Arctic Amplification

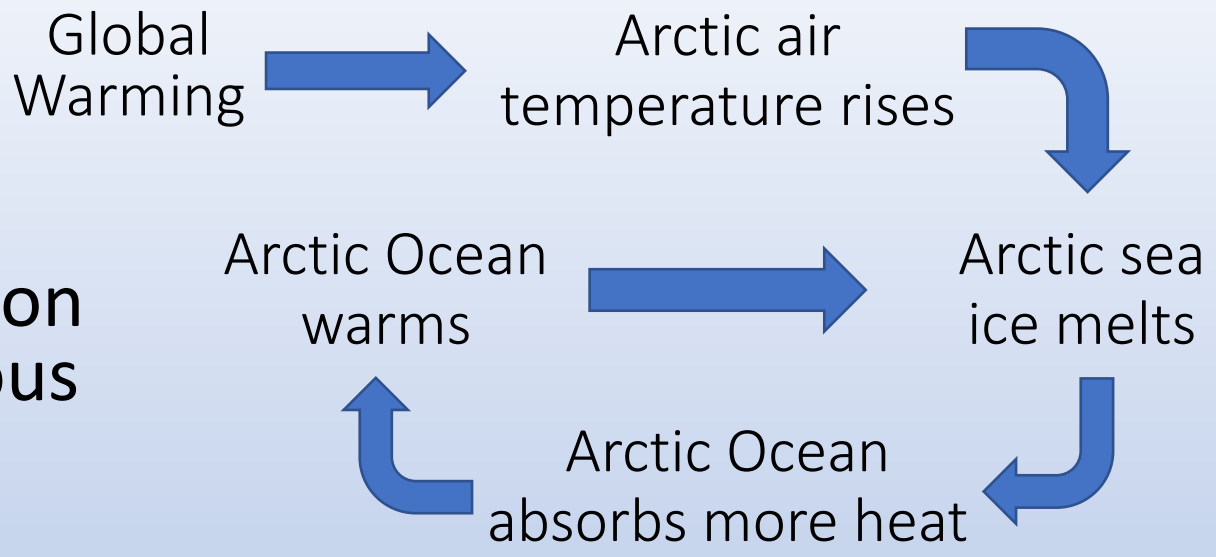
GEOG 497 – Cryosphere & Climate Systems

By Christopher Turnbull

May 3, 2022

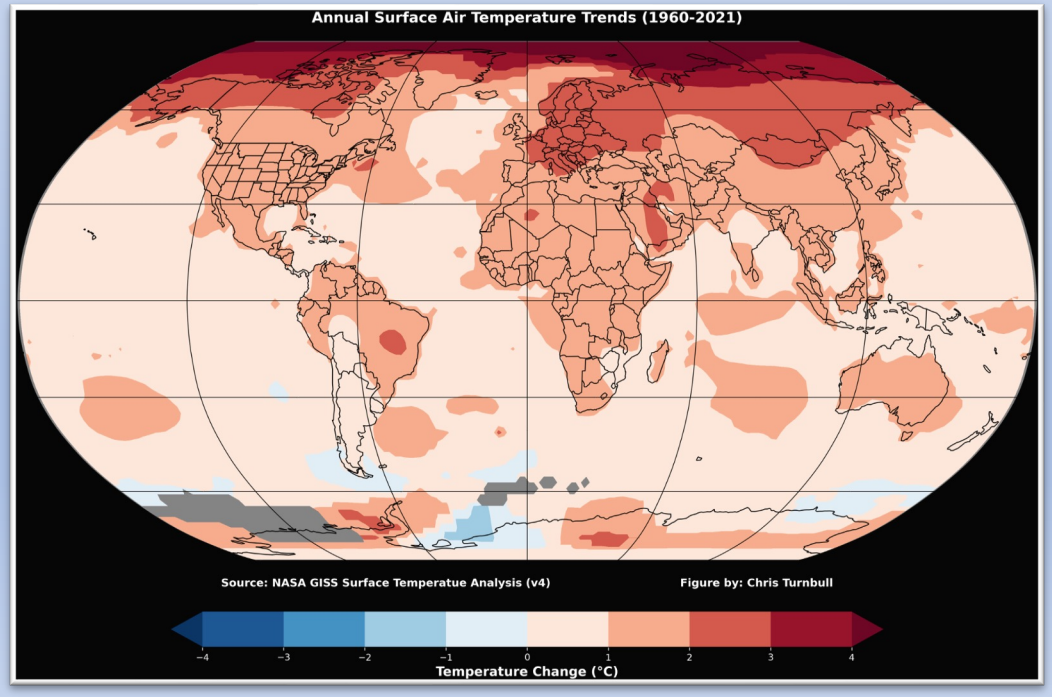
Last Updated: December 7, 2022

Arctic Amplification



- Rapid warming of the Arctic region due to global warming and various feedbacks
  - Temperature feedbacks
  - Longwave feedback
  - Changes in poleward heat transport
  - Ice-albedo feedback

- Arctic is warming 4 times faster than the rest of the world (mid-latitudes & tropics)



