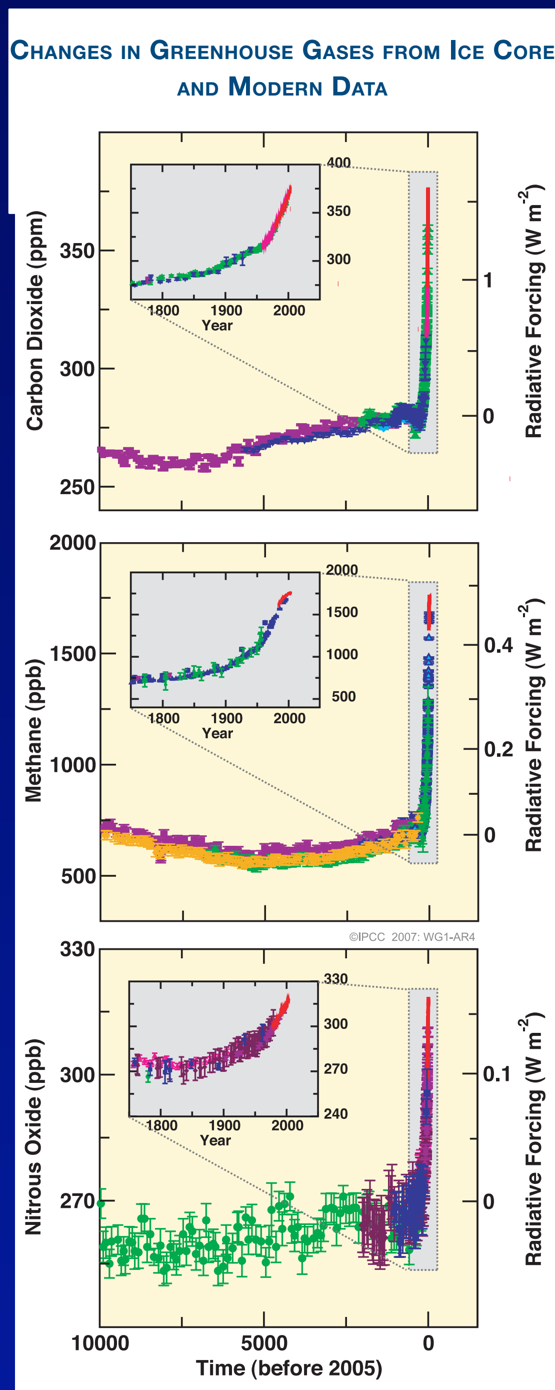
Climate forcing

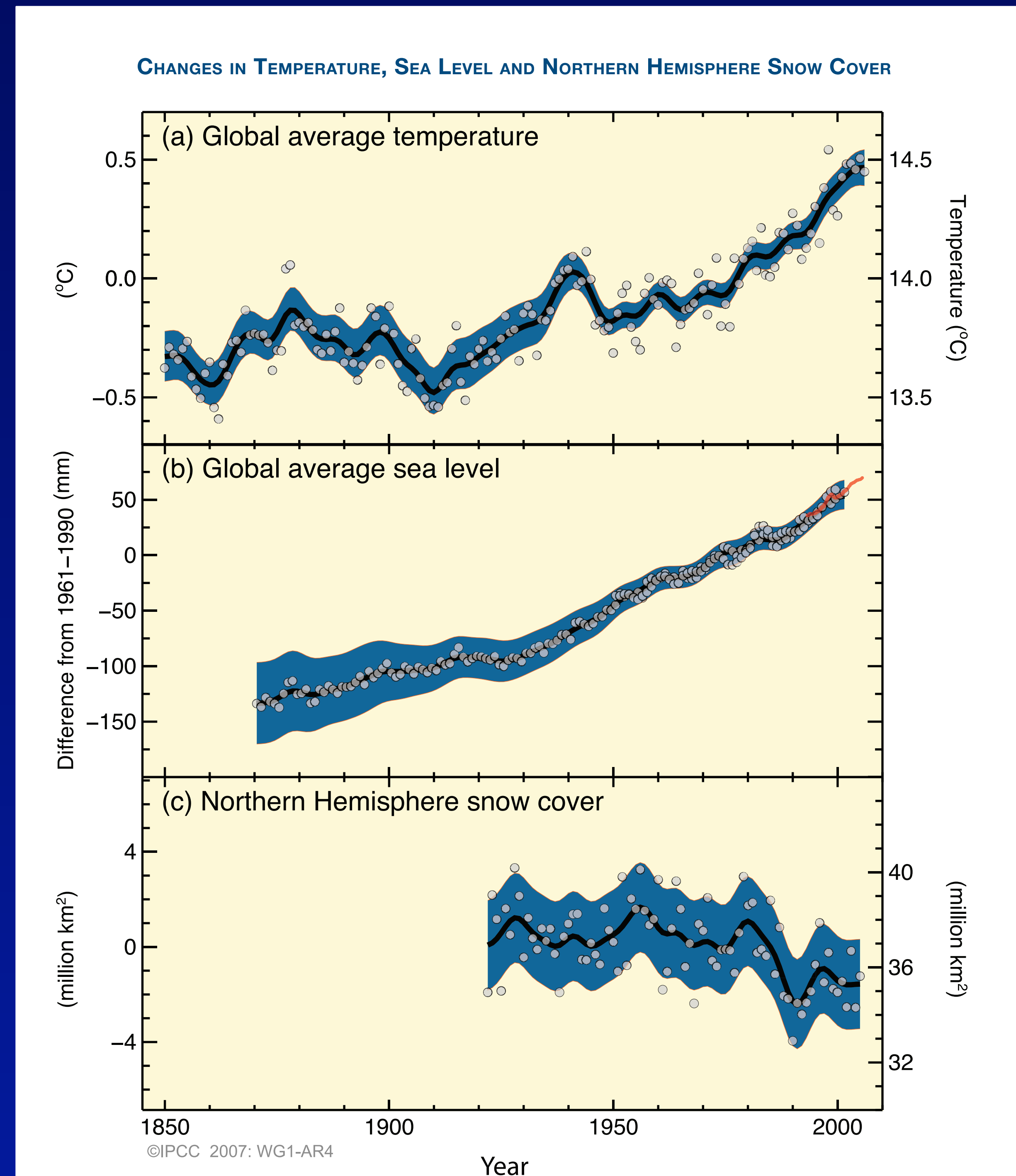
Climate forcing

External forcing for earth's climate includes

- earth orbit parameters (solar distance factors)
- solar luminosity
- moon orbit
- volcanoes and other geothermal sources
- tectonics (plate motion)
- greenhouse gases (to the extent that they are not part of the climate system itself)
- land surface (likewise with respect to the climate system)

