Imaging the Cryosphere

What you should be working on

- Assignment 4 due March 16^{th}
- Assignment 5 due March 23^{rd}

Assignment 4 Office Hours

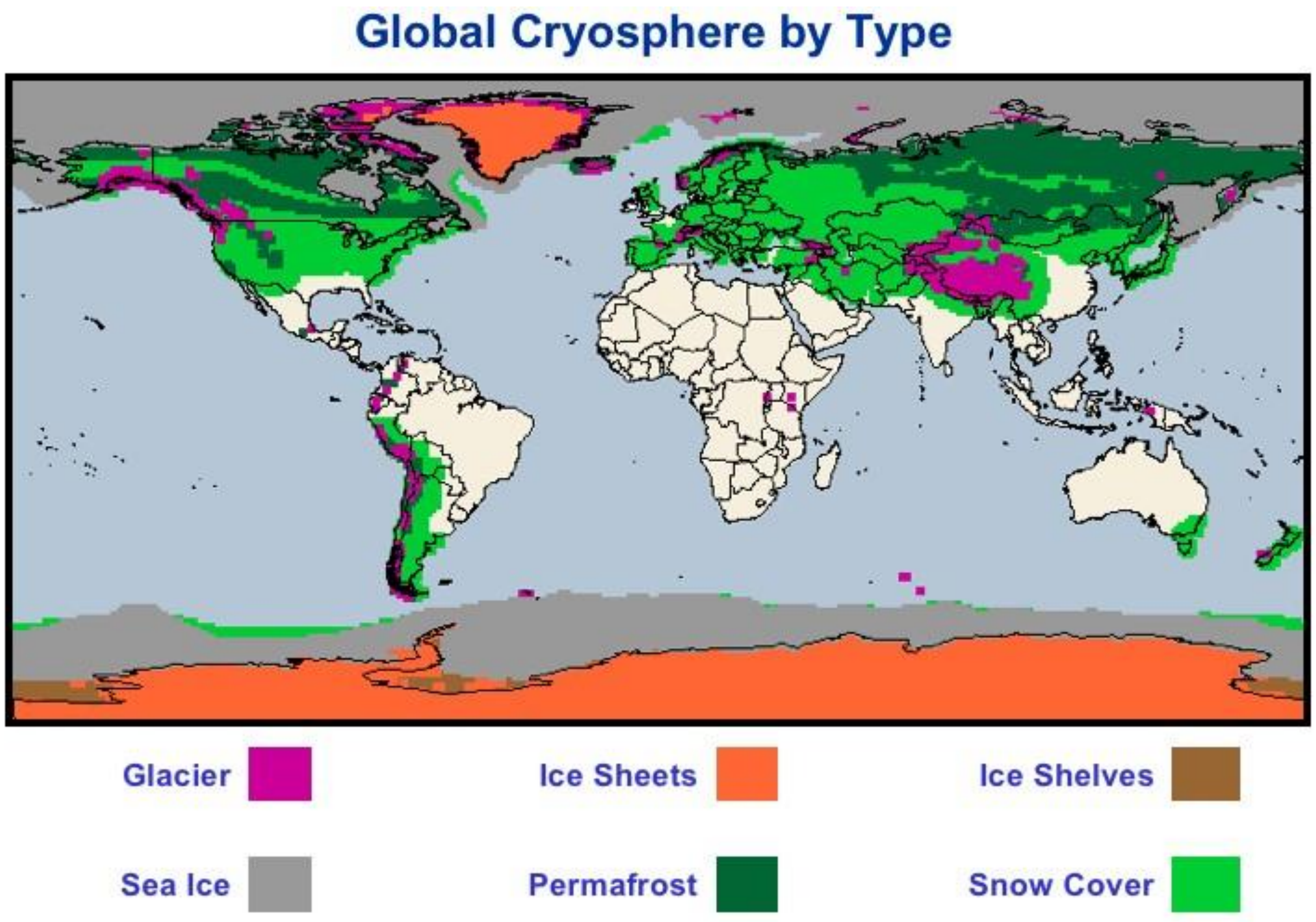
- ~~Tuesday, March 7th – 10:00am-11:00am~~
- ~~Thursday, March 9th – 2:00pm-3:00pm~~
- ~~Tuesday, March 14th – 10:00am-11:00am~~
- Thursday, March 16th – 2:00pm-3:00pm

Learning Objectives

- Cryosphere
  - What is it?
  - Why monitor it?
  - Historical monitoring
  - Remote sensing technologies used to monitor the cryosphere
  - Applications/examples

Cryosphere

- Portions of the Earth’s surface characterized by frozen water, including:
- Snow
- Ice
  - Ice sheets and ice shelves
  - Glaciers
  - Sea ice
- Permafrost



Why Monitor the Cryosphere?

- Very useful indicator of climate variability and change
  - Community impacts
  - Biodiversity impacts
- Weather and climate prediction
  - Storms
  - Transportation
- Significant freshwater storage
  - Water resource management
  - Ecosystem
  - Hydrology

Historical Monitoring of the Cryosphere

- Systematic annual measurements since the 1940's and 1950's provide powerful time series of changes in cryosphere conditions.
  - Glacial mass balance
  - Glacial extent
  - Sea-ice thickness

Table 1. Summary of Antarctic Peninsula aerial photography campaigns. FIDASE, Falkland Islands Dependencies Aerial Survey; TMA, Trimetrogon Antarctica; BAS, British Antarctic Survey; IfAG, Expedition Institut für Angewandte Geodäsie.

Year	Aerial Photography Type
1947	Ronne Antarctic Research Expedition (vertical and oblique)
1956–1957	FIDASE (vertical 1:27,000)
1964–1969	U.S. Navy TMA Trimetrogon (vertical 1:38,000 and oblique)
1972–1979, 1986, 1989, 1990–2002	British Royal Navy (vertical 1:12,000; 1:24,000)
1962, 1986, 1989–2005	BAS (vertical 1:20,000 to 1:30,000), some medium format vertical
1989	IfAG (vertical 1:70,000)

Pope, Allen, et al. "Open access data in polar and cryospheric remote sensing." *Remote Sensing* 6.7 (2014): 6183-6220.

