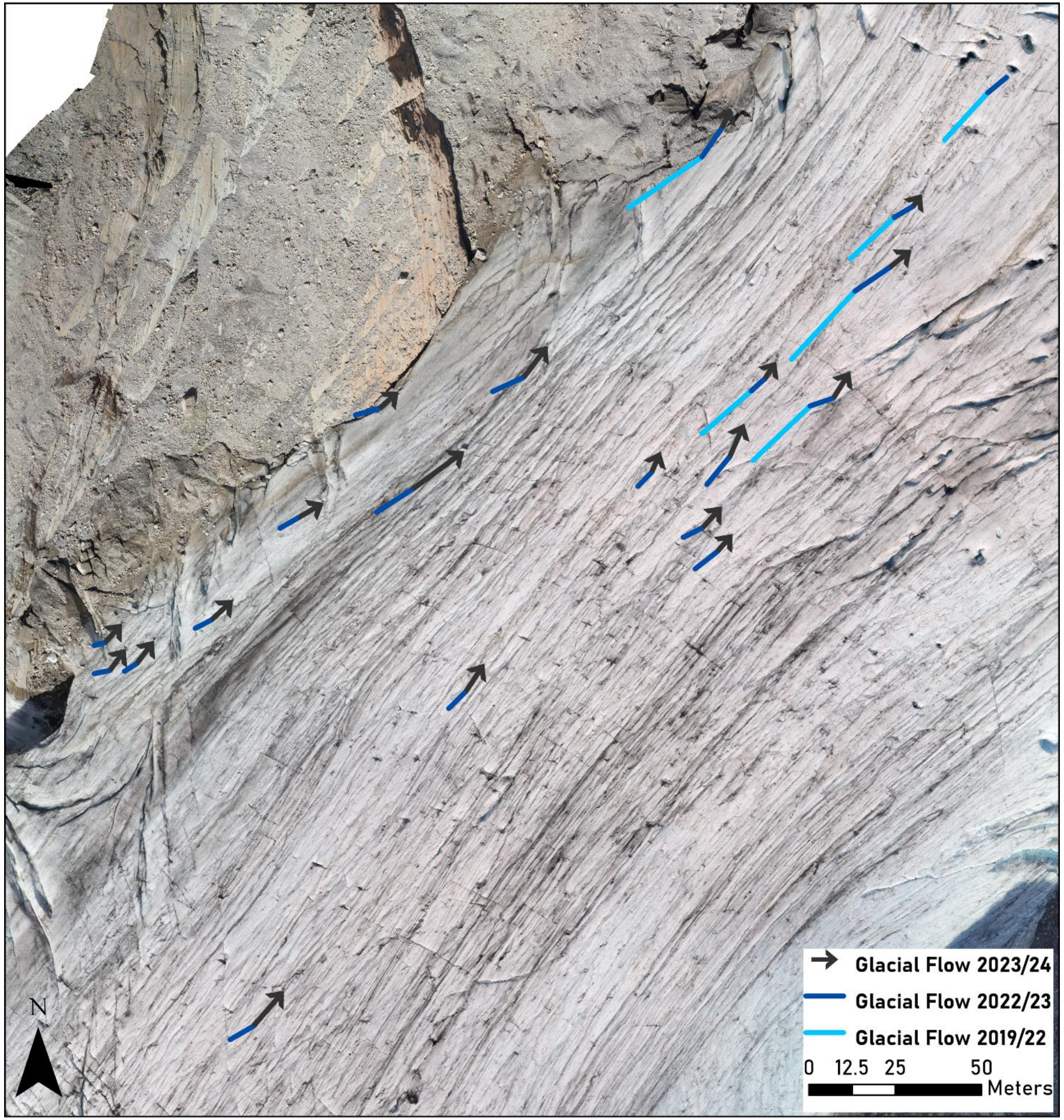

116.5° W
116° W
115.5° W
115° W
114.5° W
114° W
52° N
51.5° N
51° N
50.5° N
50° N
Peyto Glacier
Helen Creek
Upper Bow River Basin
Banff
Canmore
Cochrane
Calgary
Marmot Creek
Fortress
Burstall Creek
Elbow River Basin
British Columbia
Alberta
N
Whitehorse
Yellowknife
Assimilation Domain
Edmonton
Calgary
Vancouver
Saskatoon
Regina
Legend
Hydrometric Stations
Hydrometeorological Stations
Upper Bow River Basin
Research Basins
Drainage
Cities
Province Boundaries
Elevation (m)
3715
2100
1300
216
0 10 20 40 60 80
Km
Data Source: Canadian Digital Elevation Model and National Hydro Network
(Environment Canada)

