

Climate Change and the Cryosphere

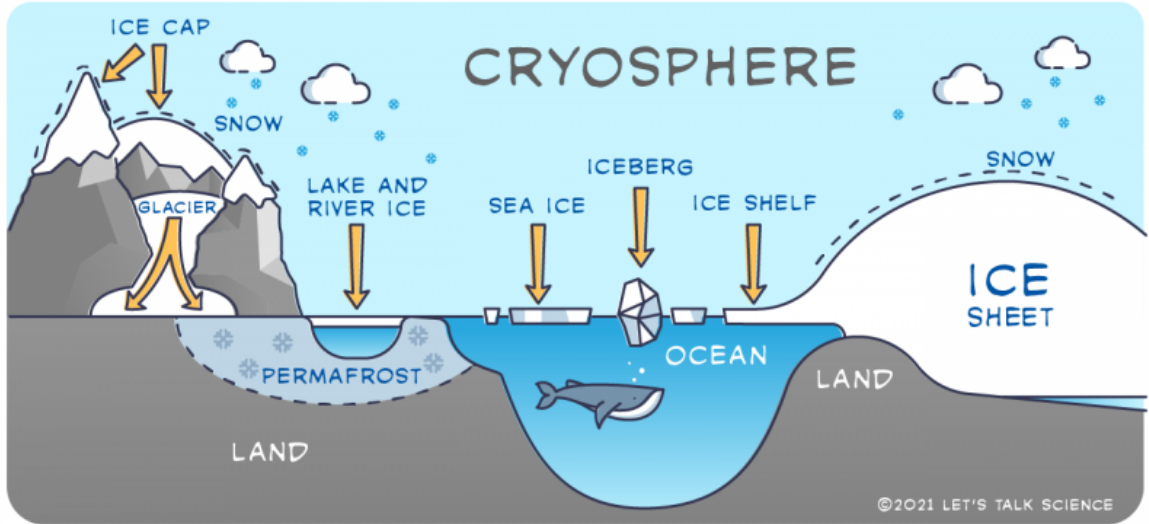
K. Arthur Endsley

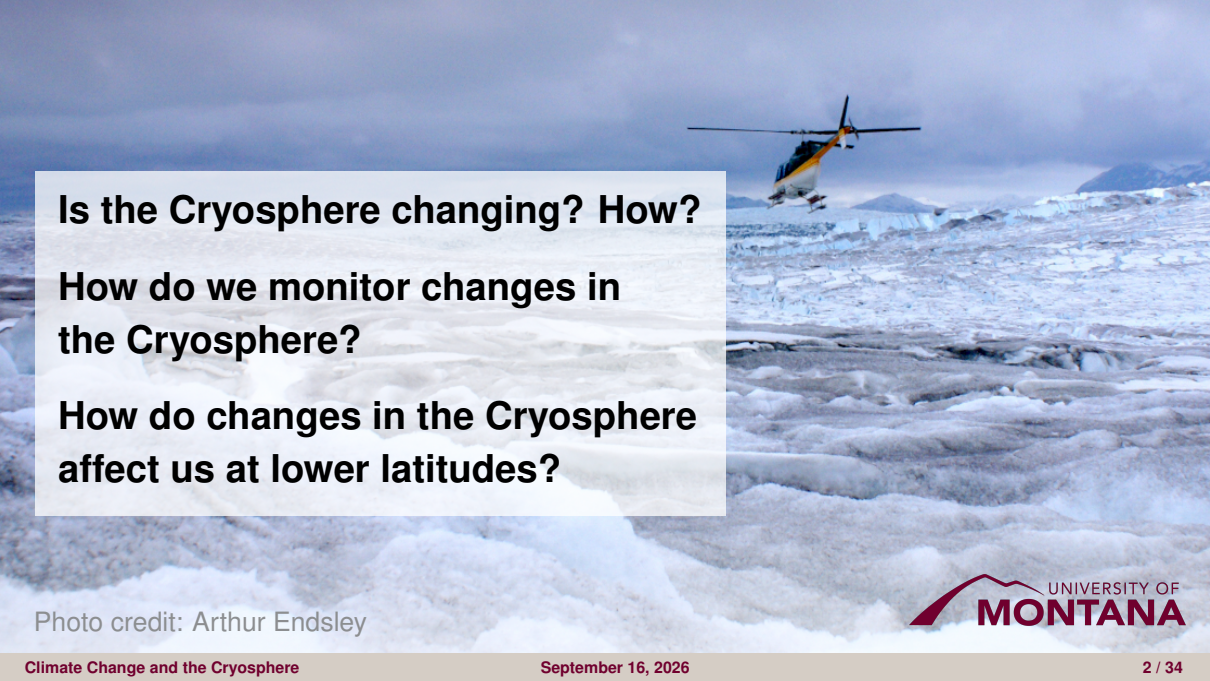
Department of Ecosystem and Conservation Sciences
W.A. Franke College of Forestry and Conservation

September 16, 2026



What is the Cryosphere?



