A mountain water resources monitoring framework using optical, lidar & radar imagery at century to season scales

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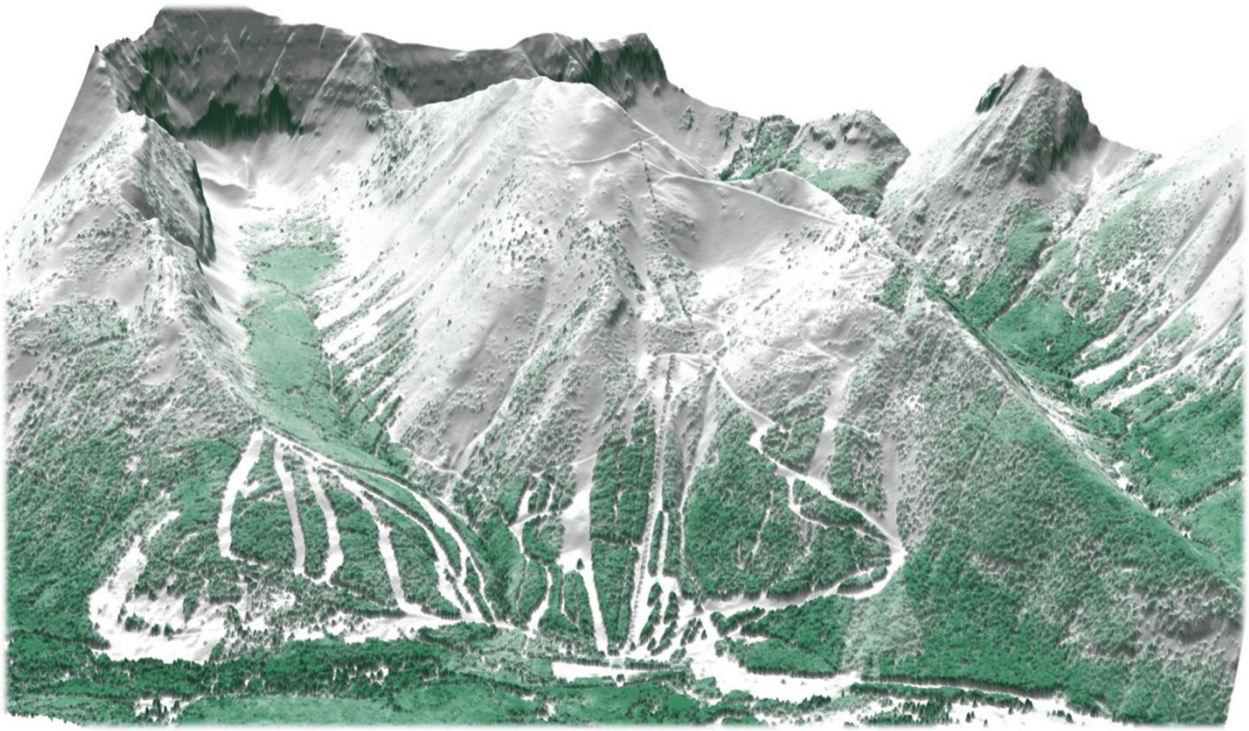


IAHS Scientific Assembly 2017
10–14 July 2017
Port Elizabeth, South Africa

Oldman River Headwaters

- Oldman River Basin ~ 26,000km^2
- Domestic, irrigation, power supply
- >70% snow melt from mountains
- Not well monitored
  - 4 x automatic snow pillows
  - 3 x manual snow courses
  - No headwater stream gauges!
- Headwater ecosystems sensitive
  - Climatic change
  - Landcover disturbance
  - Past & future water resource uncertainty

Castle Headwater Research

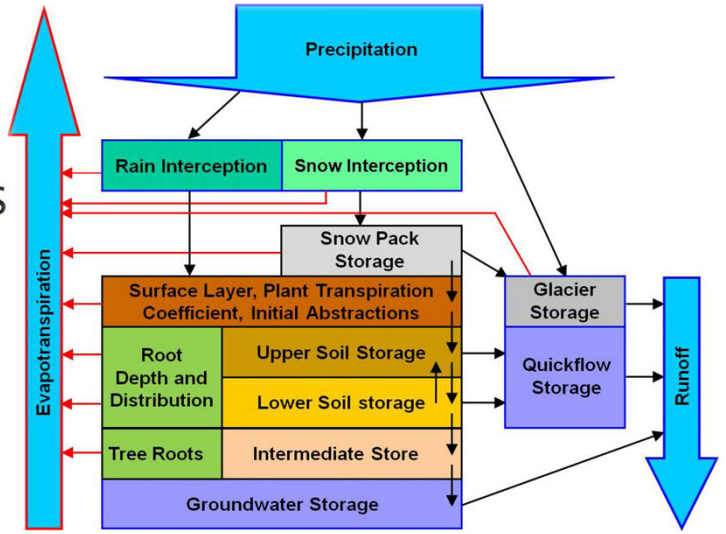
Water Resource Dynamics

Climate change impacts on runoff

- GCM/RCM & ACRU model simulations

Historical land cover change impacts

- Treeline ecotone migration
- Alpine/periglacial snow & ice storage



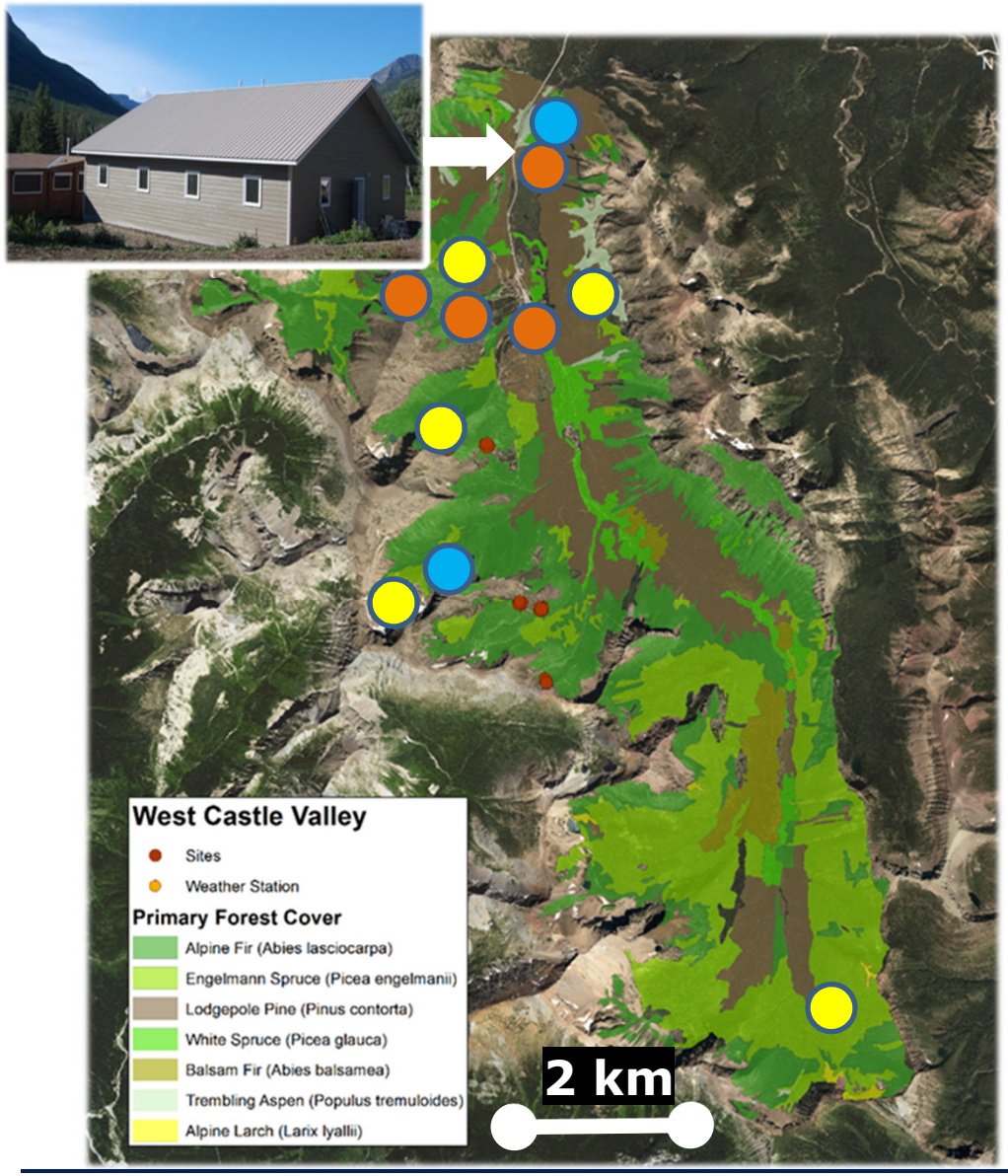
Water Resource Operations

Improved headwater snow & runoff monitoring

- In situ LEDDAR snow depth & water level profiles
- Watershed LiDAR snow sampling & modeling
- Satellite SAR snow cover mapping

ARTEMIS

Westcastle hydromet installations



- New met sites (4)

  Elevation gradient: 1400 (WFS), 1450 (valley), 1850 (treeline), 2100 (ridge)

- Planned met sites (5)

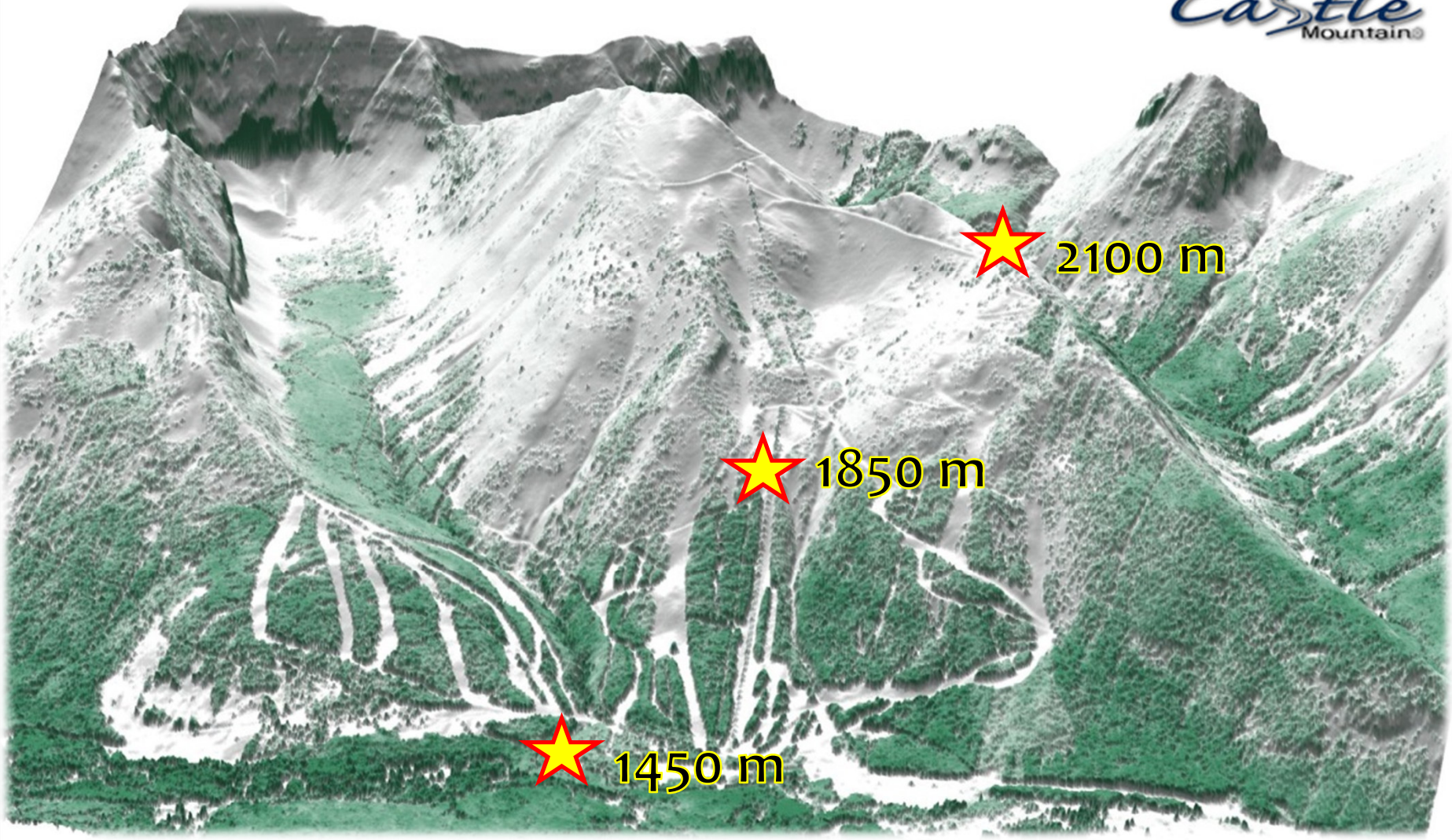
  South Valley (1650), Cirque (2150), Aspect tripods (N,S,W @ treeline - 1800-1900)

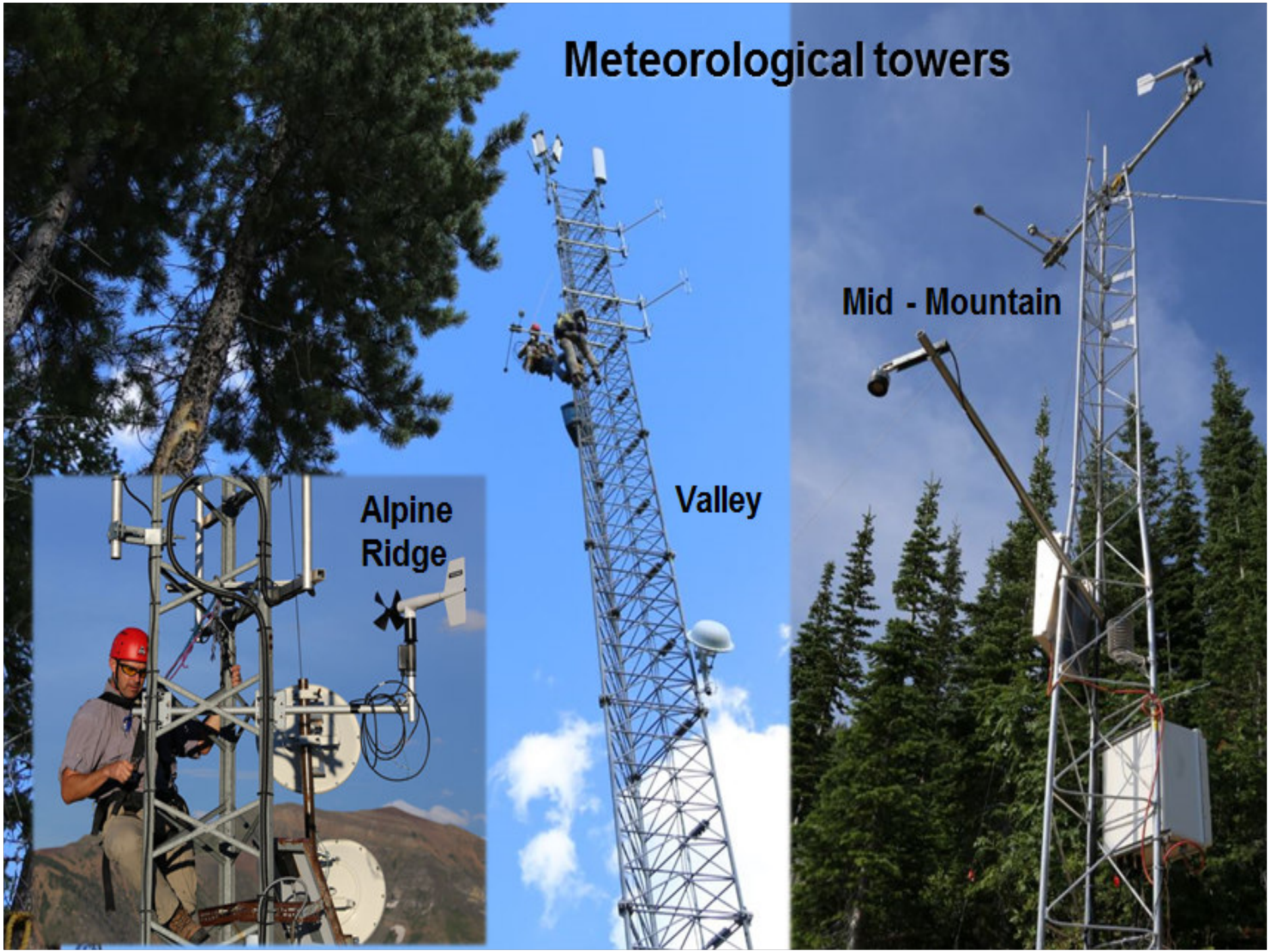
- UL Stream gauges (2)

