Climate Change and the Cryosphere

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W.A. Franke College of Forestry and Conservation

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Small-Group Discussions

Newtok, Alaska and **Coral Gables, Florida** are two coastal communities in the U.S. that are facing the consequences of rising sea levels. Both communities face a decision to relocate to higher ground.

- In Newtok, where 95% of the population is indigenous Yupik, the mean annual temperature is 31 degrees F and the ground is frozen for much of the year.
- In Coral Gables, 60% of the population is Hispanic/ Latino, 53% of households speak Spanish at home, and 1 in 5 residents is older than 65.

What are some of the differences between these communities in how they experience sea-level rise and the factors affecting a decision to move?

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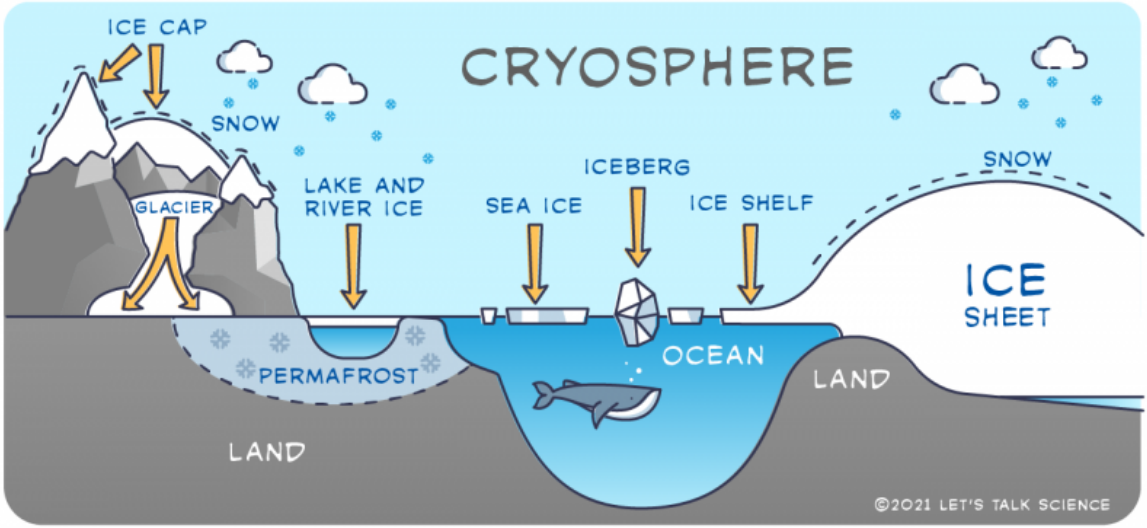
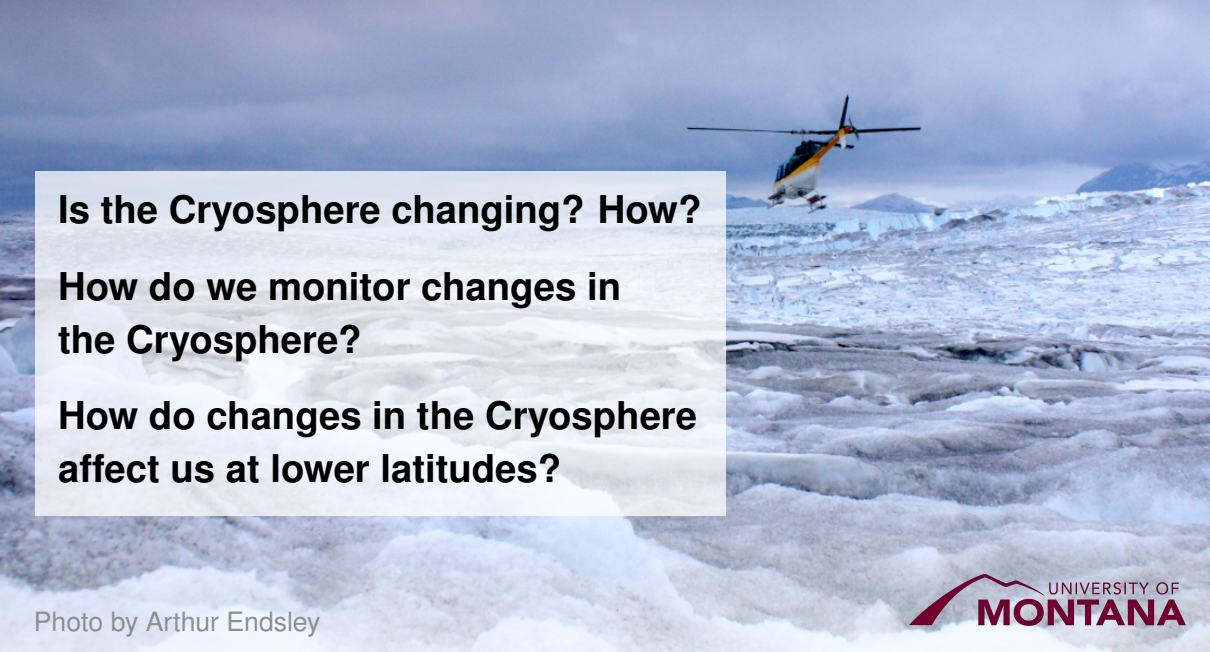
What is the Cryosphere?





