Cryosphere

What is the cryosphere?

- Cryosphere: the places on Earth where water exists in solid form (cryosphere is a word derived from kryos, the Greek word for cold)
- It includes sea ice, lake and river ice, snow cover, glaciers, ice caps and sheets, and permafrost
  - Glaciers: form in regions where the winter's snowfall does not melt completely over the summer (area >= is 0.1 km^2) .
  - Ice sheets: large areas of glacial ice (also known as continental glaciers,), covering 50,000 km^2 or more. There are two ice sheets in today's climate, covering Antarctica and Greenland.
  - Sea ice: ice that forms in the ocean. About 15% of the ocean surface is covered by sea ice for some part of the year.
  - Icebergs: form on glaciers and calve into the ocean.

See Cook 2013, and also see https://news.climate.columbia.edu/2018/02/05/glaciers-ice-sheets-polar-ice/

Why do we care about the cryosphere?

- Snow and ice are critical parts of the hydrologic cycle, especially at higher latitude or mountainous locations. The water stored in a frozen state is released during the spring, providing water during the rest of the year. Mountain snowpacks are an important source of water, especially in arid and semi-arid regions.
  - The Sierra snowpack supplies about 30% of California's water needs. The Sierra snowpack is often referred to as California's "frozen reservoir." (https://water.ca.gov/)
- Nearly 70% of Earth's fresh water is stored in glaciers and ice caps, and more than a billion people around the world rely on the cryosphere as a source of drinking water.

Connection to the Climate System

- High surface albedo; low thermal conductivity; large thermal inertia
- The cryosphere is sensitive to the Earth's temperature variations.
  - With just slight variations in Earth's temperature, thousands of square miles of snow and ice can accumulate or melt, making the cryosphere one of the most powerful indicators of climate and climate change.
- The cryosphere is an important player of climate feedback loops: such as the ice albedo feedback
- A source of predictability for the atmosphere: e.g., snow cover and monsoons
- The cryosphere provides vital information about past, present, and future climate
  - Ice cores provide air samples (air bubbles trapped in ice) and information about past temperature and precipitation through isotopic analyses

