Mid-Ocean Geothermal Flux: Impacts on the Thermohaline Circulation and Global Climate

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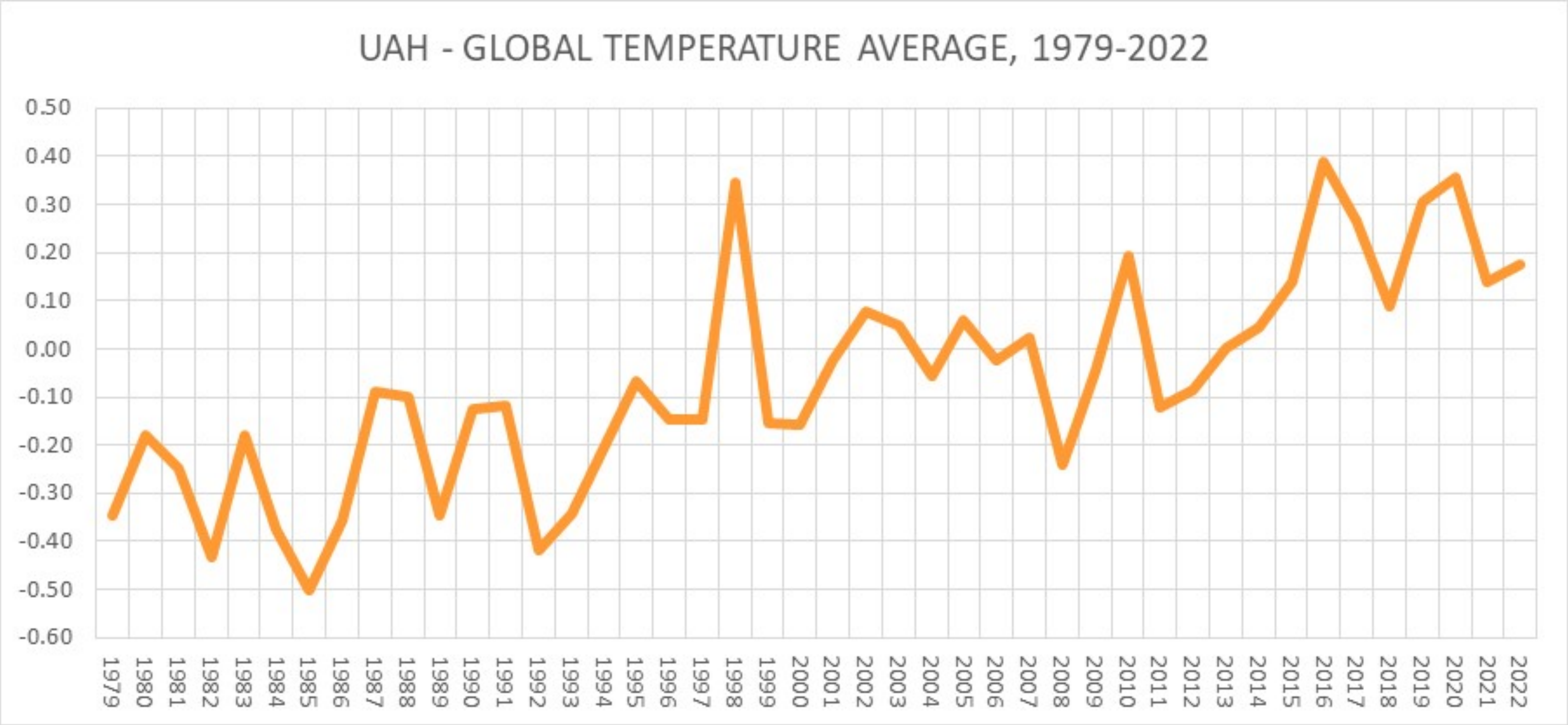
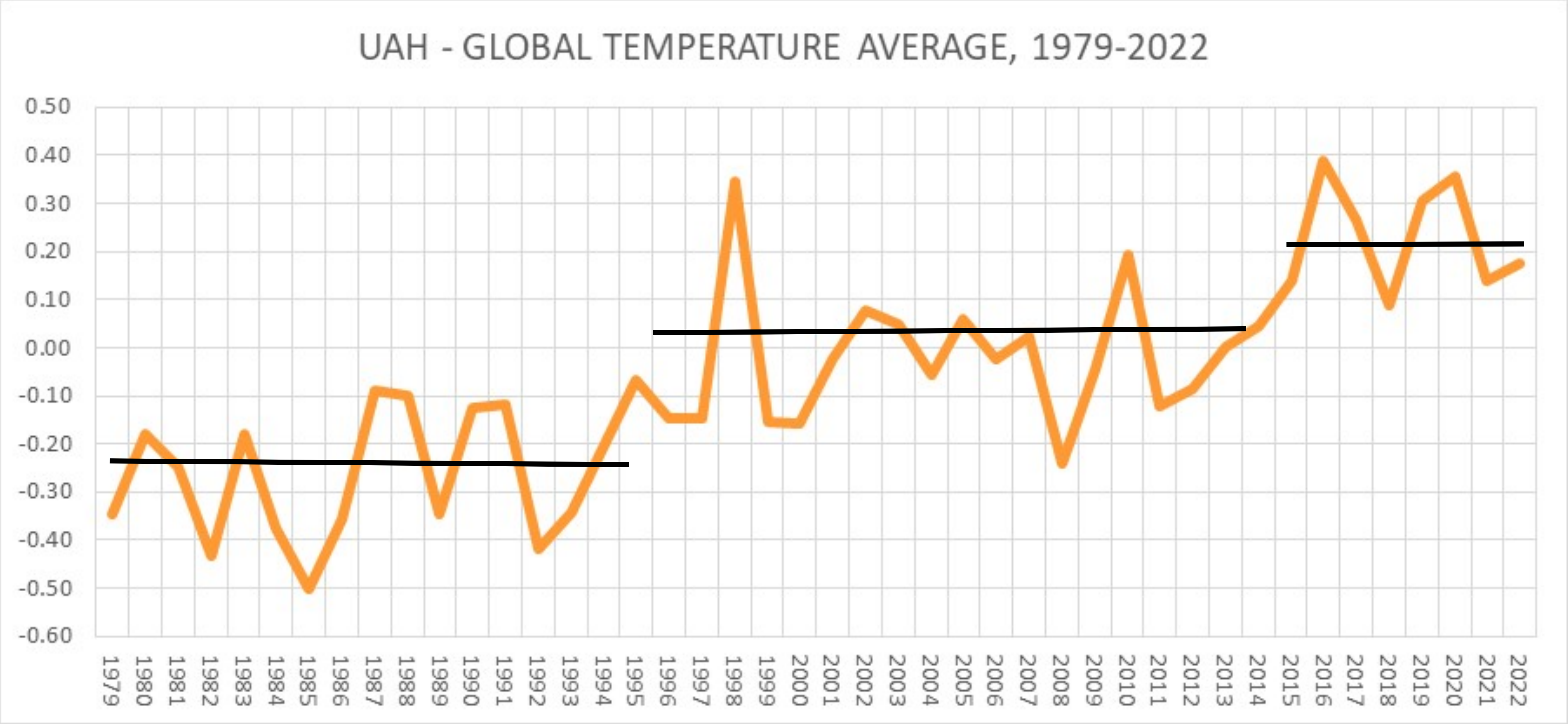
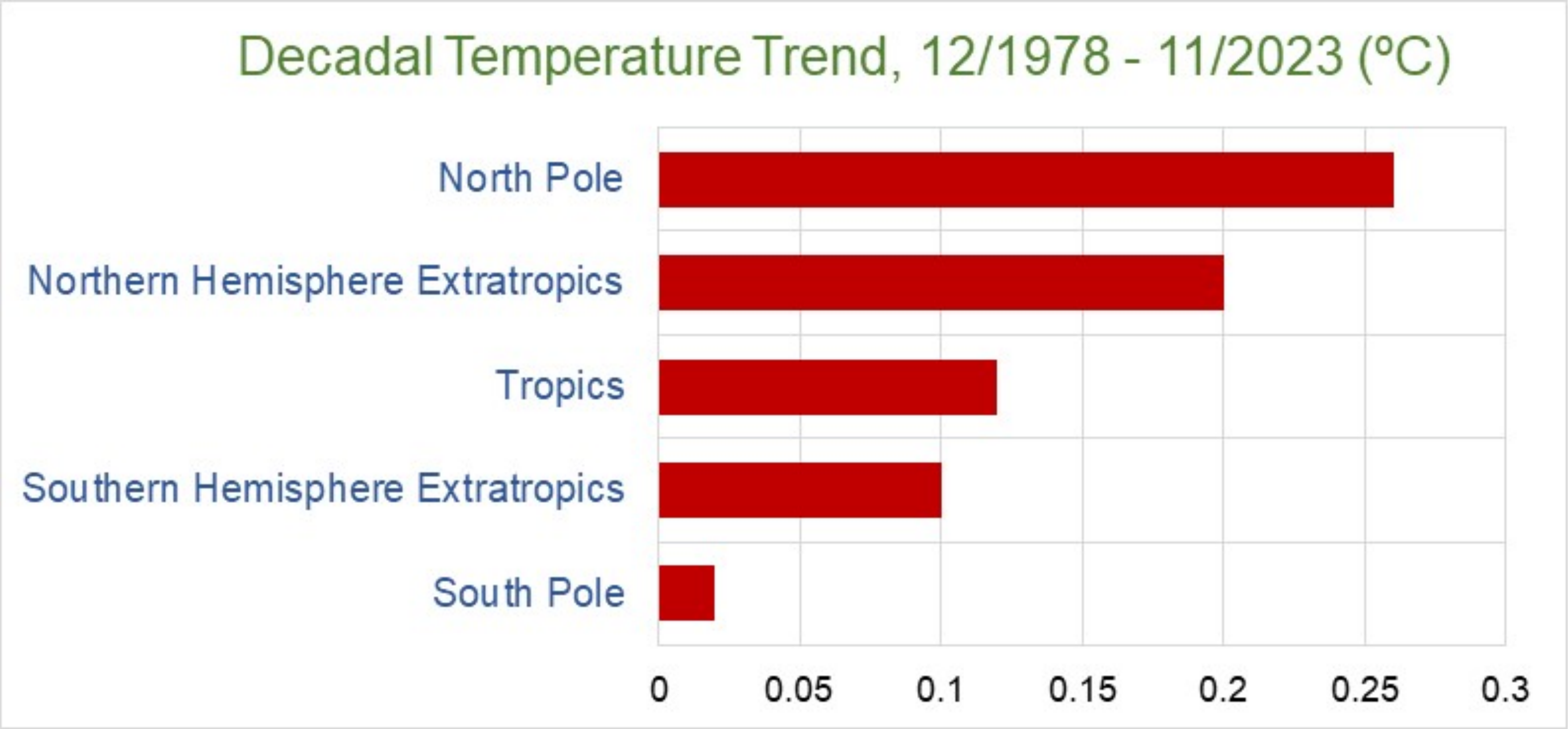
For the past 25 years, global temperatures have experienced a relatively small yet significant warming. Here is the average yearly global temperature from 1979-2022 as measured by satellites and compiled by the University of Alabama-Huntsville. The prevailing school of thought is that rising levels of anthropogenic carbon dioxide are driving this increase.



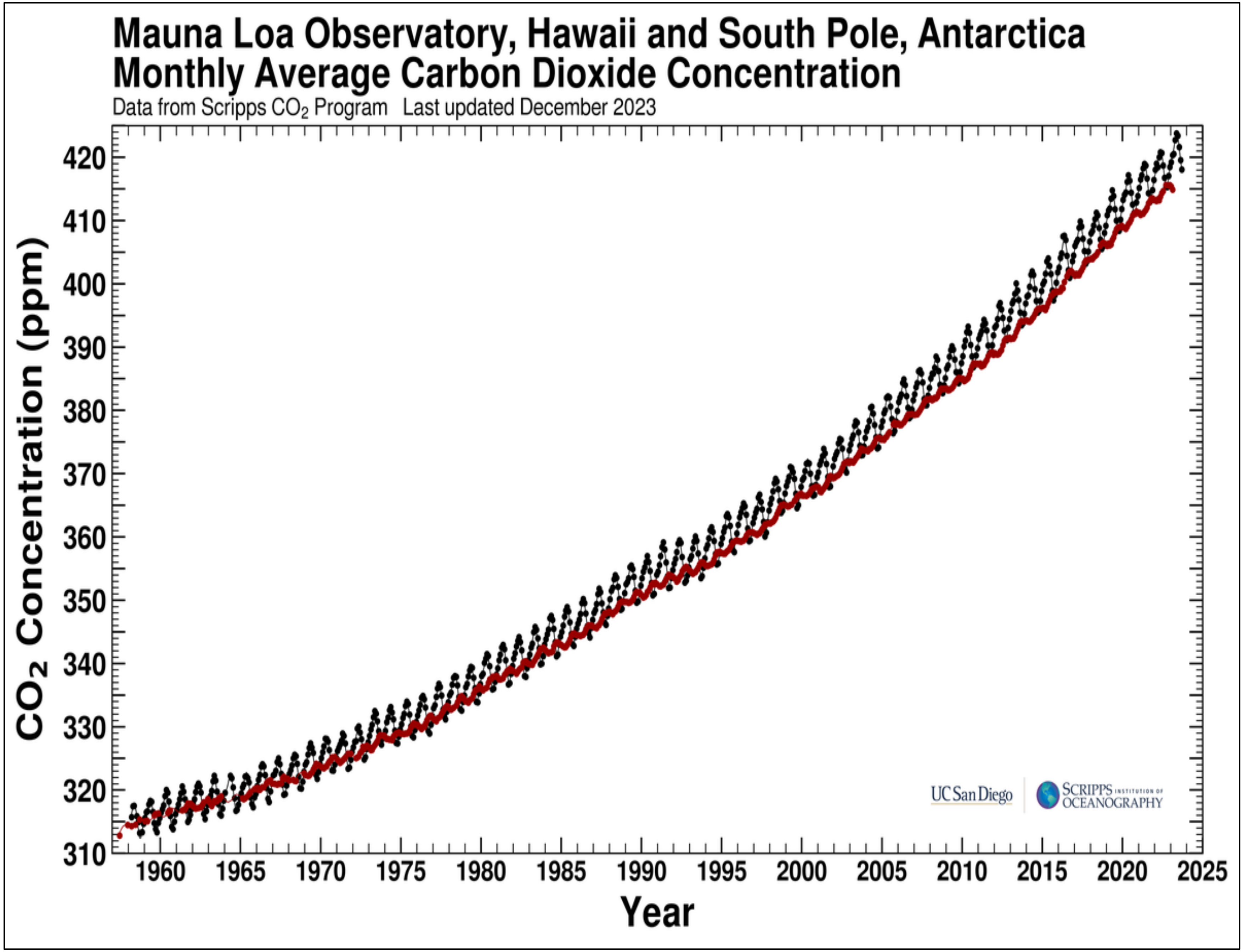
Two important features stand out from the time series of global temperatures. First, is that the warming has been punctuated by distinct inflection points.



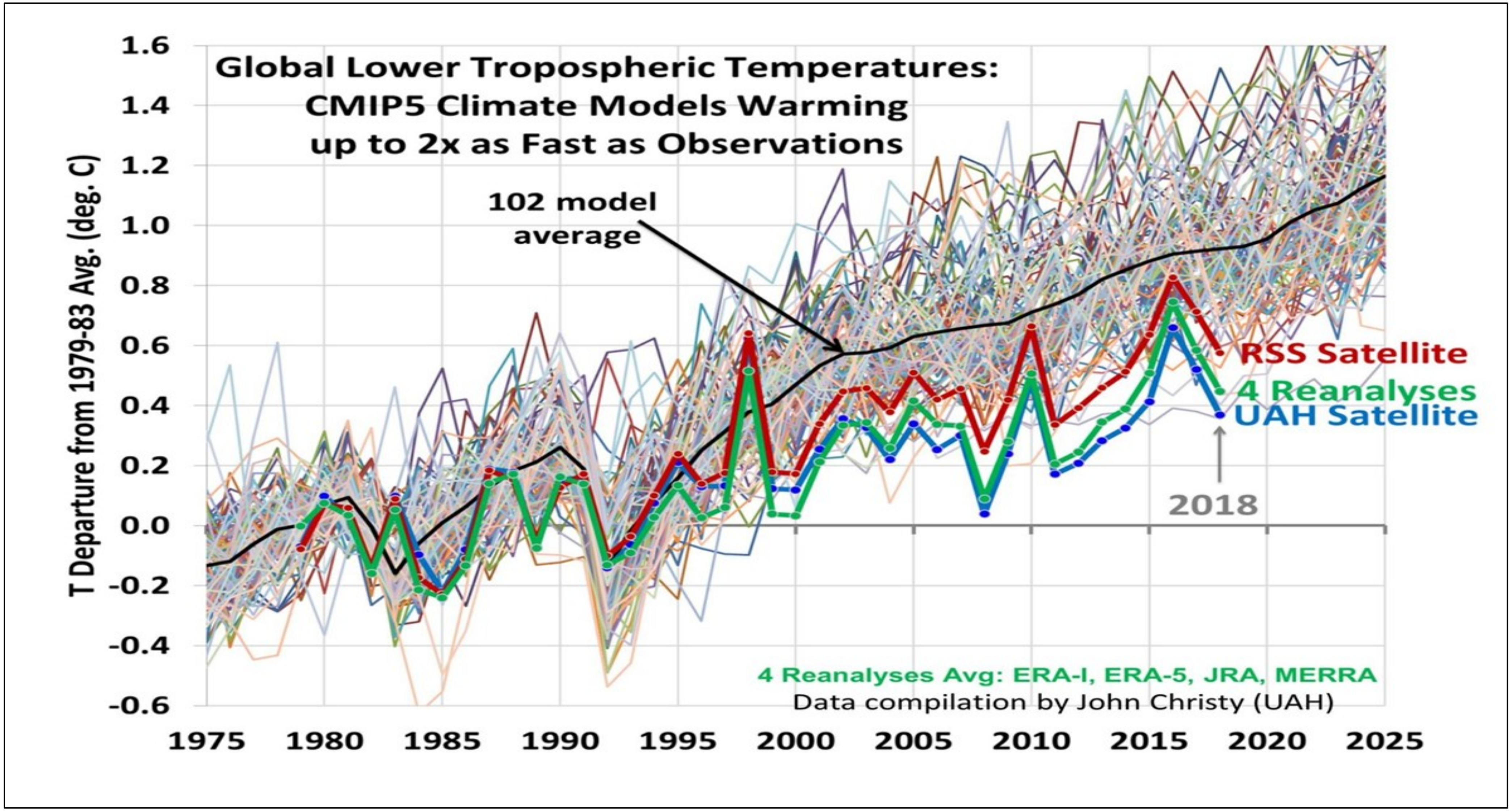
The second point is that the UAH data shows there is an uneven geographic distribution in the rates of warming. There is a clear north to south gradient with the greatest warming occurring at the North Pole (60-90 degrees north latitude). This phenomenon is well documented in the literature and is referred to as the "Arctic Amplification"



These curves from Hawaii and the South Pole cast serious doubt on the “CO2 as control knob” hypothesis. First, if the CO2 is rising steadily, then why is the temperature increasing in a punctuated fashion? Second, if we have virtually identical concentrations of CO2 at 2 distant points (equator and South Pole) then why do we have a highly irregular geographic pattern of increase?

