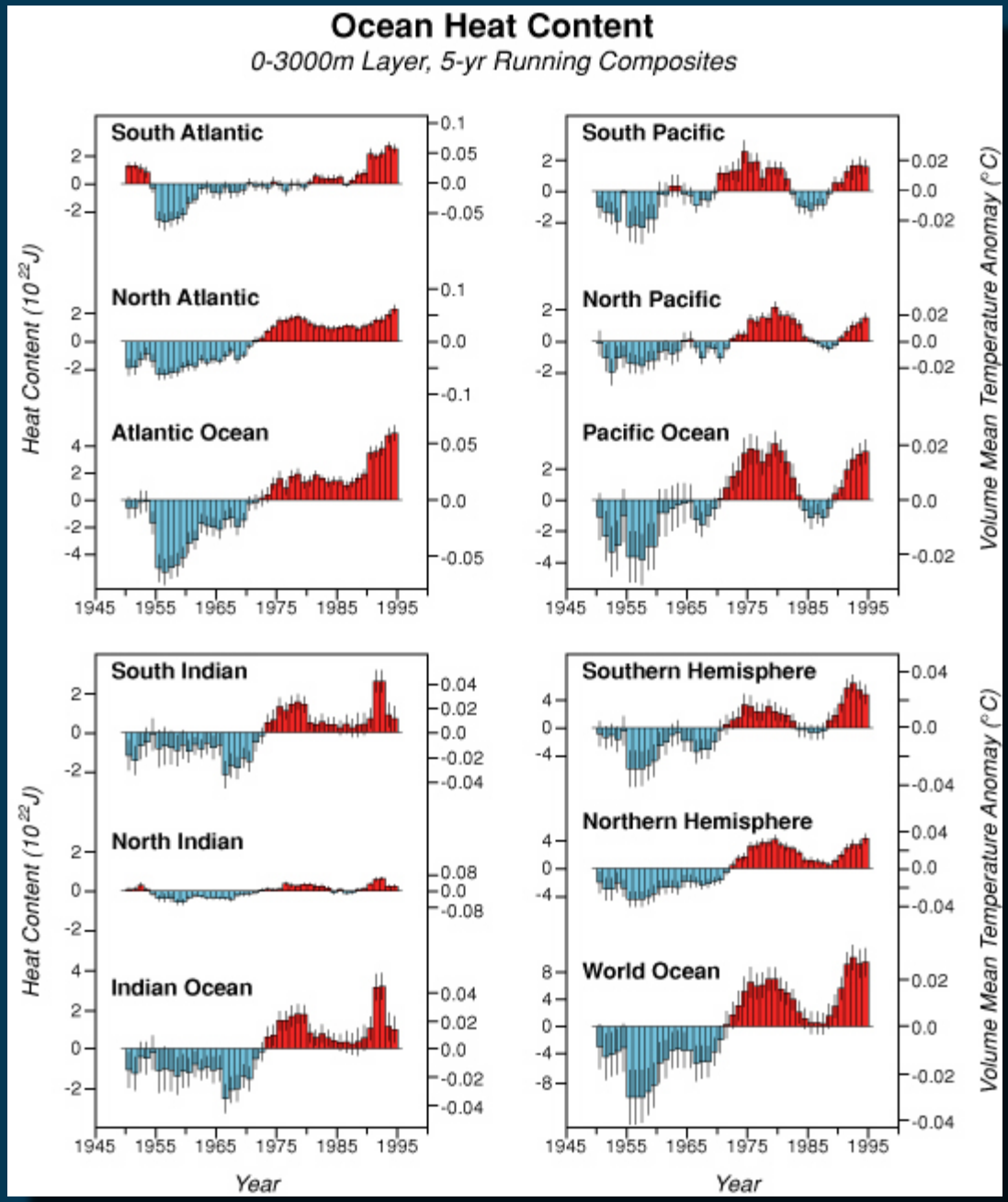
How will the Oceans Change as the Earth Warms?

- the oceans will warm, sea level will rise
- its salinity balance will be altered
- its ability to absorb CO_2 will change
- it will impact atmospheric circulation, storm tracks, severe storms, and the frequency and distribution of droughts



The oceans have been warming for the last 50 years

The net warming above 3000 m is 0.06^{o} C

The oceans have absorbed about 30 times more heat than the atmosphere since 1955

Oceans	18.2×10^{22} J
Atmosphere	6.6×10^{21} J

Levitus et al., 2001

What are the Implications?

The oceans will continue to absorb heat as the climate system warms

Warming will cause sea water to expand

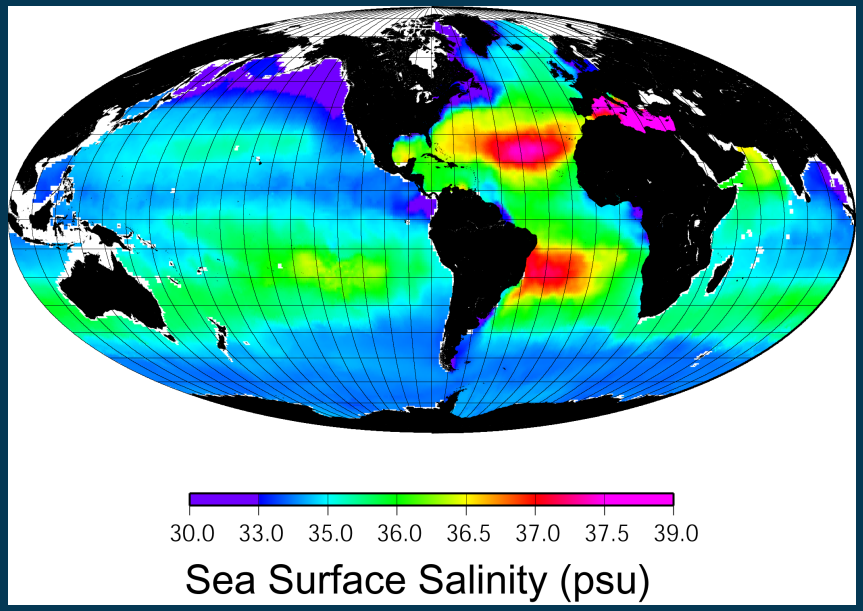
The effect of ocean heat absorption will be to delay the warming of the atmosphere

The rate and magnitude of global warming will be affected by how the ocean circulates in the future – when and where will it release the stored heat?

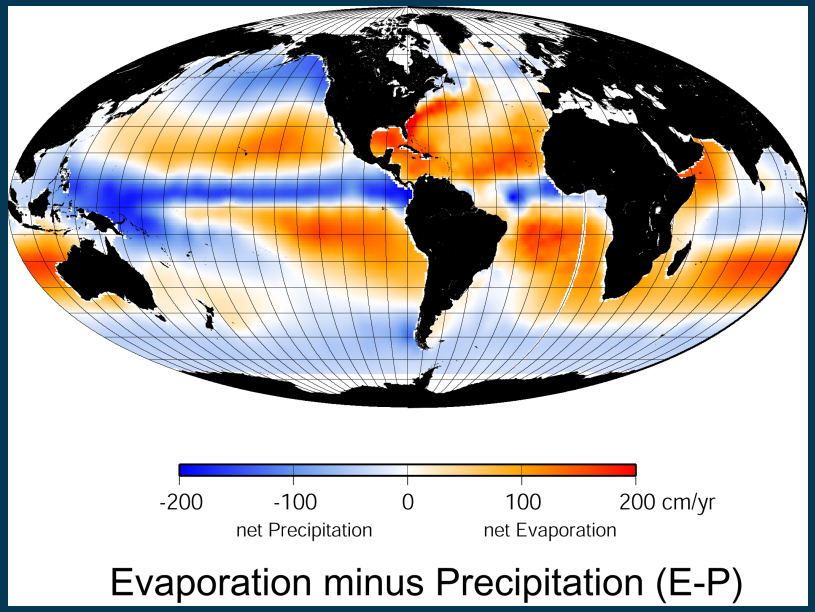
What about Salinity?

- Oceans contain 97% of Earth's water
- Oceans experience 86% of evaporation
- Oceans receive 78% of planetary precipitation
- A 1% increase in Atlantic precipitation equals the annual Mississippi runoff
- A key element of the global water cycle