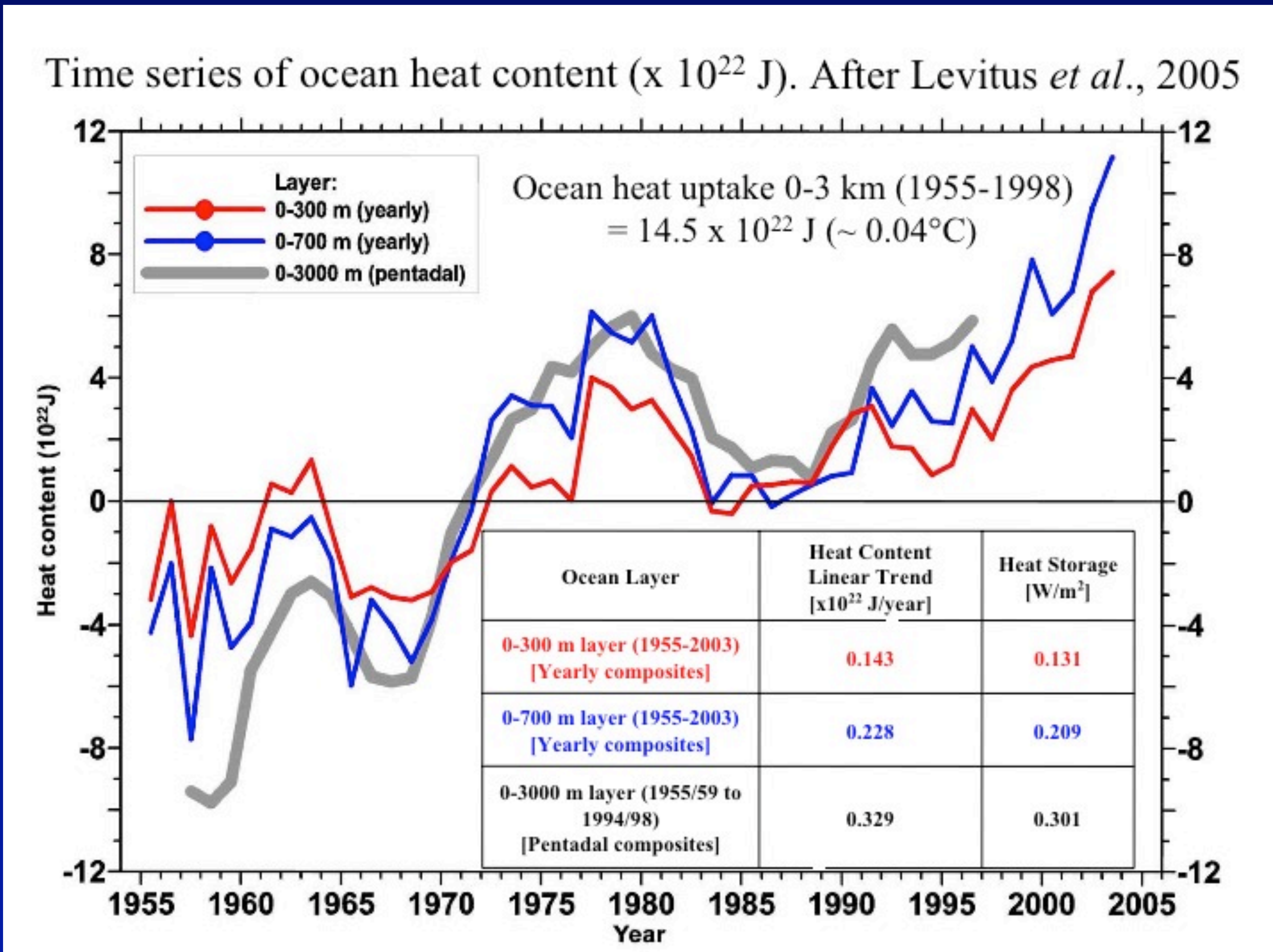
Anthropogenic Climate forcing





Intergovernmental Panel on Climate Change (IPCC), honored with the 2007 Nobel Peace Prize.

Observed global ocean changes that might be anthropogenic (Levitus et al 2005)



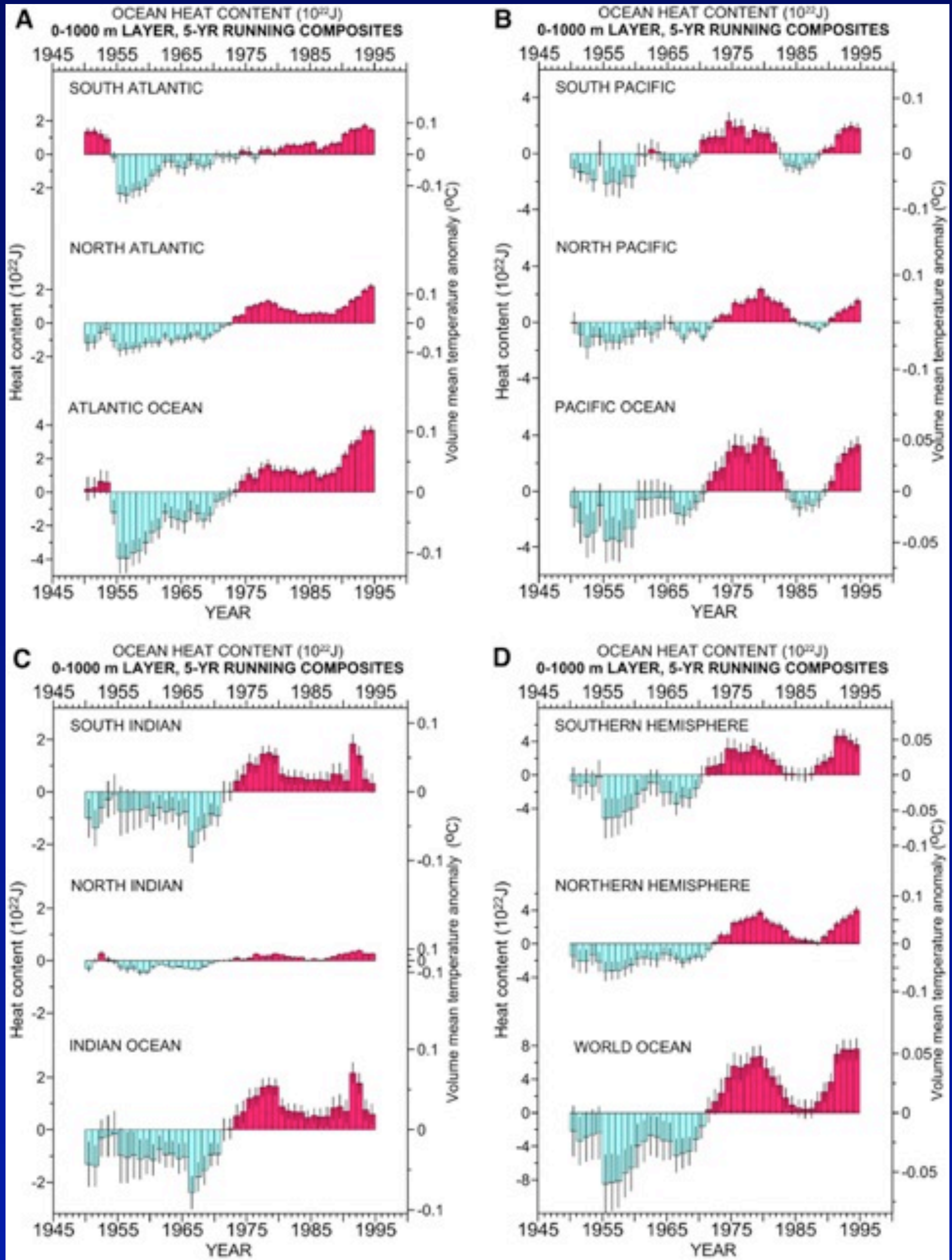
Ocean Layer	Heat Content Linear Trend [$\times 10^{22}$ J/year]	Heat Storage [W/m^2]
0-300 m layer (1955-2003) [Yearly composites]	0.143	0.131
0-700 m layer (1955-2003) [Yearly composites]	0.228	0.209
0-3000 m layer (1955/59 to 1994/98) [Pentadal composites]	0.329	0.301