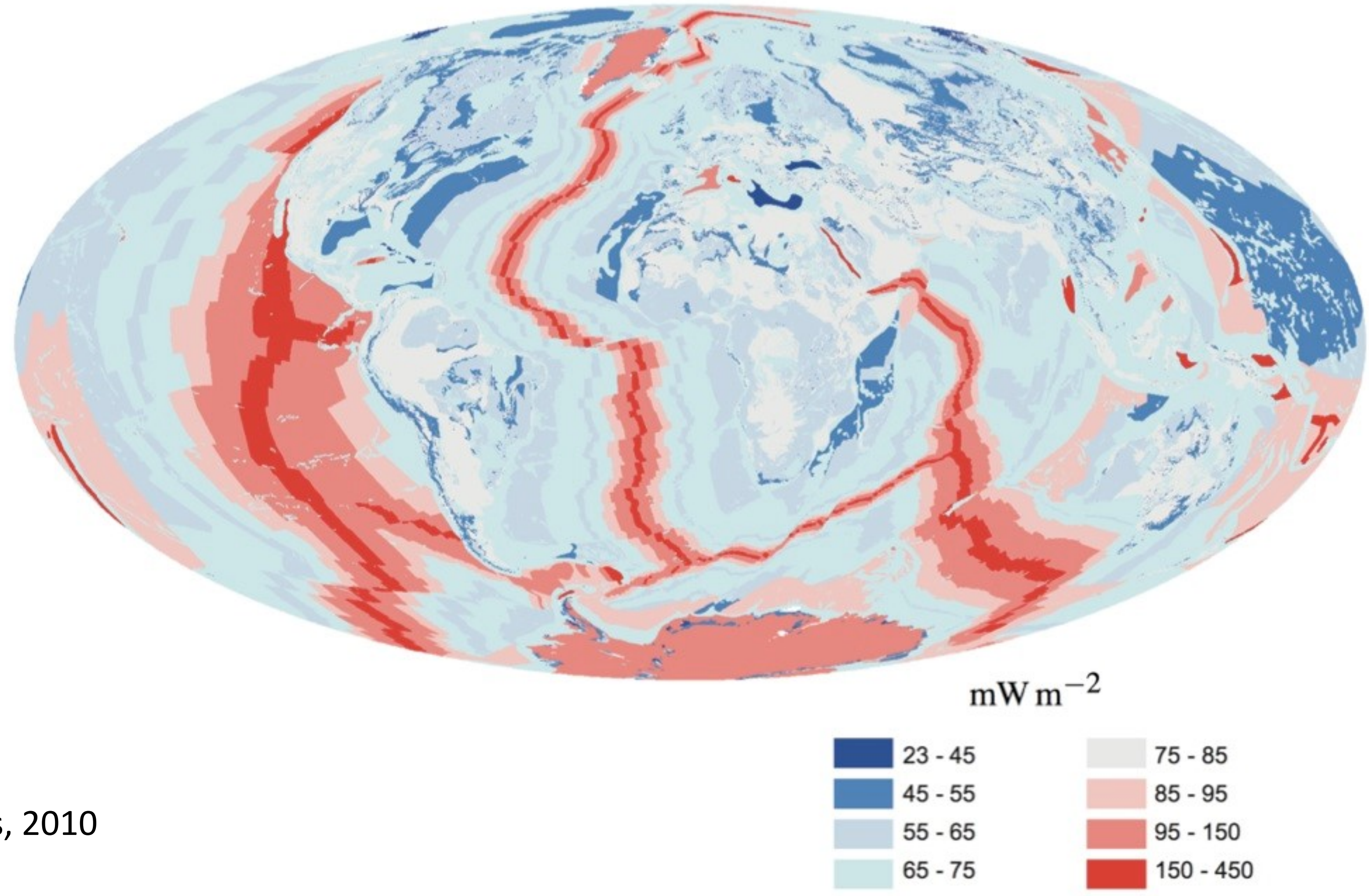


Furthermore, the models which predict future warming based on CO_2 as the "driver" are woefully inadequate, suggesting a different mechanism is probably responsible.



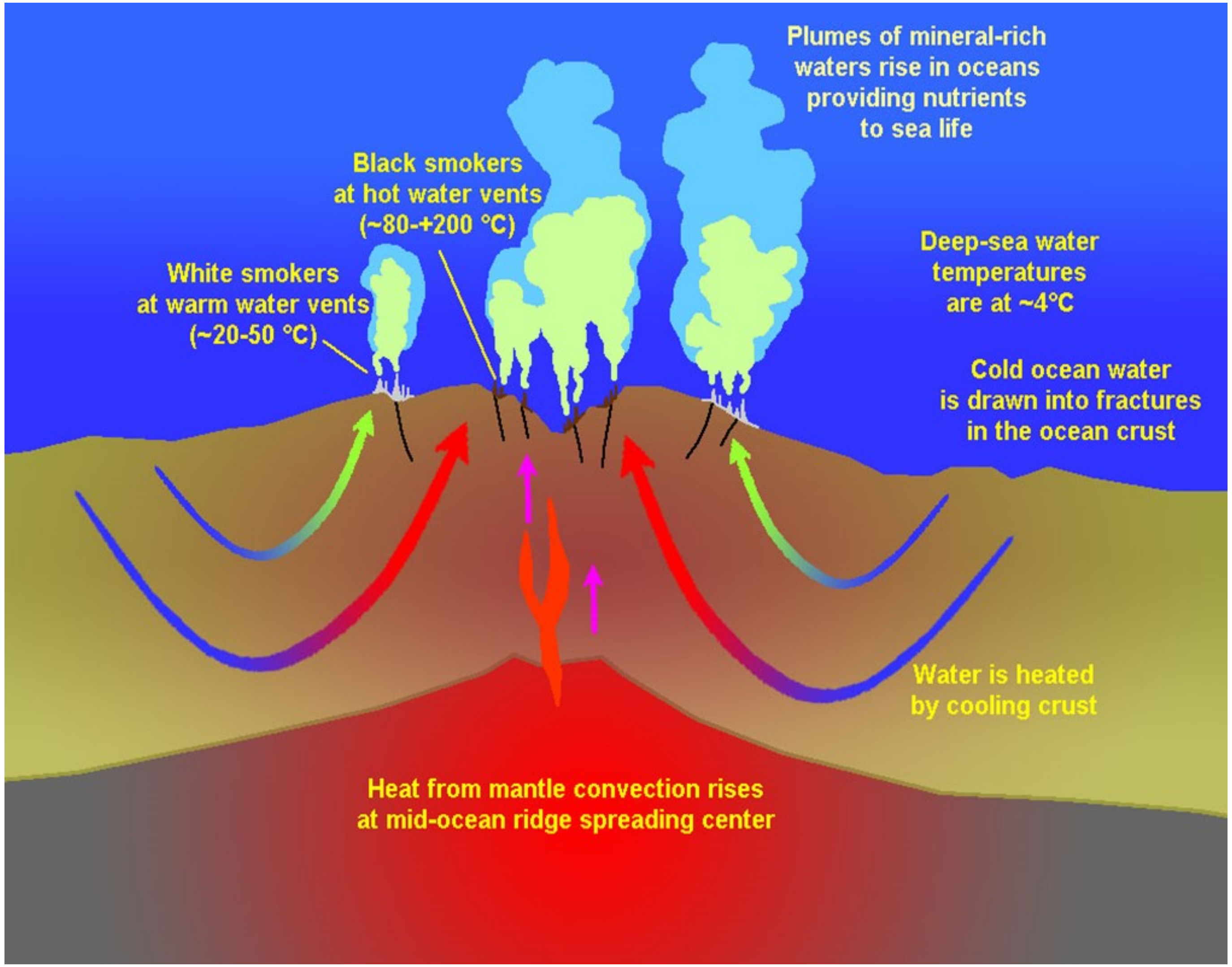
Until recently, there has been very little research on the impact geothermal heat may have on global temperature.

The vast majority of geothermal heat is emitted by volcanoes and hydrothermal vents in the middle of the world's ocean basins.



Davies and Davies, 2010

Schematic of hydrothermal vents. It is now thought that the mid-ocean ridge system may have as many as 30,0000 vent fields



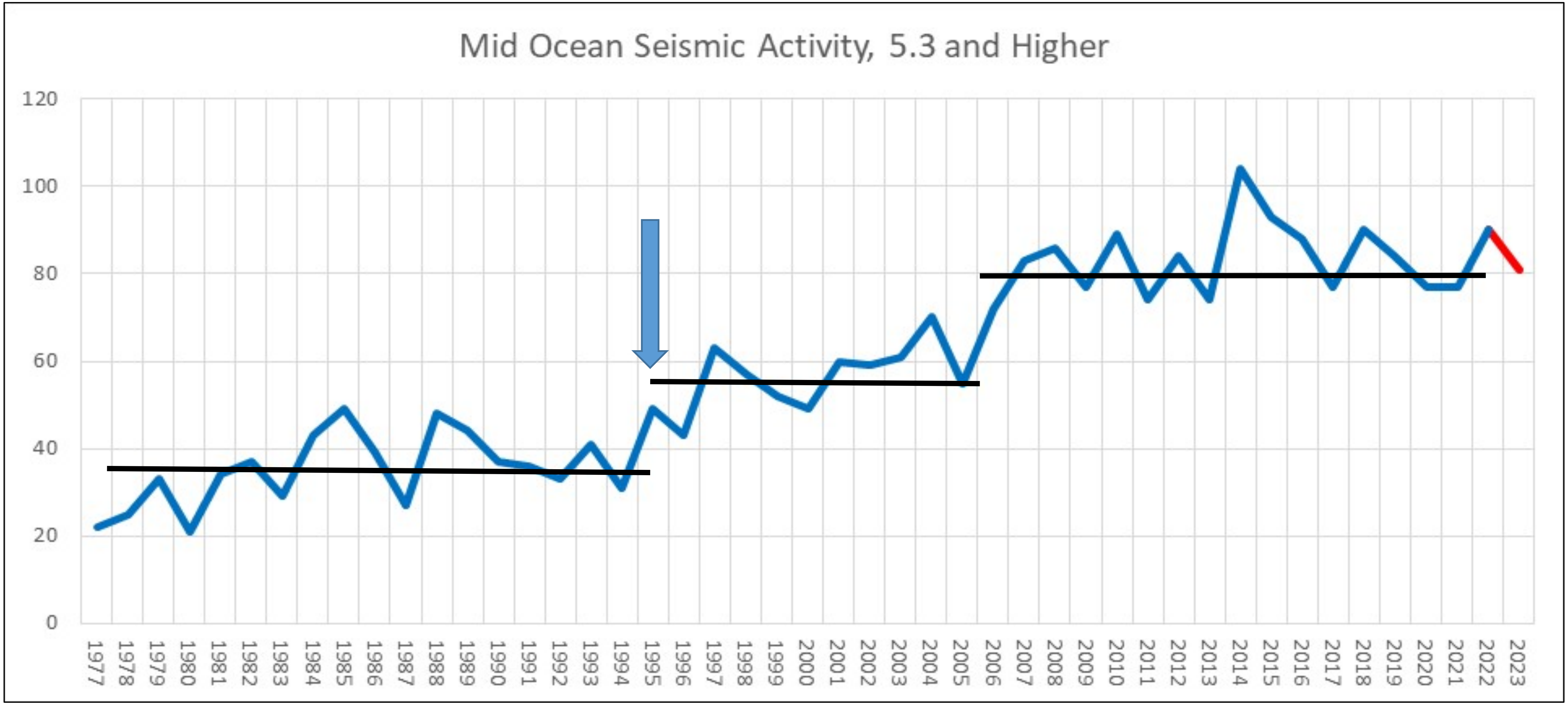
https://www.sciencemag.org/news/2016/06/our-oceans-may-have-six-times-many-hydrothermal-vents-thought

Although we have very little direct measurement of the geothermal flux in these Mid-Ocean Ridges (also called Mid-Ocean Spreading Zones), a good proxy indicator is provided by the number of seismic events in these areas.

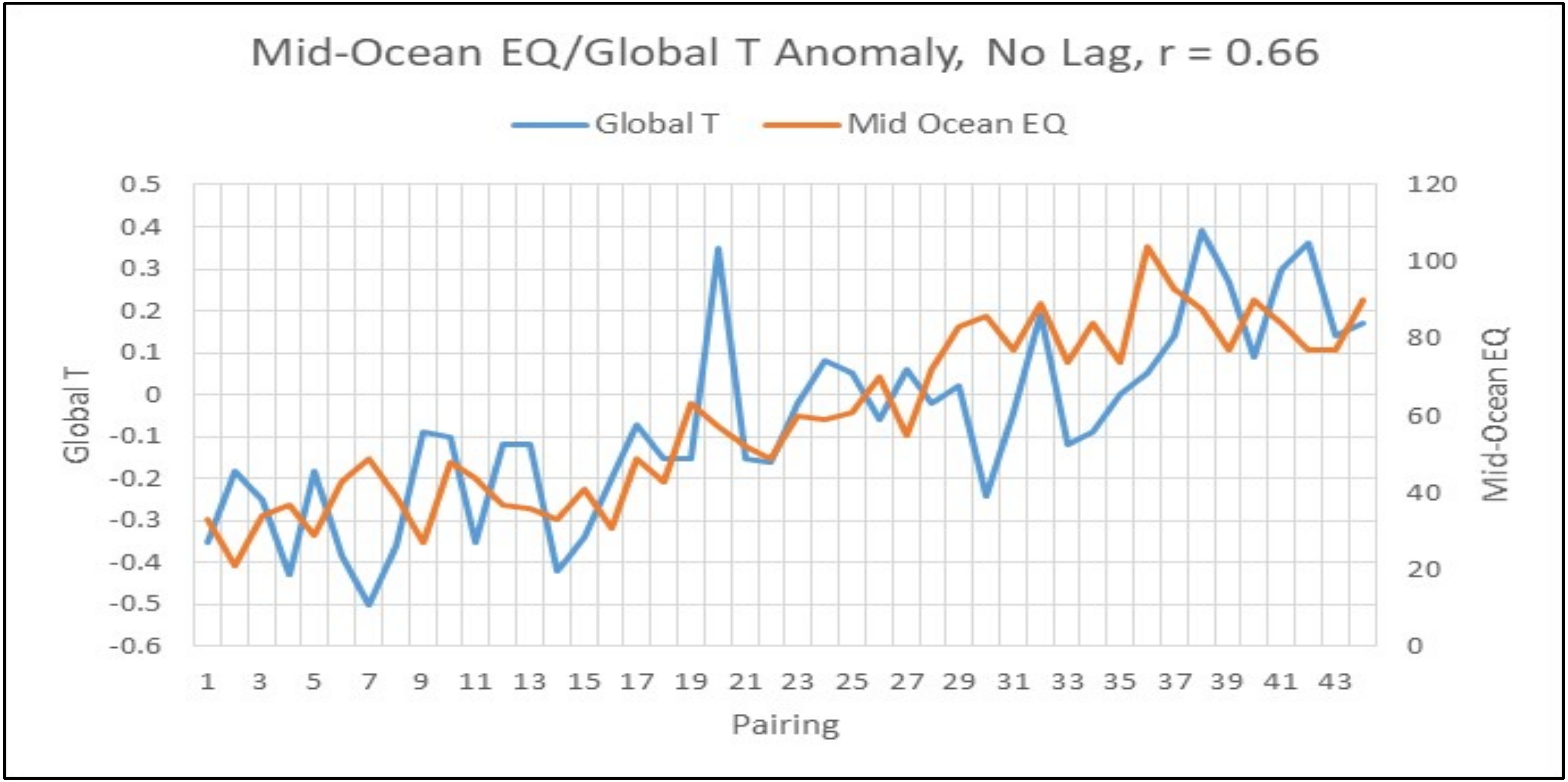
"Seafloor hydrothermal systems are known to respond to seismic and magmatic activity along mid-ocean ridges, often resulting in locally ***positive changes in hydrothermal discharge rate, temperature*** *and microbial activity, and shifts in composition occurring at the time of earthquake swarms and axial crustal dike injections.* ***Corresponding regional effects have also been observed."***

Davis E, Becker K, Dziak R, Cassidy J, Wang K, et al. (2004) Hydrological response to a seafloor spreading episode on the Juan de Fuca Ridge. *Nature* 430(6997): 335-338. DOI: 10.1038/nature02755