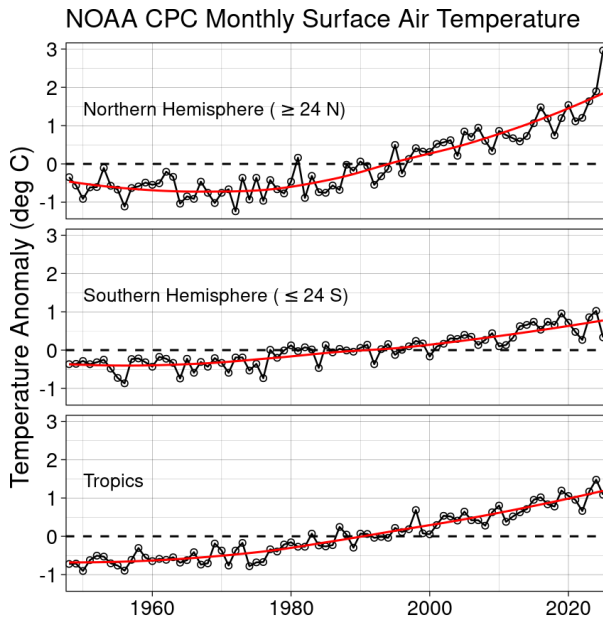
A helicopter with a yellow and black body is flying over a vast, flat, icy landscape. The ground is covered in a thick layer of ice and snow, with some darker patches visible. In the background, there are low, snow-covered hills or mountains under a cloudy sky. The helicopter is positioned in the upper right quadrant of the image.

Is the Cryosphere changing? How?

How do we monitor changes in the Cryosphere?

How do changes in the Cryosphere affect us at lower latitudes?

Photo credit: Arthur Endsley



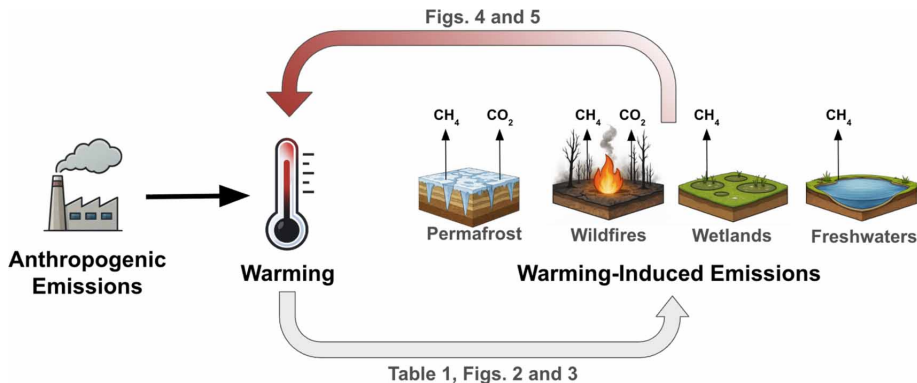
High northern latitudes are warming at 2-3 times as fast as the rest of the planet.^{1,2}

Figure produced with NOAA data from:
<http://iridl.ldeo.columbia.edu/SOURCES/.NOAA.NCEP.CPC/>

¹2021 IPCC 6th Assessment Report;

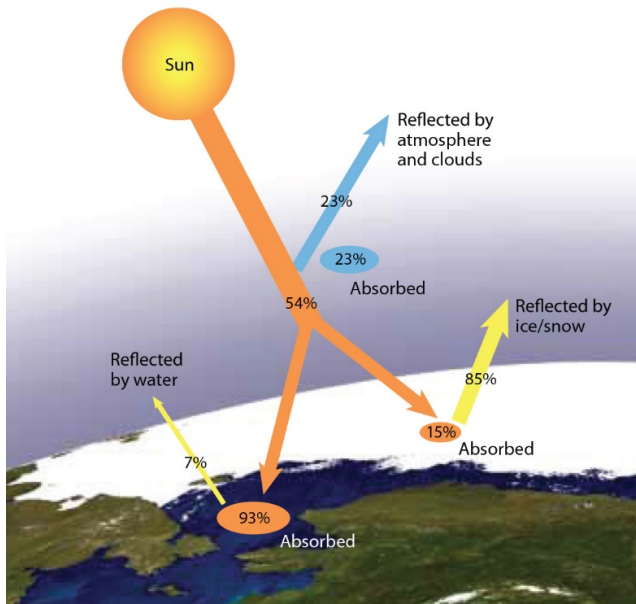
²Zhou et al. (2024, *Nature Geoscience*)

This **Arctic amplification** is caused by a positive **feedback loop** between incoming solar radiation and the land surface.