Global Salinity and E-P distributions

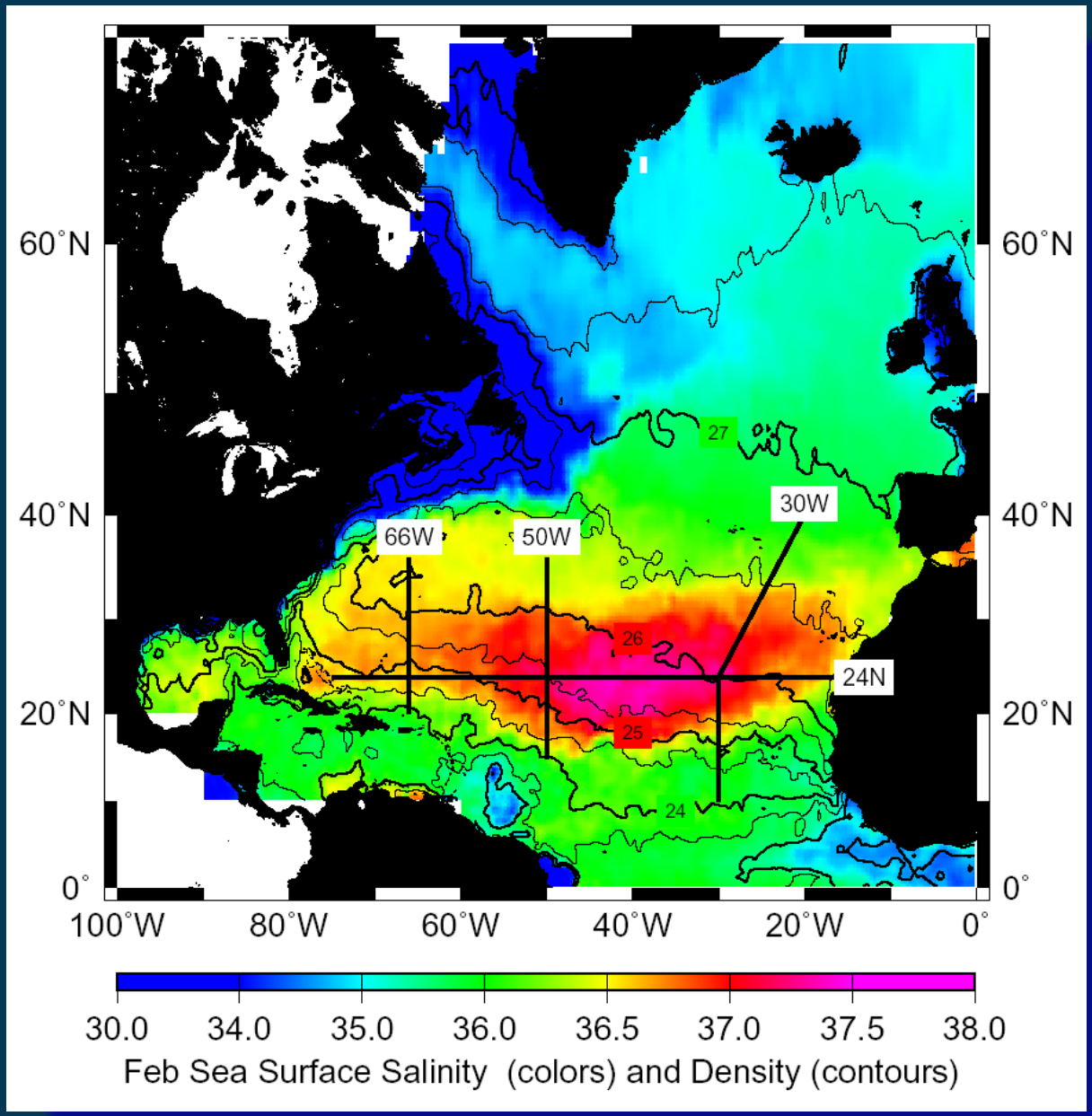


Source: HydroBase2



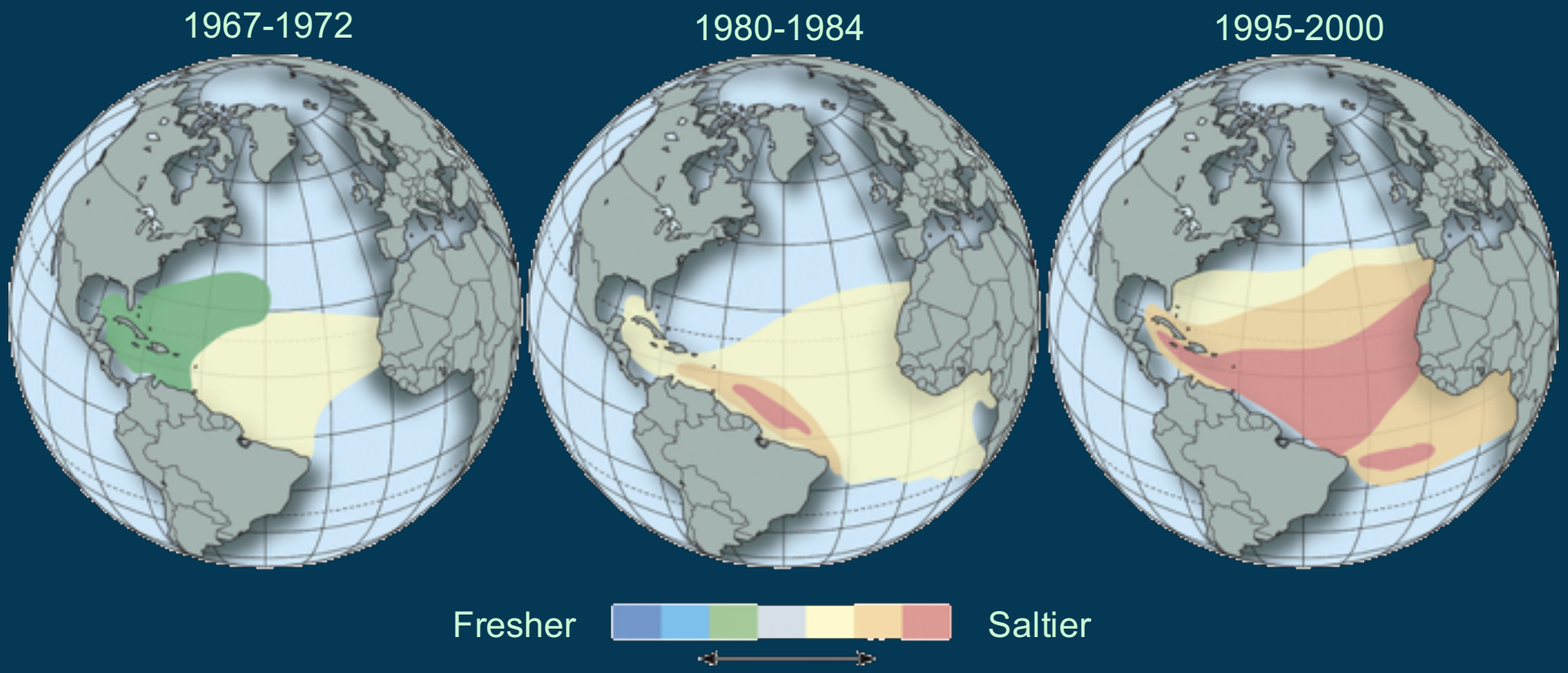
Source: R.Schmitt,WHOI

Sea surface salinity distributions are determined in large part by E-P patterns

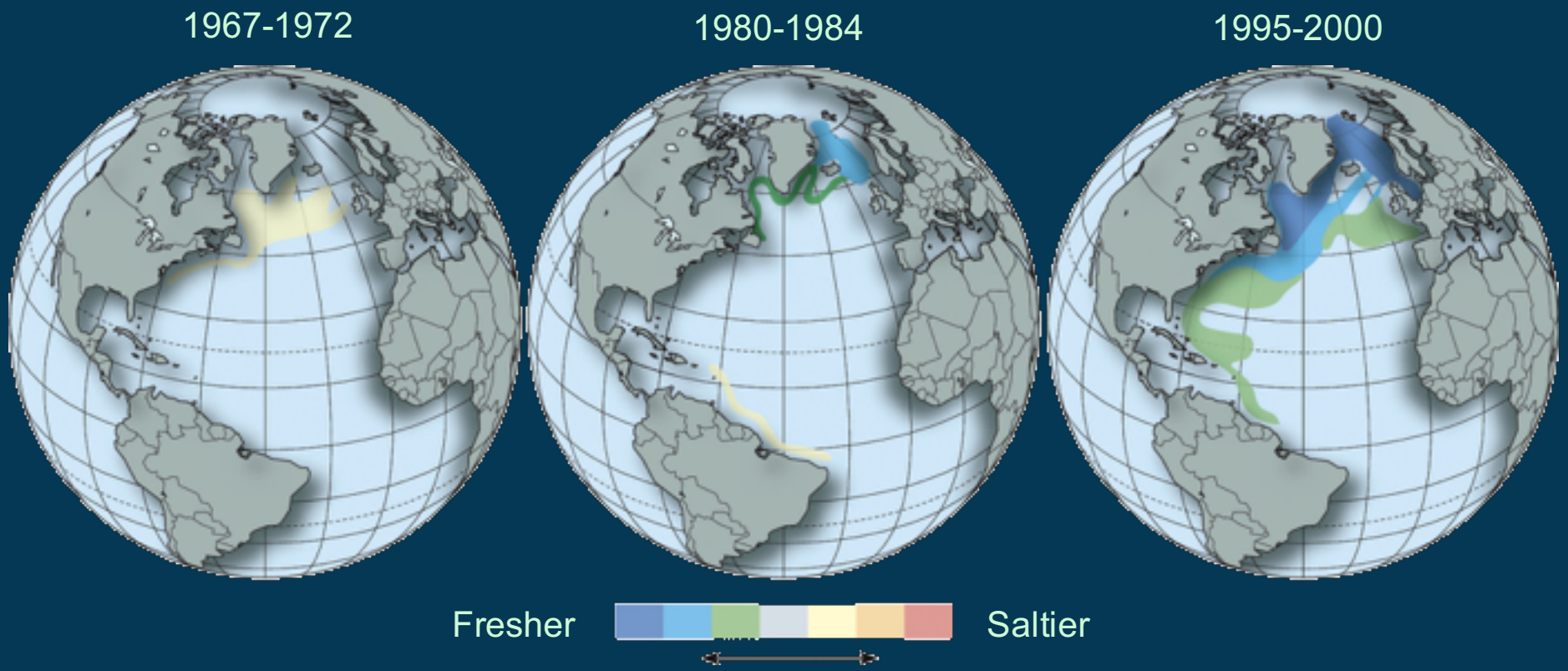


Increasing salinities in the tropical Atlantic

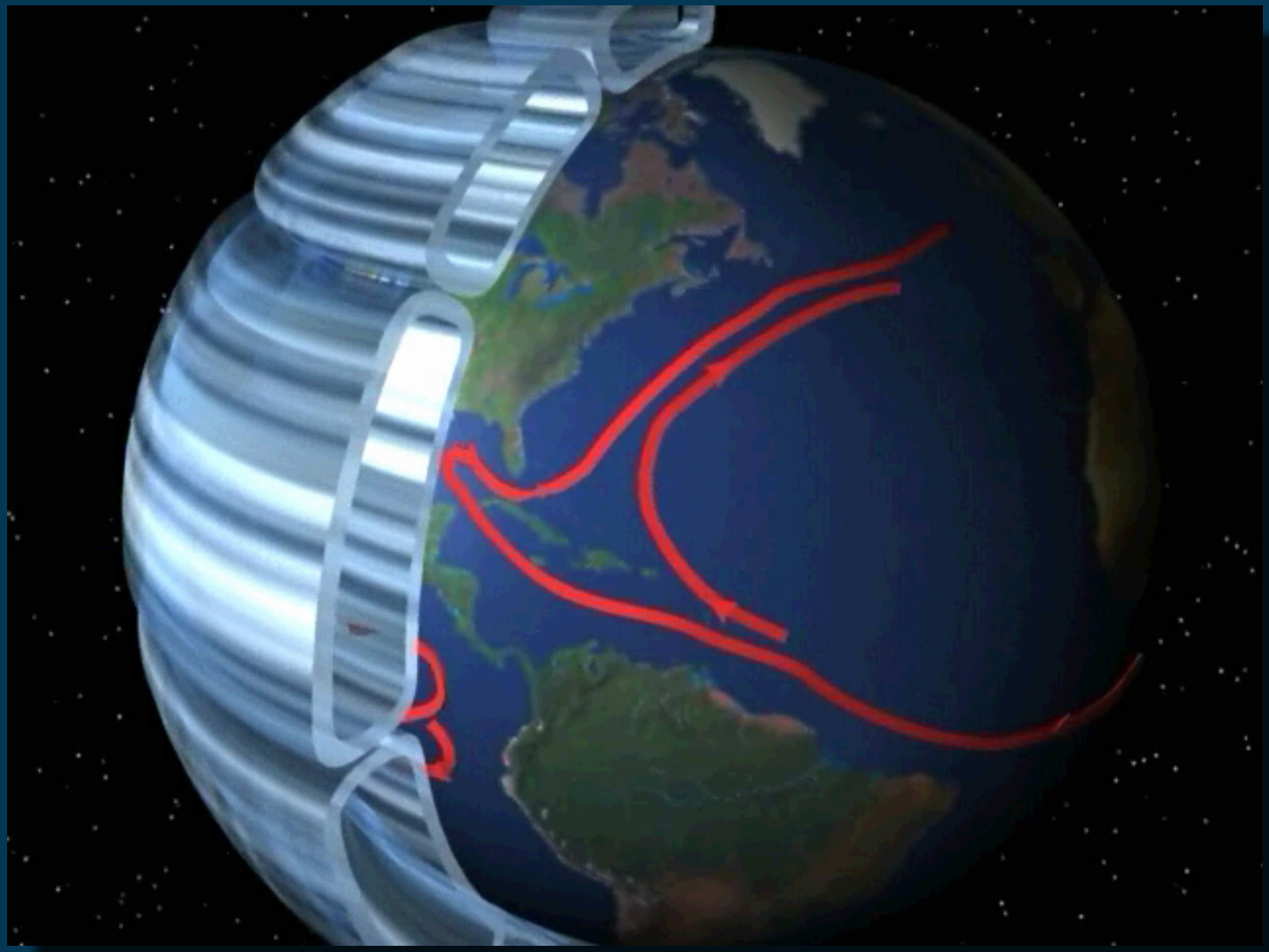
Tropical Salinities Increasing for last 40 years



Fresher Deep Water Flowing South at 3000 m



Equator to Pole Heat Transport



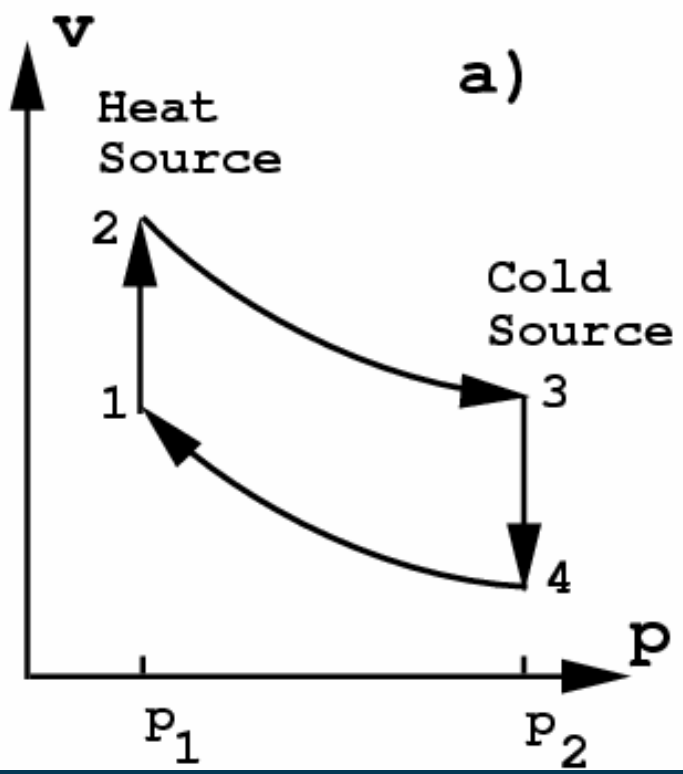
Atmosphere vs. Ocean

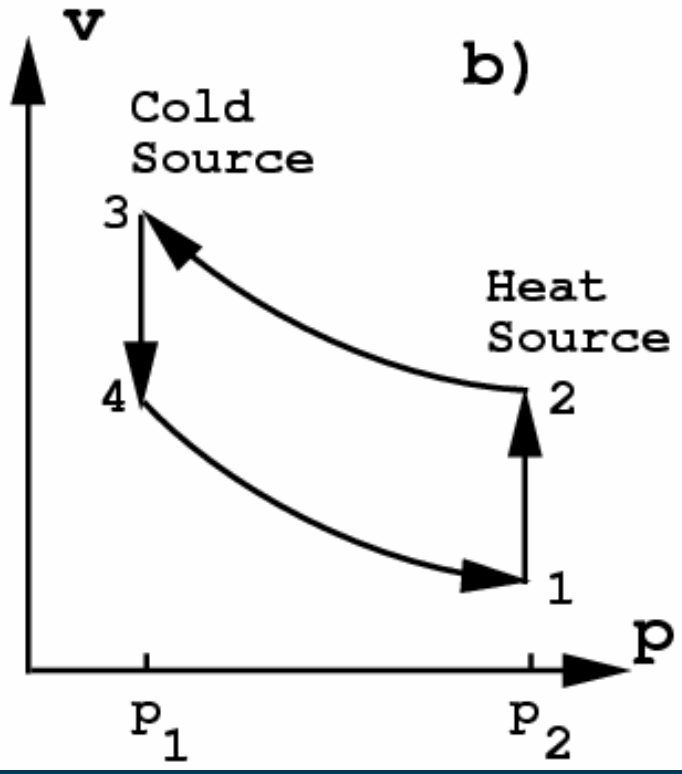
Is the ocean a heat engine?

The atmosphere and oceans work together as a heat engine, if we neglect the small contribution of tidal energy to the circulation in the oceans. The atmosphere can be considered as a heat engine, which is driven by differential heating, with an efficiency of about 33%. In this sense although the oceans is subject to differential heating similar to the atmosphere, it is not a heat engine at all. In fact, the driving force for the oceanic circulation is the mechanical energy in the forms of wind stress and tides. In comparison, differential heating is only a precondition for the thermohaline circulation, and not the driving force of the oceanic general circulation. Thus, the ocean is not a heat engine; instead, it is a machine driven by external mechanical energy that transports thermal energy, fresh water, *CO2* , and other tracers.

Sandstrom's original papers (1908, 1916) are in German, not easily accessible, but the citation from Dafant's book is very concise and accurate:

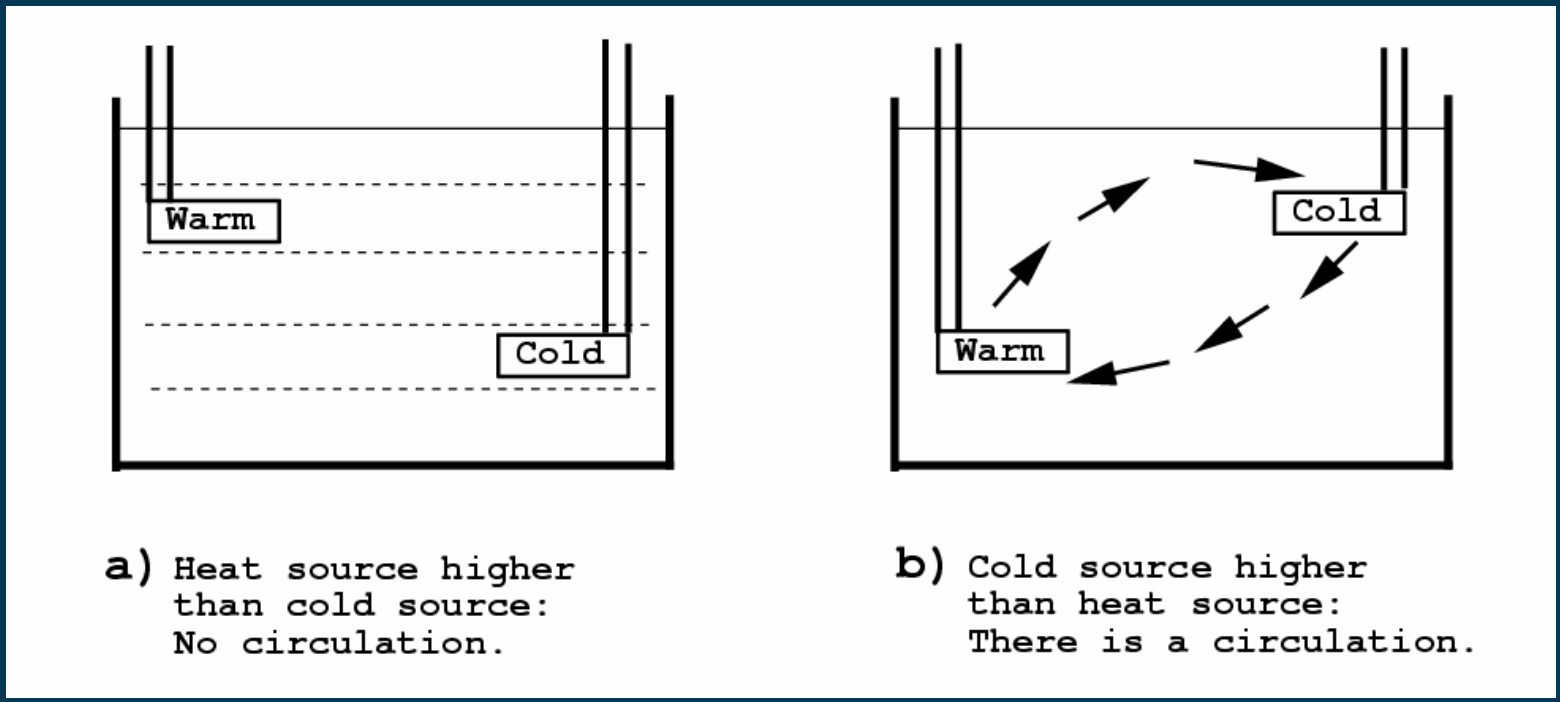
A closed steady circulation can only be maintained in the ocean if the heat sources are situated at a lower level than the cold sources (Defant, 1961, page 491).