https://www.nature.com/articles/s43247-022-00354-4

Motivation / Significance of Arctic Amplification

Evidence/Drivers for/of Arctic Amplification

Thawing Permafrost Soils

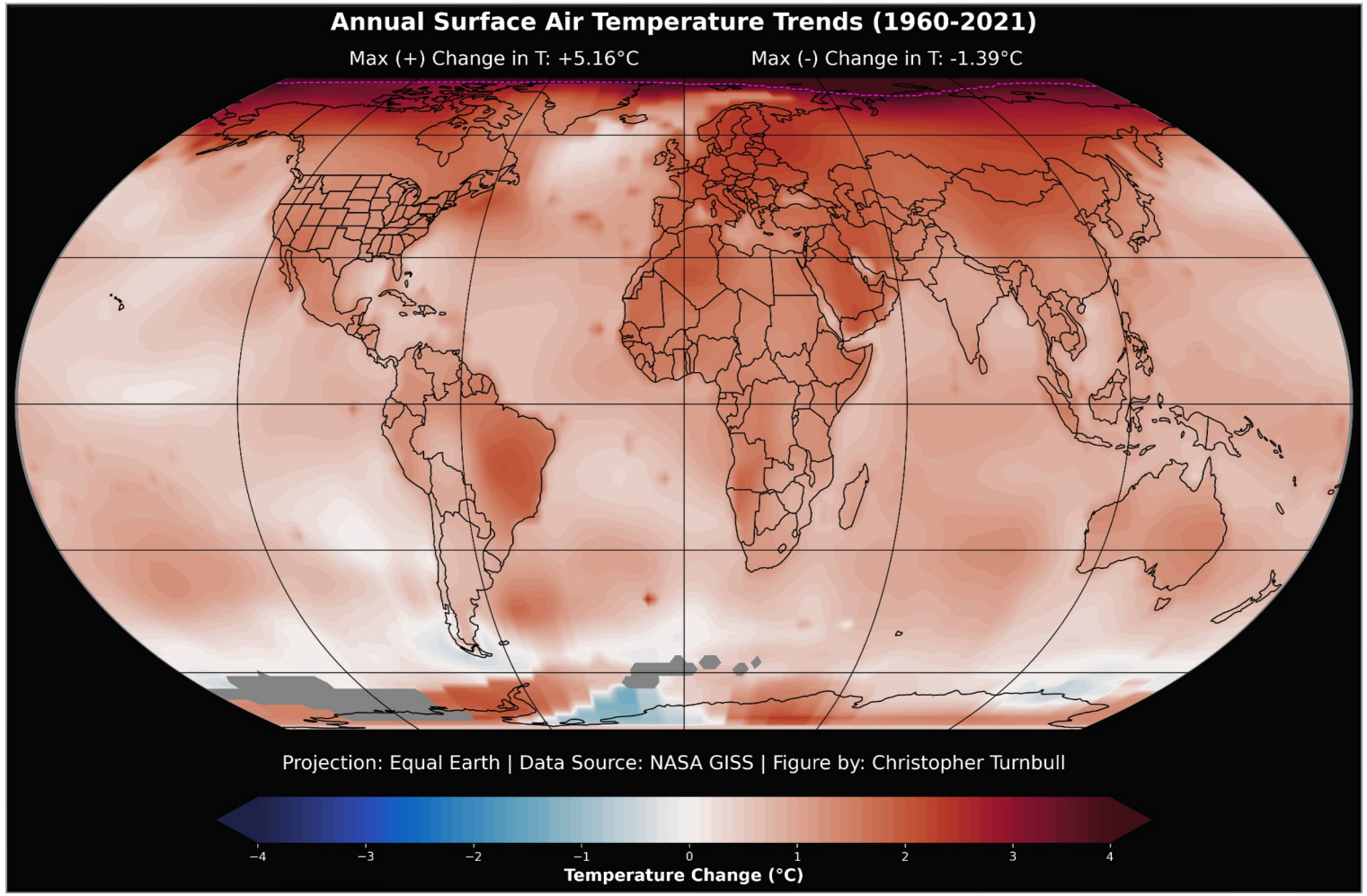
Changing Arctic Precipitation Regimes

Impacts on the large-scale atmospheric circulation

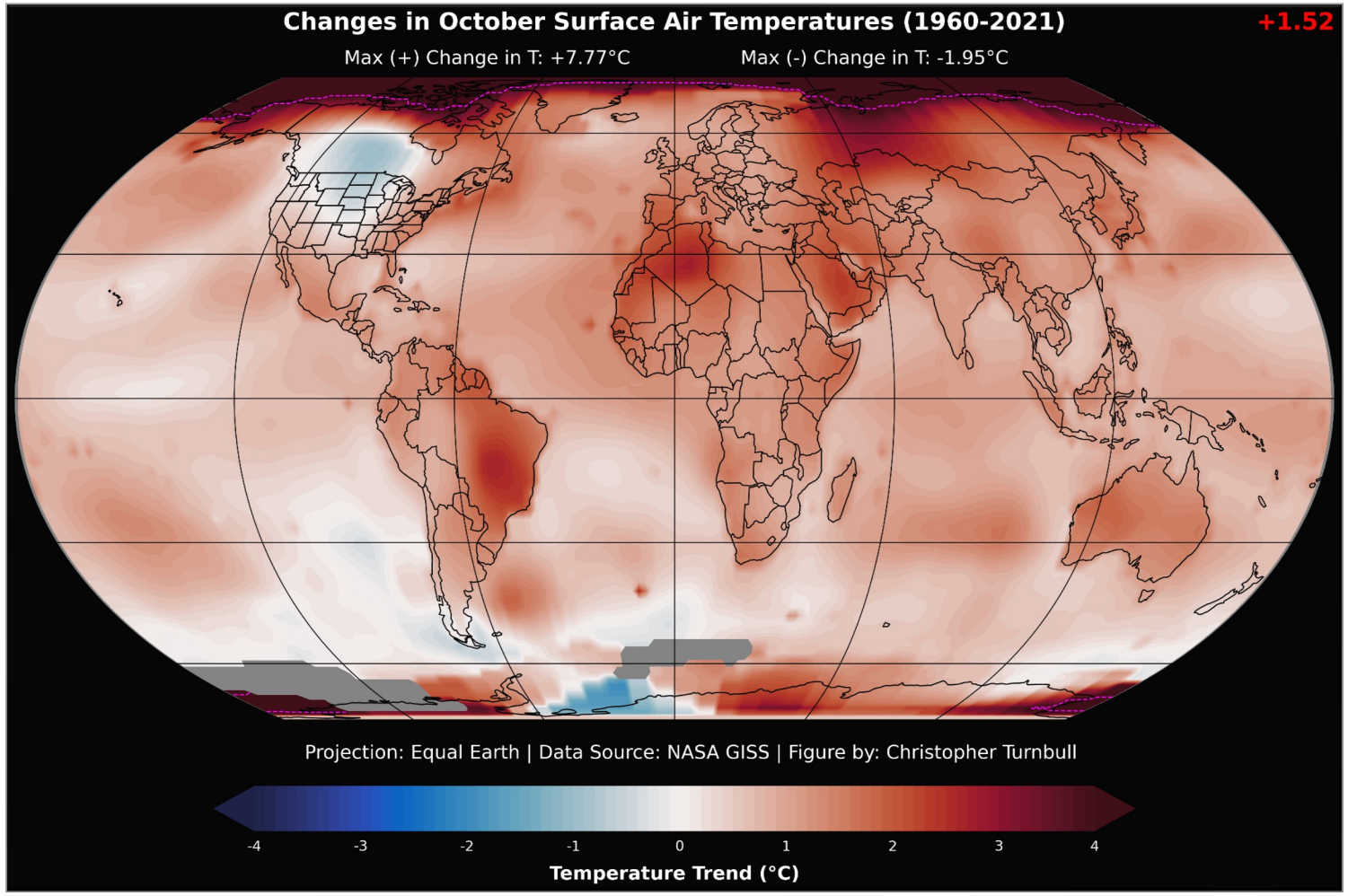
Impacts on the Arctic Ecosystem

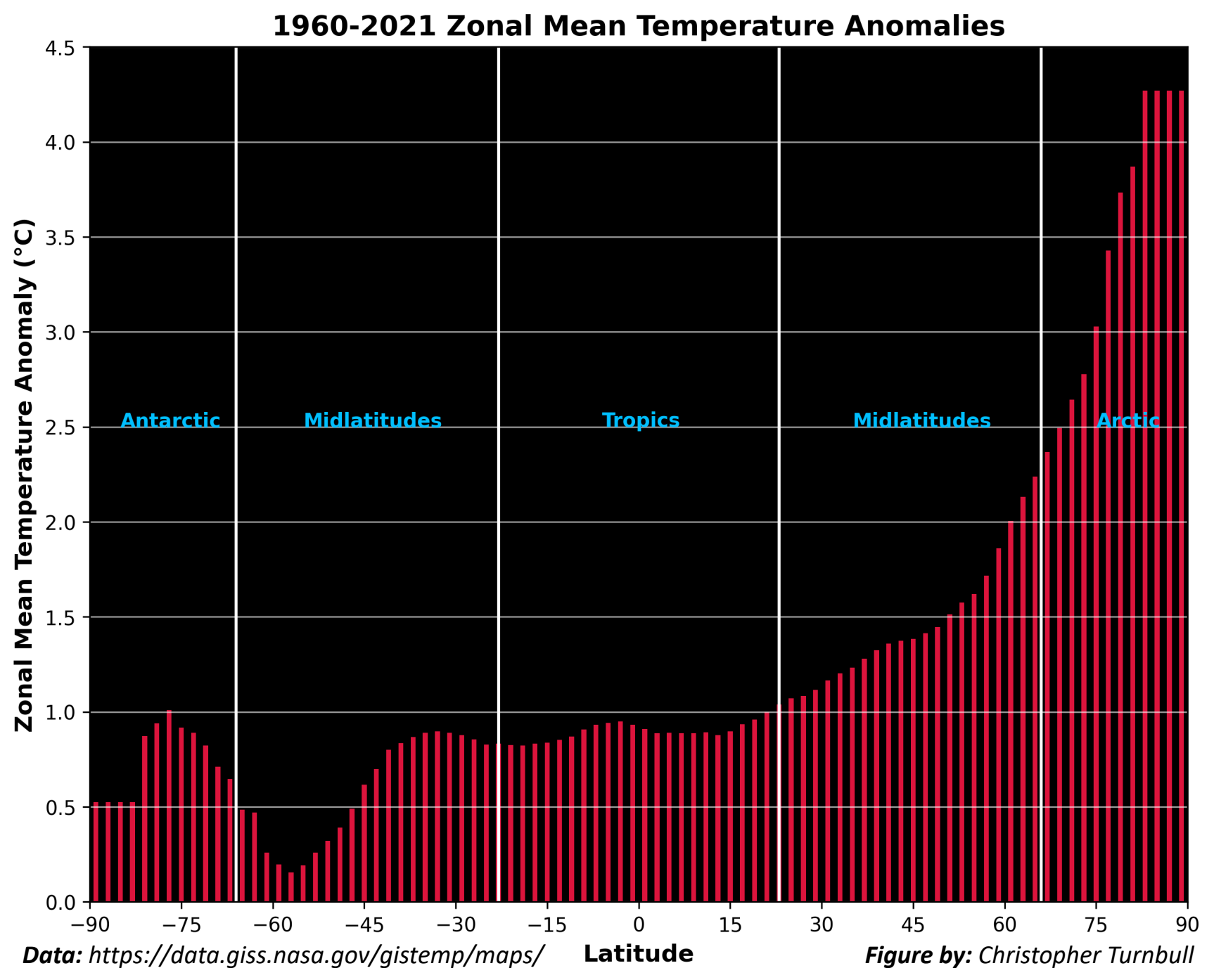
Miscellaneous findings

Annual Surface Air Temperature Trends



