

Air-sea interaction: Polar regions

ATM2106

The Arctic

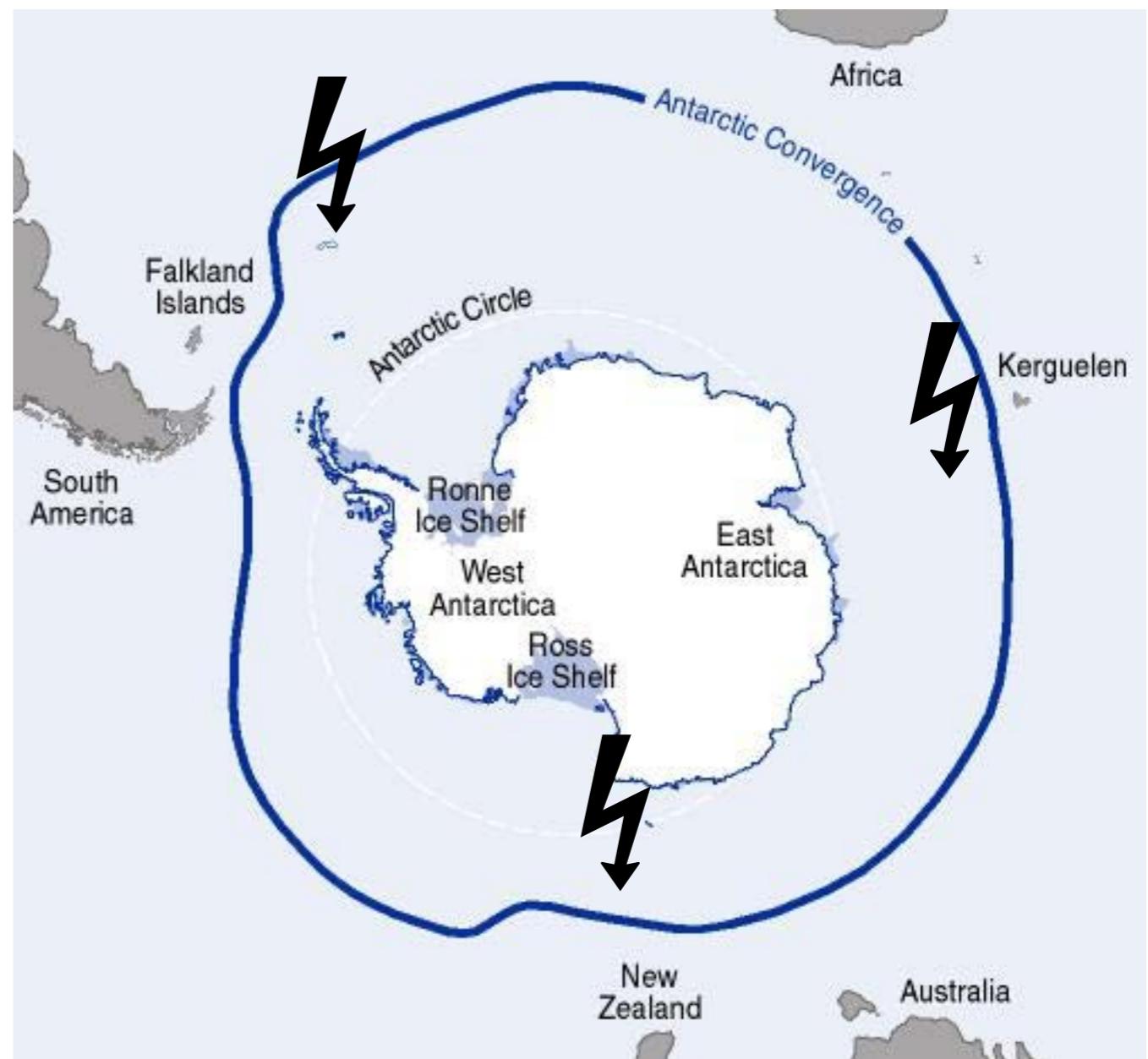
- The Arctic is defined as the area within the Arctic circle.
- Cold conditions
- Presence of ice, snow and water
- The Arctic is a frozen ocean surrounded by continental landmasses and open oceans.



Image from <https://www.cruisespecialists.com/blogs/wp-content/uploads/2017/03/arctic.jpg>

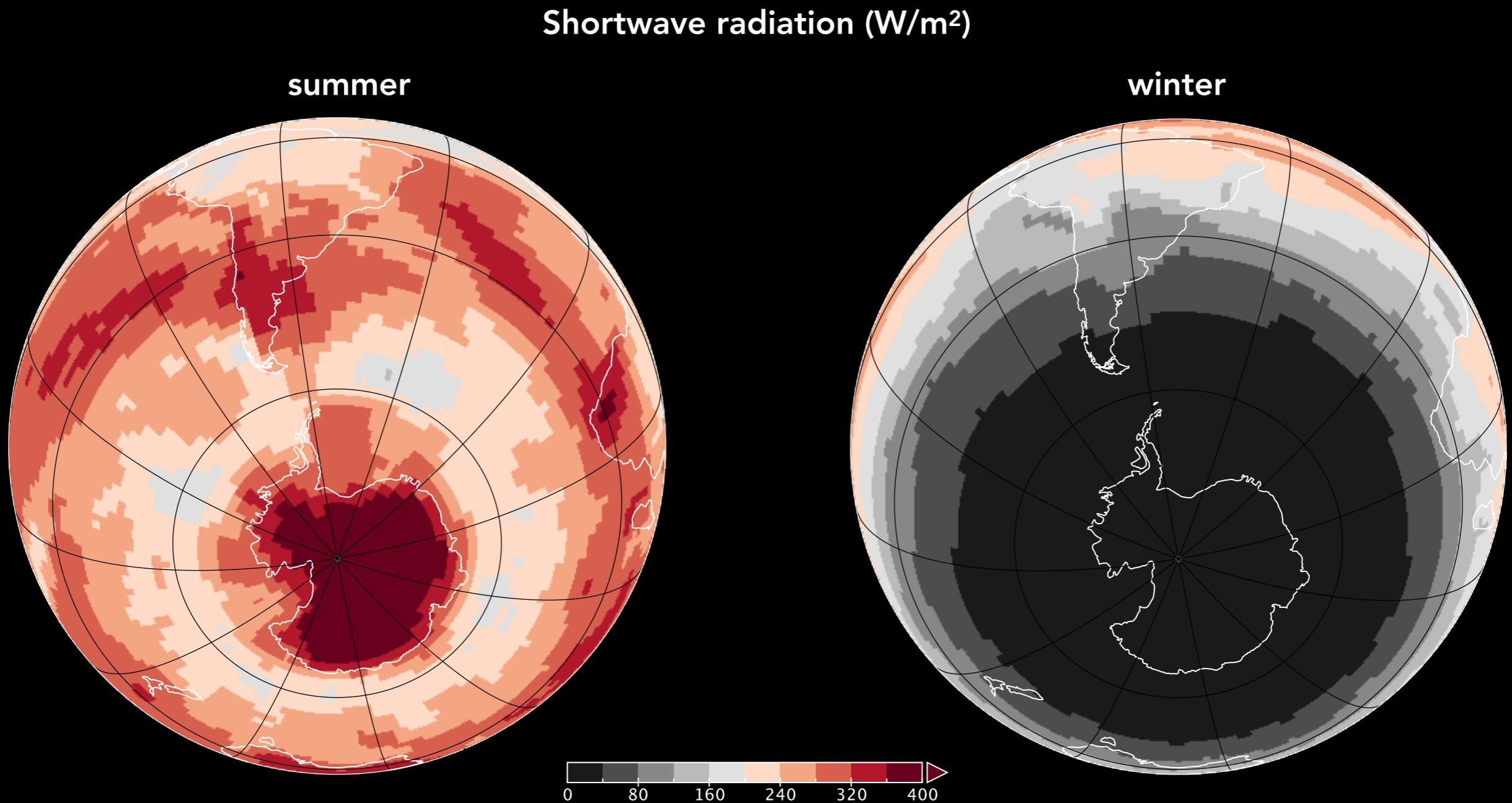
The Antarctic

- The Antarctic is defined south of the Antarctic convergence (polar front)
 - an oceanographic barrier that shifts with time and longitude but generally is close to 58 degree S.
- It includes
 - The Antarctic continent
 - Islands such as Campbell Island, Heard Island, South Georgia.
- A frozen continent surrounded by oceans



Characteristics of Polar regions

- The large seasonal variation in incoming solar radiation



Characteristics of Polar regions

- The large seasonal variation in incoming solar radiation
- The high albedo of the snow- and ice-covered polar regions
- A net loss of radiation in most months of the year.
- Very low temperatures in winter and below freezing even in summer
- A deep and stable boundary layer of very cold, dry air at the surface during the long polar night

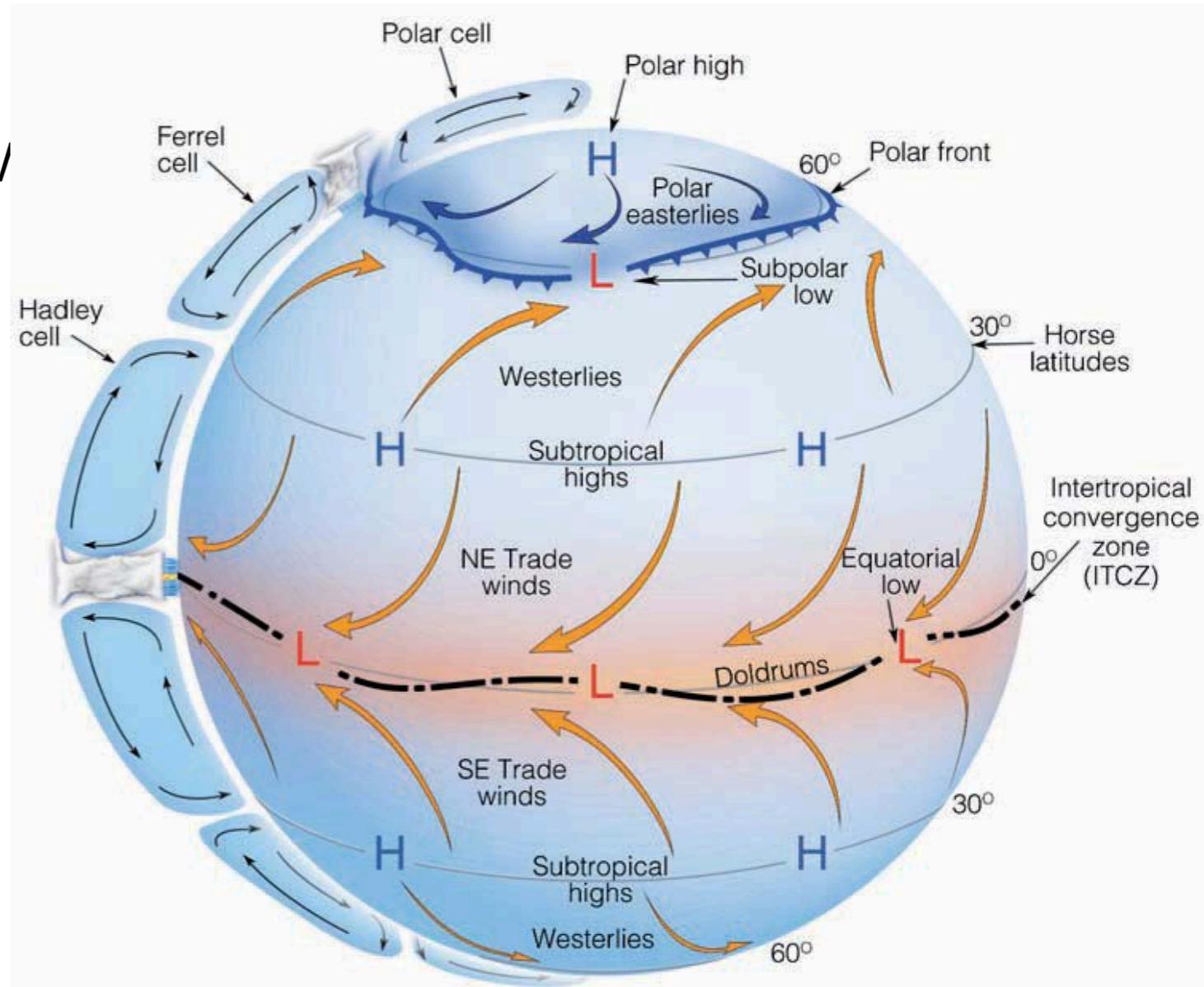
Arctic v.s. Antarctic

- The Arctic is a frozen ocean surrounded by continental landmasses and open ocean.
- The Antarctic is a frozen continent surrounded by oceans.
- The Arctic is influenced strongly by seasonal atmospheric transport and river flows from surrounding continents.
- The Antarctic is thermally isolated by the Southern Ocean and affected by the atmospheric polar vortex.

The Arctic

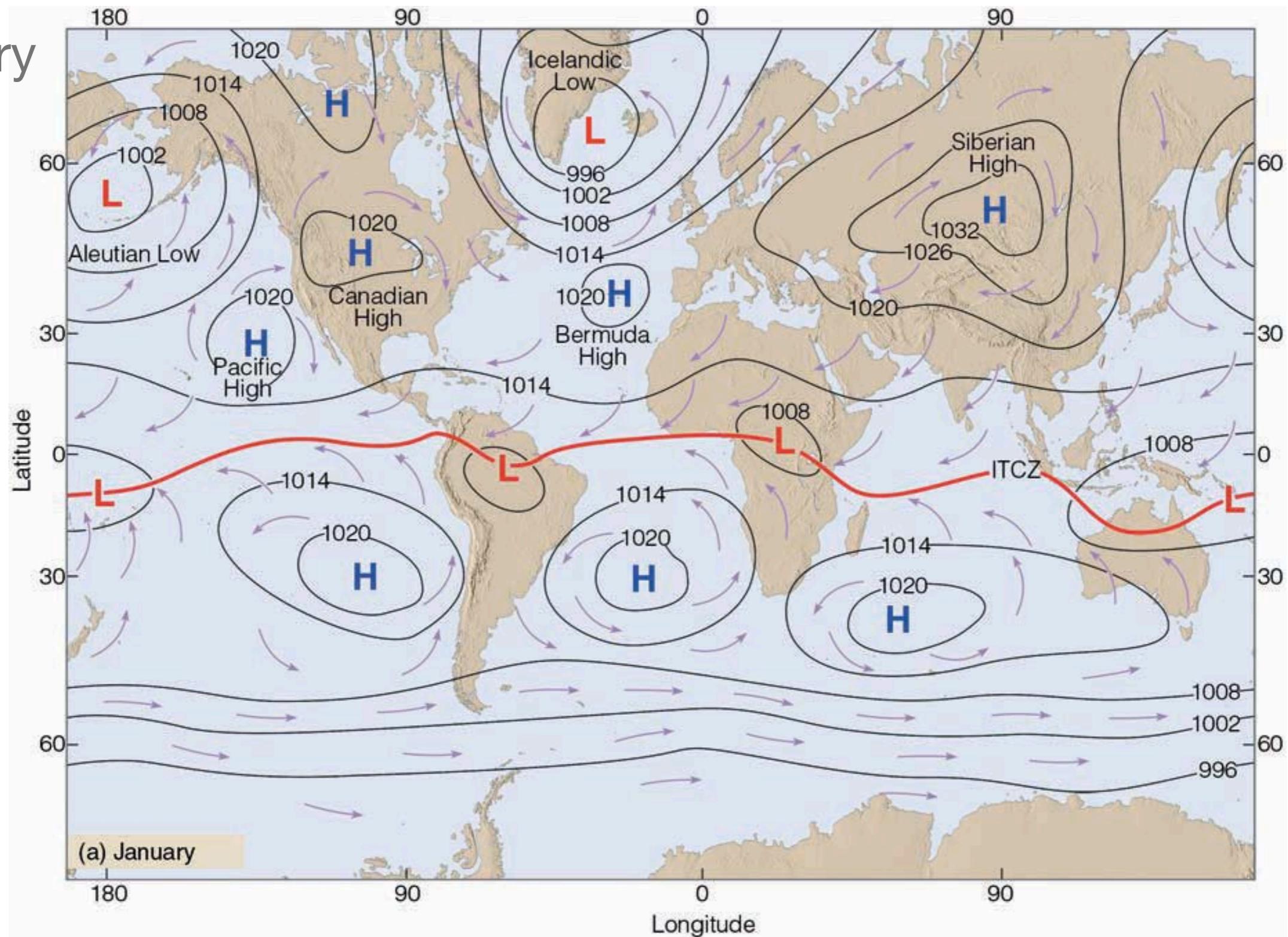
The atmospheric circulation in the Arctic

- Polar high
- Polar front -> subpolar low
- In the north of polar front, the flow of air is from northeast: polar easterlies
- Air above moving poleward is deflected to the right and sinks to the surface. —> polar cell



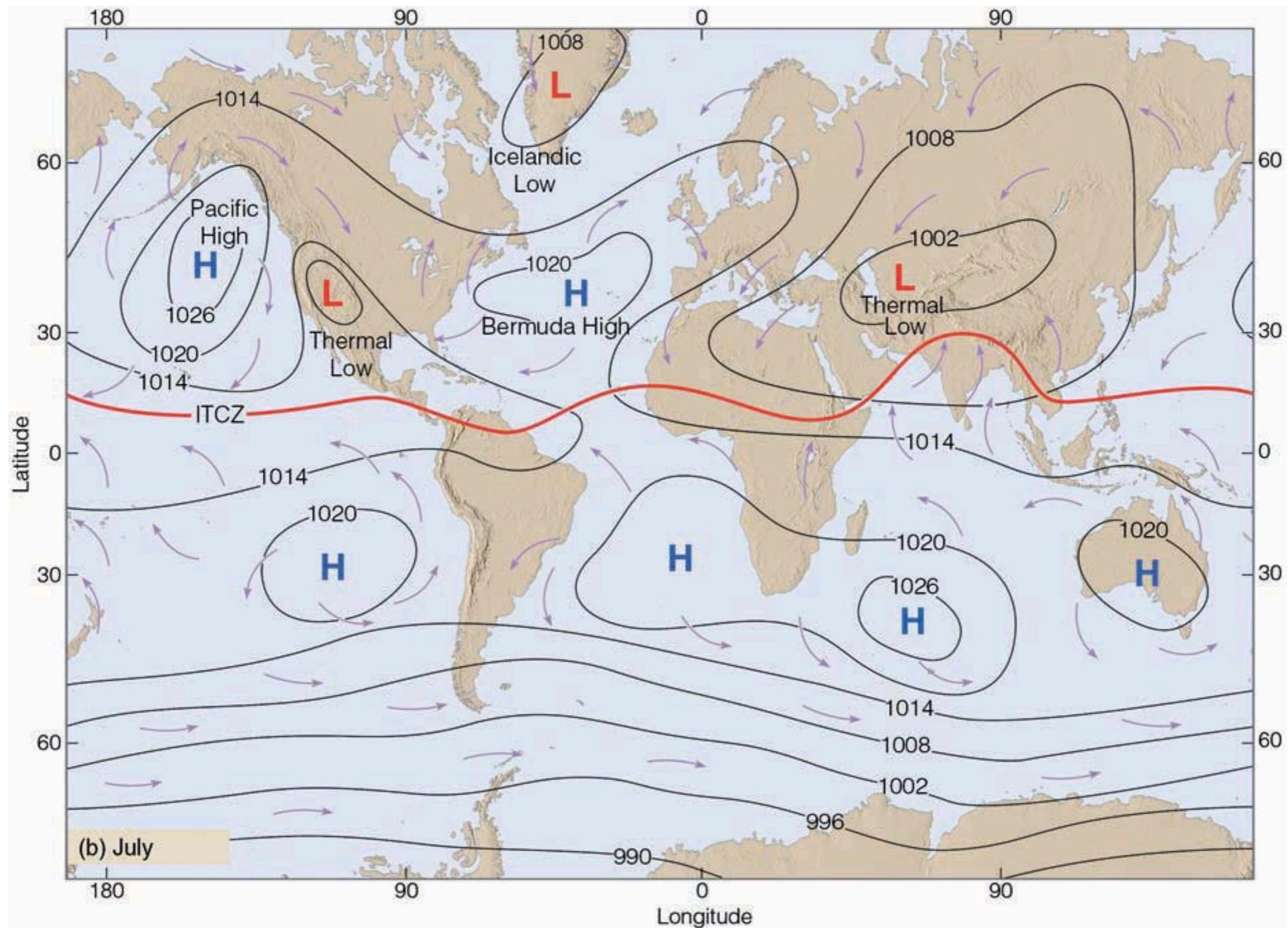
Average sea-level pressure and wind patterns