0.037°C warming (0-3000 m)

Is there anthropogenic climate change?

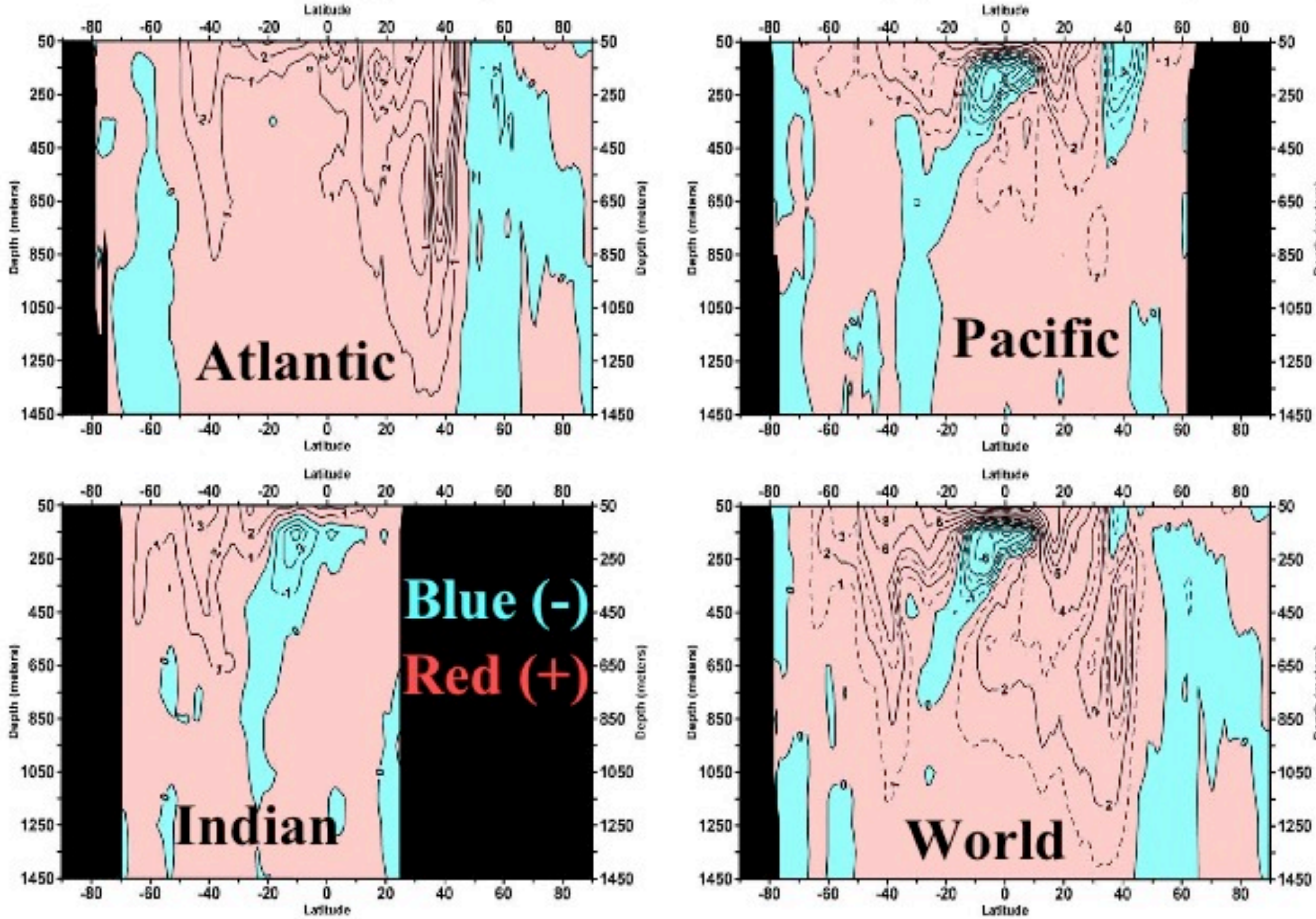
- Yes (IPCC TAR)