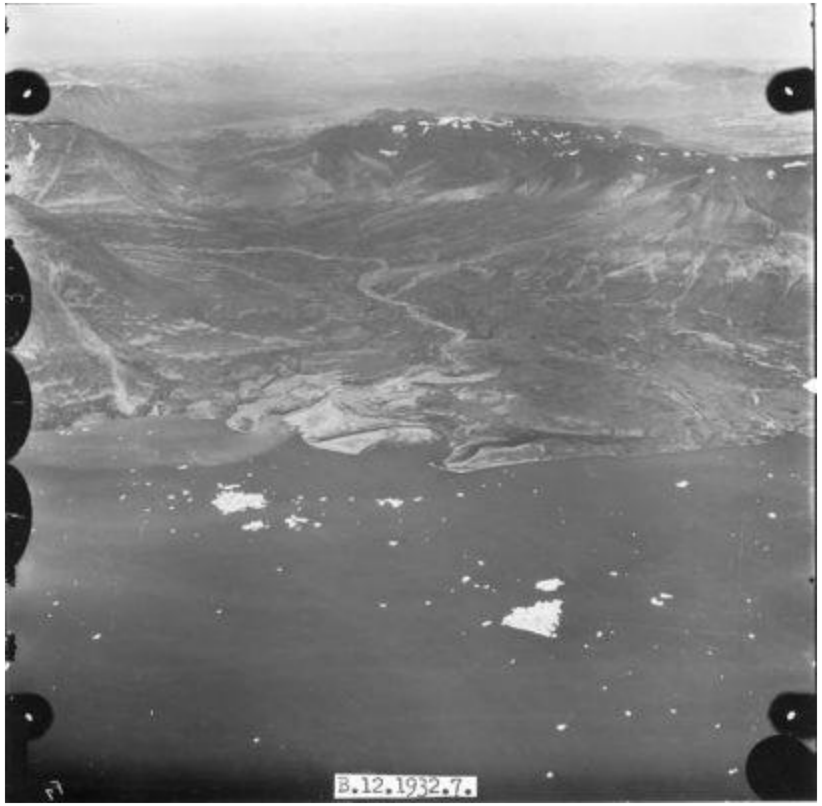
Table 2 Regional distribution of glacier areas, number of glaciers where mass balances are measured and the average length of series. Period of measurements 1946–95

Region	Glacier area (km^2)	No. glaciers	No. records (glacier-years)	Average length of series (years)
N. America (Arctic)	151 361	19	218	11
N. America (mainland)	115 184	66	506	8
S. America	32 494	3	9	3
Greenland (local glaciers)	70 000	3	13	4
Iceland	11 165	10	40	4
Svalbard	36 427	12	141	12
W. Europe (mainland)	6 454	69	1049	15
Africa	10	1	17	17
Arctic Eurasia	57 164	1	11	11
FSU + Asia	119 621	57	632	11
Oceania	823	1	6	6
Sub-Antarctic	4 912	1	3	3
Antarctic (local glaciers)	70 000	3	12	4
Total	675 614	246	2657	

Source: glaciers areas synthesized by the author from Meier (1984), Haeberli *et al.* (1988), Oerlemans (1993), Dyurgerov and Meier (1997) and the (1° × 1°) global glaciology from GGHYDRO 2.2 (Cogley, 1998)

Braithwaite, Roger J. "Glacier mass balance: the first 50 years of international monitoring." *Progress in Physical Geography* 26.1 (2002): 76-95.

Aerial Photography



https://blogs.egu.eu/divisions/cr/2016/05/27/image-of-the-week-historical-aerial-imagery-of-greenland/

https://phys.org/news/2017-02-aerial-photos-glacier.html

https://blogs.egu.eu/divisions/cr/2016/05/27/image-of-the-week-historical-aerial-imagery-of-greenland/

Repeat (Terrestrial) Photography

Figure 8. Repeat photography of the Muldrow Glacier in Denali National Park and Preserve. Photo: G.W. Adema, Denali National Park and Preserve, 2004.

Figure 6. Glacier in the Teklanika River Valley in Denali National Park and Preserve, Alaska in 1919. Photo: S.R. Capps, U.S. Geological Survey, 1919.

Figure 7. Glacier in the Teklanika River Valley in Denali National Park and Preserve, Alaska in 2004. Photo: R.D. Karpilo Jr., 2004.

Field Work (on the ground)

https://www.usgs.gov/media/images/usgs-staff-dig-snowpits-evaluate-snow-structure

https://www.icimod.org/understanding-the-mass-balance-of-yala-glacier/

Earth Observation Data for the Cryosphere

Monitoring the Cryosphere from Space

- Earth observation datasets used include:
  - Landsat
    - Fine/moderate spatial resolution
    - Data back to the 70s & 80s
    - Passive (provide spectral information)
  - MODIS
    - Fine temporal resolution
    - Applicable for imaging larger areas
    - Passive (provide spectral information)
  - RADAR (RADARSAT & airborne/terrestrial RADAR)
    - All weather system
    - Uses microwaves
    - Surface penetrating
  - Lidar (IceSat & airborne Lidar)
    - Elevation
    - 3D information on topography

Brainstorm: What do you think

- What characteristics of the cryosphere could we measure monitor with earth observation data?
- Which earth observation dataset might be most applicable for measuring that characteristic?
  - Landsat
  - MODIS
  - Lidar (IceSat & airborne Lidar)
  - RADAR (RADARSAT & airborne/terrestrial RADAR)

Monitoring the Cryosphere from Space

- Characteristics of the Cryosphere measured include snow/ice:
    - Cover
    - Extent
    - Depth
    - Type
    - Age
    - Movement
- Earth observation datasets used include:
    - Landsat
    - MODIS
    - Lidar (IceSat & airborne Lidar)
    - RADAR (RADARSAT & airborne/terrestrial RADAR)

Spectral Datasets (Landsat & MODIS)

- Why do glaciers have lower reflectance than fresh snow?