January

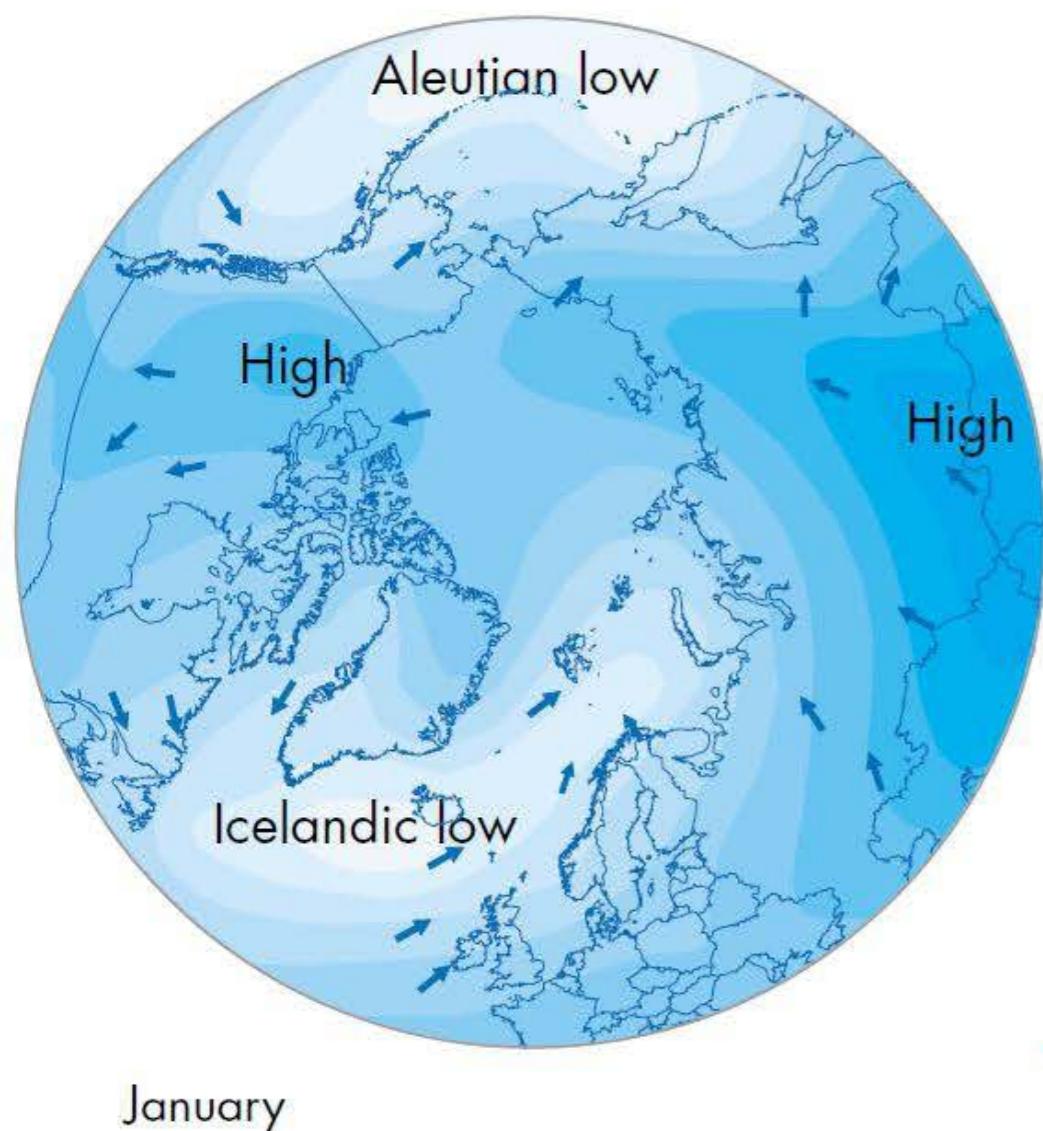


Average sea-level pressure and wind patterns

July



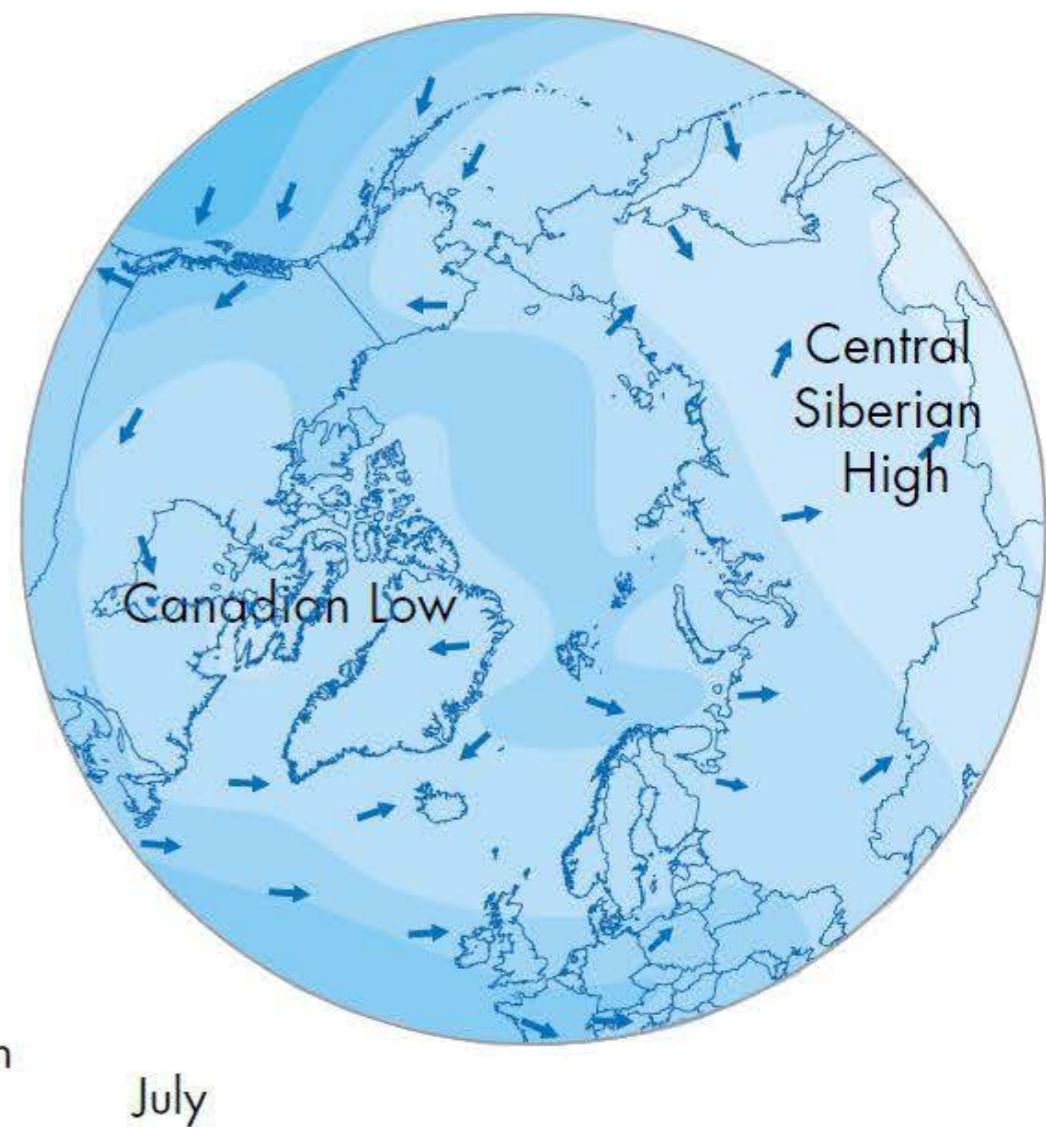
Semi-permanent pressure systems



Air pressure mbar

| |
|-------------|
| 1032 - |
| 1028 - 1032 |
| 1024 - 1028 |
| 1020 - 1024 |
| 1016 - 1020 |
| 1012 - 1016 |
| 1008 - 1012 |
| 1004 - 1008 |
| 1000 - 1004 |
| - 1000 |

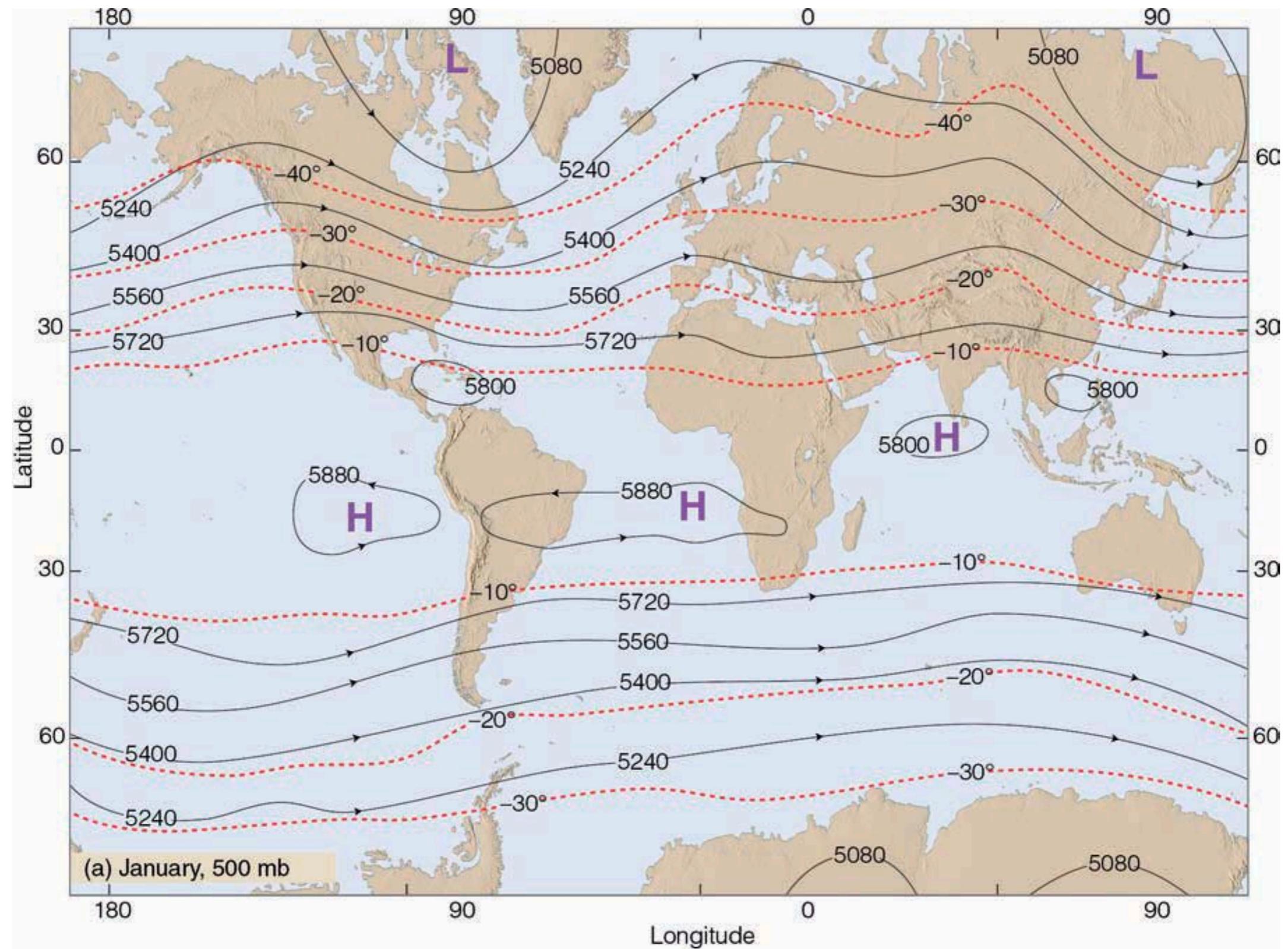
→ Prevailing wind direction



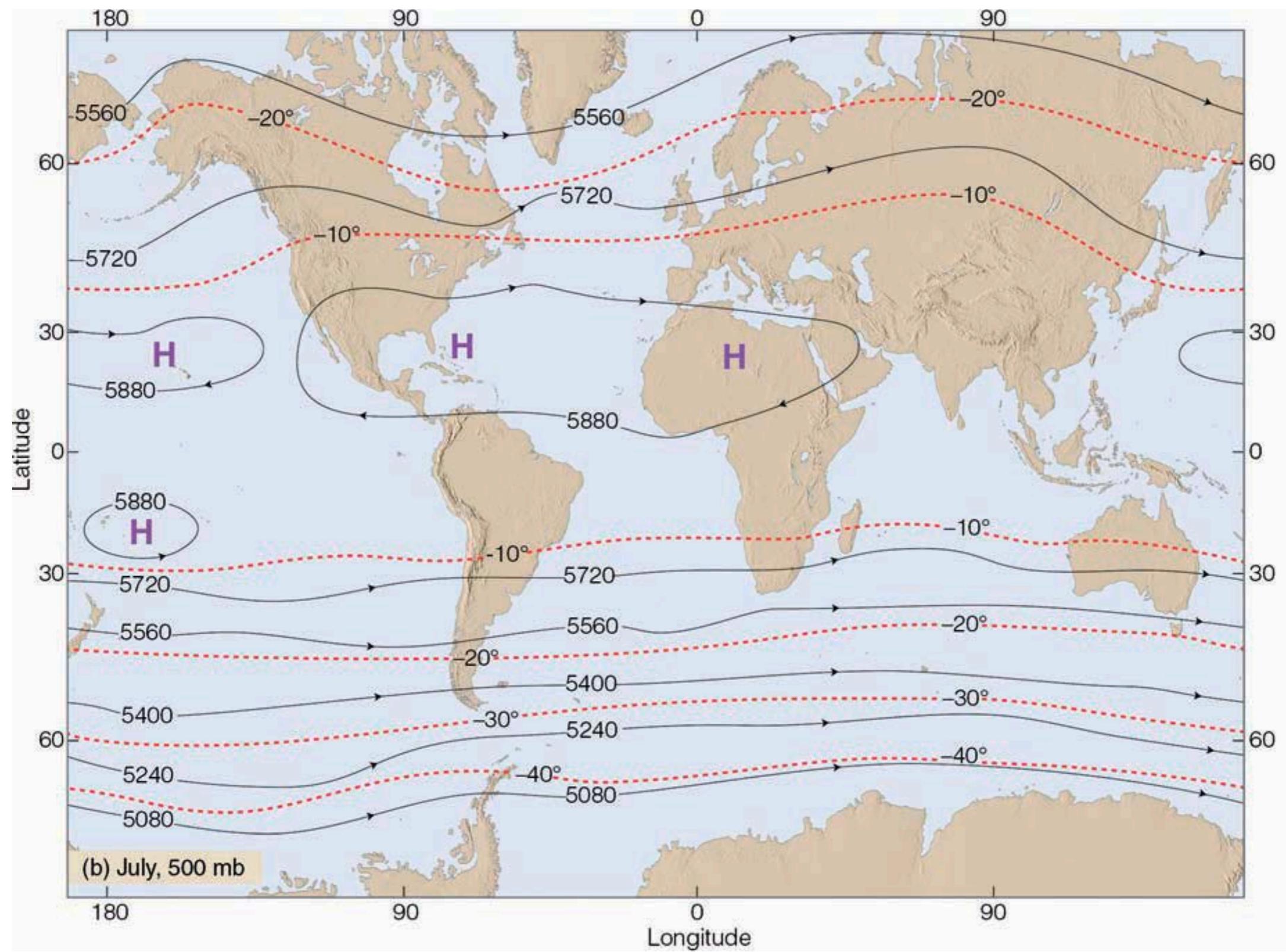
Average atmospheric sea-level air pressure in winter and summer

Average atmospheric sea-level air pressure in winter and summer
(Source: CAFFs Arctic Flora & Fauna - 2001)

Geopotential height of 500mb, July? January?



Geopotential height of 500mb, July? January?



Arctic weather

- Typically light wind
- Temperature inversion in winter: disconnects surface air from the air above
- Warmer (-40°C / 0°C) than the Antarctic (-60°C / -28.2°C) because of the ocean and elevation
- Summer is the cloudiest season (evaporation); winter has the least extensive cloud coverage (no evaporation).

Ocean circulation

Bathymetry

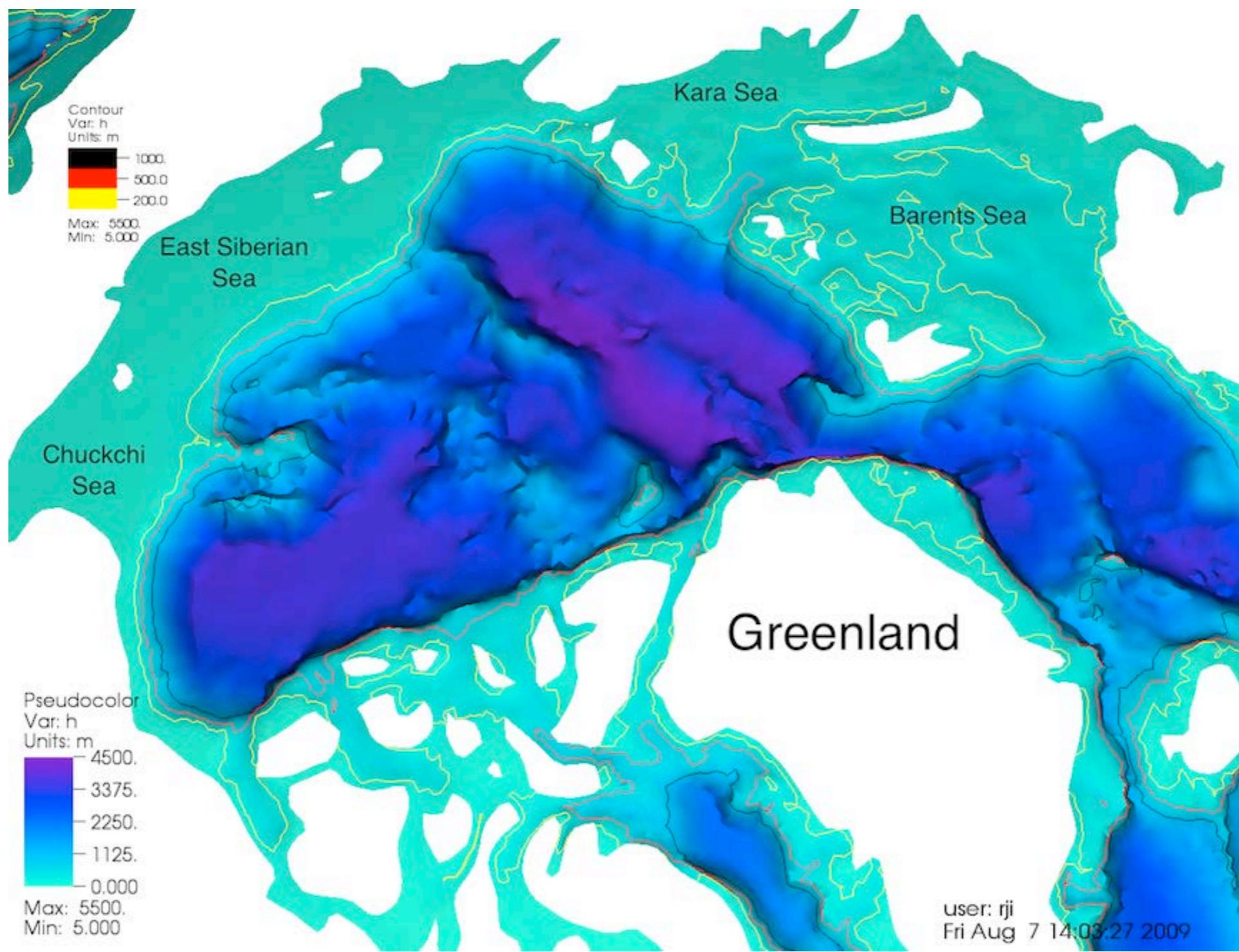
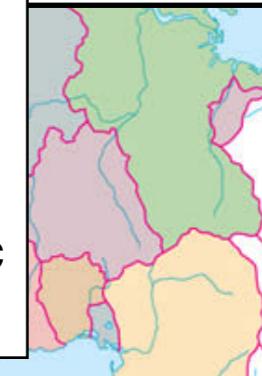


Image from http://www.whoi.edu/cms/files/arctic_all_bathy_withlabel_s_93044.png

Ocean circulation in the Arctic

Cold and relatively less salty water enters the Arctic Ocean through the narrow Bering Strait between Alaska and Siberia.

Periodically, the winds shift and the circular current weakens, allowing large volumes of fresh water to leak out and cross the Arctic in the Transpolar Current.