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 by Arthur Endsley

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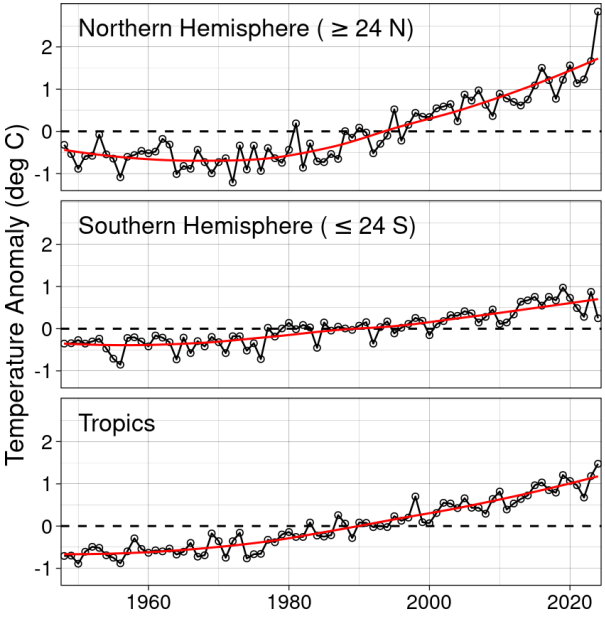

High northern latitudes are warming at 2-3 times as fast as the rest of the planet.[1,2]

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

[1]2021 IPCC 6th Assessment Report;
[2]Zhou et al. (2024, *Nature Geoscience*)

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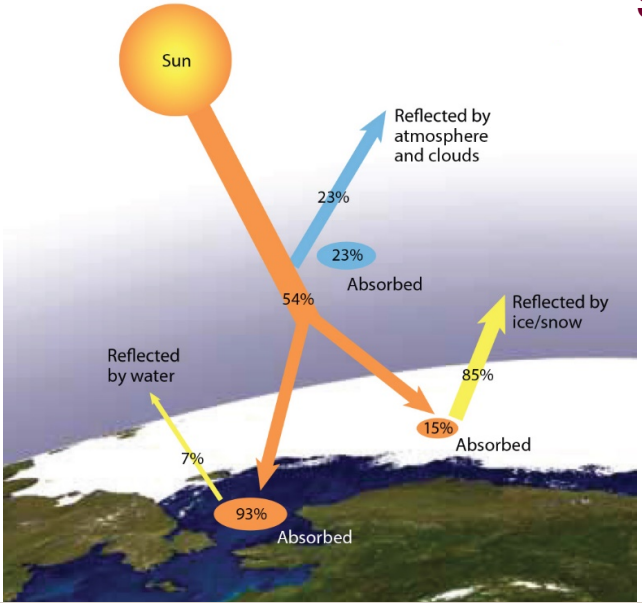
Surface Energy Balance



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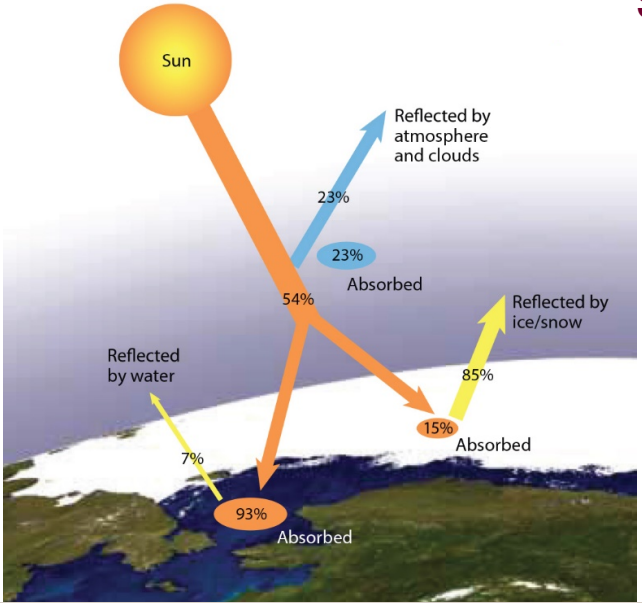

Typical albedo values:

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

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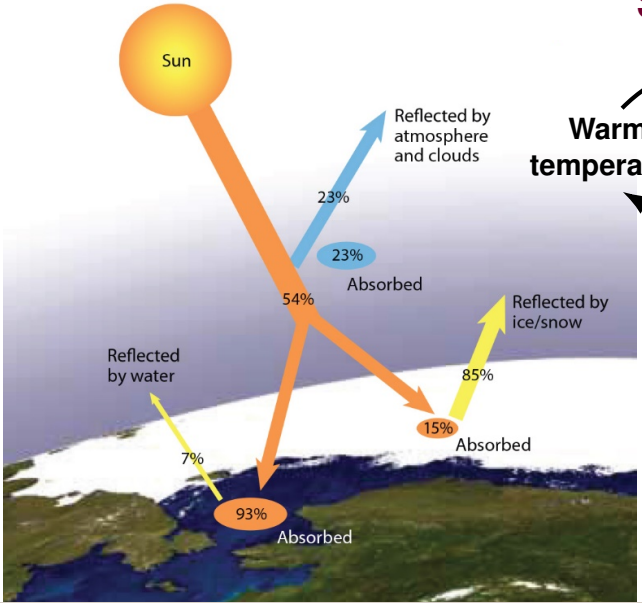
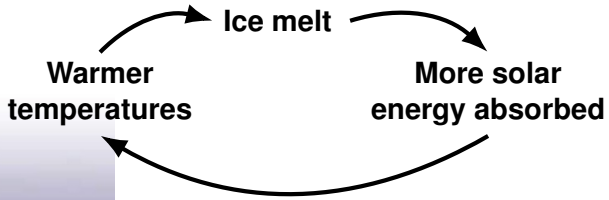
Surface Energy Balance





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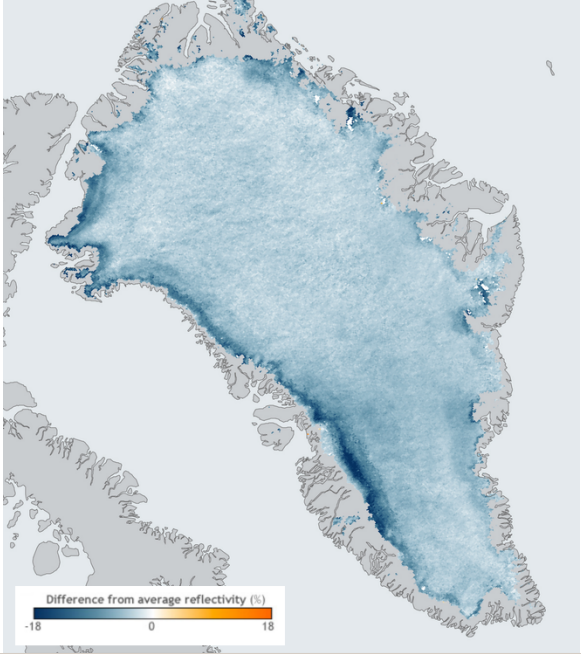

Why has Greenland's albedo changed?