Levitus et al (2000) heat storage changes in the North Pacific, Pacific, World



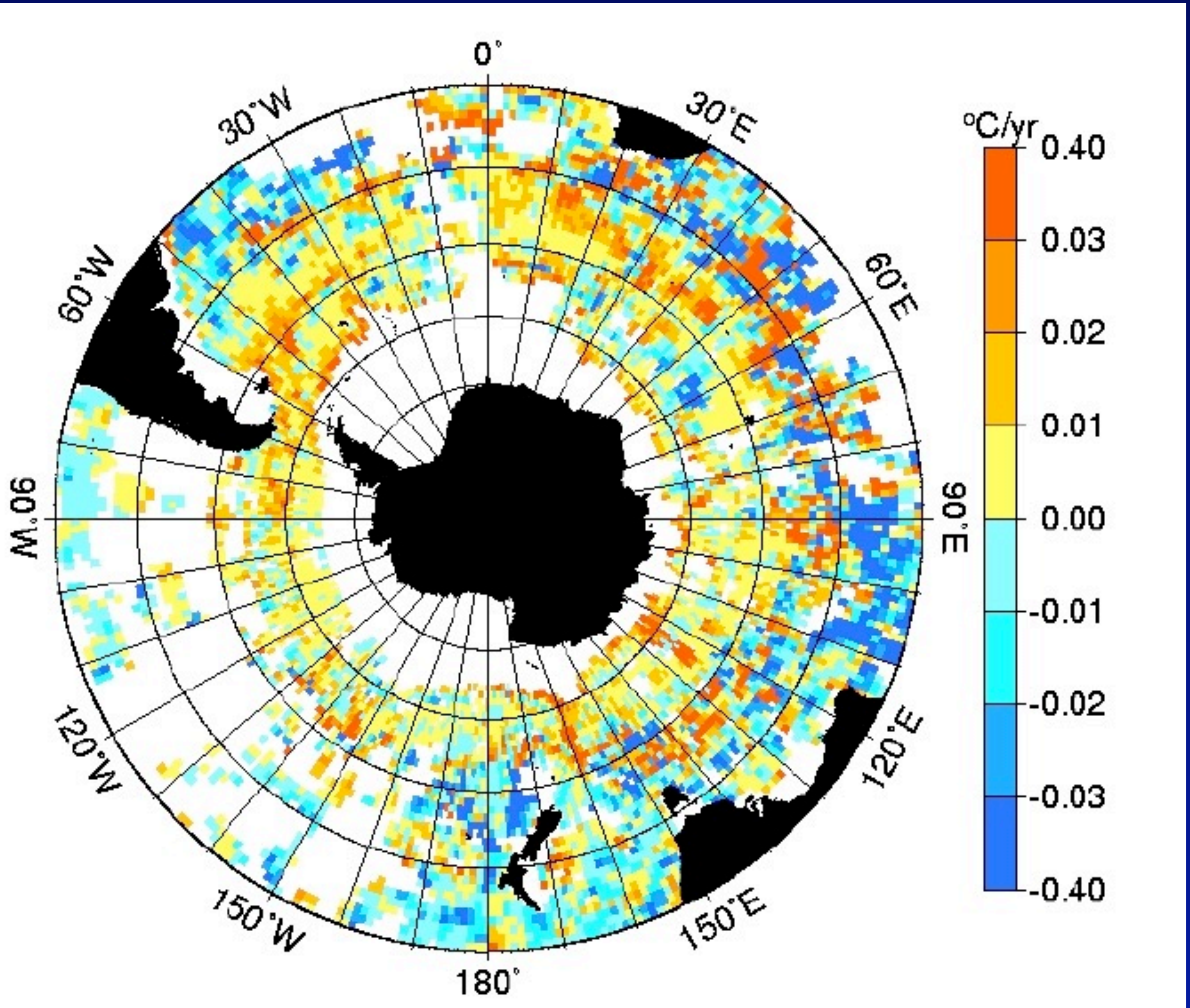
Observed changes: basin-scale temperature
Mostly warming but some cooling (presented by H. Garcia). Especially note cooling in high latitude Atlantic and Pacific, tropical Pacific and Indian. Not just noise.

Linear Trend of the zonally integrated heat content (x 10^{18} J/year) for 100 m thick layers (1955/59 to 1994/98) [Levitus *et al.*, 2005]



After Levitus et al., 2005

Observed changes: Southern Ocean
(Gille, Science 2002)



Broad warming in southern ocean at about 800 meters

Also note cooling to the north of the warm band

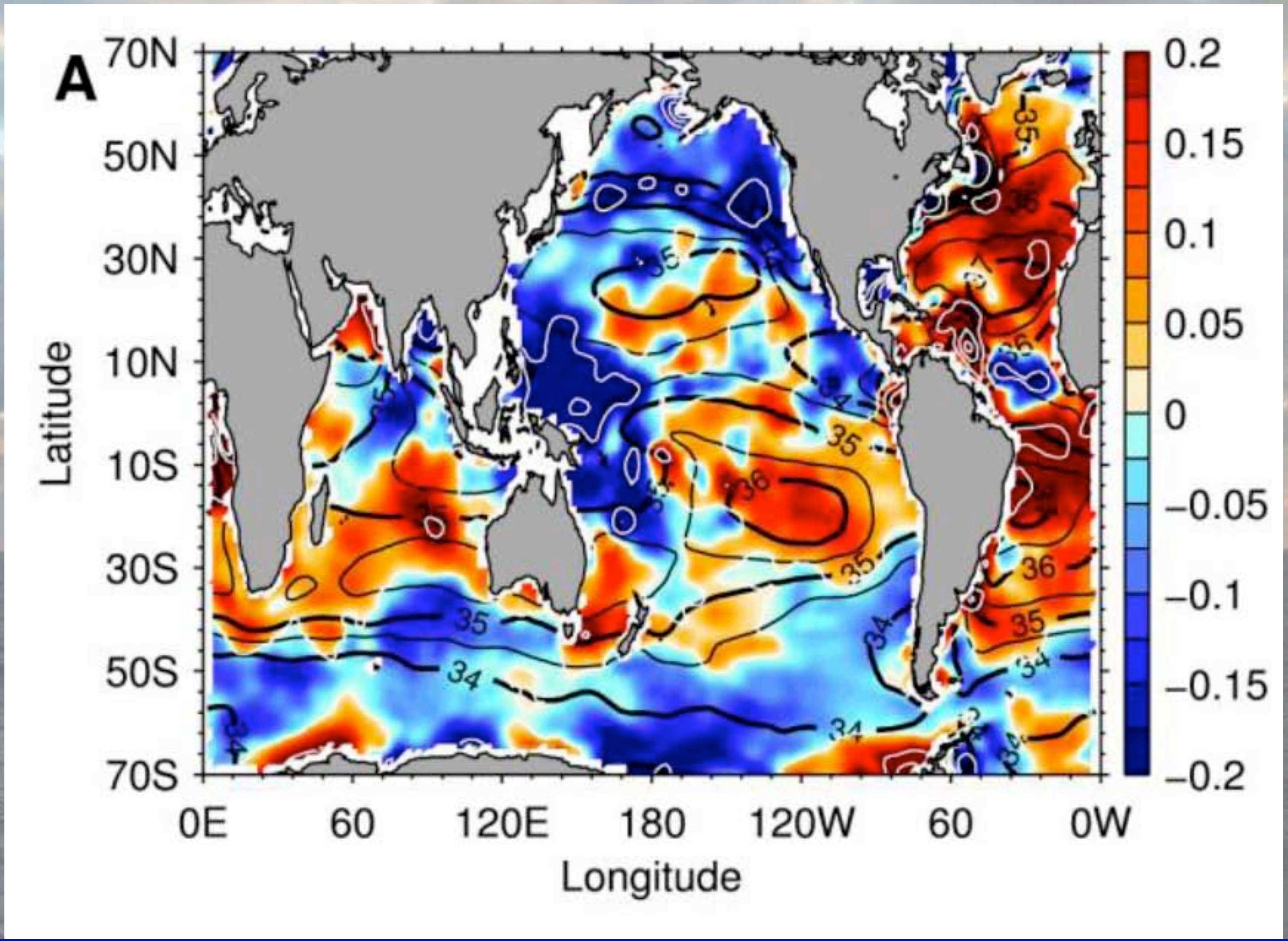
Accompanied by cooling in central Antarctica

This looks like the Southern Annular Mode pattern. Natural climate modes might also be forced by anthropogenic change.