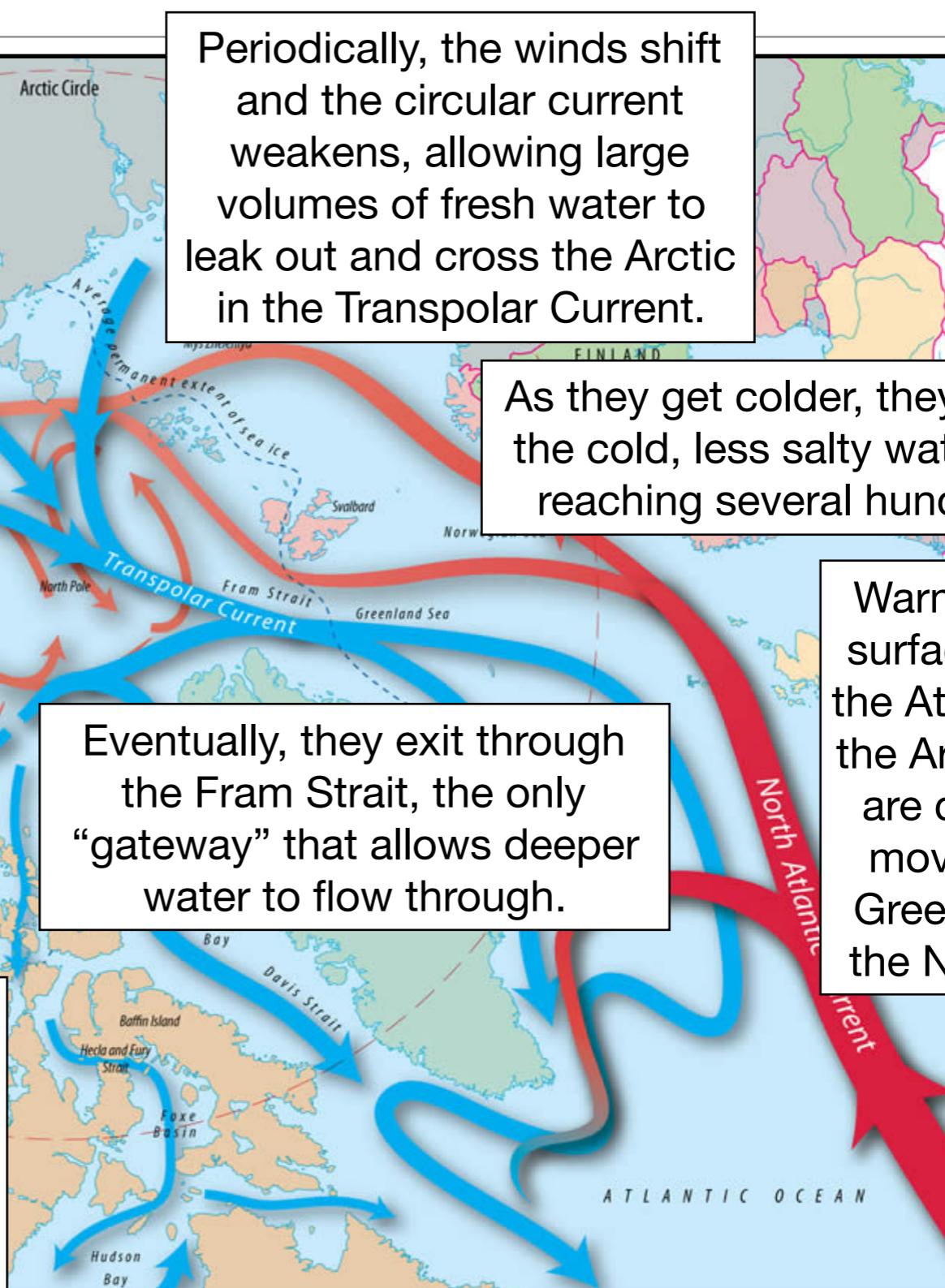
As they get colder, they sink beneath the cold, less salty waters to depths reaching several hundred meters.



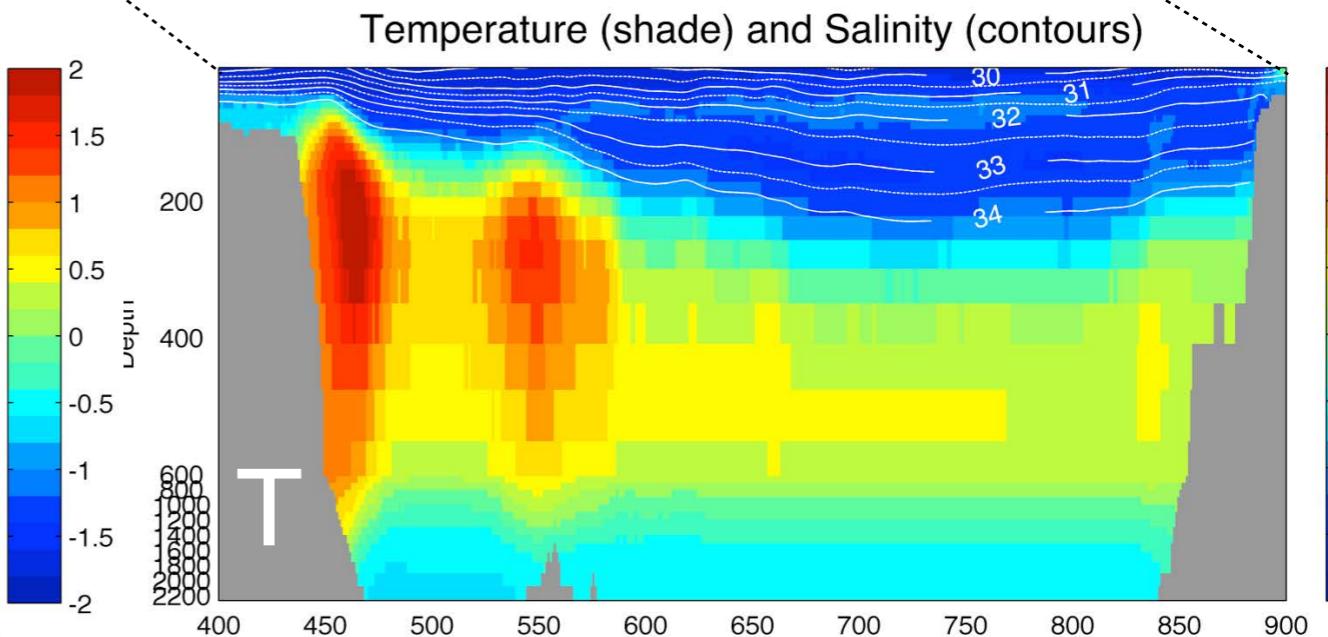
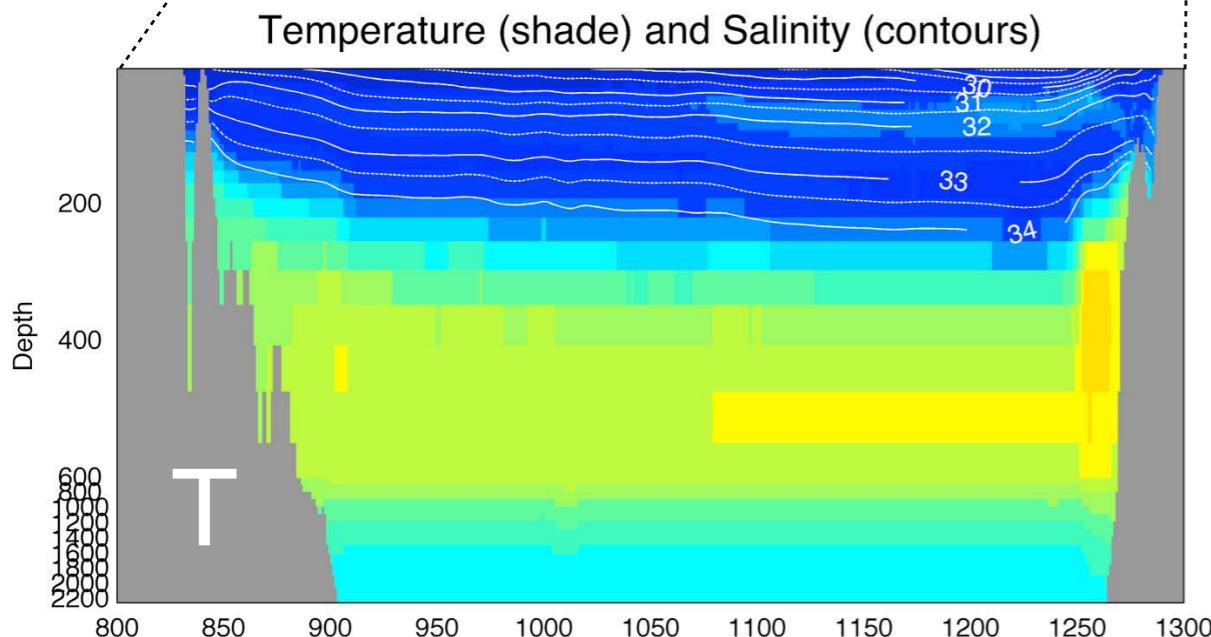
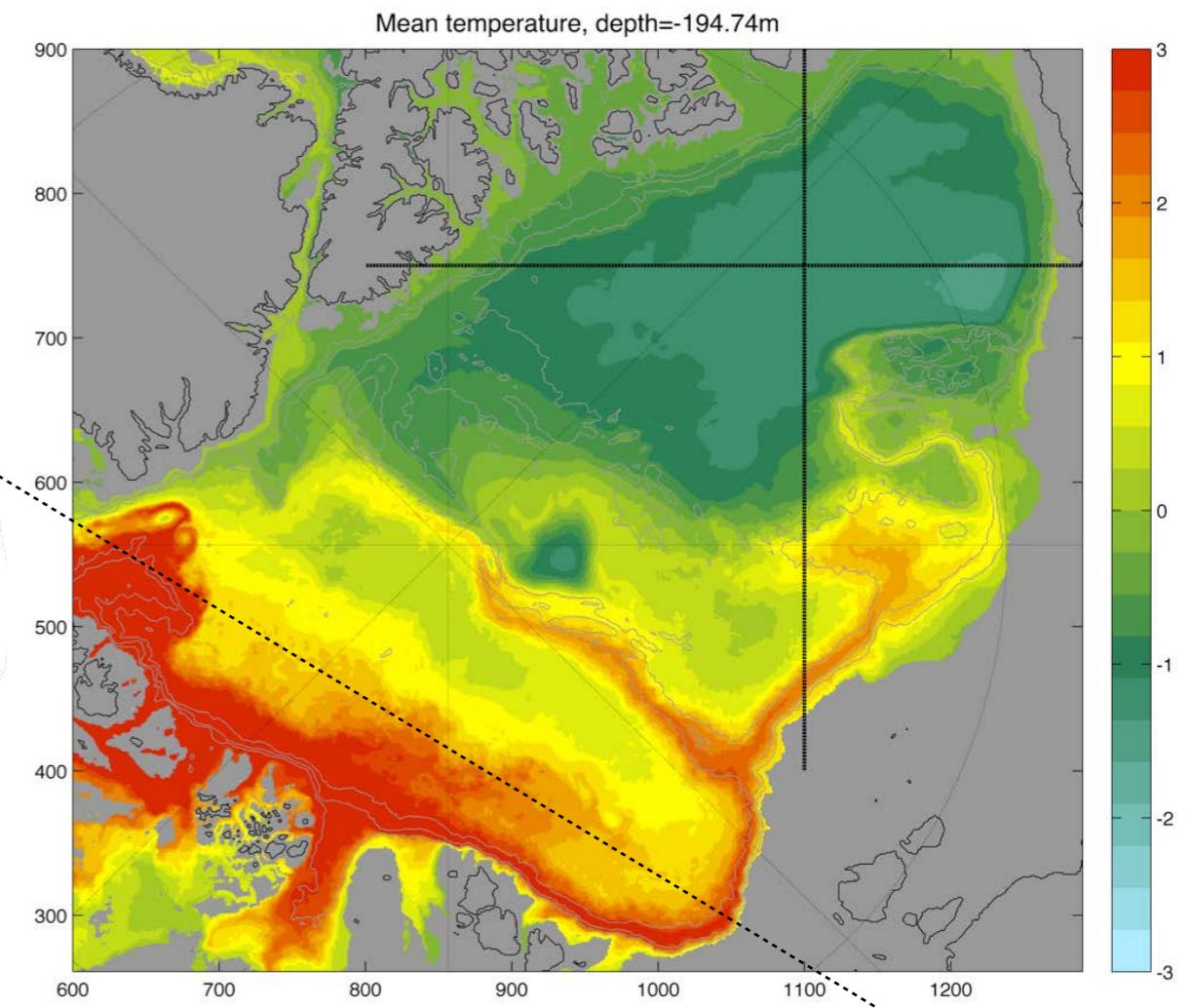
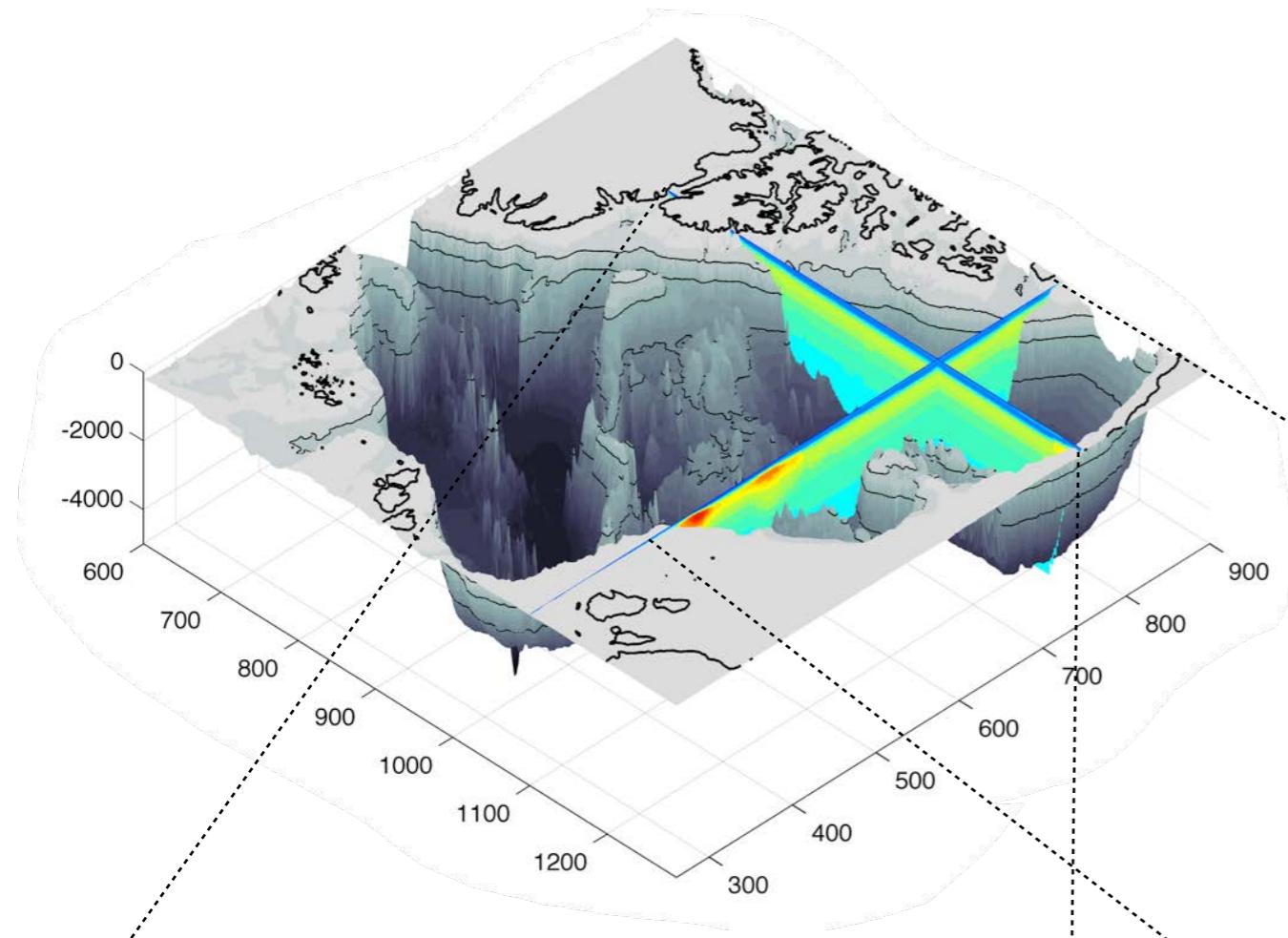
Eventually, they exit through the Fram Strait, the only “gateway” that allows deeper water to flow through.

Warmer, more salty surface waters from the Atlantic penetrate the Arctic Ocean and are cooled as they move through the Greenland Sea and the Norwegian Sea.

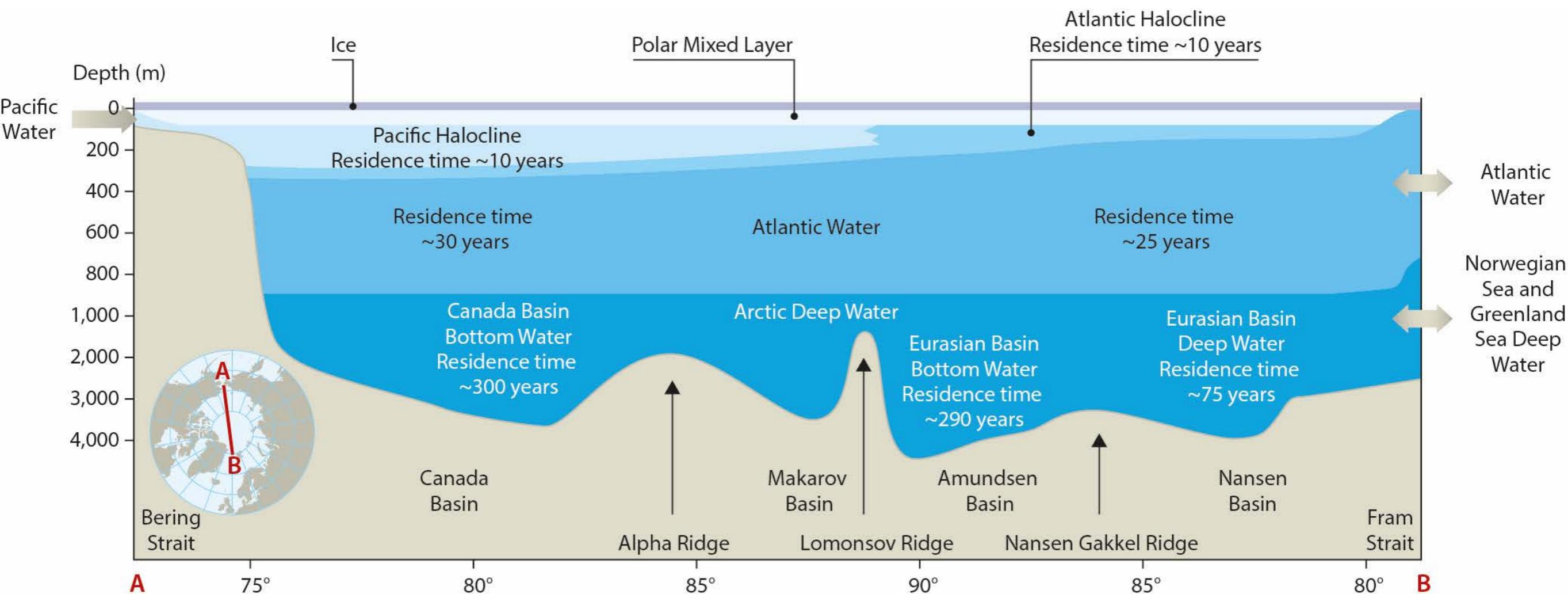
Once in the Arctic Ocean basin, the water is swept into a huge circular current—driven by strong winds—called the Beaufort Gyre. Mighty Siberian and Canadian rivers also drain into the circular current to create a great reservoir of relatively fresh water.