Left: Trend in Greenland ice albedo (2000-2011) from satellite observations (2012 NOAA Arctic Report Card)

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Why has Greenland's albedo changed?

Pitcher and Smith (2019, photos)

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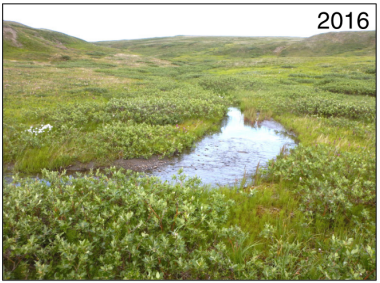
Ice-Free Areas are Changing Too

Photo by Ron Niebrugge

Shrub and Woody Plant Growth



Myers-Smith et al. (2019, *Ecological Monographs*)

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Warmer Mean Arctic Temperatures

Negative climate feedback

−

Positive climate feedback

+

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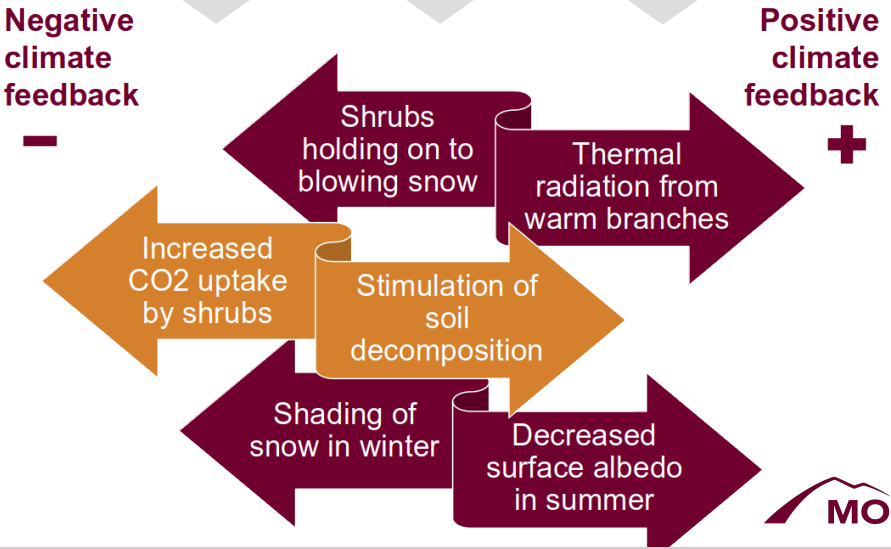
Warmer Mean Arctic Temperatures



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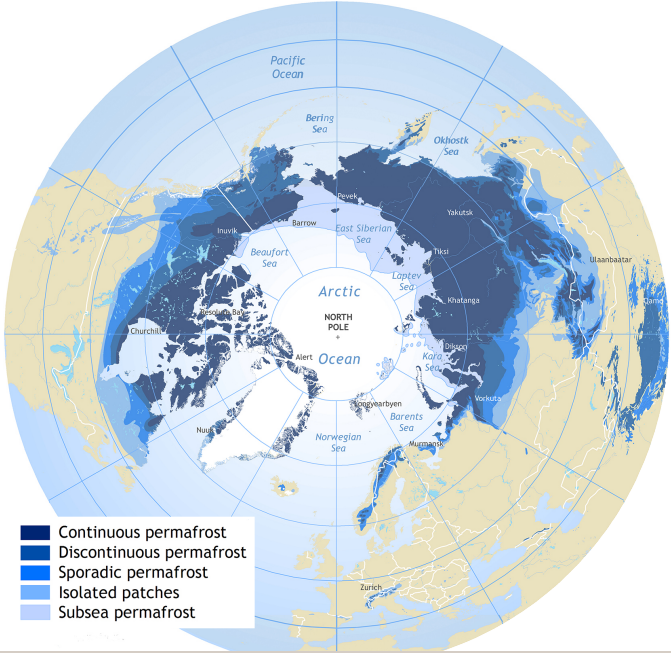
Permafrost

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

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Herschel Island, photo by Boris Radosavljevic

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Batagaika Crater, Siberia, photo by Tamina-Florentine Zuch

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Permafrost-Climate Feedbacks

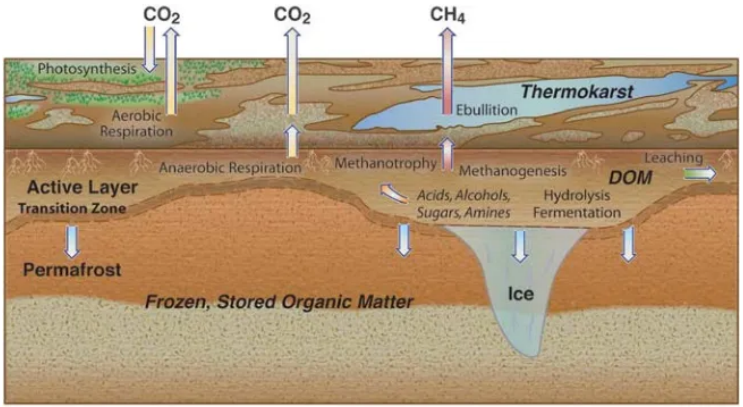

Photo: Arthur Endsley (2024)

How do we monitor changes in the Cryosphere?