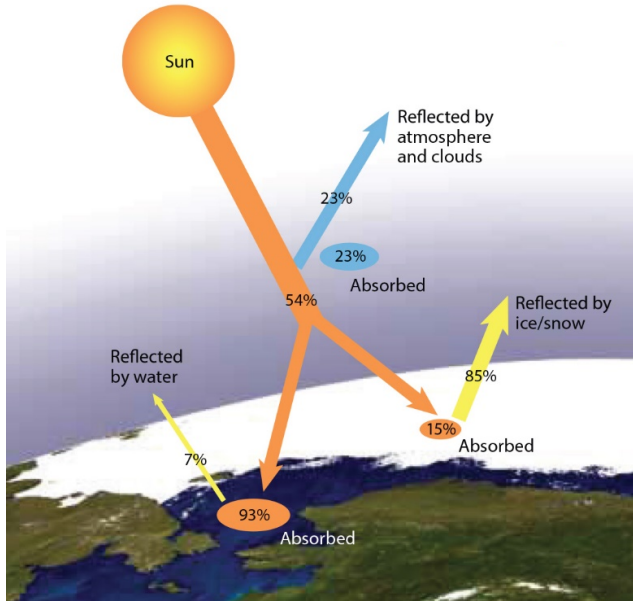


Abernethy et al. (2026)

Surface Energy Balance



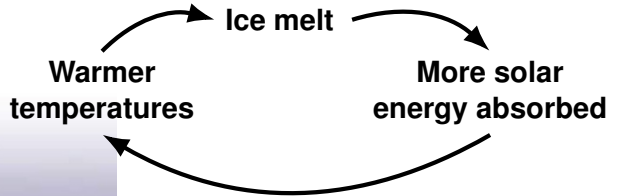
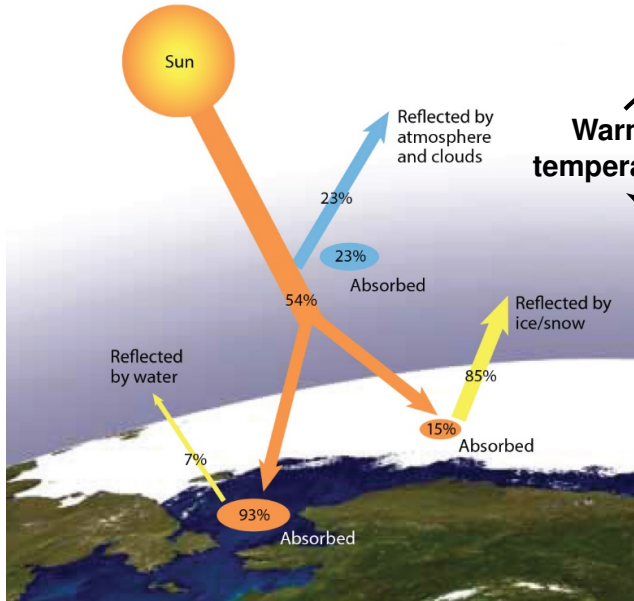
Surface Energy Balance



Typical albedo values:

- Fresh snow: 0.8-0.9
- Sea ice: 0.5-0.7
- Trees: 0.1-0.3
- Soil: 0.2
- Ocean water: <0.1

Surface Energy Balance



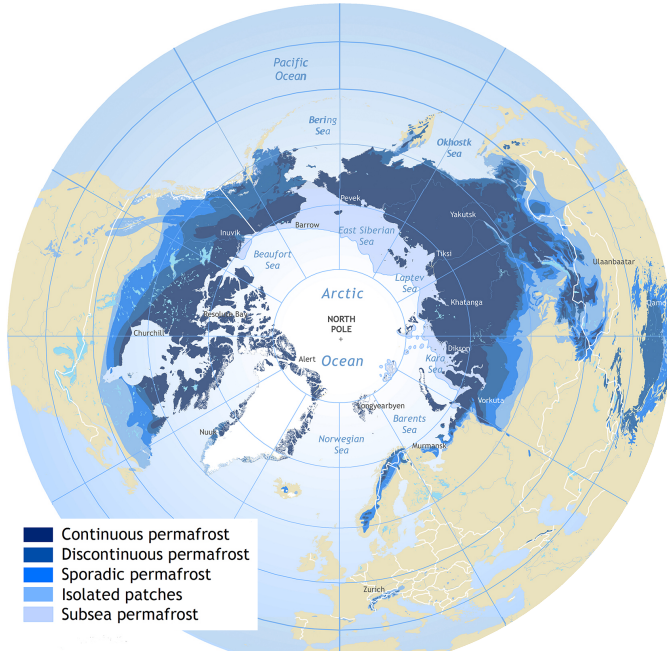
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Permafrost

Year-round frozen soil, **about 25% of the land in the Northern Hemisphere.**

Some Arctic soils are thawing for the first time in thousands of years!