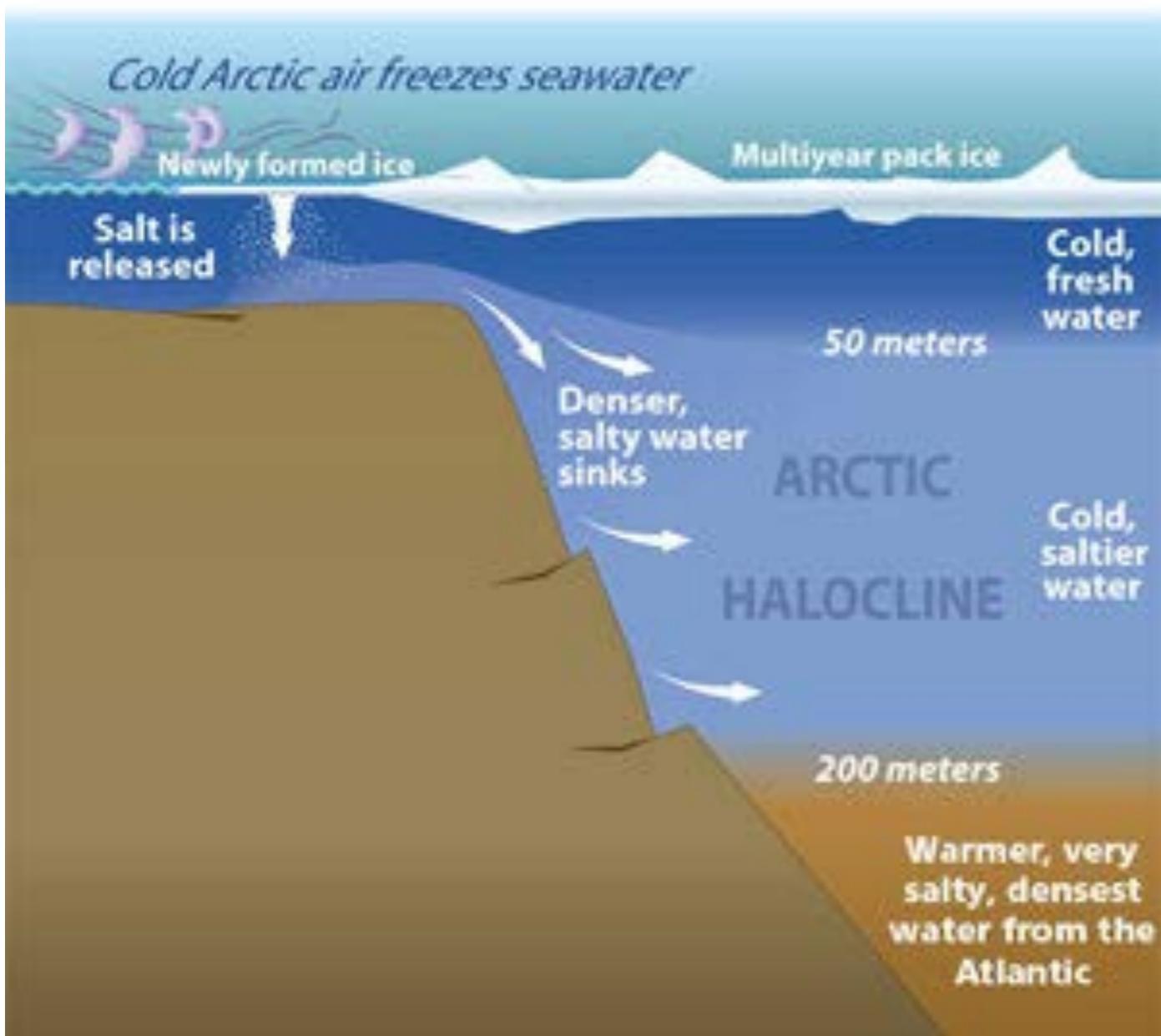
Temperature from the ocean model



Schematic of water masses



Sea-ice production



1. In winter, frigid winds from the icy Alaskan interior blast over the shallow Chukchi Sea.
2. The cold air freezes seawater into sea ice and then pushes it out to sea, leaving new pockets of seawater available for freezing.
3. This is “the ice factory” which manufactures ice.
4. When seawater freezes, it releases salt into surface waters.
5. These cold, salty waters become denser and sink, spilling over the continental shelf into the western Arctic Ocean.
6. They create a layer known as a halocline (from the Greek words for “salt” and “slope”).
7. Halocline waters lie atop a deeper layer of saltier, denser—and warmer—waters that flow into the Arctic from the Atlantic Ocean.

Sea-ice in the Arctic

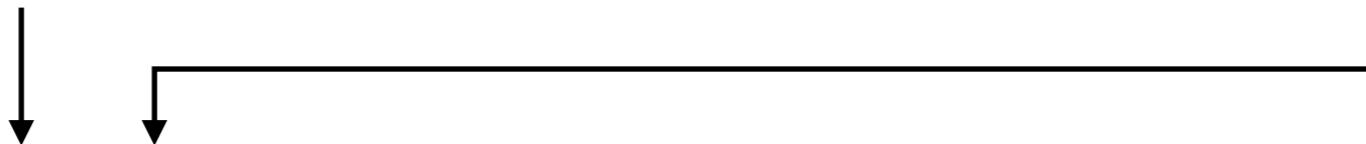
- Sea ice creates an insulating cap across the ocean surface, which reduces evaporation and heat loss to the atmosphere. As a result, the weather over ice-covered areas tends to be colder and drier than it would be without ice.
- The white surface reflects far more sunlight back to space than ocean water does.
- Sea ice also plays a fundamental role in polar ecosystems. When the ice melts in the summer, it releases nutrients into the water, stimulating the growth of phytoplankton, the center of the marine food web (krill).

Sea-ice in the Arctic

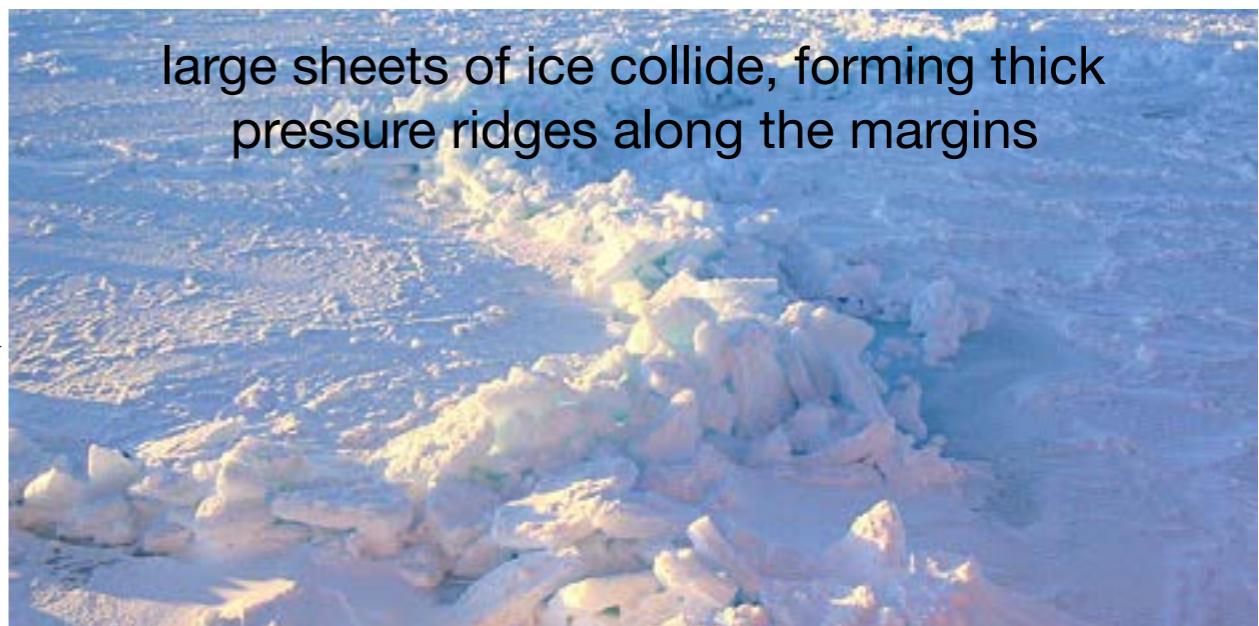
thin sheets of smooth nilas in calm water



disks of pancake ice in choppy water

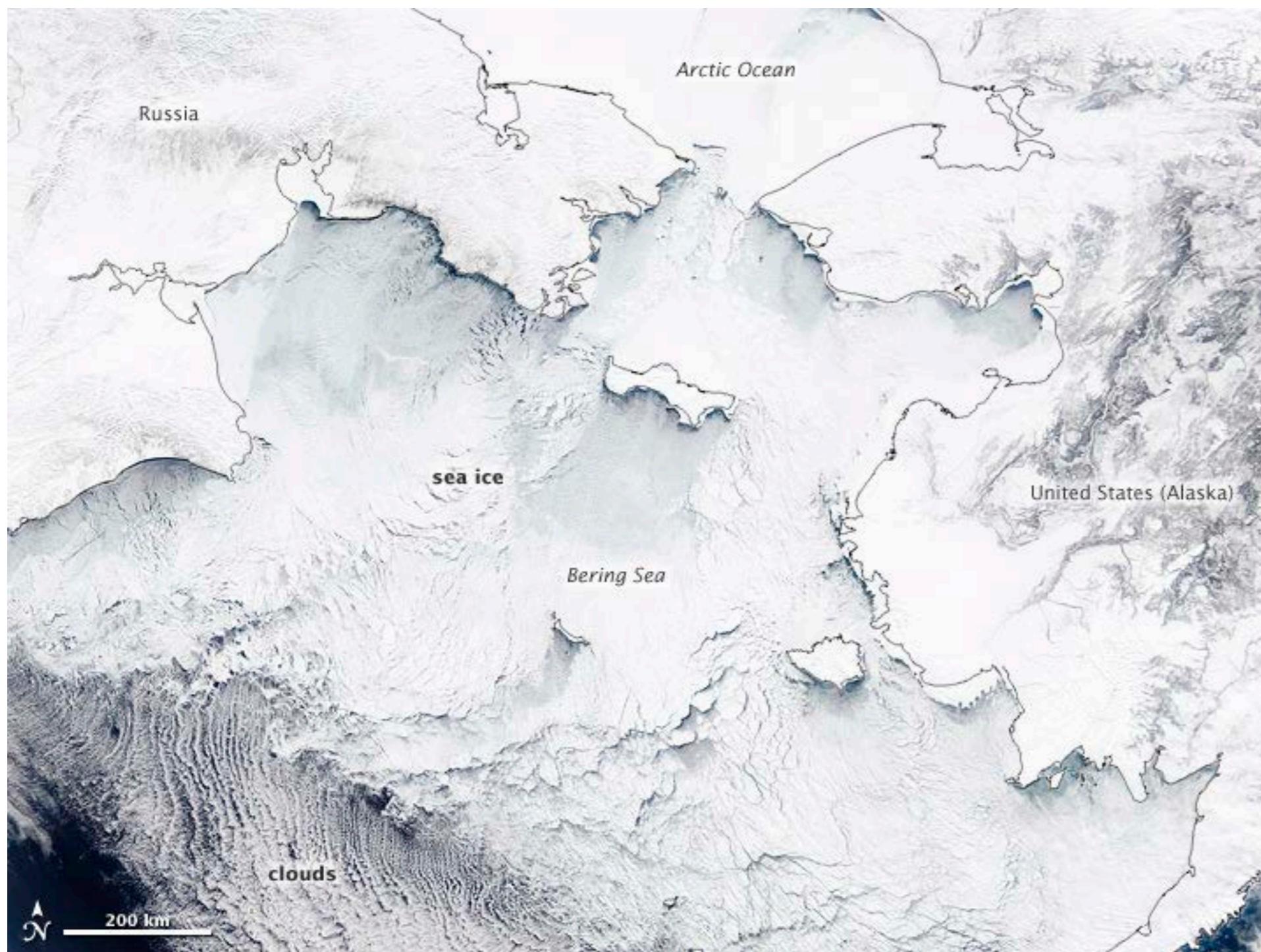


pile up to form rafts and eventually solidify



large sheets of ice collide, forming thick pressure ridges along the margins

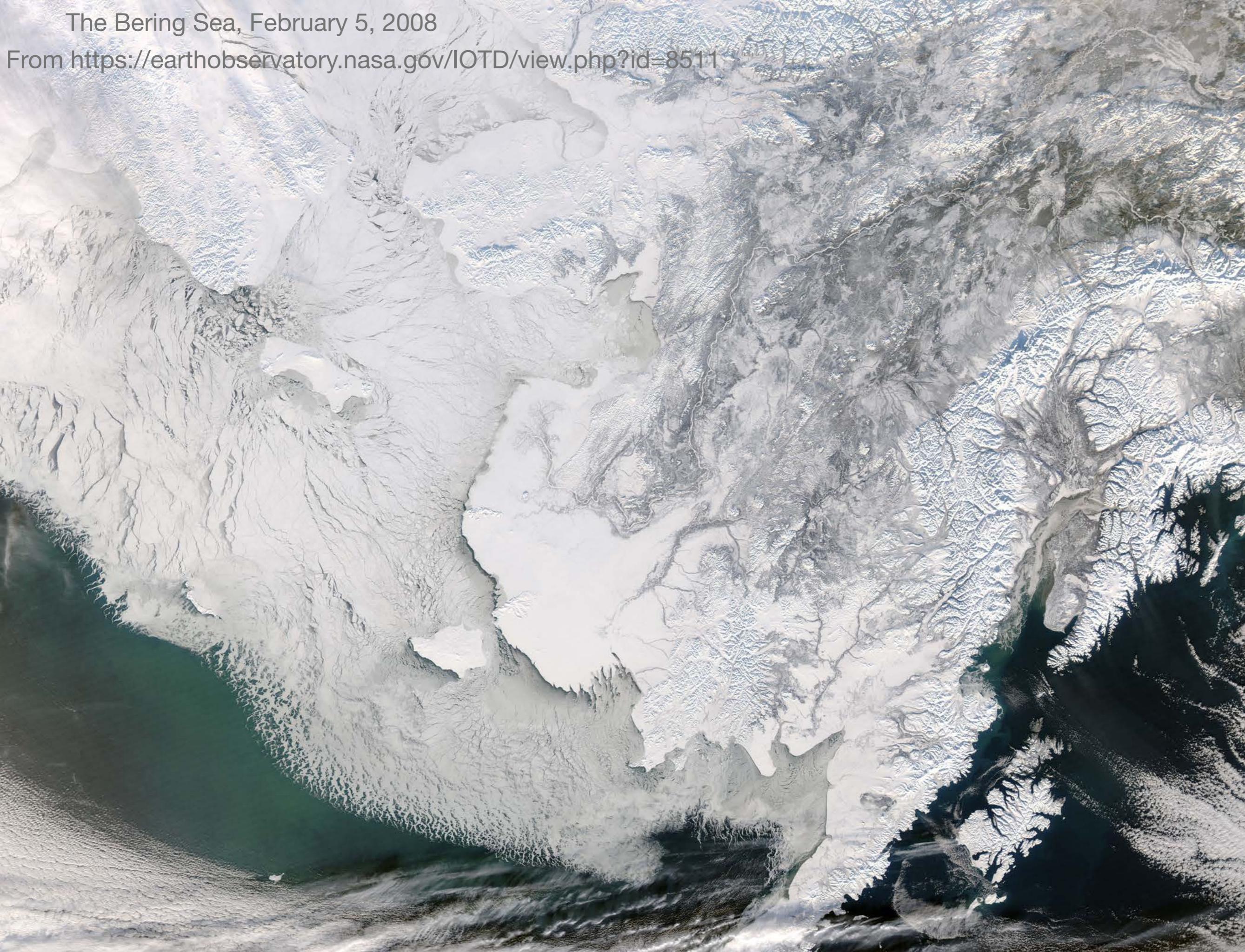
The sea-ice image from the satellite



The Bering Sea
March 19, 2012

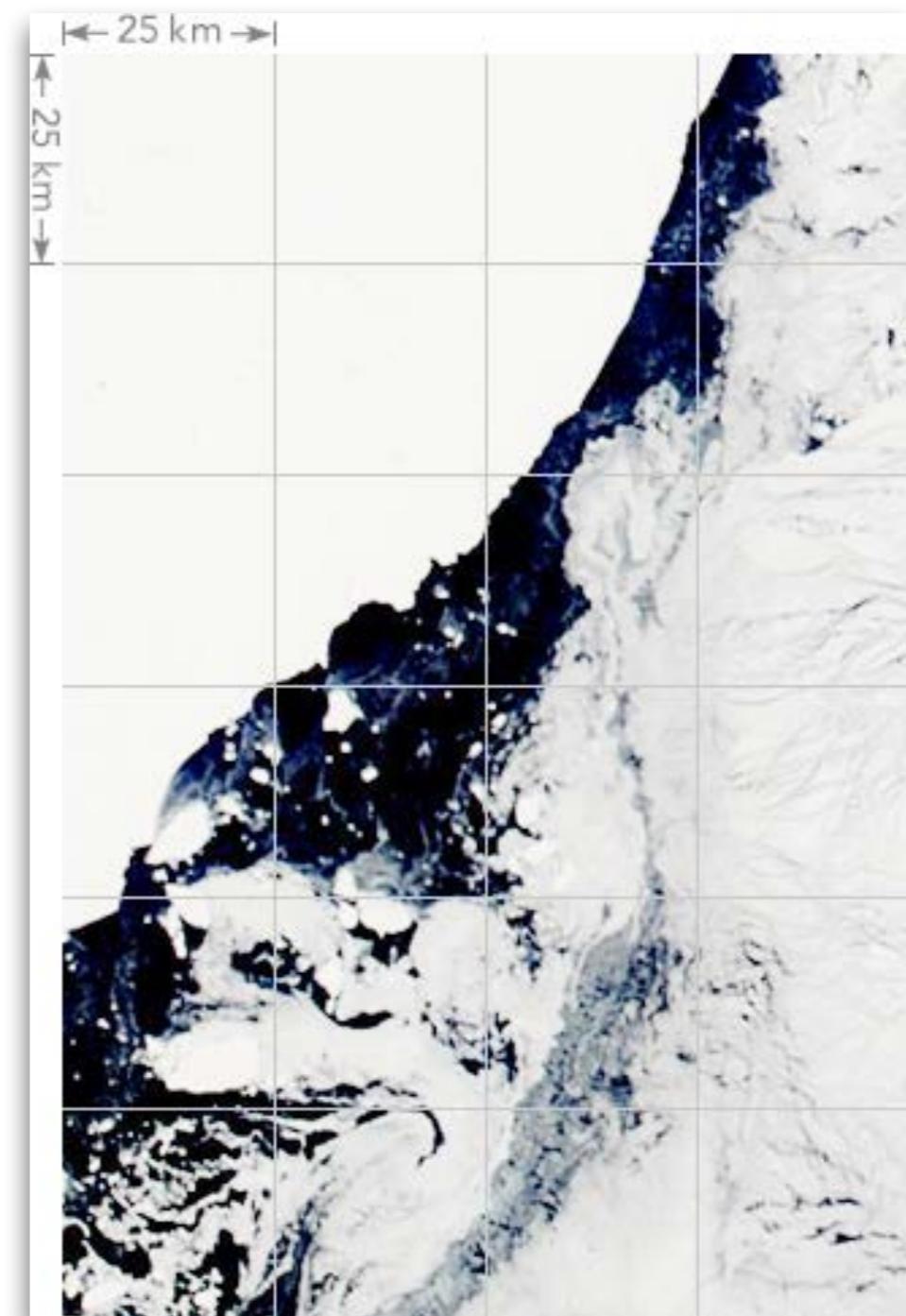
The Bering Sea, February 5, 2008

From <https://earthobservatory.nasa.gov/IOTD/view.php?id=8511>

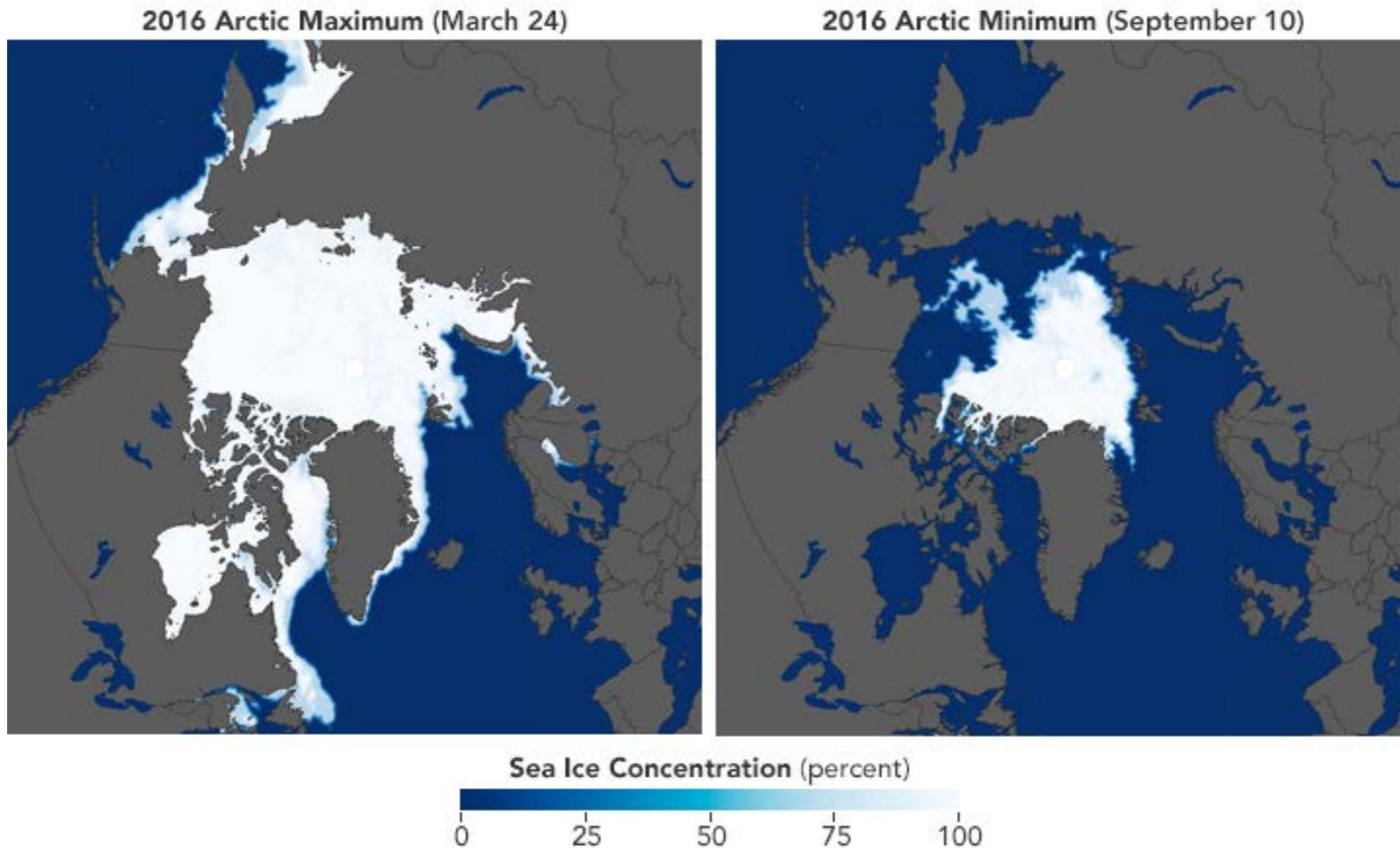


Measuring sea-ice concentration

1. Divide the image by a 25 km by 25 km grid.
2. Sea ice concentration is the percentage of each pixel that is covered by ice.
3. Sea ice extent is calculated by adding up the pixels with an ice concentration of at least 15 percent.