Canadian Rockies Hydrological Observatory





Glacier Monitoring at Peyto Glacier

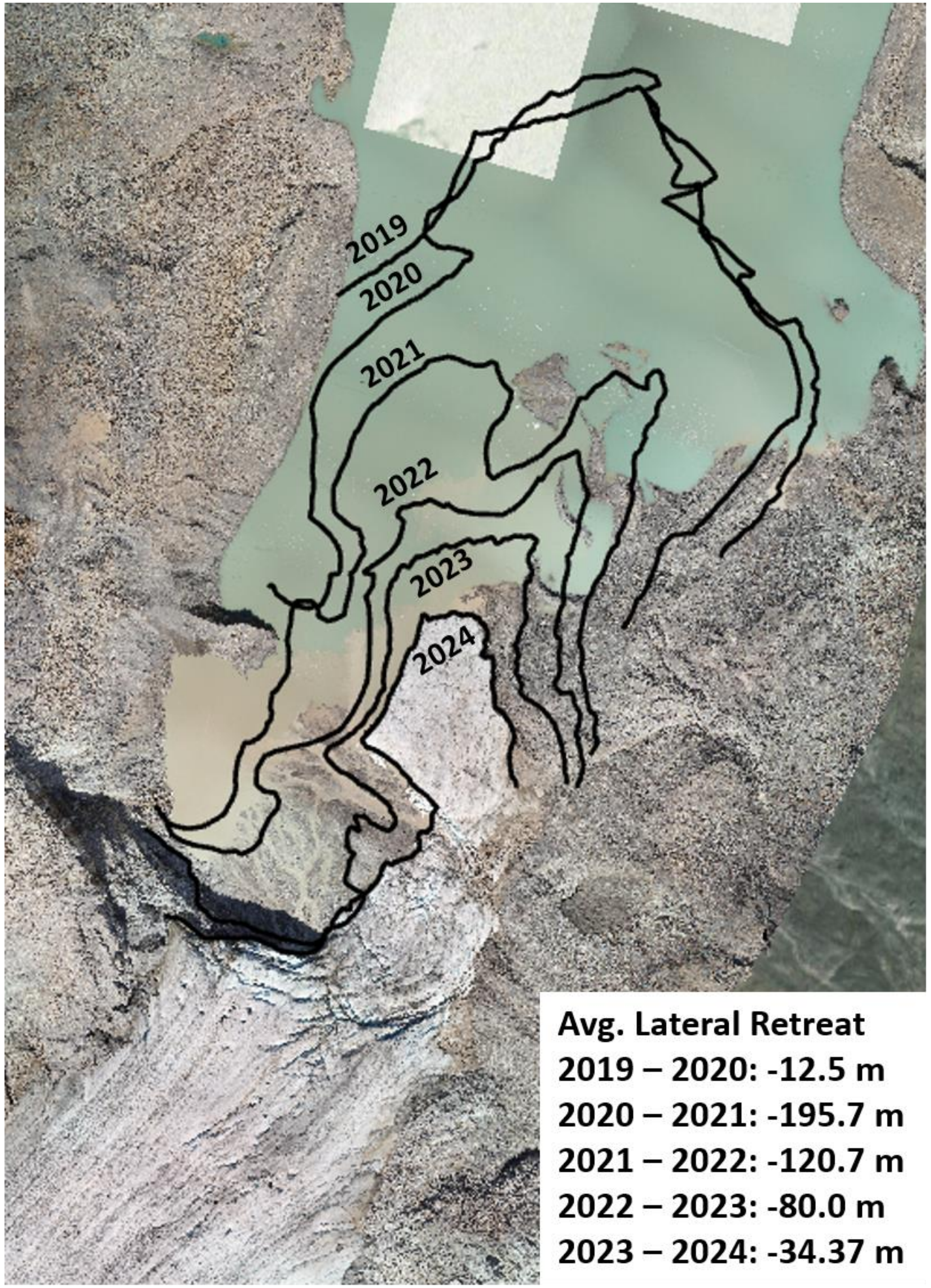


Glacier Flow Rate

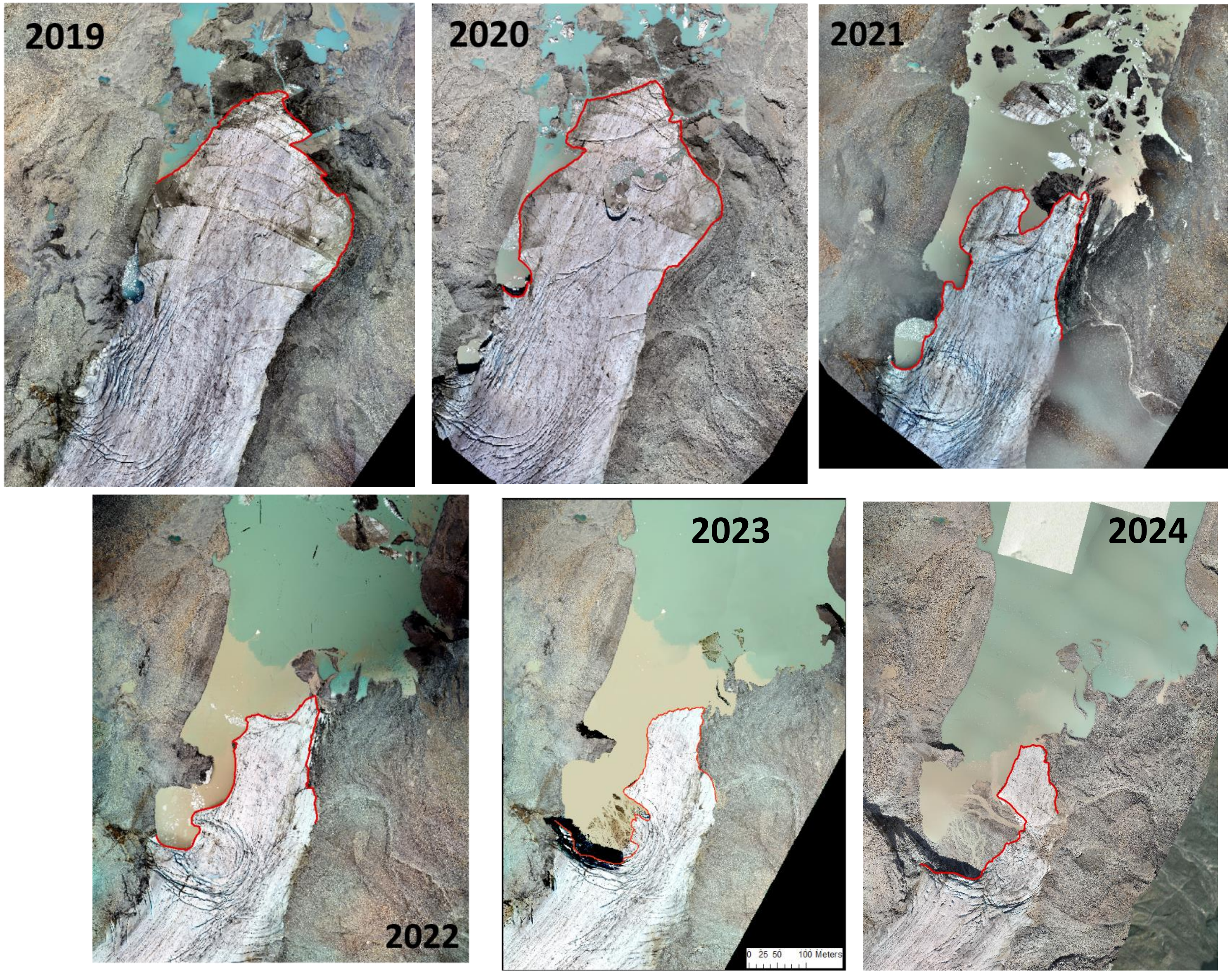
Glacier flow measured by locating rocks on the surface of the upper glacier in RGB photography from different years.