OCEAN

ATMOSPHERE

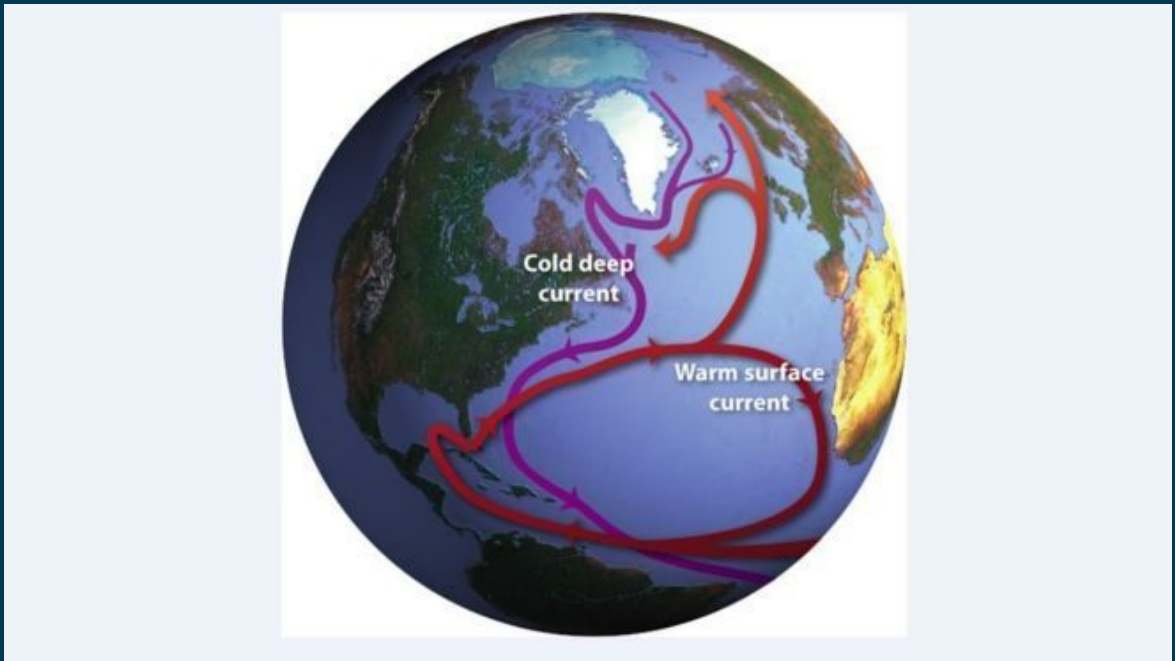


Downward mixing of heat requires energy to overcome frictional dissipation and to raise the potential energy stored in the water column, as heat penetrating downwards expands the deep water and lifts up the waters above. This is the energy supply of the thermohaline circulation: in an energetic sense, it is driven by turbulent mixing in the ocean's interior.

The power supply of the turbulence which causes this mixing is both by tidal motions and by the winds. The energy supply needed for generating the observed global overturning motion of ~30 Sv can be estimated from the advection-diffusion balance and the observed density field as ~0.4 TW ([*Munk and Wunsch*, 1998]).

Two Important Ocean Processes will be Affected

- **Convection and thermohaline circulation – the large scale ocean circulation**

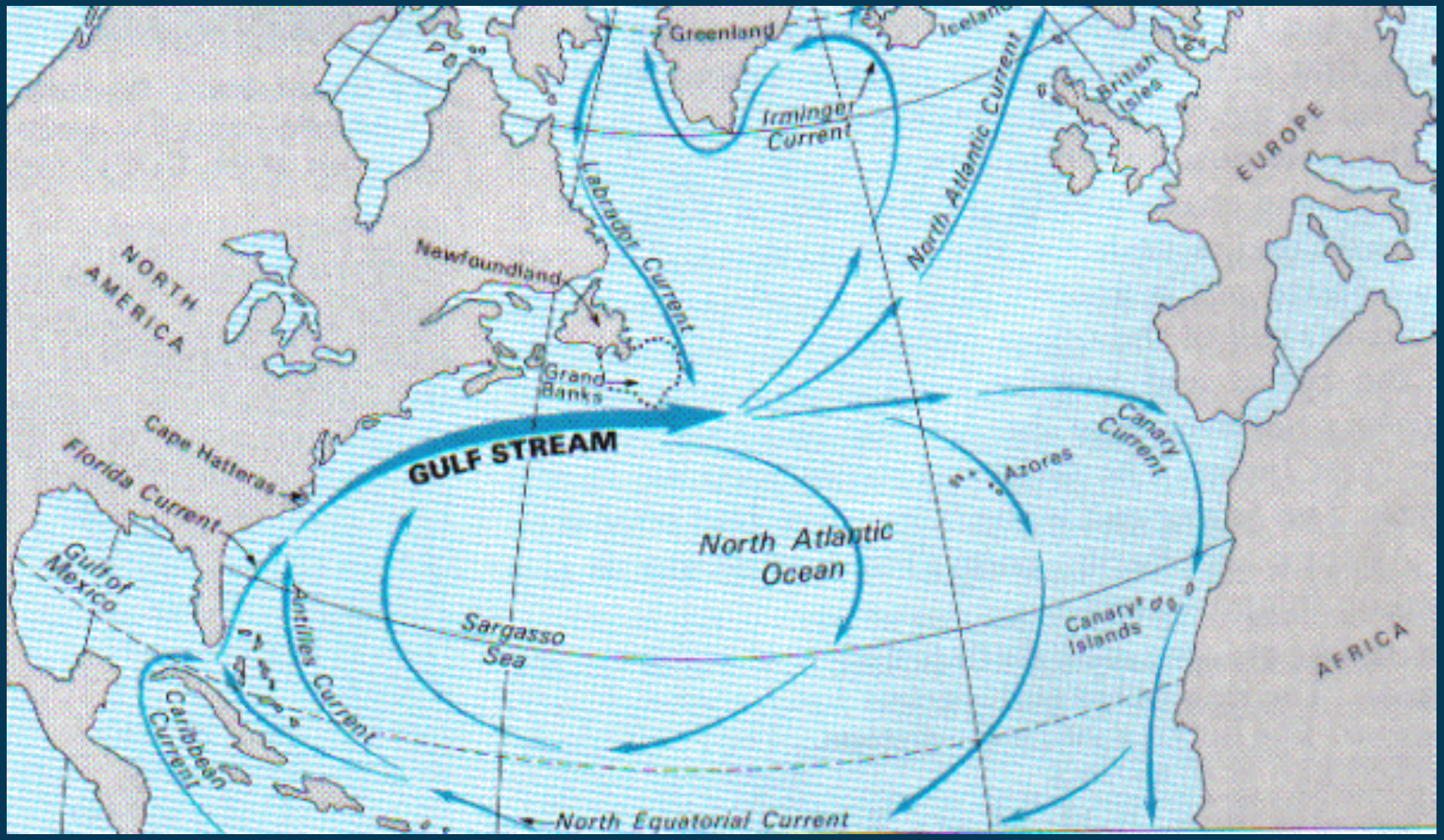


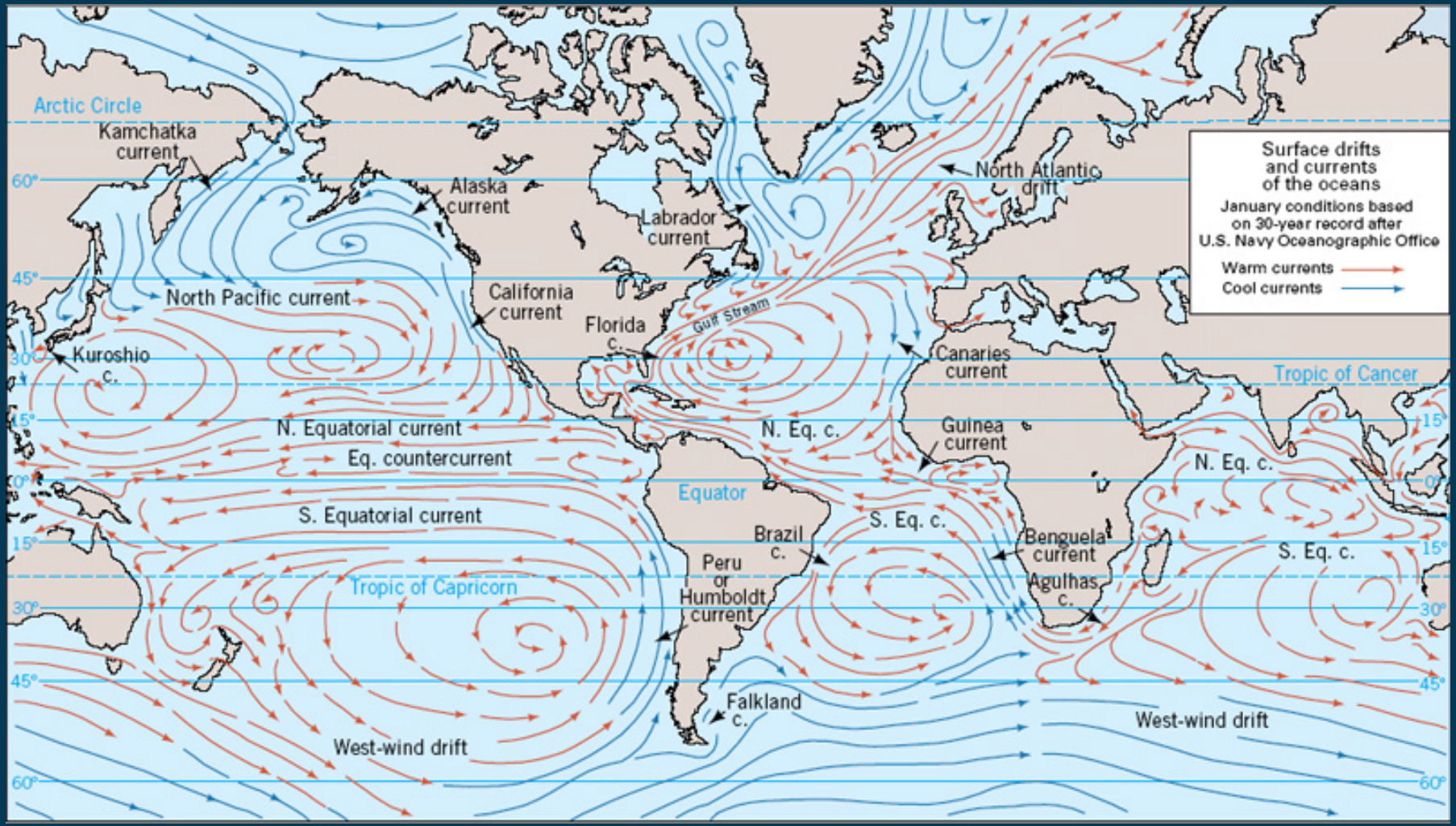
An important CAVEAT

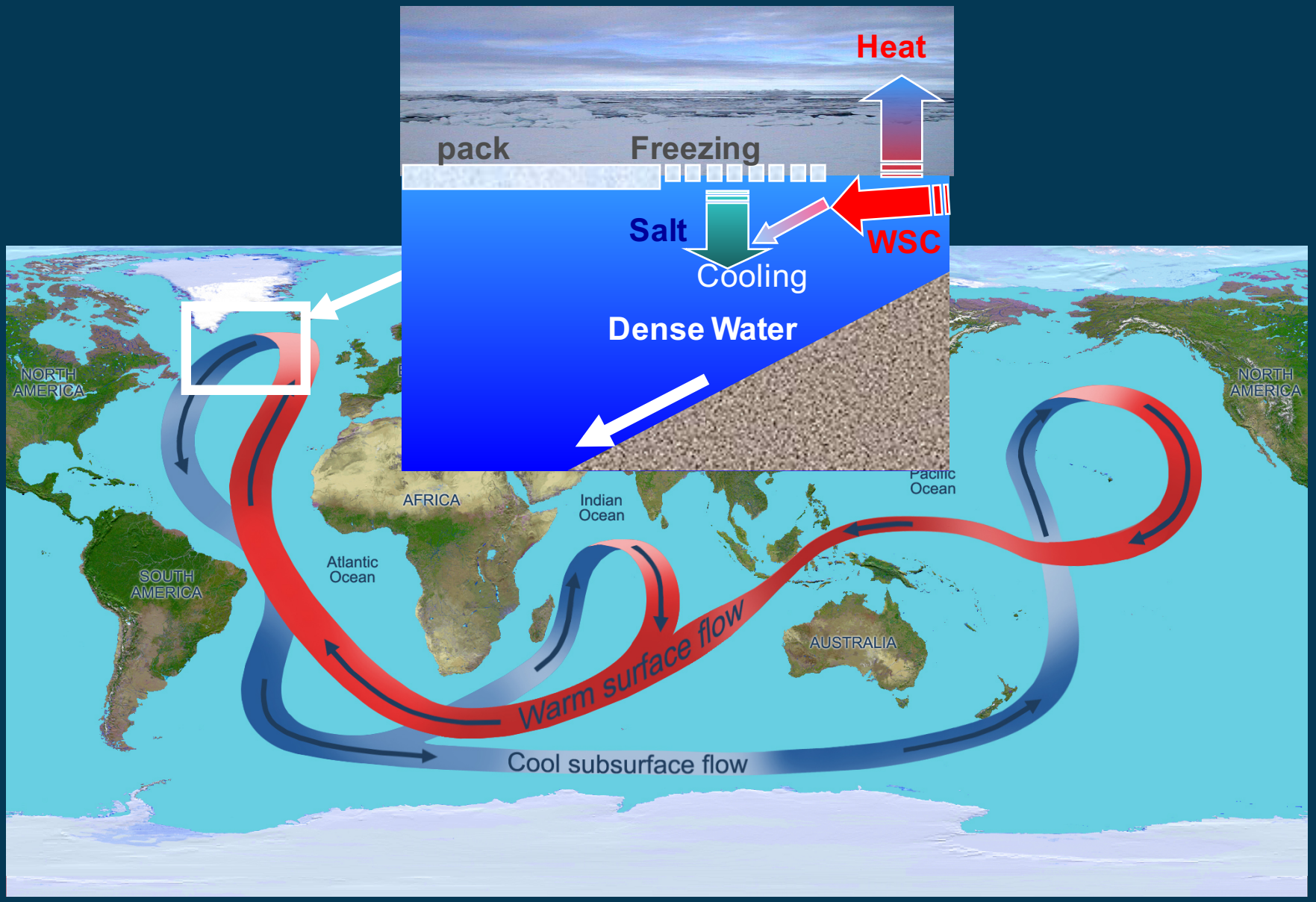
The Gulf Stream **is not** the AMOC:

- The Gulf Stream is a **Wind-Driven** intensified current in the Western Boundary of a sub-tropical gyre->NO Thermodynamics! (Adiabatic)

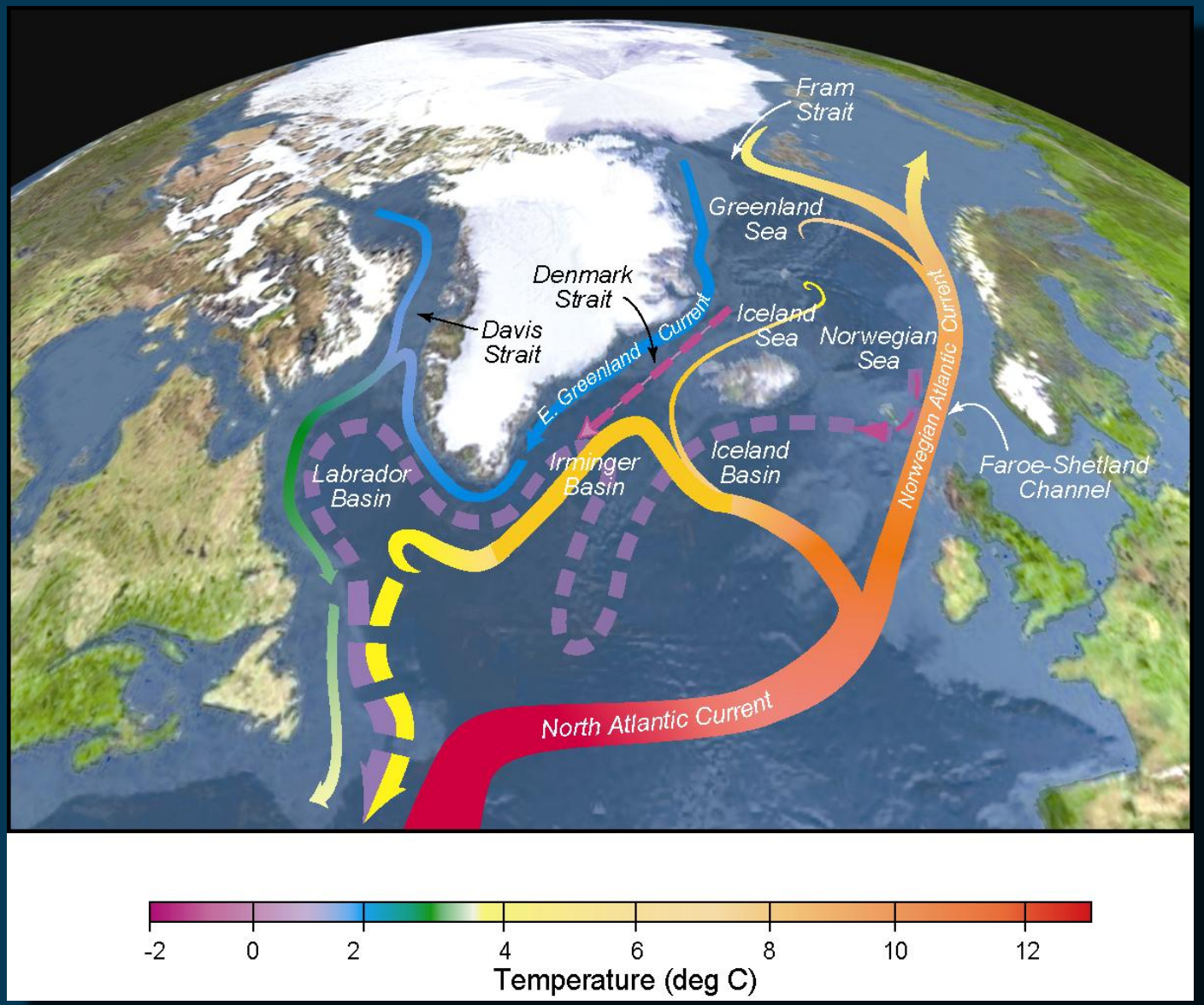
- The AMOC is a **thermohaline** current which is driven by density gradients->Thermodynamics!


Greenland
Iceland
Irminger Current
North Atlantic Current
British Isles
EUROPE
Labrador Current
Newfoundland
NORTH AMERICA
Grand Banks
GULF STREAM
Cape Hatteras
Florida Current
Azores
Canary Current
North Atlantic Ocean
Gulf of Mexico
Antilles Current
Sargasso Sea
Canary Islands
AFRICA
Caribbean Current
North Equatorial Current

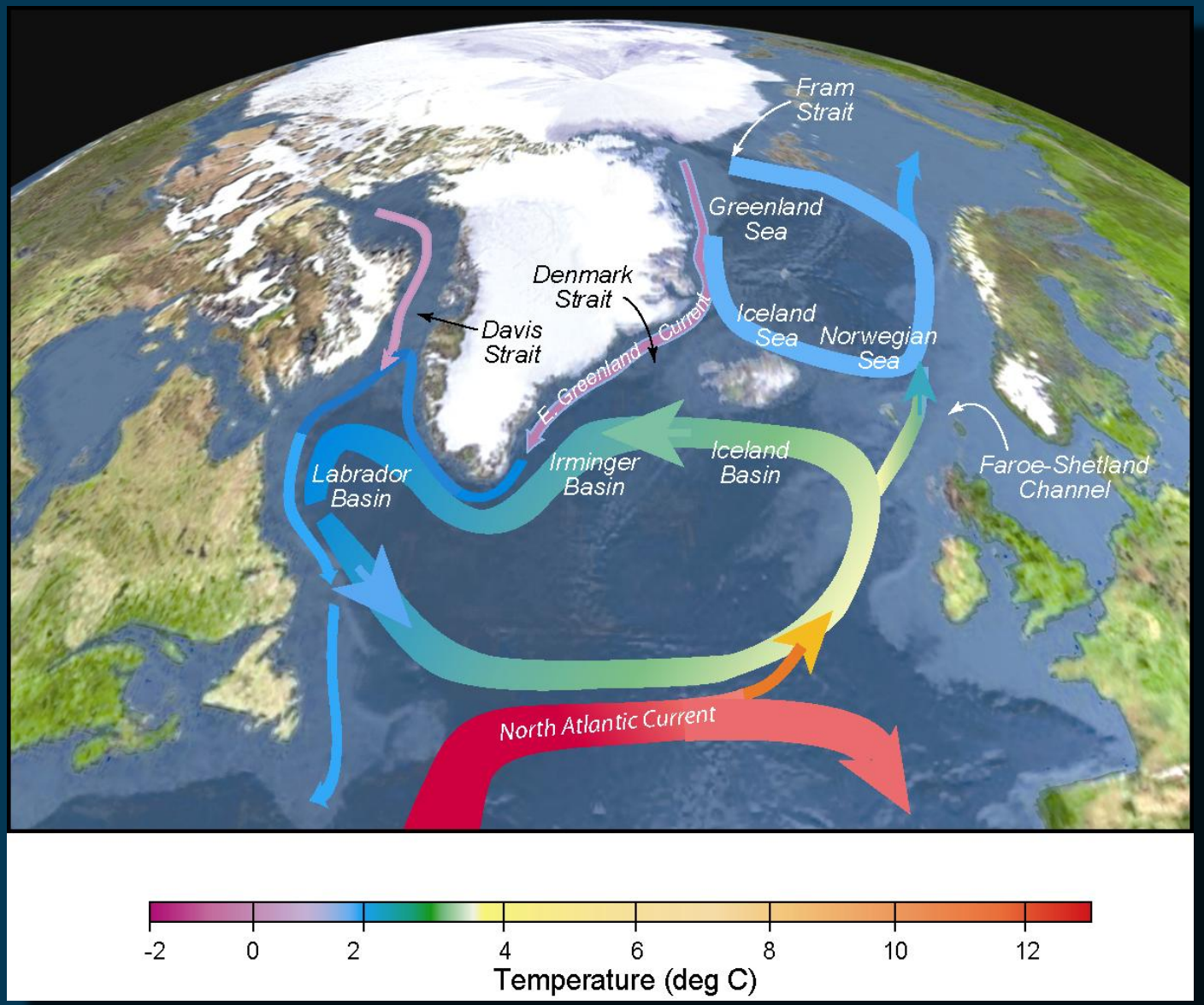

Surface drifts and currents of the oceans
January conditions based on 30-year record after U.S. Navy Oceanographic Office
Warm currents
Cool currents
Arctic Circle
Kamchatka current
Alaska current
Labrador current
North Atlantic drift
North Pacific current
California current
Florida c.
Gulf Stream
Kuroshio c.
Canaries current
Tropic of Cancer
N. Equatorial current
N. Eq. c.
Gulnea current
Eq. countercurrent
Equator
N. Eq. c.
S. Equatorial current
S. Eq. c.
Brazil c.
Benguela current
Peru or Humboldt current
Agulhas c.
S. Eq. c.
Tropic of Capricorn
Falkland c.
West-wind drift
West-wind drift
60°
45°
30°
15°
0°
15°
30°
45°
60°


Heat
pack
Freezing
Salt
WSC
Cooling
Dense Water
NORTH AMERICA
SOUTH AMERICA
AFRICA
Atlantic Ocean
Indian Ocean
Pacific Ocean
AUSTRALIA
NORTH AMERICA
Warm surface flow
Cool subsurface flow

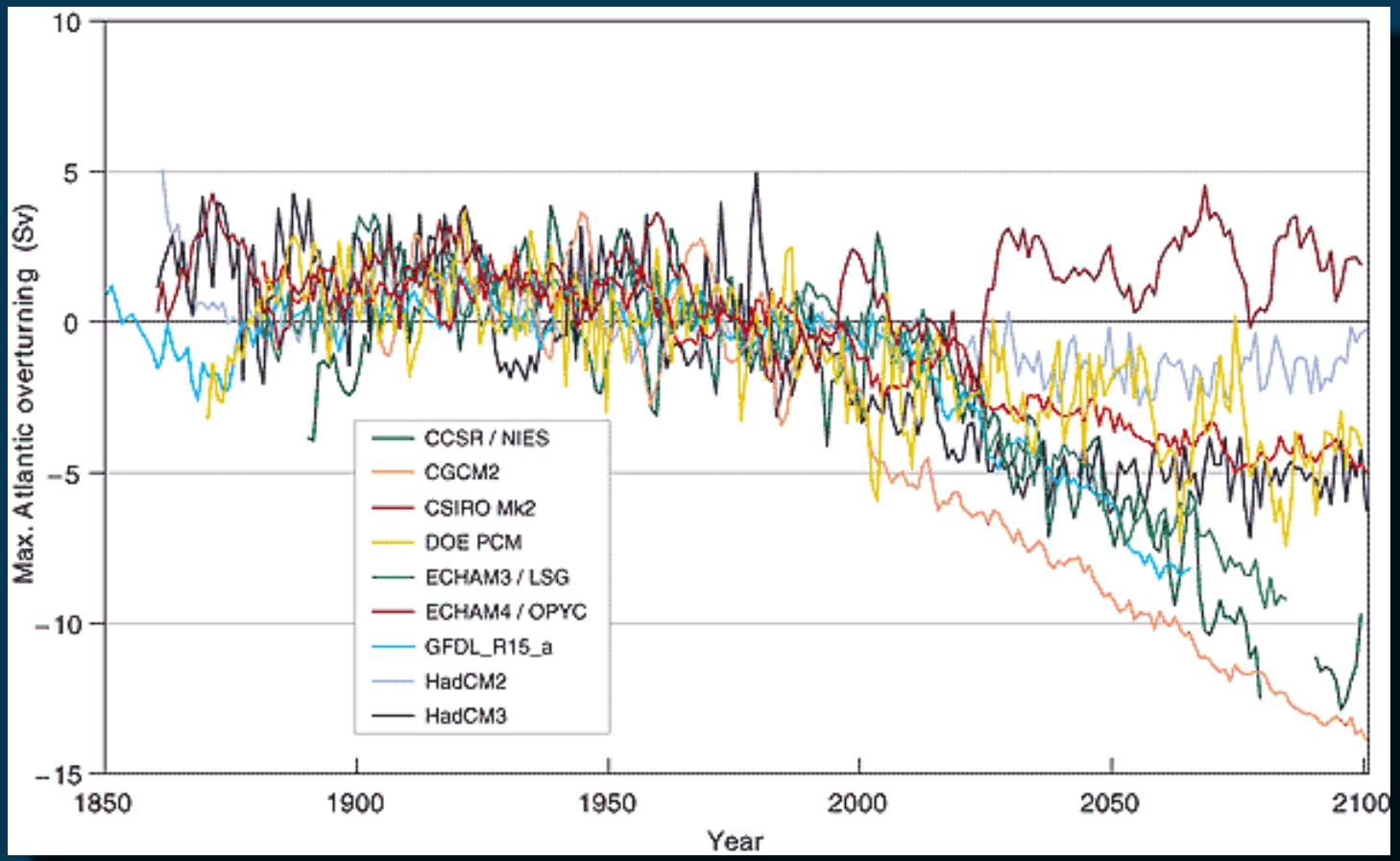
Conveyor ON


Fram Strait
Greenland Sea
Denmark Strait
Davis Strait
Iceland Sea
Norwegian Sea
E. Greenland Current
Norwegian Atlantic Current
Labrador Basin
Irminger Basin
Iceland Basin
Faroe-Shetland Channel
North Atlantic Current
-2
0
2
4
6
8
10
12
Temperature (deg C)