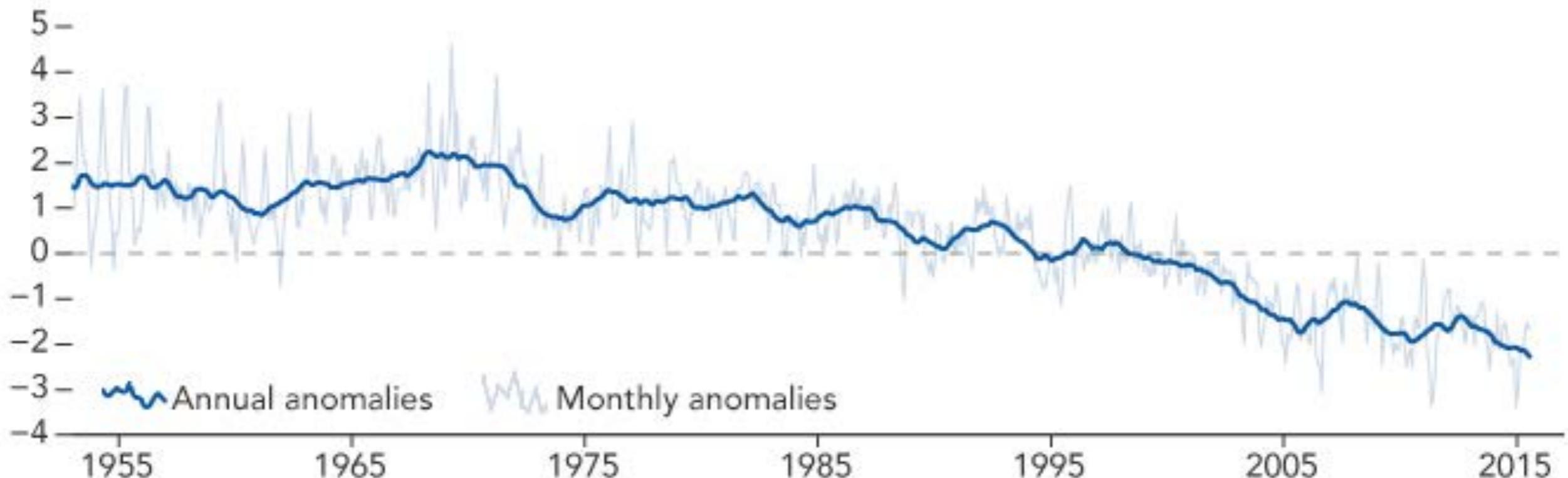
Seasonal variability of the sea-ice



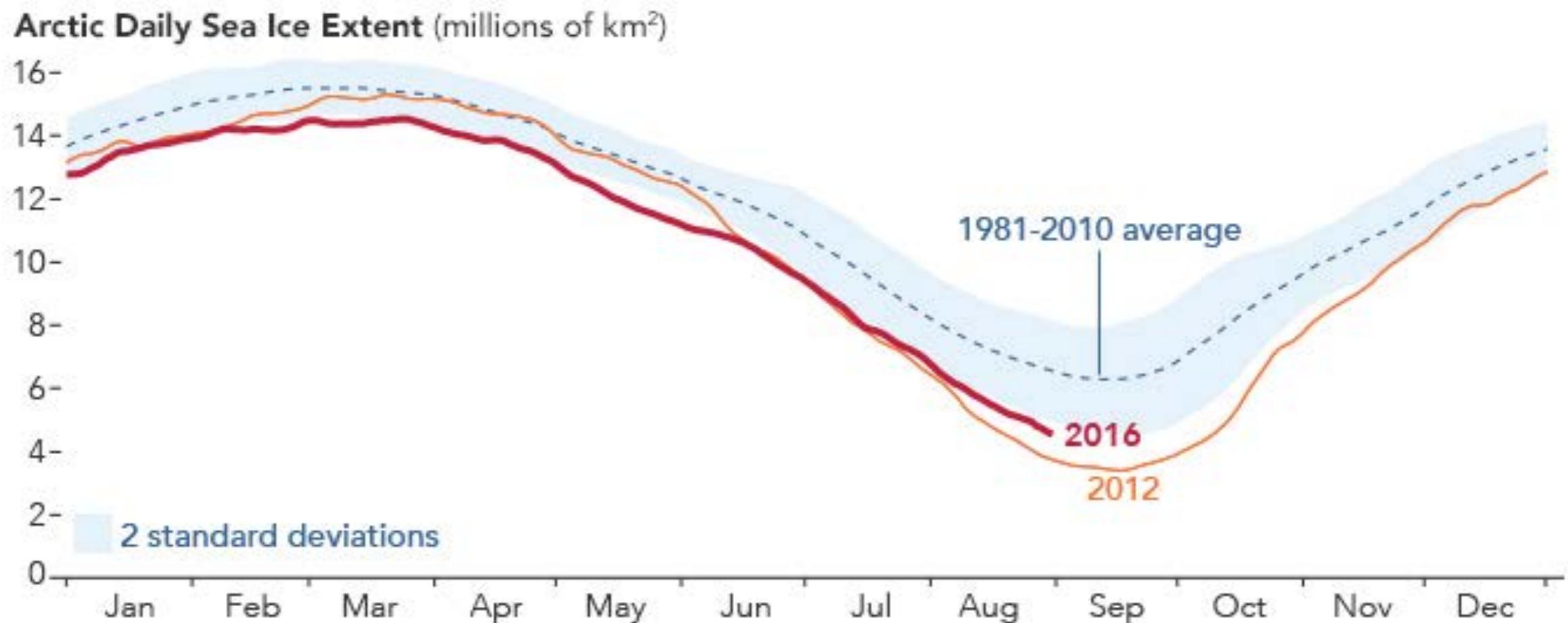
- Maximum extent in March (roughly 14-16 million km²)
- Minimum extent in September (roughly 7 million km²)

The changes in the Arctic sea-ice

Arctic Ice Extent Anomaly
(Number of standard deviations from 1981-2010 baseline)

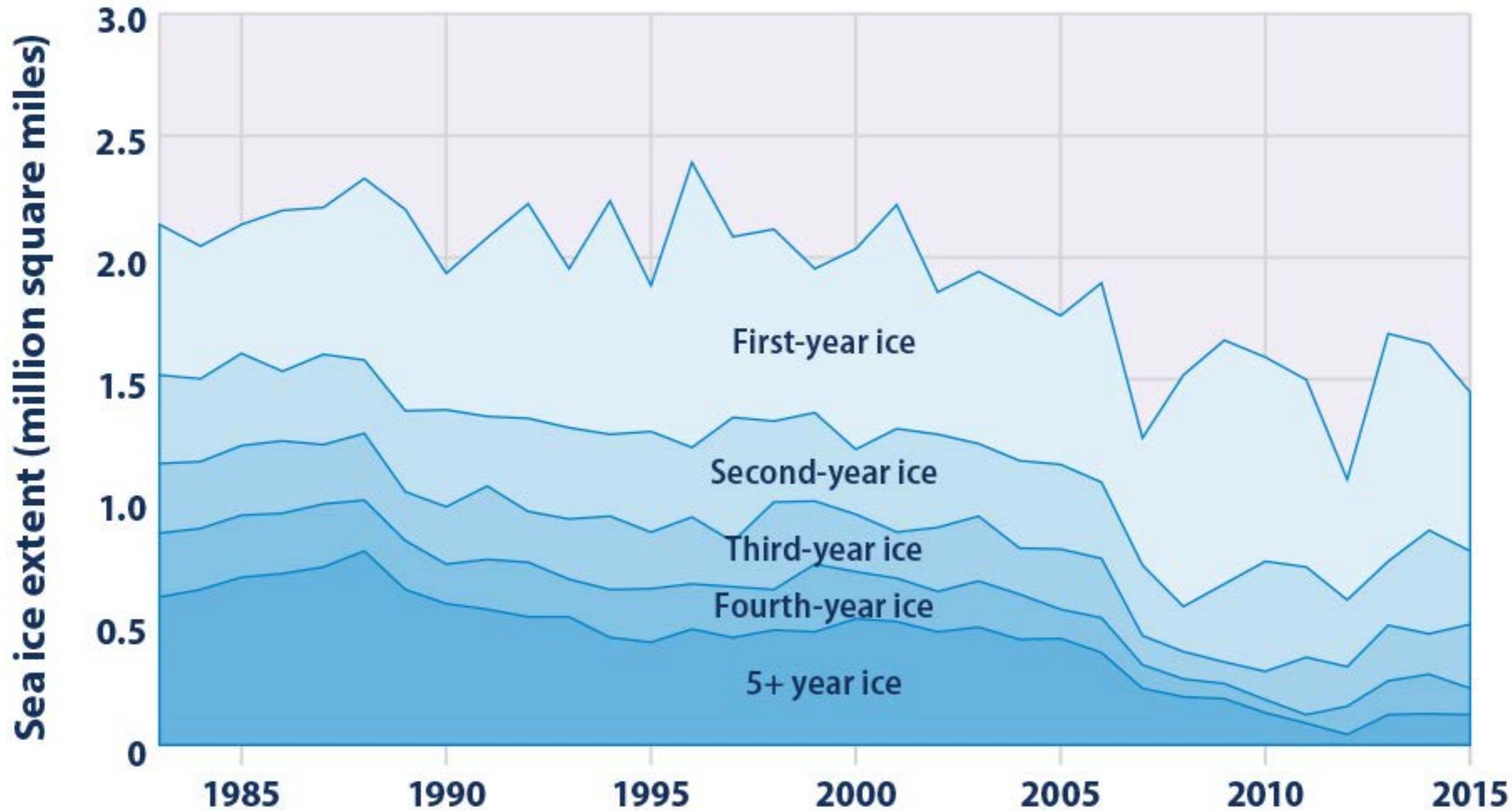


The changes in the Arctic sea-ice



In 2012 arctic ice reached the lowest extent ever recorded, well below the historical average (blue dashed line).

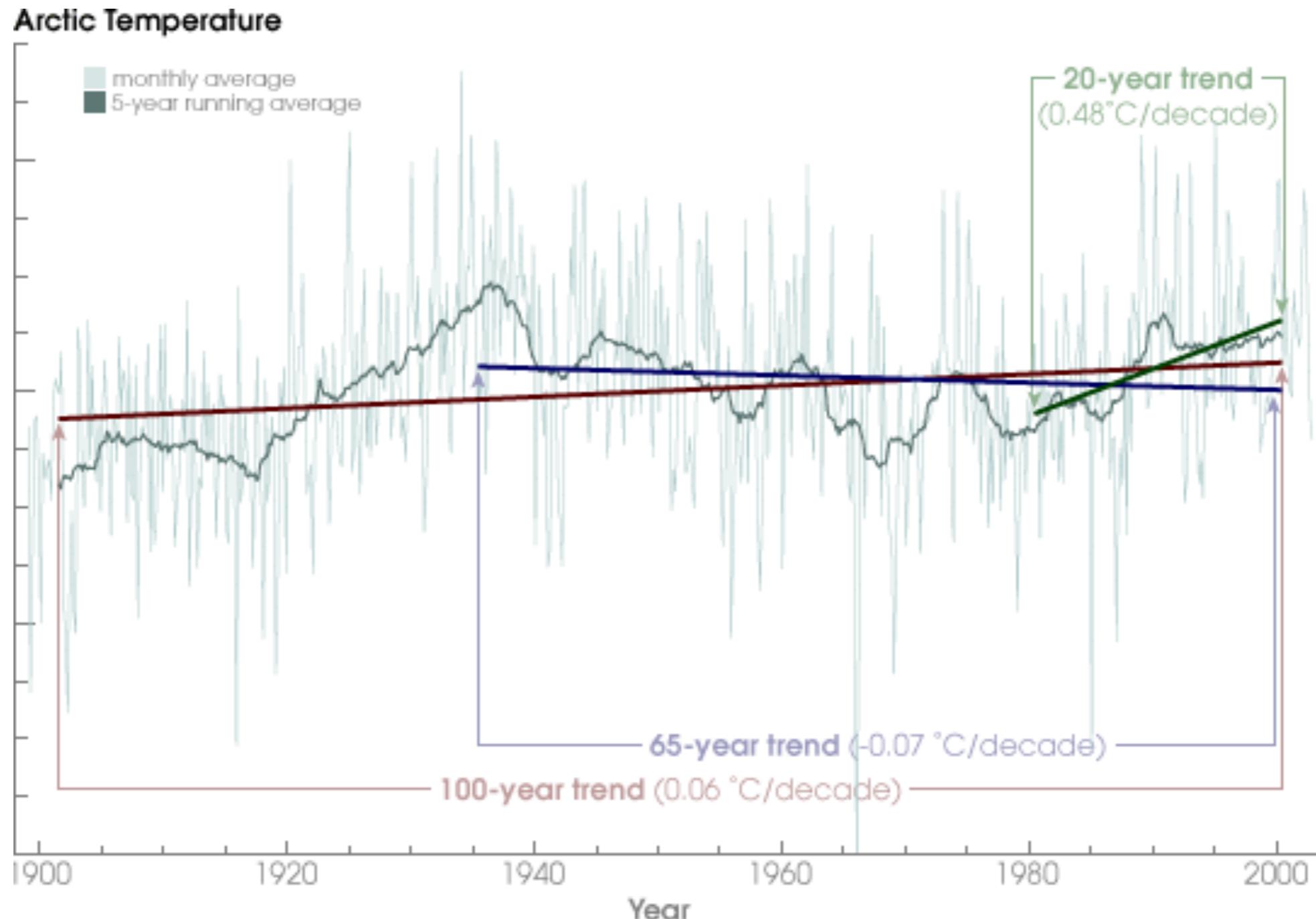
Age of Arctic Sea Ice in September



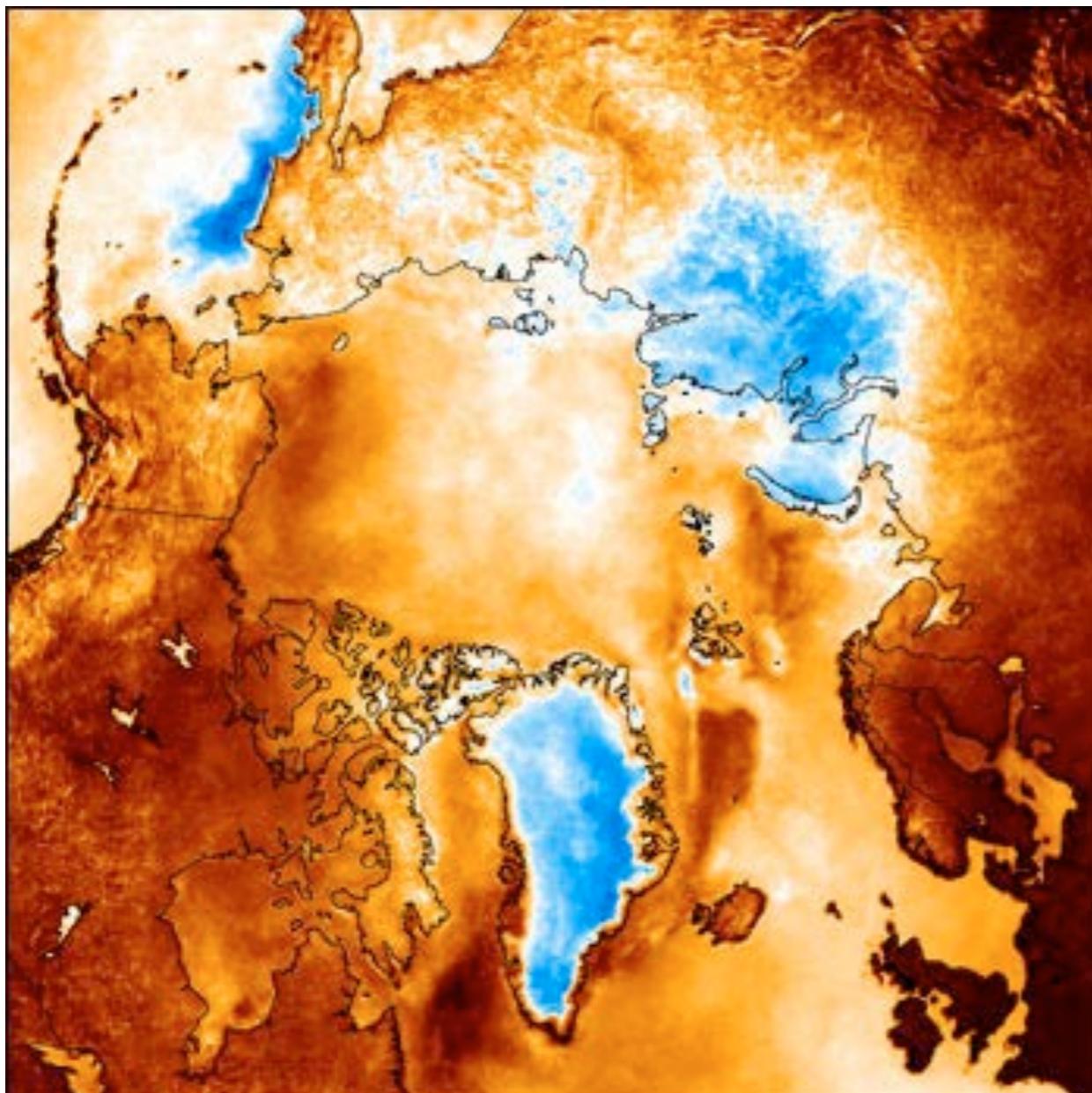
This figure shows the distribution of Arctic sea ice extent by age group during the week in September with the smallest extent of ice for each year. The total extent in Figure 2 differs from the extent in Figure 1 because Figure 1 shows a monthly average, while Figure 2 shows conditions during a single week.