Average flow:

2019-2022: 7.27m/year
2022-2023: 7.13m/year
2023-2024: 8.45m/year

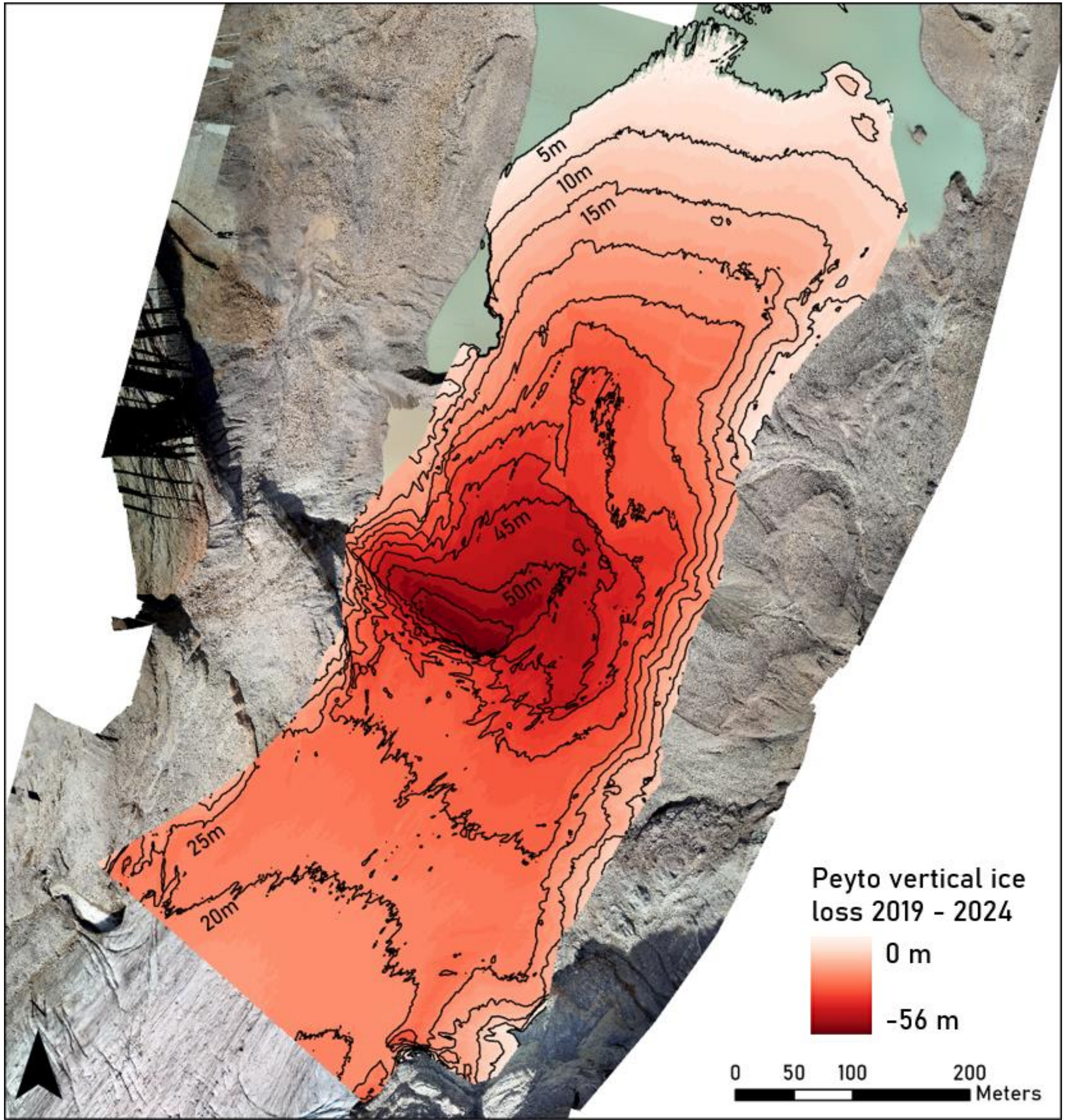


Extent of Peyto glacier toe from 2019 – 2024, overlain over aerial photography of Peyto taken in 2024