Map: International Permafrost Association



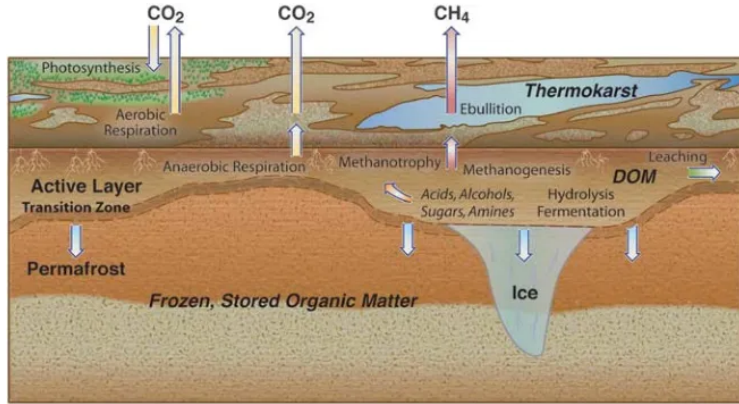


Herschel Island, photo by Boris Radosavljevic



Batagaika Crater, Siberia, photo by Tamina-Florentine Zuch

Permafrost-Climate Feedbacks



ESD11-015

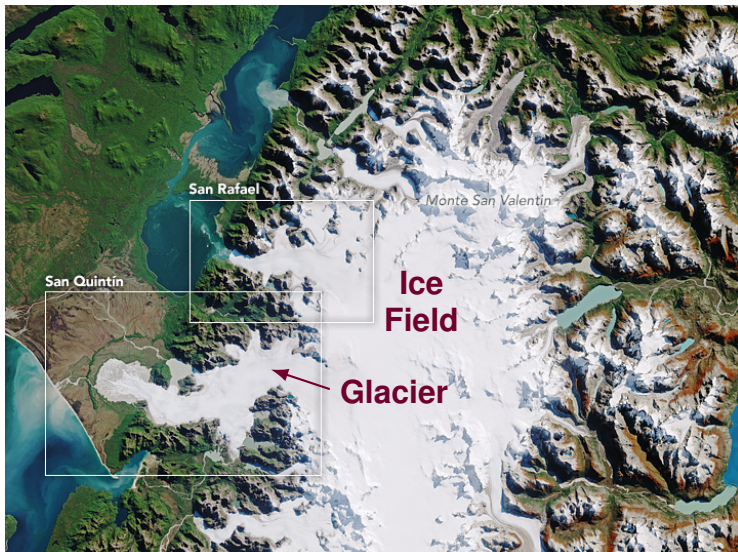


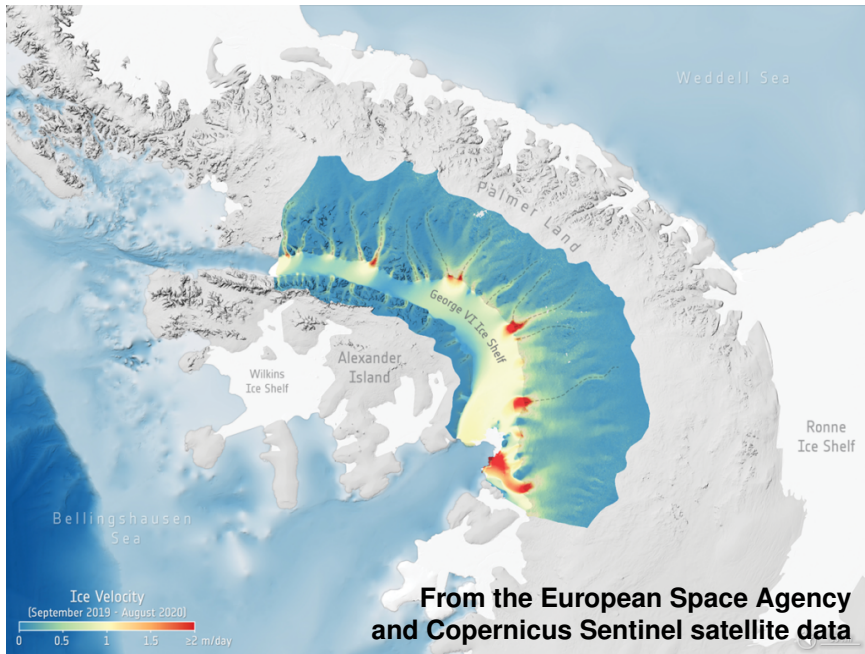
Photo: Arthur Endsley (2024)

Global Loss of Land Ice?

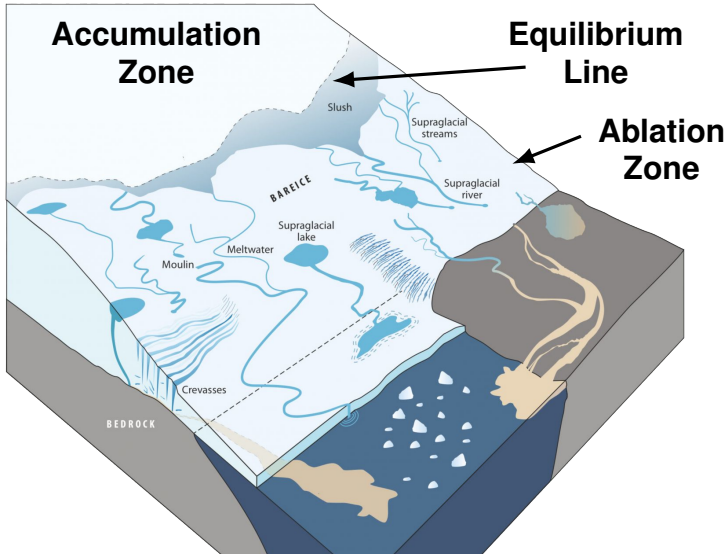
Glaciers supply water to
2 billion people world-wide.¹
What's happening to them in a
warming world?