Image from <https://www.epa.gov/climate-indicators/climate-change-indicators-arctic-sea-ice>

Arctic temperature



Temperature trend in the Arctic

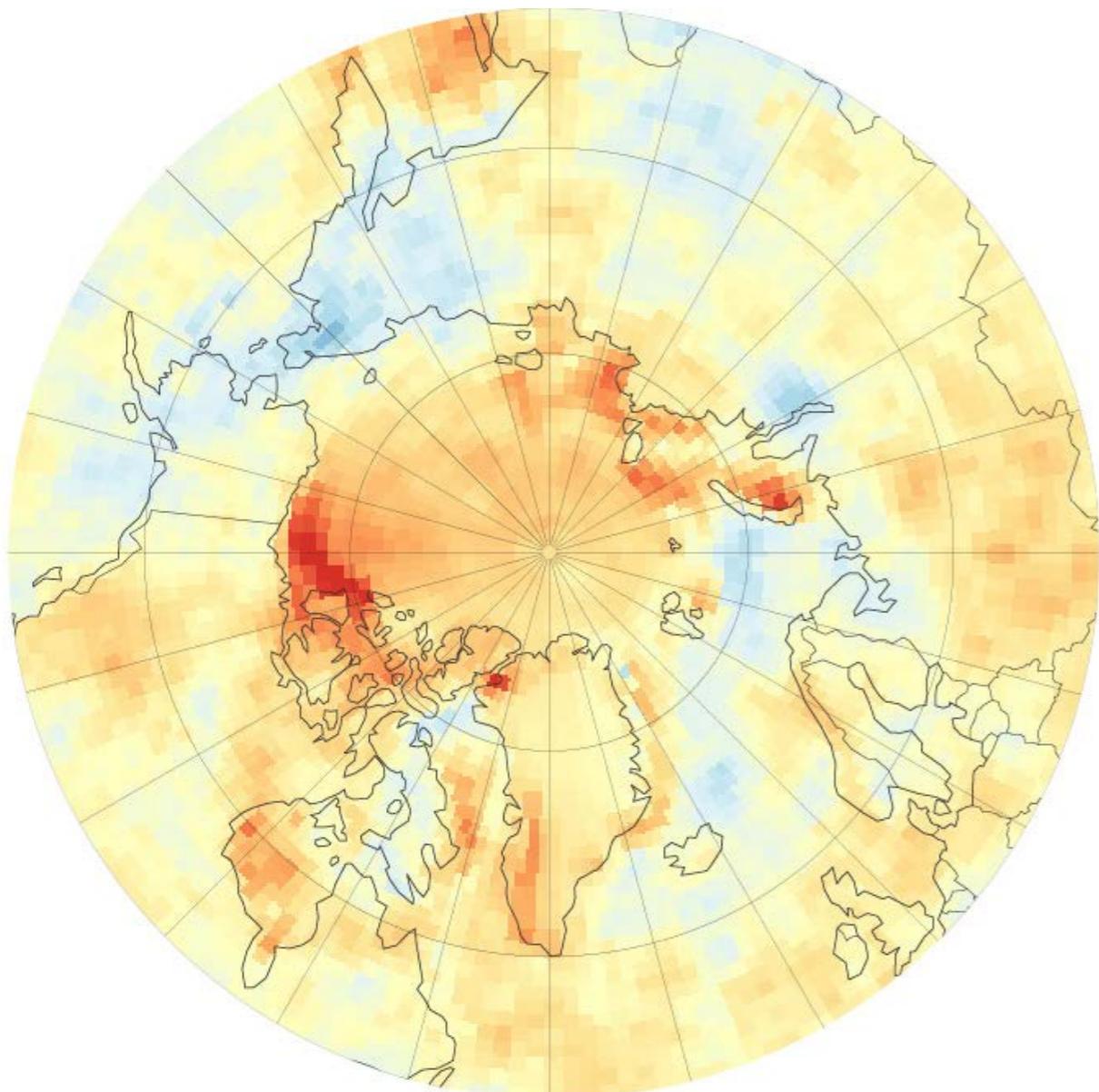


The Arctic is warming at an accelerating rate. Satellite data collected from 1981 to 2001 show that some regions are warming faster than 2.5°C per decade.



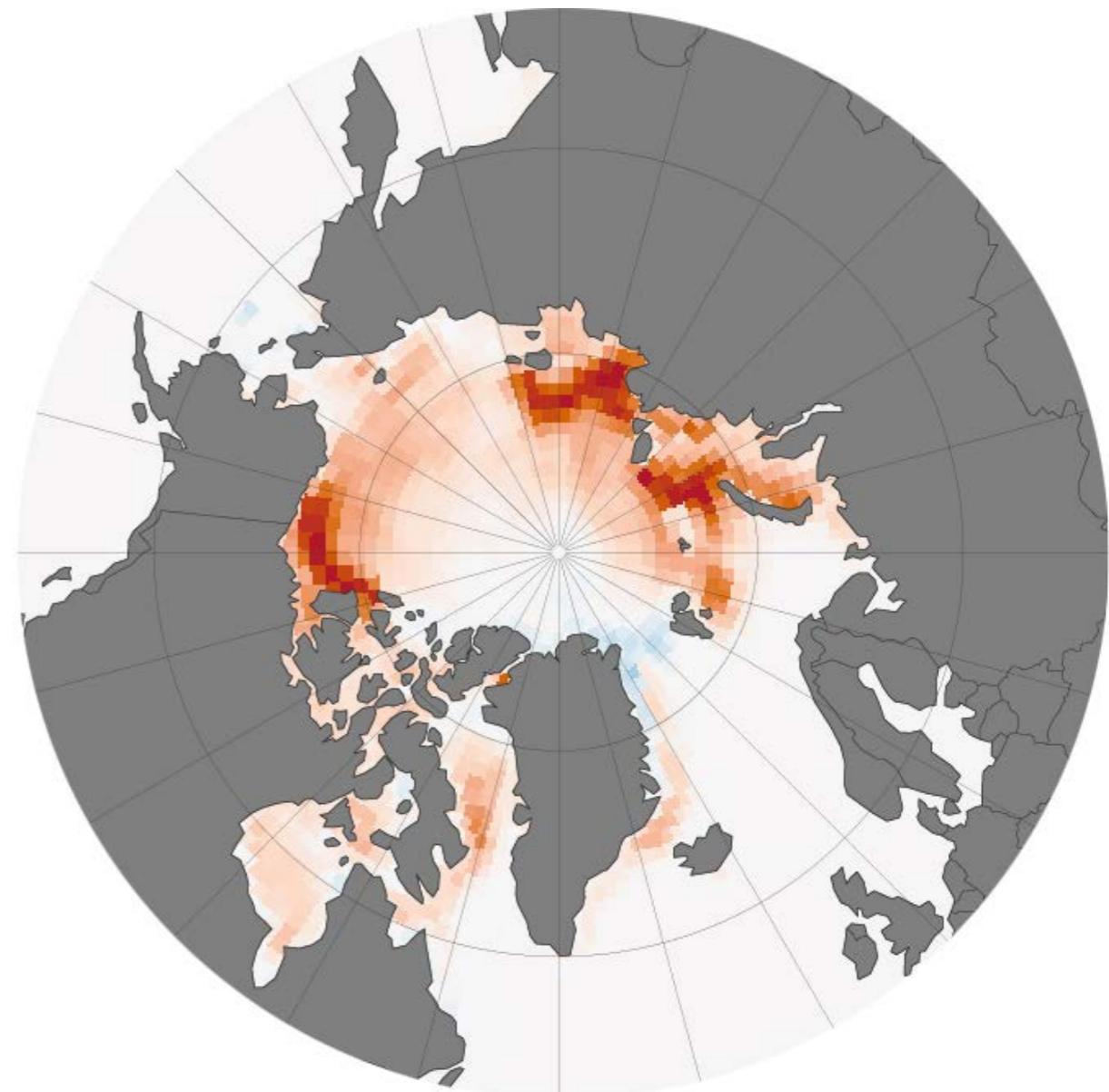
Image from <https://earthobservatory.nasa.gov/Features/ArcticIce/>

Trend in sea-ice fraction and solar radiation absorption (2000 to 2014)



Absorbed Radiation Trend, 2000-2014 (W/m²)

-45 0 45

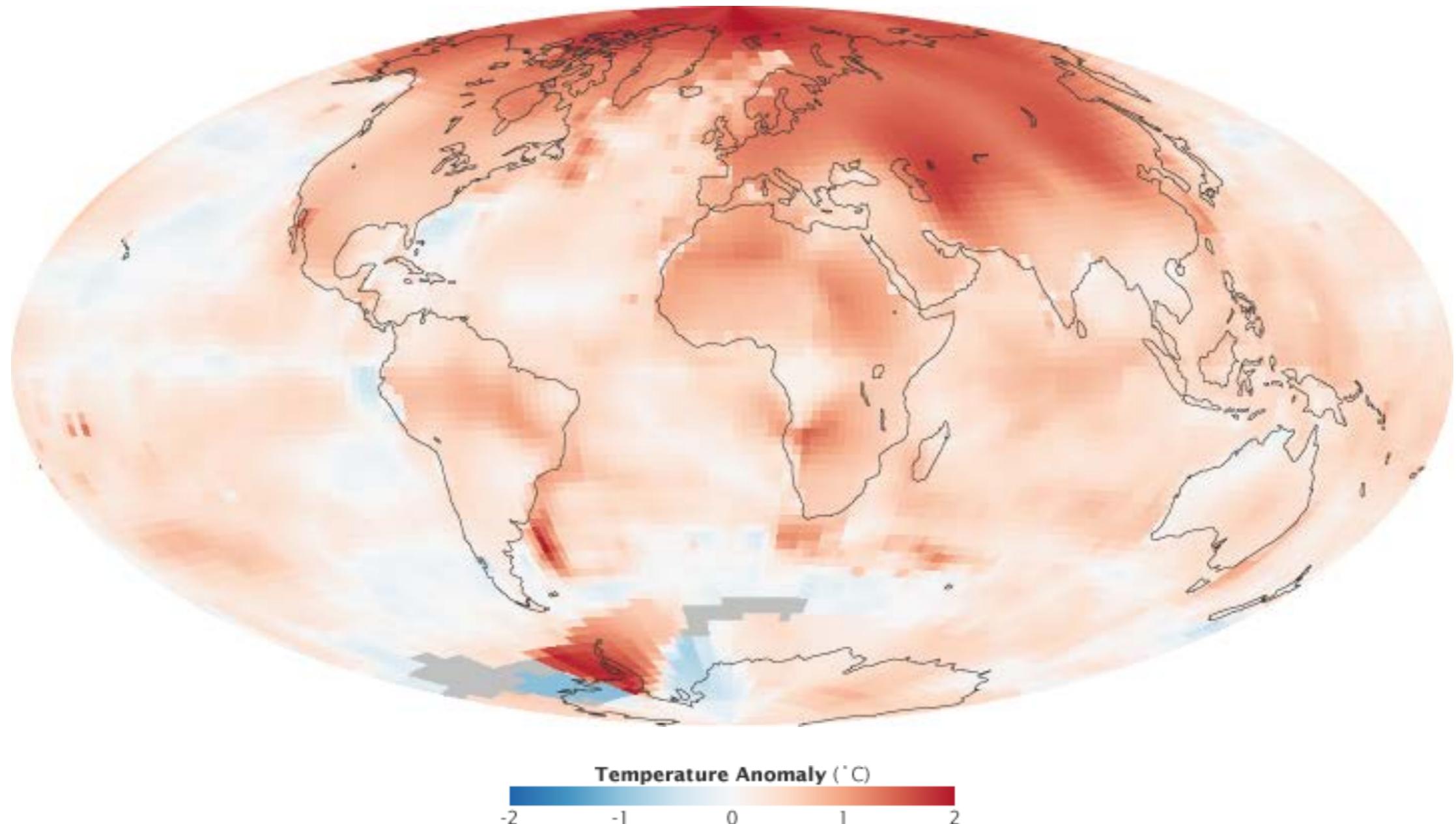


Sea Ice Fraction Trend, 2000-2014 (%)

-50 0 50

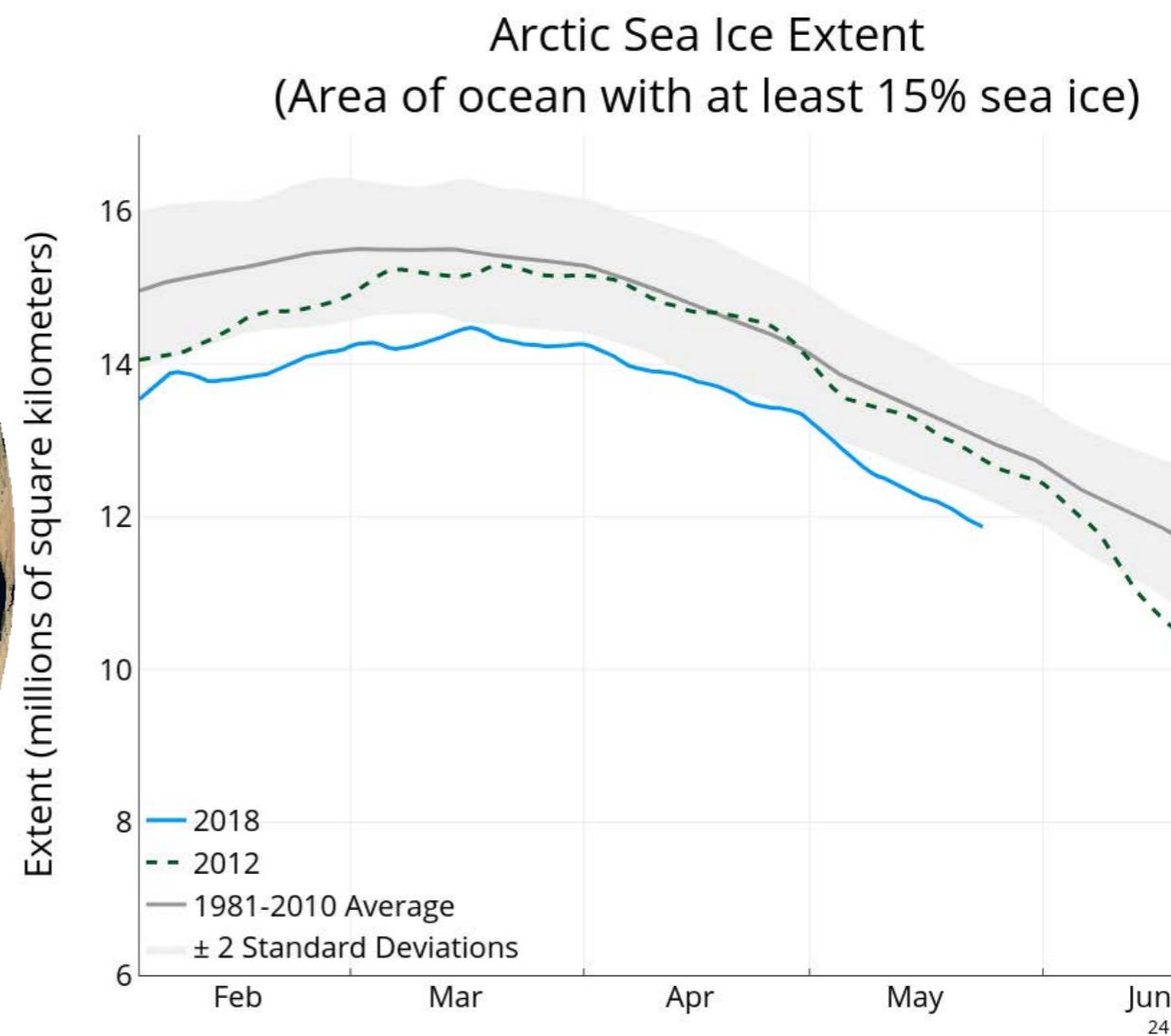
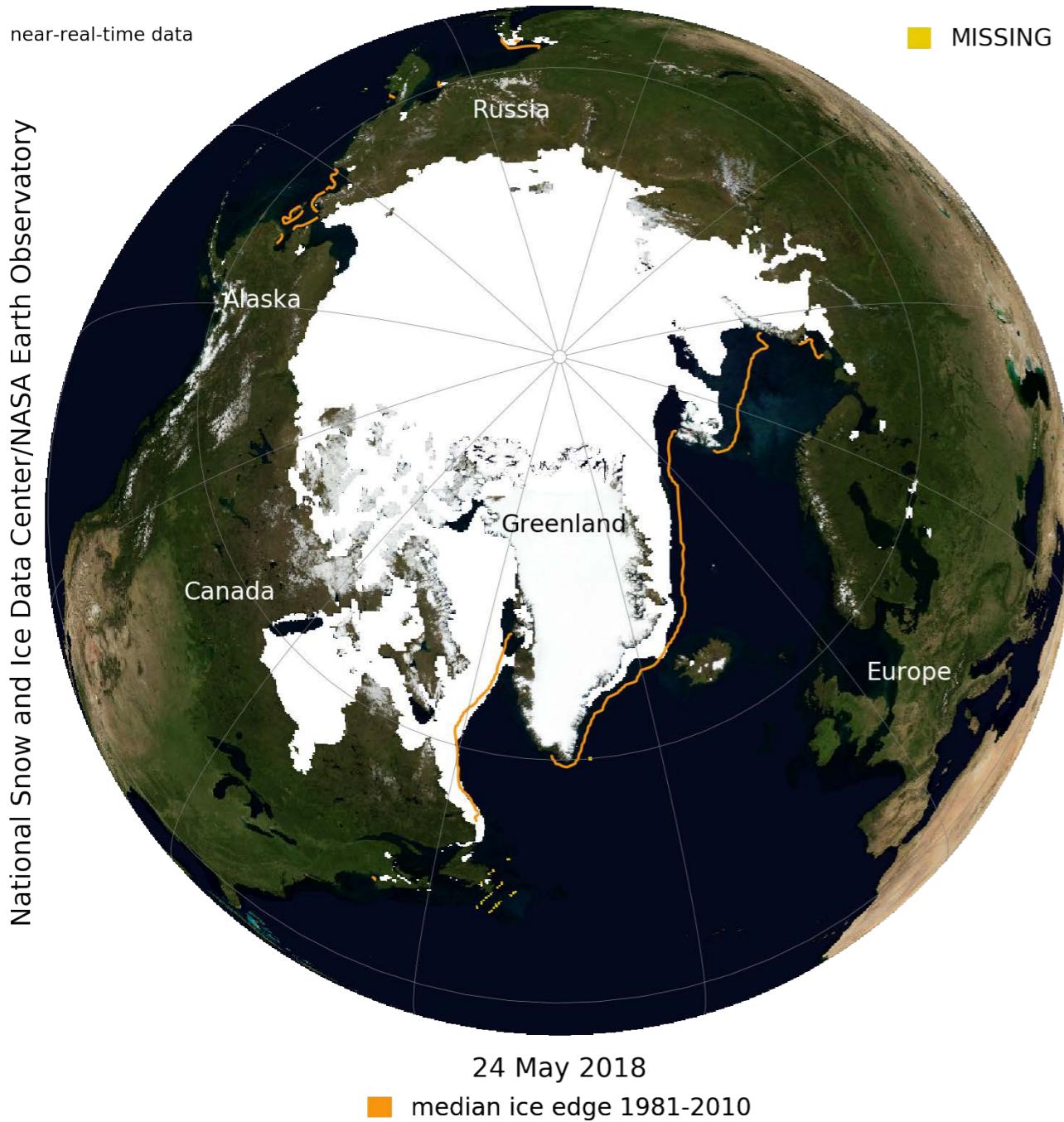
Arctic amplification

Temperature anomaly during 2000 to 2009.



It shows how much warmer or colder a region is compared to the norm for that region from 1951 to 1980. Global temperatures from 2000–2009 were on average about 0.6°C higher than they were from 1951–1980.