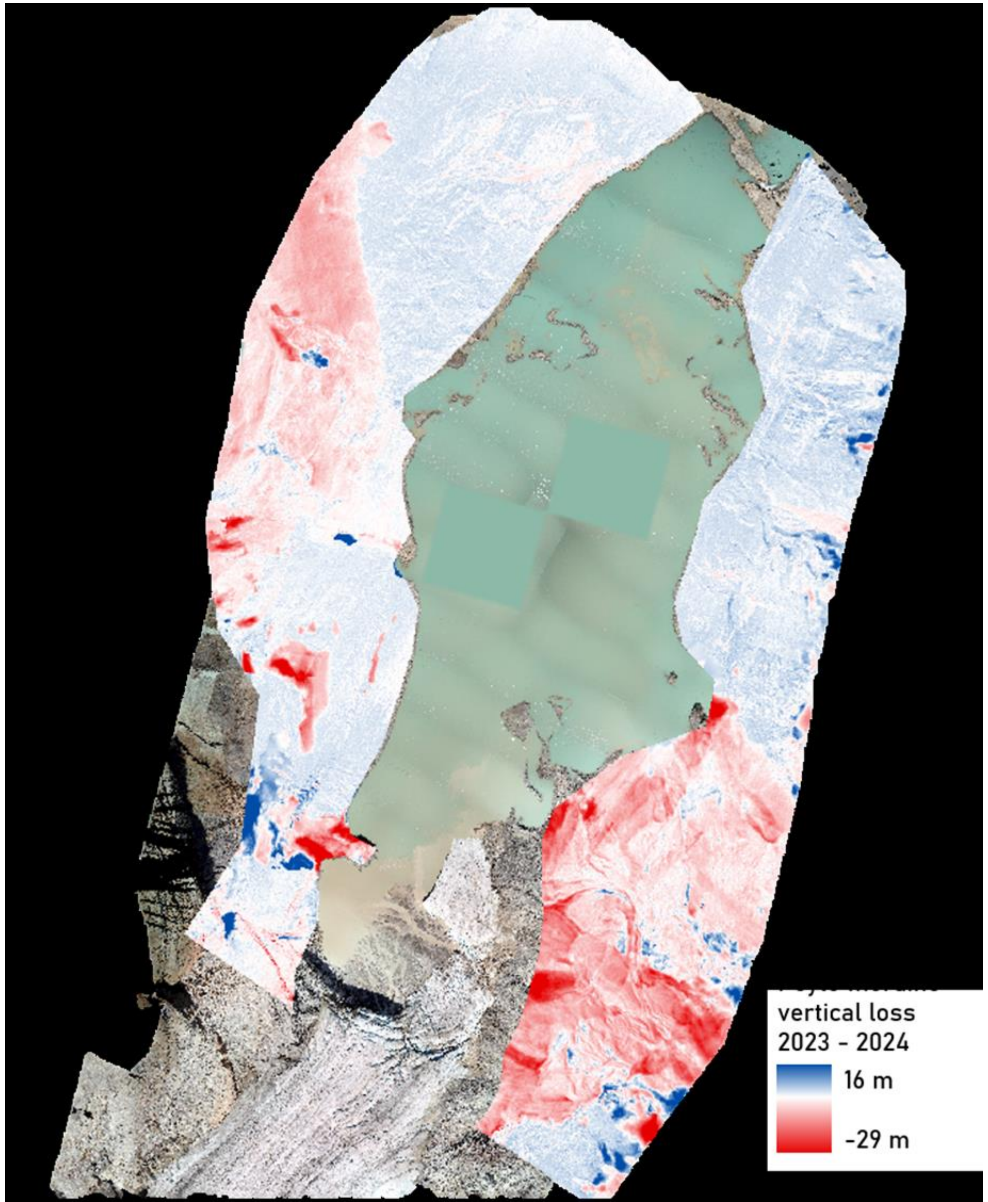


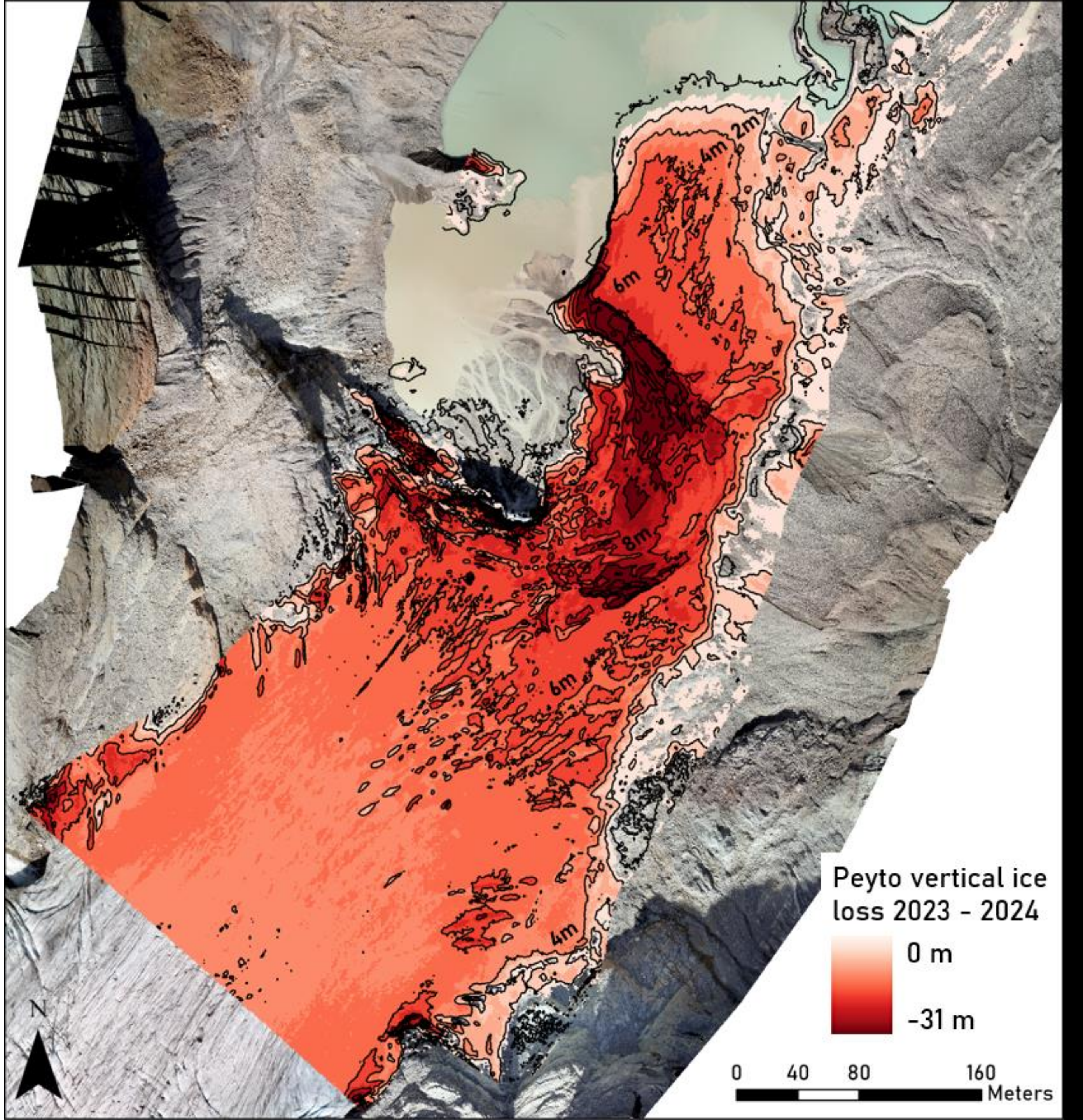
Definition of Peyto glacier toe for each year from 2019 - 2024