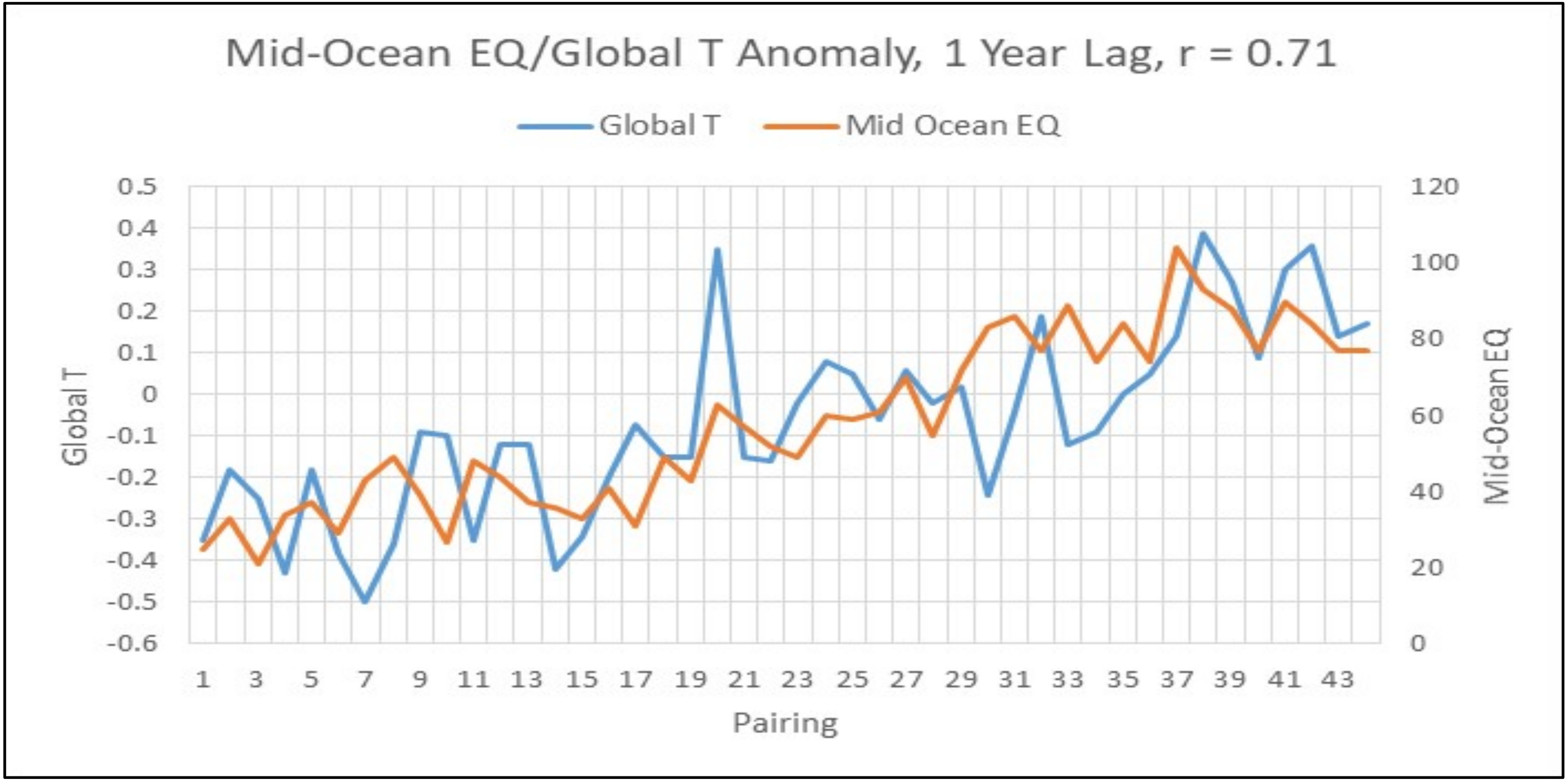
Interestingly, the earth's mid-ocean seismic activity/geothermal flux, as reported in the GCMT catalogue, has a very similar "stair-step" pattern as the global temperatures. Additionally, there appears to be a two-year lag, in that the changes in global temperatures lag the change in mid-ocean seismic activity by two years. Notice the 1995 inflection point.



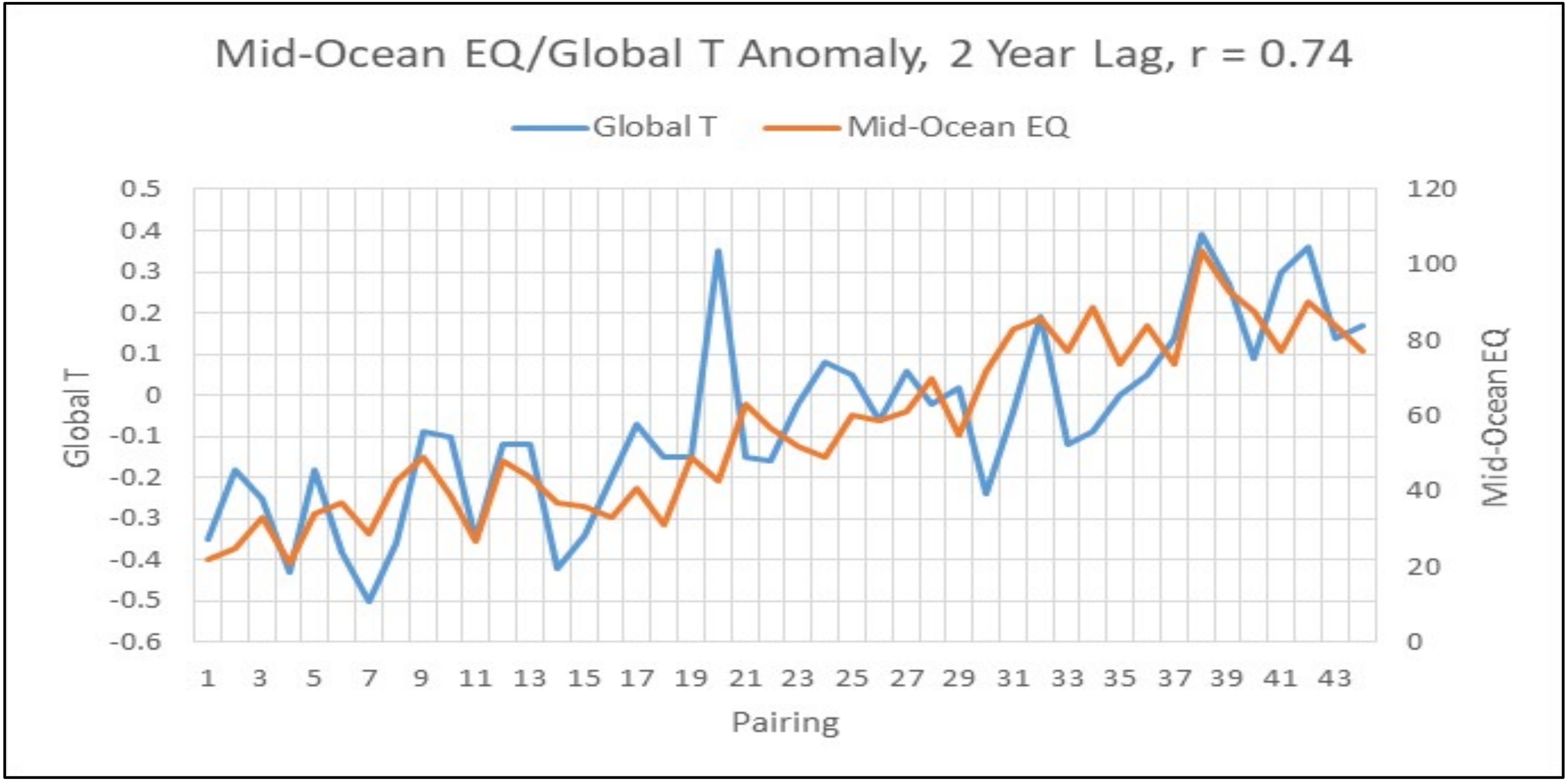
Here we see the mid-ocean seismic curve plotted against global temperatures with the time frames synchronized (i.e., the 1979 temperature reading is paired with the 1979 seismic activity reading, and so forth)



Here we see them paired together with a 1 year lag (i.e., the 1979 temperature reading is paired with the 1978 seismic reading, and so forth)



Here we see them paired together with a 2 year lag (i.e., the 1979 temperature reading is paired with the 1977 seismic reading, and so forth)



Regression analysis indicates a strong relationship between mid-ocean seismicity/ geothermal flux and global temperatures since 1979. For the 2-year lagged experiment, there is a correlation coefficient of 0.74, demonstrating that mid-ocean geothermal flux accounts for 54.8% of the variability in global temperatures. More importantly, the probability that this relationship occurred by chance is .000000009, or .0000009% !!

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.740259321
R Square	0.547983863
Adjusted R Square	0.537221574
Standard Error	0.151660379
Observations	44

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.171136167	1.171136	50.91704	9.30619E-09
Residual	42	0.966036561	0.023001		
Total	43	2.137172727			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-0.481558062	0.062339215	-7.7248	1.36E-09	-0.607363691	-0.355752433	-0.607363691	-0.355752433
X Variable 1	0.007286336	0.001021122	7.135617	9.31E-09	0.005225629	0.009347044	0.005225629	0.009347044

We have direct evidence that the bottom waters of the oceans have warmed since the mid-1990s. Keep in mind that 1995 was the first inflection point for global seismic activity.

Carmack, E. C., Williams, W. J., Zimmermann, S. L., and McLaughlin, F. A. (2012), **The Arctic Ocean warms from below,** Geophys. Res. Lett., 39, L07604, doi:10.1029/2012GL050890.

Björk, G., and P. Winsor (2006), **The deep waters of the Eurasian Basin, Arctic Ocean: Geothermal heat flow, mixing and renewal,** Deep Sea Res., Part I, 53, 1253–1271, doi:10.1016/j.dsr.2006.05.006.

Gregory C. Johnson, Sabine Mecking, Bernadette M. Sloyanand Susan E. Wijffels**, Recent Bottom Water Warming in the Pacific Ocean** J. Climate., 20 (21), 5365–5375, 2007.

Masao Fukasawa, Howard Freeland, Ron Perkin, Tomowo Watanabe, Hiroshi Uchida & Ayako Nishina, **Bottom water warming in the North Pacific Ocean.** NATURE | VOL 427 | 26 FEBRUARY 2004.

Strass, V. H., Rohardt, G., Kanzow, T., Hoppema, M. & Boebel, O. **Multidecadal warming and density loss in the deep Weddell Sea, Antarctica.** J. Clim. 33, 9863–9881 (2020).

Purkey, S. G., Johnson, G. C., Talley, L. D., Sloyan, B. M., Wijffels, S. E., Smethie, W., et al. (2019). **Unabated bottom water warming and freshening in the South Pacific Ocean.** Journal of Geophysical Research: Oceans, 124, 1778–1794.

Viviane V. Menezes et al. **Accelerated freshening of Antarctic Bottom Water over the last decade in the Southern Indian Ocean.** Sci. Adv.3,e1601426(2017).

Ballarotta et al. have clearly demonstrated that geothermal heating significantly strengthens the thermohaline circulation. The greater the geothermal flux, the greater the strength of the circulation.

"*Although the ocean is largely heated and thermally driven at the surface, several recent studies suggest that the OGH (ocean geothermal heating) can also affect the ocean dynamic and heat budget. …. By applying spatially constant or variable heat flux in Ocean General Circulation Models (OGCMs) forced with the present day climate, it is shown that the* ***OGH is a significant forcing that can weaken the stability of the water column, warm the bottom water and strengthen the thermohaline circulation…***"

Ballarotta, M. et al., (2015), "Impact of the oceanic geothermal heat flux on a glacial ocean state", *Climate of the Past Discussions*, 11, 3597-3624

Many other studies have confirmed these findings.

Thompson L, Johnson GC (1996) **Abyssal currents generated by diffusion and geothermal heating over rises**. Deep Sea Research Part I: Oceanographic Research Papers 43(2): 193-211.

Downes SM, Hogg AM, Griffies SM, Samuels BL (2016) **The transient response of Southern Ocean circulation to geothermal heating in a global climate model**. J Climate 29(16): 5689-5708.

Adcroft A, Scott J, Marotzke J (2001**) Impact of geothermal heating on the global ocean circulation**. Geophys Res Lett 28(9): 1735-1738.

Hofmann M, Morales Maqueda MA (2009) **Geothermal heat flux and its influence on the oceanic abyssal circulation and radiocarbon distribution.** Geophys Res Lett 36(3): L03603.

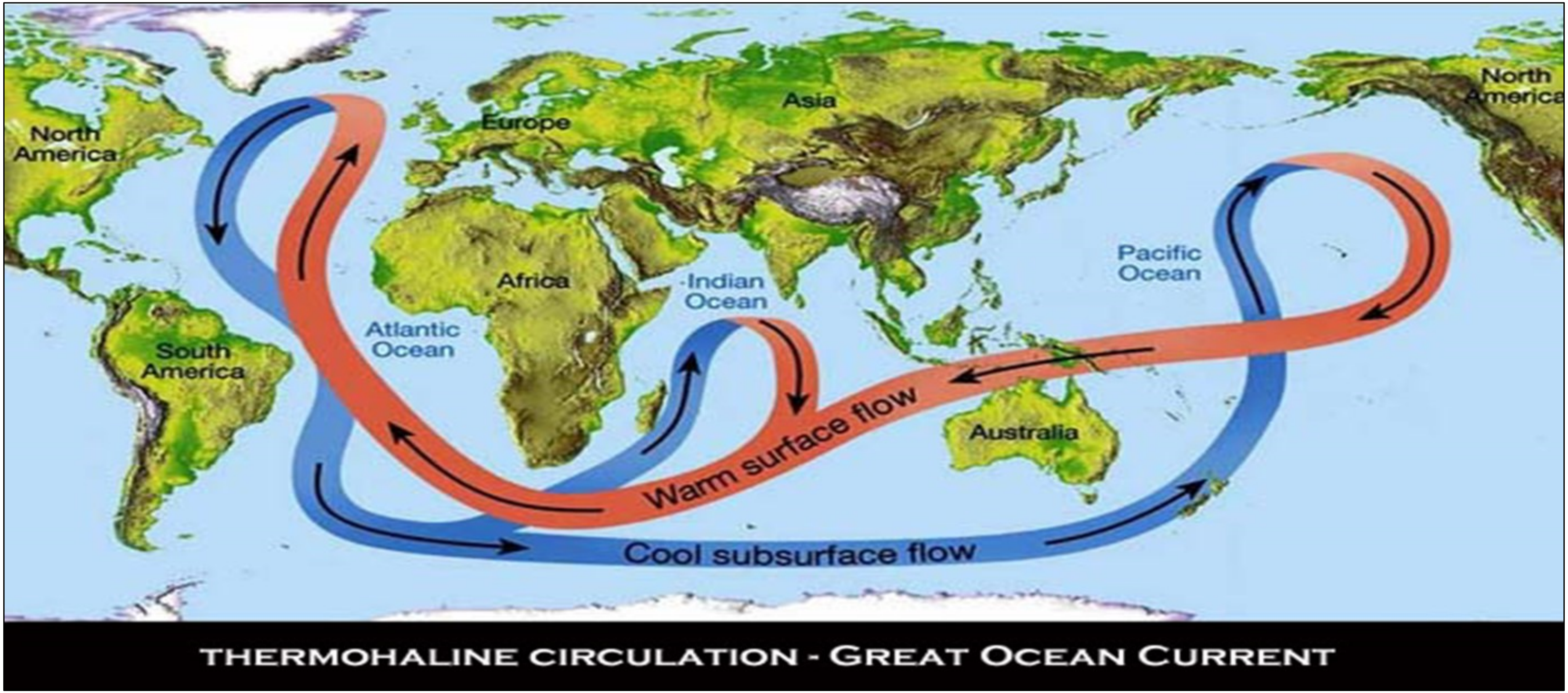
Urakawa LS, Hasumi H (2009) **A remote effect of geothermal heat on the global thermohaline circulation.** J Geophys Res Oceans 114: C07016.

Mullarney JC, Griffiths RW, Hughes GO (2006) **The effects of geothermal heating on the ocean overturning circulation.** Geophys Res Lett 33: L02607.

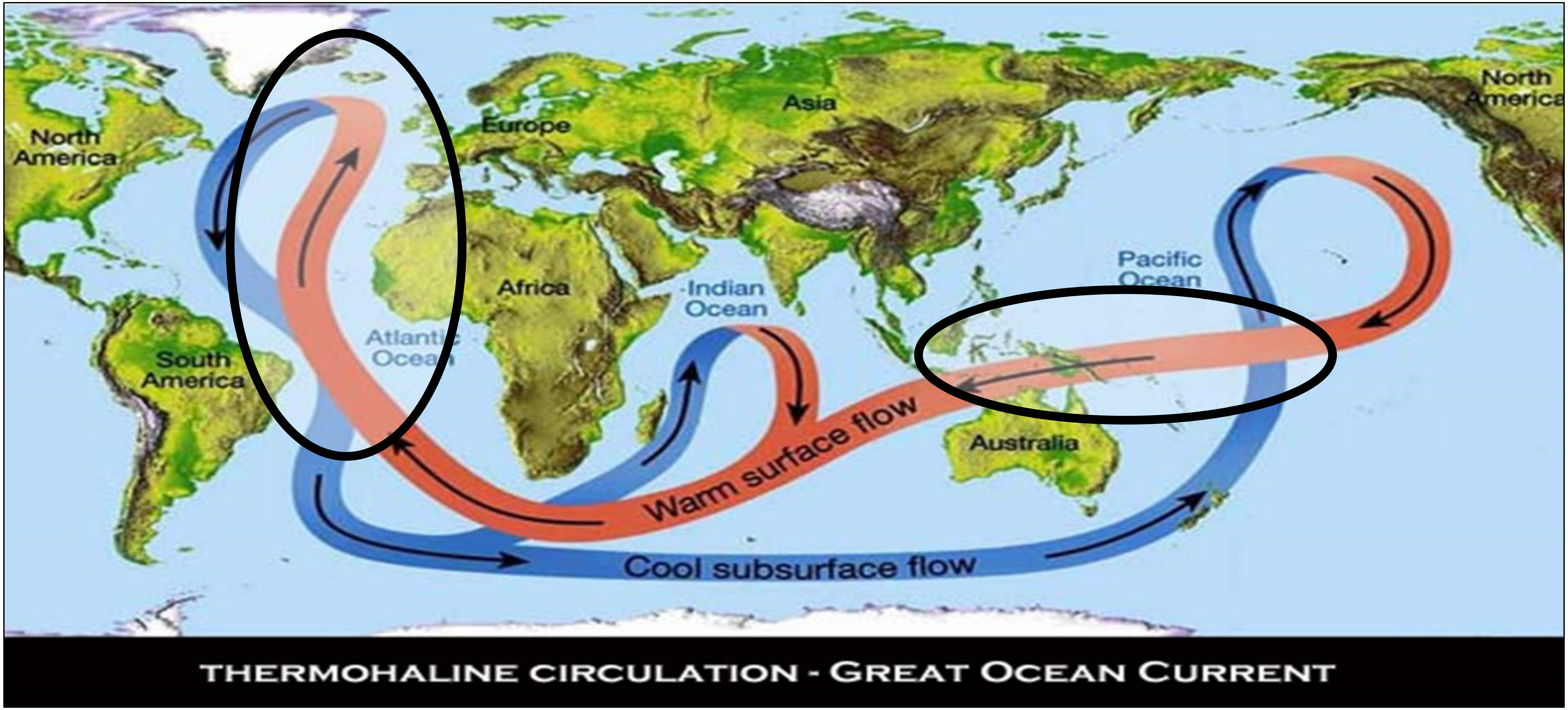
Scott JR, Marotzke J, Adcroft A (2001) **Geothermal heating and its influence on the meridional overturning circulation**. J Geophys Res 106(C12): 31141-31154.