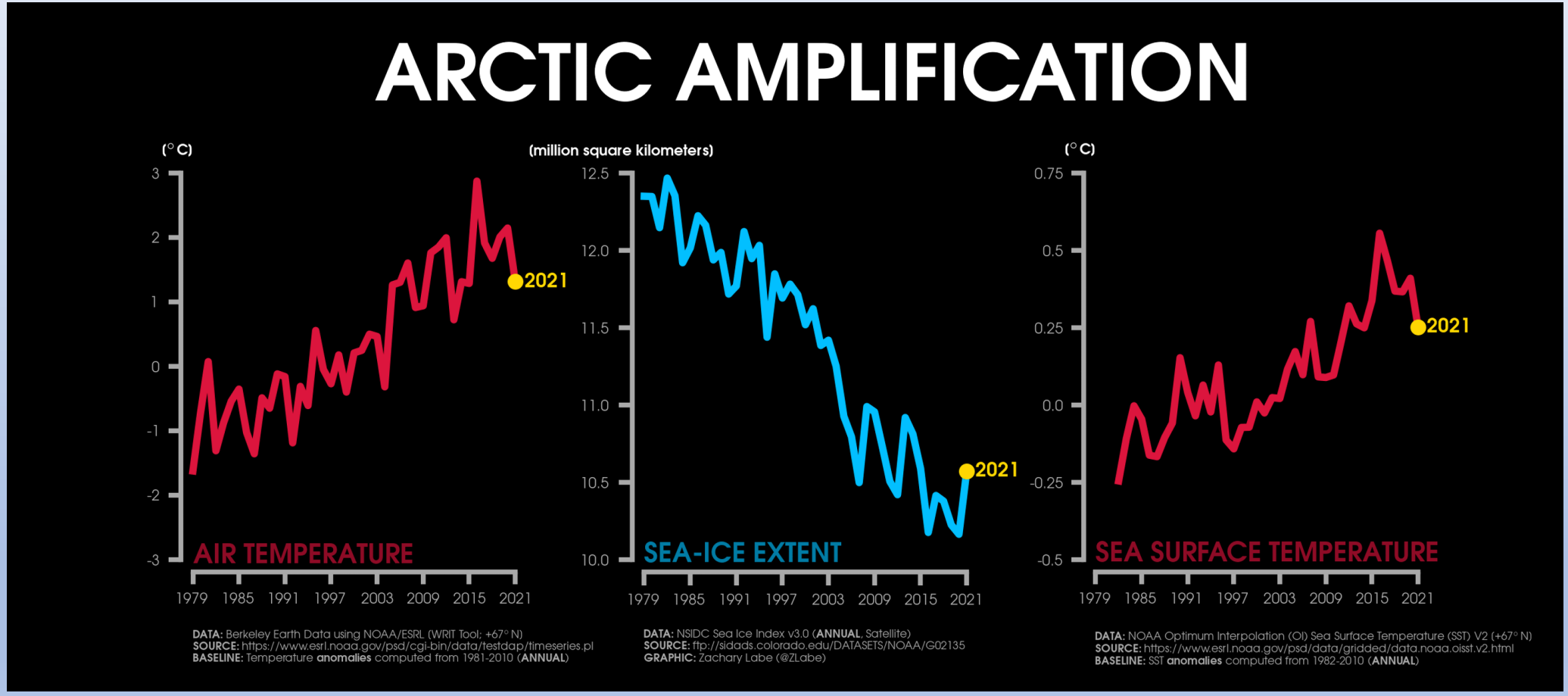
October Surface Air Temperature Trends



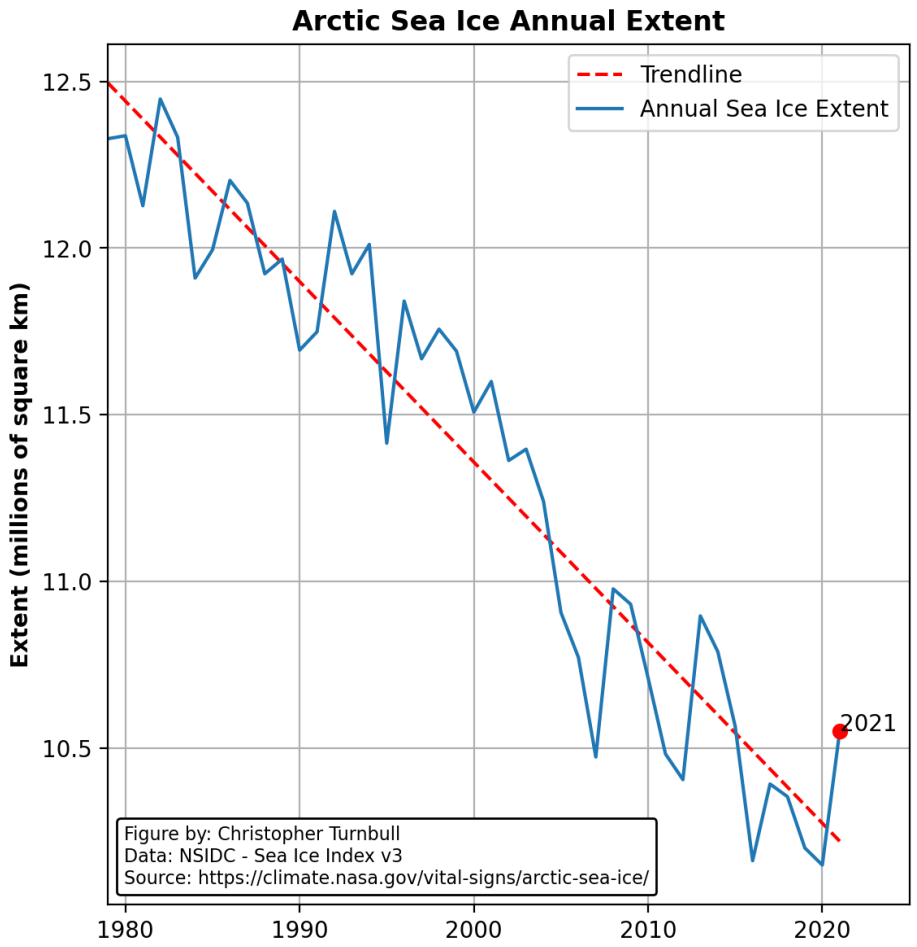

1960-2021 Zonal Mean Temperature Anomalies
Zonal Mean Temperature Anomaly (°C)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Antarctic
Midlatitudes
Tropics
Midlatitudes
Arctic
−90
−75
−60
−45
−30
−15
0
15
30
45
60
75
90
Latitude
Data: https://data.giss.nasa.gov/gistemp/maps/
Figure by: Christopher Turnbull

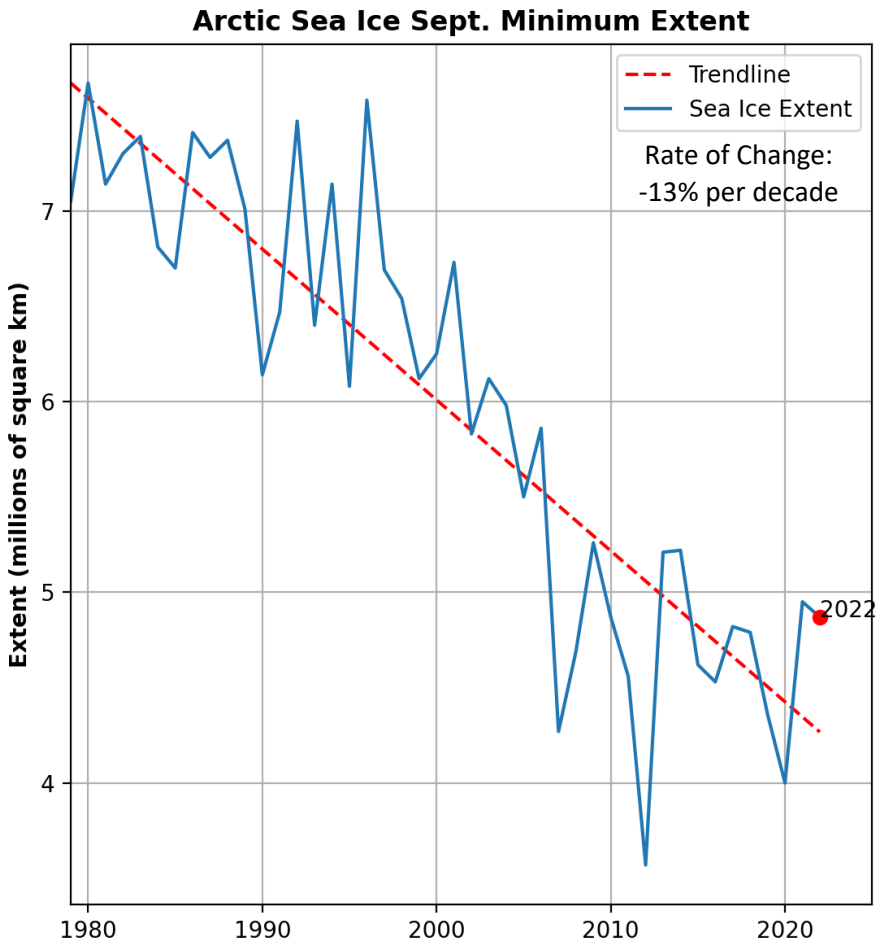
Zachary Labe – Arctic Amplification Graphic