¹Millan et al. (2022, *Nature
Geoscience*)

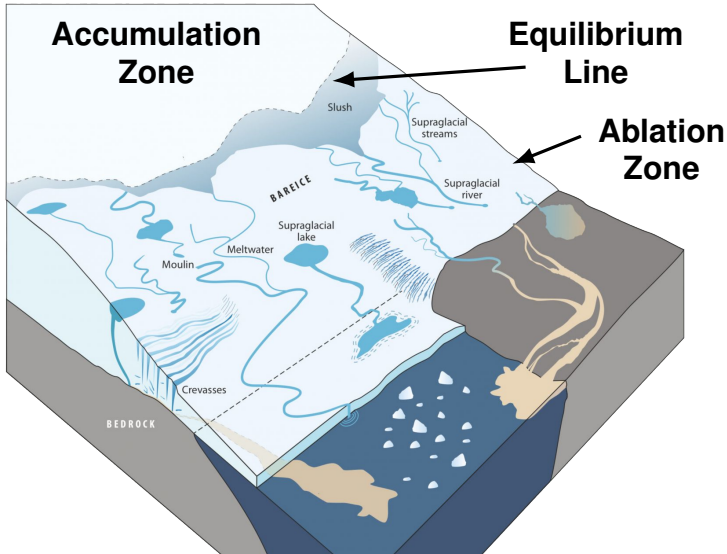




Global Loss of Land Ice?

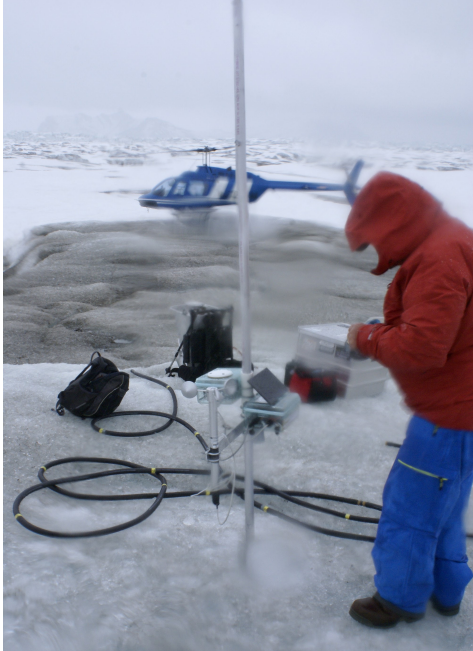


Global Loss of Land Ice?



How is the **equilibrium line altitude (ELA)** changing?

i.e., which is growing:
the Accumulation Zone
or the Ablation Zone?