  WFS (1400), Cirque/treeline (~1900)

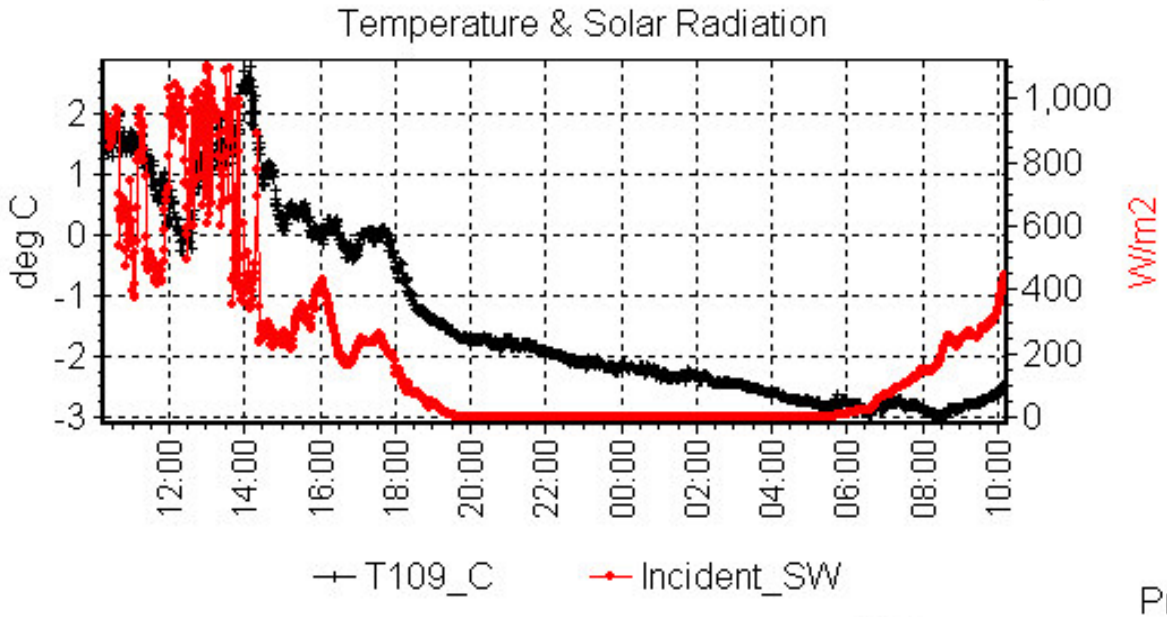
Background map: Dave McCaffrey

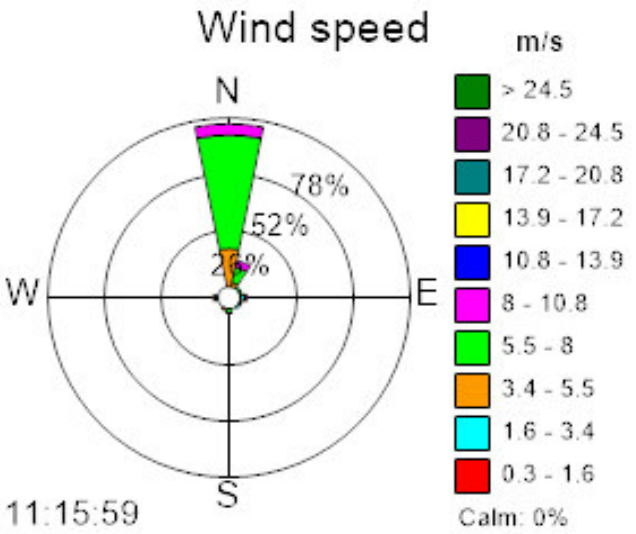
Castle Mountain ski hill access

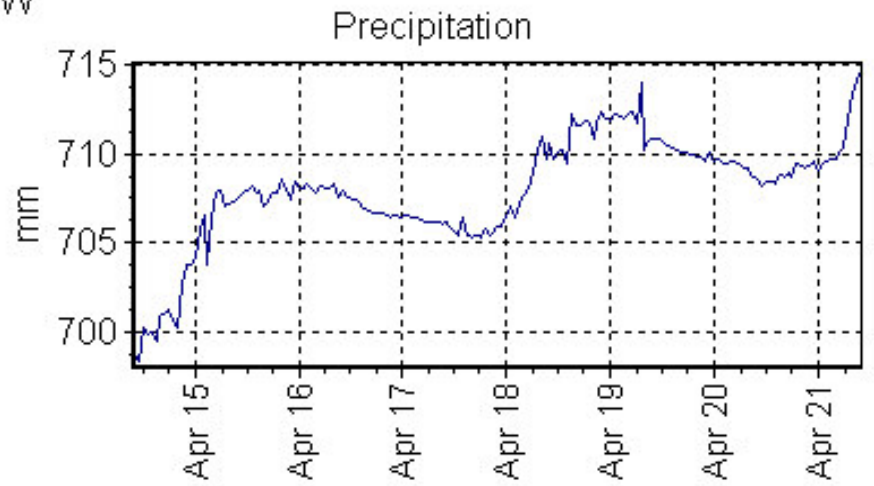



Meteorological towers
Alpine Ridge
Valley
Mid - Mountain

Castle ski hill weather data
Ridge (2100 masl)

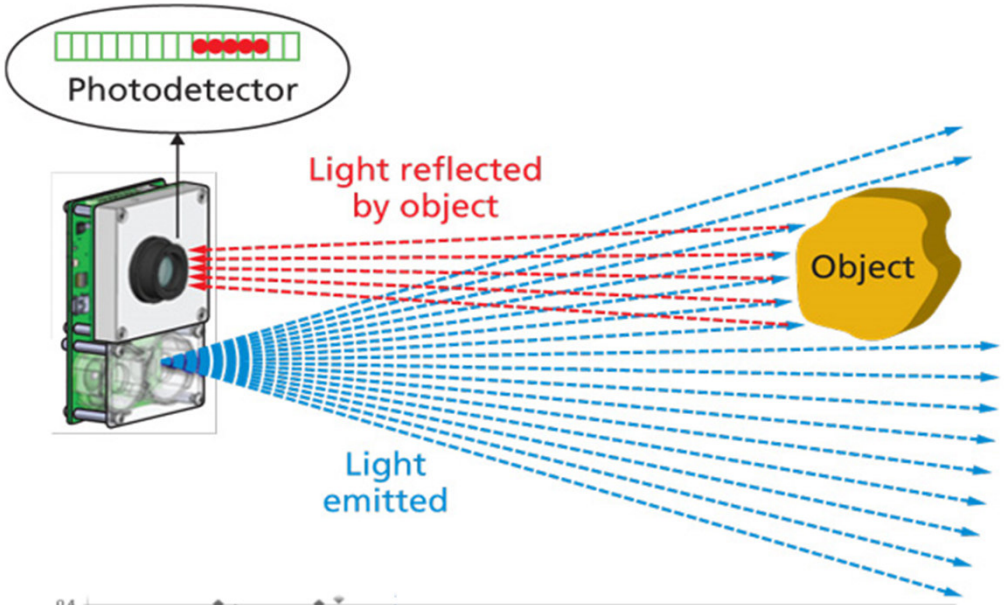


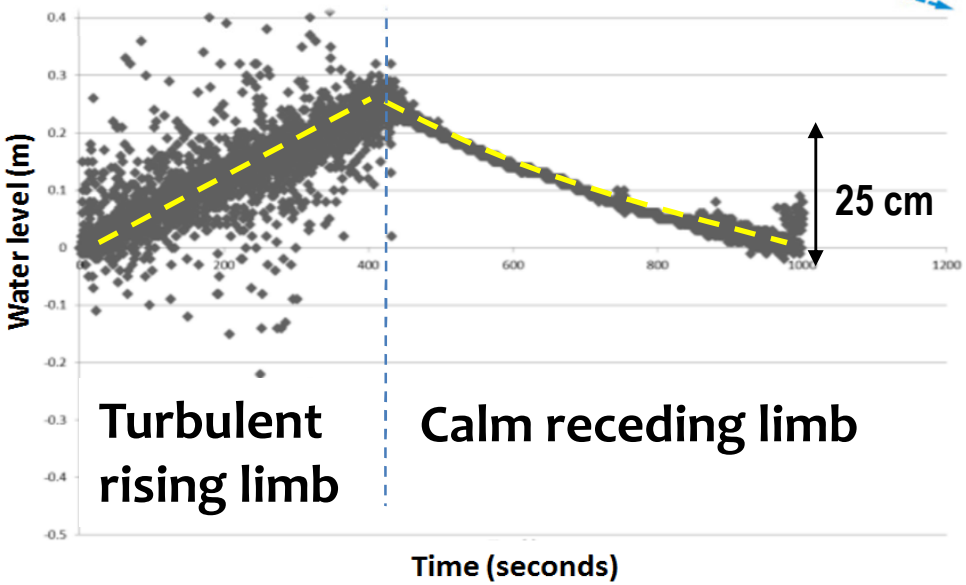




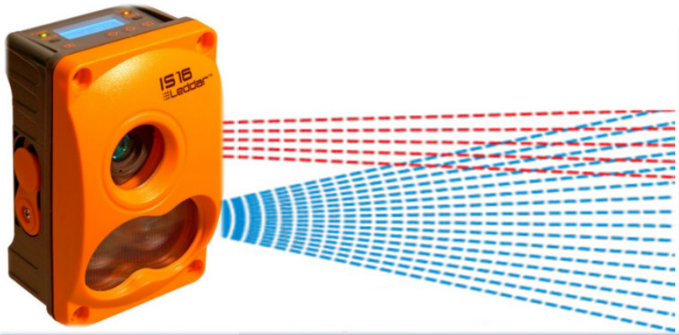
University of Lethbridge, ARTeMiS Laboratory
Contact Dr. Chris Hopkinson c.hopkinson@uleth.ca