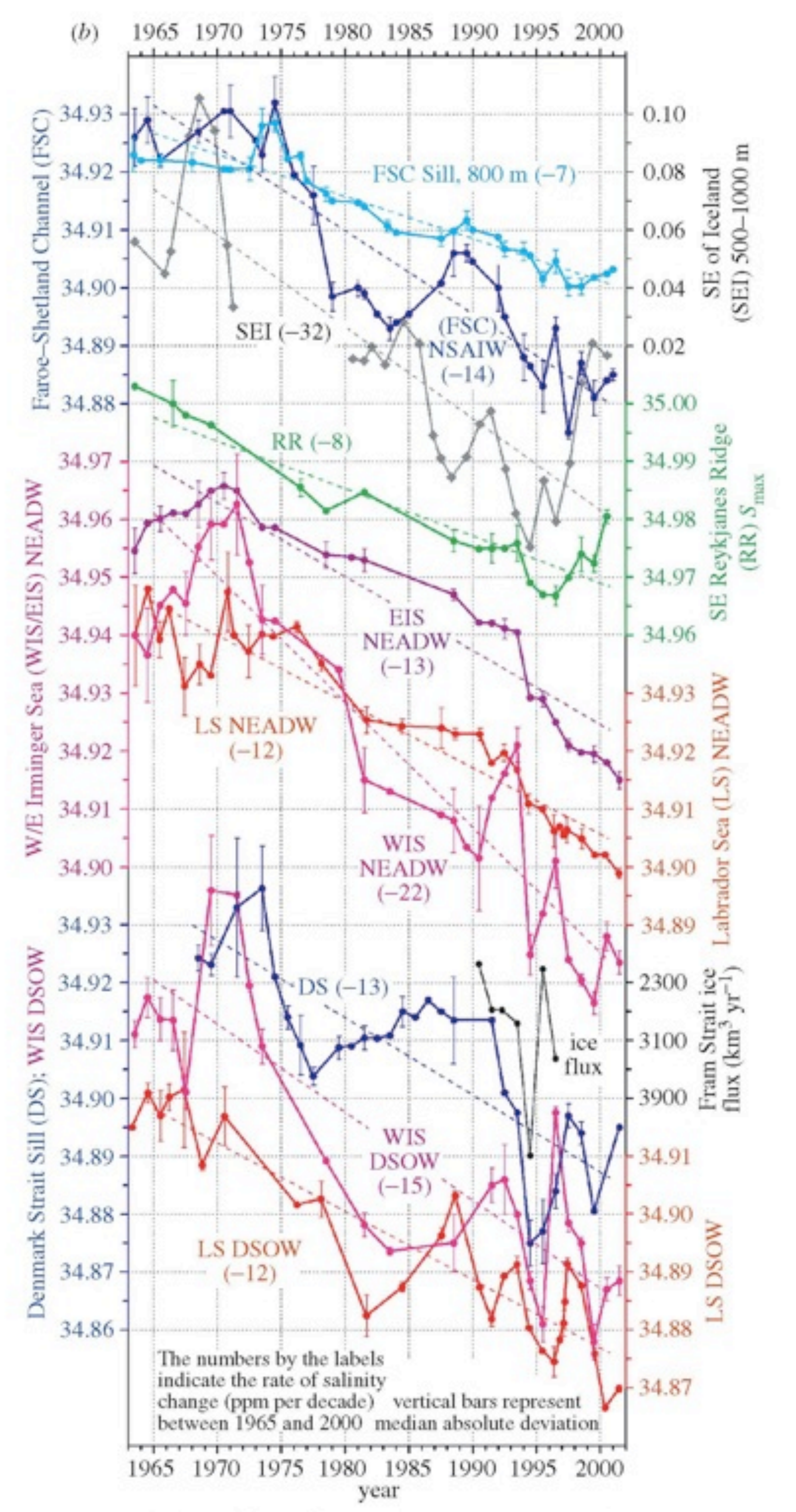
Observed changes: salinity

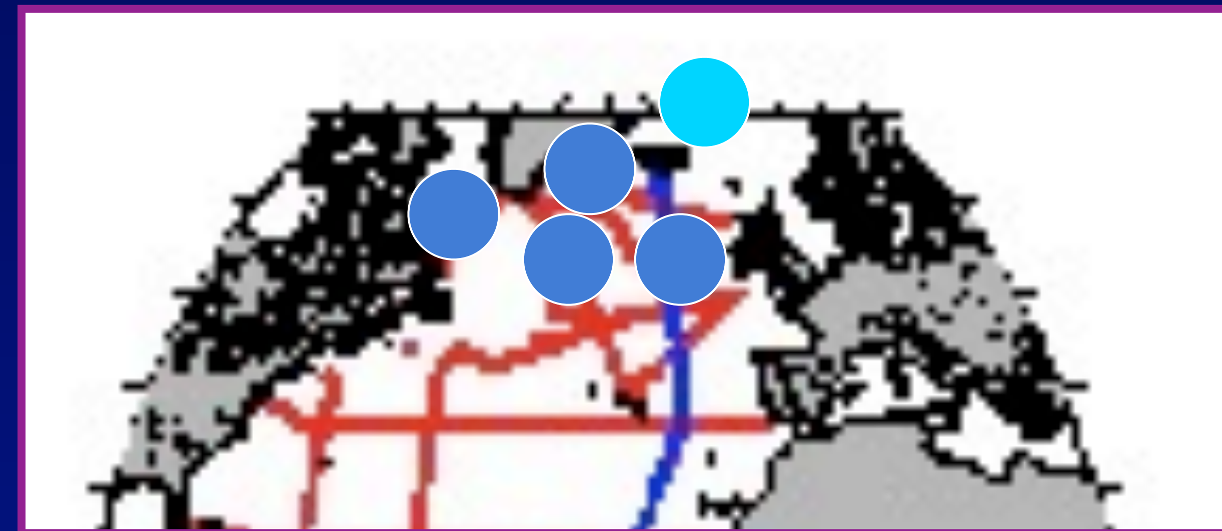
Fifty year trends in salinity

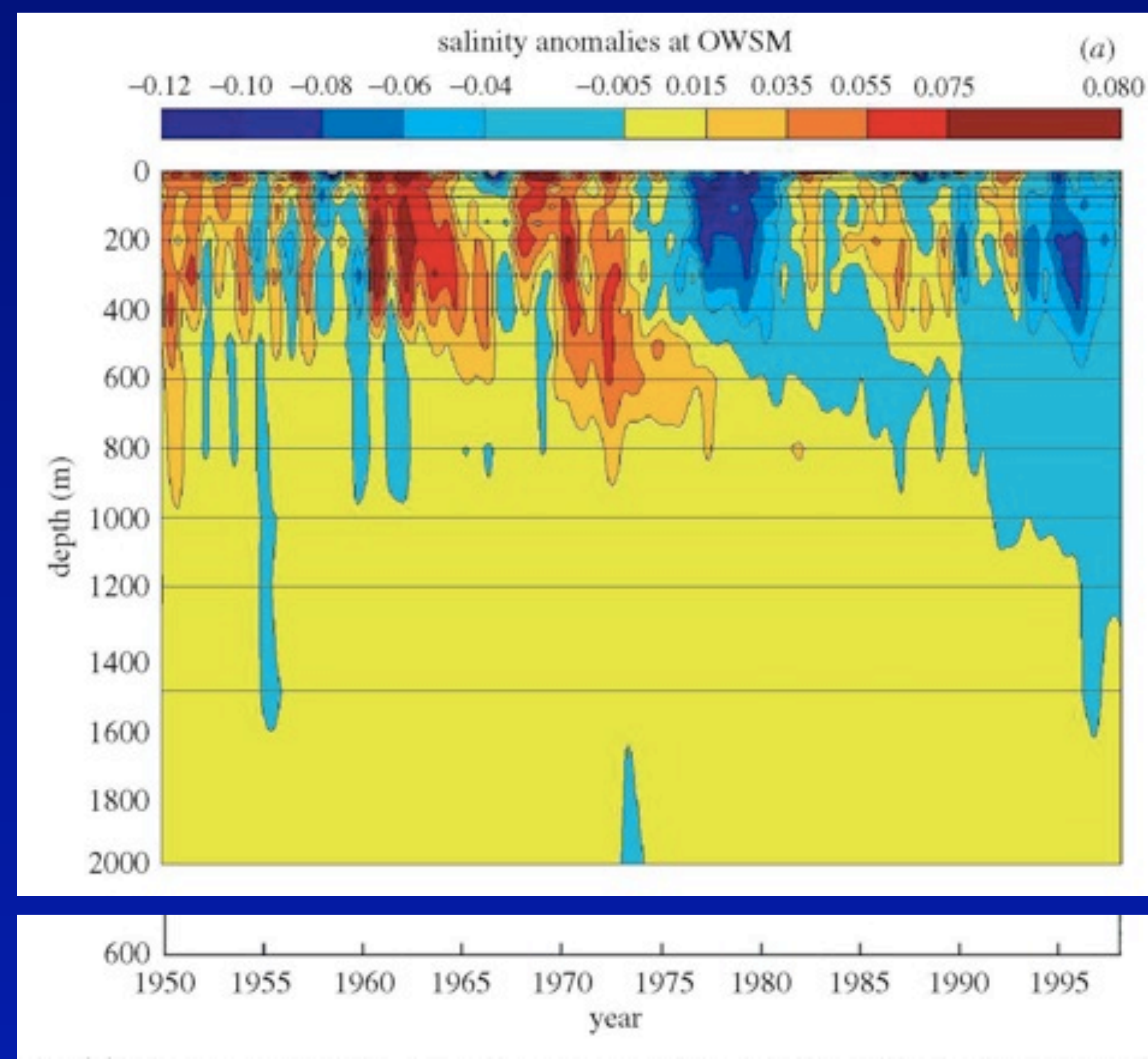