https://sites.uci.edu/zlabe/arctic-sea-ice-figures/

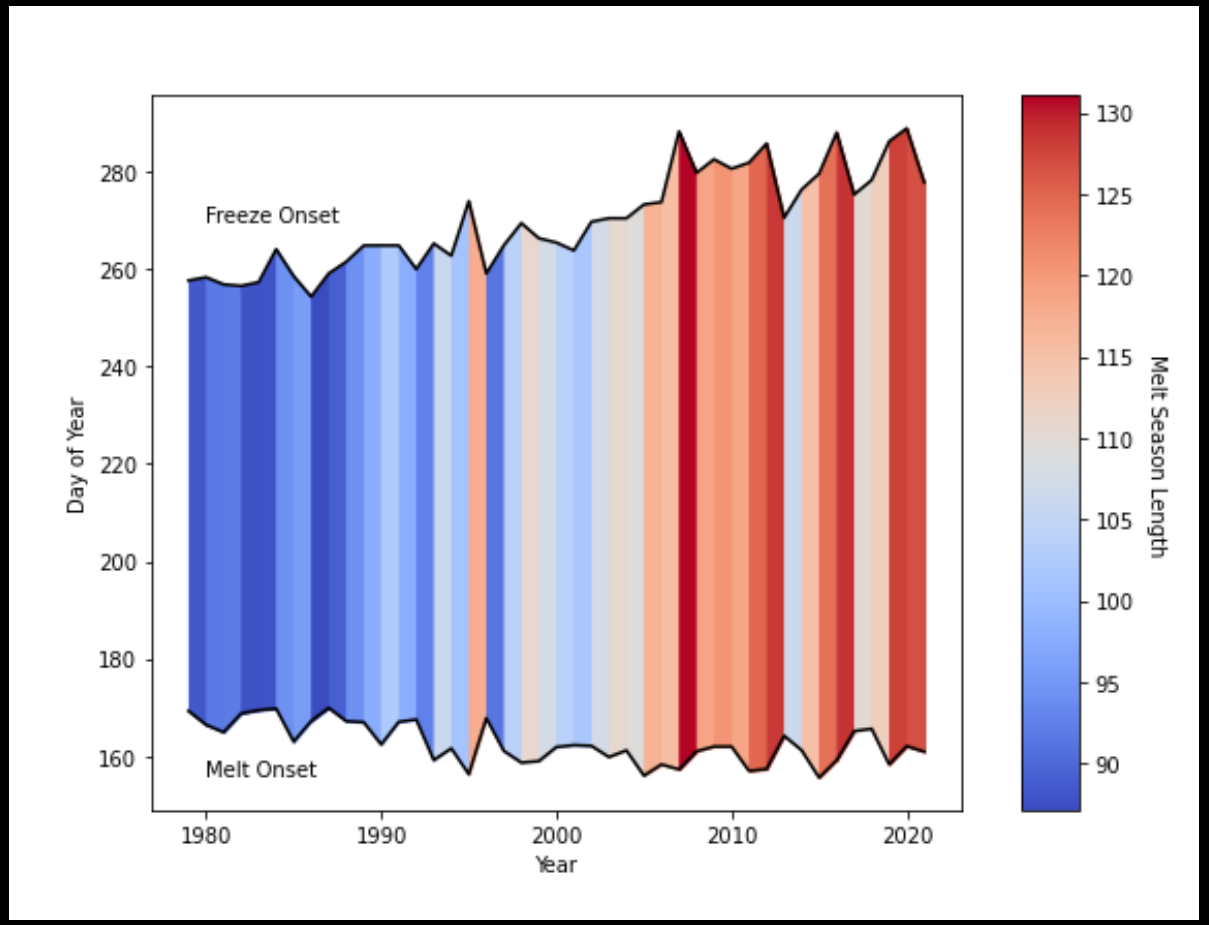


Changes in annual mean surface air temperature anomalies (Berkeley Earth Surface Temperature; BEST), annual mean Arctic sea ice extent (NSIDC, Sea Ice Index v3), and annual mean sea surface temperature anomalies (NOAA Optimum Interpolation Sea Surface Temperature V2; OISSTv2) over the satellite era and within the Arctic (>67N latitude). BEST is available from 1850 to 2021 at http://berkeleyearth.org/data/. OISSTv2 is available from 1982 to 2021 at https://www.esrl.noaa.gov/psd/data/gridded/data.noaa.oisst.v2.html. Updated 2/18/2022.


Arctic Sea Ice Annual Extent
Trendline
Annual Sea Ice Extent
Extent (millions of square km)
12.5
12.0
11.5
11.0
10.5
2021
1980
1990
2000
2010
2020
Figure by: Christopher Turnbull
Data: NSIDC - Sea Ice Index v3
Source: https://climate.nasa.gov/vital-signs/arctic-sea-ice/


Arctic Sea Ice Sept. Minimum Extent
Trendline
Sea Ice Extent
Rate of Change:
-13% per decade
Extent (millions of square km)
7
6
5
4
2022
1980
1990
2000
2010
2020

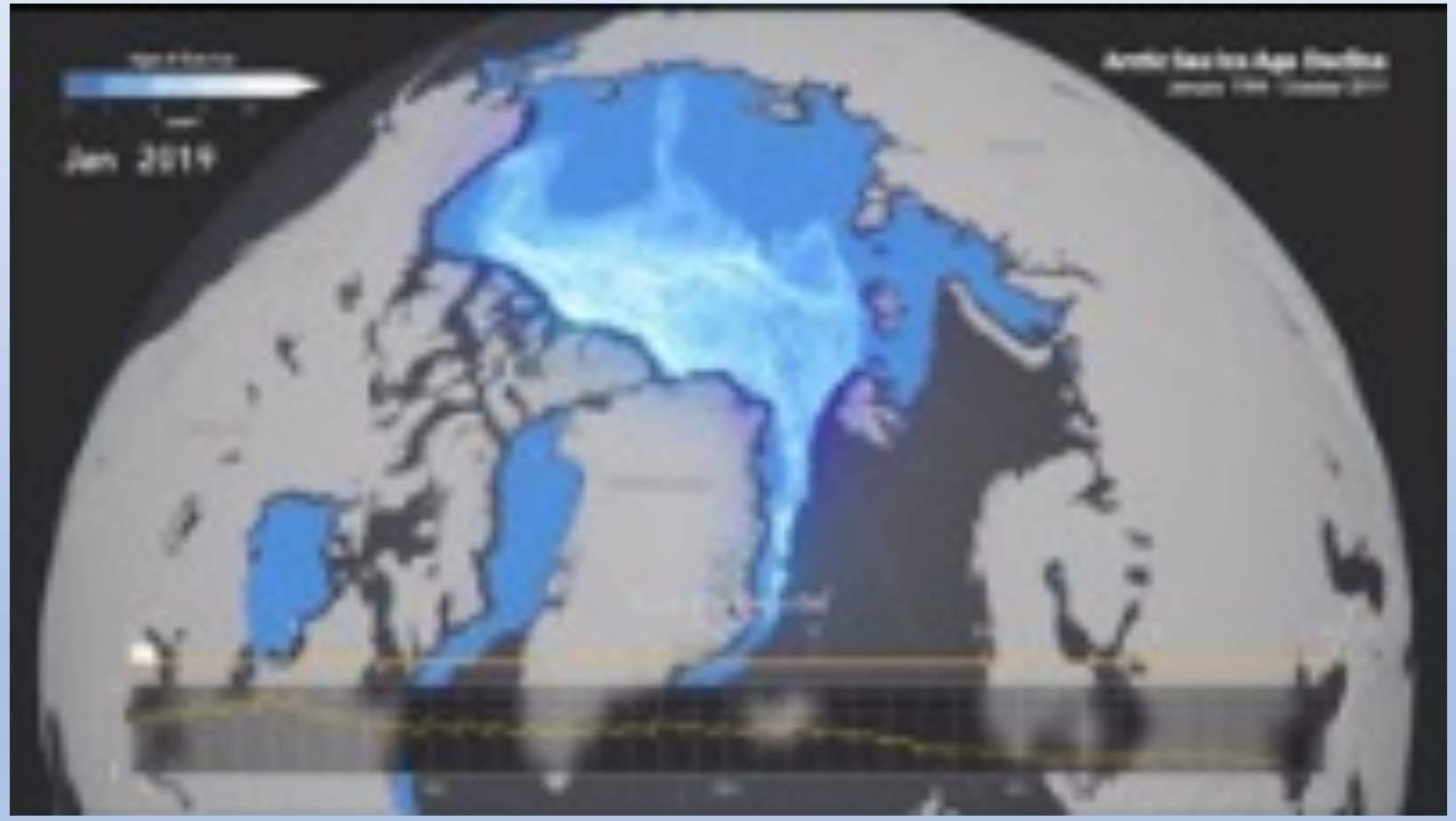
Sea Ice Melt Season



Updated through 2021

https://earth.gsfc.nasa.gov/cryo/data/arctic-sea-ice-melt

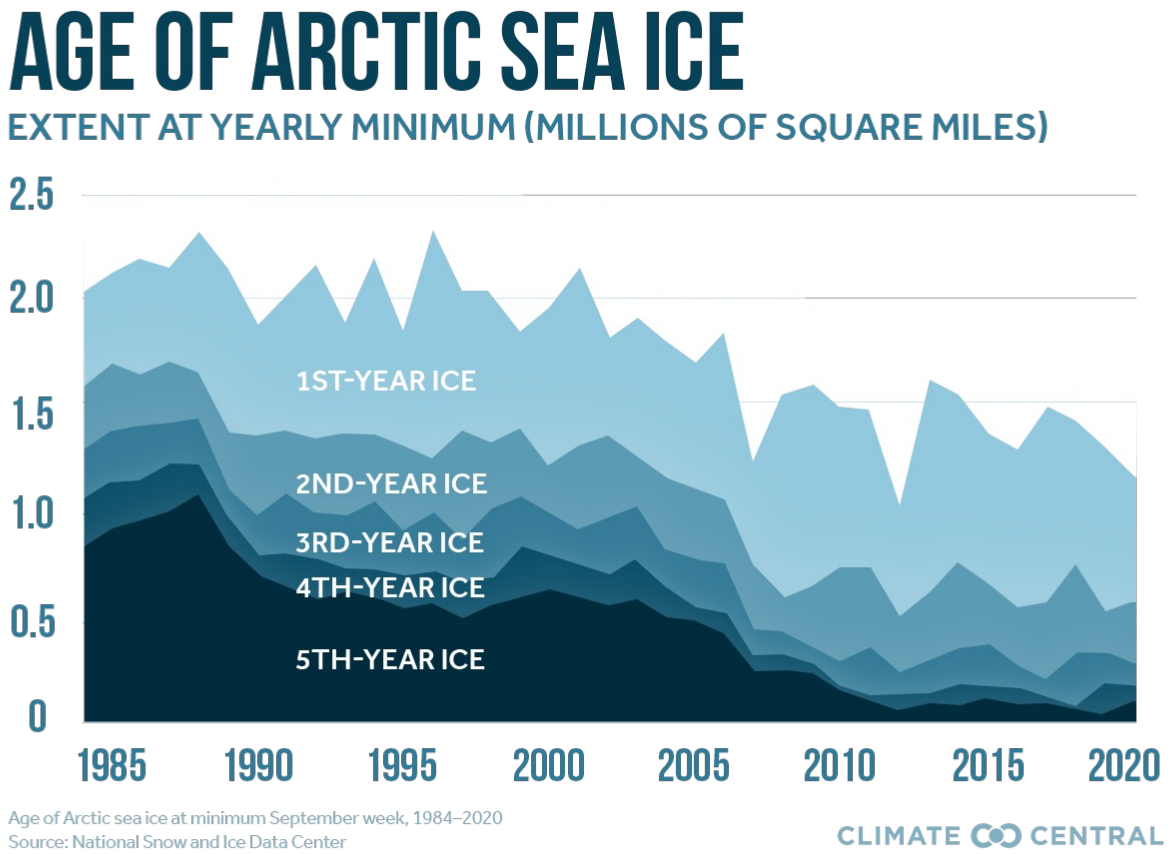
Age of Arctic Sea Ice (1984-2019)



https://youtu.be/C17-Z_sl5cI (ESRI - Animated Maps: Arctic Sea Ice Age Decline)