Patara L, Böning CW (2014) **Abyssal ocean warming around Antarctica strengthens the Atlantic overturning circulation.** Geophys Res Lett 41(11): 3972-3978

Here is an illustration of the thermohaline circulation. Intensifying its flow is a "game changer" as the oceans contain 1,000 times as much heat as the atmosphere! In effect, this enables geothermal heating to enhance the ocean's ability to transfer heat. In other words, geothermal heating of the ocean ridge system can energize the earth's oceanic "heat pump".



Two areas of intensified thermohaline flow are especially important to the global and regional temperature changes seen since 1995. These are the Western Pacific and the North Atlantic/Arctic regions



With regards to the North Atlantic/Arctic, a description from the Encyclopedia Britannica sums up the role of the thermohaline circulation quite well.

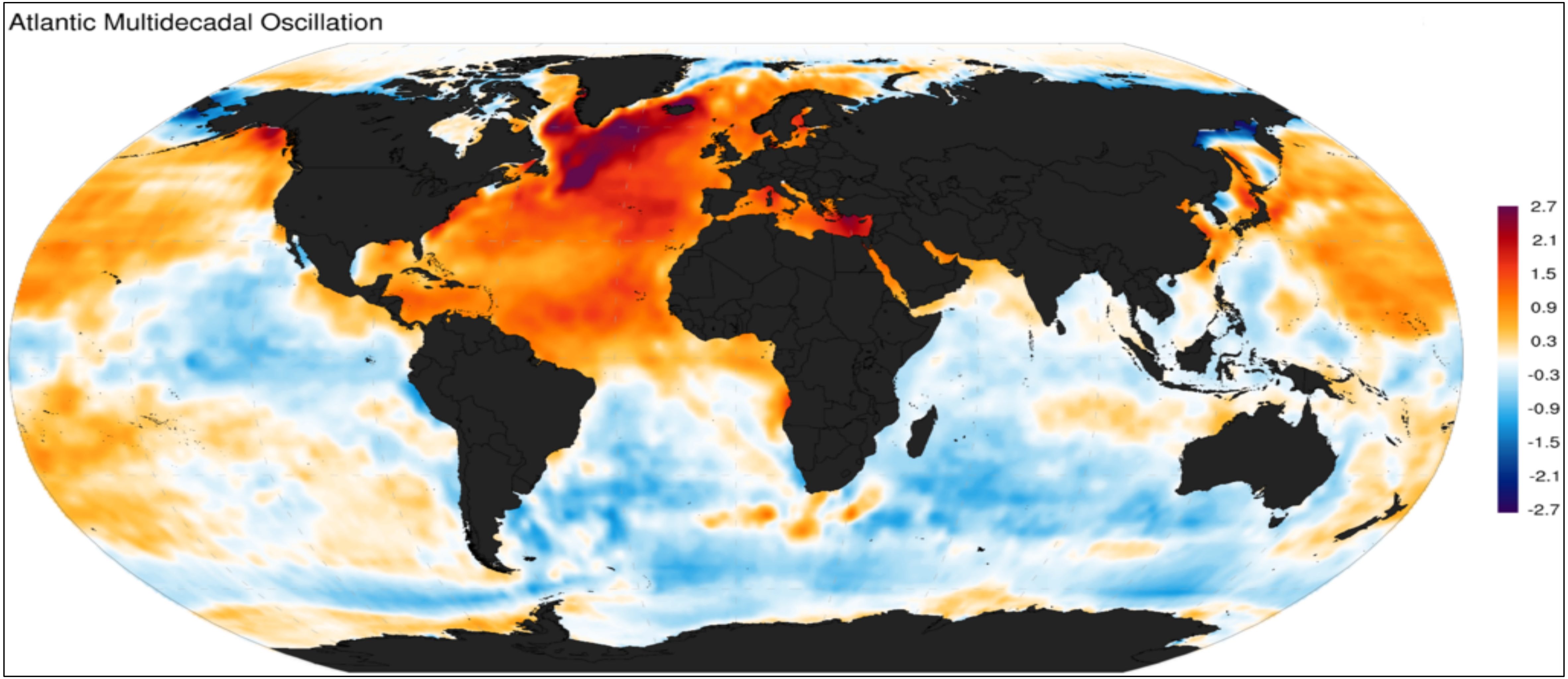
Poleward transfer of heat
Thermohaline circulation

A significant characteristic of the large-scale North Atlantic circulation is the poleward transport of heat. Heat is transferred in a northward direction throughout the North Atlantic. This heat is absorbed by the tropical waters of the Pacific and Indian oceans as well as of the Atlantic and is then transferred to the high latitudes, where it is finally given up to the atmosphere.

The mechanism for the heat transfer is principally by thermohaline circulation rather than by wind-driven circulation. Circulation of the thermohaline type involves a large-scale overturning of the ocean, with warm and saline water in the upper 1,000 metres (3,300 feet) moving northward and being cooled in the Labrador, Greenland, and Norwegian seas.

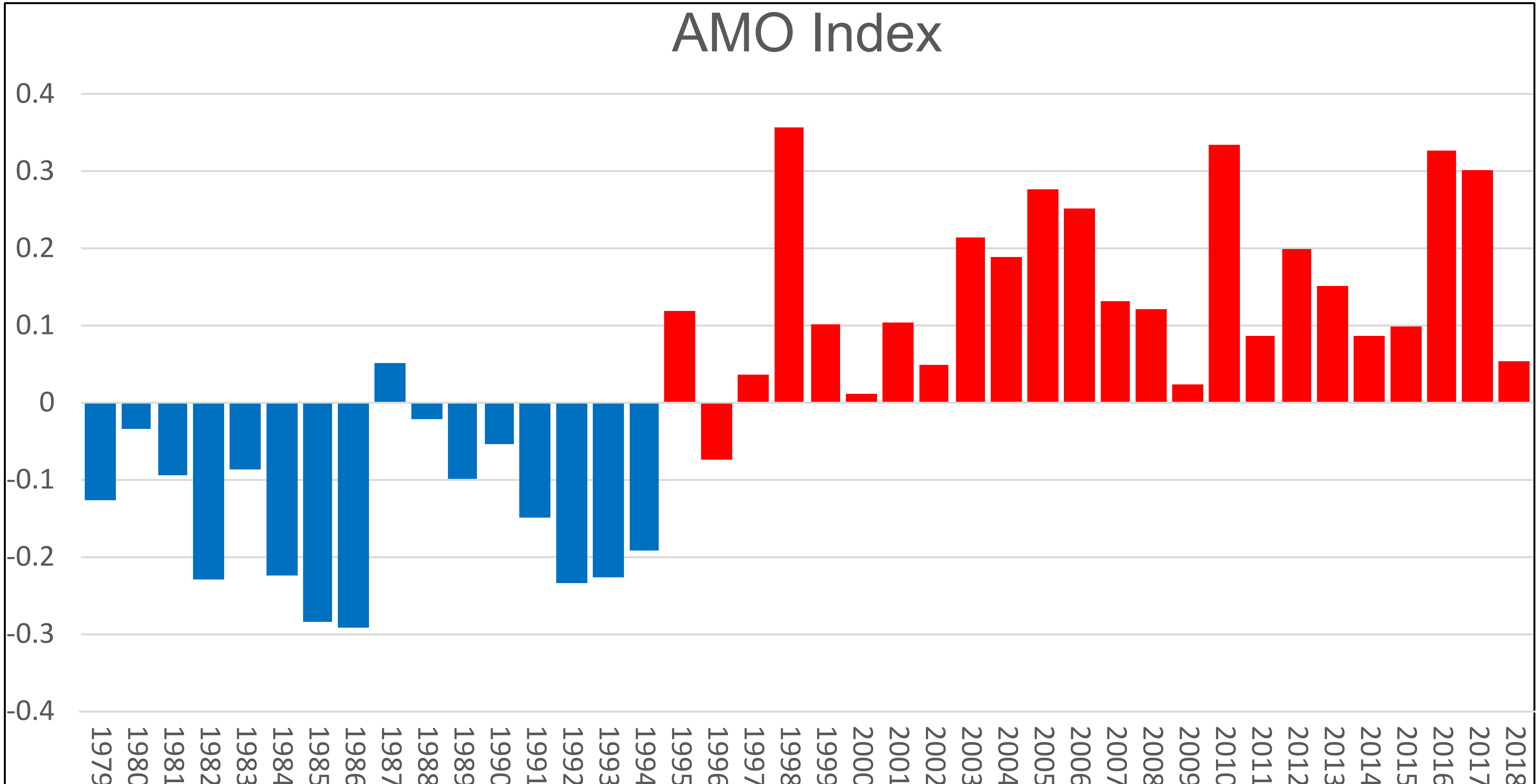
Climate - Heat Transfer, Polar Regions, Atmosphere | Britannica

This is well-illustrated when the Atlantic Multidecadal Oscillator (AMO) is in its positive, or warm phase. We are currently in that phase and have been since 1995, the year that we saw a major inflection in mid-ocean seismic activity.

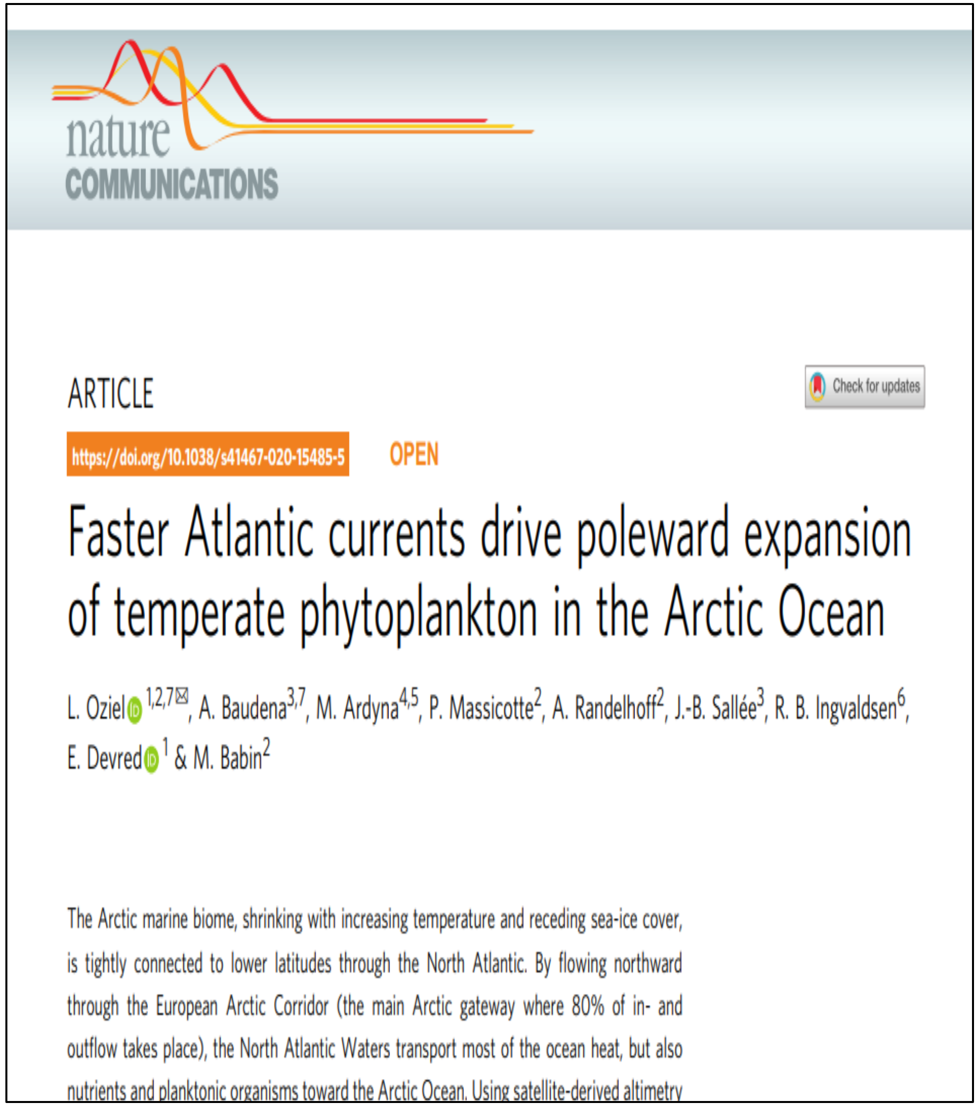


Wikipedia Commons

Here is a graph of the AMO over time. As we can see here, the AMO shifted abruptly in 1995, the same year that the mid-ocean seismic activity increased. It remains high to this day.



This rapid change in the AMO Index in 1965 is also reflected in an abrupt change in the phytoplankton populations in the Arctic. Furthermore, this sudden change in the marine flora is tied to a rapid intensification of the North Atlantic Currents in 1996.



nature COMMUNICATIONS

ARTICLE

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https://doi.org/10.1038/s41467-020-15485-5 OPEN

Faster Atlantic currents drive poleward expansion of temperate phytoplankton in the Arctic Ocean

L. Oziel[1,2,7✉], A. Baudena[3,7], M. Ardyna[4,5], P. Massicotte[2], A. Randelhoff[2], J.-B. Sallée[3], R. B. Ingvaldsen[6], E. Devred[1] & M. Babin[2]

The Arctic marine biome, shrinking with increasing temperature and receding sea-ice cover, is tightly connected to lower latitudes through the North Atlantic. By flowing northward through the European Arctic Corridor (the main Arctic gateway where 80% of in- and outflow takes place), the North Atlantic Waters transport most of the ocean heat, but also nutrients and planktonic organisms toward the Arctic Ocean. Using satellite-derived altimetry

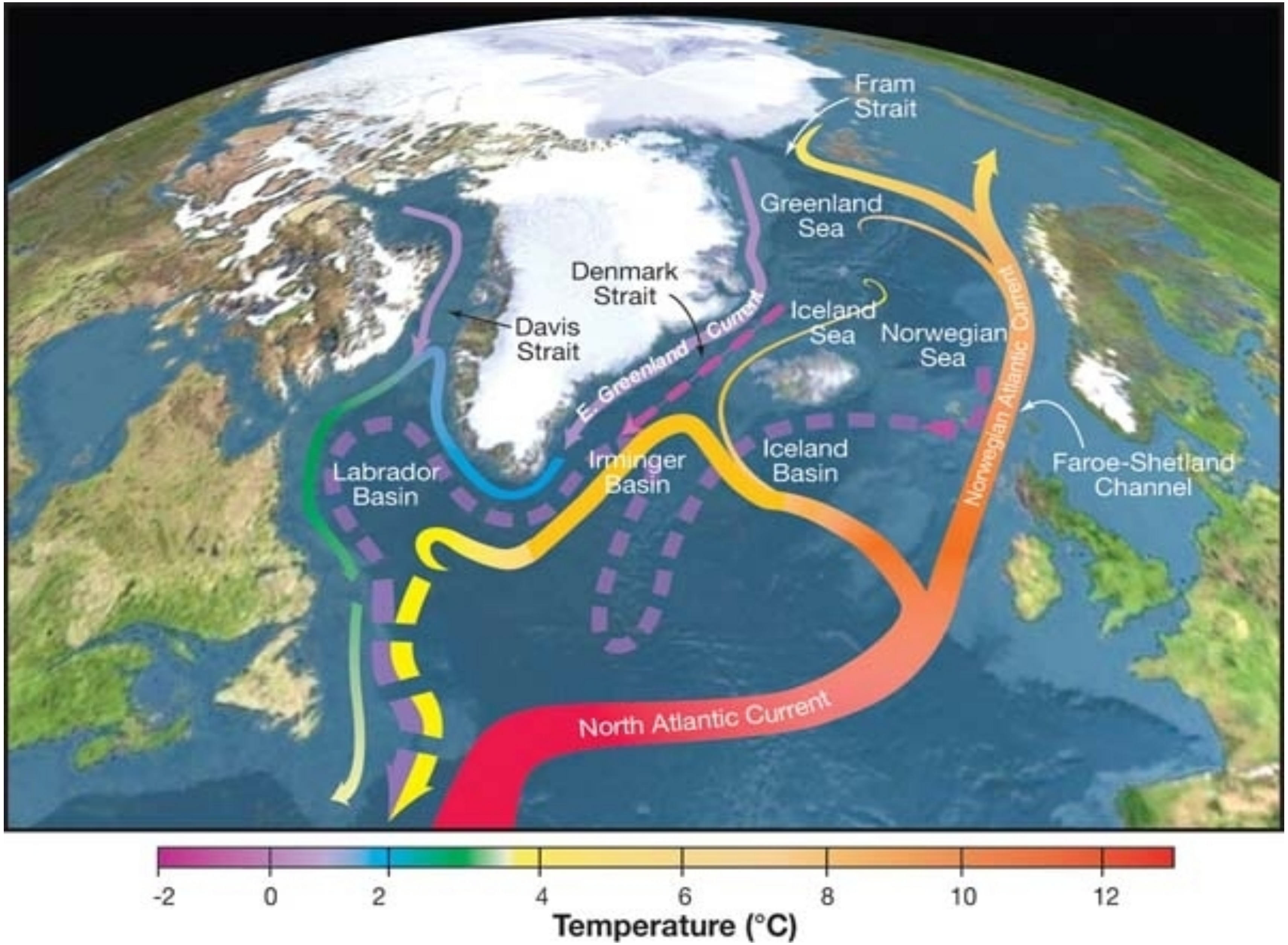
A study by Oziel et al. in Nature Communications states that:

"The Arctic marine biome, shrinking with increasing temperature and receding sea-ice cover, is tightly connected to lower latitudes through the North Atlantic. By flowing northward through the European Arctic Corridor (the main Arctic gateway where 80% of in- and outflow takes place), the North Atlantic Waters transport most of the ocean heat, but also nutrients and planktonic organisms toward the Arctic Ocean. ***Using satellite-derived altimetry observations, we reveal an increase, up to two-fold, in North Atlantic current surface velocities over the last 24 years. …"***

Oziel, L., Baudena, A., Ardyna, M. et al. Faster Atlantic currents drive poleward expansion of temperate phytoplankton in the Arctic Ocean. Nat Commun 11, 1705 (2020). https://doi.org/10.1038/s41467-020-15485-5