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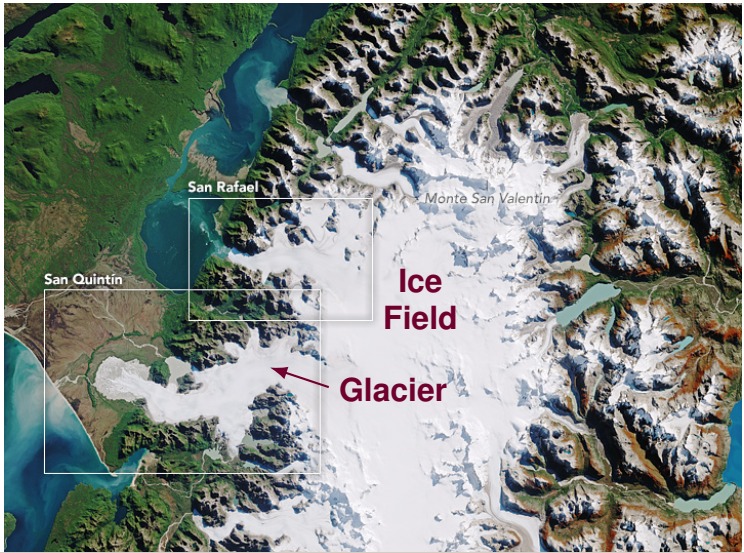
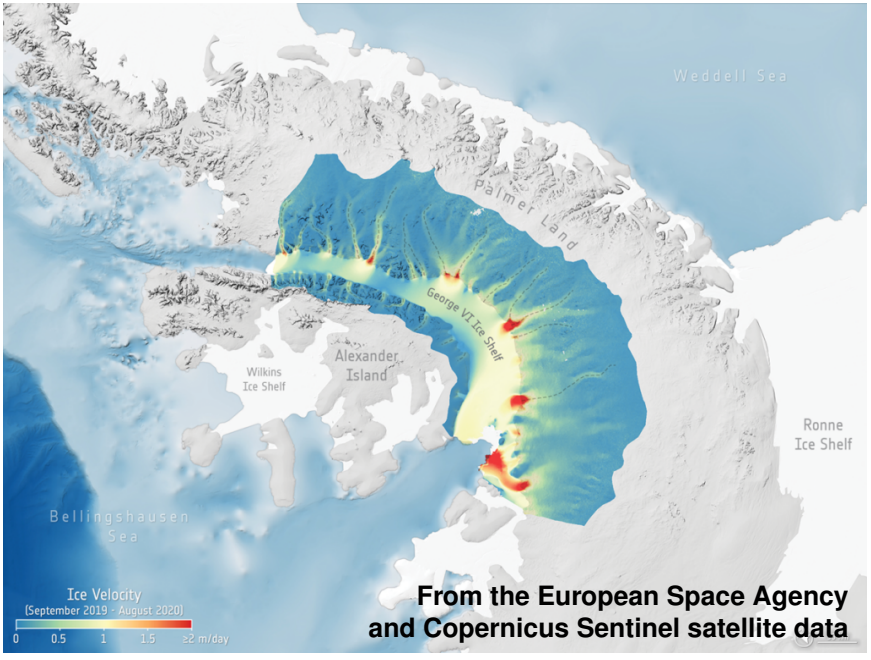
Global Loss of Land Ice?

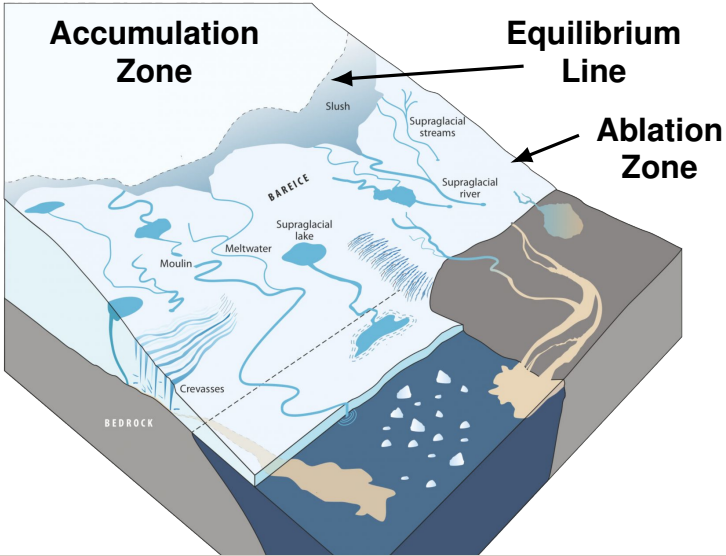
Glaciers supply water to 2 billion people world-wide.[1] What's happening to them in a warming world?



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


Weddell Sea
Palmer Land
George VI Ice Shelf
Alexander Island
Wilkins Ice Shelf
Ronne Ice Shelf
Bellingshausen Sea
Ice Velocity
(September 2019 - August 2020)
0
0.5
1
1.5
≥2 m/day
From the European Space Agency and Copernicus Sentinel satellite data

Global Loss of Land Ice?



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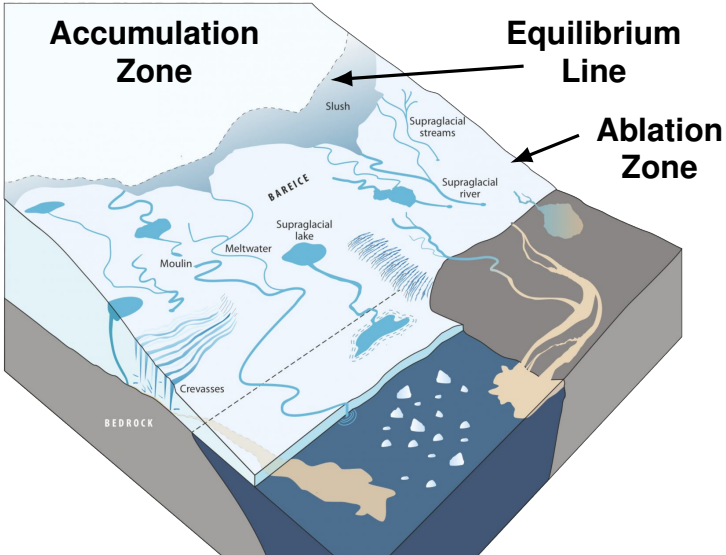
Global Loss of Land Ice?