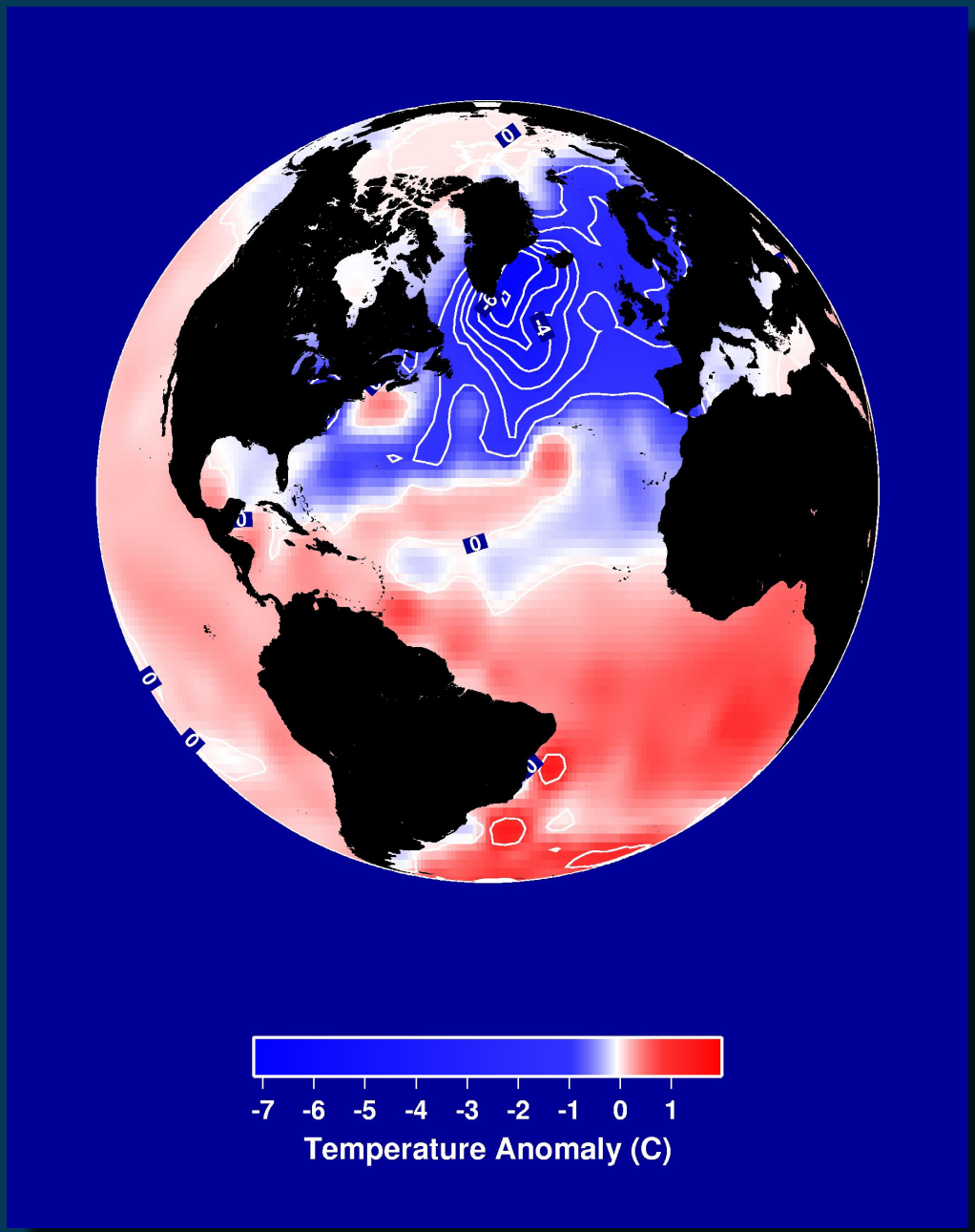
Conveyor OFF



models predict a slowdown in the deep water circulation



IPCC Report

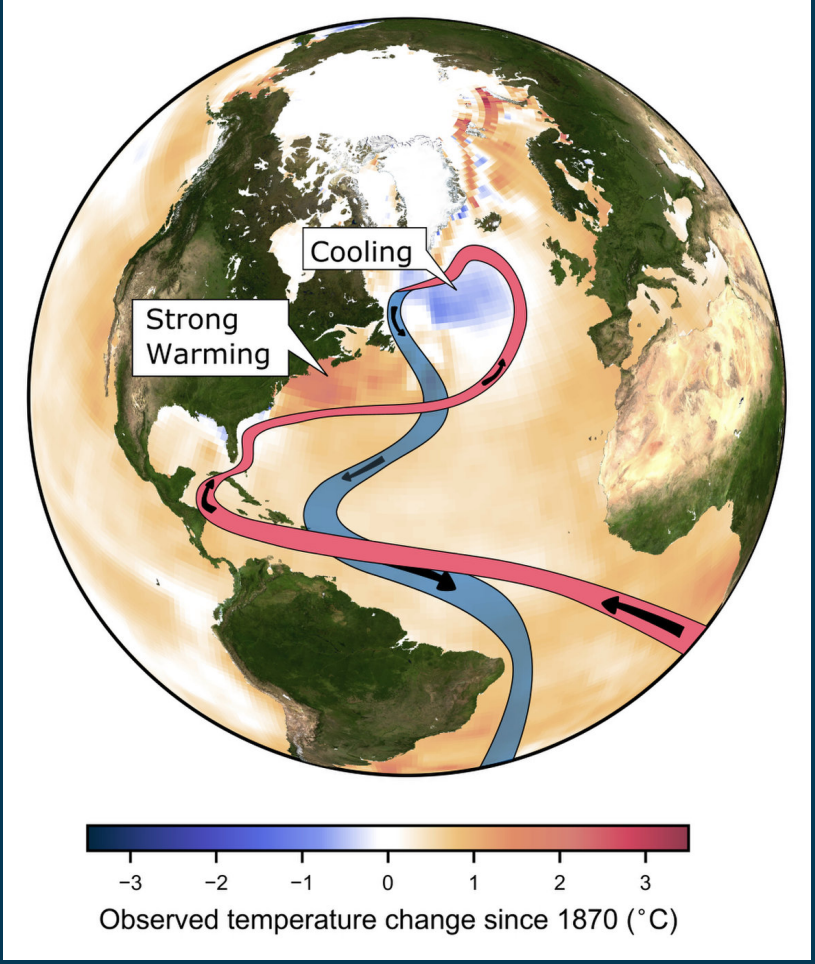


Temperature Response

- Strong cooling in North Atlantic
- Warming everywhere else
- No net global change

Manabe and Stouffer, 1997

New Data on AMOC



New Data on AMOC

Atlantic Meridional Overturning Circulation

New Data on AMOC

Two new studies published in the scientific journal *Nature* have brought a new threat to the world's attention: the shutdown of the Atlantic Ocean currents including the AMOC.
Barely a day goes by without new research emerging warning humanity of its impending doom, but the collapse of the AMOC is an event with particularly ominous connotations.
Scientists have previously linked disruptions to Atlantic currents with everything from heatwaves in Europe to rising sea levels in coastal US cities.

New Data on AMOC

Researchers used global climate models and data sets of sea surface temperature to date the onset of the weakening to more recent times, around the mid-twentieth century (L. Caesar *et al.* *Nature* **556**, 191–196; 2018). According to their models, the slowdown was about 15%; was most pronounced during winter and spring; and has led to a cooling of sea surface temperatures in parts of the northern Atlantic, together with a slight northward shift of the mean Gulf Stream path. This, the authors say, is probably a consequence of anthropogenic climate change.

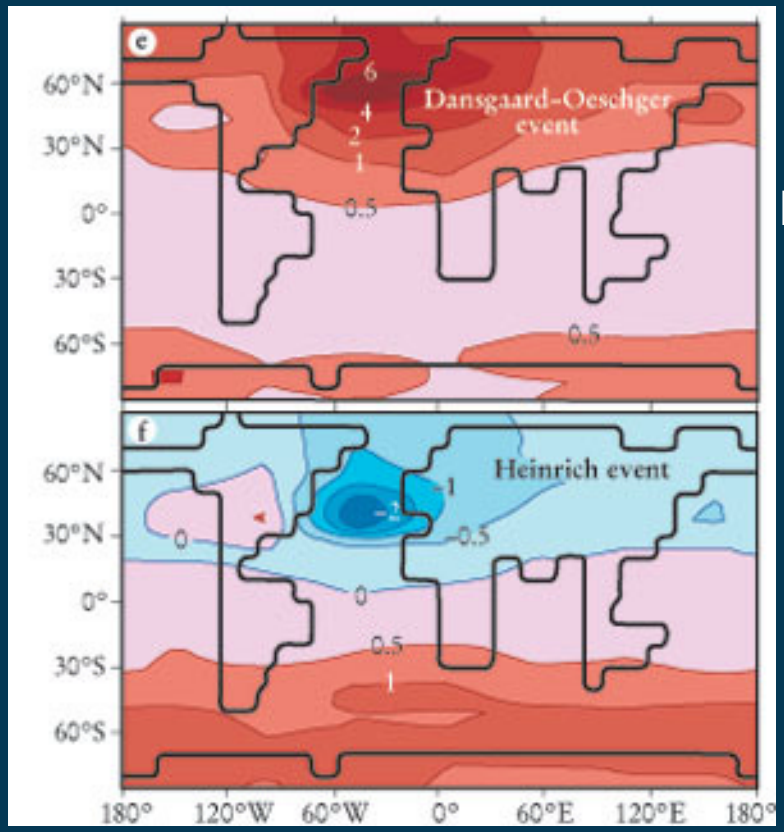
AMOC crisis in the past

- In another recent paper in *Nature*, scientists present palaeo-oceanographic evidence that deep convection of surface waters in the North Atlantic — the engine that keeps the AMOC in constant motion — began to decline as early as around 1850, probably owing to increased freshwater influx from Arctic ice that had melted at the end of a relatively cold period called the Little Ice Age (D. J. R. Thornalley *et al. Nature* **556**, 227–230; 2018). This could have caused a weakening in the ocean circulation.

Abrupt Climate Changes

- Is the ocean responsible for "rapid" climate changes?
- Did it happen in the past?
- What can we expect in the next future?