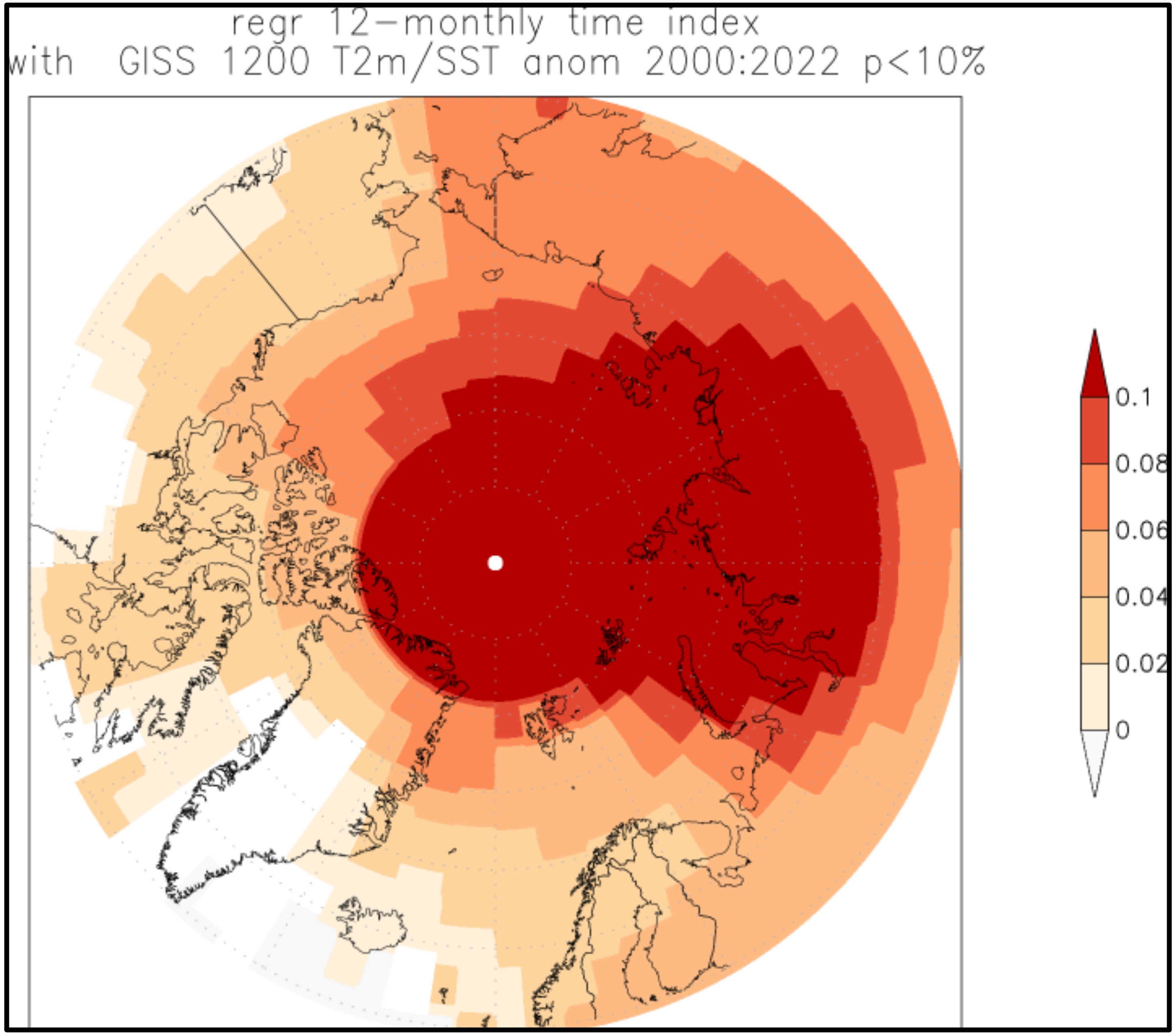
This map of the North Atlantic currents shows in greater detail the deep incursion of the North Atlantic Current into the Arctic.

R. Curry, Woods Hole Oceanographic Institution/ Science/USGCRP. -

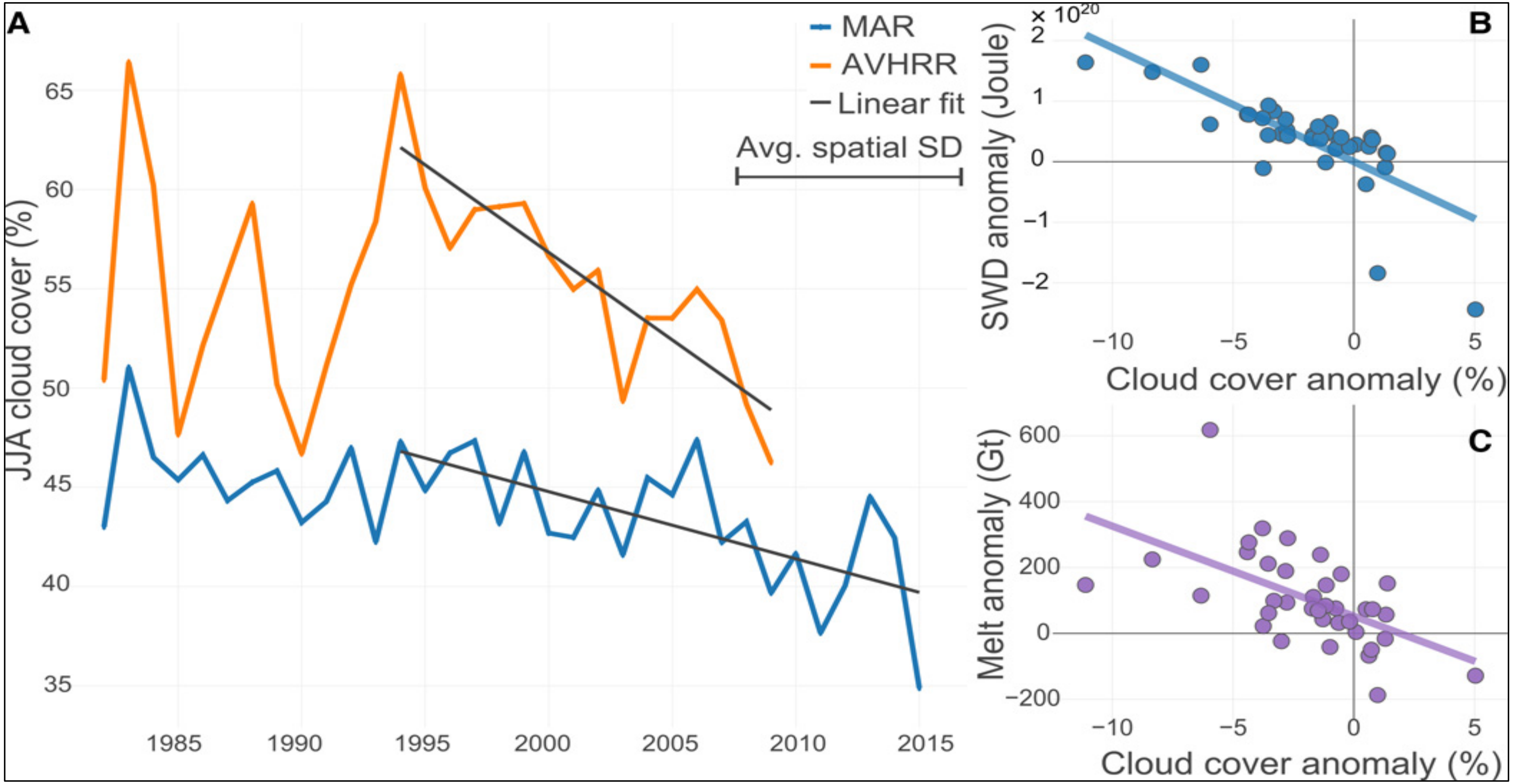


This map details the warming of the Arctic from 200-2022. This clearly parallels the spatial pattern of the Arctic currents in the previous slide.

"Tipping point" Greenland ice cream cancelled? *Climate News*, October 21, 2023. ["Tipping point" Greenland ice cream cancelled? – Climate News (klimanachrichten.de)]



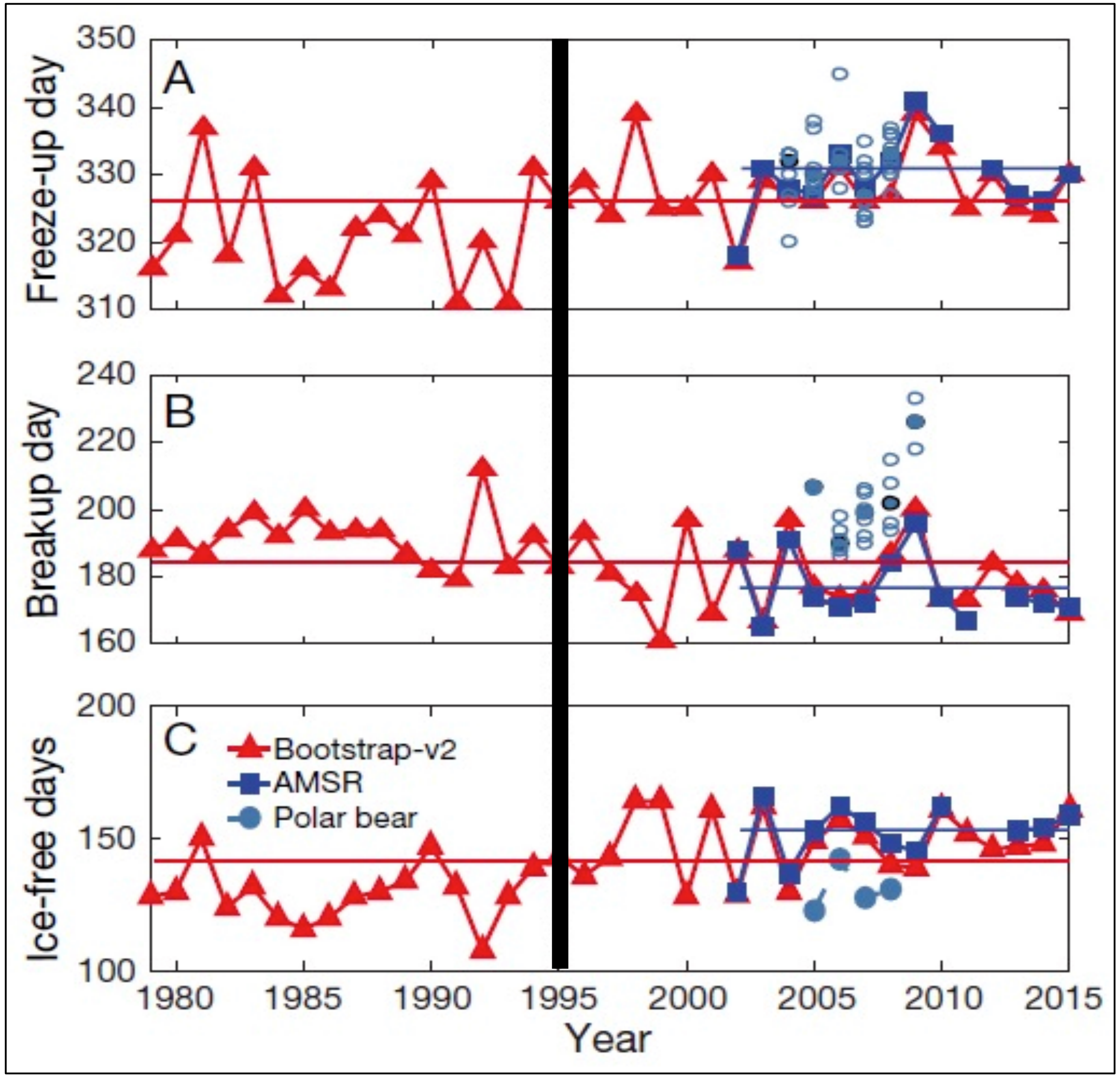
We also saw the beginning of a decline in cloud cover over Greenland in 1995. Higher temperatures lead to a greater ability of the overlying atmosphere to hold more water vapor.



Decreasing cloud cover drives the recent mass loss on the Greenland Ice Sheet Stefan Hofer1,*, Andrew J. Tedstone1, Xavier Fettweis2 and Jonathan L. Bamber *Science Advances* 28 Jun 2017: Vol. 3, no. 6, e1700584 DOI: 10.1126/sciadv.1700584

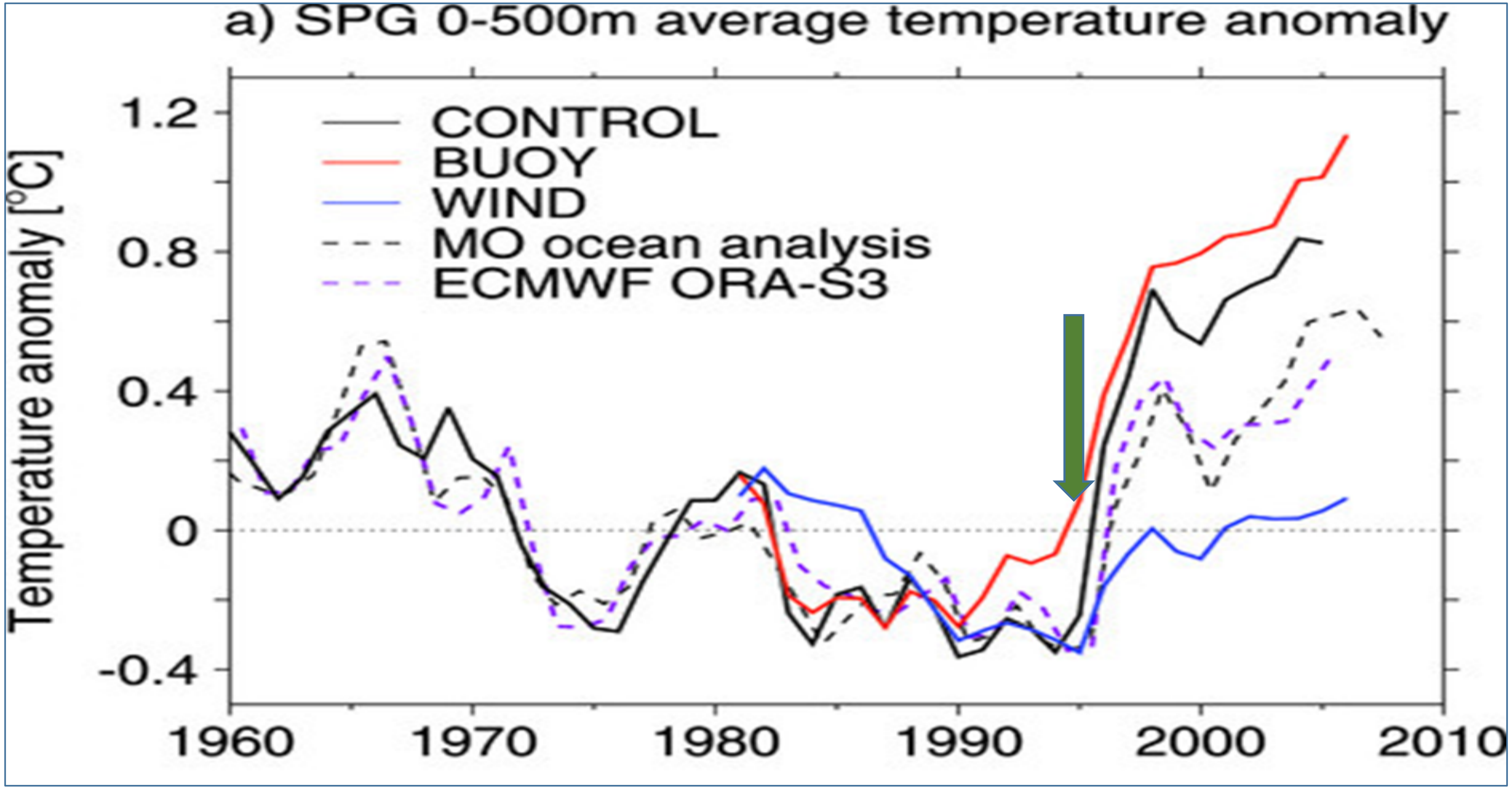
Also commencing in 1995 are changes in freeze and breakup dates of ice in the Hudson Bay region

Figure 3 from Castro de la Guardia (2017) showing freeze-up and breakup dates and ice-free days 1979-2015 for Western Hudson Bay, showing that the earliest freeze-up dates since 1979 (top panel) came on 6 November, Day 310 (in 1991 and 1993).