Peyto Glacier
5-year Vertical Loss



Peyto Glacier 1 Year Vertical Loss – ice and moraine





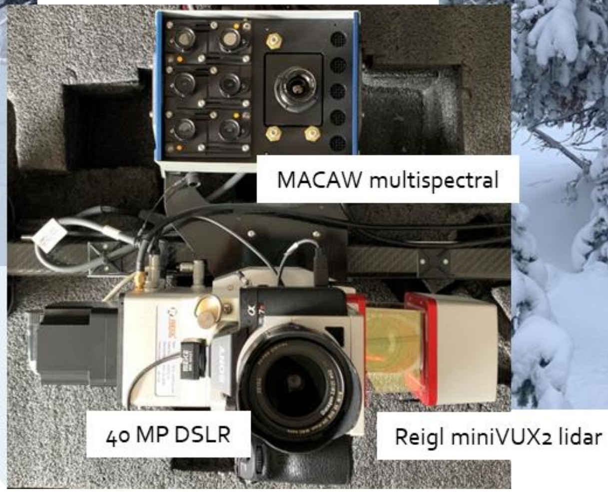
Peyto Glacier Change Summary

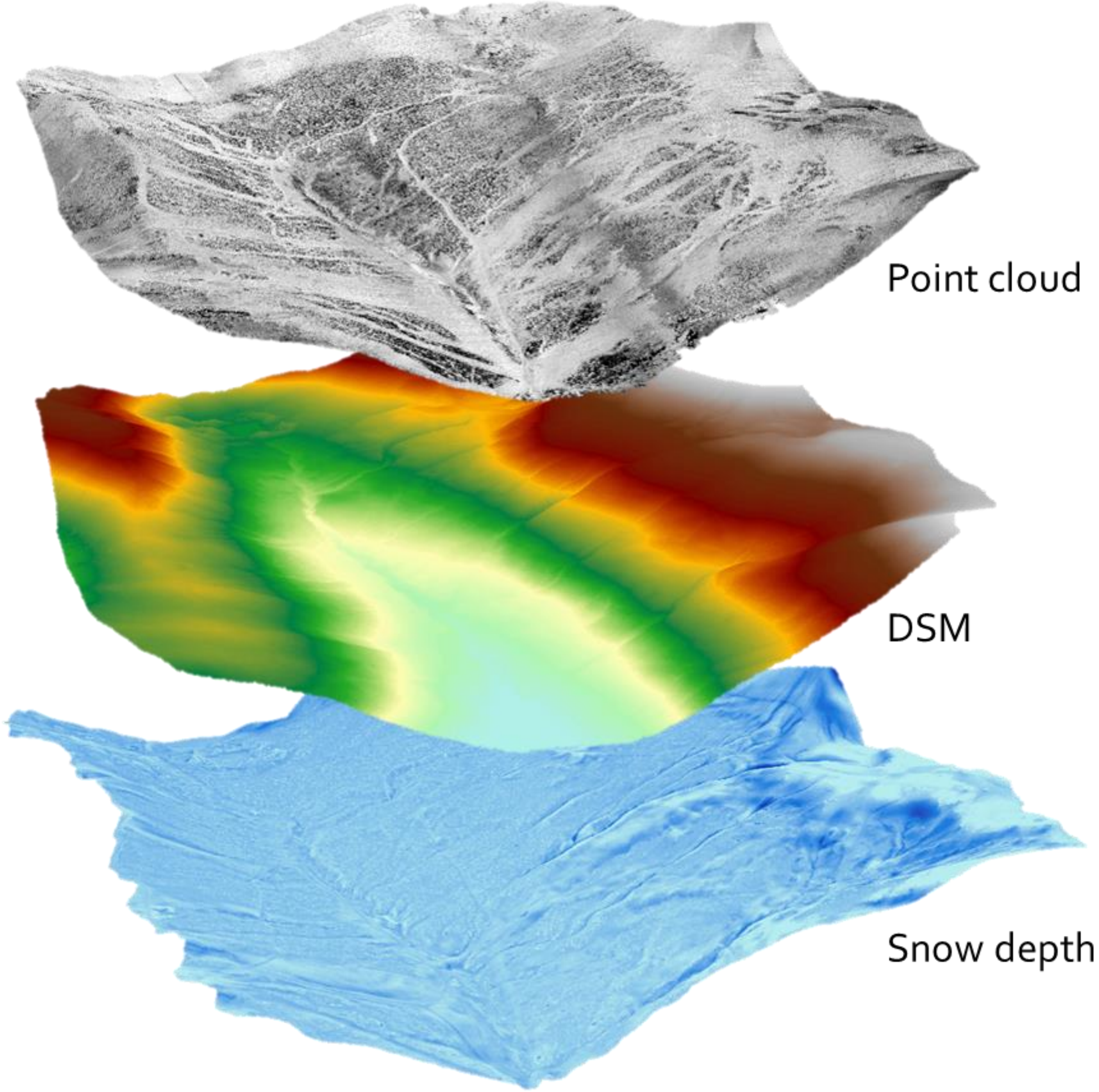
- Flow rates accelerated from 7.2 to 8.5 m/year over 2019 -2024
- 443 m of retreat since 2019
- 4 – 6.5 m of ablation due to melt in 2023-2024 – surface lowering of 31 m around ice surface collapse over internal conduit
- Substantial moraine surface change in 2023-2024 - from 29 m lowering to 16 m increase due to debris-covered ice melt and debris flows
- 30-35 m of ablation due to melt 2019-2024 with surface lowering of 56 m around ice surface collapse

SWE (kg/m^2) = snow density (kg/m^3) x snow depth (m)