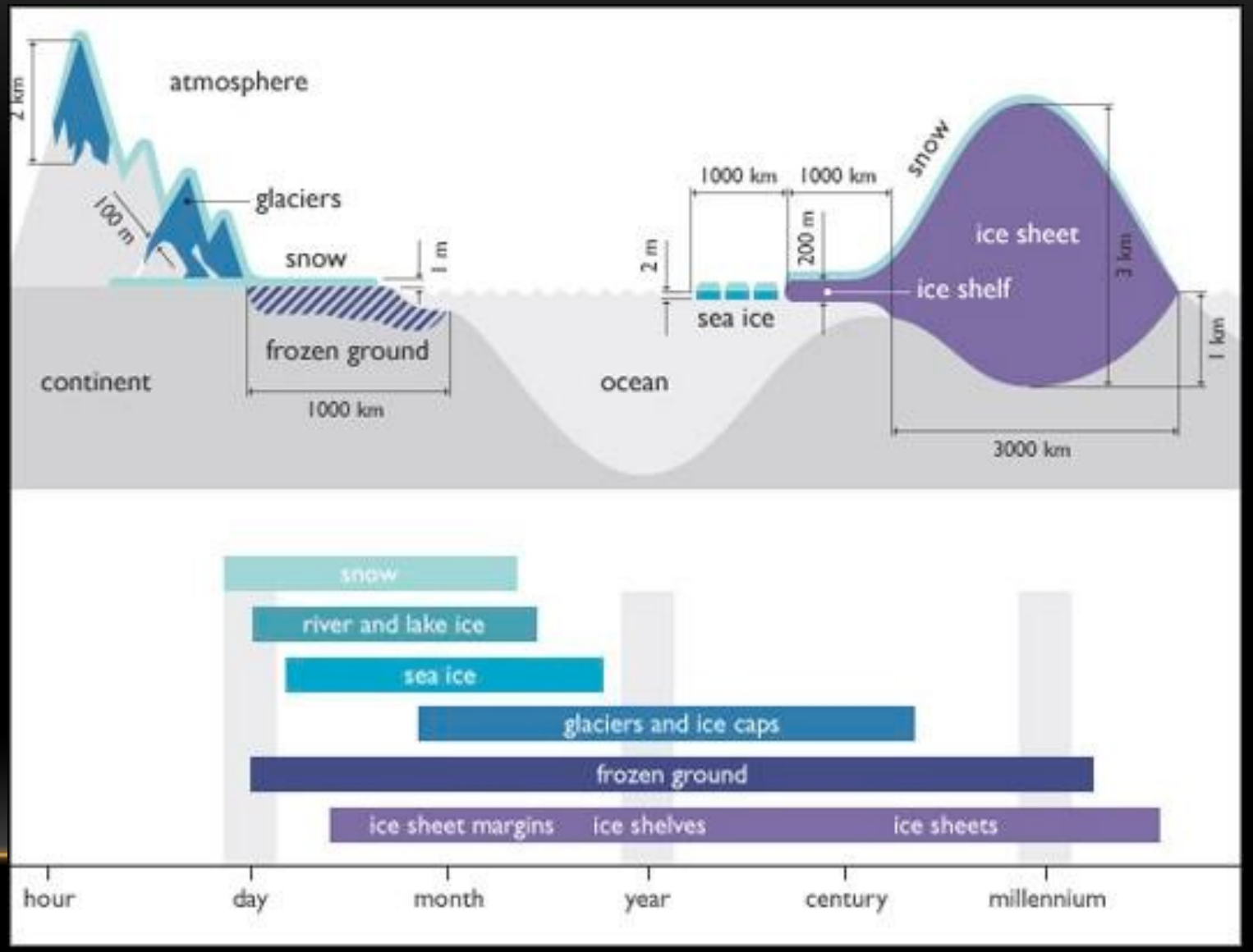
Pictures from NASA News

An ice core. Credit: NASA's Goddard Space Flight Center/Ludovic Brucker.

The dark band in this ice core from West Antarctica is a layer of volcanic ash that settled on the ice sheet approximately 21,000 years ago. Credit: Heidi Roop, National Science Foundation (NSF).

Components of the cryosphere and their time scales

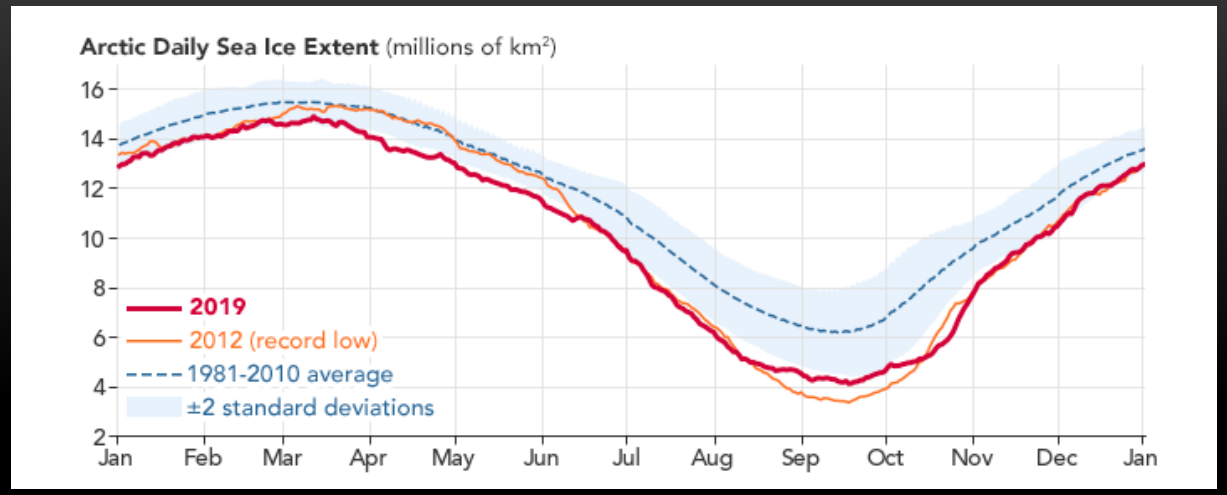
- The cryosphere is constantly changing as snow and ice go through cycles of growth and melt and get pushed around by wind, ocean currents, and other dynamic forces.
- Different parts of the cryosphere change on different timescales ranging from less than a day to more than a millennium, as shown in the figure below.