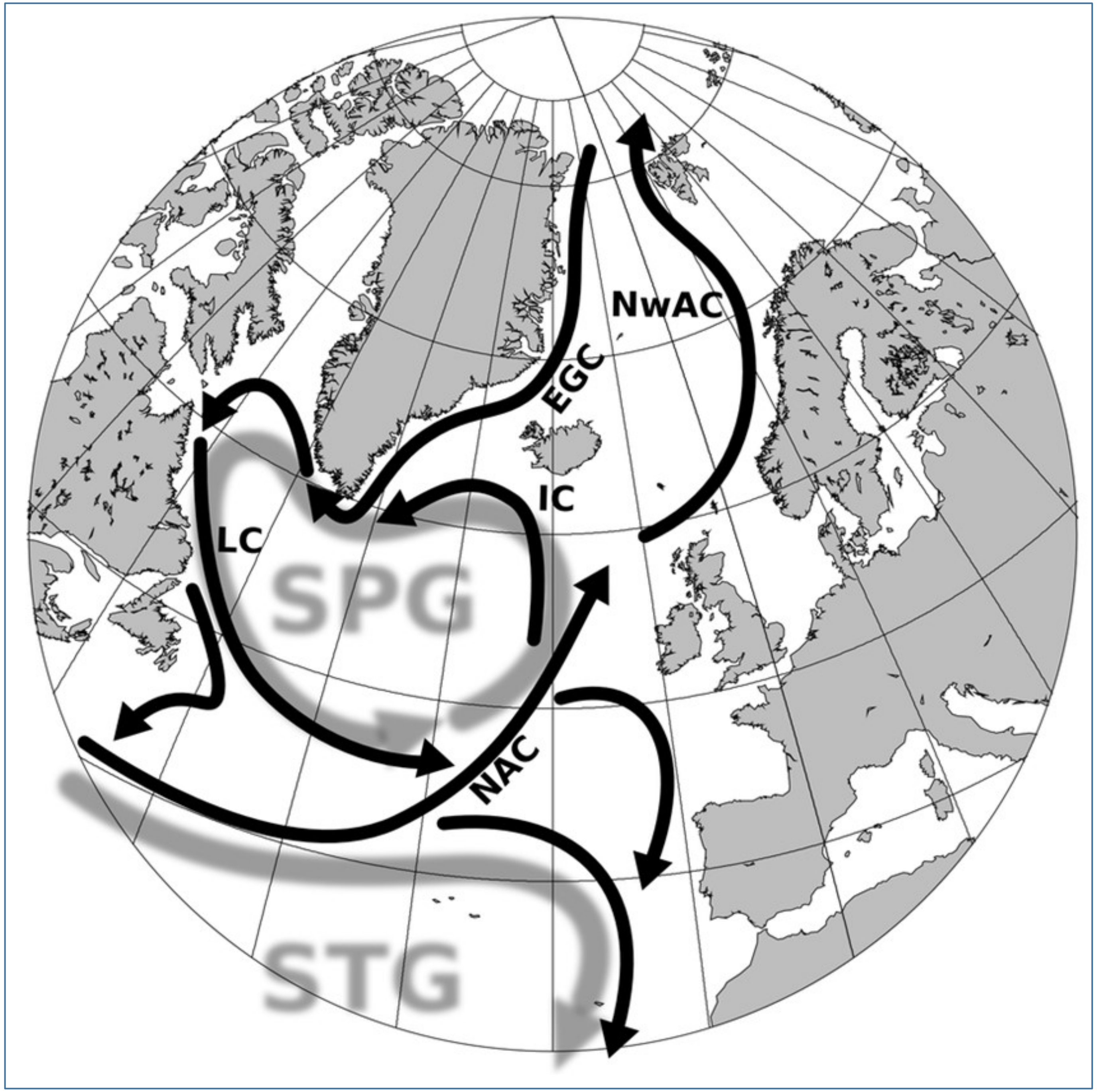
https://climatechangedispatch.com/wh-freeze-up-earlier-1980-average/

We saw rapid warming of the North Atlantic Sub-polar Gyre commencing in 1995

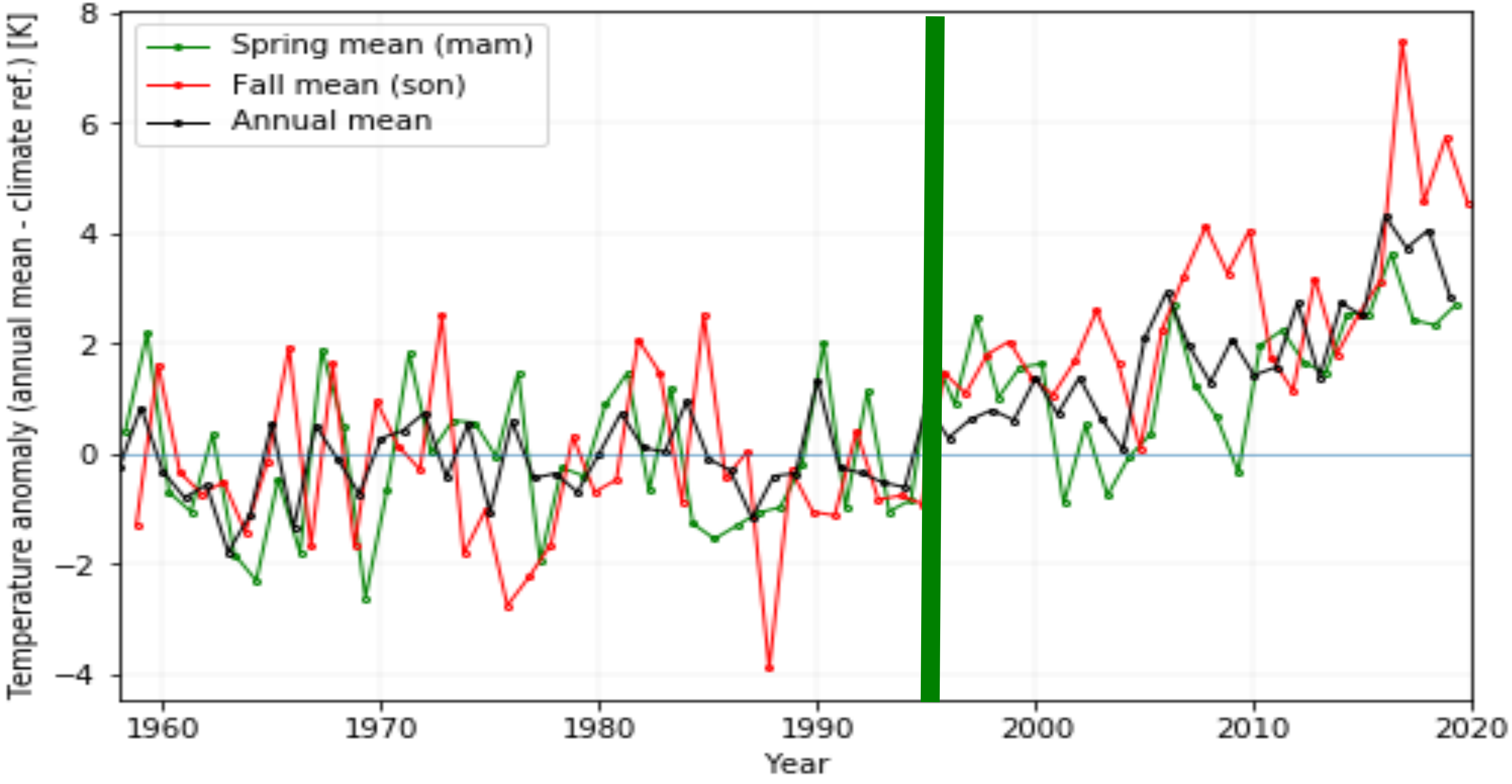


42. Robson J, Sutton R, Lohmann K, Smith D, Palmer MD (2012) Causes of the rapid warming of the North Atlantic Ocean in the mid-1990s. J Climate 25(12): 4116-4134.

Here is a map of the North Atlantic Sub-Polar Gyre (SPG)

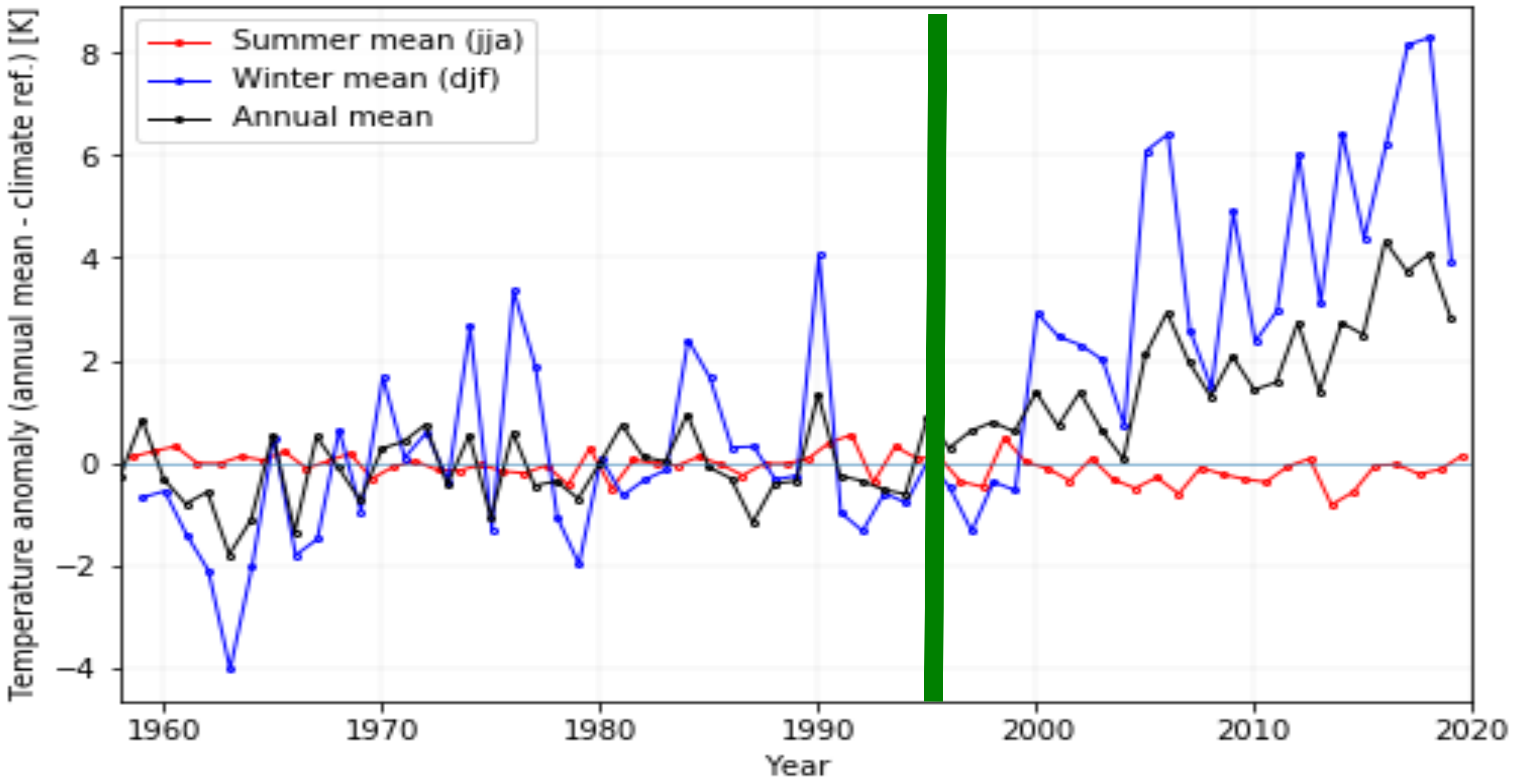


Commencing in 1995 there was an abrupt change in fall and spring Arctic (>80° N lat.) temperatures



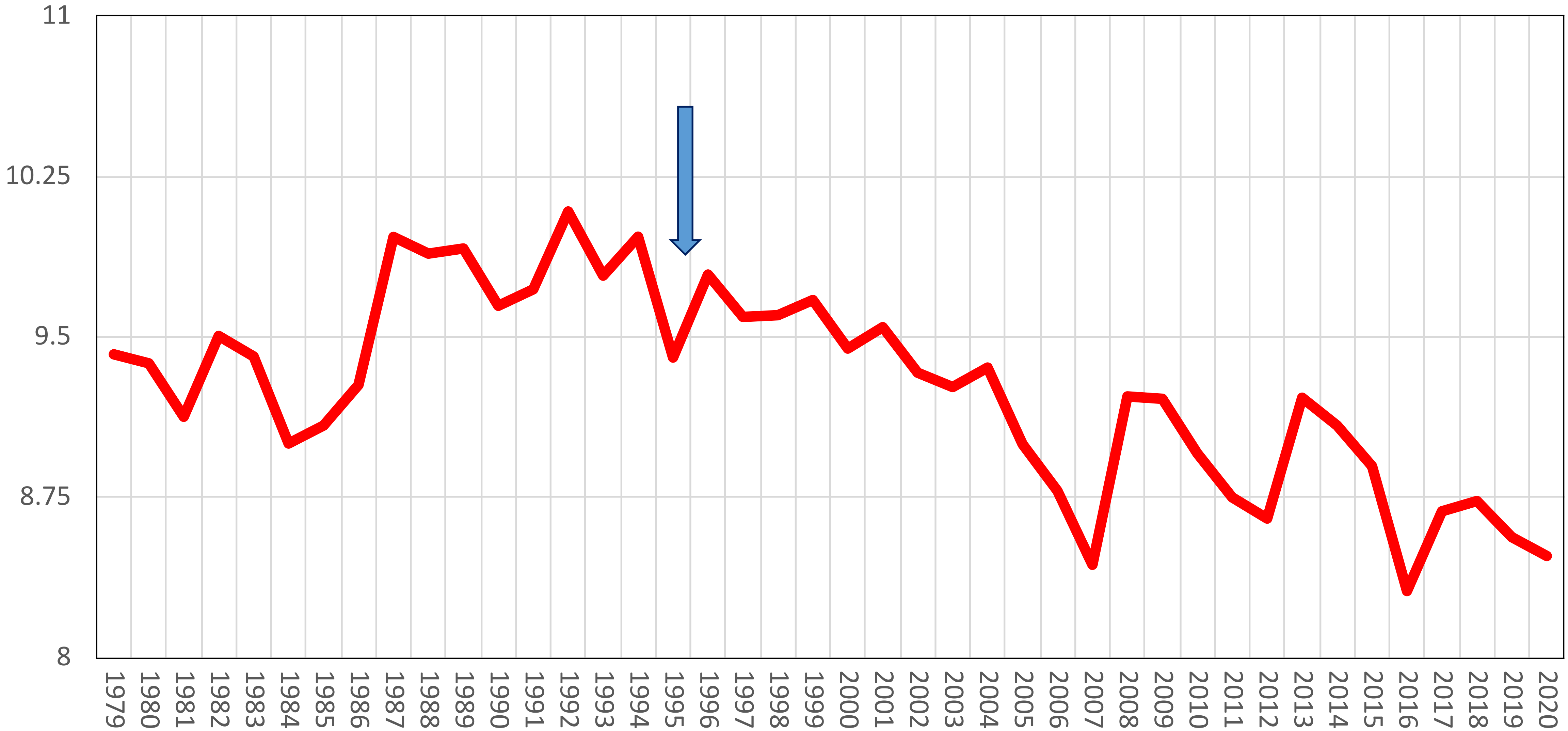
Danish Meteorological Institute

Winter temperatures followed suit shortly thereafter



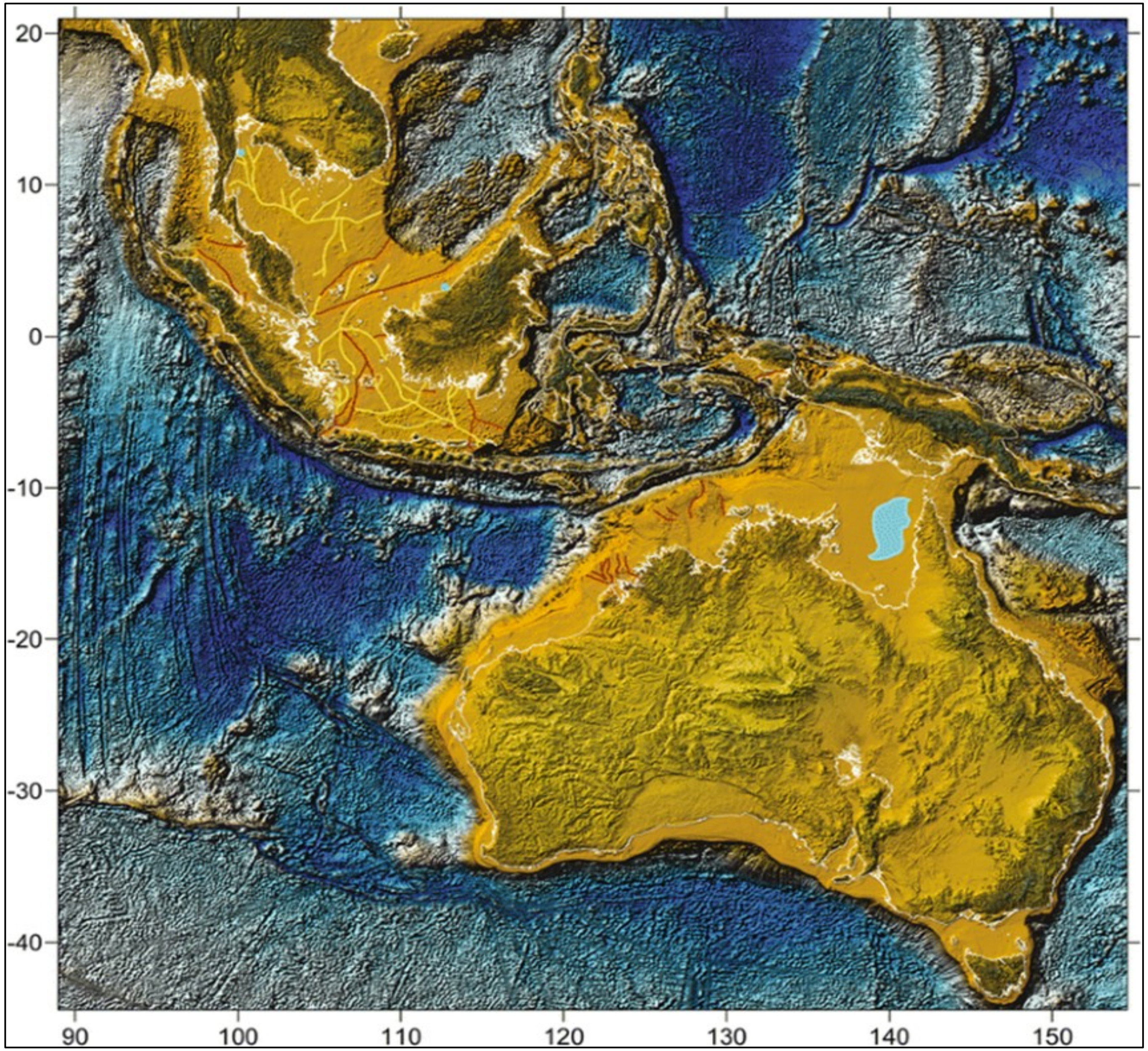
Danish Meteorological Institute

Northern Hemisphere sea ice area also started to decline in 1995.