Sea-ice in the Arctic this month

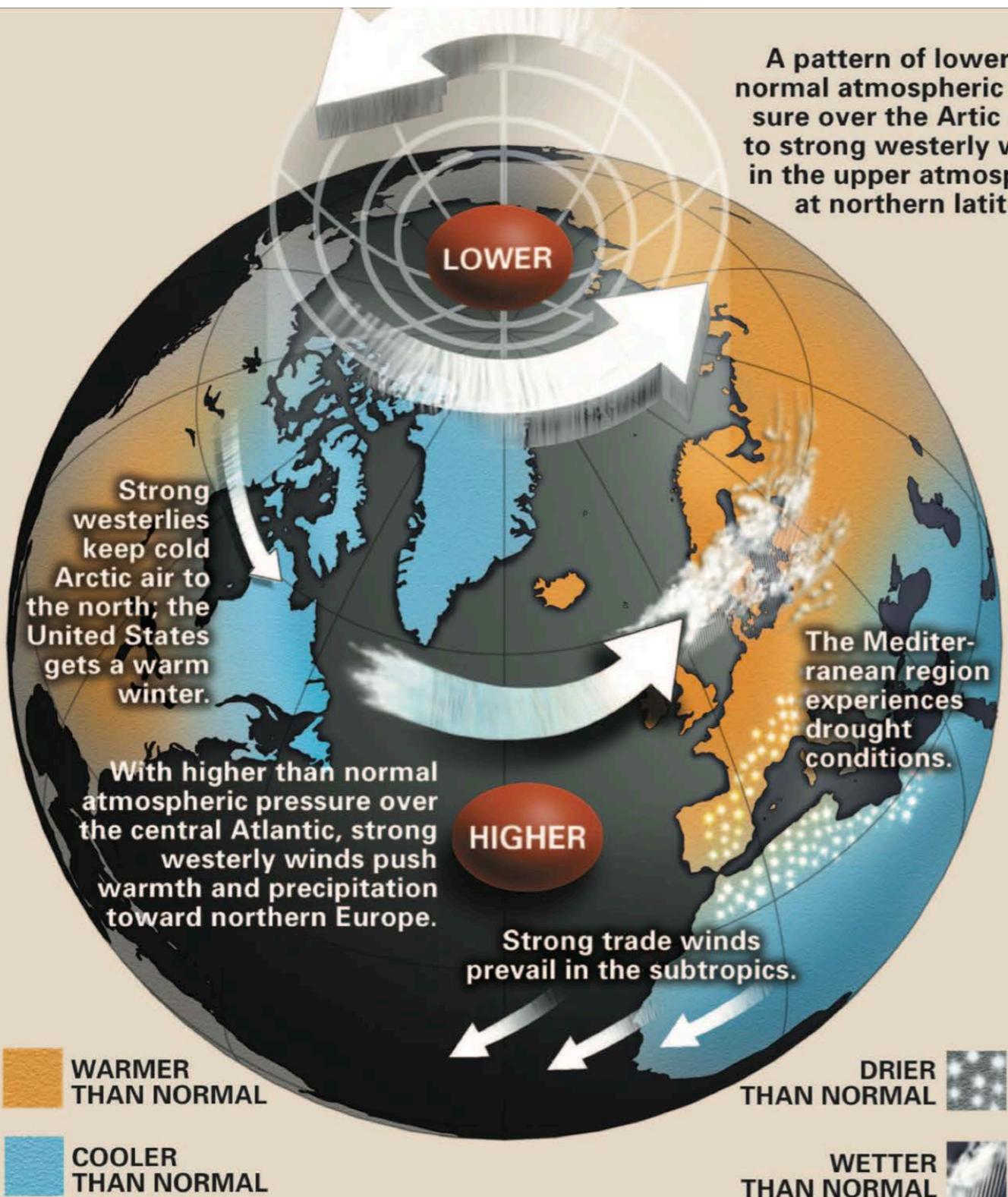


From http://nsidc.org/data/seoice_index/

Arctic Oscillation

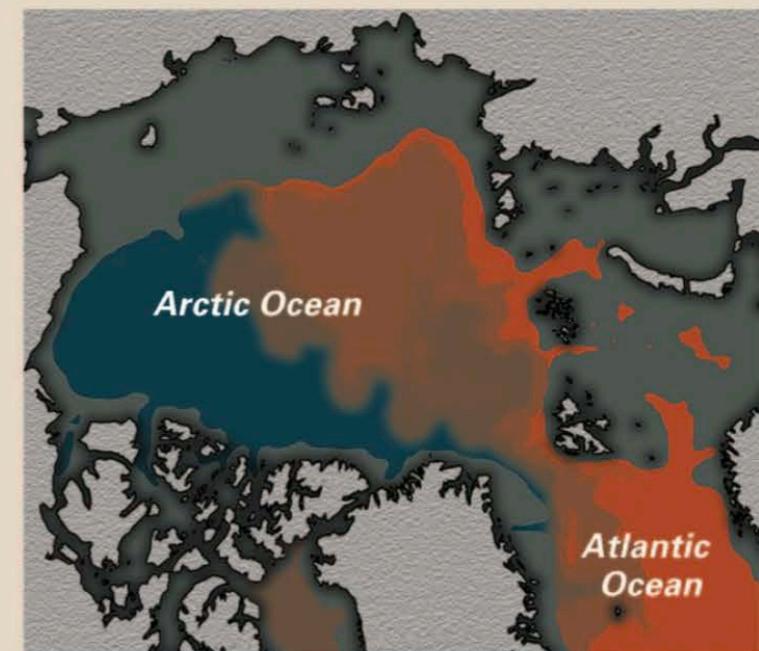
- The Arctic Oscillation refers to an opposing pattern of pressure between the Arctic and the northern middle latitudes.
- A warm positive phase of the AO, strong pressure gradient produces strong westerly winds aloft
- A cold negative phase of the AO, the pressure gradient becomes weaker, so the westerly wind also weakens.

A positive phase of the Arctic Oscillation



WARM PHASE

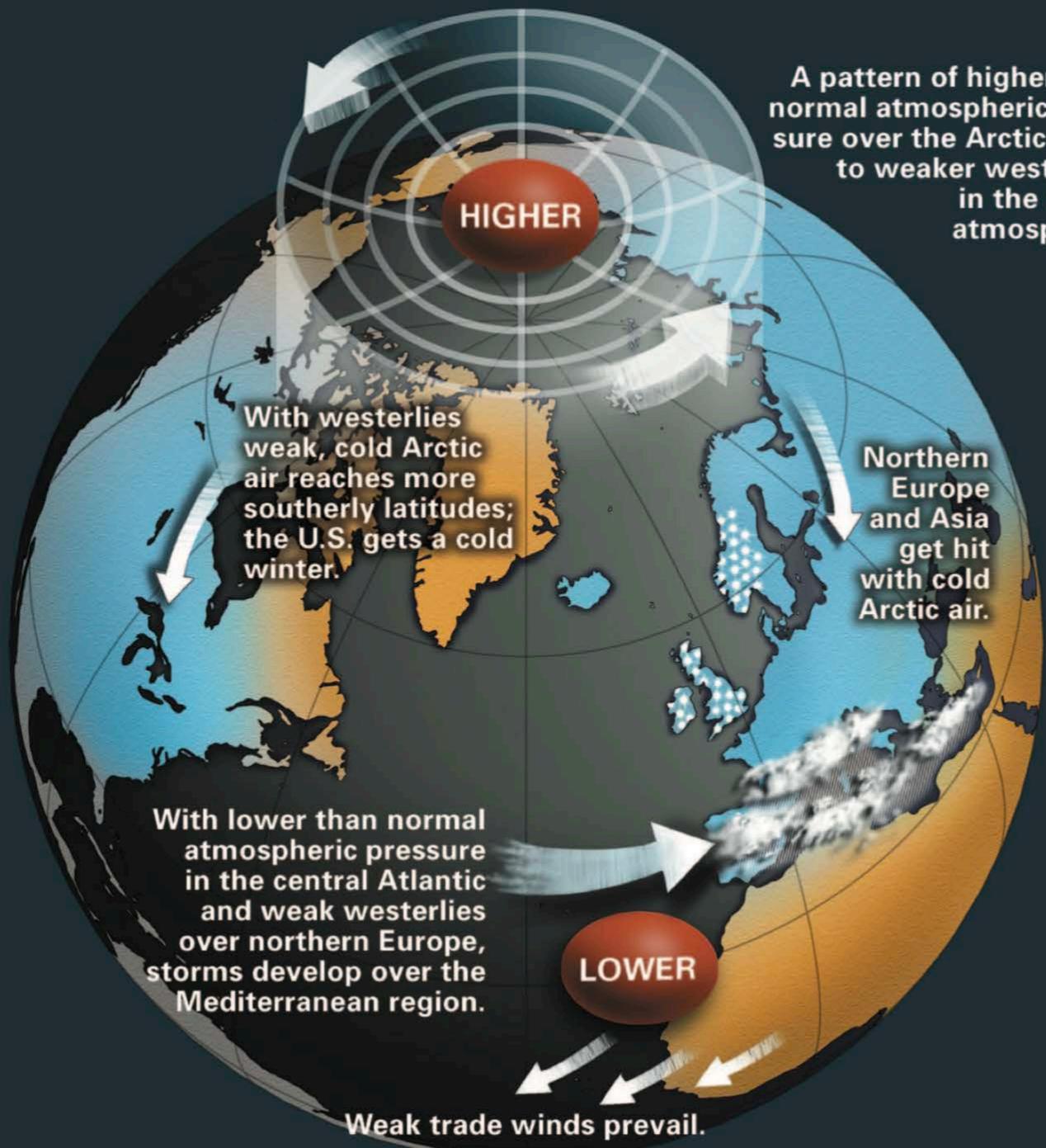
The recent warm phase has brought a number of startling changes to the Arctic Ocean. New wind and water currents have drawn relatively warm, salty Atlantic water 20 percent farther into the Arctic than usual (below). Meanwhile, the layer of especially cold water that insulates sea ice from the warmer Atlantic water has thinned across much of the Arctic—and so has the sea ice itself, by an average of four feet.



Cooler Arctic water Warmer Atlantic water

MODEL DEPICTS WATER LAYER AT
920-1,180 FEET BELOW SEA LEVEL

A negative phase of the Arctic Oscillation



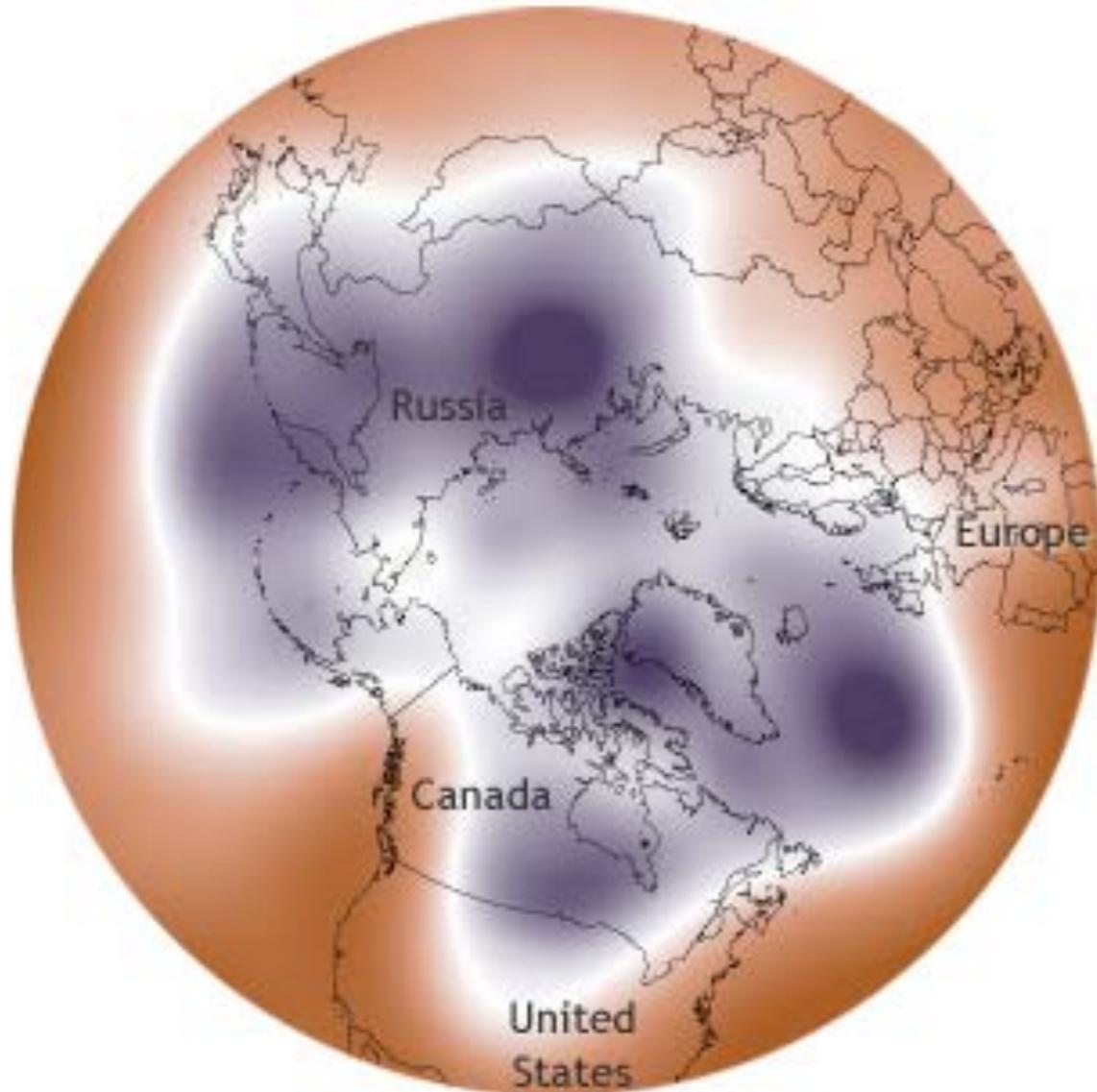
COOL PHASE

In cooler periods strong surface winds maintain a powerful clockwise gyre, or circular current, in the western Arctic that keeps Atlantic water at bay. These wind and water currents also distribute the ocean's colder, fresher insulating water layer more evenly, which inhibits the melting of ice. Until the recent warm phase, this was considered the Arctic's "normal" pattern.



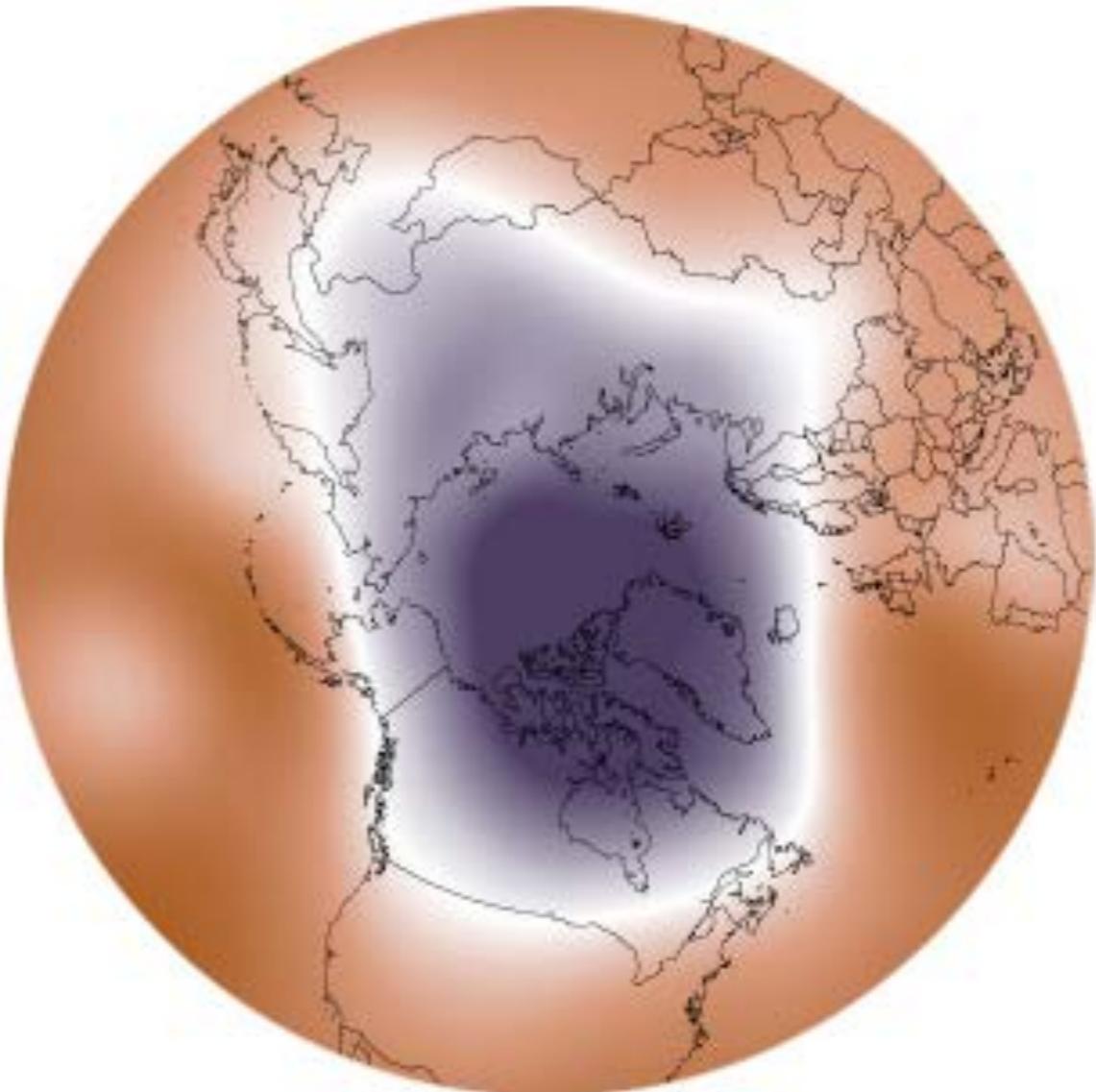
Polar vortex

Wavy polar vortex configuration



January 5, 2014

More typical, compact configuration



500-mb geopotential height (meters)

5000

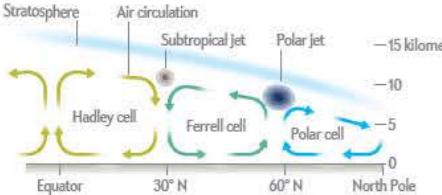
5900

A Radical Jet Stream Delivers Extreme Weather

Two jets of high-altitude wind blow around the earth in each hemisphere. When bends in the polar jet become magnified (left-hand page), abnormally warm or cold air can wallop large regions of a continent. The bends can also get stuck that way for weeks, causing droughts, floods, heat waves and deep freezes. Two leading theories can explain the big bends (right-hand page), one driven by climate change and one linked to either climate change or natural variability.

Jet Streams Form

Because the equator gets more solar energy than the poles, hot air rises there, hits the stratosphere and spreads toward the poles. The earth's spin deflects the air into three major, interlocking atmospheric circulation cells in each hemisphere. Jet streams arise along the cell boundaries to equalize pressure differences.



CIRCULATION CELLS

Polar cell

Ferrell cell

Hadley cell

ABNORMALLY WARM AND DRY

ABNORMALLY COLD AND WET

NORMAL POLAR JET STREAM
AMPLIFIED POLAR JET STREAM
SUBTROPICAL JET STREAM

Occasionally the bends, known as Rossby waves, can get stuck in place, locking in long periods of extreme weather

H High-pressure center
L Low-pressure center

Long-Term Ramifications

If the polar jet stream has crossed a tipping point to a new state in which big bends become common, the U.S. may see more heat waves in the west, cold waves in the east and drought in the central states.

Equator

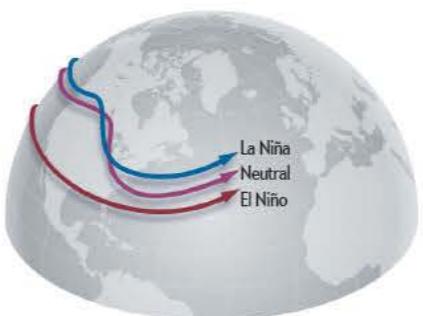
Waviness Brings Heat Waves and Deep Freezes

When mild bends in the polar jet stream become amplified (wavy blue arrow), huge warm-air masses can surge much farther north than usual, and cold-air masses—such as the winter polar vortex—can plunge far to the south. The bends typically progress across the U.S. in three to five days, delivering our daily weather.

Why Waviness Changes: Two Possibilities

1 Atmospheric Oscillations

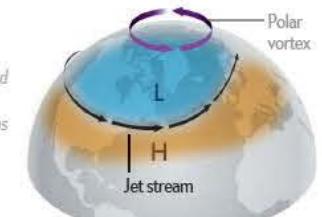
Natural phenomena in the atmosphere can alter the jet stream's path. Two prime suspects are the El Niño/Southern Oscillation and the Arctic Oscillation.



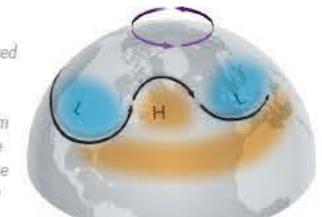
El Niño/Southern Oscillation

This cycle in tropical atmospheric pressure has two phases: El Niño brings warmer Pacific Ocean water eastward, moving the jet stream south; La Niña brings cooler water, moving the jet north. Recent, large differences in the phases, linked to a wavy jet, may be natural or driven by climate change.