Field work at the Bering Glacier, June 2012

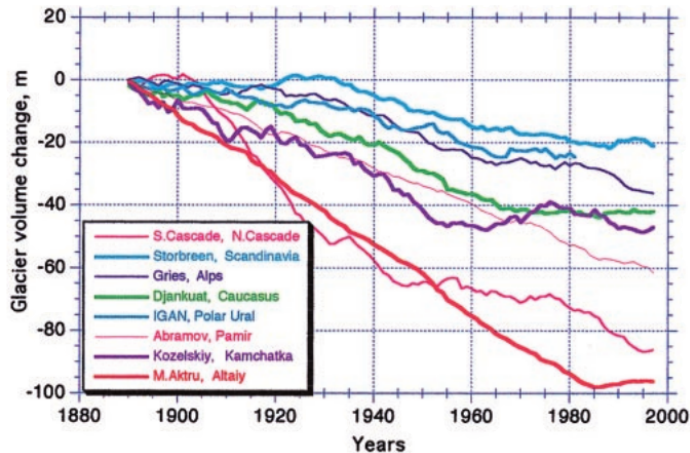


**2-3 meters
in two months**

**Returning to the Glacier,
August 2012**



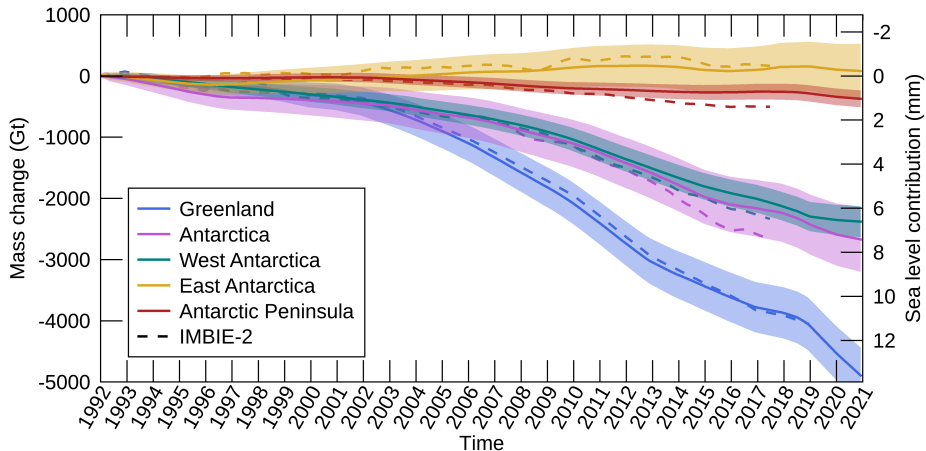
Glacial melt since 1993: 6,200 gigatons of ice or **17.1 (± 4.4) mm of equivalent sea level rise¹**



Dyurgerov & Meier (2000, *Science*)

Adding in Ice Sheet Changes

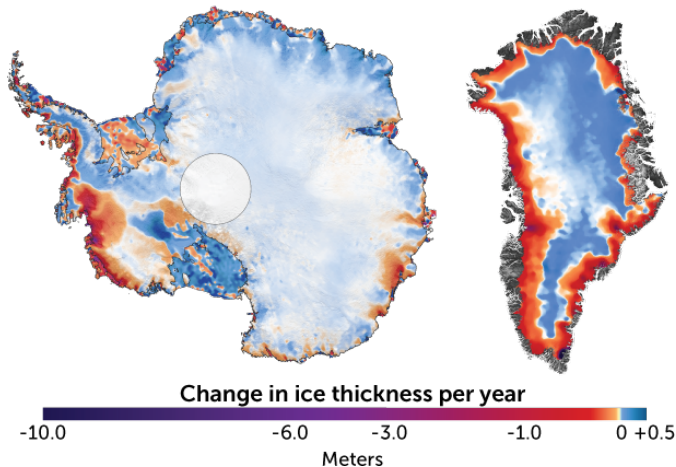
Adding Greenland, Antarctic ice sheet loss to terrestrial glacier ice loss:
38.1 mm (1.5 inches) of global sea-level rise since 1992!



Future Contributions to Sea-Level Rise

Antarctica

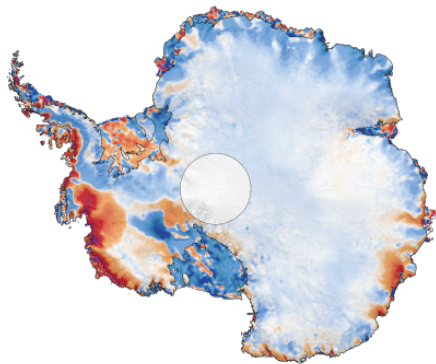
Greenland



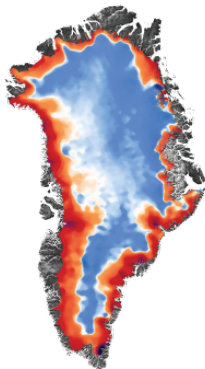
Smith et al. (2019, *Science*)

Future Contributions to Sea-Level Rise

Antarctica



Greenland



Change in ice thickness per year



Smith et al. (2019, *Science*)

If ALL the land ice melted...

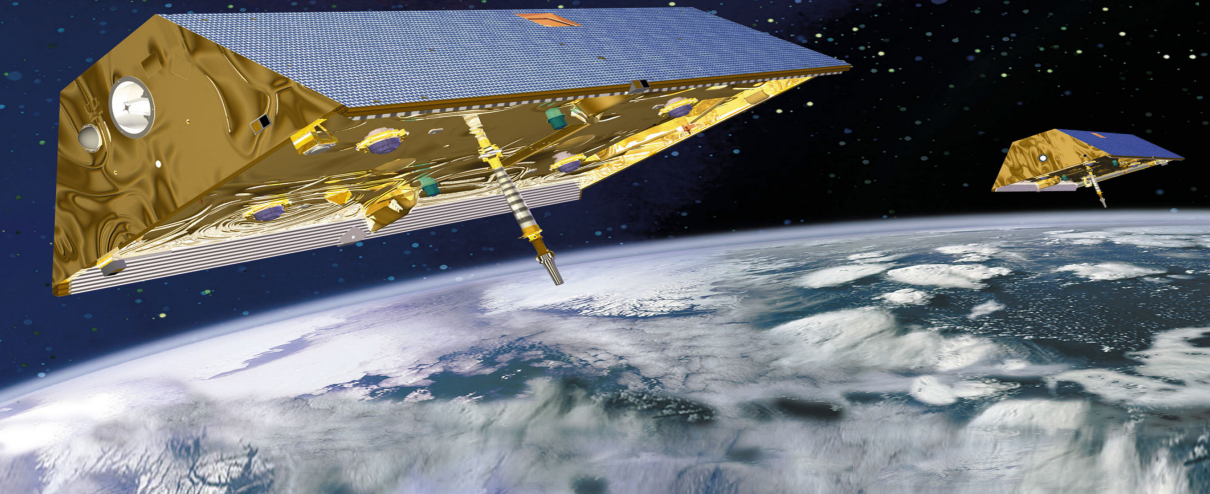
Ice on Land	Sea level equivalent (m)
Antarctica	57.9
Greenland	7.4
All other ice	0.25