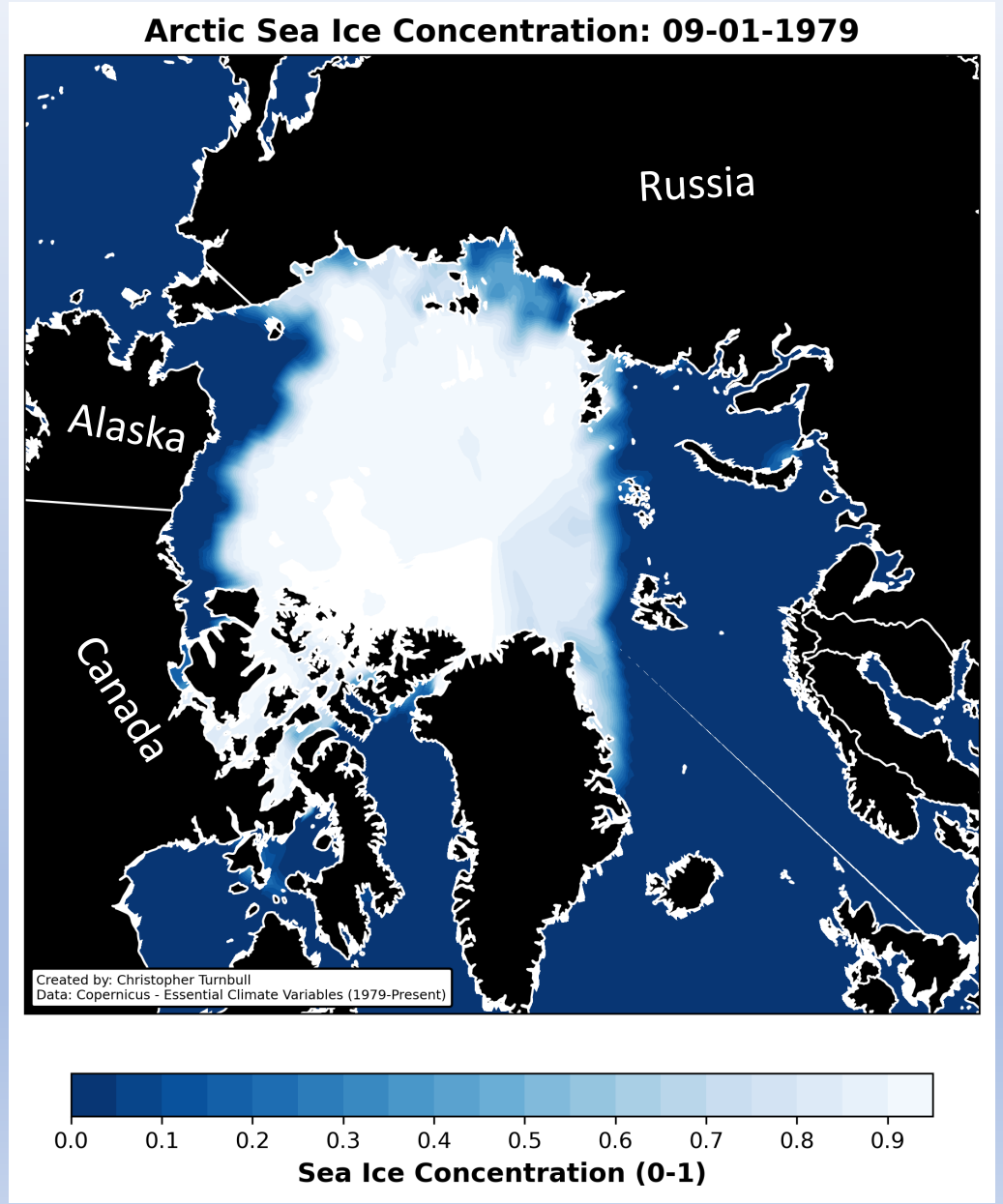
Multiyear Sea Ice

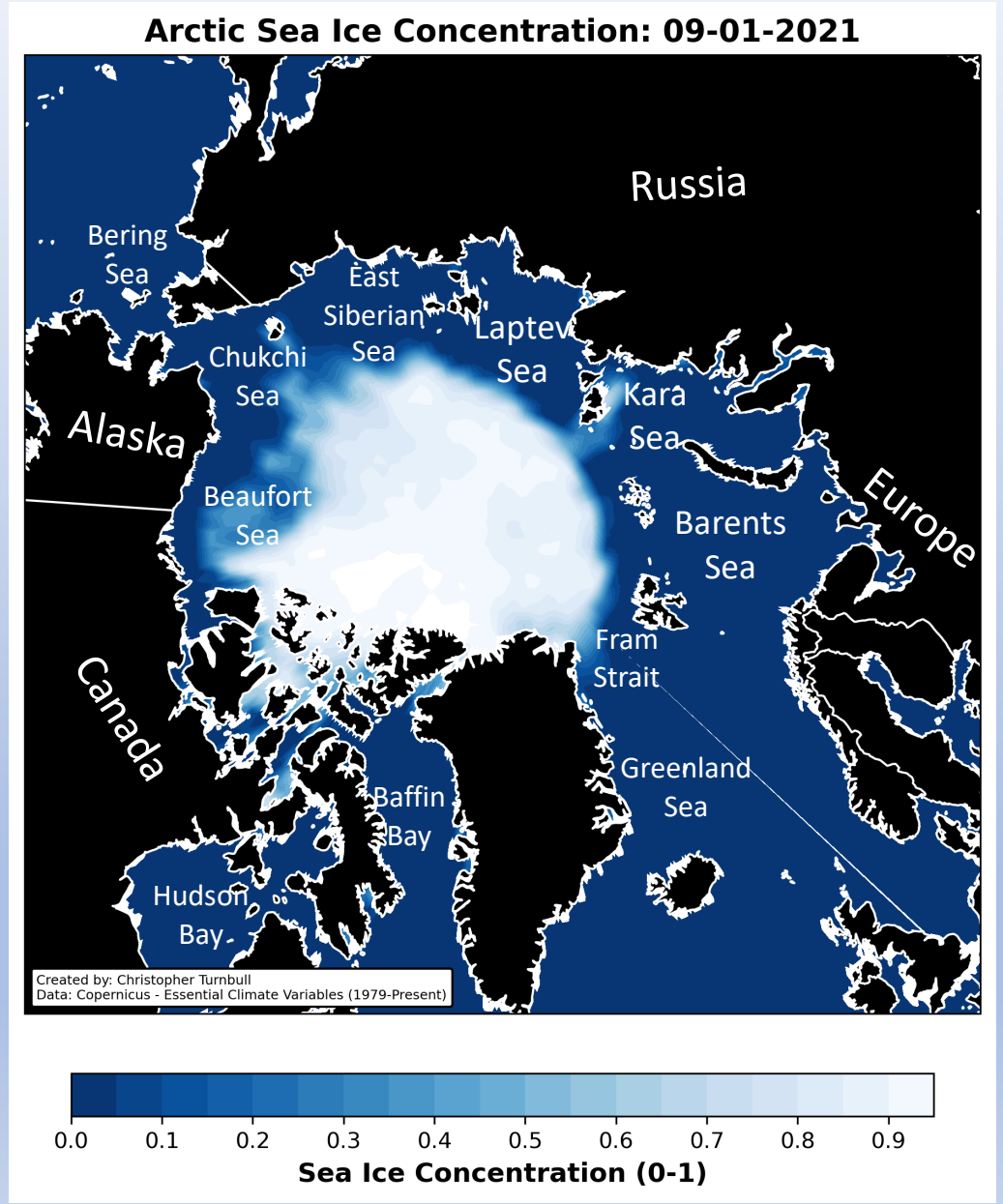
- Declined by **86%** since 1985
- March 2020:
  - Oldest sea ice only made up **2%** of sea ice cover
  - First-year ice: **70%**