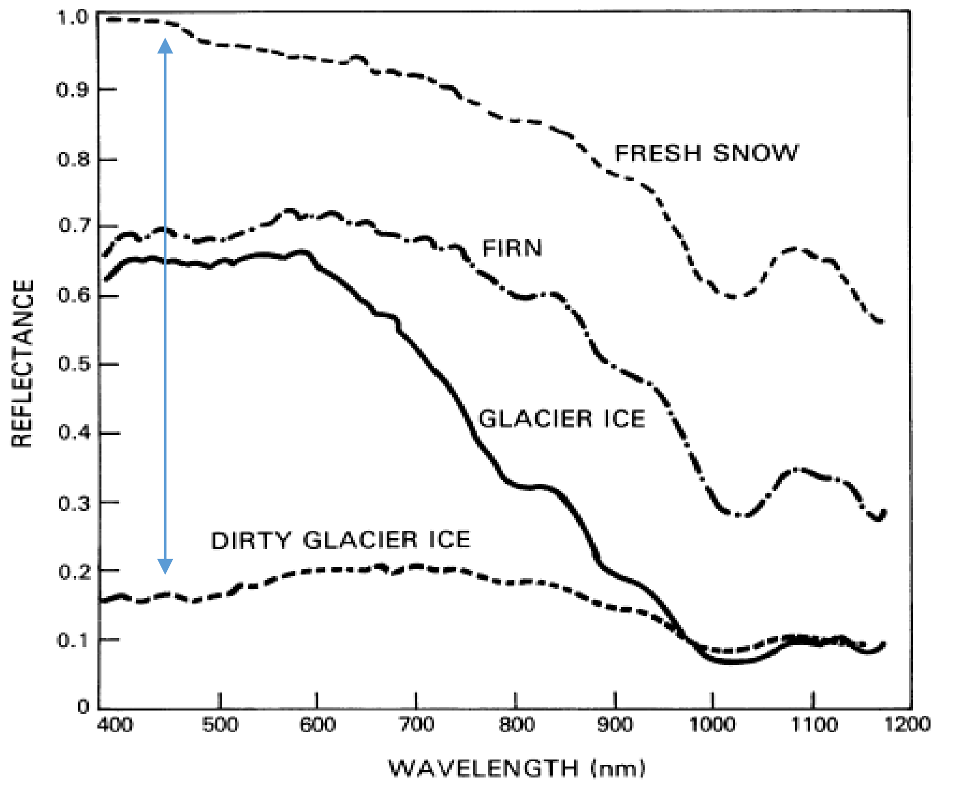
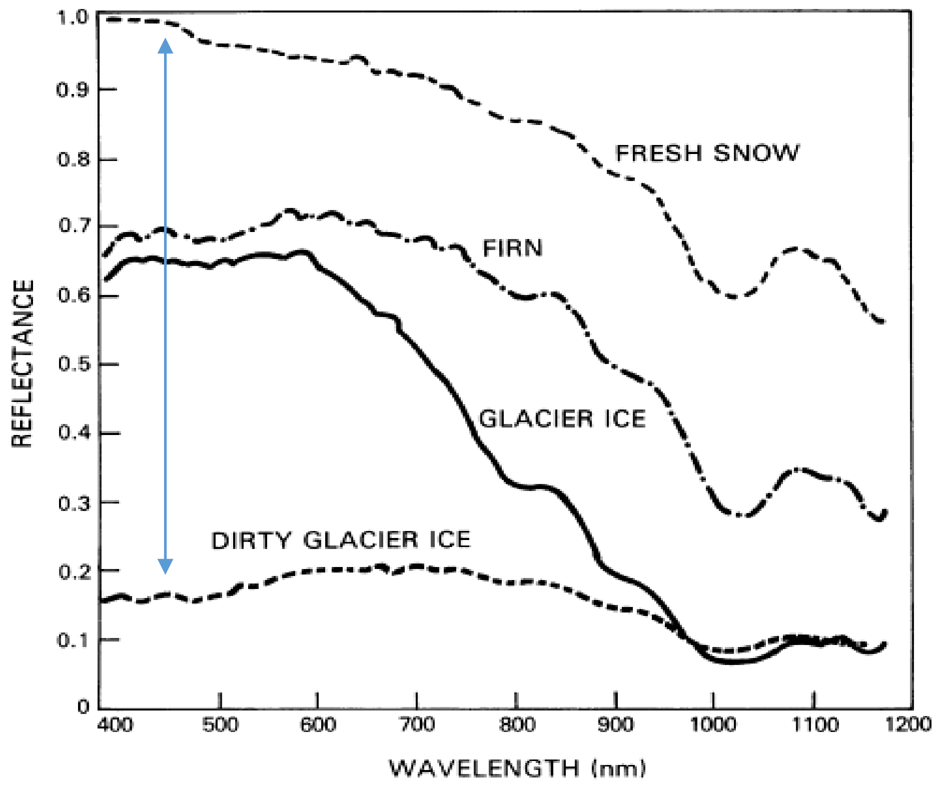


Fig. 1.4 Spectral reflectance curves for fresh snow, firn, glacier ice and dirty glacier ice. Note the extreme variability in the reflectance of ice and snow features (adapted from Qunzhu *et al.*, 1984).

Hall, Dorothy. *Remote sensing of ice and snow*. Springer Science & Business Media, 2012.

- Why do glaciers have lower reflectance than fresh snow?
  - Impurities and debris cover
  - Higher degree of surface roughness



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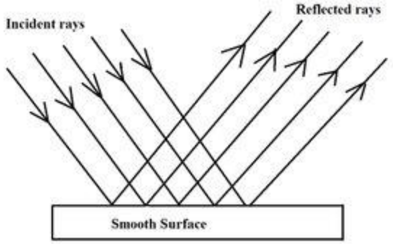
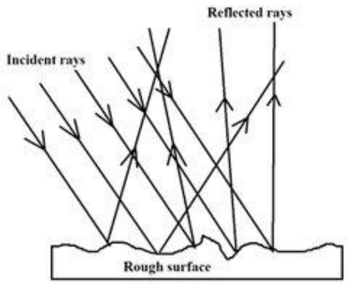
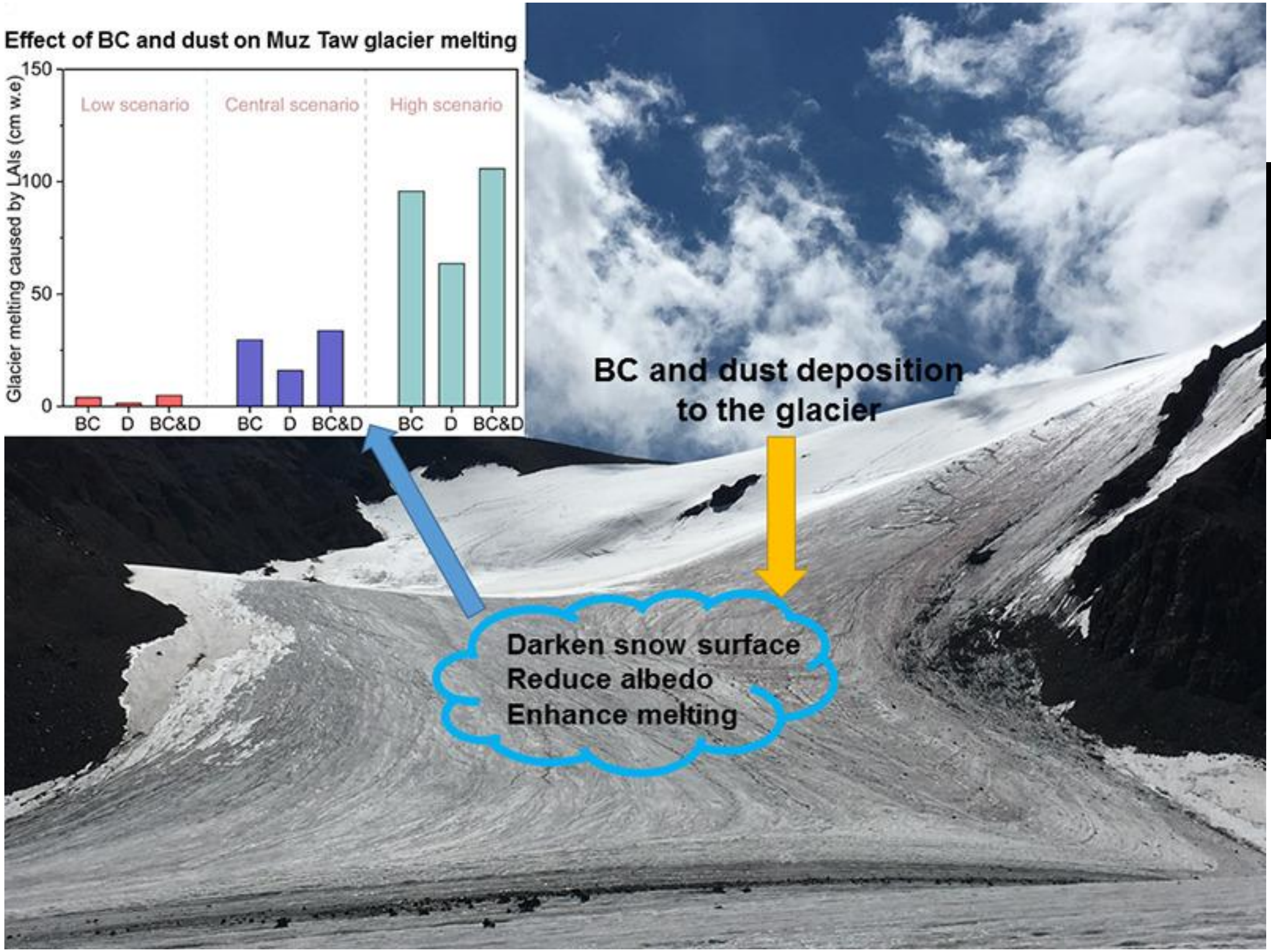