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

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

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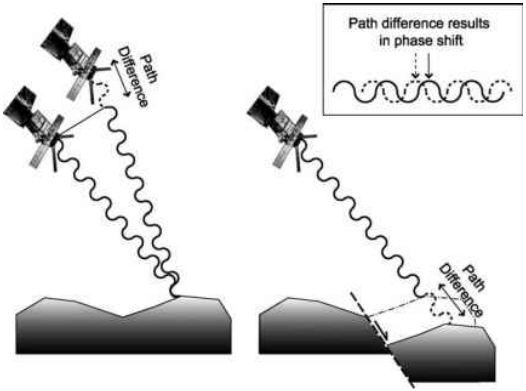
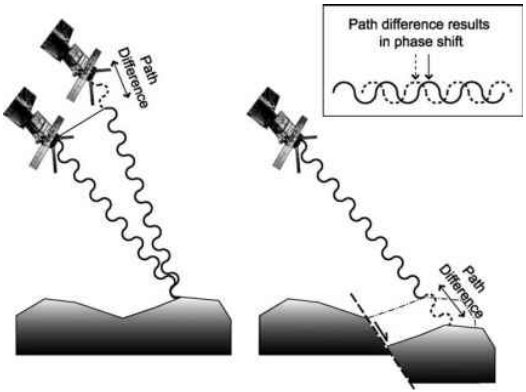
ICE, CLOUD, AND LAND ELEVATION SATELLITE
ICESat
2
NASA Goddard Space Flight Center

Monitoring Changes in Land Ice

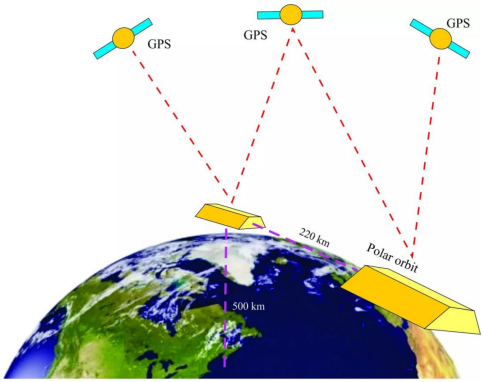


Satellite or Airborne Radar Interferometry

Monitoring Changes in Land Ice



Satellite or Airborne Radar Interferometry



Gravitational Anomalies (e.g., GRACE and GRACE-FO)

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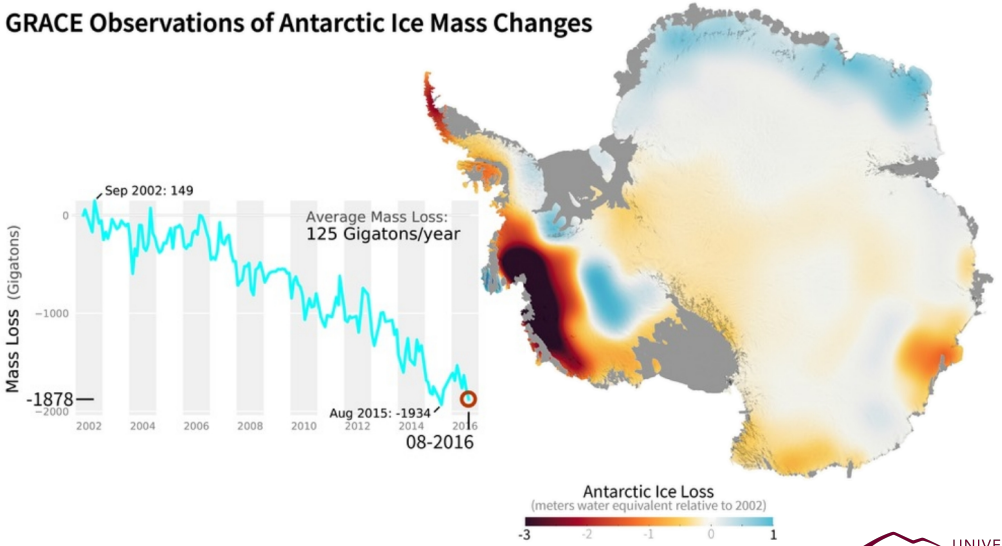

NASA JPL

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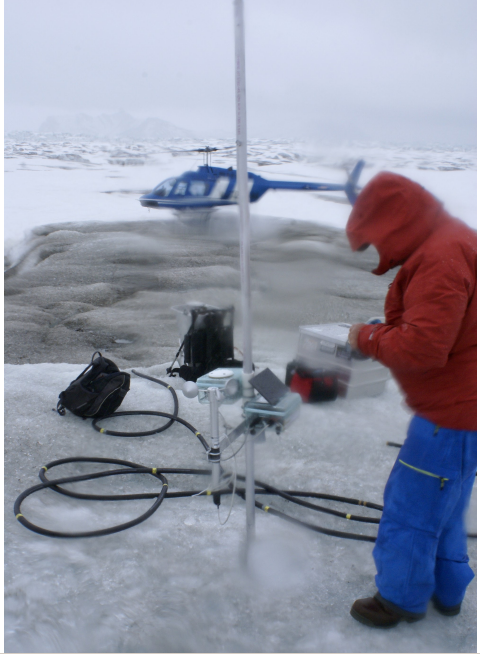

Field work at the Bering Glacier, June 2012

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Returning to the Glacier, August 2012

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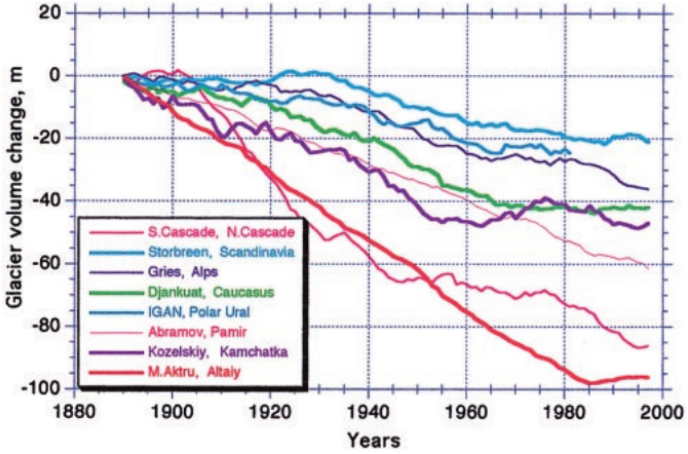
Glacial melt since 1993: 6,200 gigatons of ice or **17.1 ($\pm$4.4) mm of equivalent sea level rise**[1]