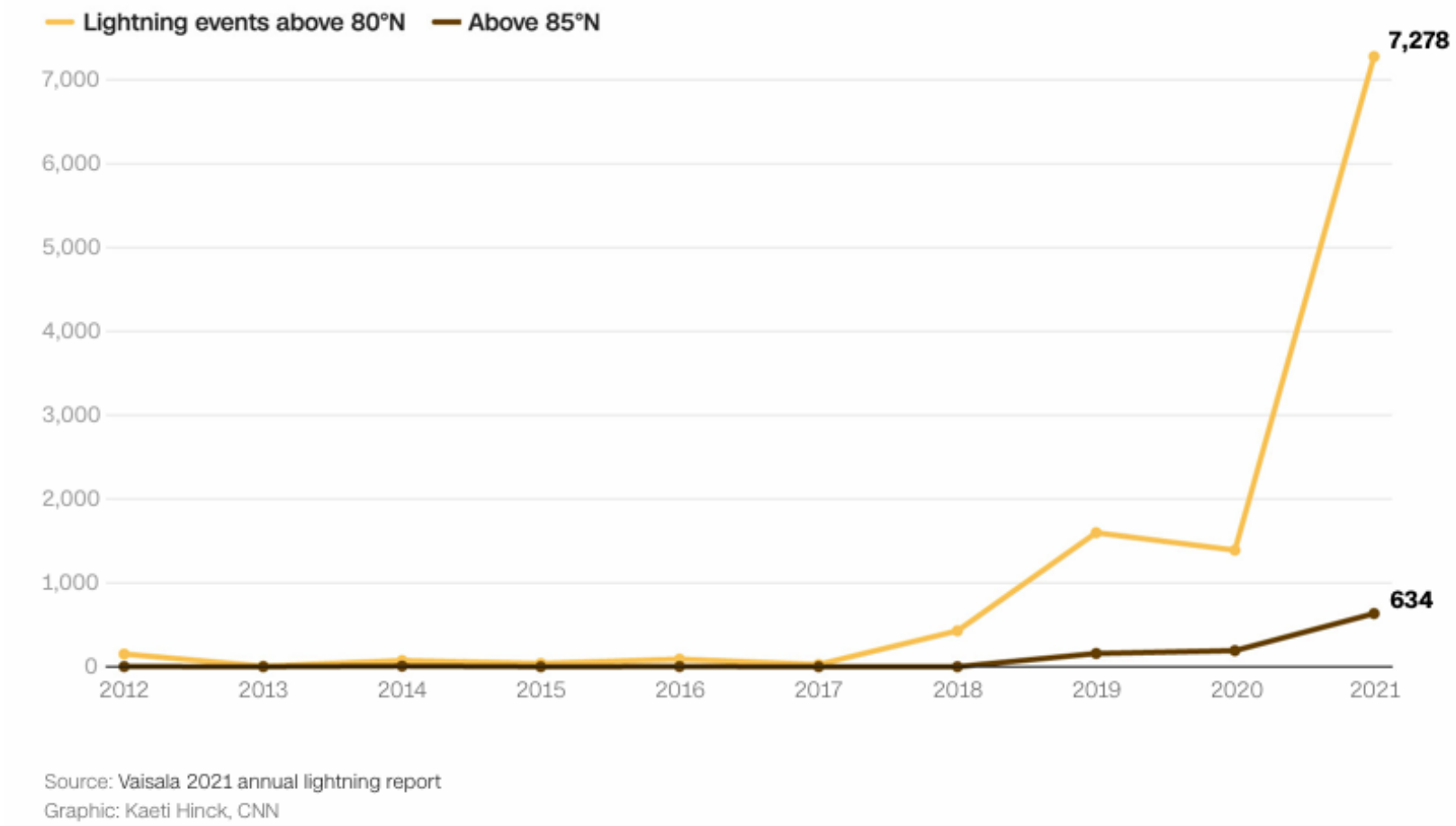
https://medialibrary.climatecentral.org/resources/arctic-sea-ice-minimum

Arctic Sea Ice September Minimum (1979 vs 2021)



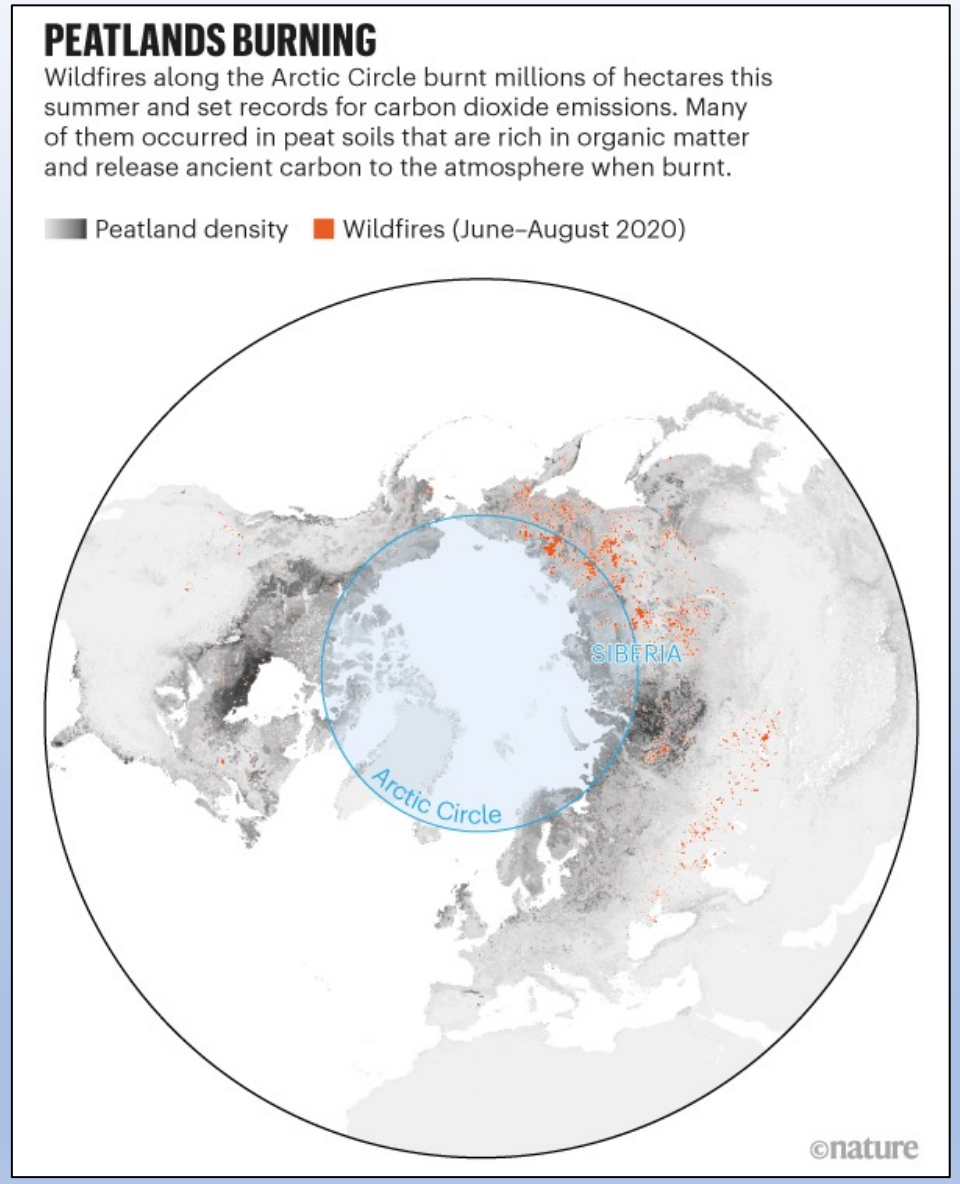


Arctic Lightning



Source: Vaisala 2021 annual lightning report
Graphic: Kaeti Hinck, CNN

2020 Arctic Wildfires



Sources: Copernicus Atmosphere Monitoring Service/European Centre for Medium-Range Weather Forecasts; Hugelius, G. *et al. Proc. Natl. Acad. Sci. USA* **117**, 20438–20446 (2020)

- 18K+ wildfires recorded in Russia's two easternmost districts in 2020
  - ~14 million hectares burnt
- Most of the burning happened in permafrost zones
  - Releases ancient carbon to the atmosphere
  - 2020 wildfires set records for CO_2 emissions
- Warming Arctic with increasing thunderstorm frequency leading to increasing wildfires

Anthrax

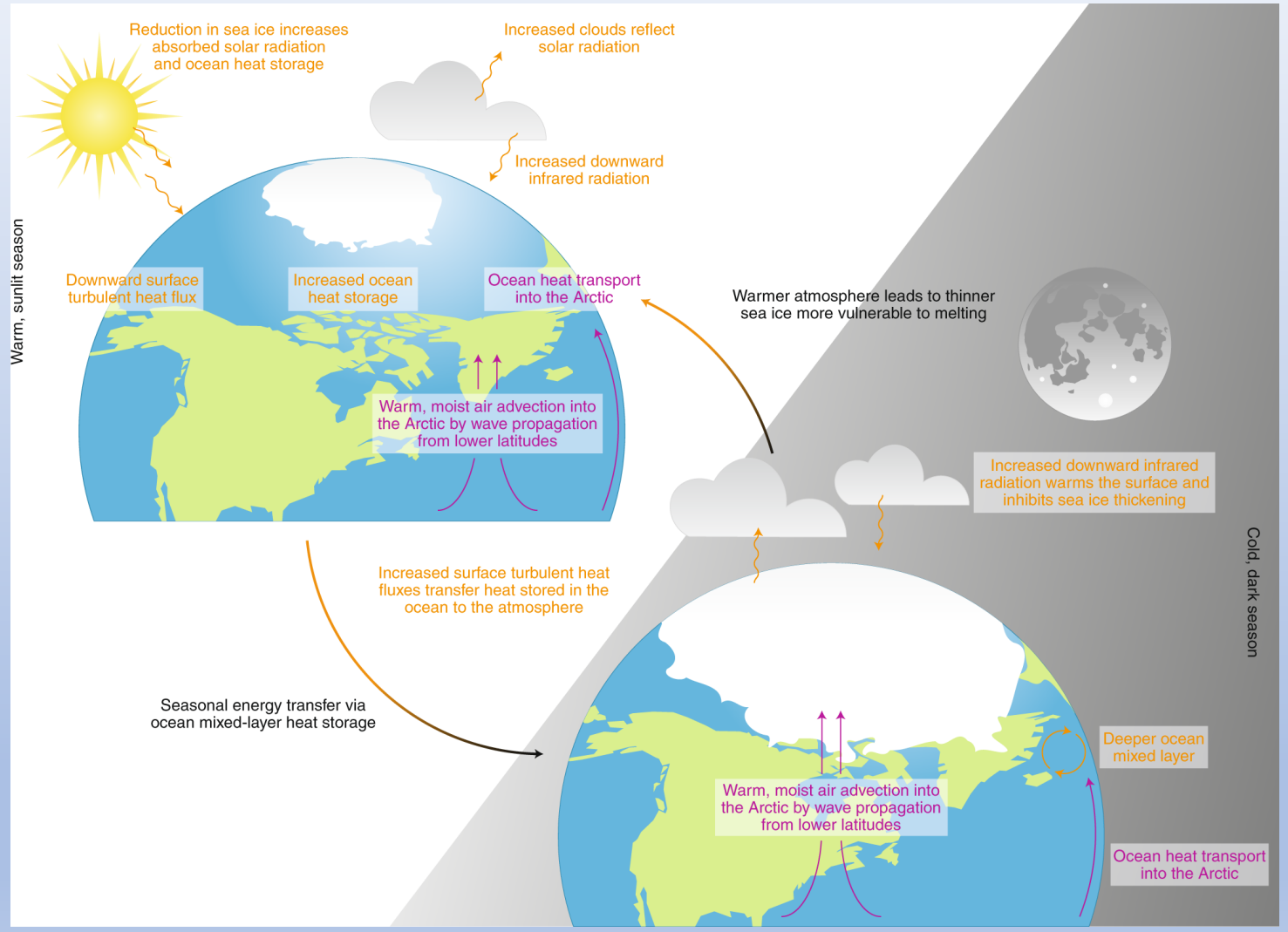
- Spiking cases of anthrax in deer and in humans as permafrost thaws
- Thousands of deer died in 2016 from an outbreak