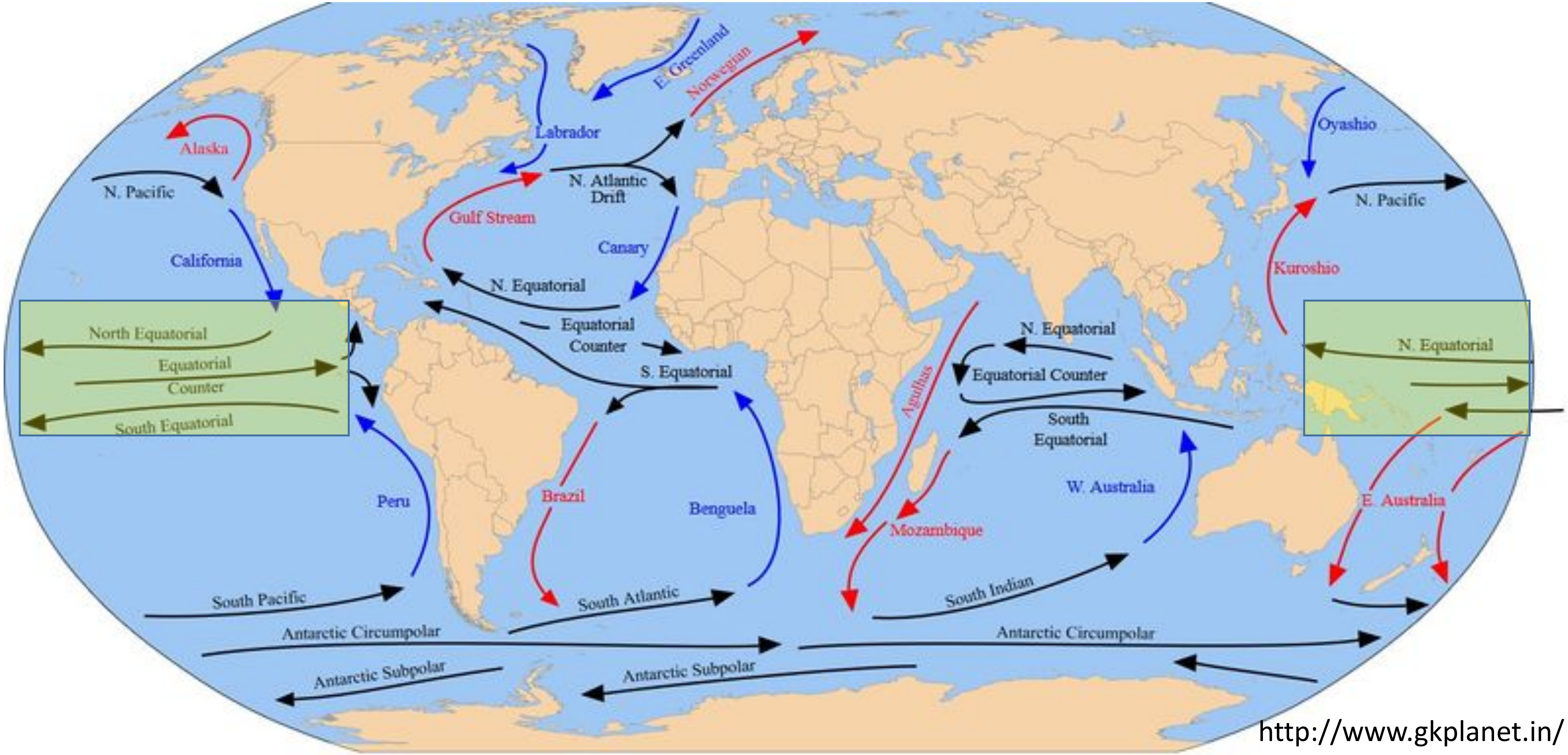
National Snow & Ice Data Center

Enhanced thermohaline flow will also cause more warm water to accumulate in the Western Pacific. The physiographic/bathymetric features of that region restrict the flow of the Equatorial Current, creating a vast reservoir of warm water, the driving force behind El Nino events.



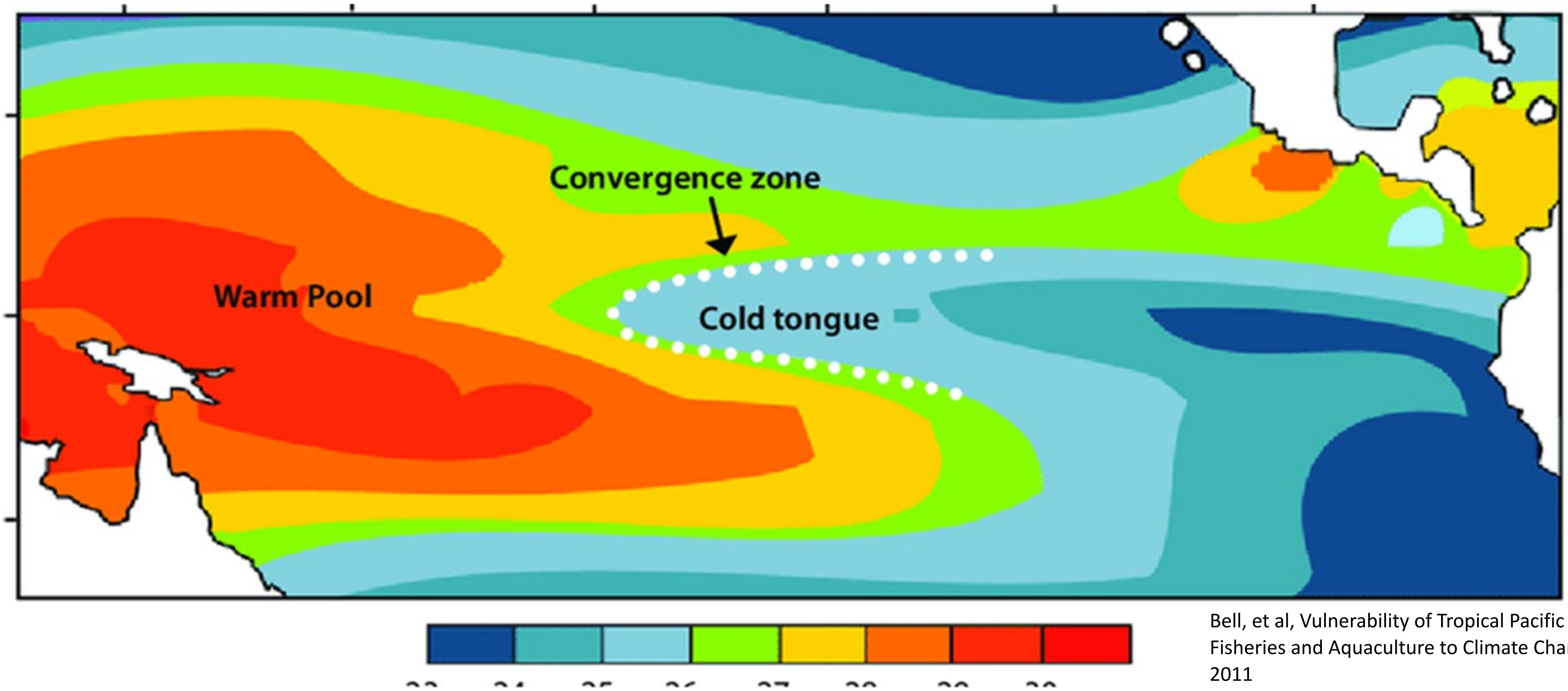
De Deckker Geosci. Lett. (2016) 3:20 DOI 10.1186/s40562-016-0054-3

North and South Equatorial Currents



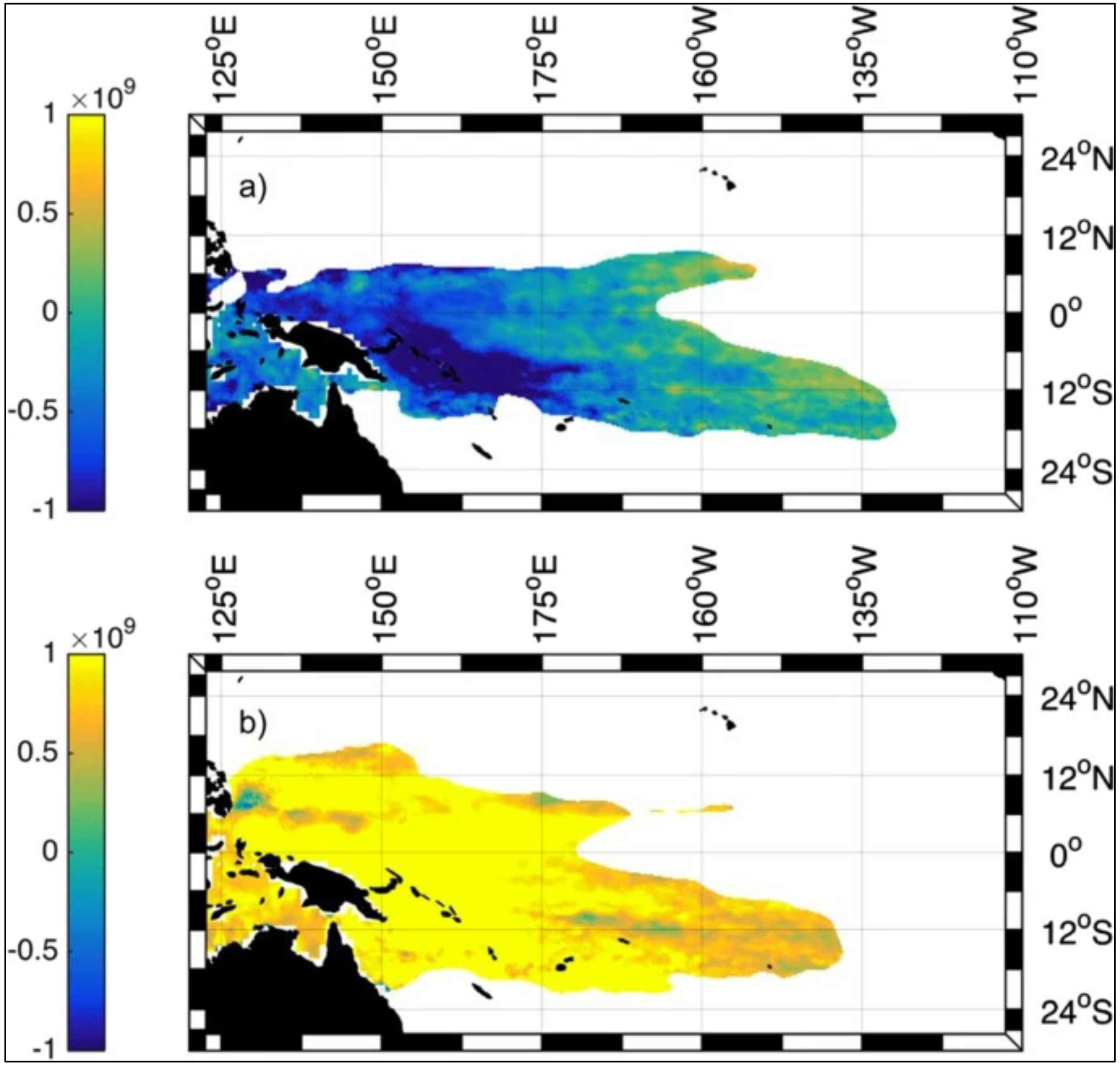
http://www.gkplanet.in/2017/05/oceanic-currents-of-world-pdf.html

The Western Pacific Warm Pool, also termed the Indo-Pacific Warm Pool, represents a massive store of heat that can be redistributed across the entire Pacific Basin when pressure and wind conditions switch from a "neutral" phase to an El Nino phase.



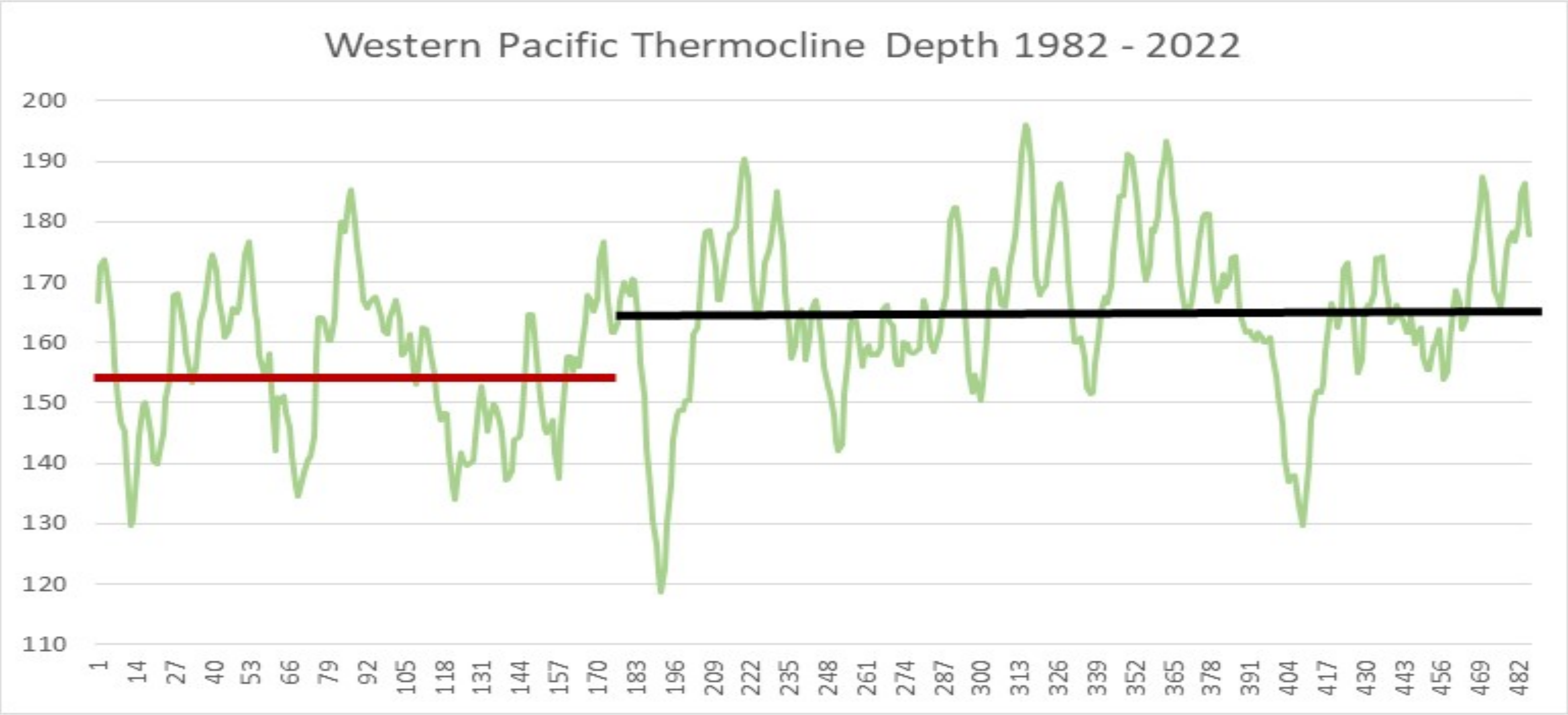
Bell, et al, Vulnerability of Tropical Pacific Fisheries and Aquaculture to Climate Change, 2011

A comparison of the 1993 heat content of the Western Pacific Warm Pool (top image) with the 2014 Pool (bottom image) under “neutral” conditions shows a large increase of heat content over that time. The area of the Pool also increased.



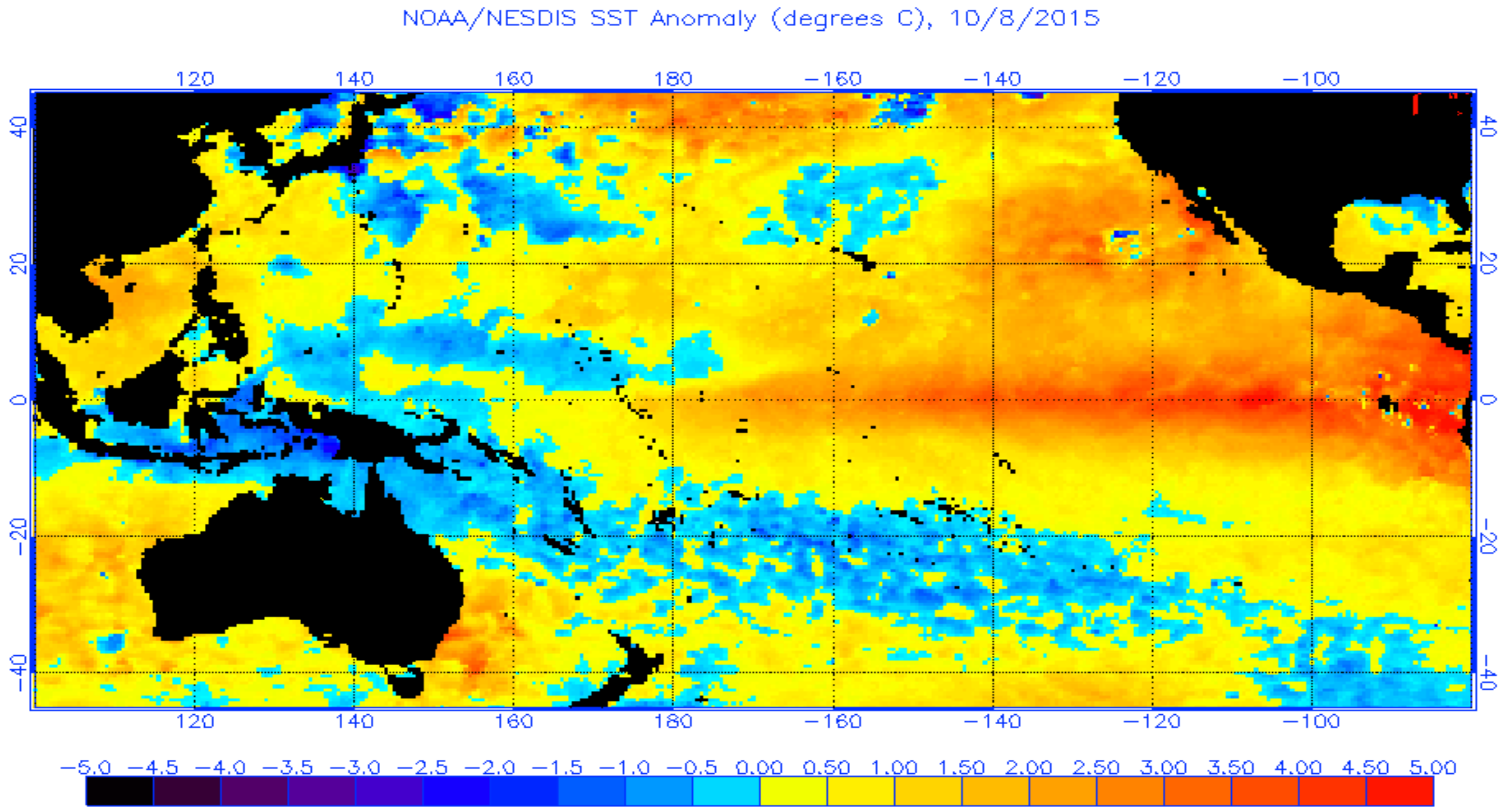
Kidwell, A., Han, L., Jo, YH. et al. Decadal Western Pacific Warm Pool Variability: A Centroid and Heat Content Study. Sci Rep 7, 13141 (2017). https://doi.org/10.1038/s41598-017-13351-x

Further evidence of Western Pacific Warm Pool intensification after 1995 (x axis demarcated in months) is presented by thermocline deepening of 10 meters in the Western Pacific.