I. Regular Reflection

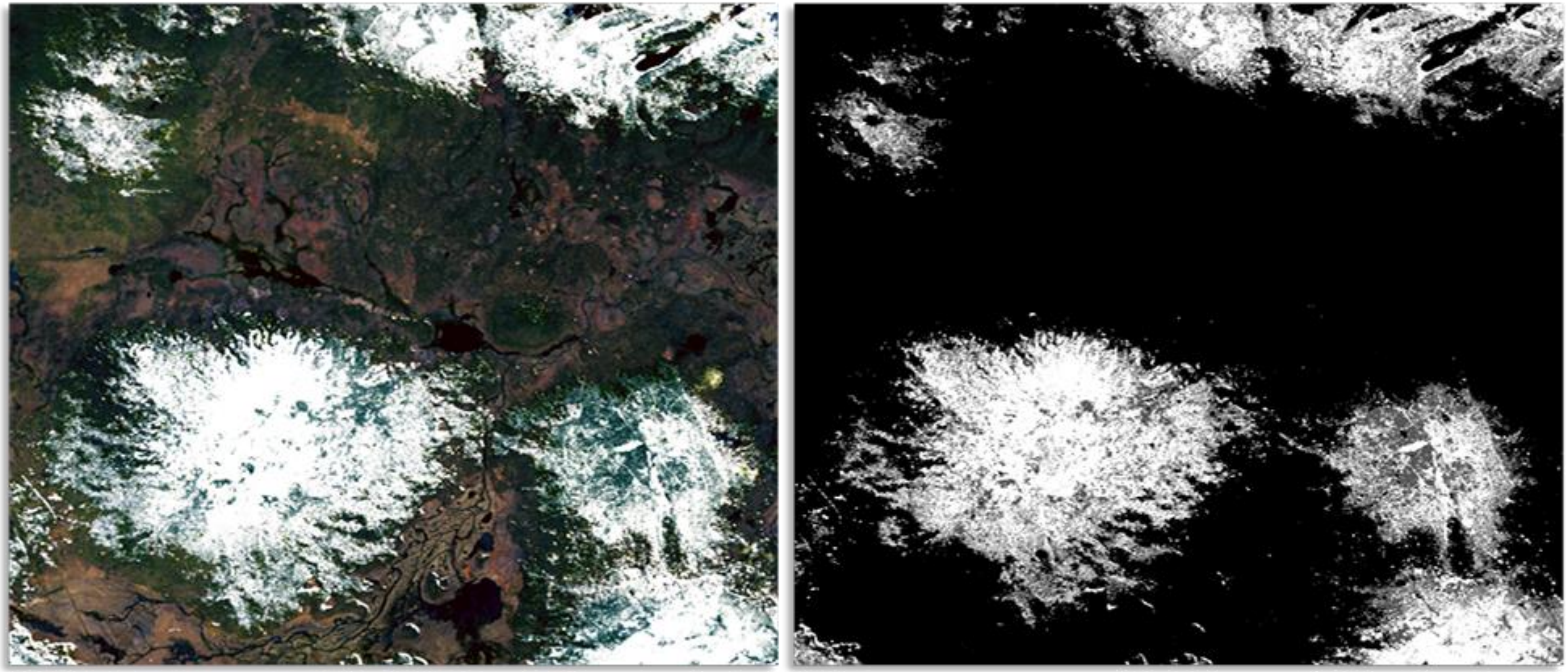


II. Irregular Reflection

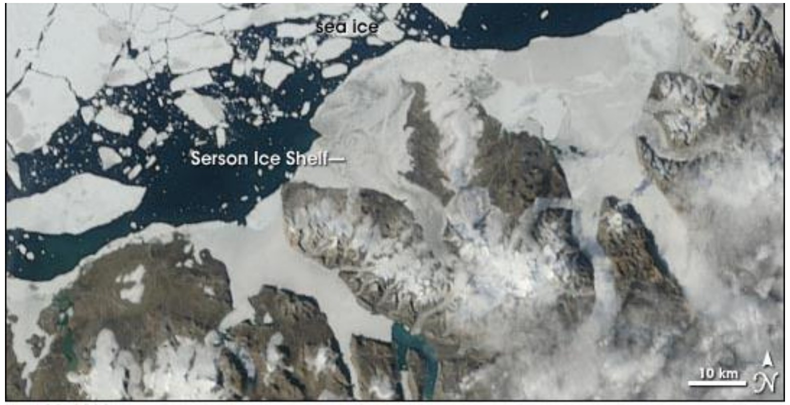


Zhang et al. 2020

Landsat



MODIS

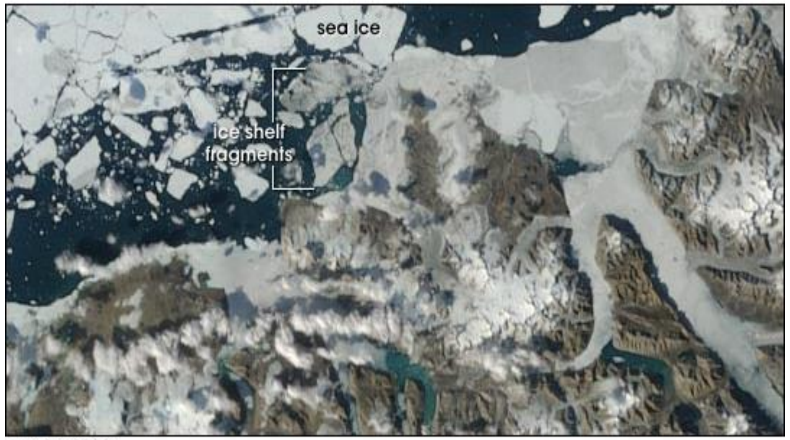


July 28, 2008

NASA


July 29, 2008

NASA

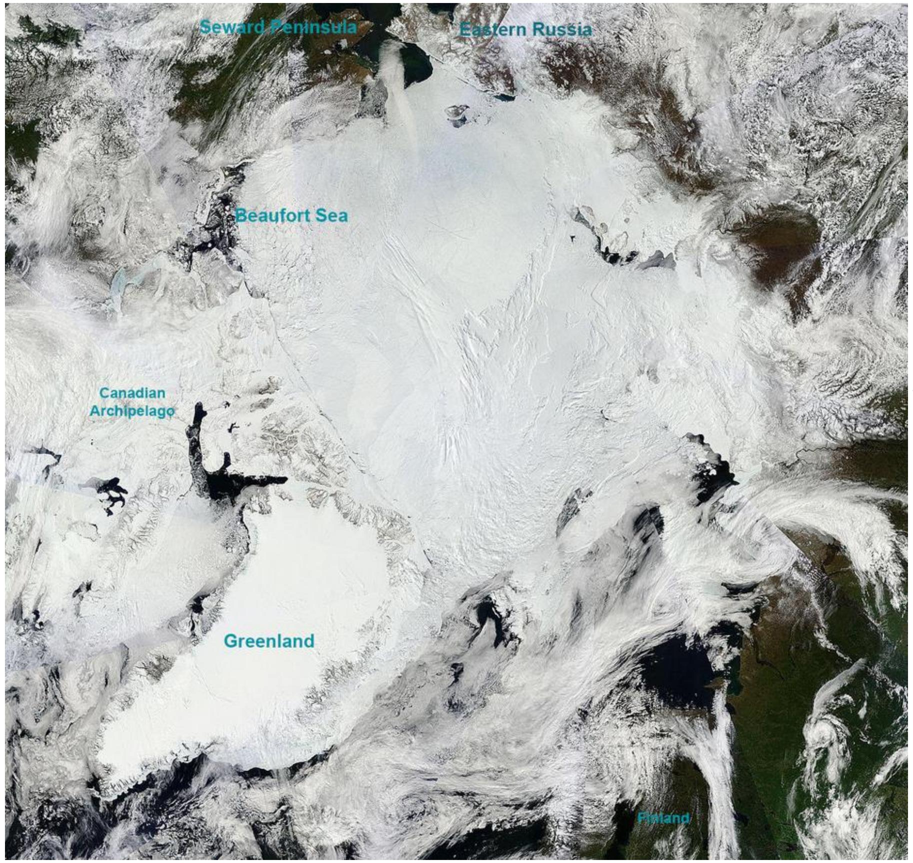


July 31, 2008

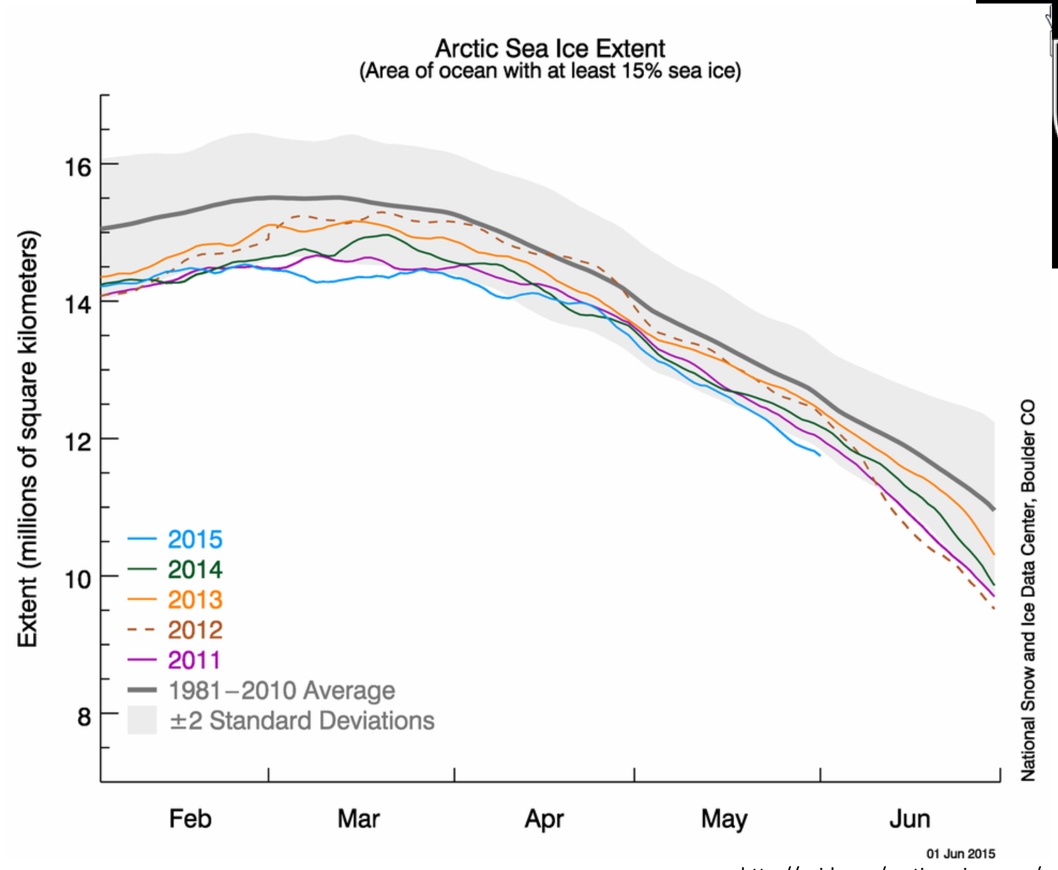
NASA

NASA's Terra satellite - rapid break up of the Serson Ice Shelf between July 28 and July 31 2008.