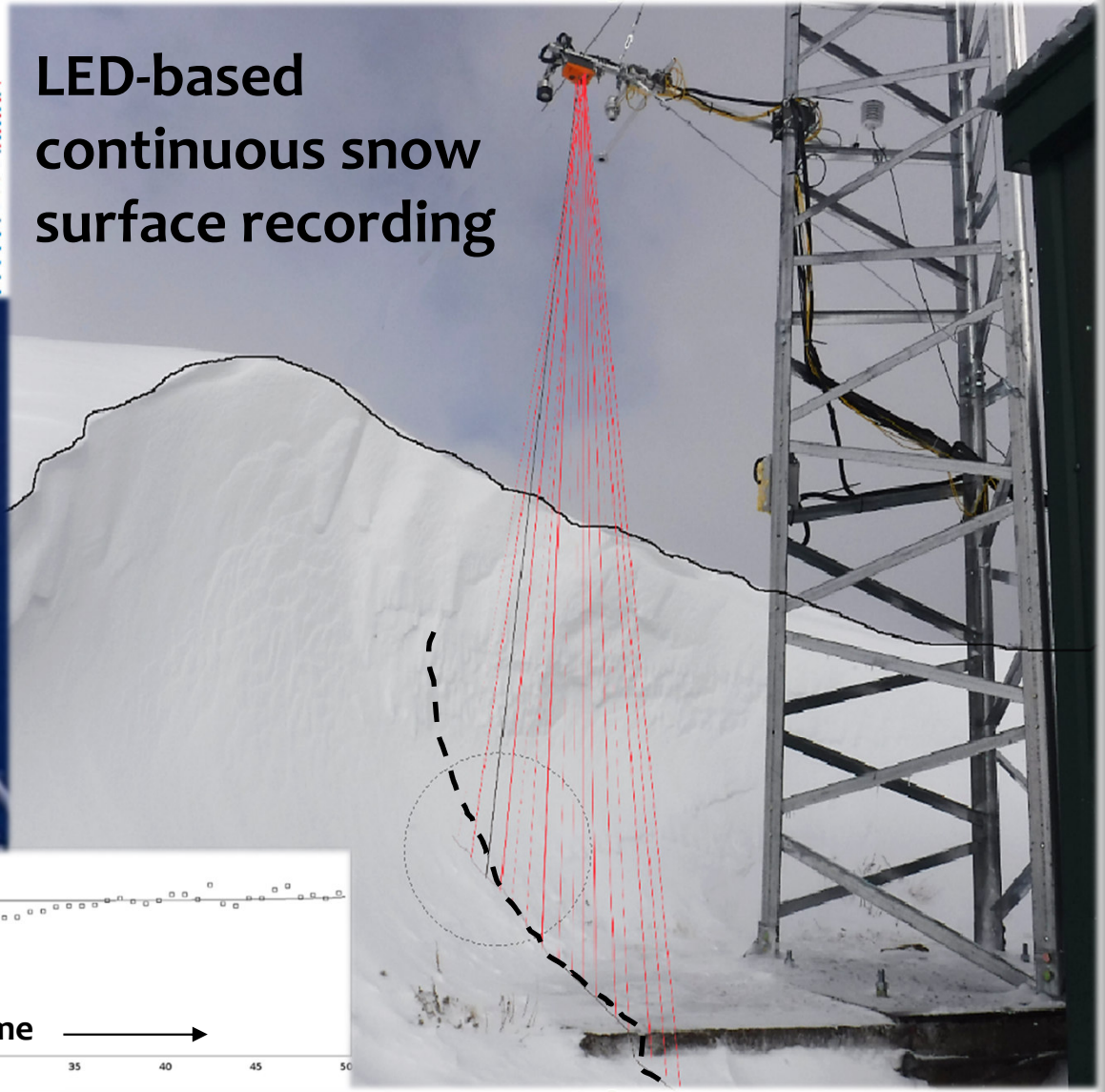
LEDDAR water level monitoring

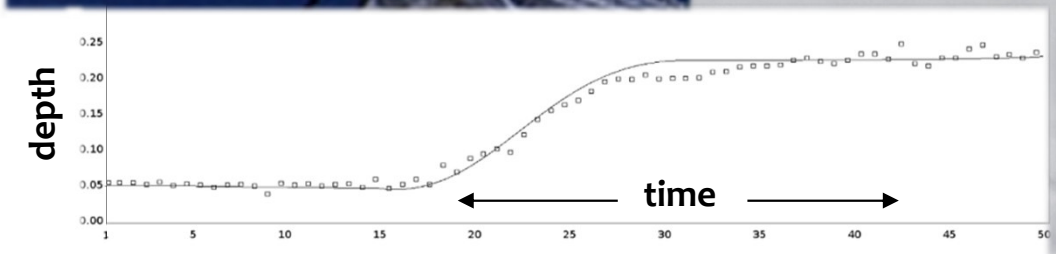




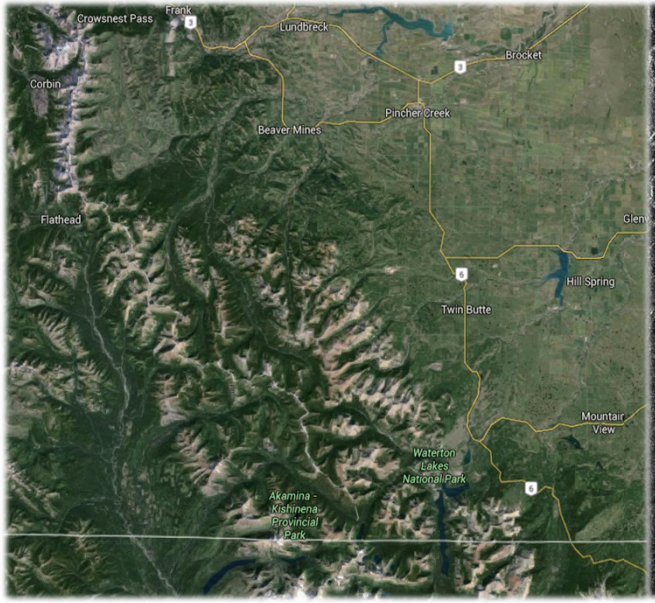
LEDDAR snow profile monitoring

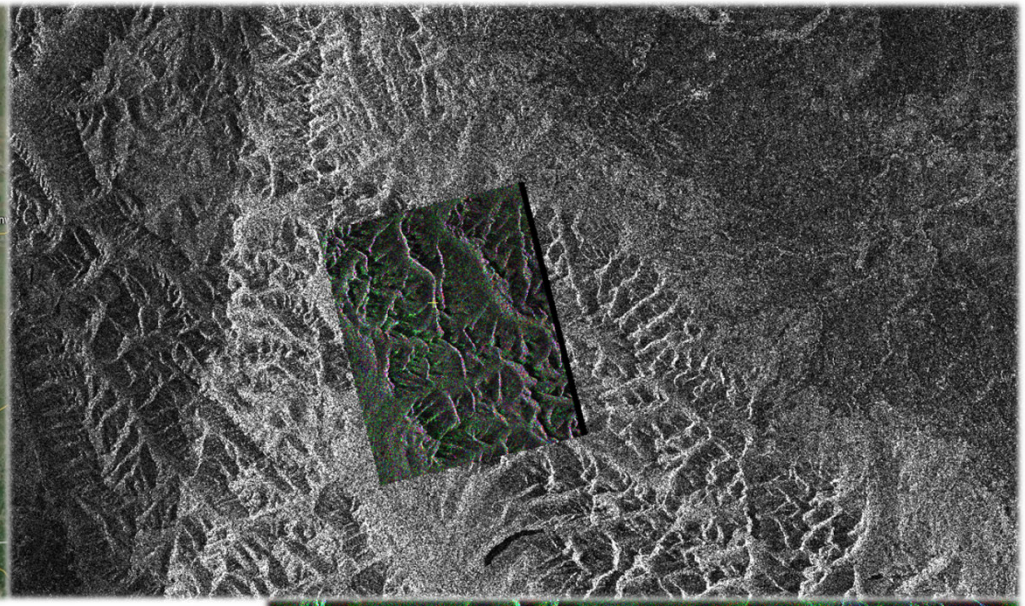


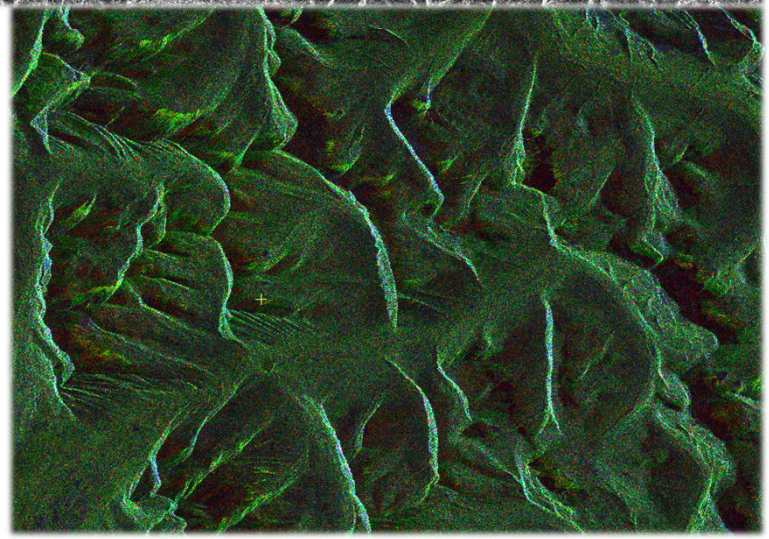




SAR snow cover mapping





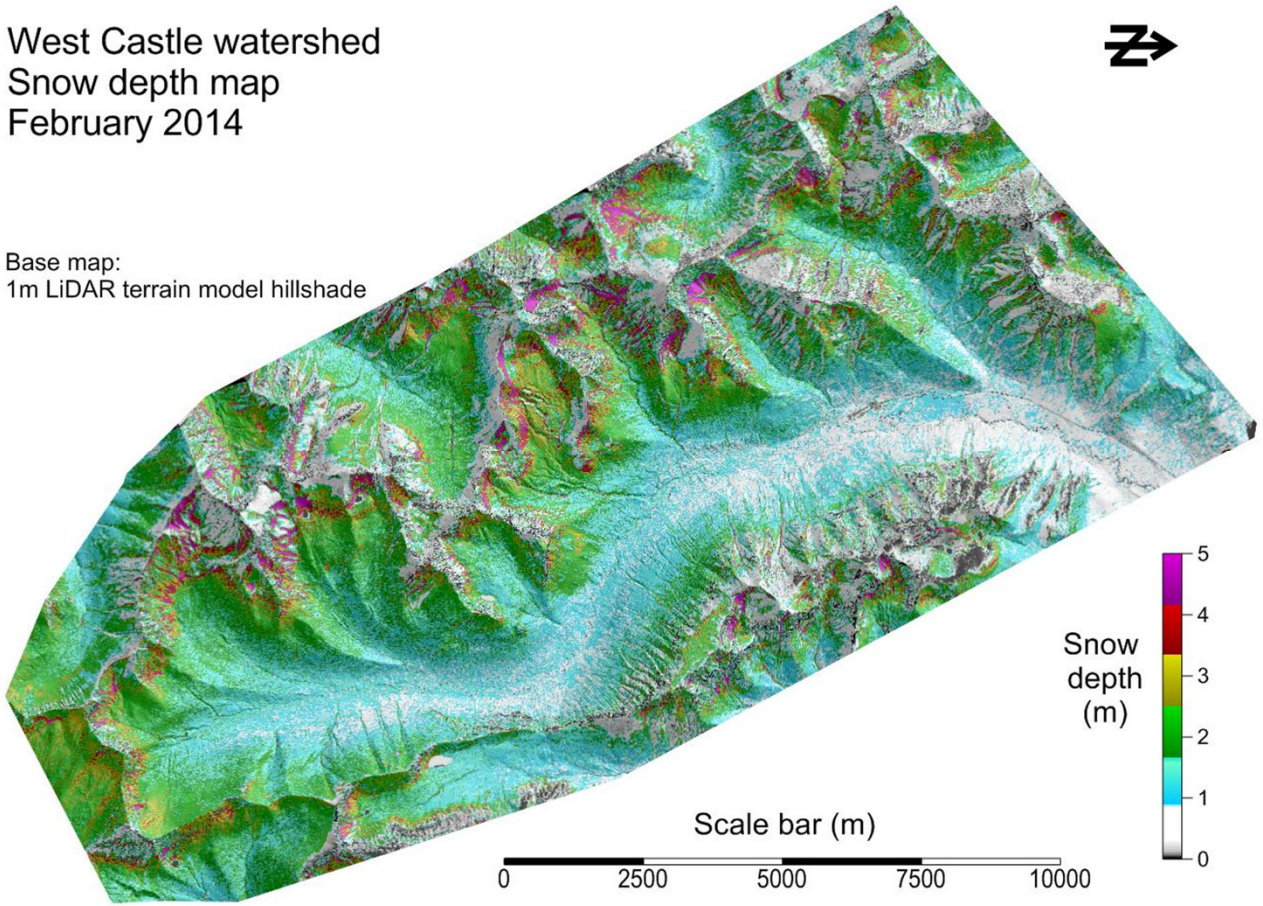


28 HH & 18 FQ scenes collected in 2016 & 2017 so far

Investigating correlation / correction with lidar snow cover & field data

In progress!

LiDAR snow depth mapping



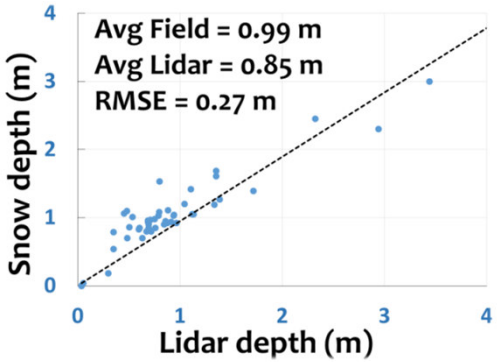
Objectives

Optimal cost-effective depth monitoring

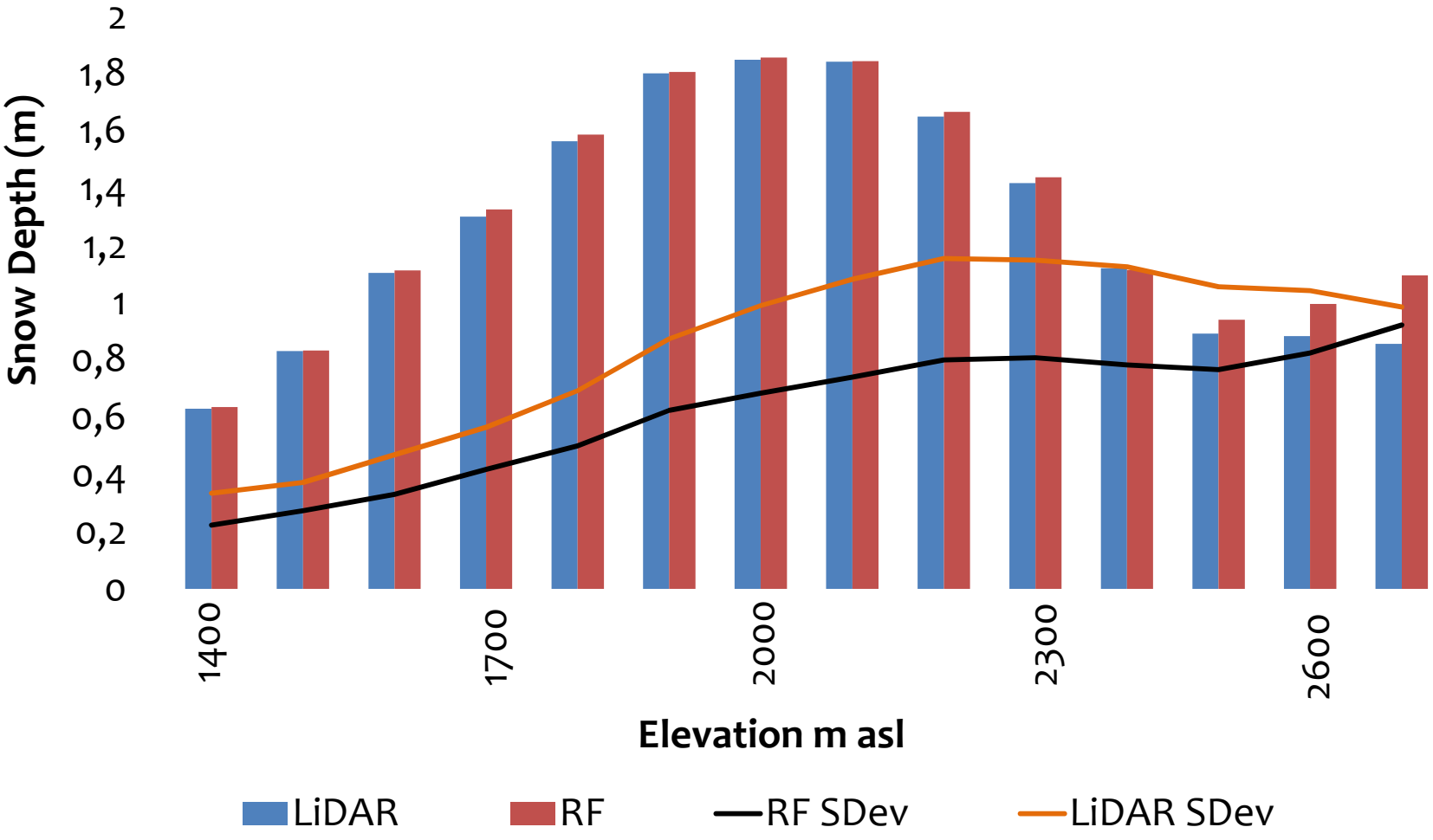
Consistency of snow depth drivers in time