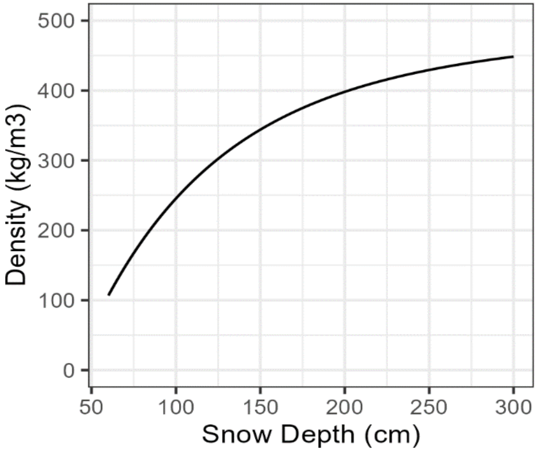
LiDAR provides snow depth, but snow density needed to calculate SWE

Drone sensor suite



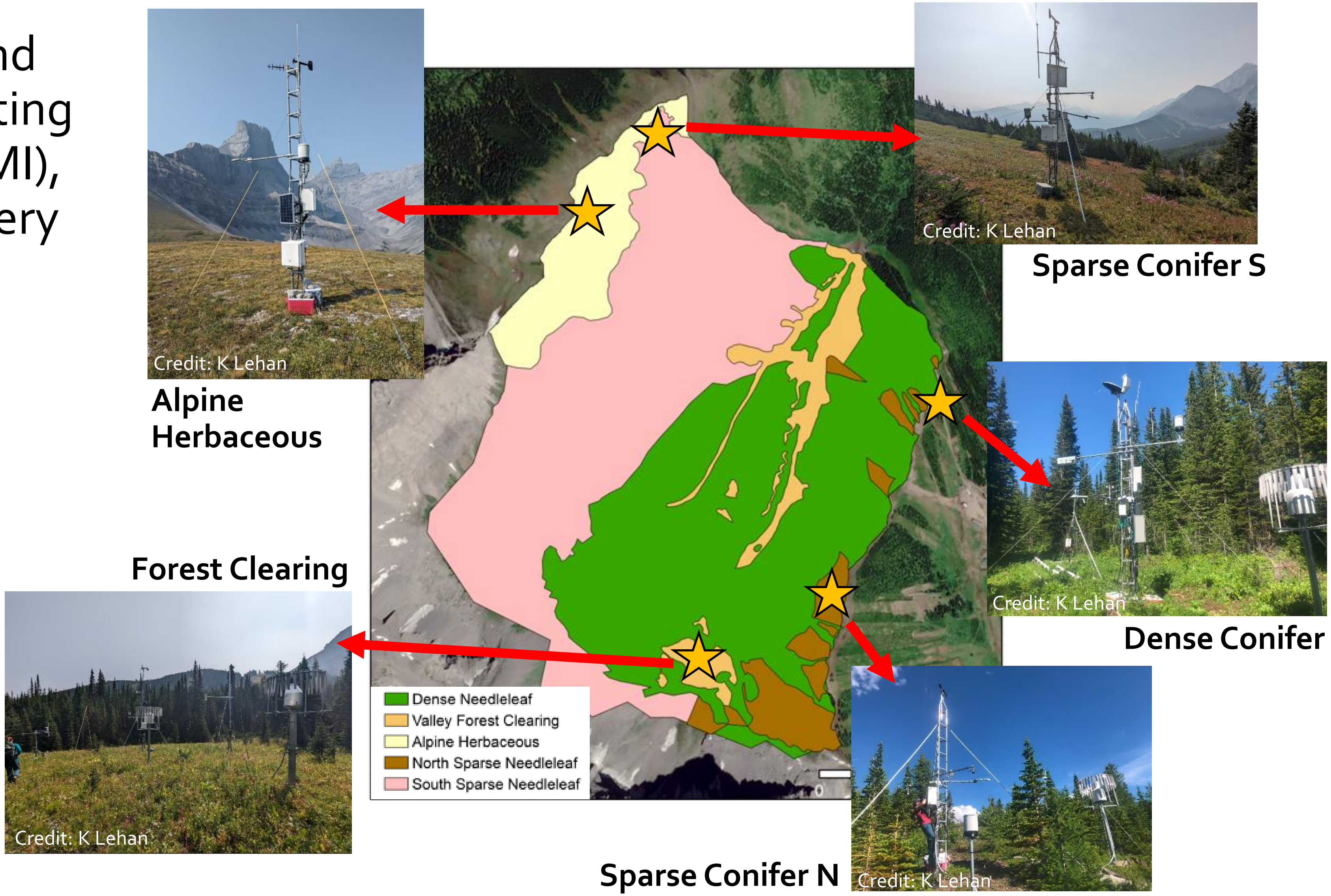


Pomeroy & Gray (1995) equation (winter)



Landscape Units from Stratified SWE Sampling

Landscape units (Steppuhn and Dyck, 1974) derived from existing landscape classifications (ABMI), and adjusted using RGB imagery and scientists' observations



SWE Calculation Workflow

Inputs: lidar snow depth maps, manual snow density measurements from 2023 snow year, snowpack temperature for season delineation

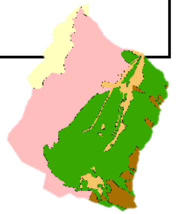
Calculate SWE using **average snow density**

Calculate SWE using **linear regression** for manual snow depth/density

Calculate SWE using equation from **Pomeroy & Gray (1995)**

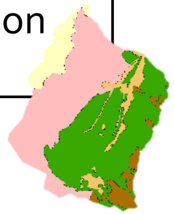
AVG. AGGREGATED: average density for whole basin, for each season