Morlighem et al. (2017, 2019), Farinotti et al. (2019) and Millan et al. (2022)

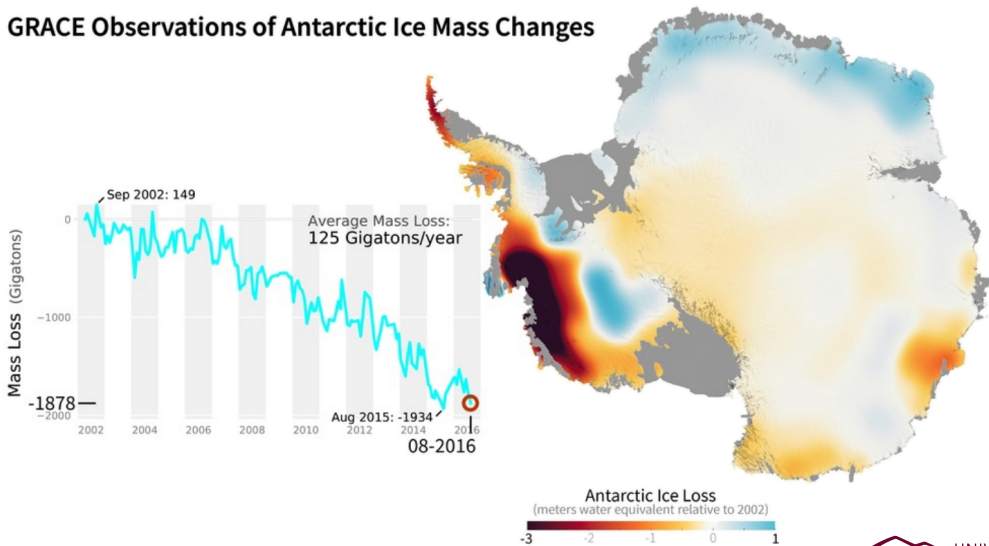
How do we monitor changes in the Cryosphere?



Gravity Recovery and Climate Experiment (GRACE)



GRACE Observations of Antarctic Ice Mass Changes



NASA JPL



Traditional Ecological Knowledge (TEK)

- Meat and fish going to waste because of over-fermentation.¹
- Warmer spring nights preventing freeze-up necessary for evening hunting.^{1,2}
- New and unfamiliar species (salmon, white-tailed deer).^{2,3}
- Changing *phenology*: Indigenous reindeer herders have reported larger and taller willow stands.⁴

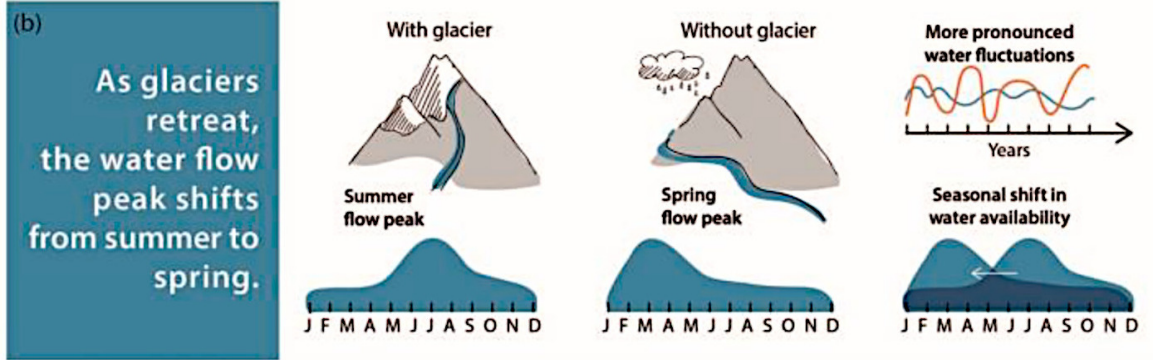
¹Fox (2002); ²Jolly et al. (2002); ³Bastedo (2007);

⁴Forbes et al. (2010); Photo credit: James Bastedo



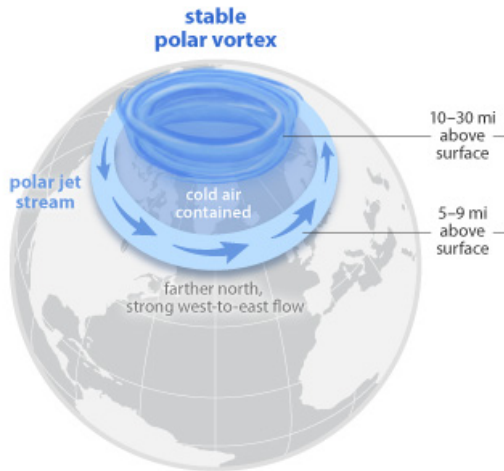
**How do changes in the Cryosphere
affect society at lower latitudes?
And at lower elevations?**