Snow course representivity

Calibrate SAR snow cover in headwaters

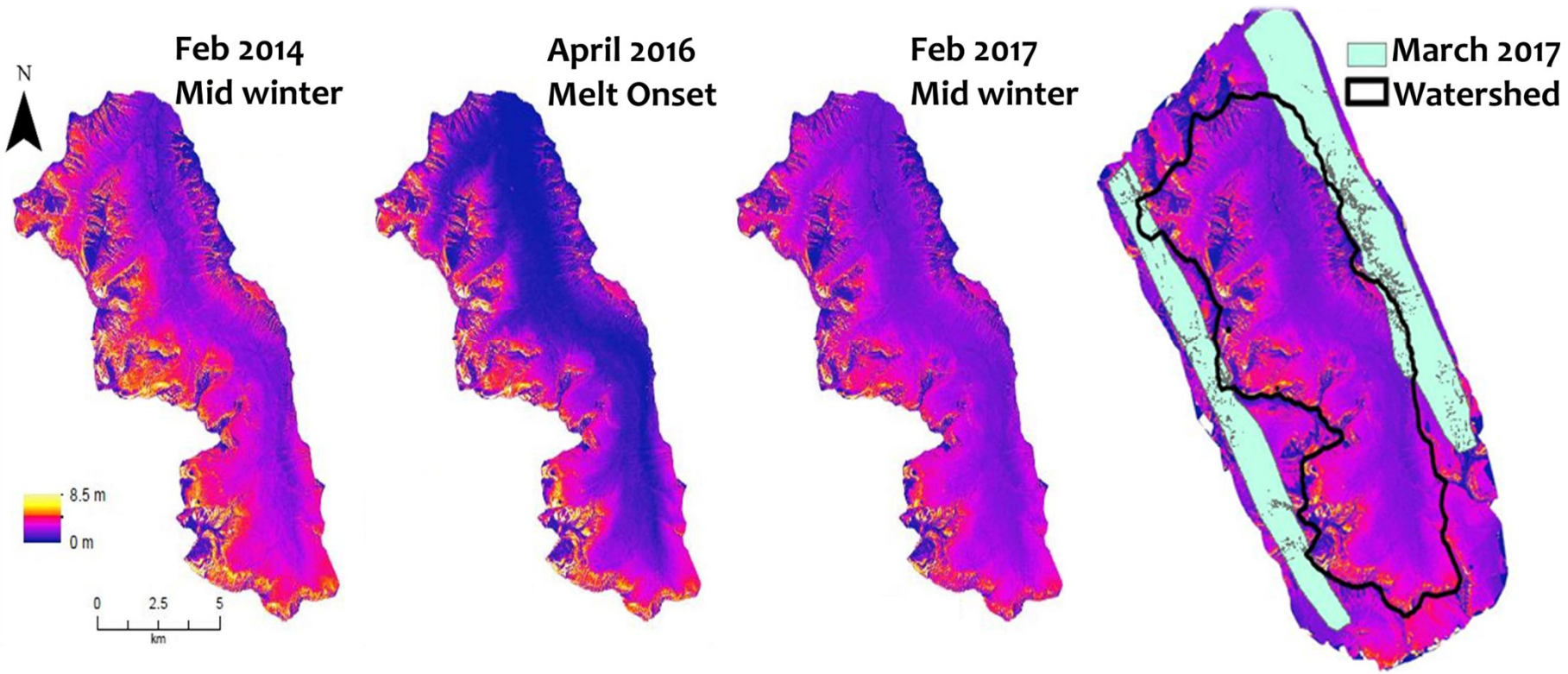


Random Forest snow depth modeling



Cartwright et al. in prep

LiDAR snow depth monitoring

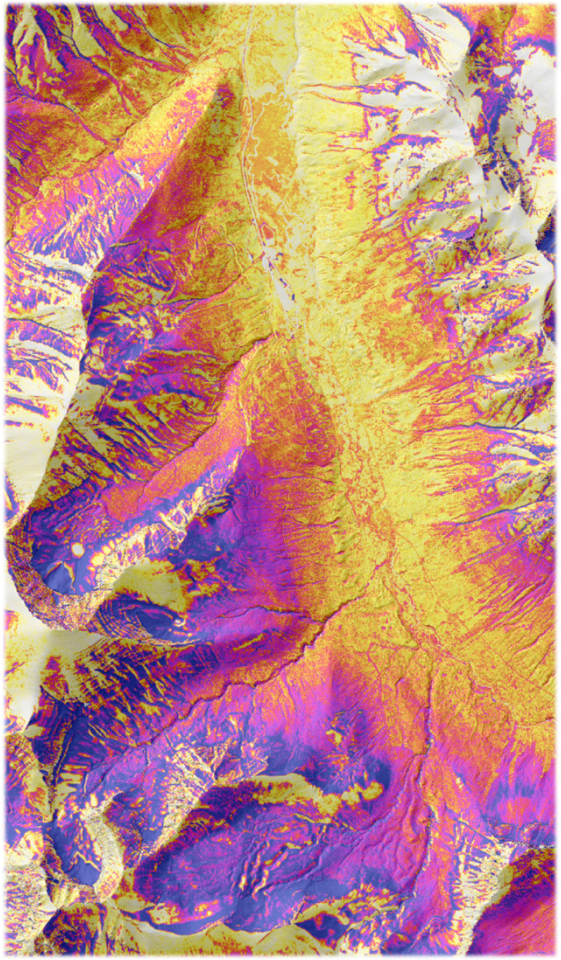


Targeting mid winter accumulation & late winter ablation period to assess consistency of model drivers

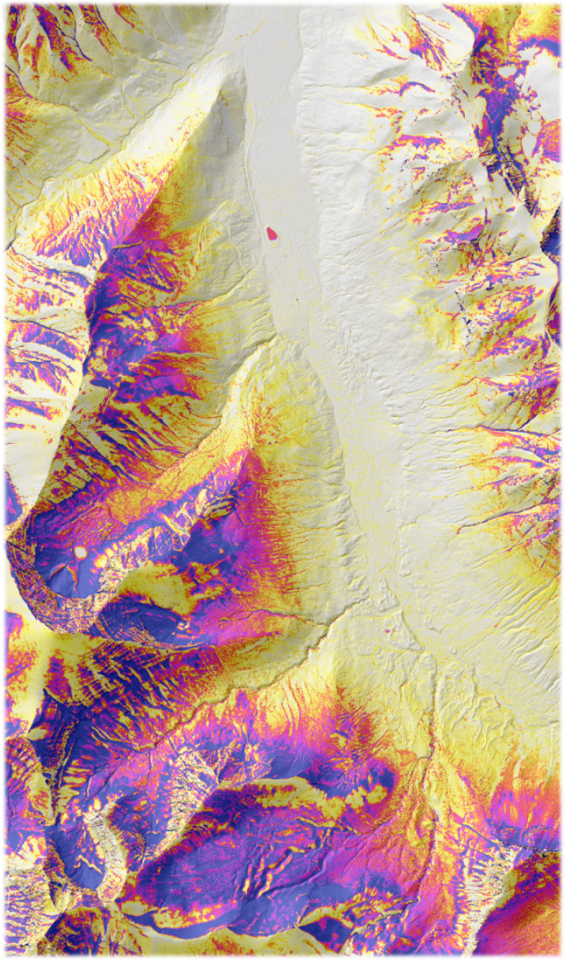
Cartwright et al. in prep

Seasonal snow depth evolution

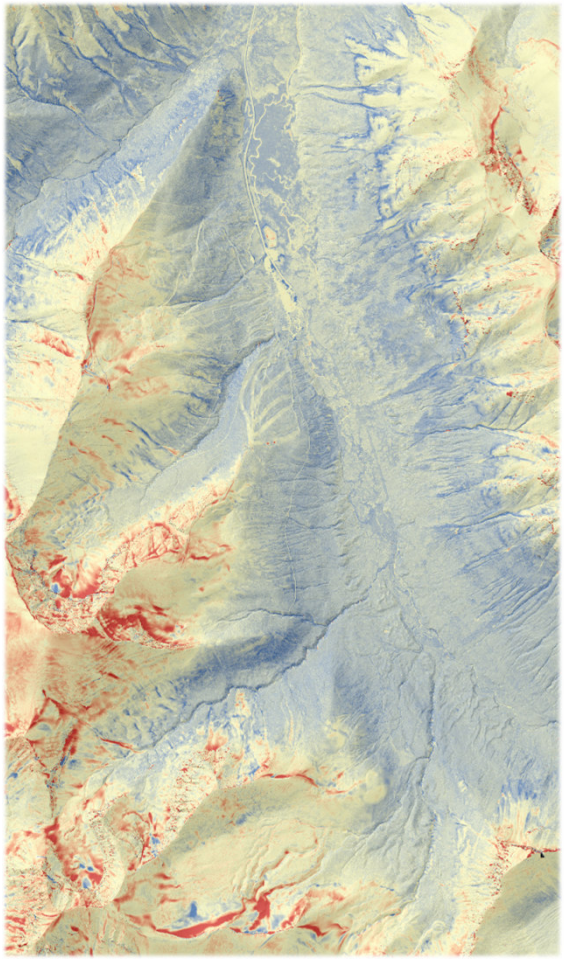
Mid winter accumulation



Late winter melt onset

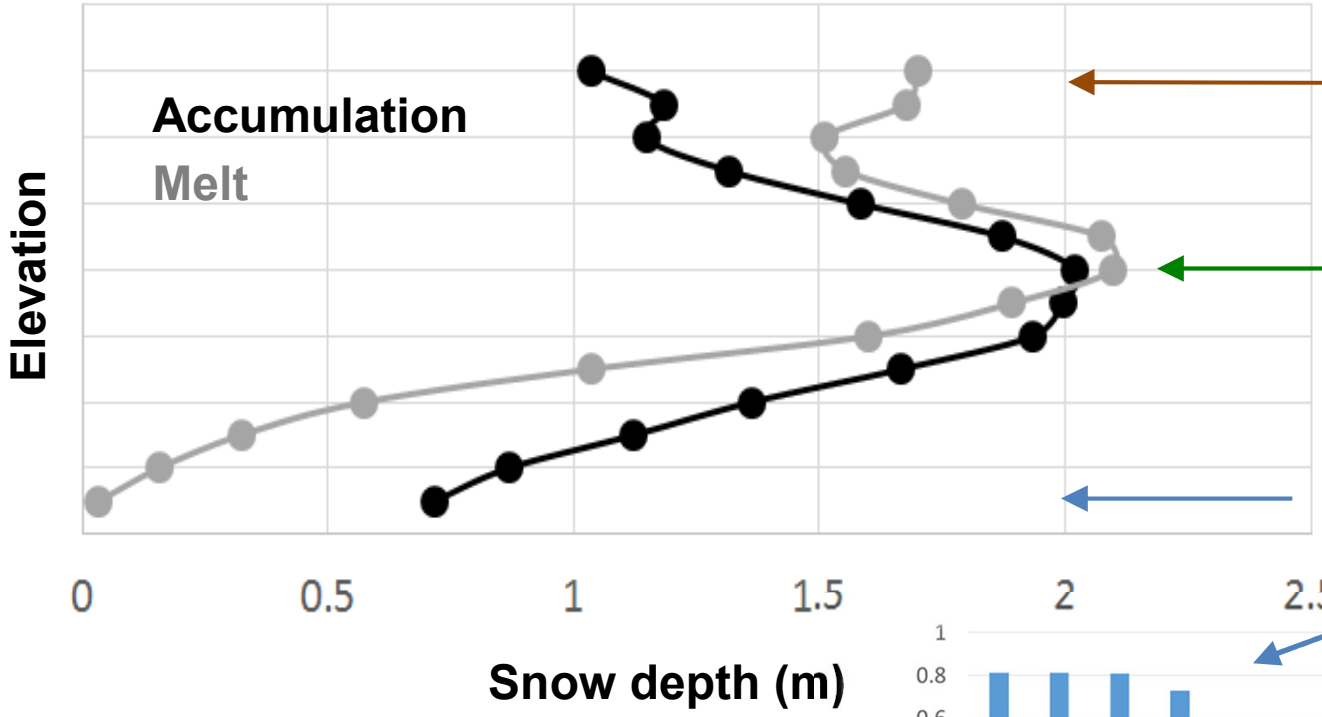


Seasonal depth difference



Snow depth:

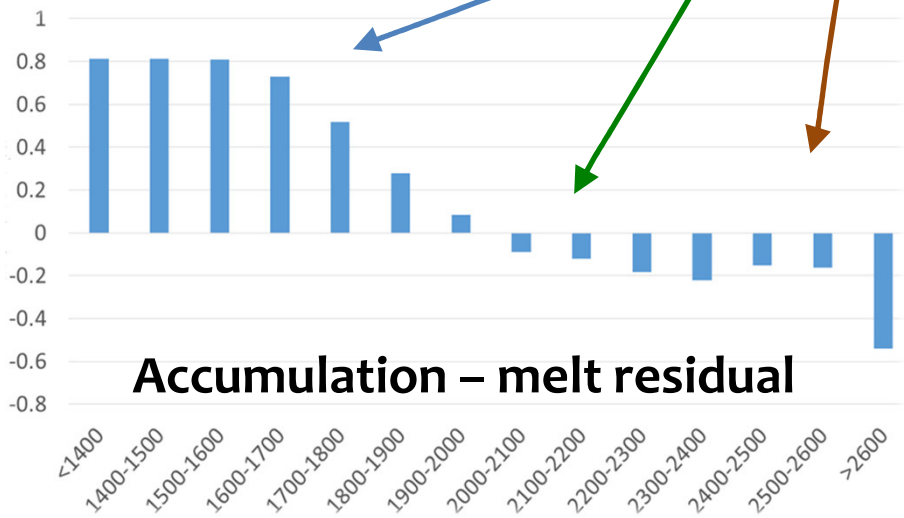
Seasonal snow depth with elevation



Ridgeline

Treeline

Valley

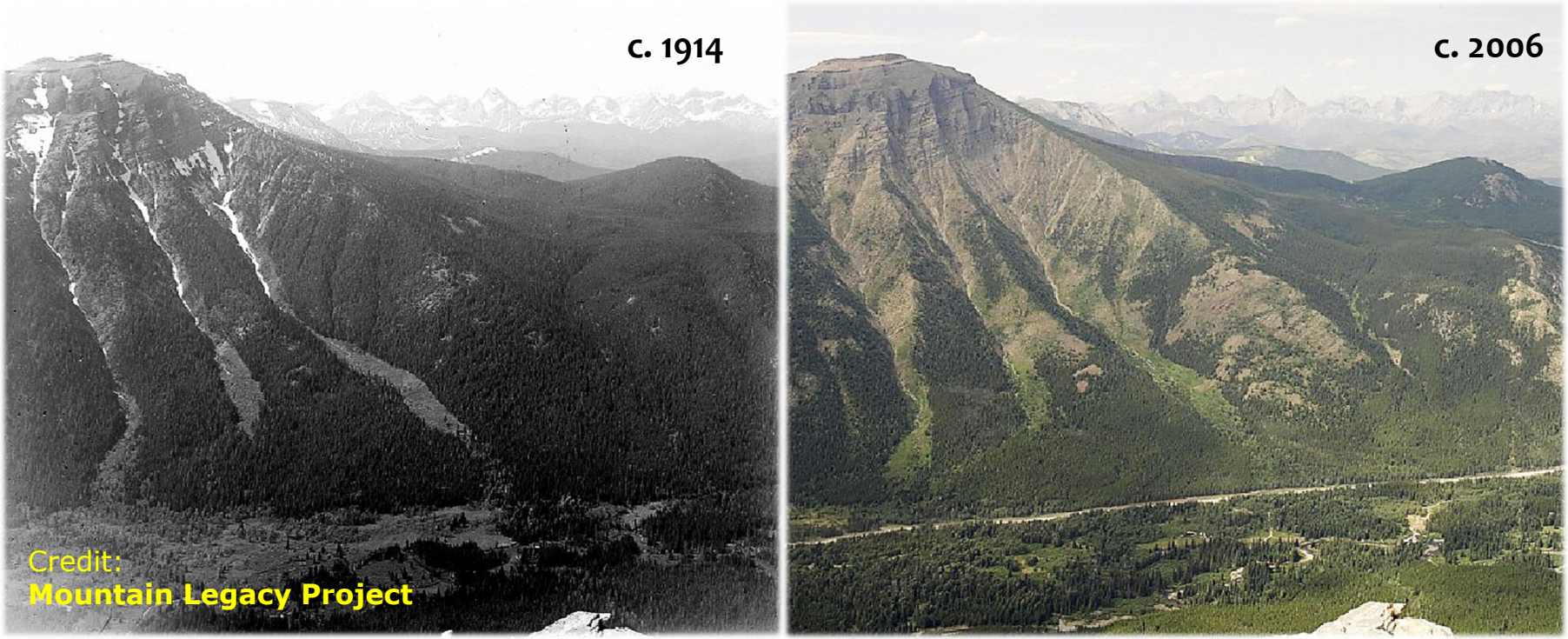


Treeline dominant component in watershed-scale snow processes

Cartwright et al. in prep

Headwater treeline ecotone change

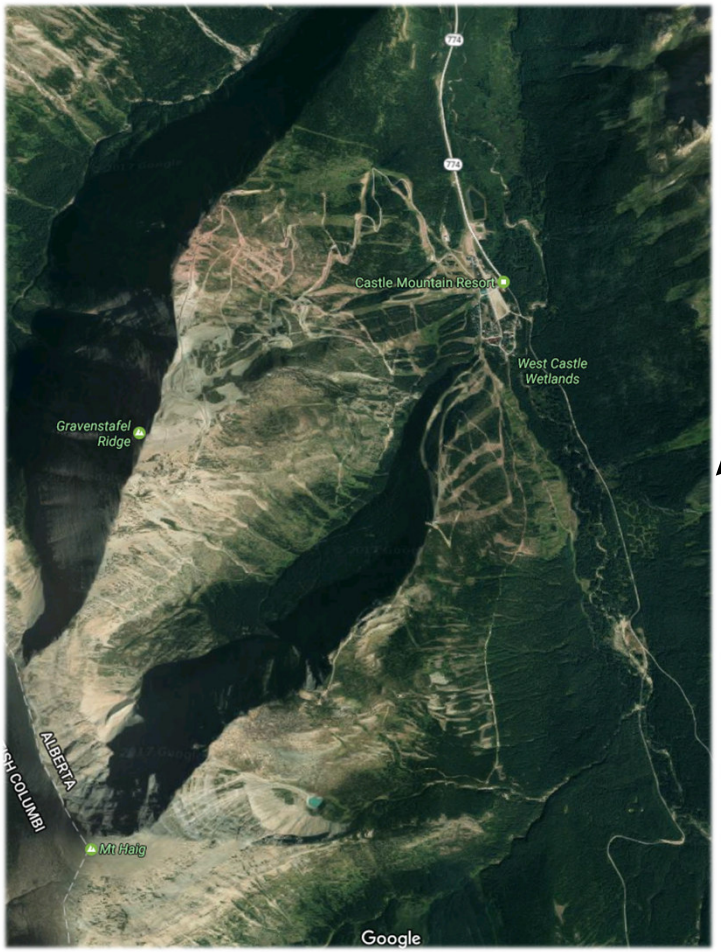
Use recent & archive imagery to map century-scale treeline & forest cover migration

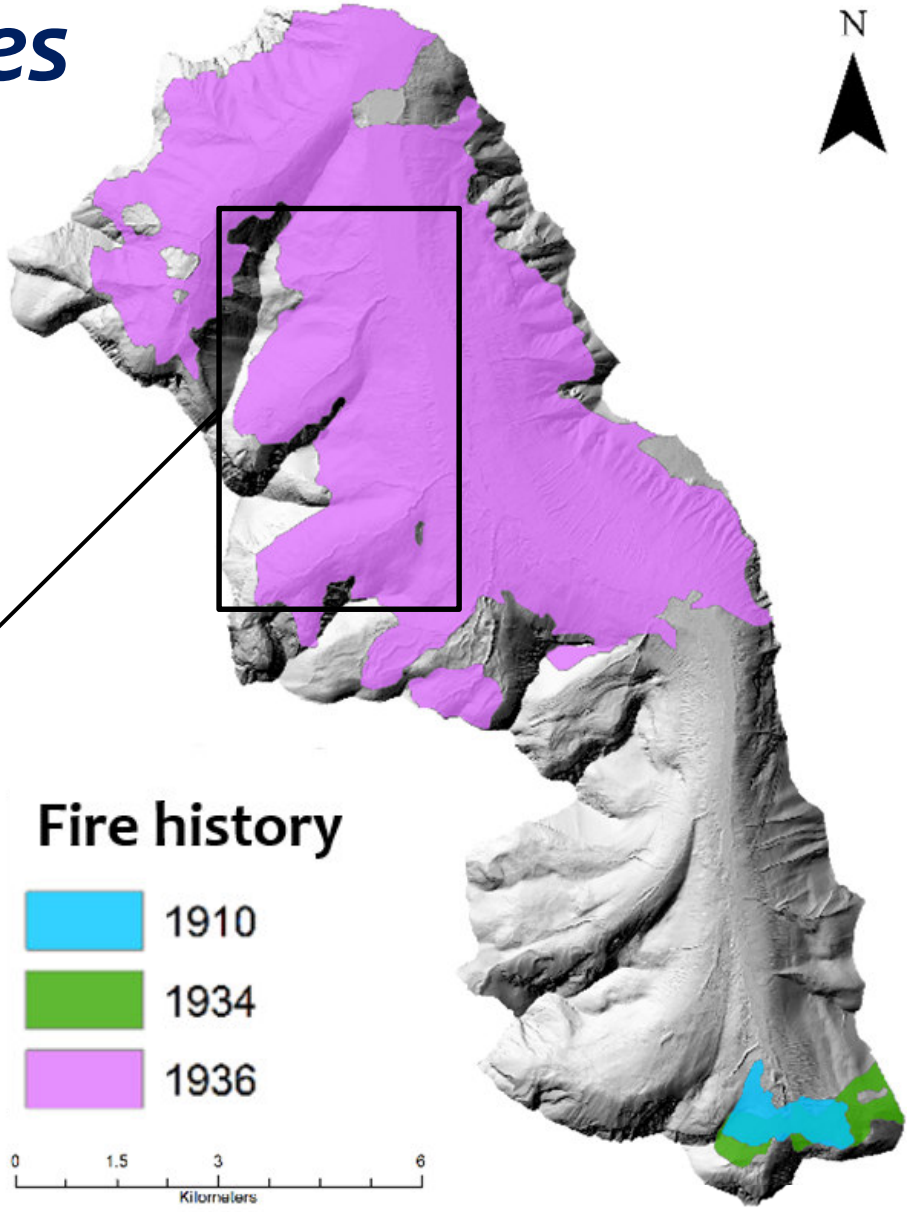


Isotherm movement? … Fire? … Pests? … Drying?