Dyurgerov & Meier (2000, *Science*)

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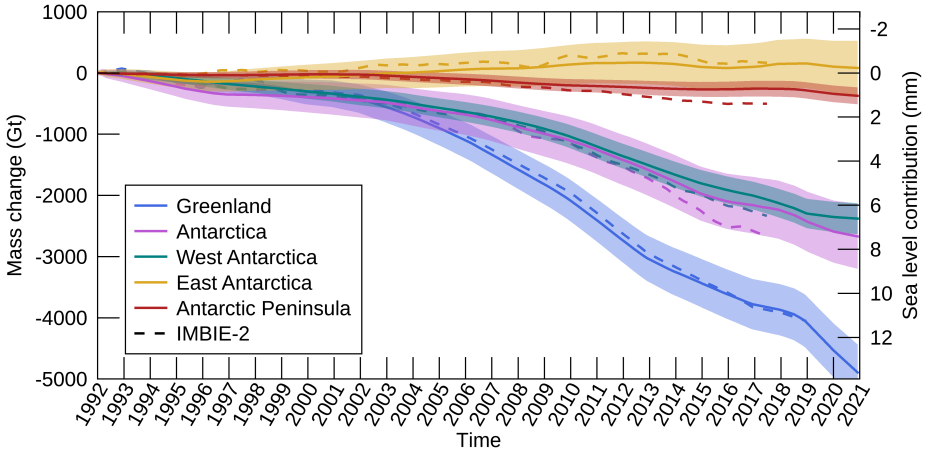
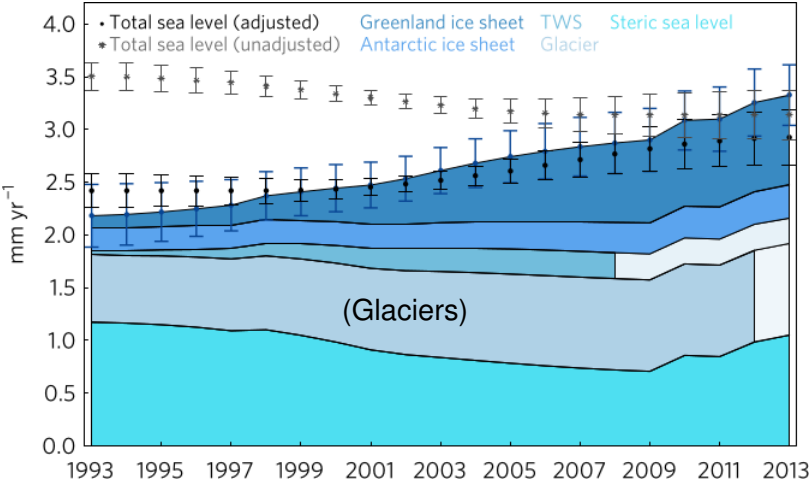
Adding in Ice Sheet Changes

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



Otosaka et al. (2023, *Earth System Science Data*)

Present Contributions to Sea-Level Rise



Chen et al. (2017, *Nature Climate Change*)

- Ice sheets
- Glaciers on land
- Aquifer depletion
- Density changes (e.g., thermal expansion of water)
- **Missing anything?**

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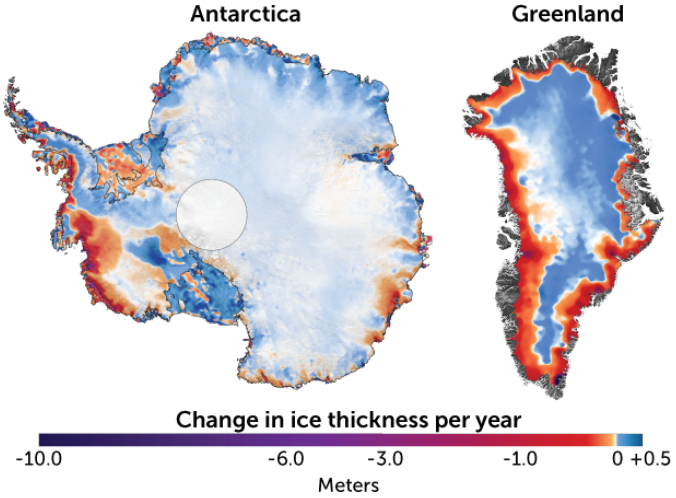
Future Contributions to Sea-Level Rise



Smith et al. (2019, *Science*)

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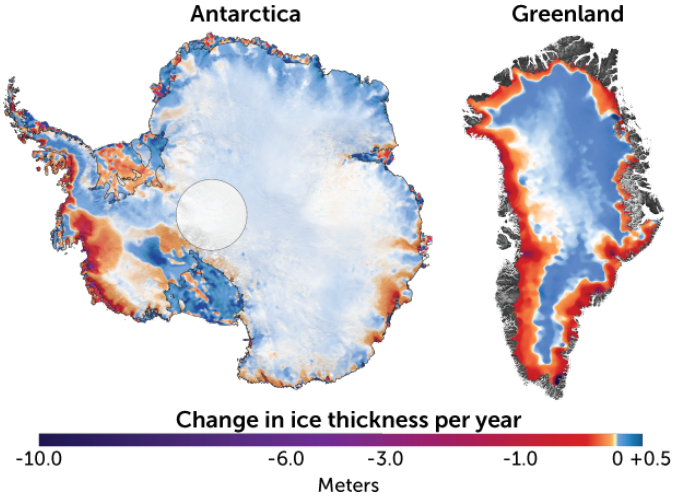
Future Contributions to Sea-Level Rise



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

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

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“The Earth is Faster Now”

“The Earth is Faster Now”

Newtok, AK voted to move their village *20 years ago* due to ground subsidence.

In Sachs Harbor, the Inuvialuit have described increased weather variability in Spring, Fall.