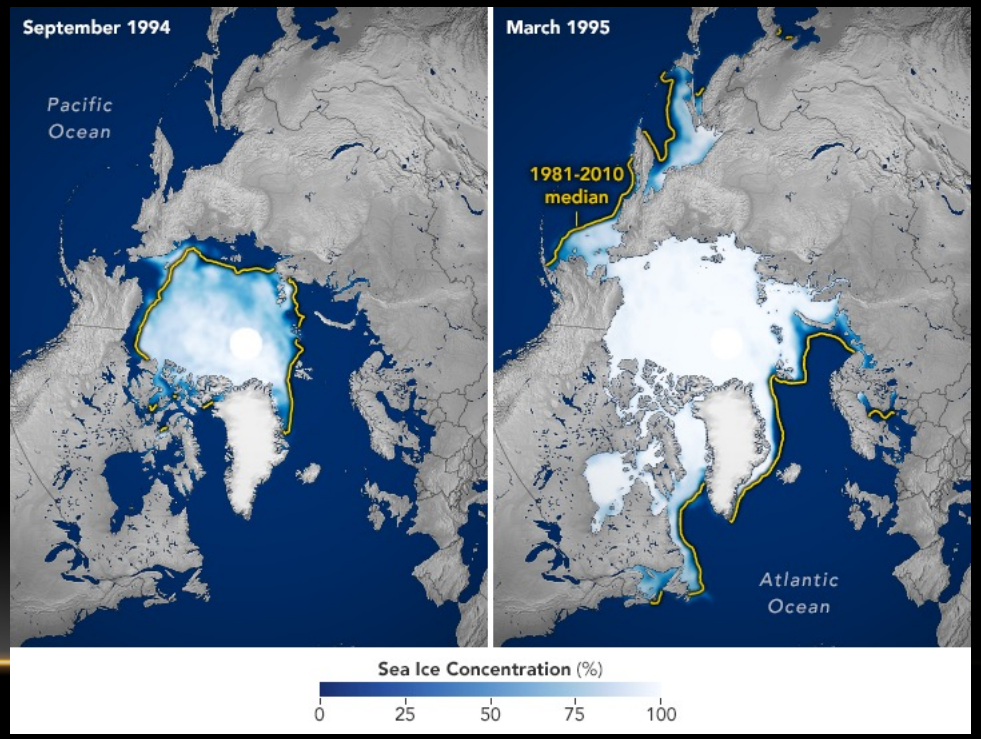


Source: IPCC Fourth Assessment Report: Climate Change 2007, Figure 4.1

Seasonal Cycle of Sea Ice

- Sea ice extent reaches its annual minimum in September in the Arctic and in March in the Antarctic.
- Antarctic sea ice extent displays an even larger seasonal variation than Arctic sea ice (largely an effect of continentality)
- See the year-to-year variability at https://earthobservatory.nasa.gov/world-of-change/sea-ice-arctic