-Durack and Wijffels, 2009



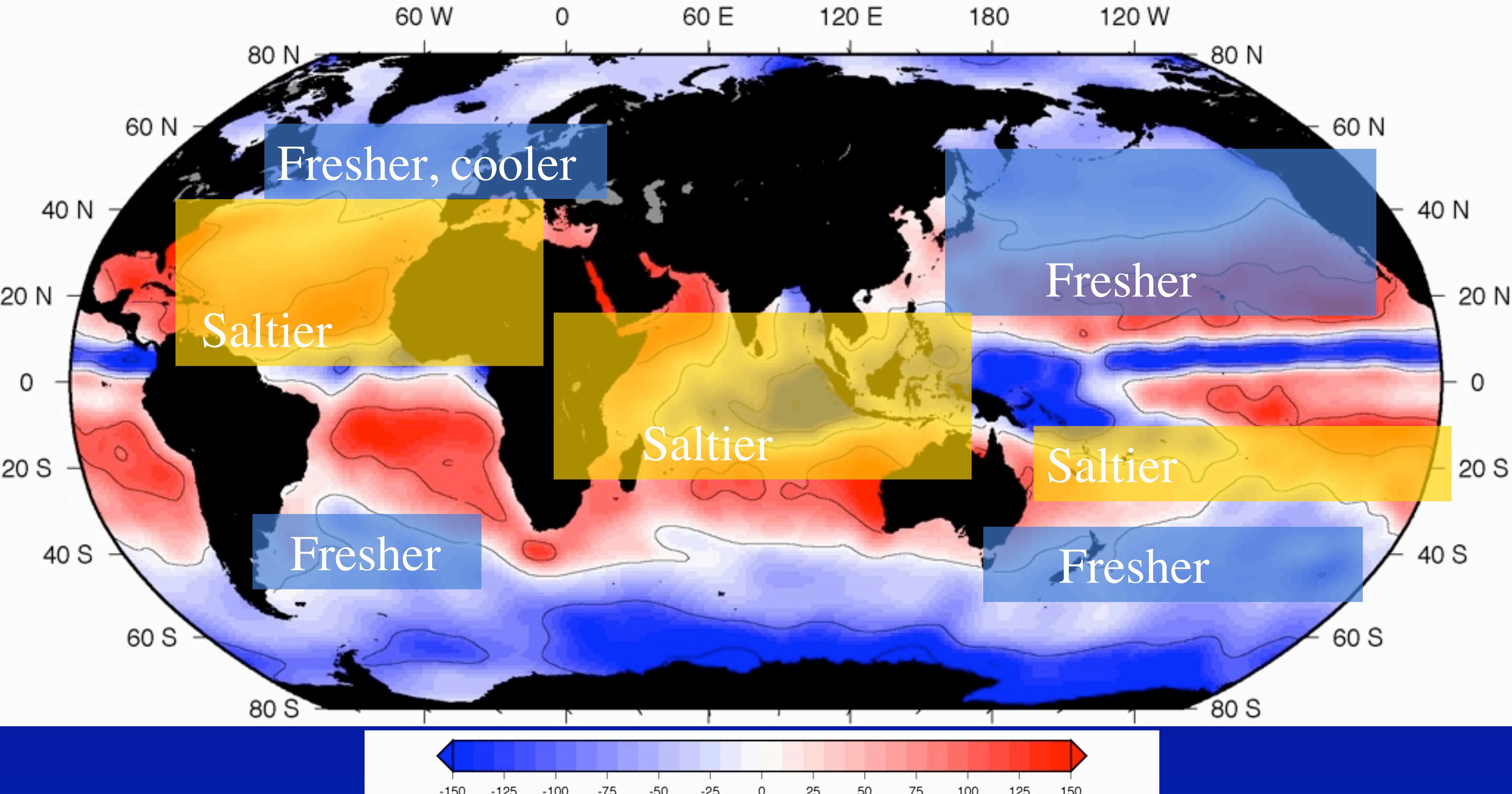
Observed changes:
Freshening of the Atlantic and Nordic Seas
(Dickson et al, Phil Trans Roy Soc 2003)