Abrupt Climate changes



DANSGAARD-OESCHGER (D/O) Warm

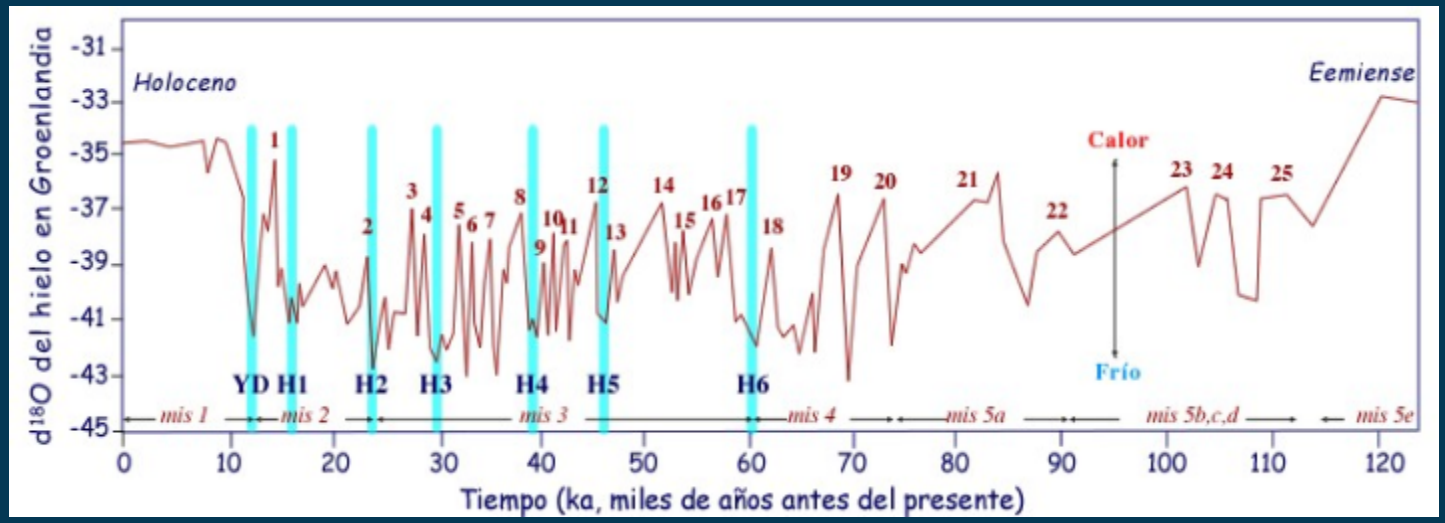
HEINRICH EVENTS (H) Cold

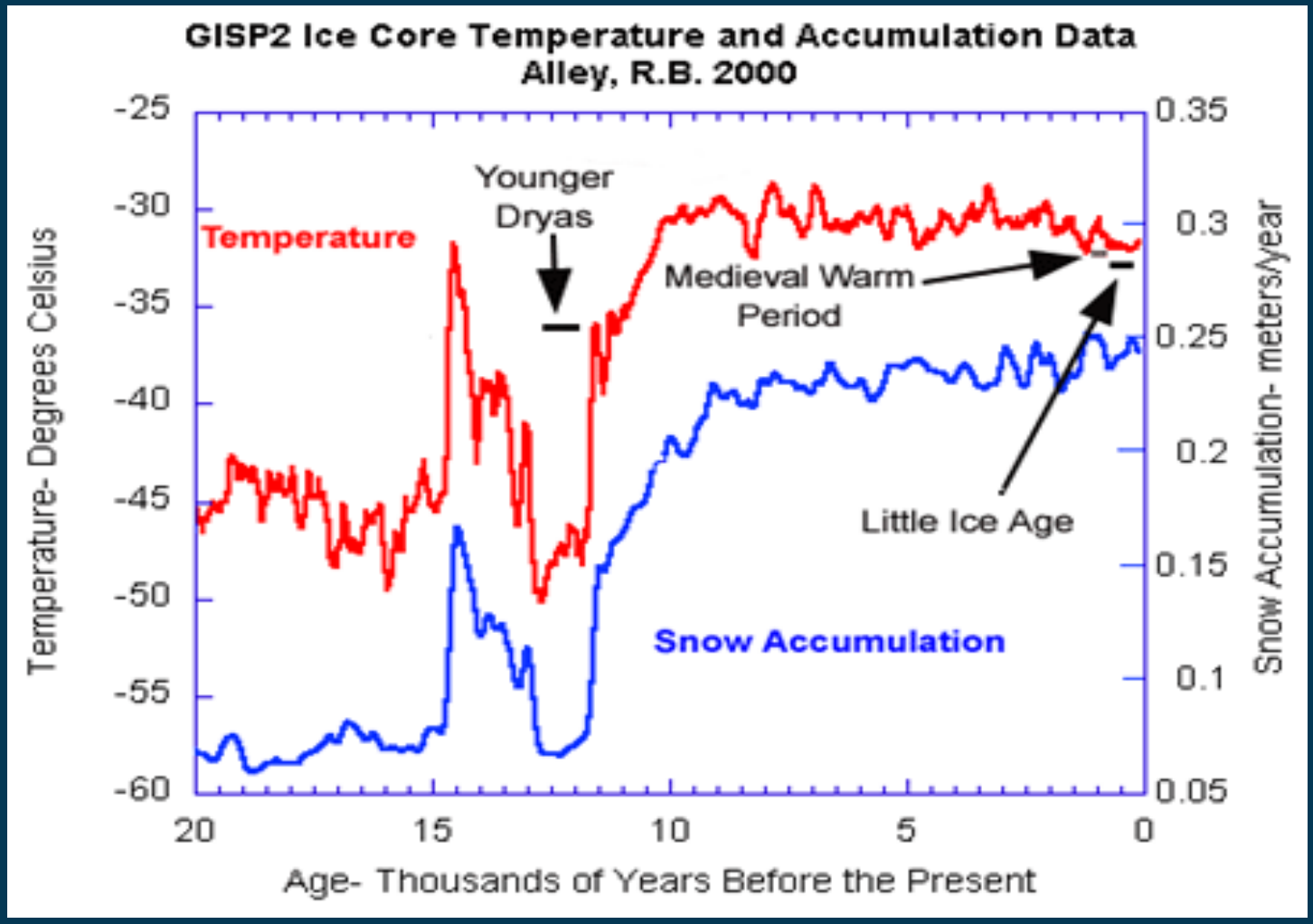
Heinrich events

- **Heinrich events**, first described by marine geologist Hartmut Heinrich, occurred during the last glacial period, or "ice age". During such events, armadas of icebergs broke off from glaciers and traversed the North Atlantic. The icebergs contained rock mass eroded by the glaciers, and as they melted, this matter was dropped onto the sea floor as "ice rafted debris". Scientists drilling through marine sediments can distinguish six distinct events in cores of mud retrieved from the sea floor, which are labelled H1-H6 going back in time; there is some evidence that H3 and H6 differ from other events.
- The icebergs' melting caused prodigious amounts of fresh water to be added to the North Atlantic. Such inputs of cold, fresh water may well have altered the density-driven thermohaline circulation patterns of the ocean, and often coincide with indications of global climate fluctuations.
- Various mechanisms have been proposed to explain the cause of Heinrich events. Most centre around the activity of the Laurentide ice sheet, but others suggest that the unstable West Antarctic Ice Sheet played a triggering role.

Heinrich Events

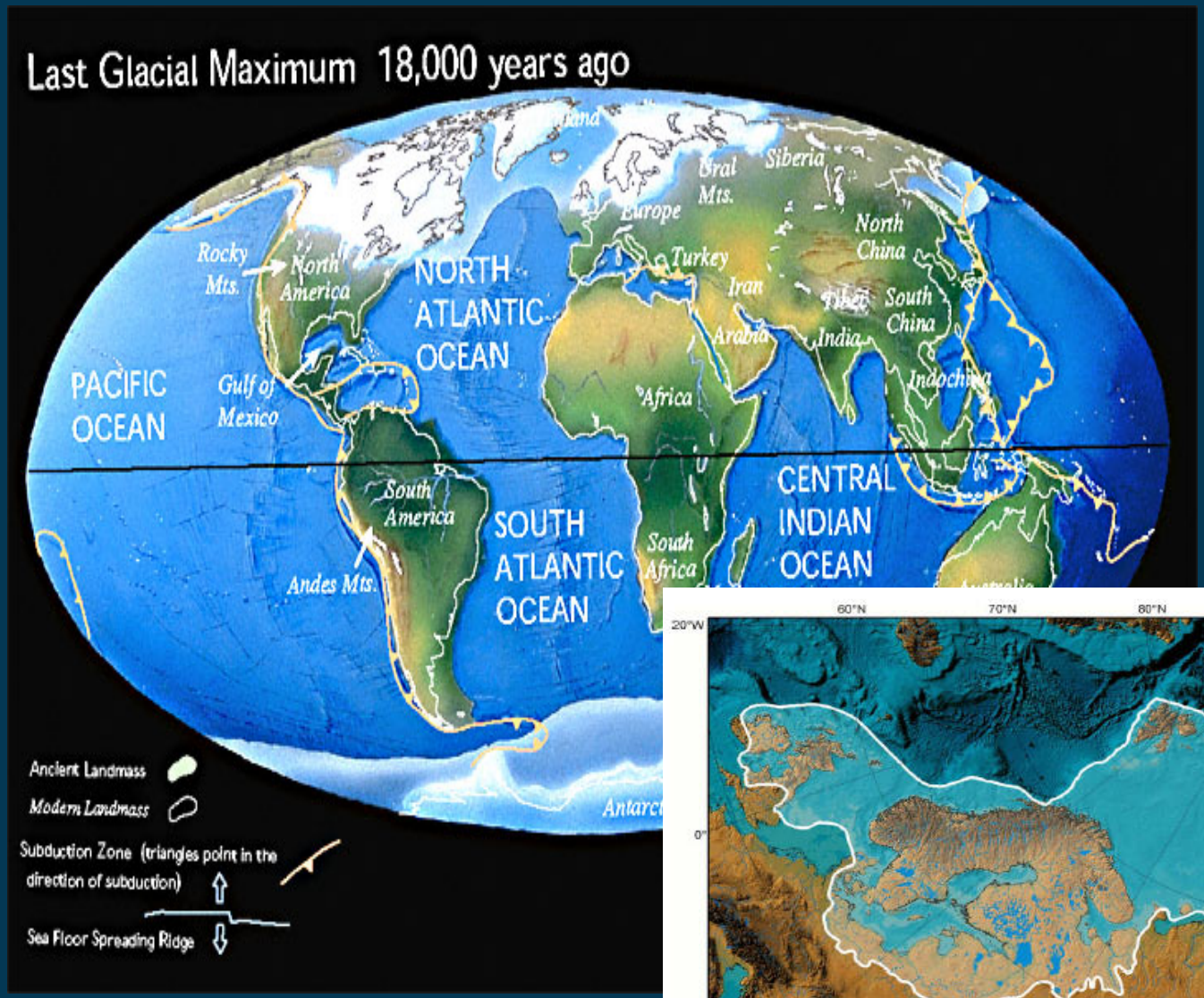
During the last 60 ka, six Heinrich events occurred!

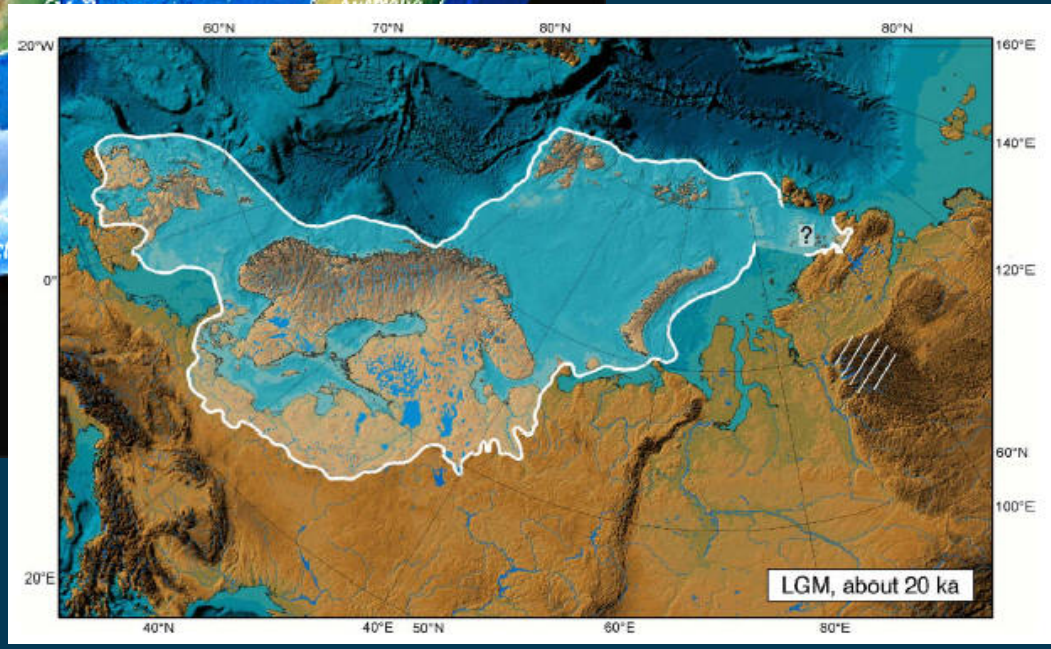



GISP2 Ice Core Temperature and Accumulation Data
Alley, R.B. 2000
Temperature- Degrees Celsius
Snow Accumulation- meters/year
Age- Thousands of Years Before the Present
-25
-30
-35
-40
-45
-50
-55
-60
0.35
0.3
0.25
0.2
0.15
0.1
0.05
20
15
10
5
0
Temperature
Younger
Dryas
Medieval Warm
Period
Little Ice Age
Snow Accumulation

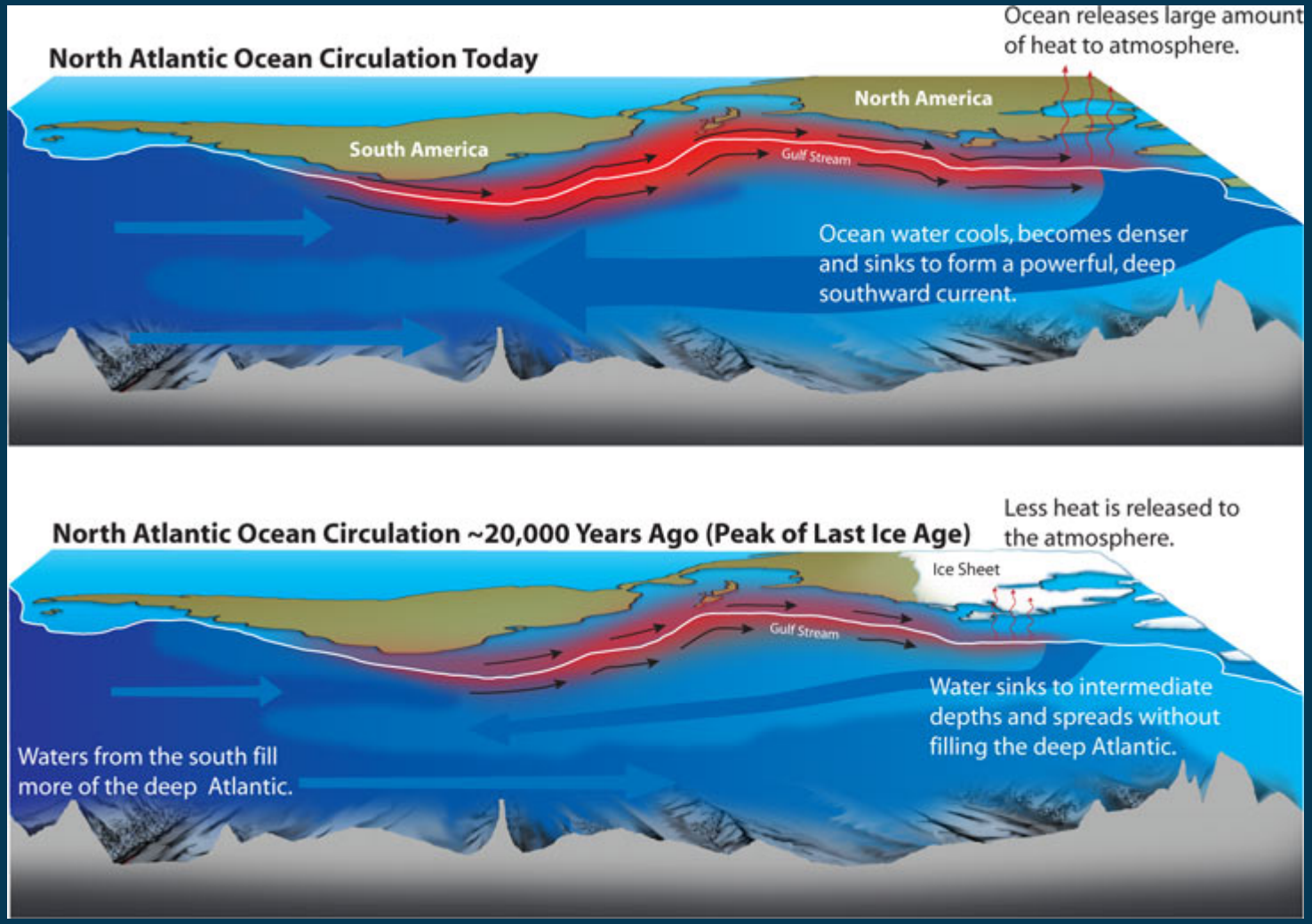
Pieter Bruegel the Elder
(probably Breda 1525/30-1569 Brussels)
The Return of the Herd 1565
Kunsthistorisches Museum, Vienna

The Younger Dryas and Older Dryas stadials are named after *Dryas octopetala*, because of the great quantities of its pollen found in cores dating from those times. During these cold spells, *Dryas octopetala* was much more widely distributed than it is today, as large parts of the northern hemisphere that are now covered by forests were replaced in the cold periods by tundra.