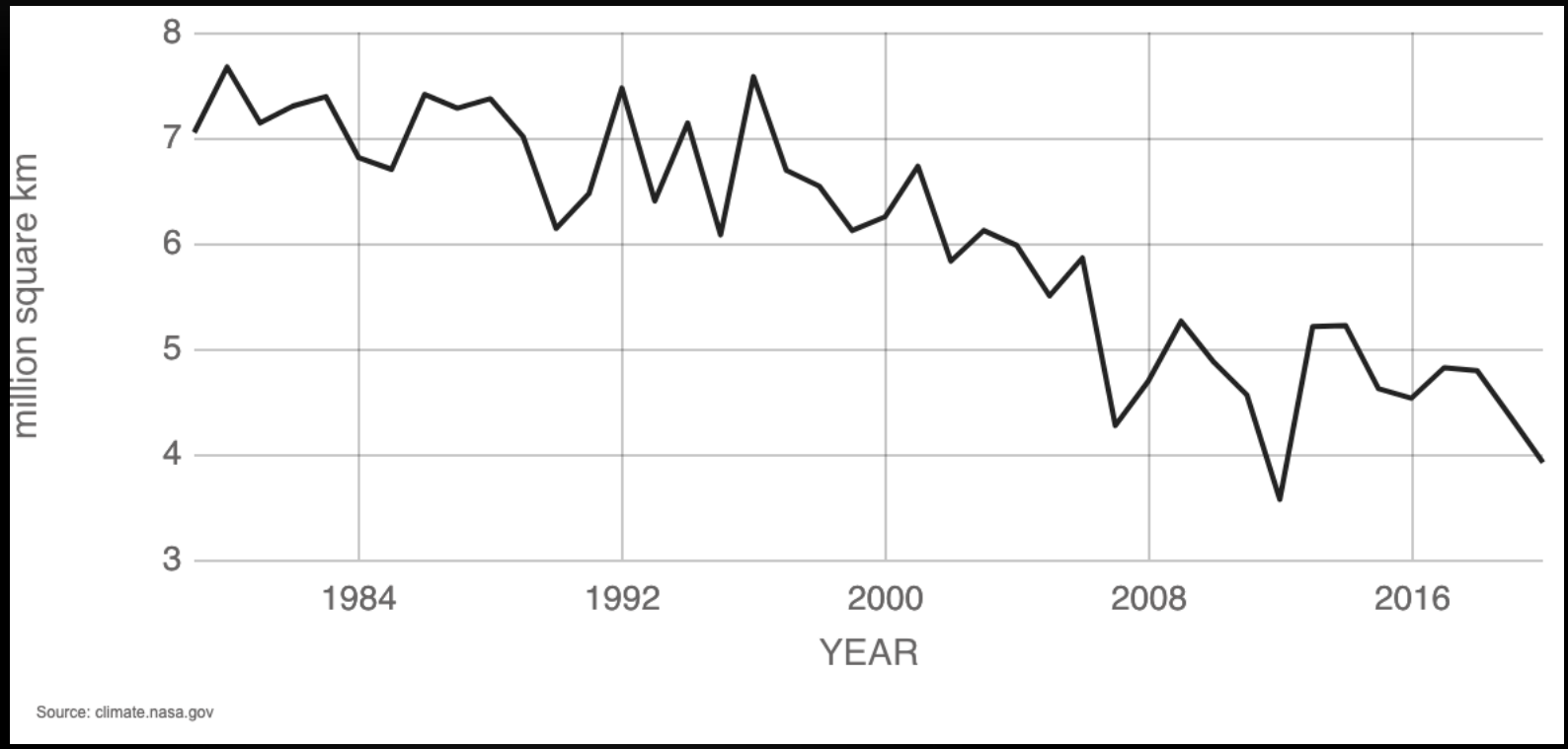




Figures from NASA: https://earthobservatory.nasa.gov/world-of-change/sea-ice-arctic

Sea Ice Decline in the Arctic

- Arctic sea ice reaches its annual minimum in September. The Arctic sea ice extent is declining at a rate of 13.1% per decade, relative to the 1981 to 2010 average. (https://climate.nasa.gov/vital-signs/arctic-sea-ice/)
- Also see animated Arctic sea ice coverage at this website.



Time series of annual minimum sea ice extent (in September), from https://climate.nasa.gov/vital-signs/arctic-sea-ice/

Ice Sheets

- The Antarctic Ice Sheet is the largest in the world.
- The Greenland ice sheet is the second largest in the world and is the largest terrestrial ice mass in the Arctic.
- The estimated ice volume is 2.93 × 10^6 km^3. The complete melt of the Greenland Ice Sheet would cause an approximate global sea level rise equivalent of 7.2 m.
- The mass balance of both ice sheets is negative, contributing to the current estimated sea level rise of 3.1 mm per year
- The mass losses for Greenland are larger than for the Antarctic Ice Sheet, and the mass loss from Greenland in particular has accelerated over the recent decades.