AVG. STRATIFIED: average density for each landscape unit, for each season



REGRESSED AGGREGATED: linear regression for whole basin, for each season

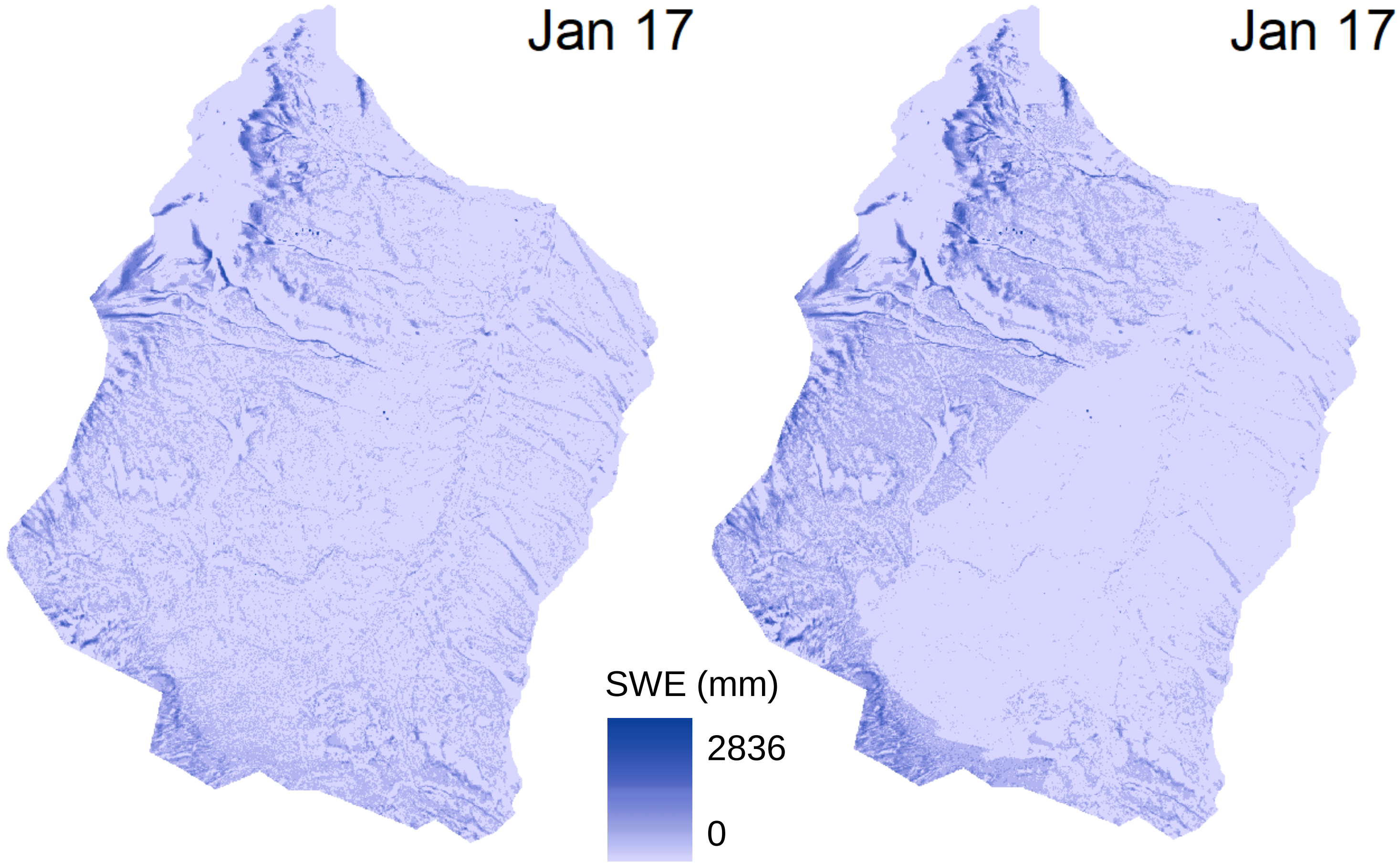
REGRESSED STRATIFIED: linear regression for each landscape unit, for each season



P & G LOGARITHMIC (1995): Deep snow equations for each snow season, snow depth >= 60cm

Average basin density used for snow < 60 cm

Methods – SWE Calculation Workflow



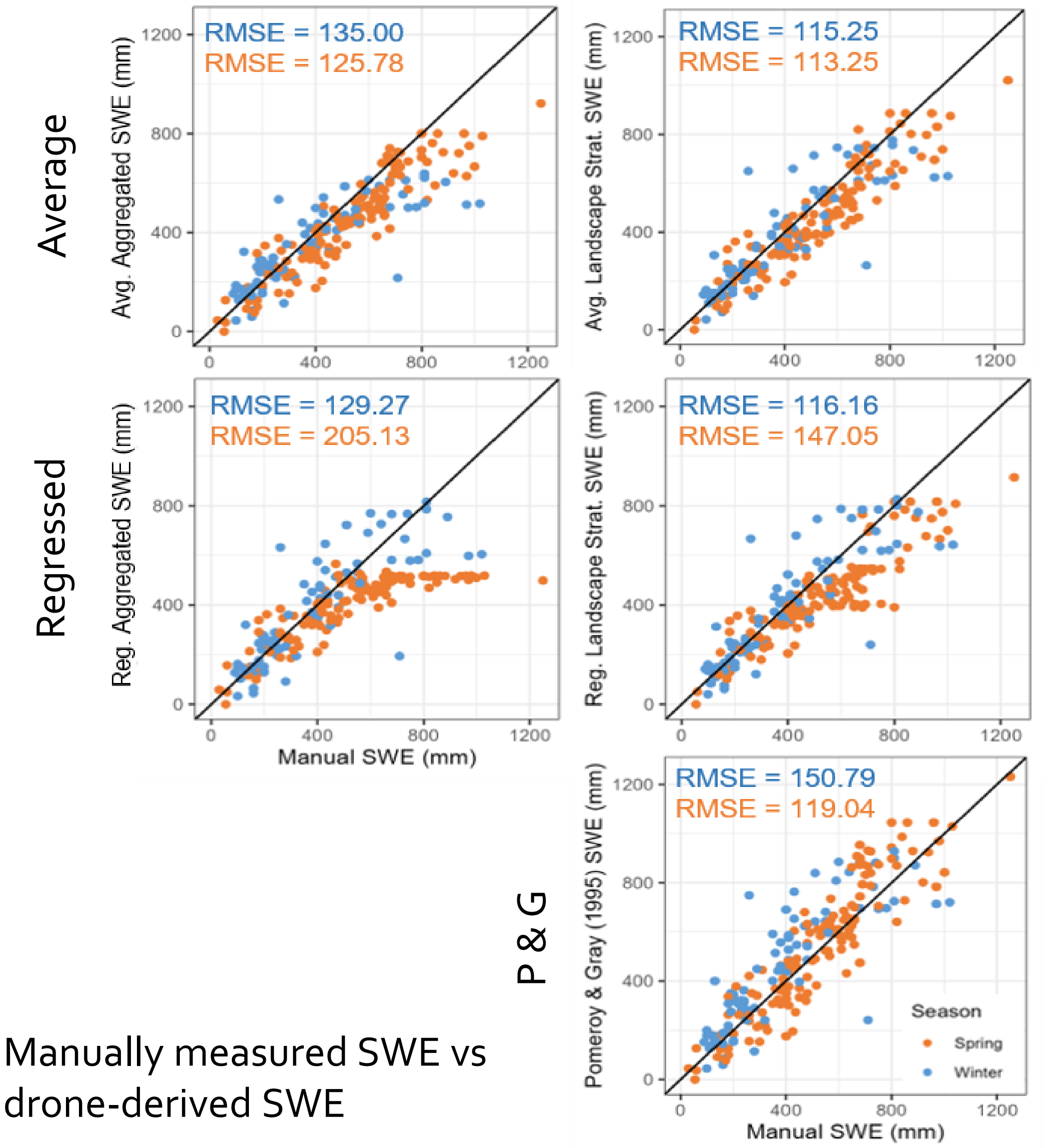
SWE calculated using basin aggregated average density (2023 snow year)