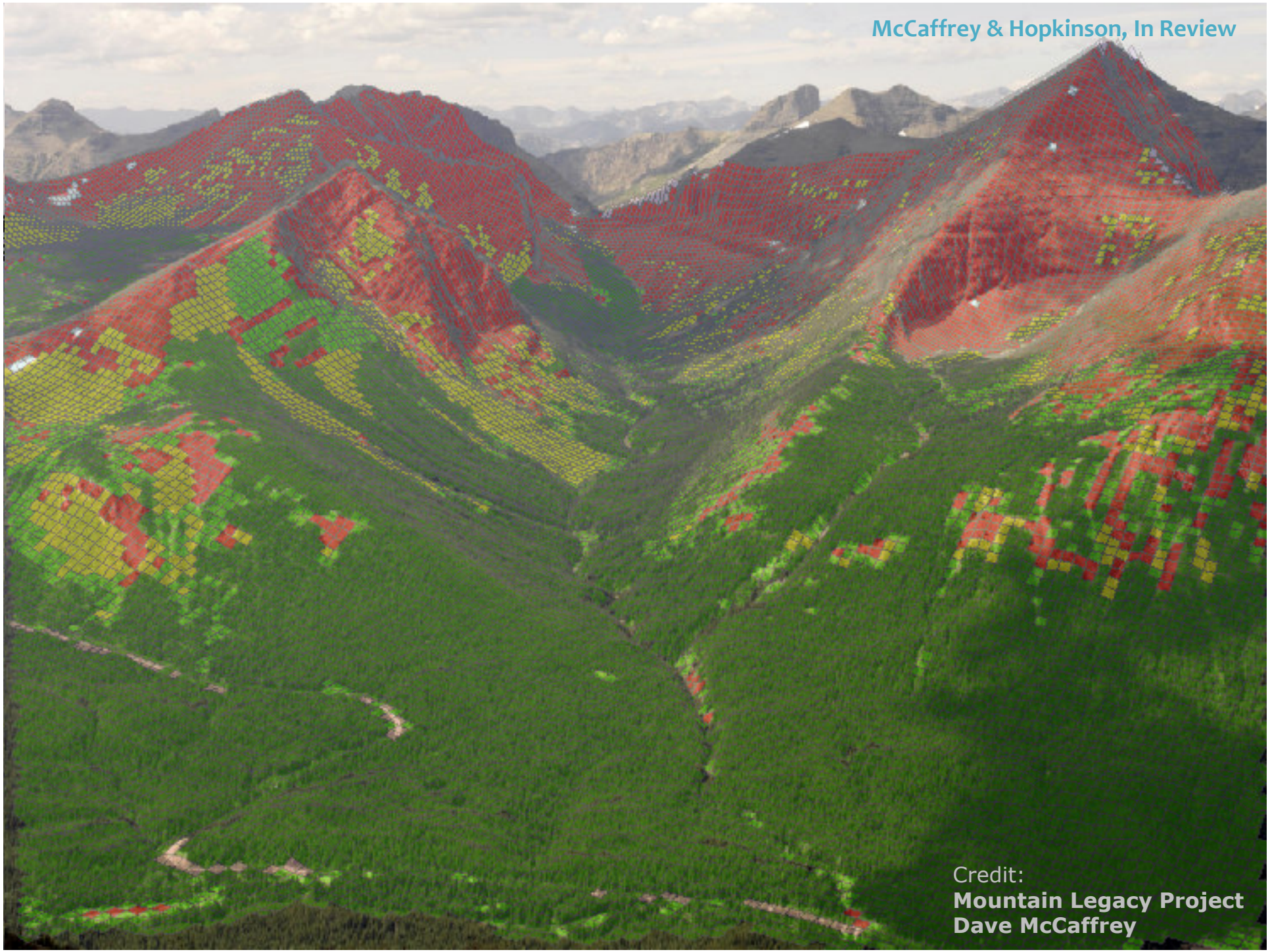
Known disturbances

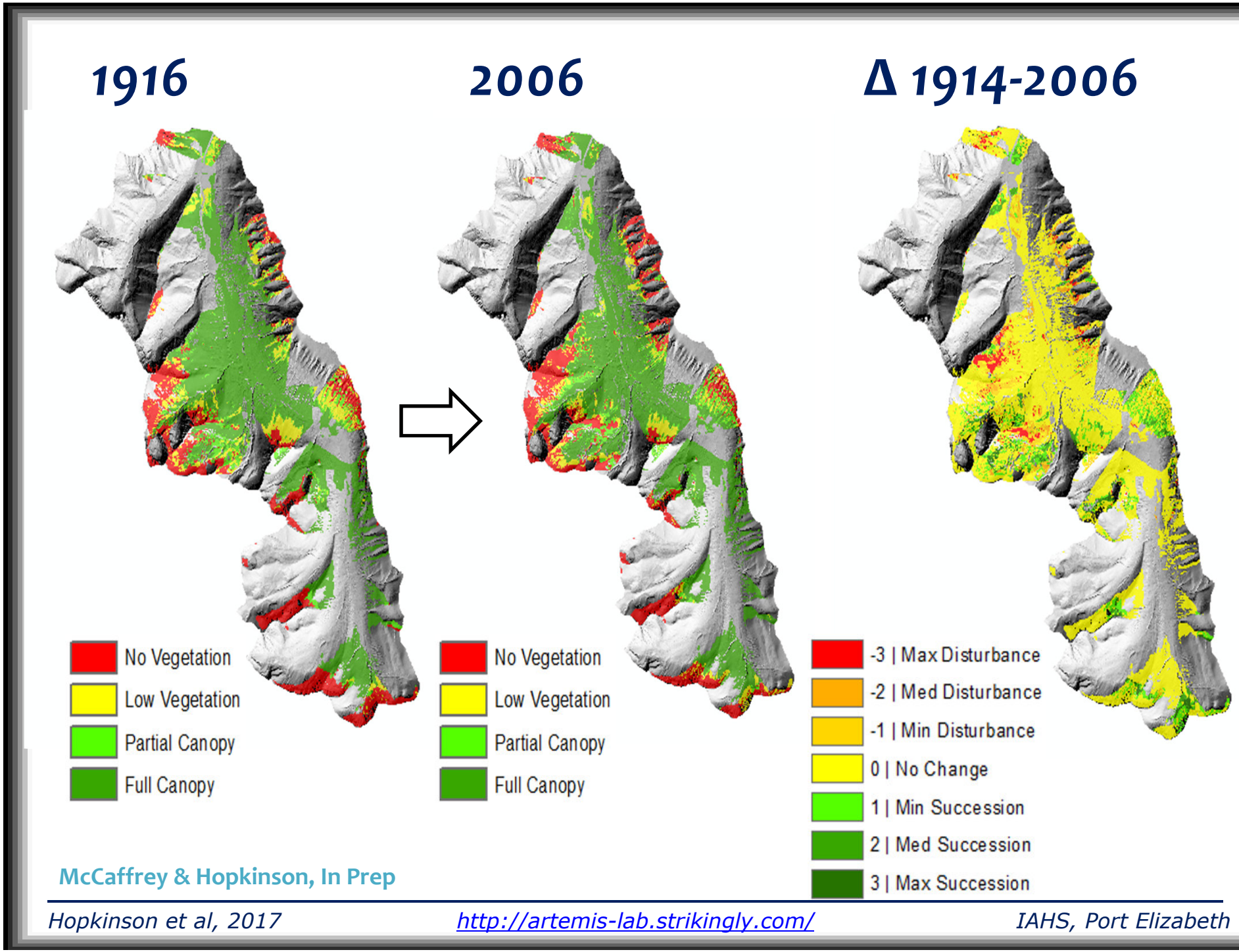
Castle Mountain Ski Resort



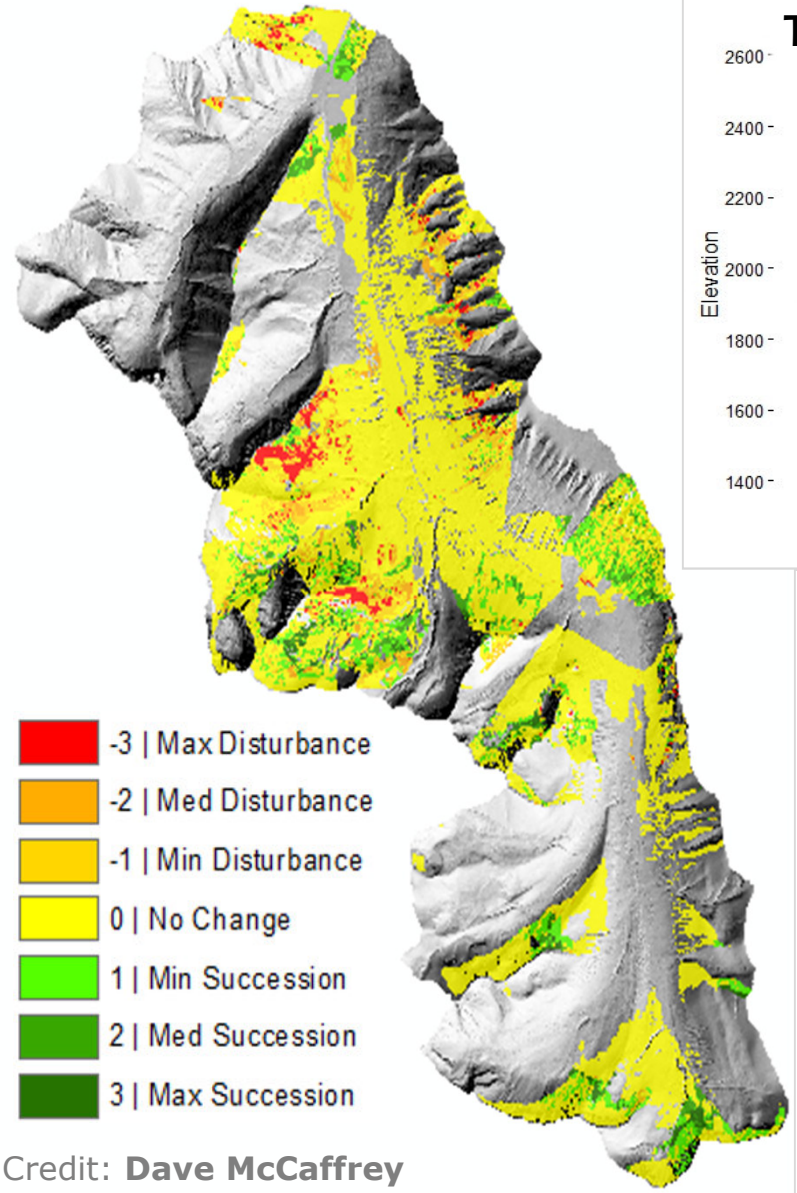


Credit: **Dave McCaffrey**

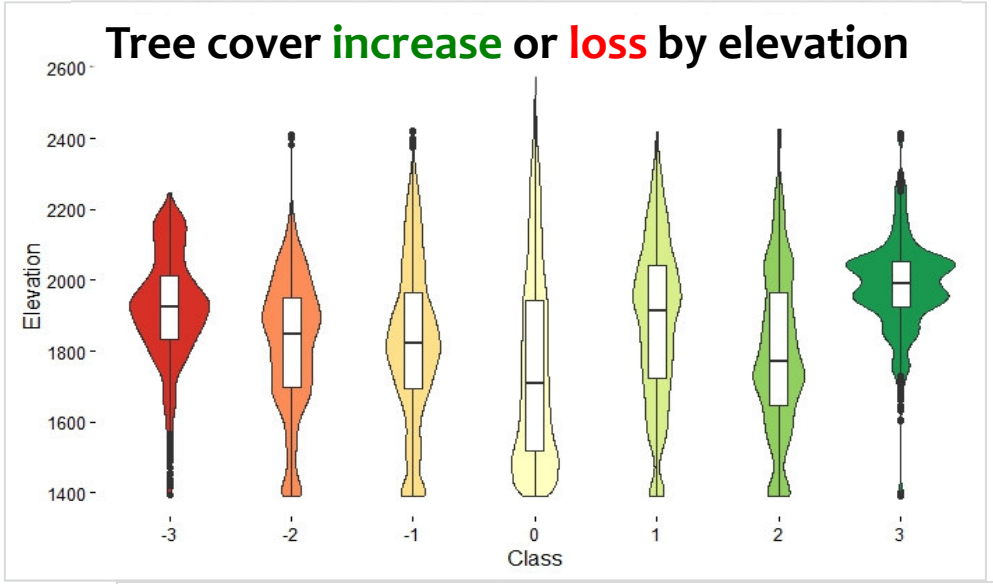

McCaffrey & Hopkinson, In Review
Credit:
Mountain Legacy Project
Dave McCaffrey

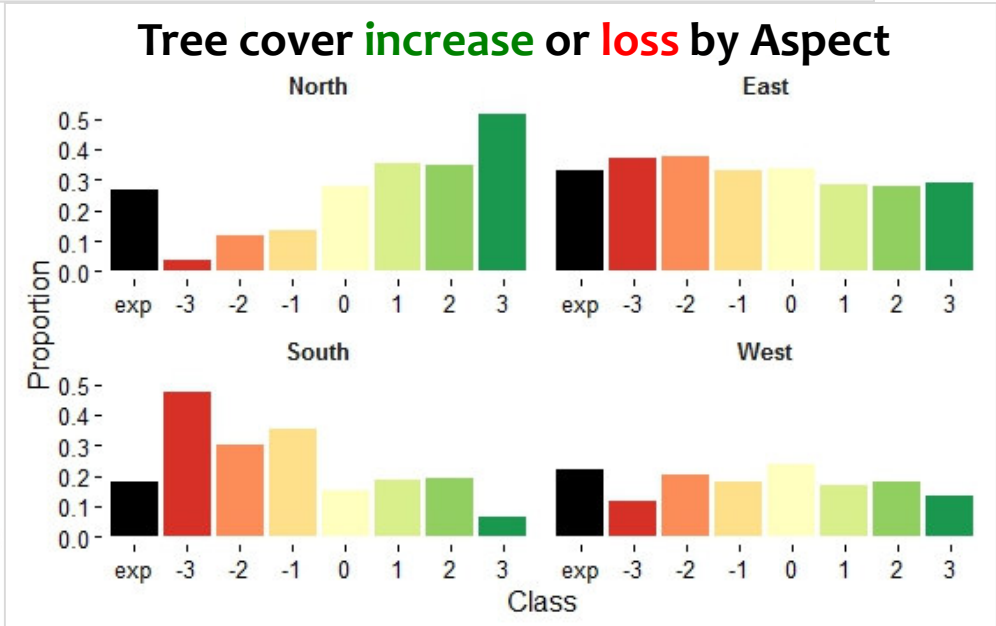

1916
2006
Δ 1914-2006
No Vegetation
Low Vegetation
Partial Canopy
Full Canopy
No Vegetation
Low Vegetation
Partial Canopy
Full Canopy
-3 | Max Disturbance
-2 | Med Disturbance
-1 | Min Disturbance
0 | No Change
1 | Min Succession
2 | Med Succession
3 | Max Succession
McCaffrey & Hopkinson, In Prep

Most pronounced changes



Credit: **Dave McCaffrey**



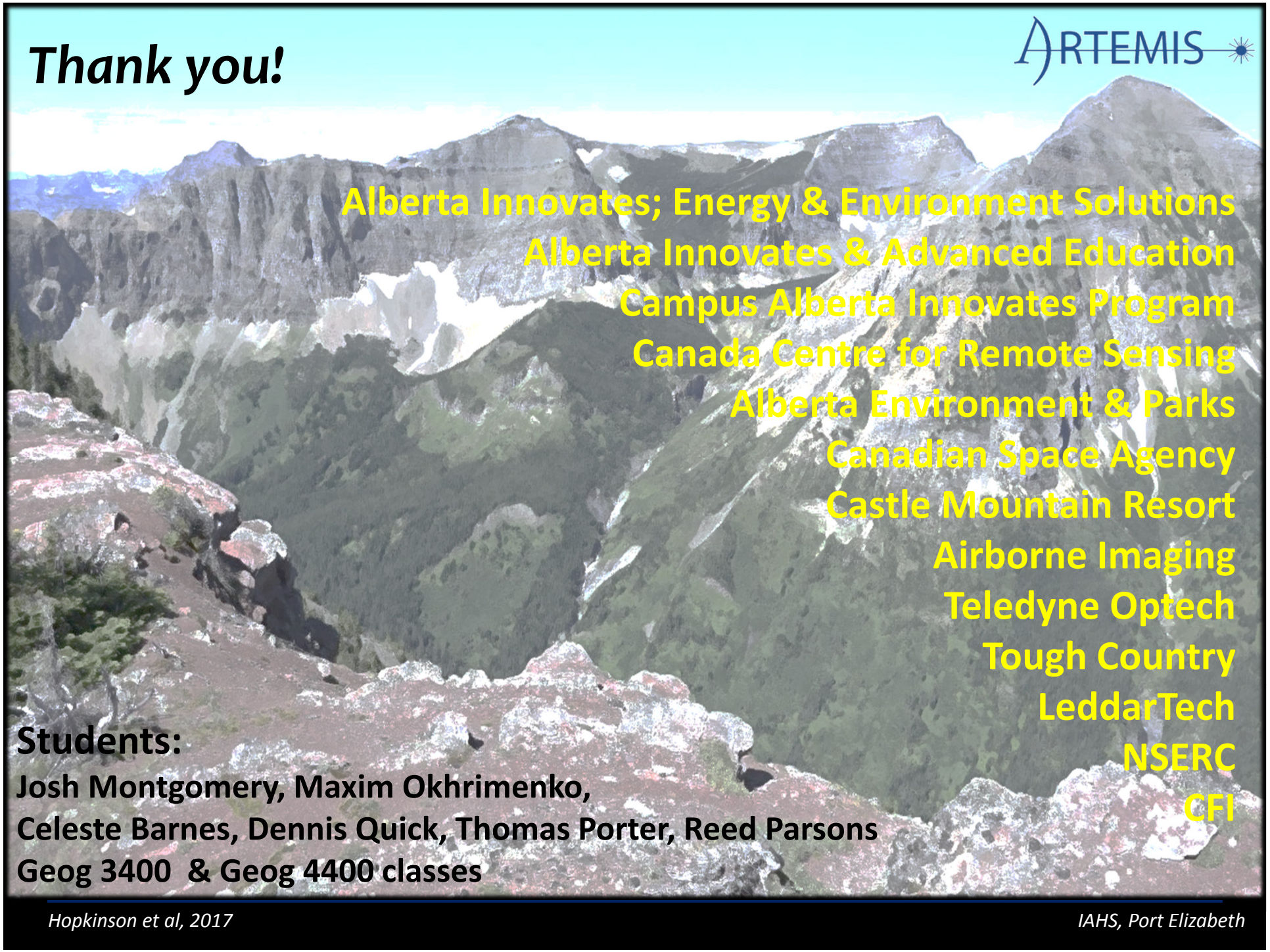


Summary

- Framework for cost-effective RS mountain water resource change & monitoring in development
- LEDDAR effective for snow & water level assessment
  - Some technical challenges
- Aerial LiDAR effective snow sampling tool
  - Random Forest effective depth spatialization method
  - North facing cirques disproportionate snow depth / duration
  - Mountain snow yield / melt dominated by treeline overall
- Castle treeline changed significantly in last century
  - Fire disturbance
  - Hydroclimatic changes
  - Advance on cooler moist slopes & recession on warm drier slopes
- SAR snow cover mapping promising but under-developed

ARTEMIS

Thank you!

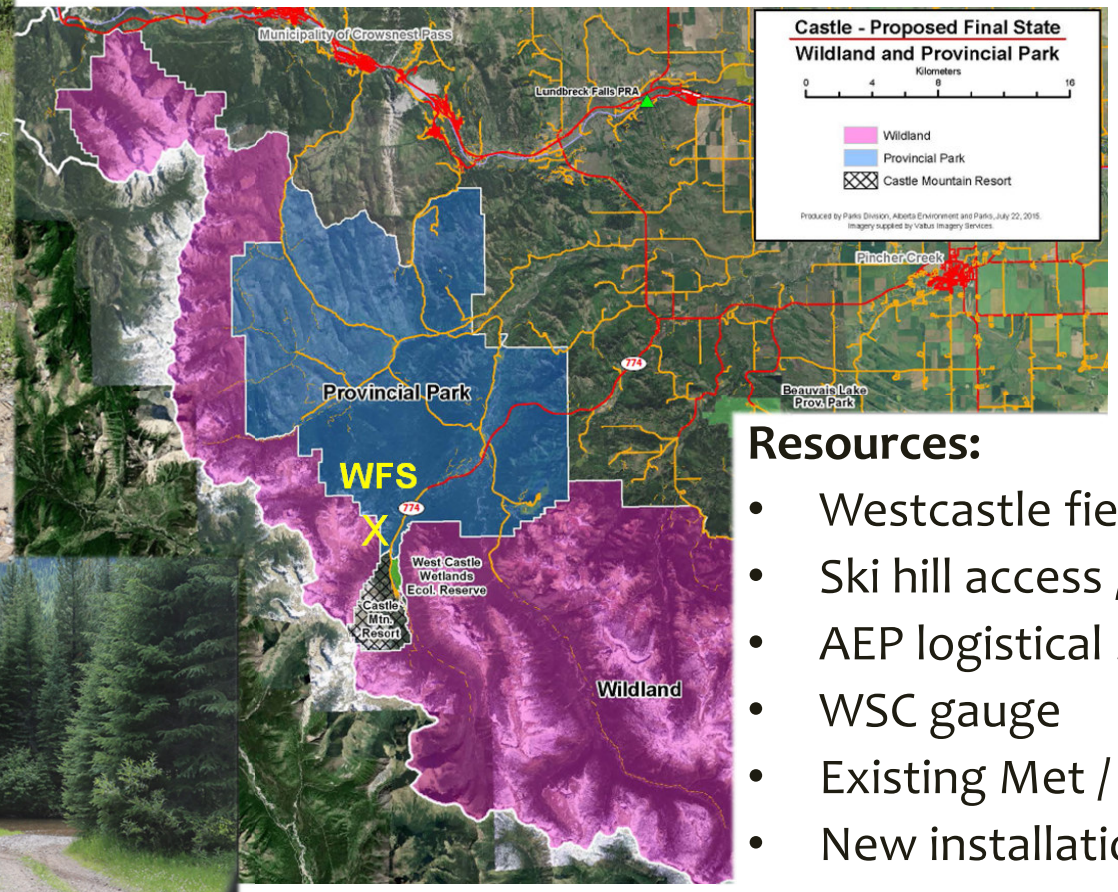


Alberta Innovates; Energy & Environment Solutions
Alberta Innovates & Advanced Education
Campus Alberta Innovates Program
Canada Centre for Remote Sensing
Alberta Environment & Parks
Canadian Space Agency
Castle Mountain Resort
Airborne Imaging
Teledyne Optech
Tough Country
LeddarTech
NSERC
CFI

Students:
Josh Montgomery, Maxim Okhrimenko,
Celeste Barnes, Dennis Quick, Thomas Porter, Reed Parsons
Geog 3400 & Geog 4400 classes