Positive phase is linked to a large pressure difference, which helps the jet stream take a straighter path, and to a strong polar vortex, which keeps cold air north

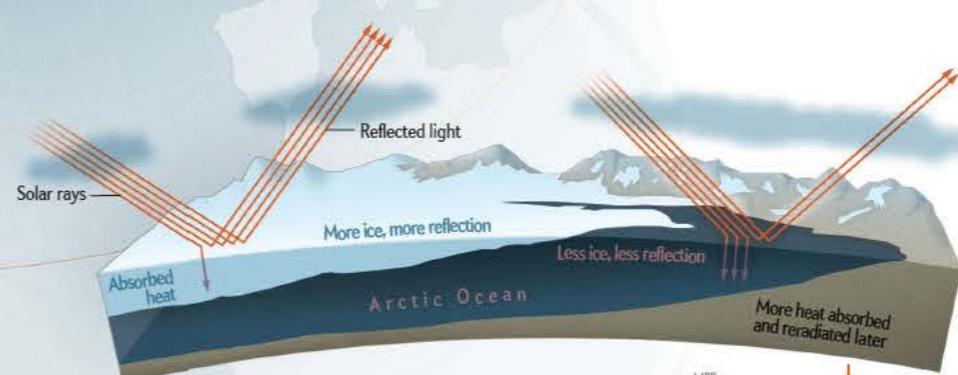


Negative phase is linked to a small pressure difference, which weakens the jet stream so big bends are more likely, and weakens the polar vortex, allowing cold air to drift south



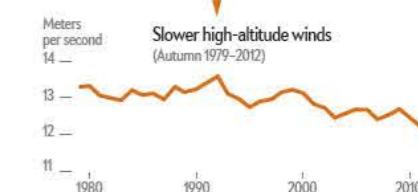
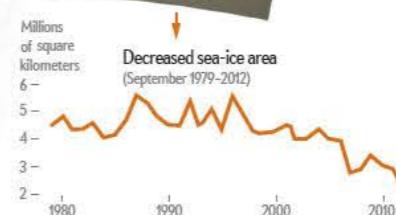
Arctic Oscillation

Week-to-week changes in sea-level pressure between the Arctic and midlatitudes cause this phenomenon; factors not fully understood shift it between positive and negative phases.

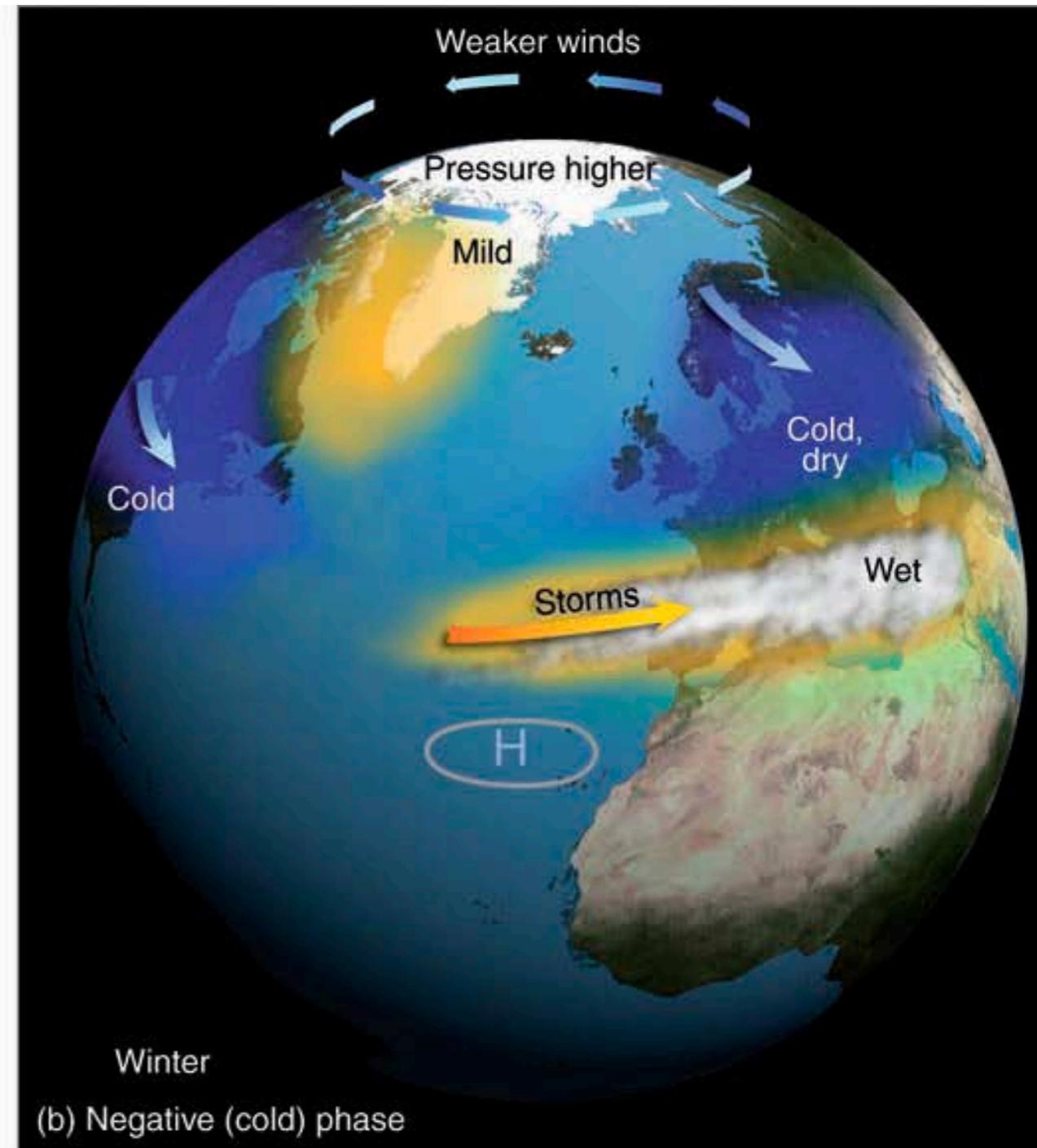
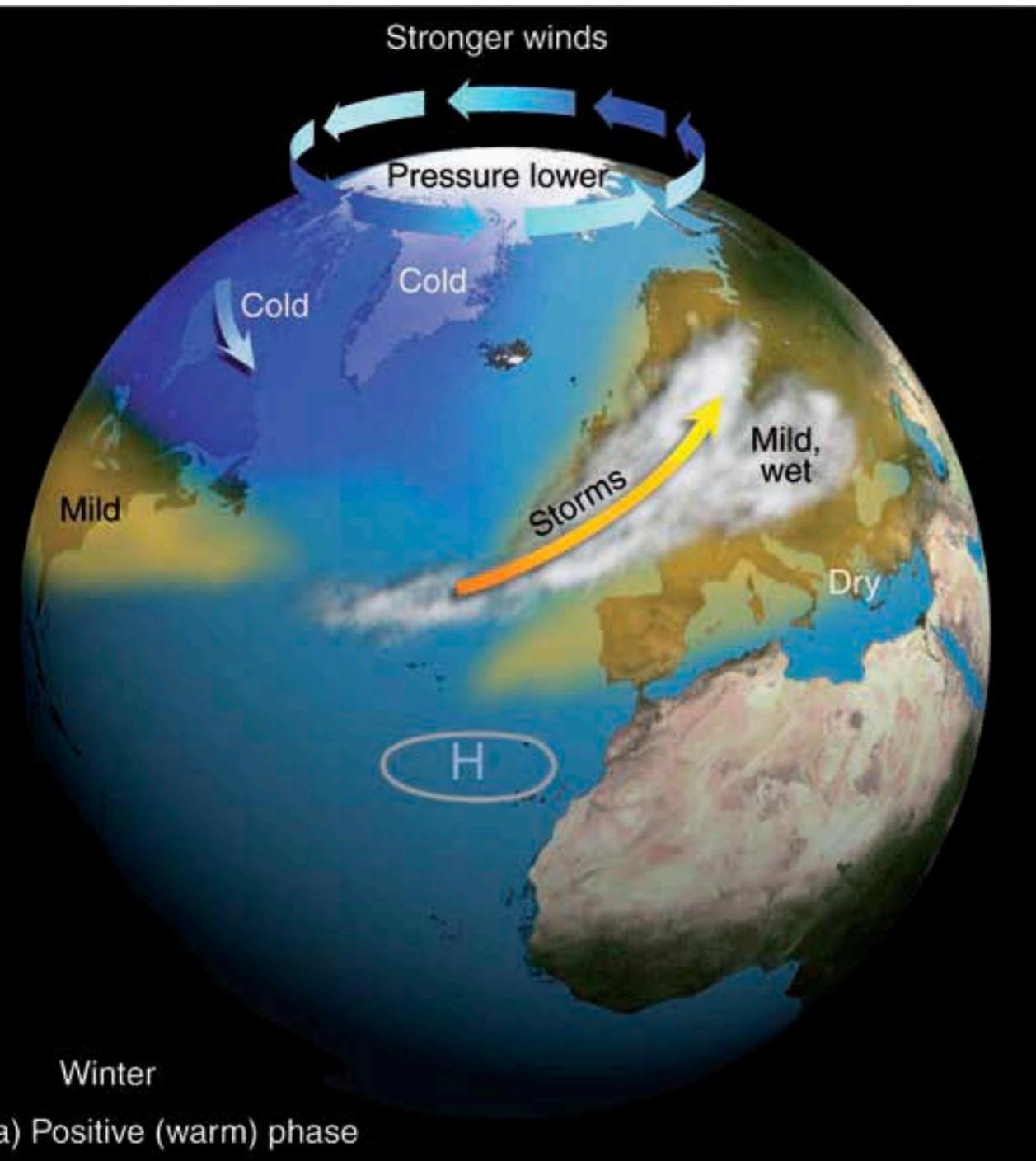


Less Ice, Weaker Winds

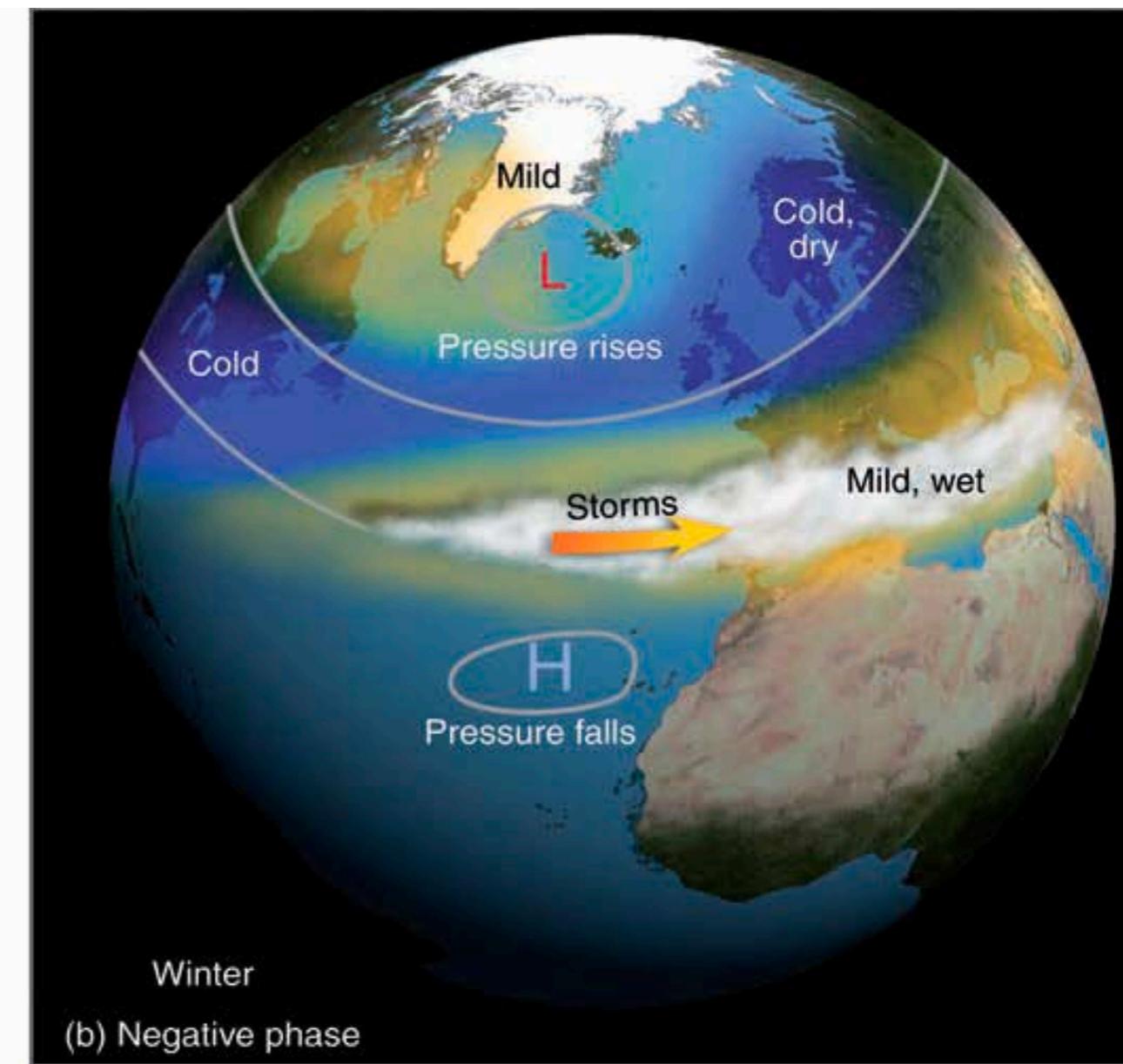
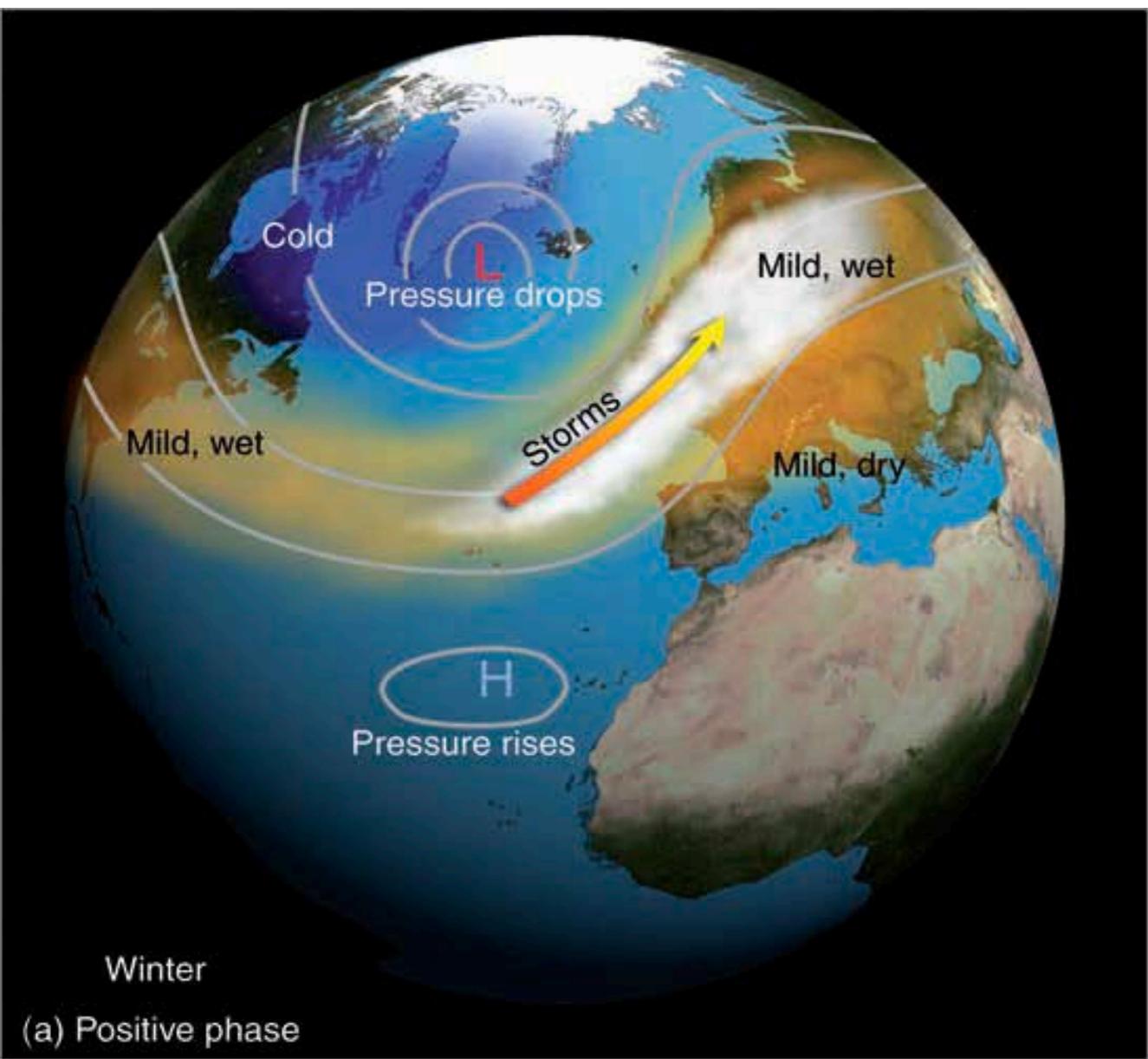
From 1979 to 2012 the minimum area of Arctic sea ice dropped 40 percent, and autumn winds high over North America slowed 10 percent (graphs). Slower winds are associated with big, problematic bends in the jet stream.



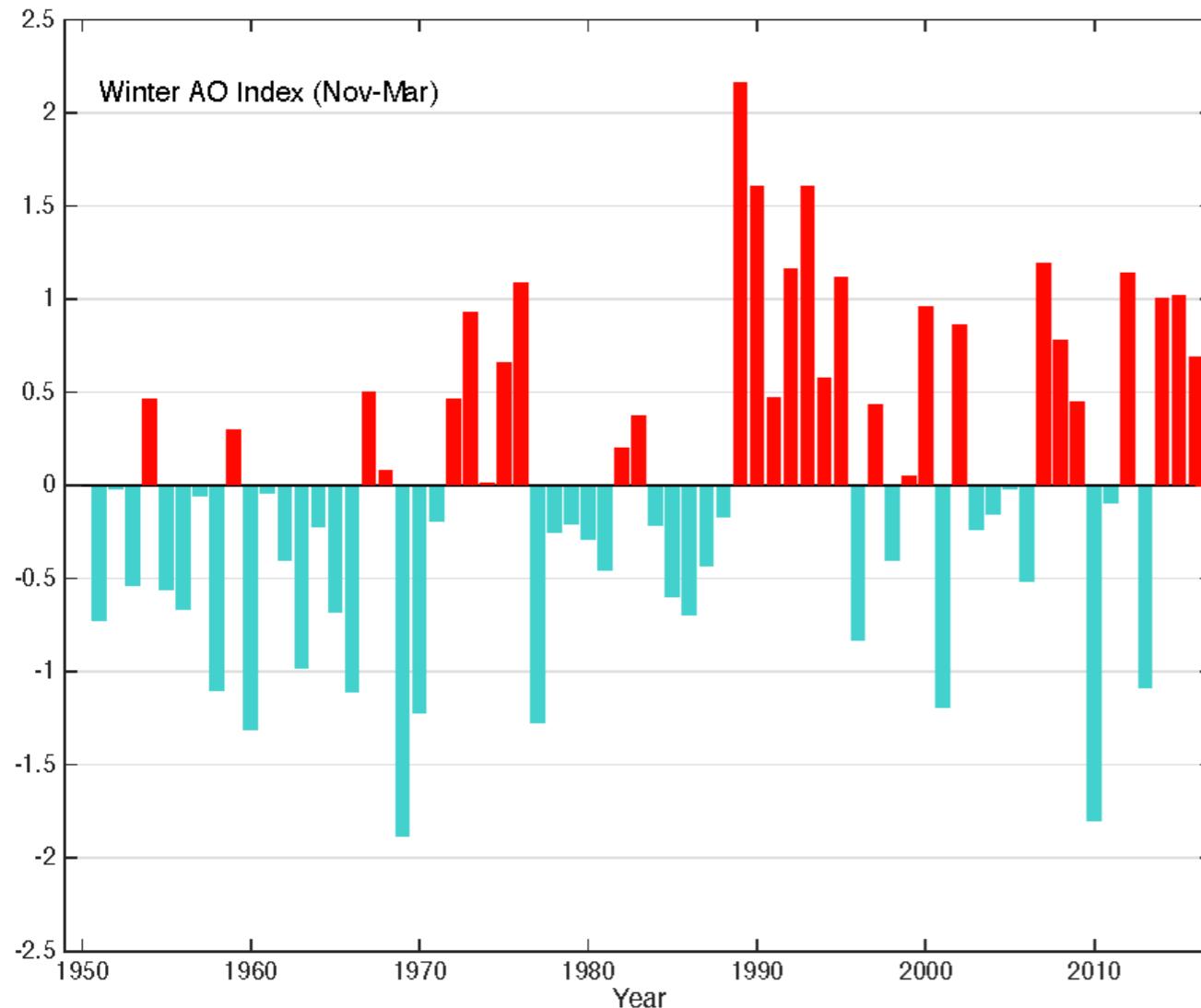
Arctic Oscillation v.s. North Atlantic Oscillation



Arctic Oscillation v.s. North Atlantic Oscillation



Winter AO index



“...freezing precipitation or snowfall events over inland China (Korea and Japan) are likely to occur more frequently during the positive (negative) AO periods.”

Park et al., 2011

Snowfall in Korea

2004



2010