https://www.nature.com/articles/d41586-020-02568-y

https://www.npr.org/sections/goatsandsoda/2016/08/03/488400947/anthrax-outbreak-in-russia-thought-to-be-result-of-thawing-permafrost

Arctic Amplification Mechanisms

- **Local forcings**
  - Feedbacks
    - Snow and sea ice albedo
    - Cloud
    - Ice insulation
- **Remote forcings**
  - Tropics → Arctic
  - Atmospheric & ocean heat transport
  - Atmospheric moisture transport
- Both types may interact and amplify one another



Cohen, J., Zhang, X., Francis, J. *et al.* Divergent consensuses on Arctic amplification influence on midlatitude severe winter weather. *Nat. Clim. Chang.* **10,** 20–29 (2020). https://doi.org/10.1038/s41558-019-0662-y

Contributors to Arctic Warming

- Emissions of greenhouse gases
  - CO_2, CH_4, NO_x
  - Energy Imbalance
- Increased atmospheric water vapor
  - 7% capacity increase / 1°C warming
  - Water vapor is a greenhouse gas
- Increased cloud coverage
  - Can have a warming effect, esp. in winter
  - Can have a cooling effect in summer

- Changes to ocean heat content and atmospheric circulation patterns
- Changes in poleward heat transport by the atmosphere and ocean

Recent Findings

- Arctic Amplification is stronger in the **low-emission** scenario after the mid-2040s
  - Sea ice continues to exist beyond 2040 and the ice-albedo feedback continues to drive Arctic warming

- In the **high-emission** scenario, summer sea ice melts away by 2050

- Climate change mitigation side effect
  - Arctic warming **continues** even if global warming is stabilized!

https://www.nature.com/articles/s43247-022-00354-4

The Role of Clouds

- CMIP5 model results disagree on whether Arctic cloud changes dampen or amplify AA
  - Evidence suggesting that LW_{down} from cloud cover during winter can hinder the growth of sea ice

- Analysis indicates that changes in downward LW radiation flux from a cloudless atmosphere, rather than the sea ice albedo feedback, is the largest contributing factor to simulated AA
  - Positive trends in downward LW radiation
    - Due to increased atmospheric water vapor over the Arctic Ocean for all seasons

Cohen et al: https://www.nature.com/articles/s41558-019-0662-y

Arctic Precipitation

- General agreement that Arctic precip. will **increase** through the 21st century
  - Estimates from 30% to 60% by 2100
    - Results from:
      - Increased evaporation
      - Higher air temperatures
      - Increasing the atmosphere's ability to carry moisture
      - Increased poleward moisture transport
- Impacts on GrIS Mass Balance, global sea level, river discharge, Arctic sea ice extent and permafrost

Arctic Precipitation (continued)

Transition from snow-dominated to rain-dominated precipitation regime	Some studies have concluded that rainfall will:	A rainfall-dominated precipitation regime could have pronounced impacts on:
• Transition already being observed over the Atlantic sector • But uncertainty exists regarding the regional extent and seasonality of these changes	• Increase in spring, autumn and winter • Whereas rainfall and snowfall are projected to increase over some regions during autumn and winter	• Greenland Ice Sheet mass balance • Global sea level • River discharge • Arctic sea ice extent and thickness • Permafrost • Flora, fauna and linked social-ecological systems

https://www.nature.com/articles/s41467-021-27031-y

Emerging Disruptions

Ocean noise

- Sea ice loss, more ship traffic are increasing underwater noise

Beaver range expansion

- Beaver ponds on Alaskan tundra doubled in most areas since 2000

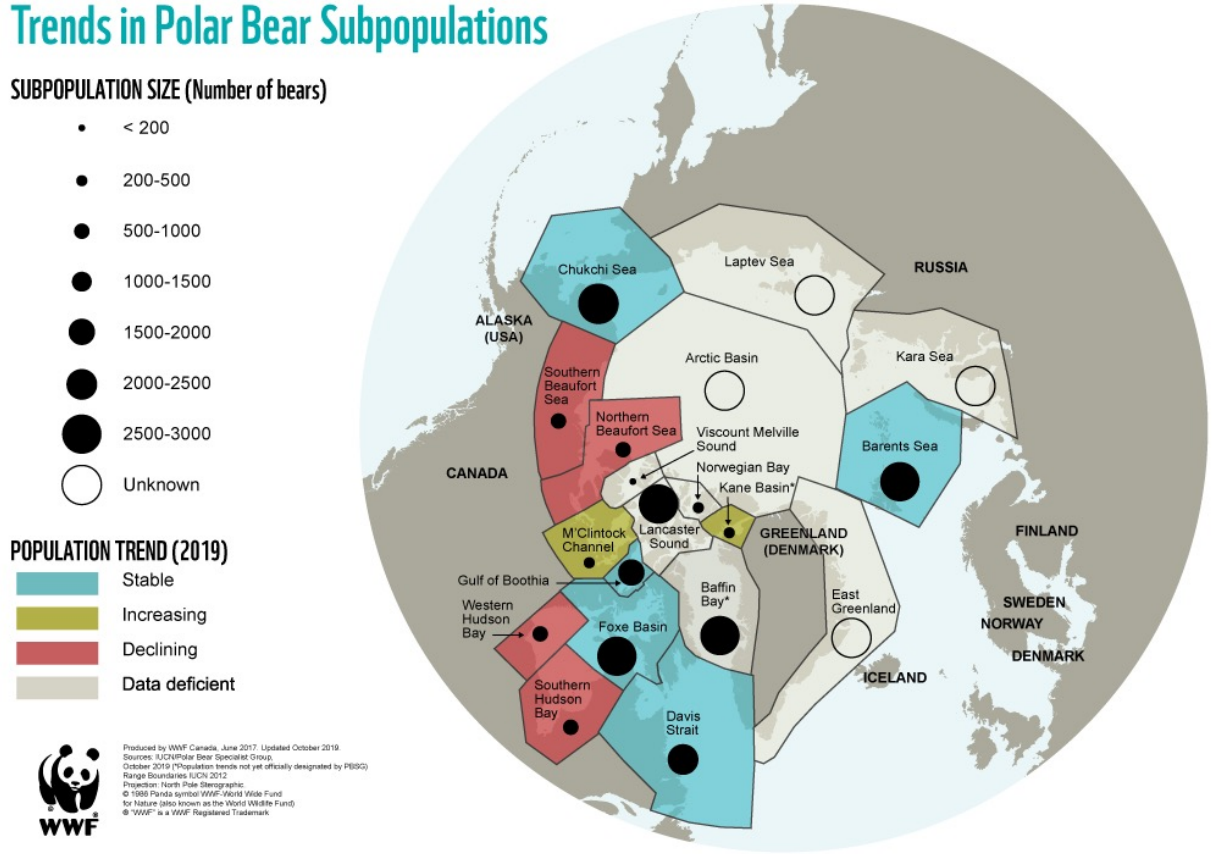
Glacier, permafrost hazards

- Glacier retreat, permafrost thaw bring landslides, infrastructure collapse

https://arctic.noaa.gov/Portals/7/ArcticReportCard/Documents/ArcticReportCard_full_report2021.pdf