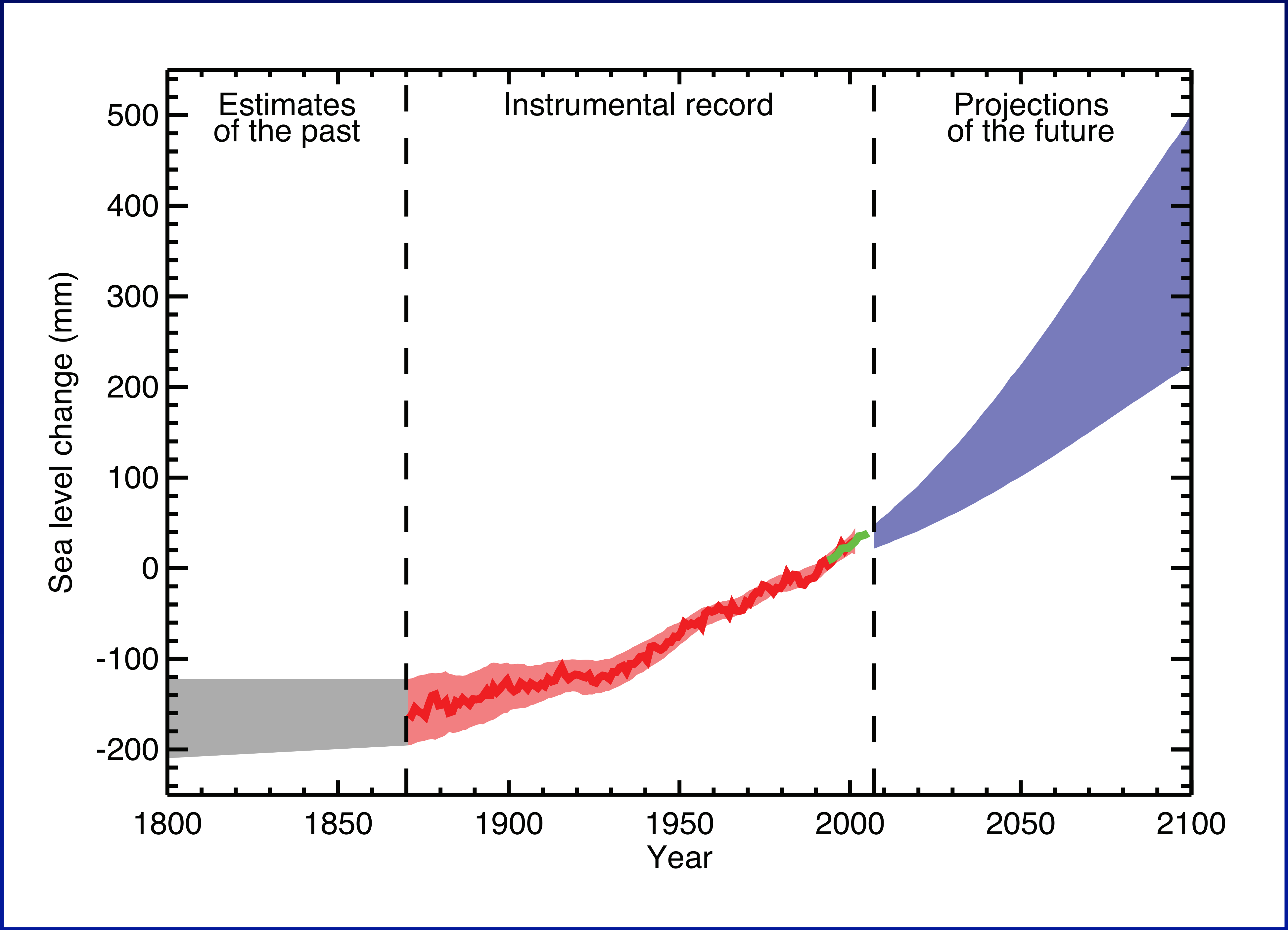




Large-scale salinity changes: fresh areas freshening and salty areas getting saltier. Suggests increase in atmospheric hydrological cycle, which would be expected in a warmer world. This can only be observed with ocean salinities rather than with trends in evaporation-precipitation since the latter data sets are very noisy.



Observed changes: Sea level rise



IPCC

Scientific uncertainty and the public

Scientific consensus on the following statement: "Human activities ... are modifying the concentration of atmospheric constituents ... that absorb or scatter radiant energy. ... [M]ost of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations"

928 abstracts, published in refereed scientific journals between 1993 and 2003, and listed in the ISI database with the keywords "climate change. Of all the papers, 75% either explicitly or implicitly accepting the consensus view; 25% dealt with methods or paleoclimate, taking no position on current anthropogenic climate change. Remarkably, none of the papers disagreed with the consensus position. [Naomi Oreskes, UCSD, Science 2004.]