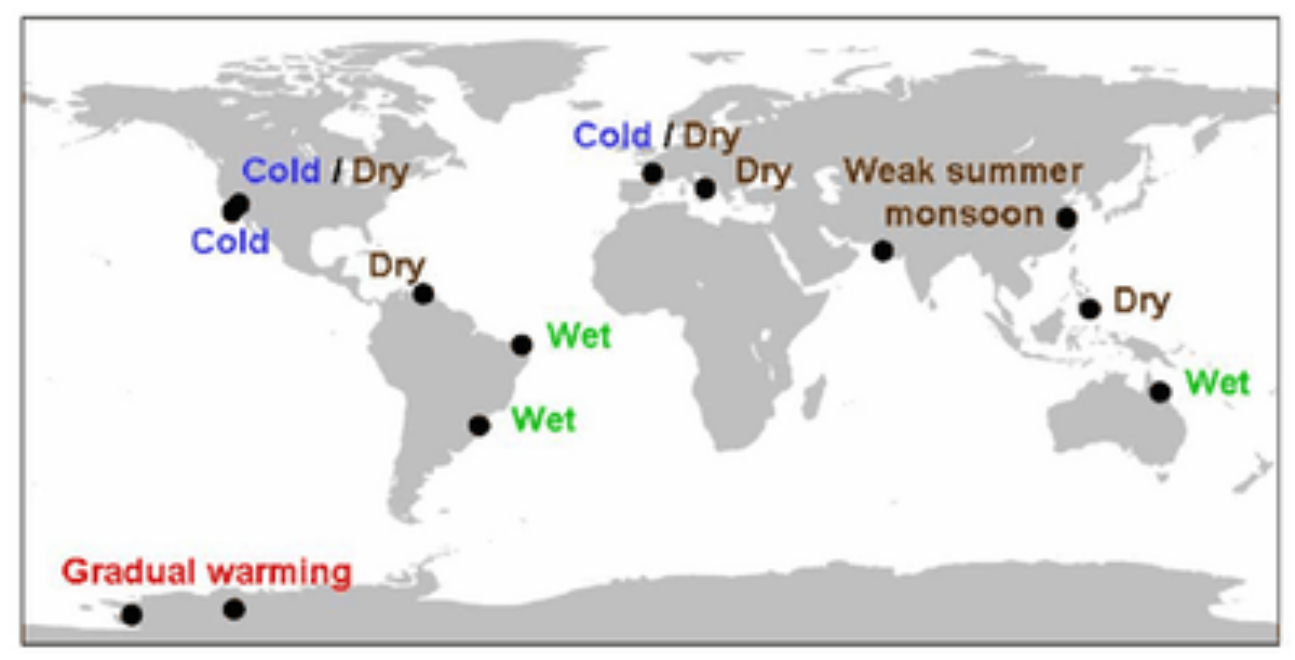

Last Glacial Maximum 18,000 years ago
Ural Mts.
Siberia
Europe
North China
Rocky Mts.
North America
NORTH ATLANTIC OCEAN
Turkey
Iran
Tibet
South China
Arabia
India
Indochina
PACIFIC OCEAN
Gulf of Mexico
Africa
South America
SOUTH ATLANTIC OCEAN
South Africa
CENTRAL INDIAN OCEAN
Andes Mts.
Ancient Landmass
Modern Landmass
Subduction Zone (triangles point in the direction of subduction)
Sea Floor Spreading Ridge


60°N
70°N
80°N
80°N
20°W
160°E
140°E
0°
120°E
60°N
100°E
20°E
?
LGM, about 20 ka
40°N
40°E
50°N
60°E
80°E


Océano Artico
Groenlandia
Mar de Labrador
agua dulce
Manto de hielo Laurentino
retroceso
San Lorenzo
Lago Agassiz
Corrriente del Golfo
avance
Misisipi
corriente profunda termohalina
Golfo de Mexico


North Atlantic Ocean Circulation Today
Ocean releases large amount of heat to atmosphere.
North America
South America
Gulf Stream
Ocean water cools, becomes denser and sinks to form a powerful, deep southward current.
North Atlantic Ocean Circulation ~20,000 Years Ago (Peak of Last Ice Age)
Less heat is released to the atmosphere.
Ice Sheet
Gulf Stream
Water sinks to intermediate depths and spreads without filling the deep Atlantic.
Waters from the south fill more of the deep Atlantic.

Global climate anomalies during
Younger Dryas



Some effects :

•Replacement of forest in Scandinavia with glacial tundra (which is the habitat of the plant *Dryas octopetala*).

•Glaciation or increased snow in mountain ranges around the world..

•More dust in the atmosphere, originating from deserts in Asia.

•extinction of some animal species in North America

Summary

- The ocean and atmosphere work together to affect climate

- Surface conditions of the ocean set atmospheric circulation – the surface conditions are changing

- Deep water produced in the Atlantic is exported to the world

- The circulation system is density driven – warm, salty water becomes cold, dense, salty deep water

- The salinity balance appears to be changing

Summary

- Heat released to the atmosphere by the oceans is an important source of heat to the Atlantic region

- Several models of future climate produce a significantly altered Atlantic circulation

- Some of the changes predicted by the models may be occurring in the Atlantic today

THE DEBATE

- Negationism or Skepticism?
- Remember Popper:

I shall require that [the] logical form [of the theory] shall be such that it can be singled out, by means of empirical tests, in a negative sense: it must be possible for an empirical scientific system to be refuted by experience.

— *Karl Popper, Popper 1959.*

Top Pro & Contra Arguments

- **Overwhelming scientific consensus says human activity is primarily responsible for global climate change.** The 2010 Anderegg study found that 97-98% of climate researchers publishing most actively in their field agree that human activity is primarily responsible for global climate change. The study also found that the expertise of researchers unconvinced of human-caused climate change is "substantially below" that of researchers who agree that human activity is primarily responsible for climate change. The 2013 Cook review of 11,944 peer-reviewed studies on climate change found that only 78 studies (0.7%) explicitly rejected the position that humans are responsible for global warming. A separate review of 13,950 peer-reviewed studies on climate change found only 24 that rejected human-caused global warming. A survey by German Scientists Bray and Von Storch found that 83.5% of climate scientists believe human activity is causing "most of recent" global climate change. A separate survey in 2011 also found that 84% of earth, space, atmospheric, oceanic, and hydrological scientists surveyed said that human-induced global warming is occurring.

- **More than one thousand scientists disagree that human activity is primarily responsible for global climate change.** In 2010 Climate Depot released a report featuring more than 1,000 scientists, several of them former UN IPCC scientists, who disagreed that humans are primarily responsible for global climate change. The Cook review of 11,944 peer-reviewed studies found 66.4% of the studies had no stated position on anthropogenic global warming, and while 32.6% of the studies implied or stated that humans are contributing to climate change, only 65 papers (0.5%) explicitly stated "that humans are the primary cause of recent global warming." A 2012 Purdue University survey found that 47% of climatologists challenge the idea that humans are primarily responsible for climate change and instead believe that climate change is caused by an equal combination of humans and the environment (37%), mostly by the environment (5%), or that there's not enough information to say (5%). In 2014 a group of 15 scientists dismissed the US National Climate Assessment as a "masterpiece of marketing," that was "grossly flawed," and called the NCA's assertion of human-caused climate change "NOT true."

- **Rising levels of human-produced gases released into the atmosphere create a greenhouse effect that traps heat and causes global warming.** As sunlight hits the earth, some of the warmth is absorbed by greenhouse gases in the atmosphere such as carbon dioxide (CO2), methane (CH4), and nitrous oxide (NO2). These gases trap heat and cause the planet to warm through a process called the greenhouse effect. Since 1751 about 337 billion metric tons of CO2 have been released into the atmosphere from the burning of fossil fuels and cement production, increasing atmospheric CO2 from the pre-industrial level of about 280 ppm (parts per million), to a high of 400 ppm in 2013. Methane, which is increasing in the atmosphere due to agriculture and fossil fuel production, traps 84 times as much heat as CO2 for the first 20 years it is in the atmosphere, and is responsible for about one-fifth of global warming since 1750. Nitrous oxide, primarily released through agricultural practices, traps 300 times as much heat as CO2. Over the 20th century, as the concentrations of CO2, CH4, and NO2 increased in the atmosphere, the earth warmed by approximately 1.4°F.

- **Earth's climate has always warmed and cooled, and the 20th century rise in global temperature is within the bounds of natural temperature fluctuations over the past 3,000 years.** Although the planet has warmed 1-1.4°F over the 20th century, it is within the +/- 5°F range of the past 3,000 years. A 2003 study by researchers at the Harvard-Smithsonian Center for Astrophysics found that "many records reveal that the 20th century is probably not the warmest nor a uniquely extreme climatic period of the last millennium." A 2005 study published in *Nature* found that "high temperatures - similar to those observed in the twentieth century before 1990 - occurred around AD 1000 to 1100" in the Northern Hemisphere. A 2013 study published in Boreas found that summer temperatures during the Roman Empire and Medieval periods were "consistently higher" than temperatures during the 20th century. According to a 2010 study in the *Chinese Science Bulletin*, the recent global warming period of the 20th century is the result of a natural 21-year temperature oscillation, and will give way to a "new cool period in the 2030s."

- **The rise in atmospheric CO2 over the last century was clearly caused by human activity, as it occurred at a rate much faster than natural climate changes could produce.** Over the past 650,000 years, atmospheric CO2 levels did not rise above 300 ppm until the mid-20th century. Atmospheric levels of CO2 have risen from about 317 ppm in 1958 to 415 ppm in 2019. CO2 levels are estimated to reach 450 ppm by the year 2040. According to the Scripps Institution of Oceanology, the "extreme speed at which carbon dioxide concentrations are increasing is unprecedented. An increase of 10 parts per million might have needed 1,000 years or more to come to pass during ancient climate change events." Some climate models predict that by the end of the 21st century an additional 5°F-10°F of warming will occur.

- **Rising levels of atmospheric CO2 do not necessarily cause global warming, which contradicts the core thesis of human-caused climate change.** Earth's climate record shows that warming has preceded, not followed, a rise in CO2. According to a 2003 study published in Science, measurements of ice core samples show that over the last four climactic cycles (past 240,000 years), periods of natural global warming preceded global increases in CO2. In 2010 the *Proceedings of the National Academy of Sciences* published a study of the earth's climate 460-445 million years ago which found that an intense period of glaciation, not warming, occurred when CO2 levels were 5 times higher than they are today. According to ecologist and former Director of Greenpeace International Patrick Moore, PhD, "there is some correlation, but little evidence, to support a direct causal relationship between CO2 and global temperature through the millennia."

- **The specific type of CO2 that is increasing in earth's atmosphere can be directly connected to human activity.** CO2 produced by burning fossil fuels such as oil and coal can be differentiated in the atmosphere from natural CO2 due to its specific isotopic ratio. According to the Intergovernmental Panel on Climate Change (IPCC), 20th century measurements of CO2 isotope ratios in the atmosphere confirm that rising CO2 levels are the result of human activity, not natural processes such as ocean outgassing, volcanic activity, or release from other "carbon sinks." US greenhouse gas emissions from human activities in 2012 totaled 6.5 million metric tons, which is equivalent to about 78.3 billion shipping containers filled with greenhouse gases.

- **Human-produced CO2 is re-absorbed by oceans, forests, and other "carbon sinks," negating any climate changes.** According to a 2011 study published in the *Asia-Pacific Journal of Atmospheric Science*, many climate models that predict additional global warming to occur from CO2 emissions "exaggerate positive feedbacks and even show positive feedbacks when actual feedbacks are negative." About 50% of the CO2 released by the burning of fossil fuels and other human activities has already been re-absorbed by the earth's carbon sinks. From 2002-2011, 26% of human-caused CO2 emissions were absorbed specifically by the world's oceans. A 2010 study published in the *Proceedings of the National Academy of Sciences* found evidence that forests are increasing their growth rates in response to elevated levels of CO2, which will in turn, lower atmospheric CO2 levels in a negative feedback. According to an Aug. 2012 study in *Nature*, the rate of global carbon uptake by the earth's carbon sinks, such as its forests and oceans, doubled from 1960-2010 and continues to increase.

- **Average temperatures on earth have increased at a rate far faster than can be explained by natural climate changes.** A 2008 study compared data from tree rings, ice cores, and corals over the past millennium with recent temperature records. The study created the famous "hockey stick" graph, showing that the rise in earth's temperature over the preceding decade had occurred at a rate faster than any warming period over the last 1,700 years. In 2012 the Berkeley scientists found that the average temperature of the earth's land increased 2.5°F over 250 years (1750-2000), with 1.5°F of that increase in the last 50 years. Lead researcher Richard A. Muller, PhD, said "it appears likely that essentially all of this increase [in temperature] results from the human emission of greenhouse gases." In 2013, a surface temperature study published in Science found that global warming over the past 100 years has proceeded at a rate faster than at any time in the past 11,300 years. According to the IPCC's 2014 Synthesis Report, human actions are "extremely likely" (95-100% confidence) to have been the main cause of 20th century global warming, and the surface temperature warming since the 1950s is "unprecedented over decades to millennia."

- **CO2 is already saturated in earth's atmosphere, and more CO2, manmade or natural, will have little impact on climate.** As CO2 levels in the atmosphere rise, the amount of additional warming caused by the increased concentration becomes less and less pronounced. According to Senate testimony by William Happer, PhD, Professor of Physics at Princeton University, "additional increments of CO2 will cause relatively less direct warming because we already have so much CO2 in the atmosphere that it has blocked most of the infrared radiation that it can. The technical jargon for this is that the CO2 absorption band is nearly 'saturated' at current CO2 levels." According to the Heartland Institute's 2013 Nongovernmental International Panel on Climate Change (NIPCC) report, "it is likely rising atmospheric CO2 concentrations will have little impact on future climate."

- **Natural changes in the sun's activity cannot explain 20th century global warming.**According to a Dec. 2013 study in *Nature Geoscience*, the sun has had only a "minor effect" on the Northern Hemisphere climate over the past 1,000 years, and global warming from human-produced greenhouse gases has been the primary cause of climate change since 1900. Another 2013 study found that solar activity could not have contributed to more than 10% of the observed global warming over the 20th century. Measurements in the upper atmosphere from 1979-2009 show the sun's energy has gone up and down in cycles, with no net increase. According to a 2013 IPCC report, there is "high confidence" (8 out of 10 chance) that changes in the sun's radiation could not have caused the increase in the earth's surface temperature from 1986-2008. Although warming is occurring in the lower atmosphere (troposphere), the upper atmosphere (stratosphere) is actually cooling. If the sun were driving global warming, there would be warming in the stratosphere also, not cooling.