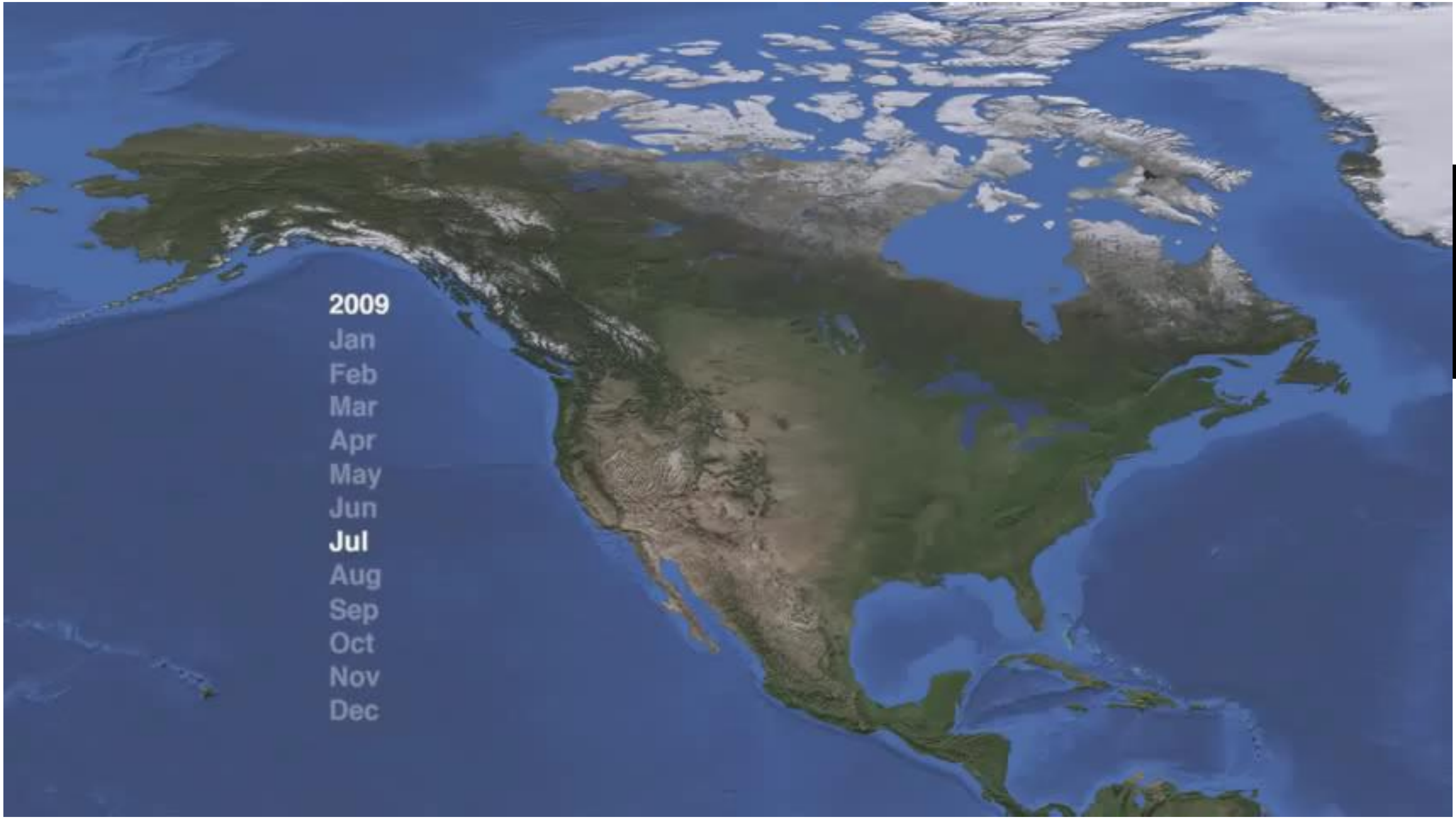
MODIS - Time Series



Land Atmosphere Near-Real Time Capability for EOS (LANCE) System, NASA/GSFC



http://nsidc.org/arcticseaicenews/



Cryosphere

RADARSAT

- Estimation of snow mass
  - Backscatter
- Ice cover
  - Backscatter
- Permafrost
  - Ranging
  - Quantify soil stability
  - Important for northern communities