Extent of summer melt on Greenland

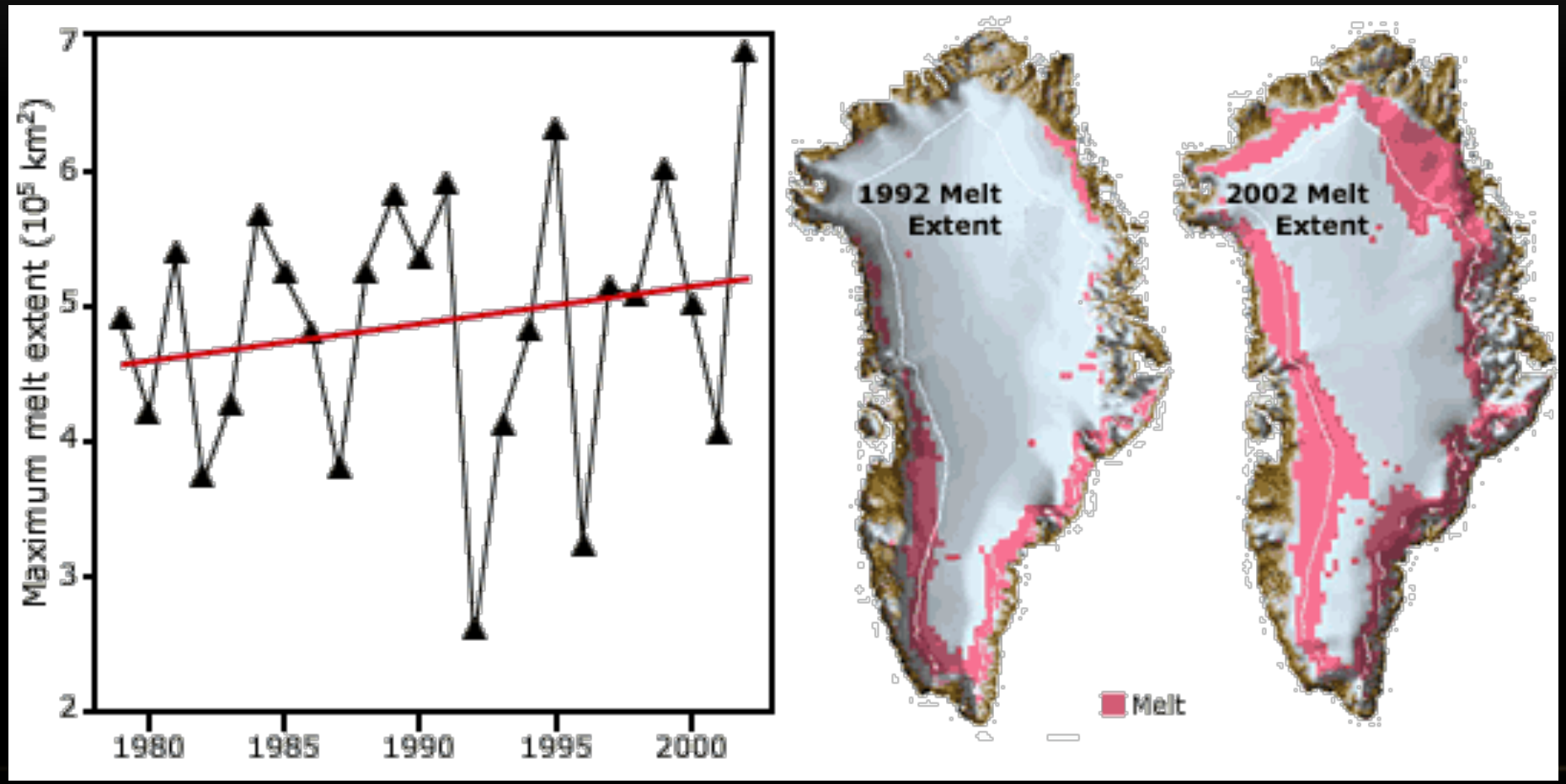
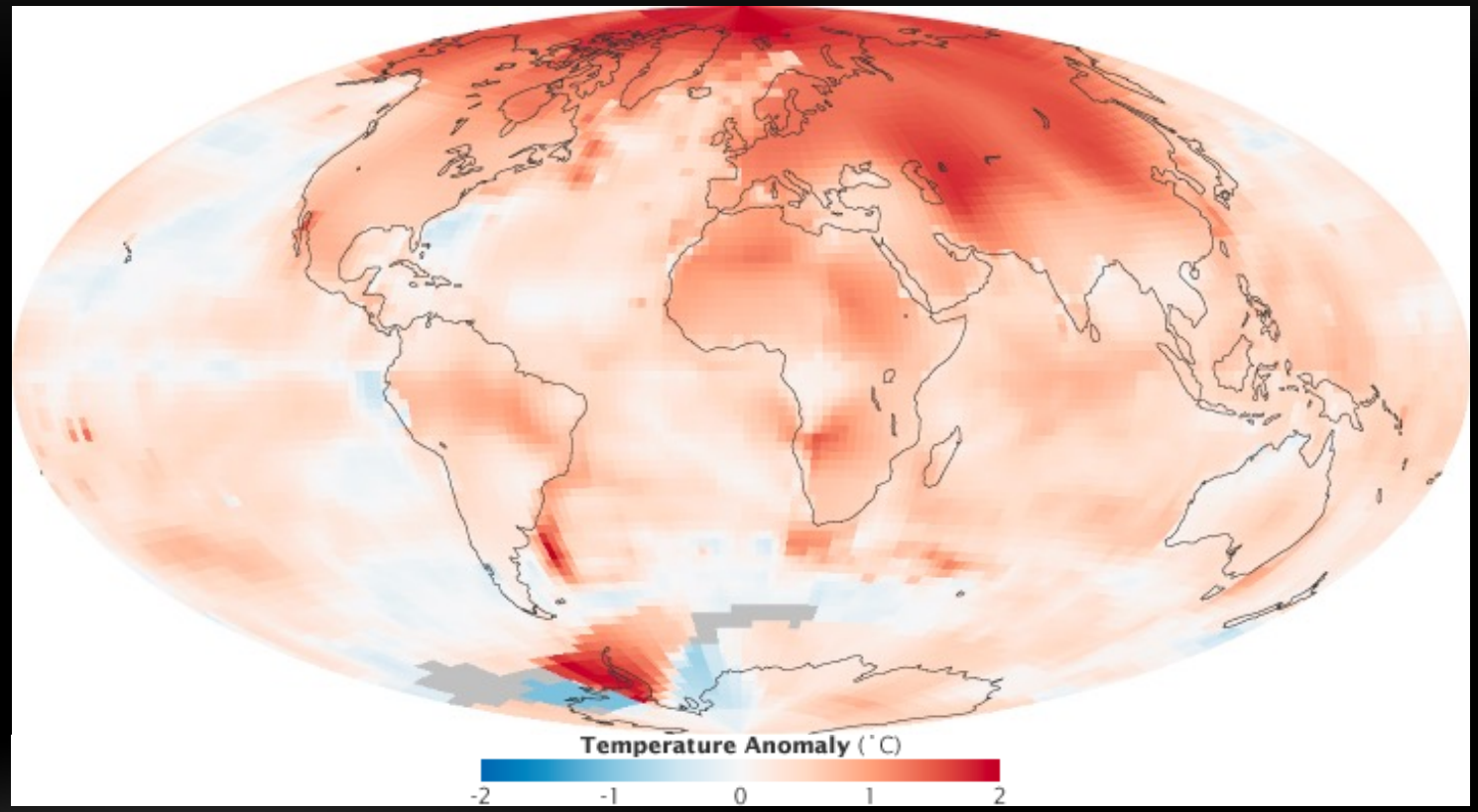


Figure from https://www.pmel.noaa.gov/arctic-zone/detect/ice-glacier.shtml

Arctic Amplification

- Temperatures warm faster in the Arctic than the rest of the world
- Positive climate feedbacks (including ice-albedo feedback) contribute to Arctic amplification.



Temperature anomalies for 2000-2009 with respect to 1951-1980

Figure from https://earthobservatory.nasa.gov/images/81214/arctic-amplification

References

- Cook, K. H., 2013: section 2.4
- NASA video, *A Tour of the Cryosphere 2009*
- Arctic essays: Sea Ice, https://arctic.noaa.gov/Report-Card/Report-Card-2019/ArtMID/7916/ArticleID/841/Sea-Ice
- EarthLabs: Climate and the Cryosphere (https://serc.carleton.edu/eslabs/cryosphere/1a.html)
- Serreze, M. and Barry, R., 2014: The Arctic Climate System. Chapter 8