Impacts on Water Supplies in Mountain Communities



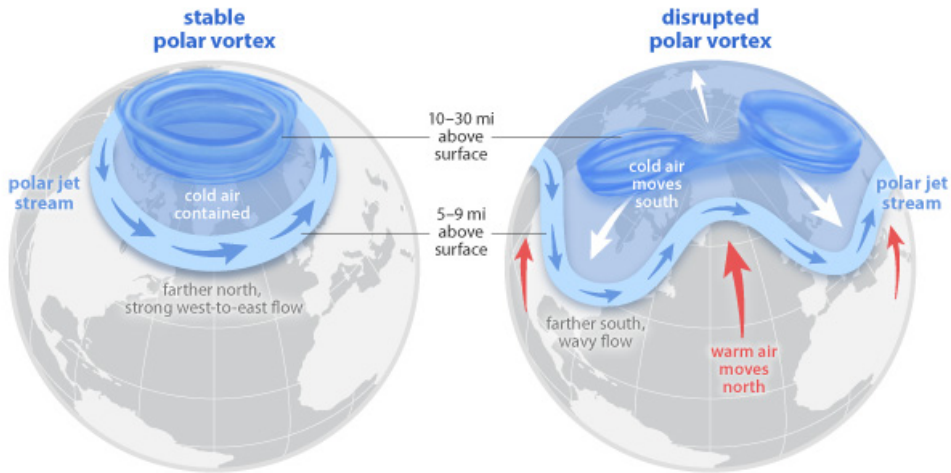
Barandun et al. (2020, *Water Security*)

Upper Stratospheric Warming



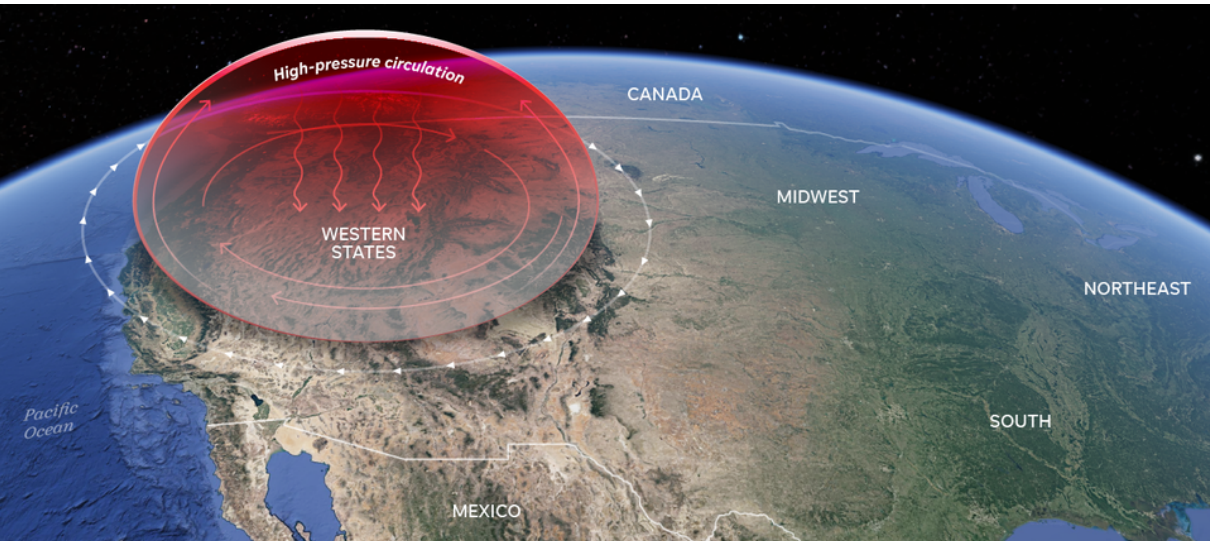
NOAA and Climate.gov (2021)

Upper Stratospheric Warming



NOAA and Climate.gov (2021)

Persistent Atmospheric Blocking: Summer 2024



Atmospheric Blocking Impacts Air Quality



Photo: ABC News

Winter Haze in China (2013)

PM2.5 concentrations
exceeded **766 $\mu\text{g m}^{-3}$**

(Missoula experienced
around **125 $\mu\text{g m}^{-3}$** at the
peak of 2026's smoke
season.)

Arctic Amplification and Extreme Weather



Extreme cold snaps in fall and winter due to sudden stratospheric warming events:

- Have doubled in frequency since 1980¹
- Will become much more common in the future²

Texas Ice Storm (2021)

is then the costliest natural disaster in the state's history

¹ Cohen et al. (2021);

² Mann et al. (2018)



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