Castle Park area context

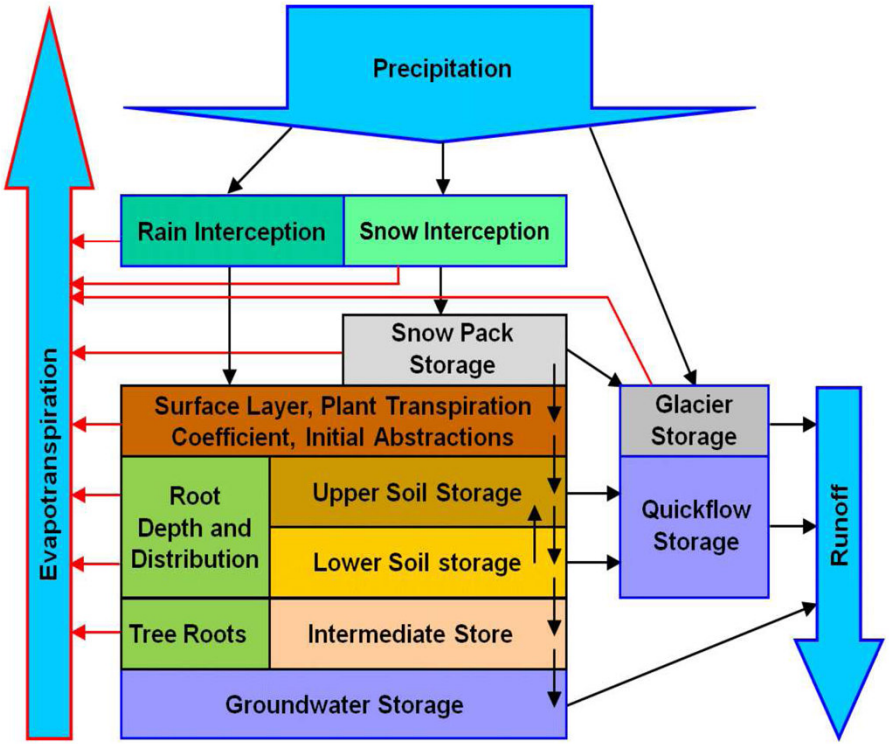
New Park & Wildland areas to mitigate anthropogenic disturbance, protect source water & habitat



Resources:

- Westcastle field station
- Ski hill access / support
- AEP logistical support
- WSC gauge
- Existing Met / Snow sites
- New installations

ACRU Model enhancement / implementation



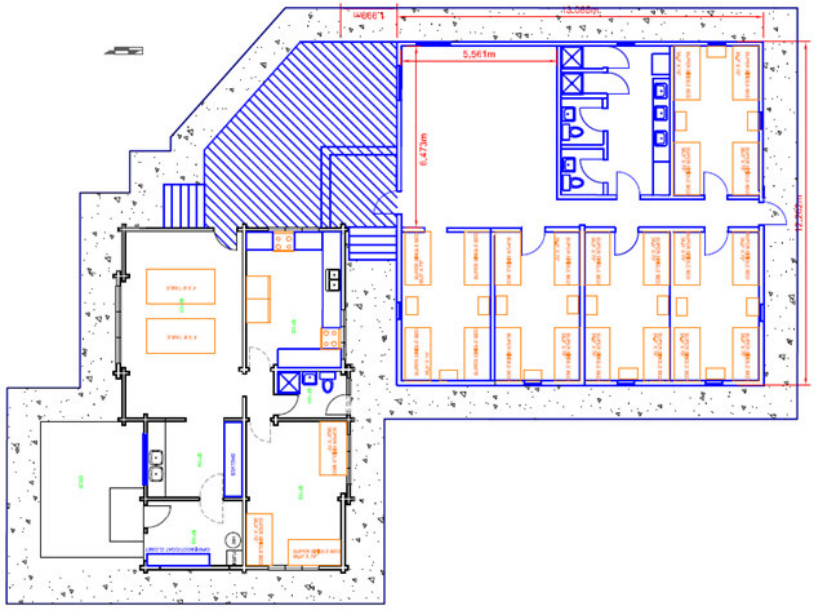
Castle modeling objectives

- Couple to GCM simulations
- Historical runoff reconstruction
- Future runoff prediction

Model spatialization needs

- Updated energy / mass params
- Snow pack data
- Headwater runoff data
- HRU surface geology / cover
- Past/future landcover change

Westcastle Field Station

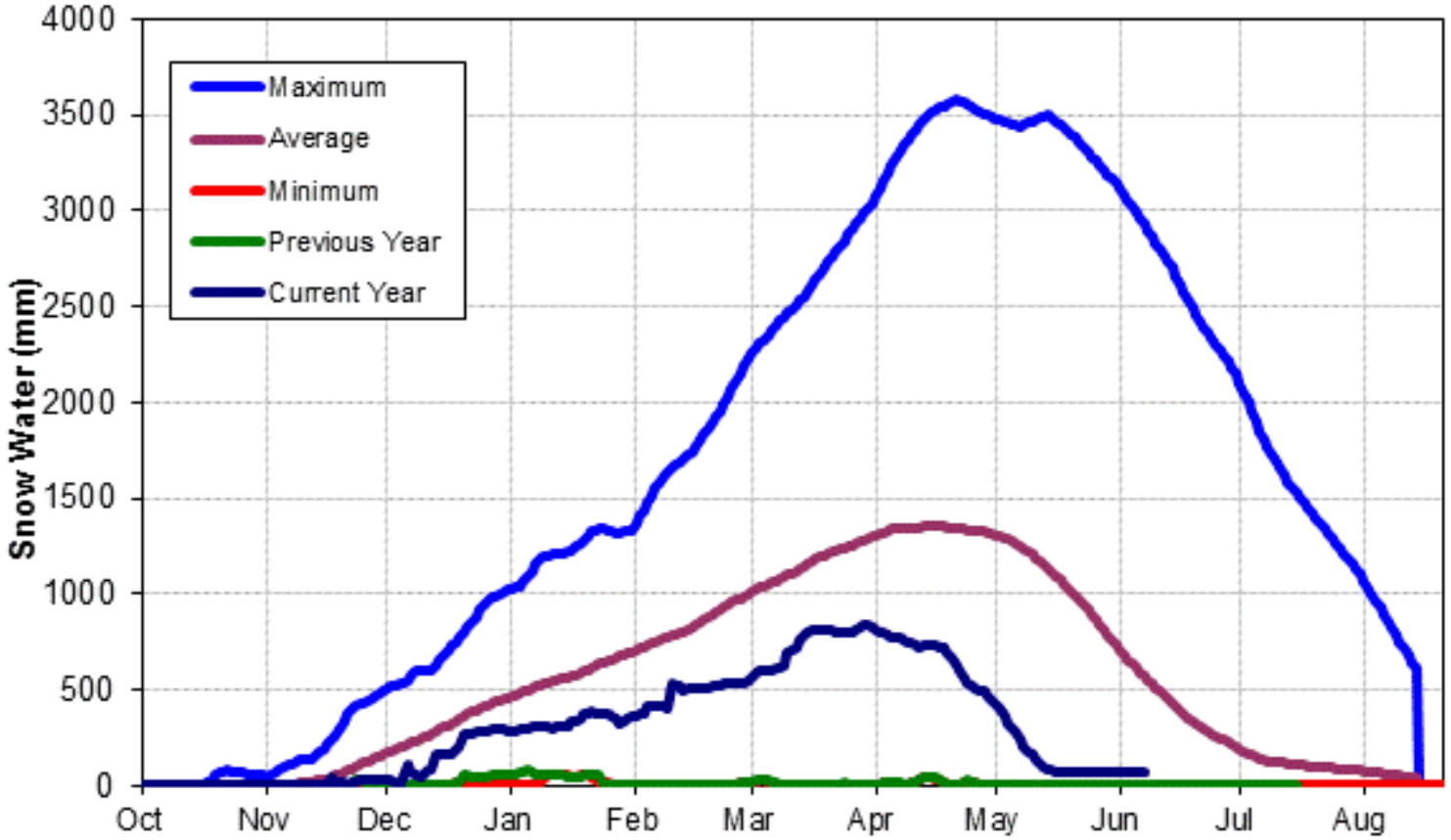


Hopkinson et al, 2016

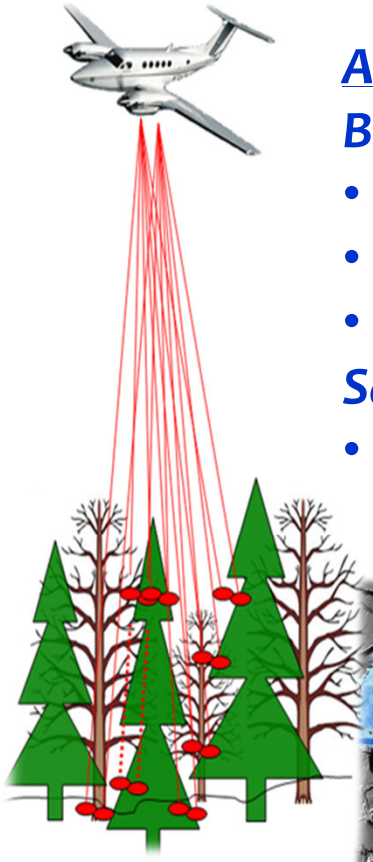
AIEES, Edmonton

Water resource & modeling constraint

Sparse sampling of pillows & snow course stns does not represent terrain population to be modeled



Active Remote Sensing data



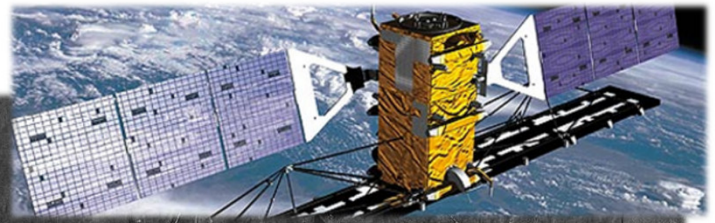
Airborne LiDAR

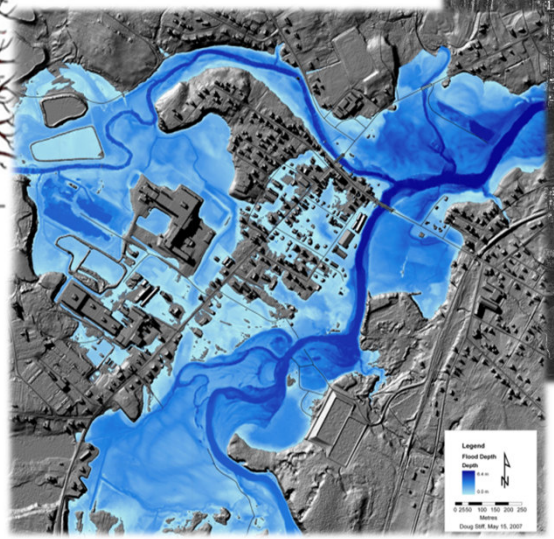
Baseline data:

- Terrain
- Vegetation
- Bathymetry

Sample data:

- Snow depth

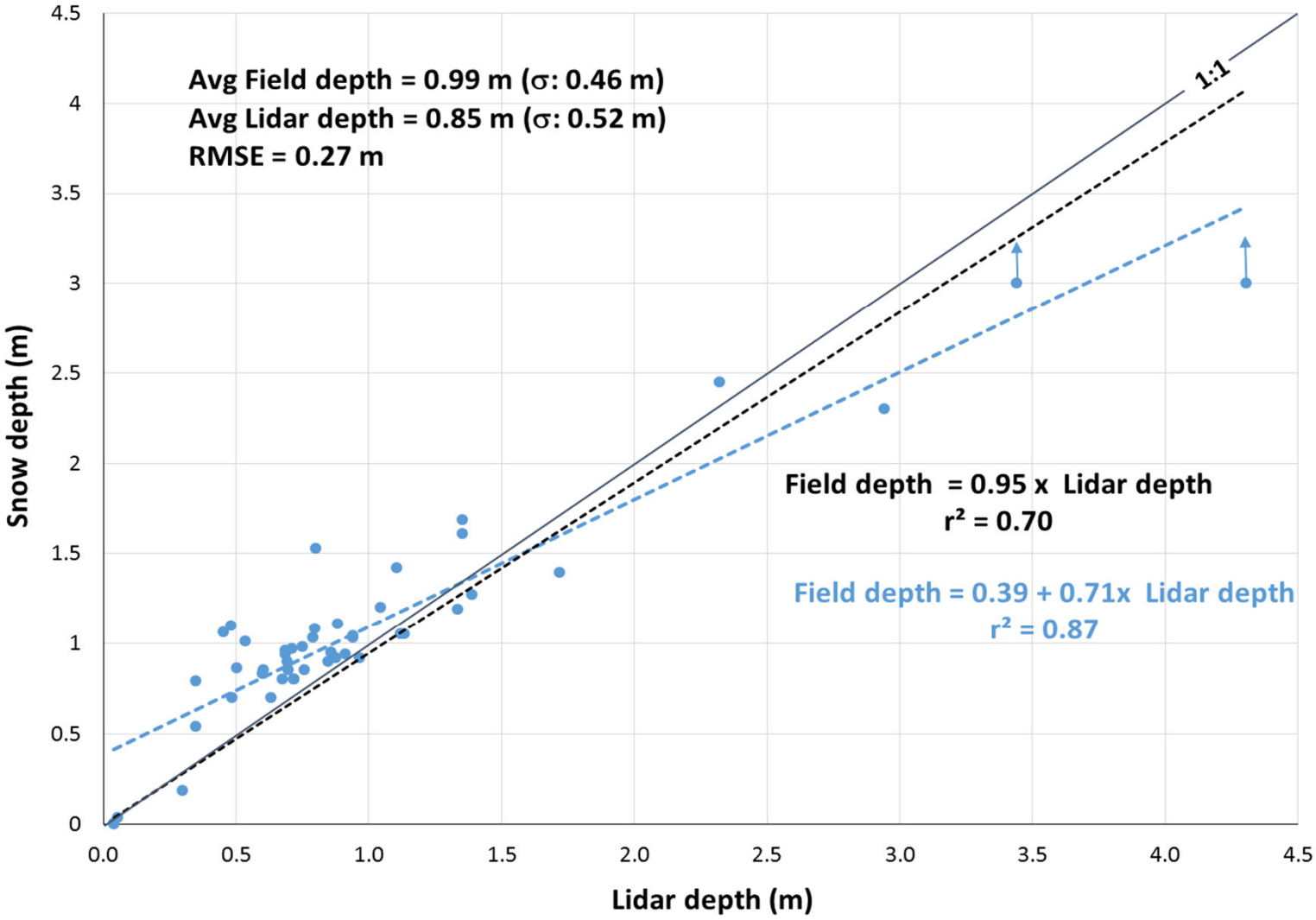


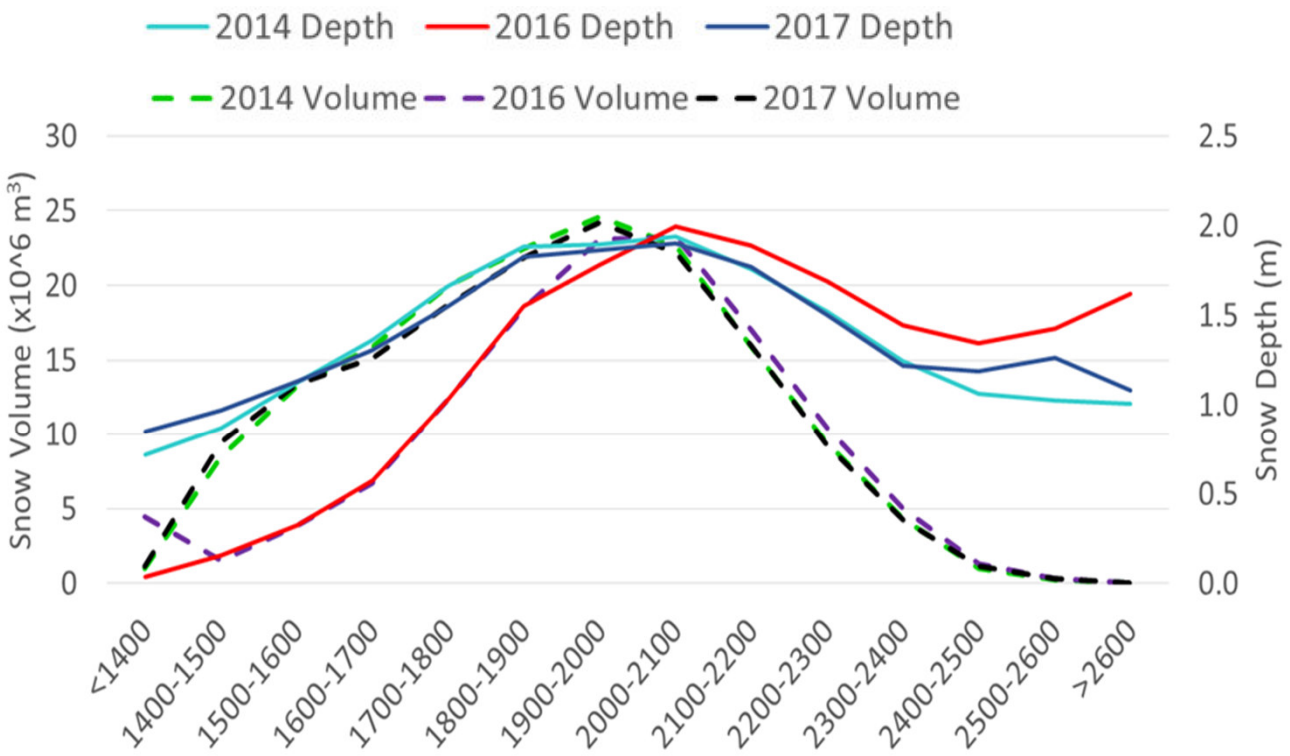


Radarsat II & Constellation Mission:

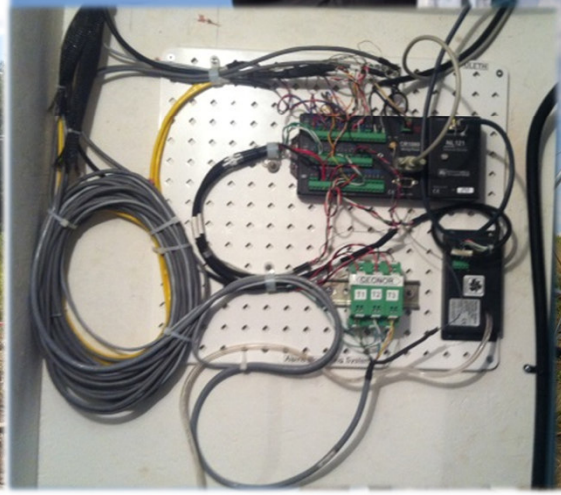
Monitor open water extent & snow cover

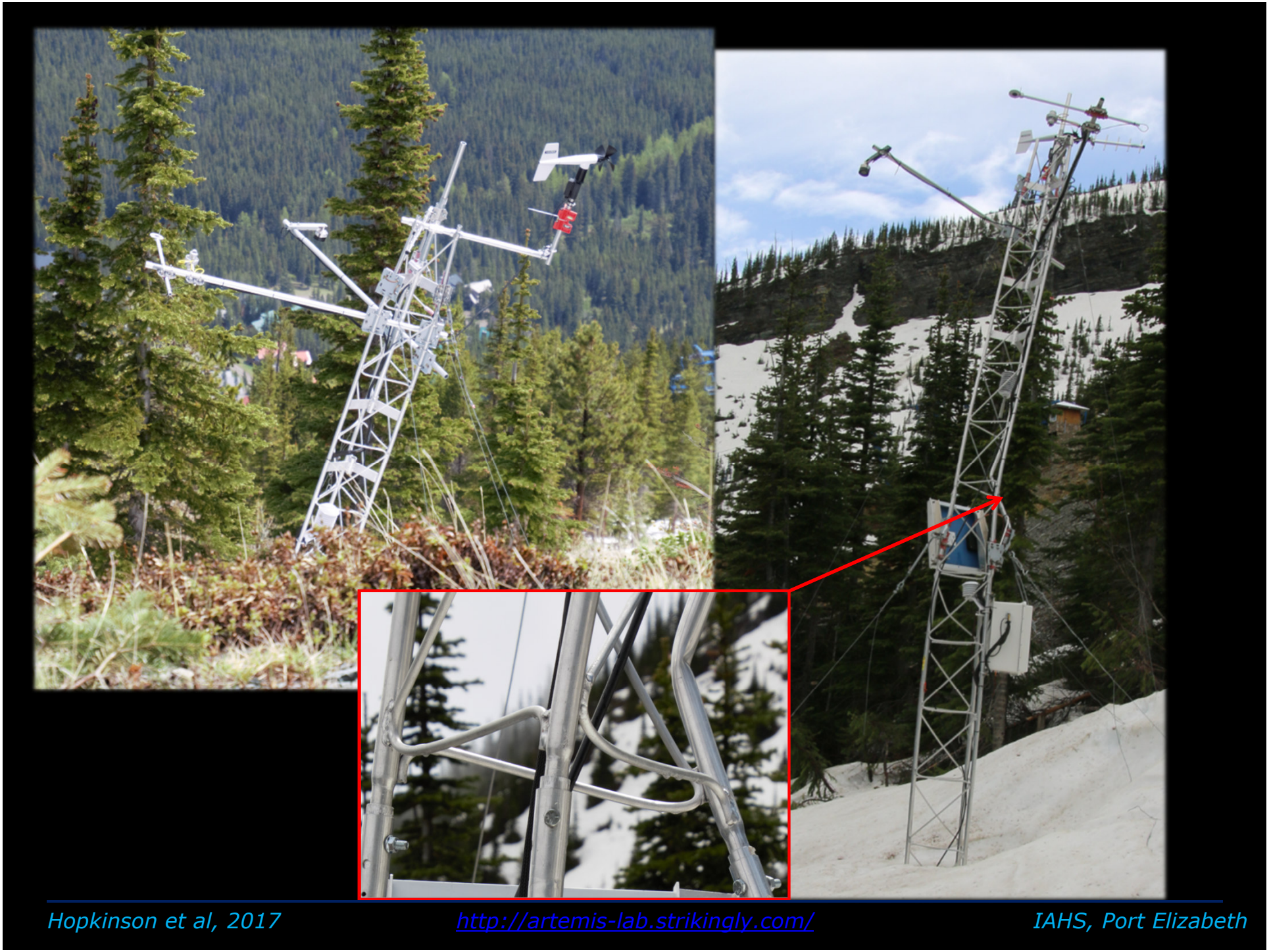
Limited error analysis around ski hill in 2014




2014 Depth
2016 Depth
2017 Depth
2014 Volume
2016 Volume
2017 Volume
Snow Volume (x10^6 m³)
Snow Depth (m)
30
25
20
15
10
5
0
2.5
2.0
1.5
1.0
0.5
0.0
<1400
1400-1500
1500-1600
1600-1700
1700-1800
1800-1900
1900-2000
2000-2100
2100-2200
2200-2300
2300-2400
2400-2500
2500-2600
>2600

Hydromet Installation & Repairs
Ski hill & Field stn



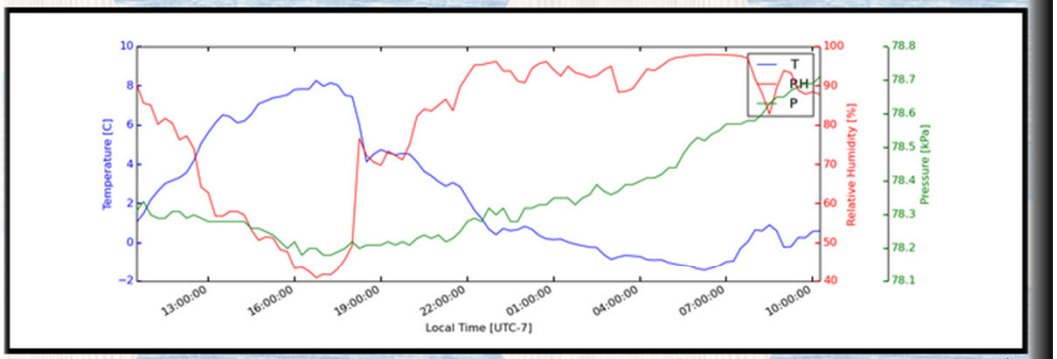


Real time Met data

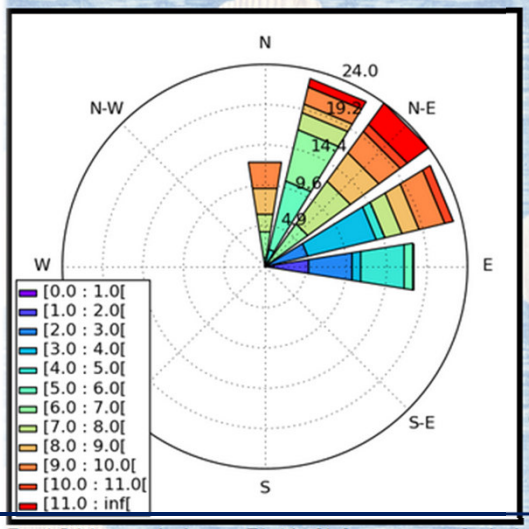
- 3 x EB towers
- 2 x RT telemetry

Ridge Current Weather Condition.

```
Current Condition:
NOW: 2016-05-30 10:40:17(MDT)
Update: 2016-05-30 10:15:00
Temperature:    0.606 °C
Windspeed:      4.934 m/s
Wind Direc.:    -- °
Humidity:       87.9 %
Pressure:       78.71 kPa
Snow Depth:  3.219066 m
Net Rad.:  320.4133 W/m2
Inc. SW:    80.01803 W/m2
Ref. SW:  41.53022 W/m2
Precipitation: 1251.489 GN!
```



Past 24 hour history graph of Temperature, Relative Humidity and Pressure. West Castle Ridge sta$

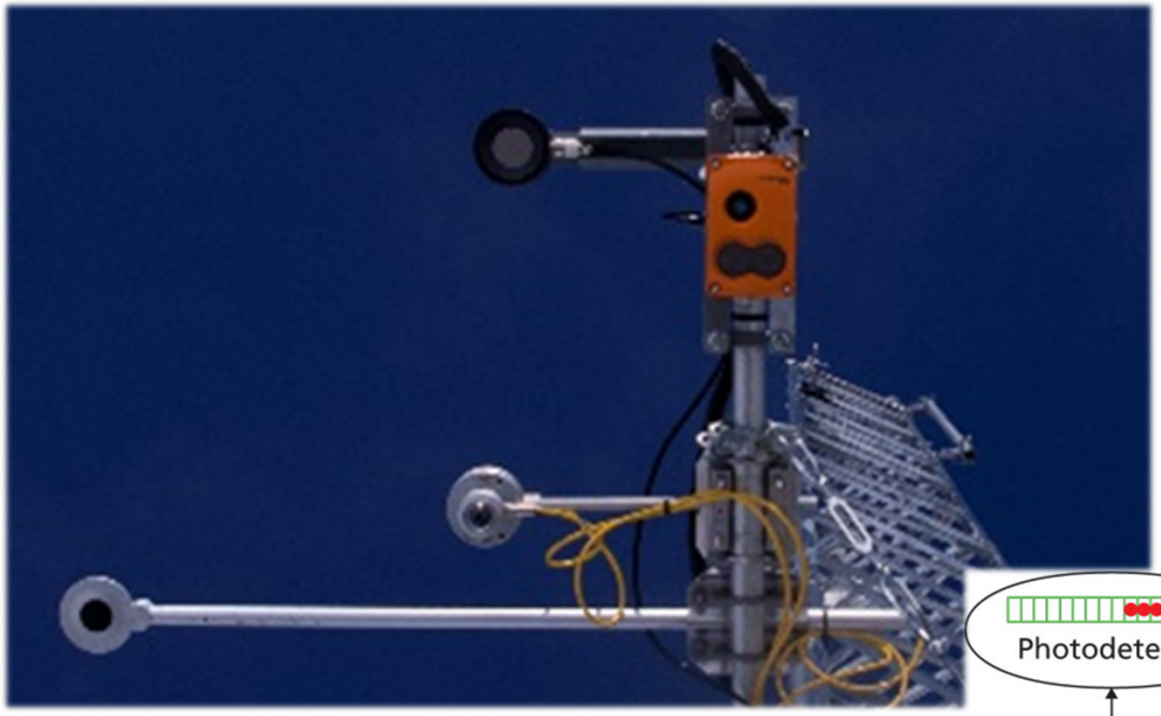


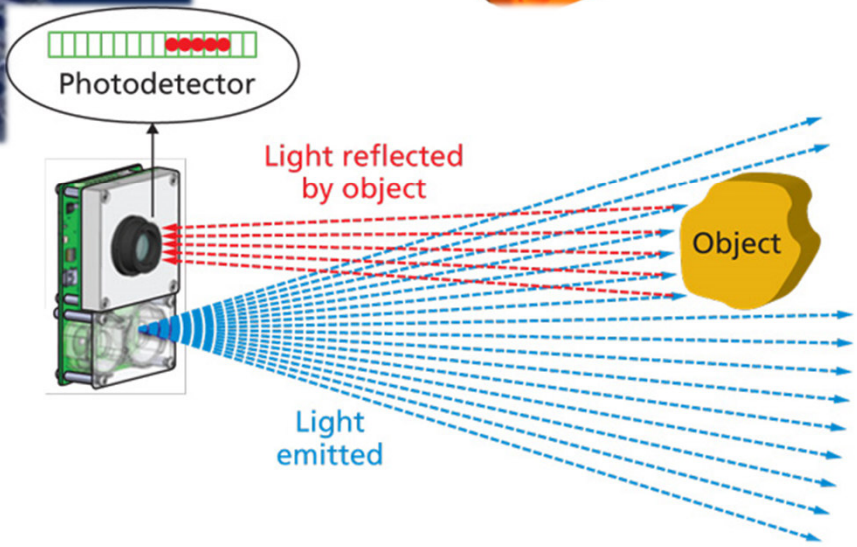
Past 24 hour windrose. Plot is % frequency of winds blowing from particular directions. legend is$

Hopkinson et al, 2017

Hardware development

LED Detection & Ranging - LEDDAR





LEDDAR water level & snow depth monitoring

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Alpine changes