“We can’t predict the weather like we used to.”[1]

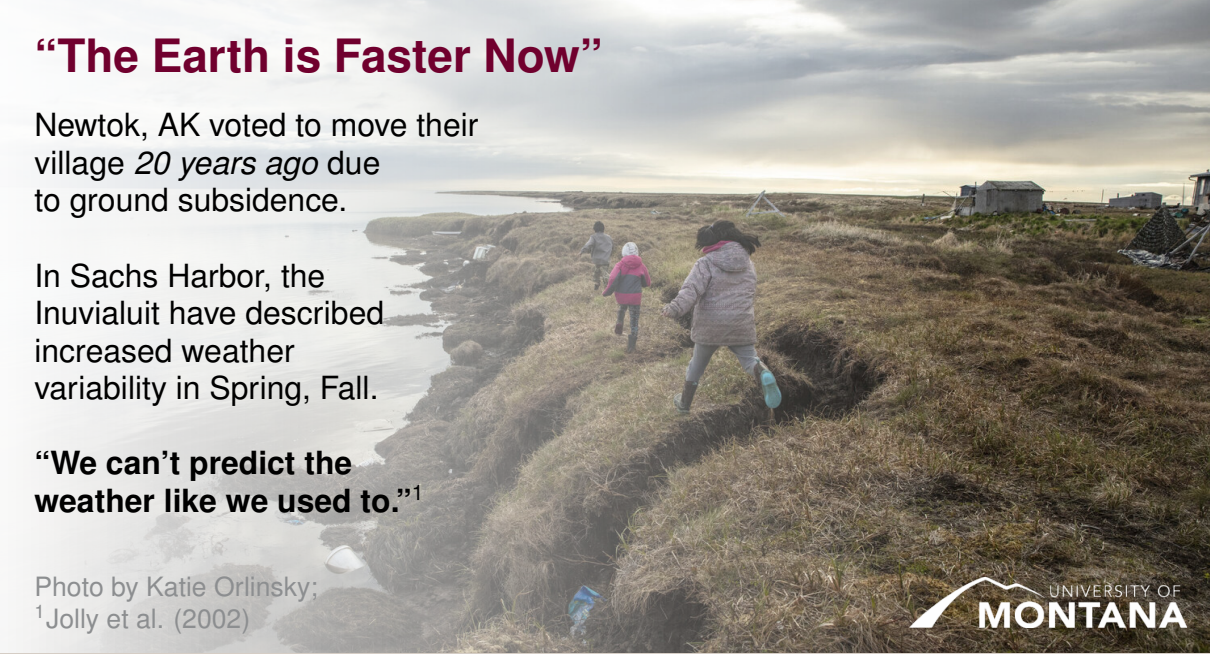

Photo by Katie Orlinsky;
[1]Jolly et al. (2002)

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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]

[1]Fox (2002); [2]Jolly et al. (2002); [3]Bastedo (2007); [4]Forbes et al. (2010); Photo by James Bastedo

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

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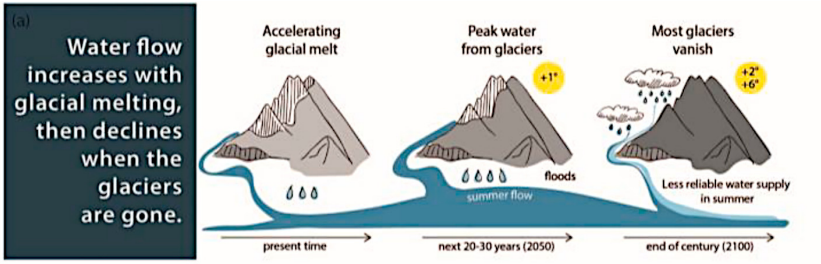
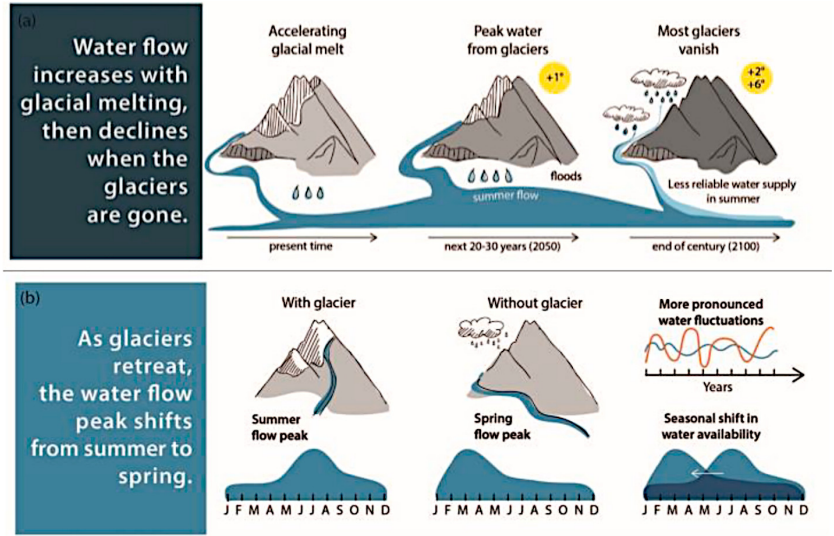
Impacts on Water Supplies in Mountain Communities

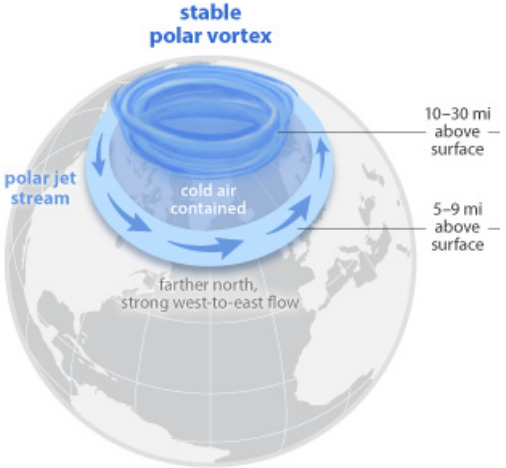


Impacts on Water Supplies in Mountain Communities



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

Upper Stratospheric Warming



NOAA and Climate.gov (2021)