Polar Bears

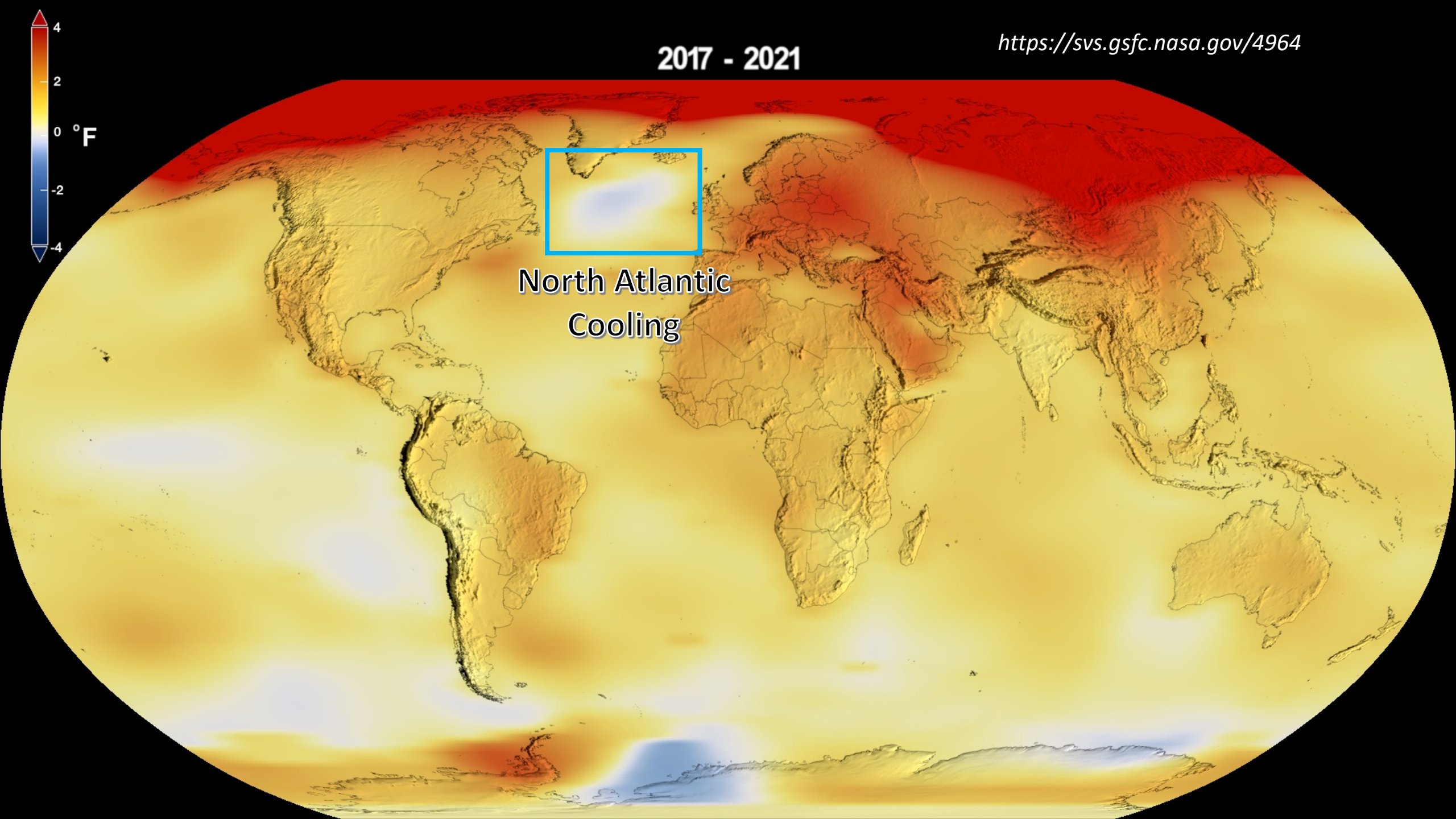
- All 19 subpopulations of polar bears have experienced ice loss
- Sea ice loss is the biggest threat to their numbers
- Classified as vulnerable by the IUCN in 2015
- Sea Ice loss affect polar bears' ability to find food
  - Longer periods without food
    - Lower average weight in adult females
    - Fewer cubs survive; ones that do are smaller
- Some ability to adapt
  - Foraging for food on land
  - But, increasing encounters with humans



https://www.carbonbrief.org/polar-bears-and-climate-change-what-does-the-science-say

https://arcticwwf.org/species/polar-bear/population/

https://www.worldwildlife.org/species/polar-bear


2017 - 2021
https://svs.gsfc.nasa.gov/4964
4
2
0
°F
-2
-4
North Atlantic
Cooling

Atlantic Meridional Overturning Circulation

- Driven by two components of ocean water: temperature and salt
- Climate change is weaking this circulation
  - Increased precipitation (rain and snow)
  - Melting of Arctic sea ice
  - Huge freshwater pulses from Greenland
- Consequences for our climate
  - Rapid return to glacial or near-glacial conditions?
  - Advances in ice sheets?
  - Rapid temperature drops?
- Steady weaking expected in the future
  - Shutdown is possible → not likely

https://www.washingtonpost.com/climate-environment/2021/02/25/atlantic-ocean-currents-weakening-amoc-gulf-stream/

https://www.nature.com/articles/s41558-020-0819-8

https://www.science.org/content/article/global-cold-snap-wasnt

Linking Sea Ice Melt to Midlatitude Weather

- Exposed Arctic Ocean in Fall → thinner sea ice in winter → heating of the atmosphere
  - Possible mechanism linking AA to midlatitude weather
- Heating of the Arctic troposphere leads to a weakening temperature gradient between the Arctic and mid-latitudes
  - Slows down of the polar jet stream
  - Theorized that weakened winds may lead to more amplified weather patterns
    - Blocking patterns associated with temperature/precipitation extremes
    - Changing the speed/tracks of Hurricanes
  - Remains a controversial subject in the scientific community

https://www.nature.com/articles/s41558-019-0662-y

Arctic Amplification - Key Takeaways

Major Impacts on:

The Arctic Ecosystem (animals, productivity, permafrost)

Marine Traffic (noise, garbage, security, commerce)

Local populations (food security)

Global / Local Climate

More Research Still Needed on:

Extreme weather events → Blocking Patterns

Effects on the Polar Vortex / Polar Jet Stream

Depletion of Arctic Ozone

Climate impacts from slowing AMOC

Interactions between local and remote forcings

Arctic Amplification and Future Climate

- Linkages between future Arctic climate change and mid-latitude weather remains unclear in climate modeling
  - Barnes et al. 2015, Cohen et al. 2020
- Due to:
  - Internal variability in the climate system
  - Competing influences on the jet stream
  - Nonlinear interactions
  - Model biases
- PAMIP will try to answer some of these questions

https://sites.uci.edu/zlabe/arctic-amplification/

Post-Presentation Updates (July 2022)

Polar Bear News

- https://www.weforum.org/agenda/2022/06/isolated-greenland-polar-bear-population-adapts-to-climate-change

AMOC News

- https://www.nature.com/articles/s41558-022-01380-y.pdf

Extreme Weather Events

- https://www.nature.com/articles/s41558-022-01380-y.pdf

Data sources:

- NASA – Goddard Institute for Space Studies
- NASA's Jet Propulsion Laboratory - Global Climate Change – Vital Signs of the Planet (https://climate.nasa.gov/vital-signs/)
- NSIDC – Sea Ice Index v3 (ftp://sidads.colorado.edu/DATASETS/NOAA/G02135)
- NASA Earth Sciences – Goddard Earth Science Projects (*https://earth.gsfc.nasa.gov/cryo/data/arctic-sea-ice-melt*)

Data sources (continued)

- ECMWF's Copernicus – Climate Data Store
- *https://www.nature.com/articles/s41467-021-27031-y*
- https://www.nature.com/articles/d41586-020-02568-y
- https://www.cnn.com/2022/01/05/world/lightning-increased-north-pole-arctic-2021-climate/index.html
- https://earthobservatory.nasa.gov/images/81214/arctic-amplification

More Data Sources

- https://sites.uci.edu/zlabe/arctic-amplification/
- https://medialibrary.climatecentral.org/resources/arctic-sea-ice-minimum
- https://yaleclimateconnections.org/2021/11/2021-pacific-northwest-heat-wave-virtually-impossible-without-global-warming-scientists-find/
- https://www.nature.com/articles/s41612-018-0031-y
- https://www.nature.com/articles/s41558-019-0662-y
- https://www.science.org/content/article/global-cold-snap-wasnt

Other

- https://www.nature.com/articles/s41467-018-04173-0#Sec16
- https://iopscience.iop.org/article/10.1088/1748-9326/aade56#erlaade56s5
- https://www.nature.com/articles/ngeo2234
- https://www.nature.com/articles/s41467-022-28283-y
- https://www.nature.com/articles/s41467-021-24089-6
- https://www.climate.gov/news-features/featured-images/2020-arctic-air-temperatures-continue-long-term-warming-streak
- https://climatedataguide.ucar.edu/climate-data/hurrell-wintertime-slp-based-northern-annular-mode-nam-index

News

- https://www.vox.com/2020/6/23/21300279/arctic-siberia-temperature-heat-wave-record-russia-fire-climate-change
- https://arctic.noaa.gov/Report-Card/Report-Card-2020/ArtMID/7975/ArticleID/903/Wildland-Fire-in-High-Northern-Latitudes
- https://www.climate.gov/news-features/understanding-climate/climate-change-arctic-sea-ice-summer-minimum?fbclid=IwAR23iY58tkeB5MS18UQFUpOjEFKdZG8FzeRhtc8AEI8Zs1hCBpVb8NxhNwI
- https://arctic.noaa.gov/Portals/7/ArcticReportCard/Documents/ArcticReportCard_full_report2021.pdf

More News

- https://arctic.noaa.gov/Report-Card/Report-Card-2021/ArtMID/8022/ArticleID/948/Surface-Air-Temperature
- https://www.epa.gov/climate-indicators/climate-change-indicators-arctic-sea-ice
- https://www.worldwildlife.org/pages/six-ways-loss-of-arctic-ice-impacts-everyone
- https://nsidc.org/cryosphere/arctic-meteorology/climate_change.html
- https://www.nbcnews.com/science/science-news/heat-wave-snowfall-researchers-are-puzzled-antarcticas-recent-weather-rcna21120?cid=sm_npd_nn_tw_ma