SWE calculated using landscape stratified average density (2023 snow year)

Results – SWE Point RMSE

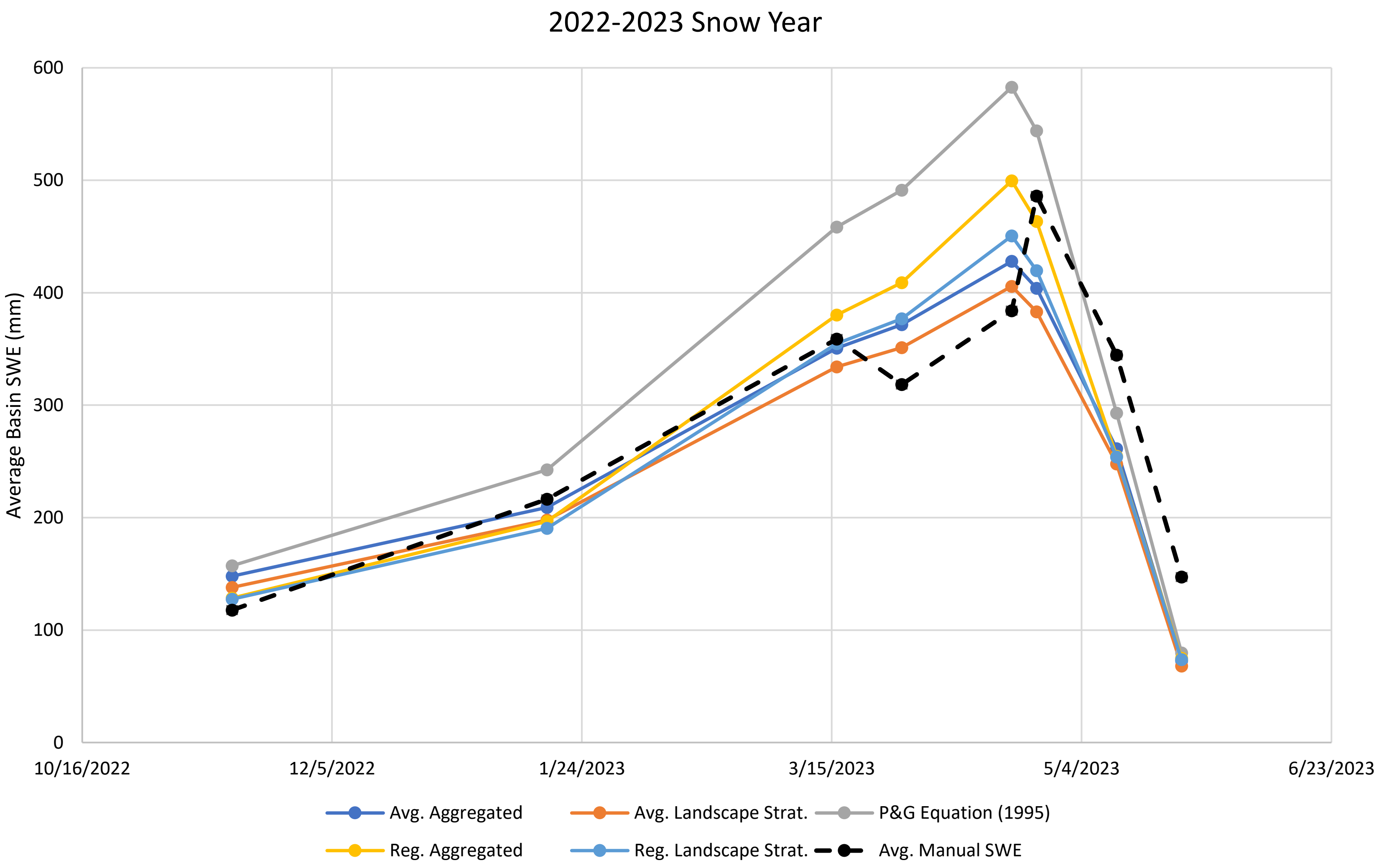
Plotting manual point SWE against calculated point SWE reveals:

- Regression methods fail in spring (expected!)
- Pomeroy and Gray (1995) equation surprisingly suitable in spring
- Landscape-stratified mean density provided the closest estimate of point SWE overall



Manually measured SWE vs drone-derived SWE

Areal-weighted Basin SWE



UAV-LiDAR snow survey summary

Applying 5 methods of density interpolation for basin-wide SWE calculation revealed:

Point SWE was best estimated by using a landscape stratified mean density (RMSE 114 mm, mean bias -51.9 mm)

- Landscape stratified methods outperformed aggregated approaches
- All methods failed to represent point SWE in the spring – P&G (1995) equation predicts spring point SWE best, but bias was large

Conclusions:

i) landscape-stratified snow density measurements improve SWE estimates from UAV-LiDAR snow depths

ii) if density cannot be measured, Pomeroy and Gray (1995) equation can be used to estimate SWE in mountain environments