- Ice flow mapping
  - Backscatter and ranging

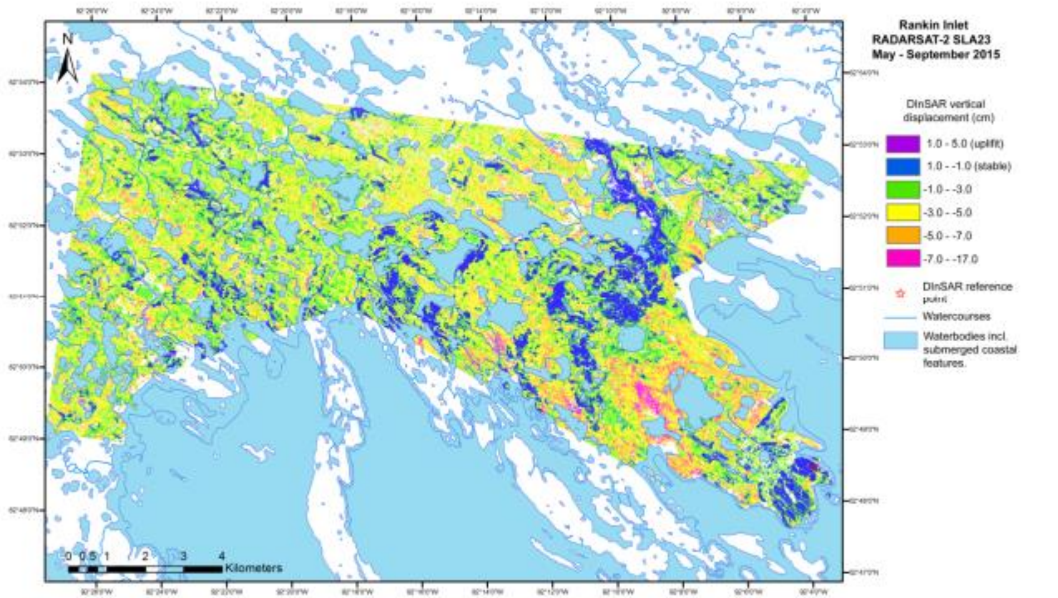


Figure 9. RADARSAT-2 Spotlight 23 DInSAR derived displacement for Rankin Inlet, summer 2015. Bedrock area near the community was used as the DInSAR reference point.

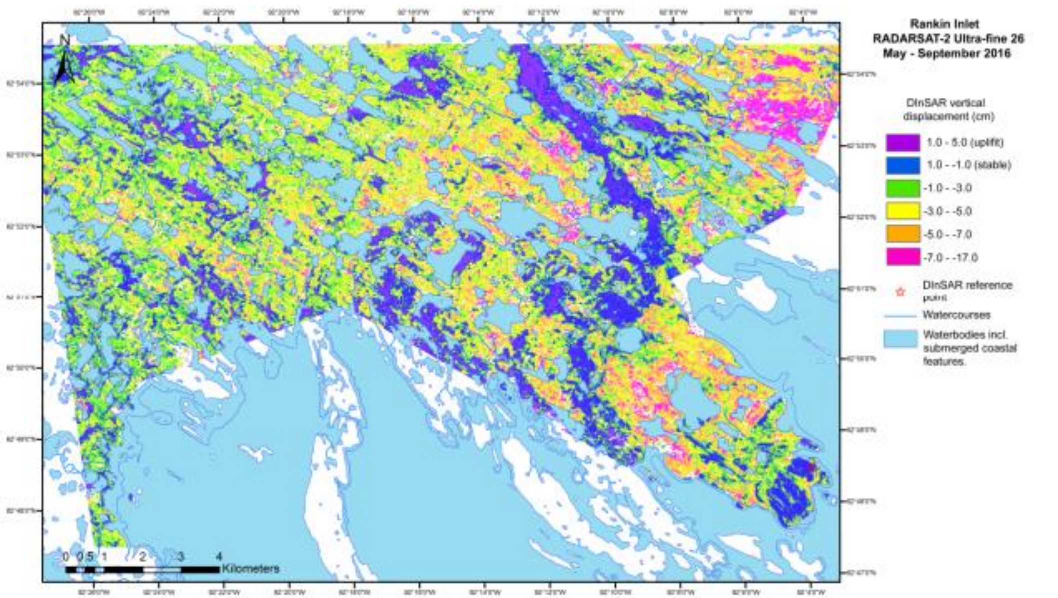
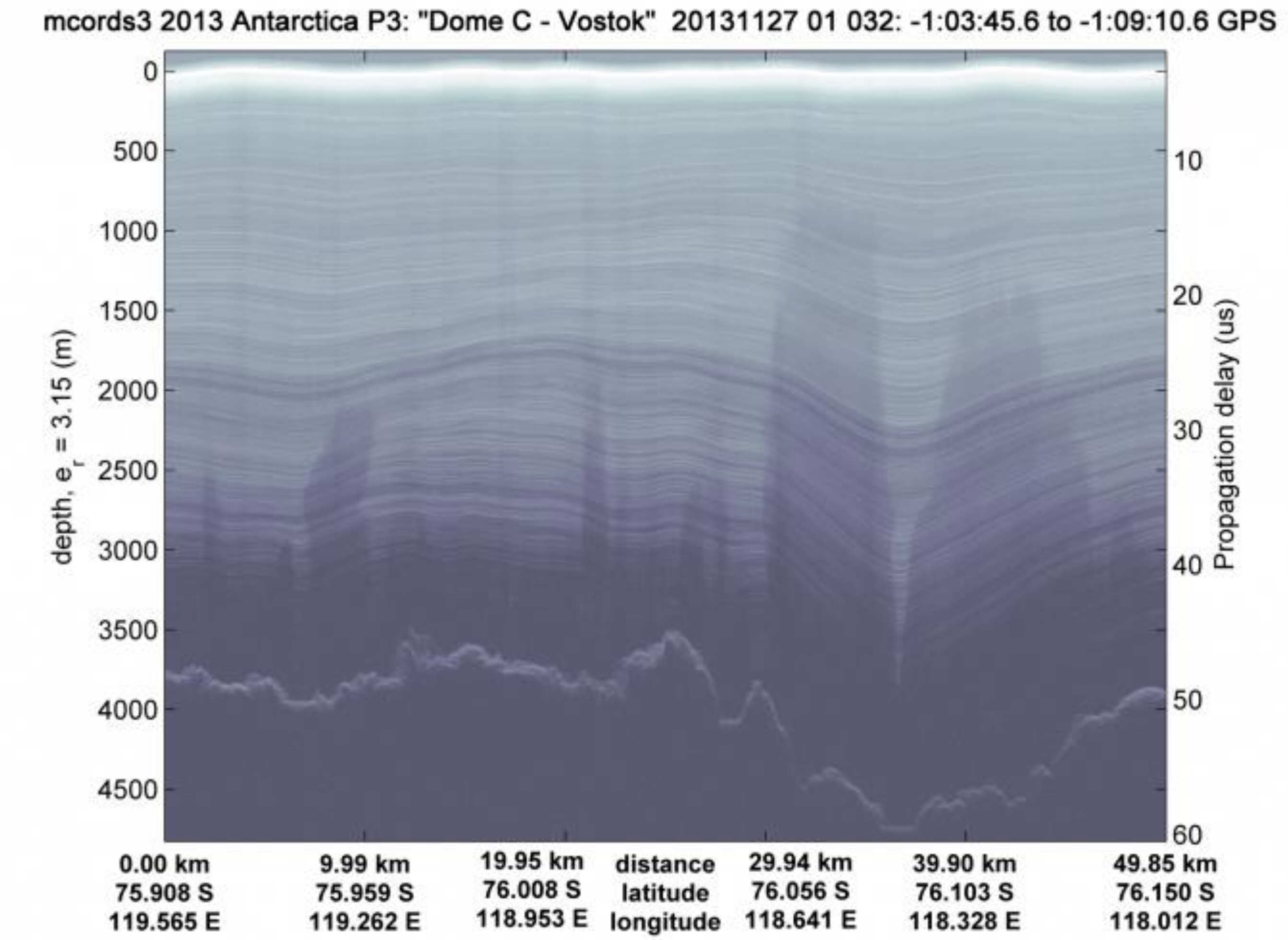