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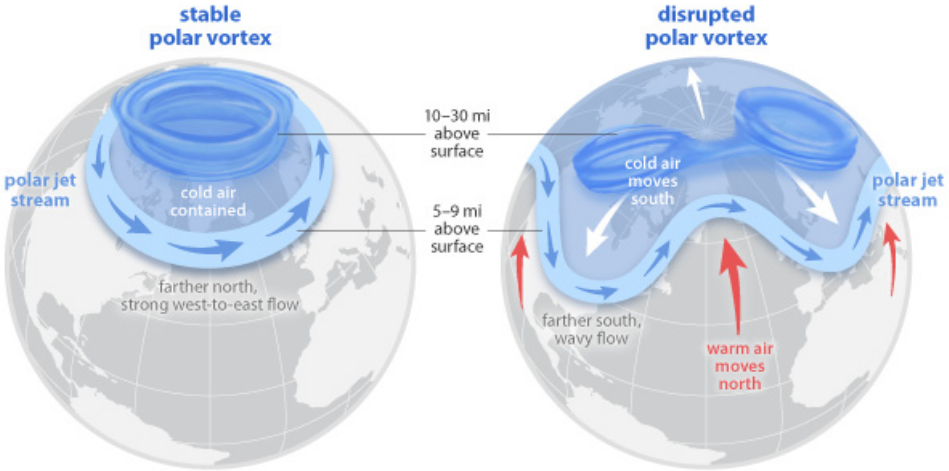
Upper Stratospheric Warming



NOAA and Climate.gov (2021)

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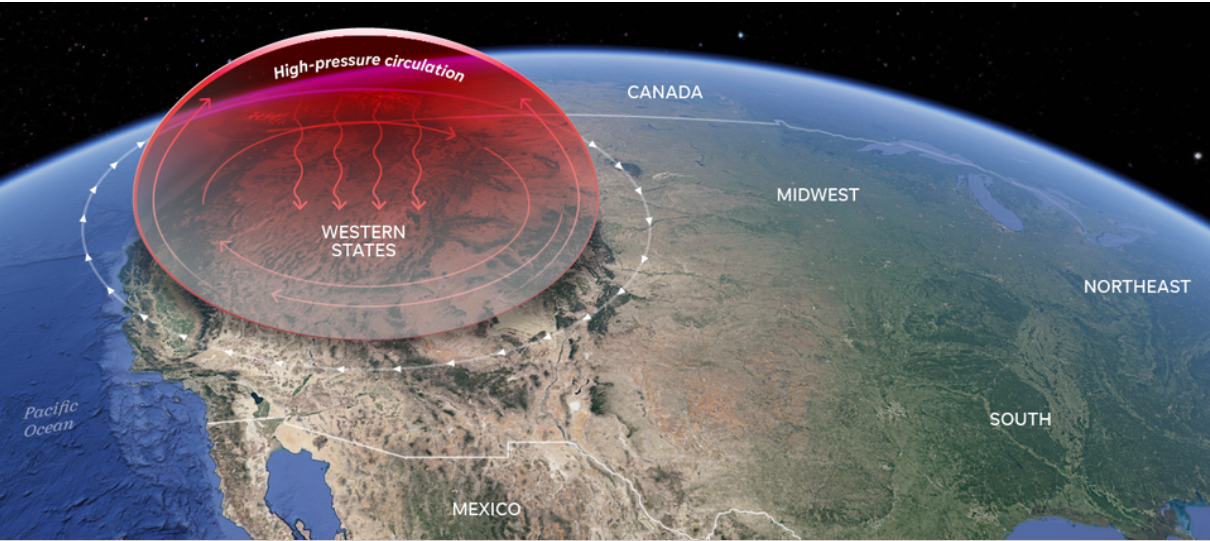
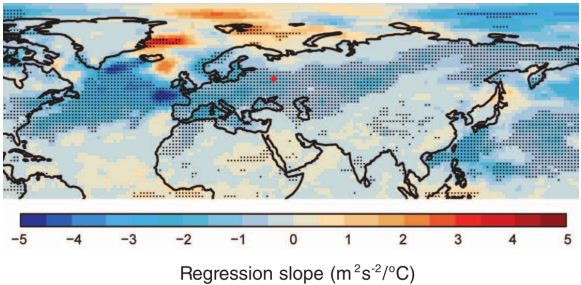
Remember Summer 2021? (And 2024)



Persistent Atmospheric Blocking

Global warming $\rightarrow$ **Reduces temperature contrast between Arctic and mid-latitudes** $\rightarrow$ **Weakening the jet stream** $\rightarrow$ **Reducing summer air circulation**



Relationship between eddy kinetic energy (measure of jet stream disruption) and summer temperatures

Coumou et al. (2015)

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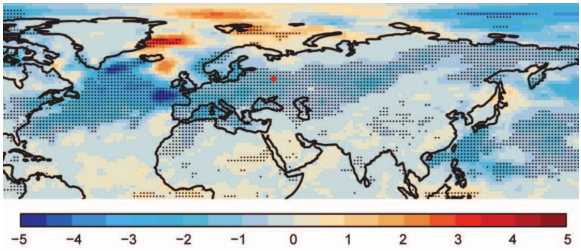
Persistent Atmospheric Blocking

Global warming → Reduces temperature contrast between Arctic and mid-latitudes → Weakening the jet stream → Reducing summer air circulation

2010 Russian Heat Dome:

- Wildfires
- 11,000 deaths from heat
- 55,000+ deaths after including smoke-related causes[1]
- Grain harvest losses of 30%
- Ban on grain exports

[1]USAID, Center for Research on the Epidemiology of Disasters



Relationship between eddy kinetic energy (measure of jet stream disruption) and summer temperatures

Coumou et al. (2015)

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Reduced Air Circulation

Photo: ABC News

Winter Haze in China (2013)

PM2.5 concentrations exceeded **766 ug m^{-3}**

(Missoula experienced **125+ ug m^{-3}** at the peak of 2024's smoke season.)

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Arctic Amplification

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

- **Have doubled in frequency since 1980**[1]
- **Will become much more common in the future**[2]

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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Questions?

Photo by Arthur Endsley

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