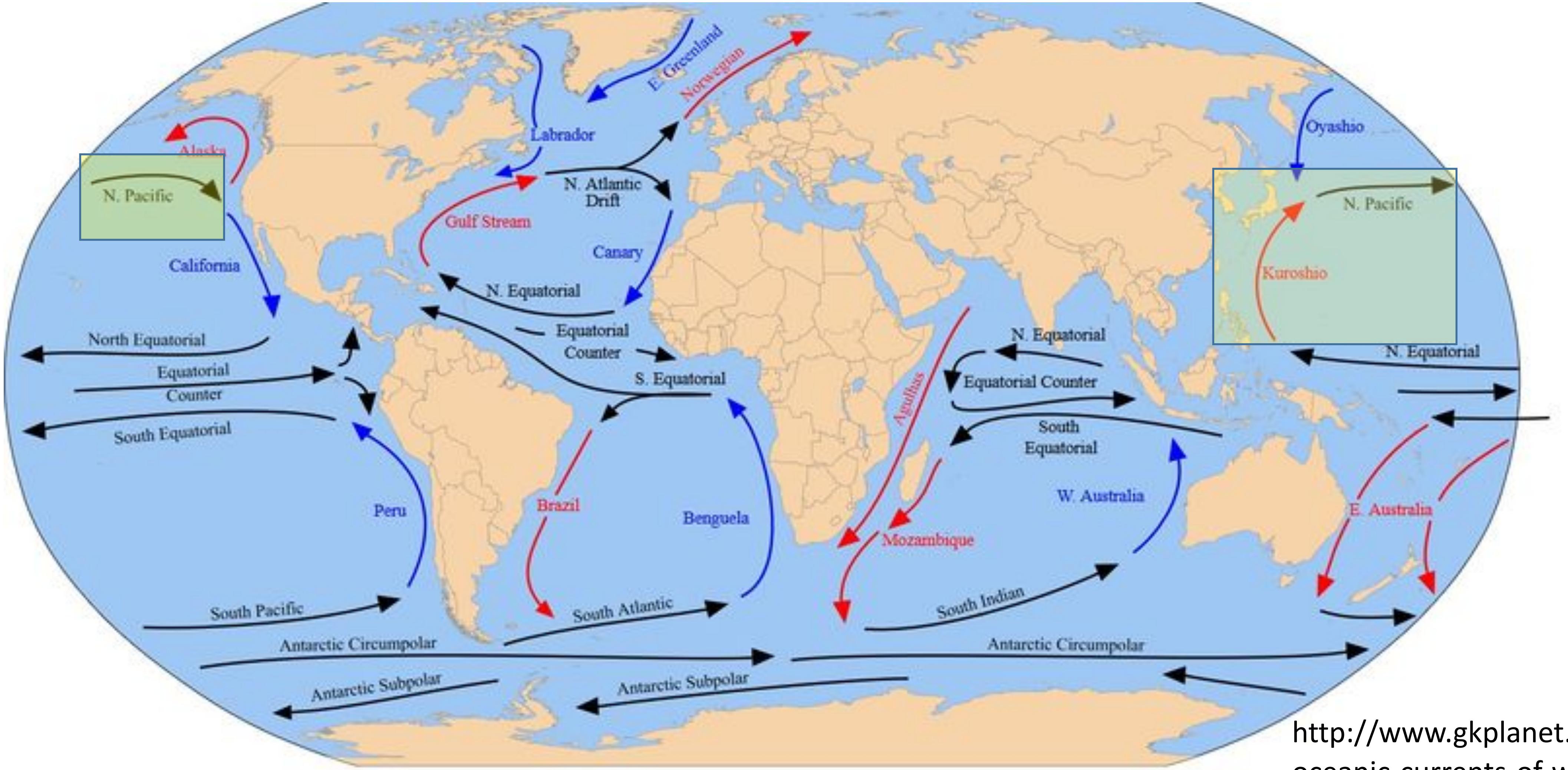


Columbia Climate School /International Research Institute For Climate And Society

As this map from the 2015 "Super El Nino" shows, the deepened, anomalously warm Western Pacific Warm Pool spread out over an immense area, raising sea surface temperatures down the west coast of South America, while stretching as far north as Central and North America, and as far west as the International Date Line.

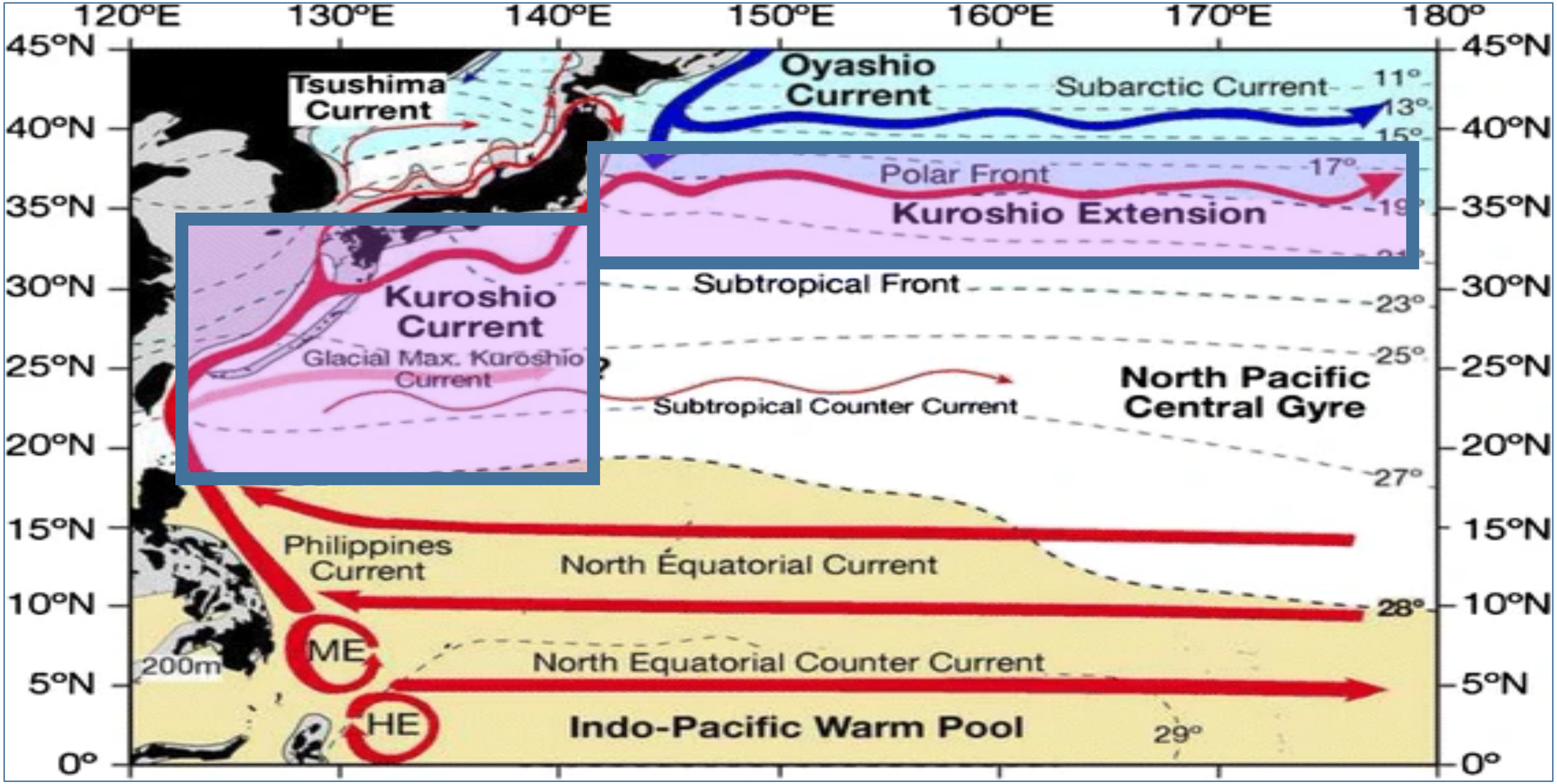


The strengthening of the Western Pacific Warm Pool has also warmed and strengthened the Kuroshio Current and the Kuroshio Extension.



http://www.gkplanet.in/2017/05/oceanic-currents-of-world-pdf.html

A more detailed map of the Kuroshio Current and the Kuroshio Extension



Gallagher, S.J., Kitamura, A., Iryu, Y. et al. The Pliocene to recent history of the Kuroshio and Tsushima Currents: a multi-proxy approach. Prog. in Earth and Planet. Sci. 2, 17 (2015). https://doi.org/10.1186/s40645-015-0045-6

Science News *from research organizatio*

Major ocean current could warm greatly

Date: September 28, 2021

Source: Binghamton University

Summary: A new study found that the Kuroshio Current Extension is sensitive to global climate change and has the potential to warm greatly with increased carbon dioxide levels.

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- Oceanography

FULL STORY

A new study led by researchers at Binghamton University, State University of New York found that the Kuroshio Current Extension is sensitive to global climate change and has the potential to

As reported in Science Daily, a study by Lam et al., shows:

"…warmth stems from the surface waters that collect in the western Pacific Ocean along the equator, called the Western Pacific Warm Pool. The Kuroshio Current takes these waters north, past the Japanese coast, and then eastward at the 36°N latitude, where it joins the open Pacific Ocean. At this point, it becomes the Kuroshio Current Extension….Today, these currents ***are warming two to three times faster than other areas of the ocean****…Ocean model studies and observational data also show that the* ***Kuroshio Current Extension is shifting northward and increasing its transport capacity****…"*

Adriane R. Lam, Kenneth G. MacLeod, Solveig H. Schilling, R. Mark Leckie, Andrew J. Fraass, Molly O. Patterson, Nicholas L. Venti. **Pliocene to Earliest Pleistocene (5–2.5 Ma) Reconstruction of the Kuroshio Current Extension Reveals a Dynamic Current**. *Paleoceanography and Paleoclimatology*, 2021; 36 (9) DOI: 10.1029/2021PA004318

The following slide highlights all of the main “hot spots” that would be expected from enhanced thermohaline flow (SST snapshot, 8/18/2023) .

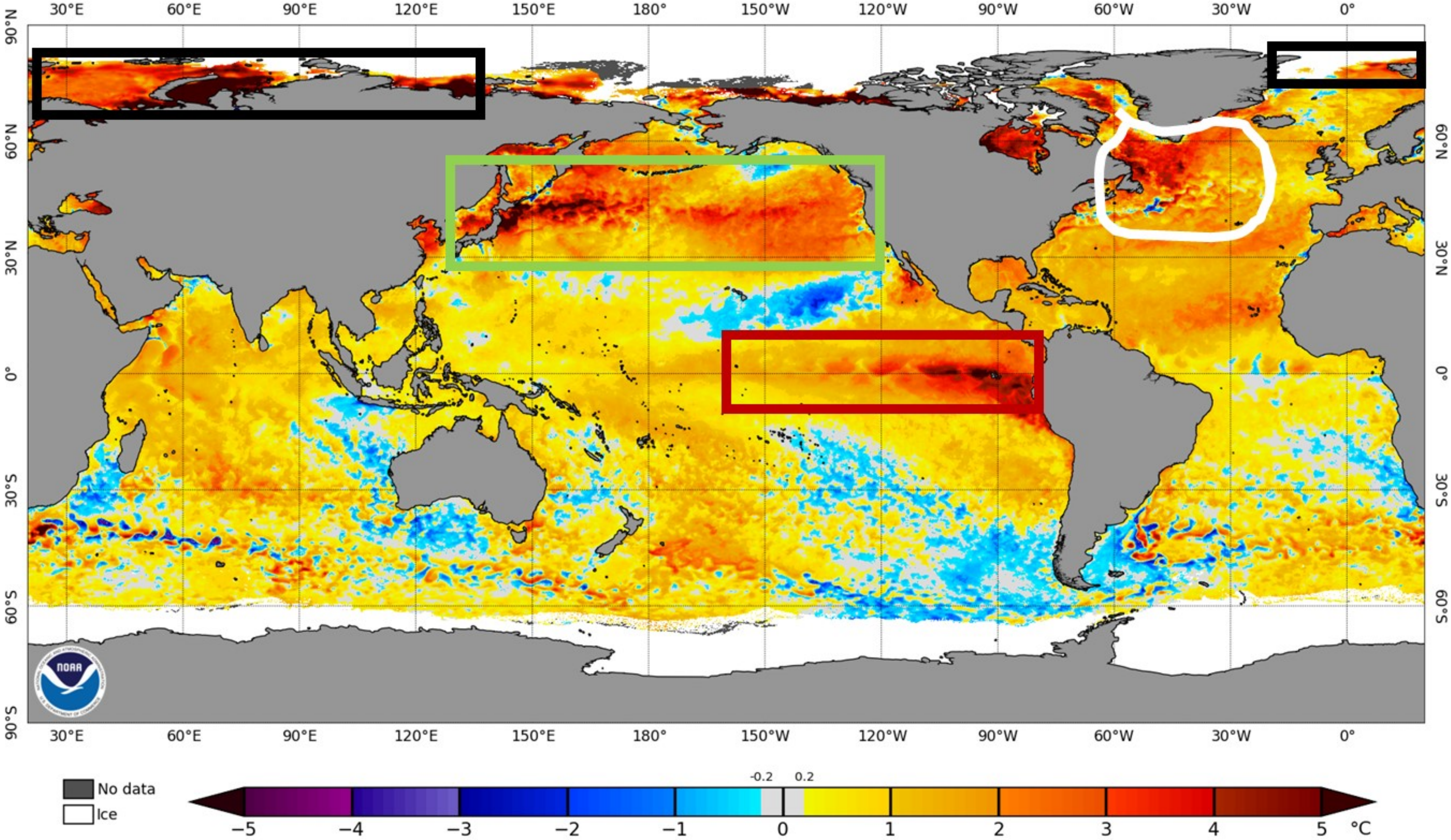
Black boxes: The “Atlantified/Amplified” Arctic

White circular area: Warmed Sub-Polar Gyre

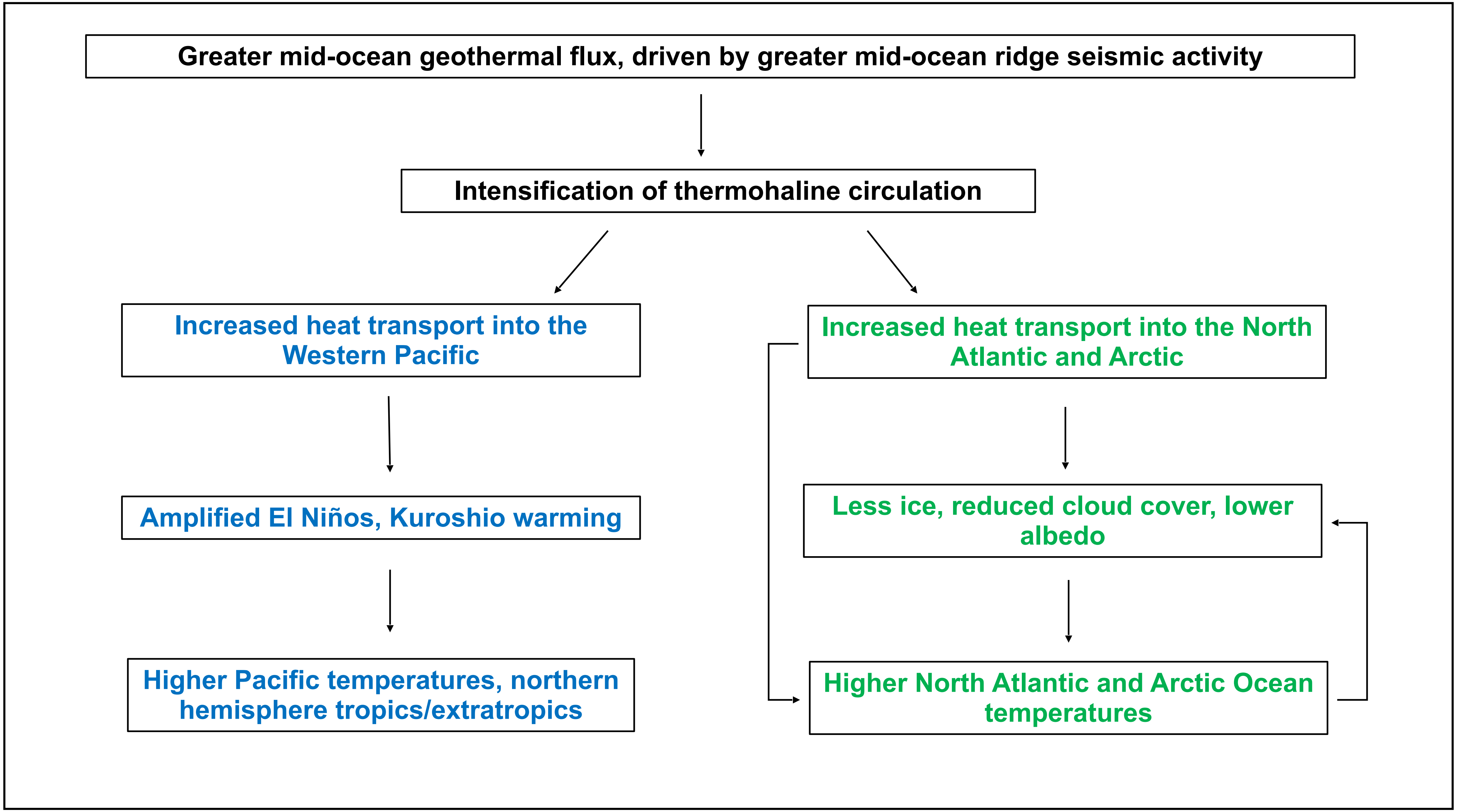
Green box: Warmed and intensified Kuroshio Current and Kuroshio Extension

Maroon box: Current El Nino with anomalously warm temperatures

NOAA Coral Reef Watch Daily 5km SST Anomalies (v3.1) 18 Aug 2023



In Summary


Greater mid-ocean geothermal flux, driven by greater mid-ocean ridge seismic activity
Intensification of thermohaline circulation
Increased heat transport into the Western Pacific
Amplified El Niños, Kuroshio warming
Higher Pacific temperatures, northern hemisphere tropics/extratropics
Increased heat transport into the North Atlantic and Arctic
Less ice, reduced cloud cover, lower albedo
Higher North Atlantic and Arctic Ocean temperatures

Thank You!

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