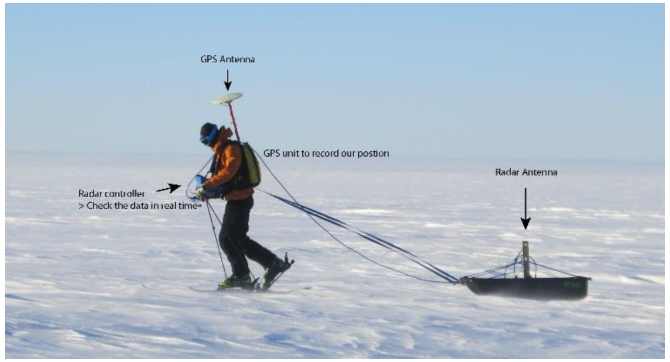
Figure 10. RADARSAT-2 Ultra-fine 26 DInSAR derived displacement in the Rankin Inlet region from summer 2016.

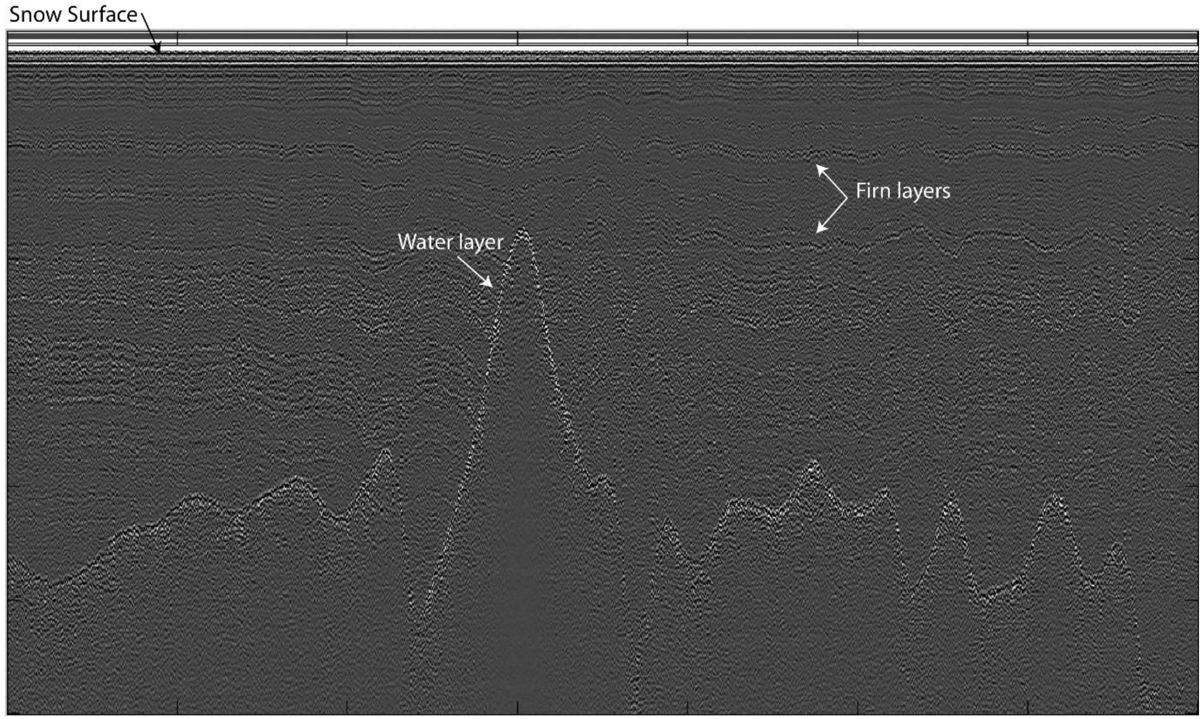
Airborne & Terrestrial RADAR

Ice Penetrating RADAR



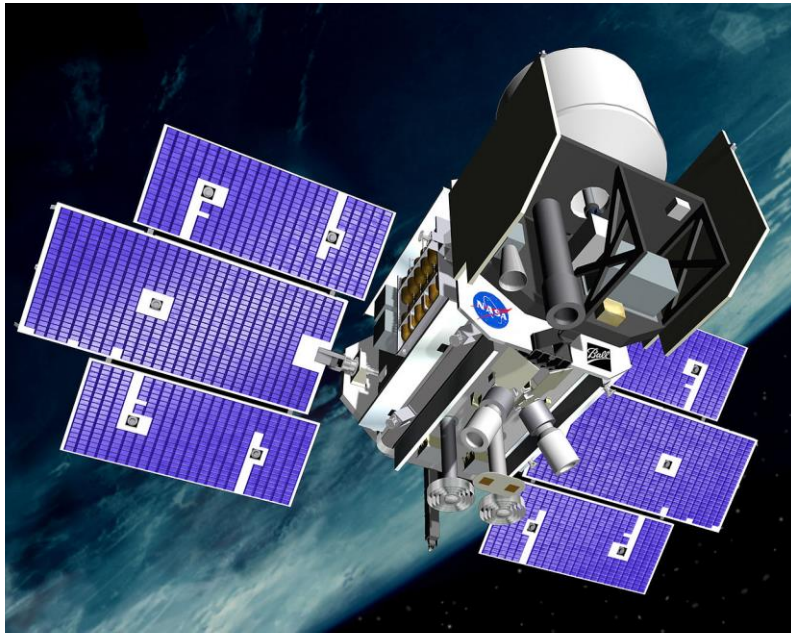
Ice Penetrating RADAR



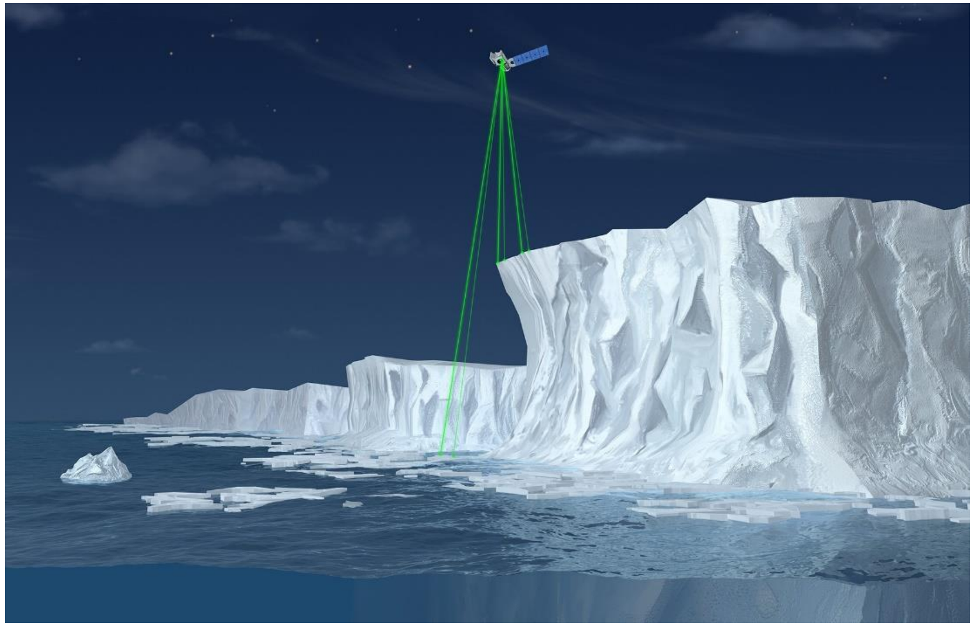


Lidar

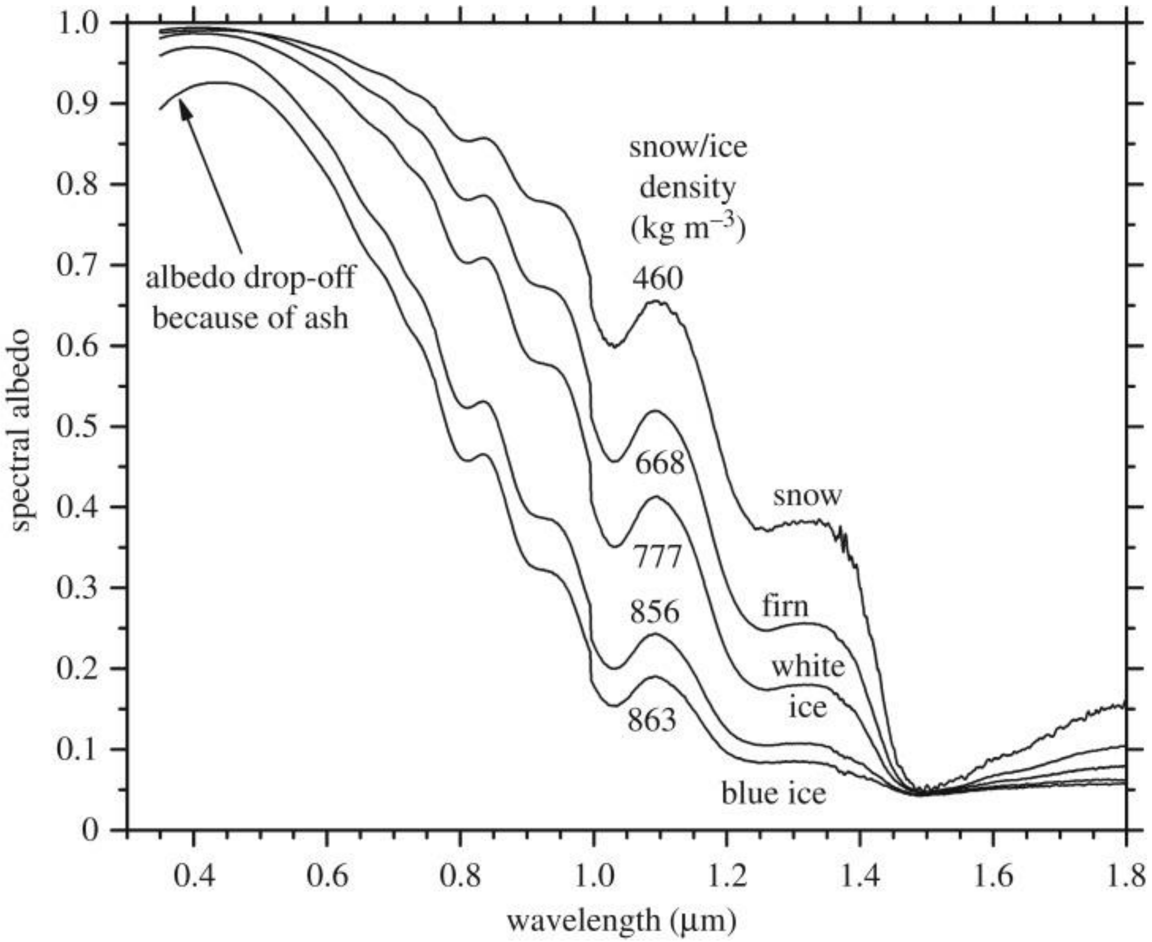
- Airborne Lidar
  - High resolution 3D information
- IceSat
  - Spaceborne Lidar
  - Launched for monitoring cryosphere
  - Also measures clouds and elevation
  - IceSat-1 operated from 2003 – 2009
  - IceSat-2 was launched in 2018
    - Uses visible green laser pulses
    - 532nm



ICESat. Credit: NASA/Ball Aerospace - http://www.csr.utexas.edu/glas/ (image link)



Why might IceSat use green light?



Advantages of Earth Observation Data for Cryosphere

Depending on the dataset:

- Standardized data
- Efficient collection
- Coverage (in space)
- Resolutions
  - Spatial
  - Temporal
  - Spectral

Seeing a pattern yet?

Important Topics

- How was the cryosphere monitored historically?
- Is snow always white? Why or why not?
  - How do spectral earth observation datasets take advantage of this phenomena?
- Name one cryosphere specific application of RADARSAT
- How is ice penetrating RADAR typically collected?
- What is IceSat?
  - What type of laser light does it use? Why?