- **Global warming and cooling are primarily caused by fluctuations in the sun's heat (solar forcing), not by human activity.** Over the past 10,000 years, solar minima (reduced sun spot activity) have been "accompanied by sharp climate changes." Between 1900 and 2000 solar irradiance increased 0.19%, and correlated with the rise in US surface temperatures over the 20th century. According to a 2007 study published in *Energy & Environment*, "variations in solar activity and not the burning of fossil fuels are the direct cause of the observed multiyear variations in climatic responses." In a 2012 study by Willie Soon, PhD, Physicist at the Harvard-Smithsonian Center for Astrophysics, a strong correlation between solar radiation and temperatures in the Arctic over the past 130 years was identified. According to a 2012 study published in the *Journal of Atmospheric and Solar-Terrestrial Physics*, "up to 70% of the observed post-1850 climate change and warming could be associated to multiple solar cycles."

- **Global warming caused by human-produced greenhouse gases is causing the Arctic ice cap to melt at an increasing rate.** From 1953–2006, Arctic sea ice declined 7.8% per decade. Between 1979 and 2006, the decline was 9.1% each decade. As of 2014, Arctic sea ice was being lost at a rate of 13.3% per decade. As the Arctic ice cover continues to decrease, the amount of the sun's heat reflected by the ice back into space also decreases. This positive-feedback loop amplifies global warming at a rate even faster than previous climate models had predicted. Some studies predict the Arctic could become nearly ice free sometime between 2020-2060.

- **The rate of global warming has slowed over the last decade even though atmospheric CO2 continues to increase.** The Intergovernmental Panel on Climate Change (IPCC) recognized a slowdown in global warming over the past 15 years in its 2013 report. According to the Heartland Institute's 2013 NIPCC report, the earth "has not warmed significantly for the past 16 years despite an 8% increase in atmospheric CO2." In Aug. 2014 a study in the *Open Journal of Statistics* analyzed surface temperature records and satellite measurements of the lower atmosphere and confirmed that this slowdown in global warming has occurred. According to Emeritus Professor of Meteorology at the Massachusetts Institute of Technology Richard Lindzen, PhD, the IPCC's "excuse for the absence of warming over the past 17 years is that the heat is hiding in the deep ocean. However, this is simply an admission that the [climate] models fail to simulate the exchanges of heat between the surface layers and the deeper oceans"

- **Sea levels are rising at an unprecedented rate due to global warming.** As human-produced greenhouse gases warm the planet, sea levels are rising due to thermal expansion of warming ocean waters as well as melt water from receding glaciers and the polar ice cap. According to the IPCC, there has been a "substantial" human contribution to the global mean sea-level rise since the 1970s, and there is "high confidence" (8 out of 10 chance) that the rate of sea-level rise over the last half century has accelerated faster than it has over the previous 2,000 years. A 2006 study found that "significant acceleration" of sea-level rise occurred from 1870 to 2004. Between 1961 and 2003 global sea levels rose 8 inches. An Oct. 2014 study published in the *Proceedings of the National Academy of Sciences* concluded that the rate of sea level rise over the past century is unprecedented over the last 6,000 years. A separate Oct. 2014 study said that the global sea level is likely to rise 31 inches by 2100, with a worst case scenario rise of 6 feet. Climate Central predicts that 147 to 216 million people live in areas that will be below sea level or regular flood areas by the end of the century if human-produced greenhouse gas emissions continue at their current rate.

- **Sea levels have been steadily rising for thousands of years, and the increase has nothing to do with humans.** A 2014 report by the Global Warming Policy Foundation found that a slow global sea level rise has been ongoing for the last 10,000 years. When the earth began coming out of the Pleistocene Ice Age 18,000 years ago, sea levels were about 400 feet lower than they are today and have been steadily rising ever since. According to Professor of Earth and Atmospheric Sciences at the Georgia Institute of Technology, Judith Curry, PhD "it is clear that natural variability has dominated sea level rise during the 20th century, with changes in ocean heat content and changes in precipitation patterns." Freeman Dyson, Emeritus Professor of Mathematical Physics and Astrophysics at the Institute for Advanced Study at Princeton University, has stated that there is "no evidence" that rising sea levels are due to anthropogenic climate change.

- **Ocean acidity levels are increasing at an unprecedented rate that can only be explained by human activity.** As excess human-produced CO2 in the atmosphere is absorbed by the oceans, the acidity level of the water increases. Acidity levels in the oceans are 25-30% higher than prior to human fossil fuel use. According to a 2014 US Government Accountability Office (GAO) report, oceans have absorbed about 30% of the CO2 emitted by humans over the past 200 years, and ocean acidity could rise approximately 100-200 percent above preindustrial levels by 2100. According to a 2013 report from the World Meteorological Organization, the current acceleration in the rate of ocean acidification "appears unprecedented" over the last 300 million years. High ocean acidity levels threaten marine species, and slows the growth of coral reefs. According to a 2014 report by the Convention on Biological Diversity, "it is now nearly inevitable" that within 50-100 years continued human produced CO2 emissions will increase ocean acidity to levels that "will have widespread impacts, mostly deleterious, on marine organisms and ecosystems."

- **The acidity levels of the oceans are within past natural levels, and the current rise in acidity is a natural fluctuation, not the result of human caused climate change.** The pH of average ocean surface water is 8.1 and has only decreased 0.1 since the beginning of the industrial revolution (neutral is pH 7, acid is below pH 7). In 2010 Science published a study of ocean acidity levels over the past 15 million years, finding that the "samples record surface seawater pH values that are within the range observed in the oceans today." Increased atmospheric CO2 absorbed by the oceans results in higher rates of photosynthesis and faster growth of ocean plants and phytoplankton, which increases pH levels keeping the water alkaline, not acidic. According to a 2010 paper by the Science and Public Policy Institute, "our harmless emissions of trifling quantities of carbon dioxide cannot possibly acidify the oceans."

- **Ocean temperatures are rising at an unprecedented rate due to global warming, and are causing additional climate changes.** The IPCC stated in a 2013 report that due to human-caused global warming, it is "virtually certain" (99-100% probability) that the upper ocean warmed between 1971 and 2010. An Oct. 2014 *Nature Climate Change* study said that the oceans are the "dominant reservoir of heat uptake in the climate system." A separate Oct. 2014 study found that the oceans absorb more than 90% of the heat generated by human-caused global warming. Since 1970 the upper ocean (above 700 meters) has been warming 24-55% faster than previous studies had predicted. A May 2013 study published in *Geophysical Research Letters* found that between 1958-2009 the rates of warming in the lower ocean (below 700m) "appear to be unprecedented." According to an Oct. 2013 study, the middle depths of the Pacific Ocean have warmed "15 times faster in the last 60 years than they did during apparent natural warming cycles in the previous 10,000." Warmer ocean waters can harm coral reefs and impact many species including krill, which are vital to the marine food chain and which reproduce significantly less in warmer water. Warming oceans also contribute to sea level rise due to thermal expansion, and warmer ocean waters can add to the intensity of storm systems.

- **Predictions of accelerating human-caused climate change are based upon computerized climate models that are inadequate and incorrect.** Climate models have been unable to simulate major known features of past climate such as the ice ages or the very warm climates of the Miocene, Eocene, and Cretaceous periods. If models cannot replicate past climate changes they should not be trusted to predict future climate changes. A 2011 *Asia-Pacific Journal of Atmospheric Science* study using observational data rather than computer climate models concluded that "the models are exaggerating climate sensitivity" and overestimate how fast the earth will warm as CO2 levels increase. Two other studies using observational data found that IPCC projections of future global warming are too high. In a 2014 article, climatologist and former NASA scientist Roy Spencer, PhD, concluded that 95% of climate models have "over-forecast the warming trend since 1979." According to Emeritus Professor of Geography at the University of Winnipeg, Tim Ball, PhD, "IPCC computer climate models are the vehicles of deception… [T]hey create the results they are designed to produce."

- **Glaciers are melting at unprecedented rates due to global warming, causing additional climate changes.** About a quarter of the globe's glacial loss from 1851-2010, and approximately two thirds of glacial loss between 1991-2010, is attributable directly to global warming caused by human-produced greenhouse gases.] According to the National Snow and Ice Data Center, global warming from human-produced greenhouse gases is a primary cause of the "unprecedented" retreat of glaciers around the world since the early 20th century. Since 1980 glaciers worldwide have lost nearly 40 feet (12 meters) in average thickness. According to a 2013 IPCC report, "glaciers have continued to shrink almost worldwide" over the prior two decades, and there is "high confidence" (about an 8 out of 10 chance) that Northern Hemisphere spring snow continues to decrease. If the glaciers forming the Greenland ice sheet were to melt entirely, global sea levels could increase by up to 20 feet. Melting glaciers also change the climate of the surrounding region. With the loss of summer glacial melt water, the temperatures in rivers and lakes increase. According to the US Geological Service, this disruption can include the "extinction of temperature sensitive aquatic species."

  Glaciers have been growing and receding for thousands of years due to natural causes, not human activity. The IPCC predicted that Himalayan glaciers would likely melt away by 2035, a prediction they disavowed in 2010. In 2014 a study of study of 2,181 Himalayan glaciers from 2000-2011 showed that 86.6% of the glaciers were not receding. According to a 2013 study of ice cores published in *Nature Geoscience*, the current melting of glaciers in Western Antarctica is due to "atmospheric circulation changes" that have "caused rapid warming over the West Antarctic Ice Sheet" and cannot be directly attributed to human caused climate change. According to one of the study authors, "if we could look back at this region of Antarctica in the 1940s and 1830s, we would find that the regional climate would look a lot like it does today, and I think we also would find the glaciers retreating much as they are today." According to Christian Schlüchter, Professor of Geology at the University of Bern, 4,000 year old tree remains have been found beneath retreating glaciers in the Swiss Alps, indicating that they were previously glacier-free. According to Schlüchter, the current retreat of glaciers in the Alps began in the mid-19th century, before large amounts of human caused CO2 had entered the atmosphere.

- **Human-caused global warming is changing weather systems and making heat waves and droughts more intense and more frequent.** The May 2014 National Climate Assessment report said human-caused climate changes, such as increased heat waves and drought, "are visible in every state." A Sep. 2014 American Meteorological Society study found that human-caused climate change "greatly increased" (up to 10 times) the risk for extreme heat waves in 2013. According to an Aug. 2012 study published in the *Proceedings of the National Academy of Sciences*, there is a "high degree of confidence" that the Texas and Oklahoma heat waves and drought of 2011, and heat waves and drought in Moscow in 2010, "were a consequence of global warming" and that "extreme anomalies" in weather are becoming more common as a direct consequence of human-caused climate change. A 2015 study found that globally, 75% of extremely hot days are attributable to warming caused by human activity.

- **Deep ocean currents, not human activity, are a primary driver of natural climate warming and cooling cycles.** Changes in ocean currents are primarily responsible for the melting Greenland ice sheet, Arctic sea ice, and Arctic permafrost. Over the 20th century there have been two Arctic warming periods with a cooling period (1940-1970) in between. According to a 2009 study in *Geophysical Research Letters*, natural shifts in the ocean currents are the major cause of these climate changes, not human-generated greenhouse gases. According to William Gray, PhD, Emeritus Professor of Atmospheric Science at Colorado State University, most of the climate changes over the last century are natural and "due to multi-decadal and multi-century changes in deep global ocean currents." Global cooling from 1940 to the 1970s, and warming from the 1970s to 2008, coincided with fluctuations in ocean currents and cloud cover driven by the Pacific Decadal Oscillation (PDO) - a naturally occurring rearrangement in atmospheric and oceanic circulation patterns. According to a 2014 article by Don Easterbrook, PhD, Professor Emeritus of Geology at Western Washington University, the "PDO cool mode has replaced the warm mode in the Pacific Ocean, virtually assuring us of about 30 years of global cooling, perhaps much deeper than the global cooling from about 1945 to 1977."

- **Dramatic changes in precipitation, such as heavier storms and less snow, are another sign that humans are causing global climate change.** As human-produced greenhouse gases heat the planet, increased humidity (water vapor in the atmosphere) results. Water vapor is itself a greenhouse gas. In a process known as a positive feedback loop, more warming causes more humidity which causes even more warming. Higher humidity levels also cause changes in precipitation. According to a 2013 report published in the *Proceedings of the National Academy of Sciences*, the recorded changes in precipitation over land and oceans "are unlikely to arise purely due to natural climate variability." Higher temperatures from global warming are also causing some mountainous areas to receive rain rather than snow. According to researchers at the Scripps Institution of Oceanography, up to 60% of the changes in river flow, winter air temperature, and snow pack in the western United States (1950-1999) were human-induced. Since 1991, heavy precipitation events have been 30% above the 1901-1960 average in the Northeast, Midwest, and upper Great Plains regions. A 2015 study found that global warming caused by human actions has increased extreme precipitation events by 18% across the globe, and that if temperatures continue to rise an increase of 40% can be expected.

Increased hurricane activity and other extreme weather events are a result of natural weather patterns, not human-caused climate change. According to a 2013 report from the Tropical Meteorology Project at Colorado State University, the increase in human-produced CO2 over the past century has had "little or no significant effect" on global tropical cyclone activity. The report further states that specific hurricanes, including Sandy, Ivan, Katrina, Rita, Wilma, and Ike, were not a direct consequence of human-caused global warming. Between 1995-2015 increased hurricane activity (including Katrina) was recorded, however, according to the NOAA, it was not the result of human-induced climate change; it was the result of cyclical tropical cyclone patterns, driven primarily by natural ocean currents. Many types of recorded extreme weather events over the past half-century have actually become less frequent and less severe. Professor of Earth and Atmospheric Sciences at the Georgia Institute of Technology, Judith Curry, PhD, states that she is "unconvinced by any of the arguments that I have seen that attributes a single extreme weather event, a cluster of extreme weather events, or statistics of extreme weather events" to human-caused climate change. Richard Lindzen, PhD, Emeritus Professor of Meteorology at the Massachusetts Institute of Technology, also states that there is a lack of evidence connecting extreme weather events such as hurricanes, tornadoes, droughts, or floods, to human-caused global warming.]