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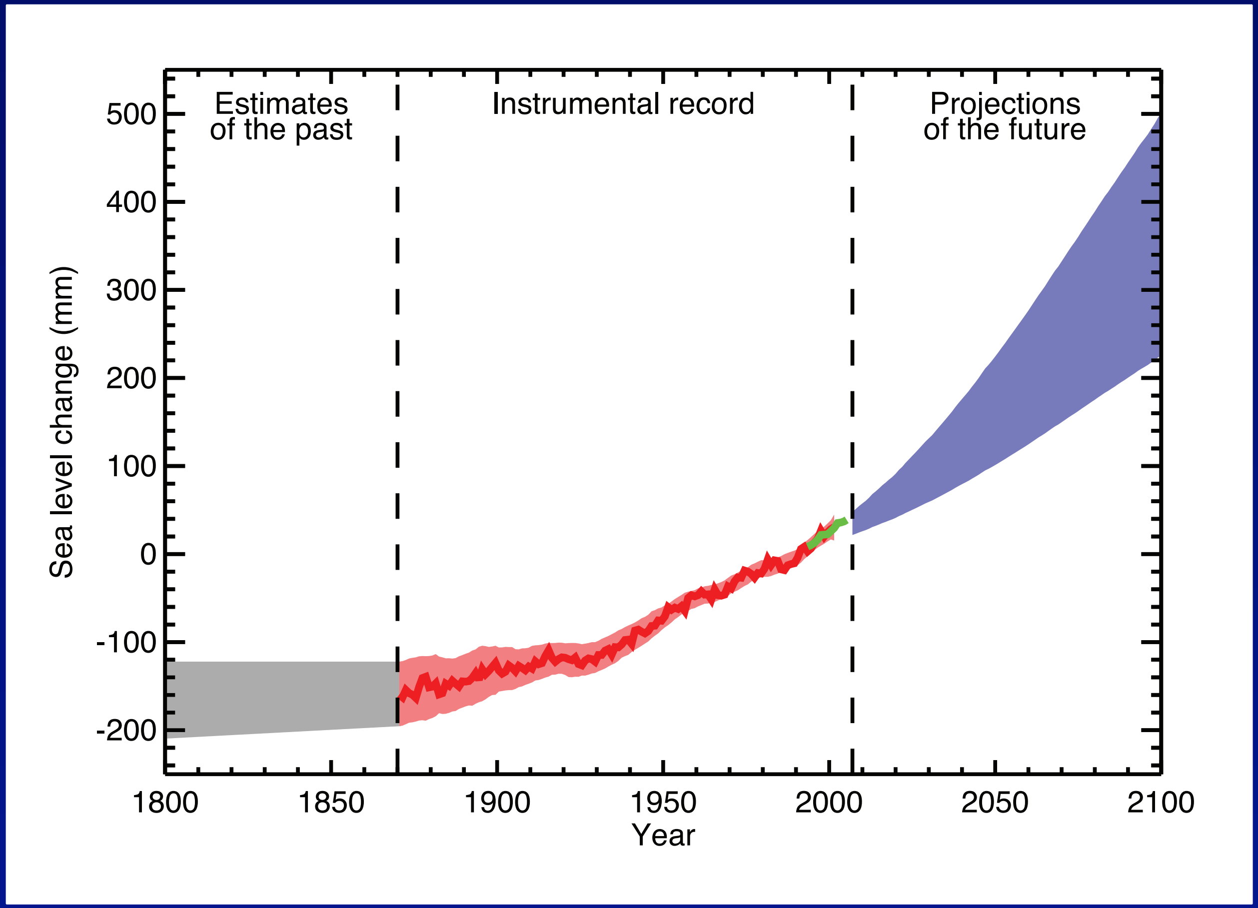
However, only 57% of Americans believe that the earth is warming, and 36% think there is warming caused by human activity. [Pew research study, October 2009]

Why???

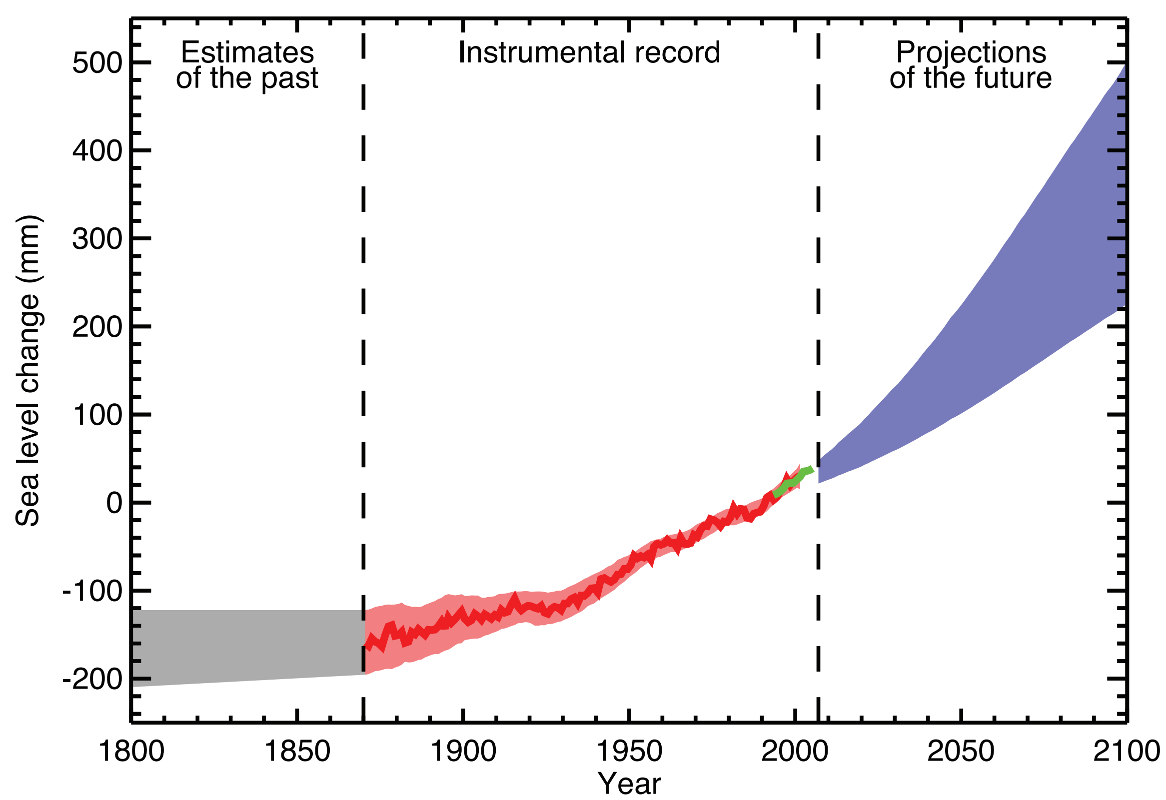
“Uncertainties”

- While C02 rise and overall warming are NOT in doubt, some of the specific consequences are. Why? Because they depend on details of circulation.

Sea level rise depends on circulation



Sea level rise depends on circulation



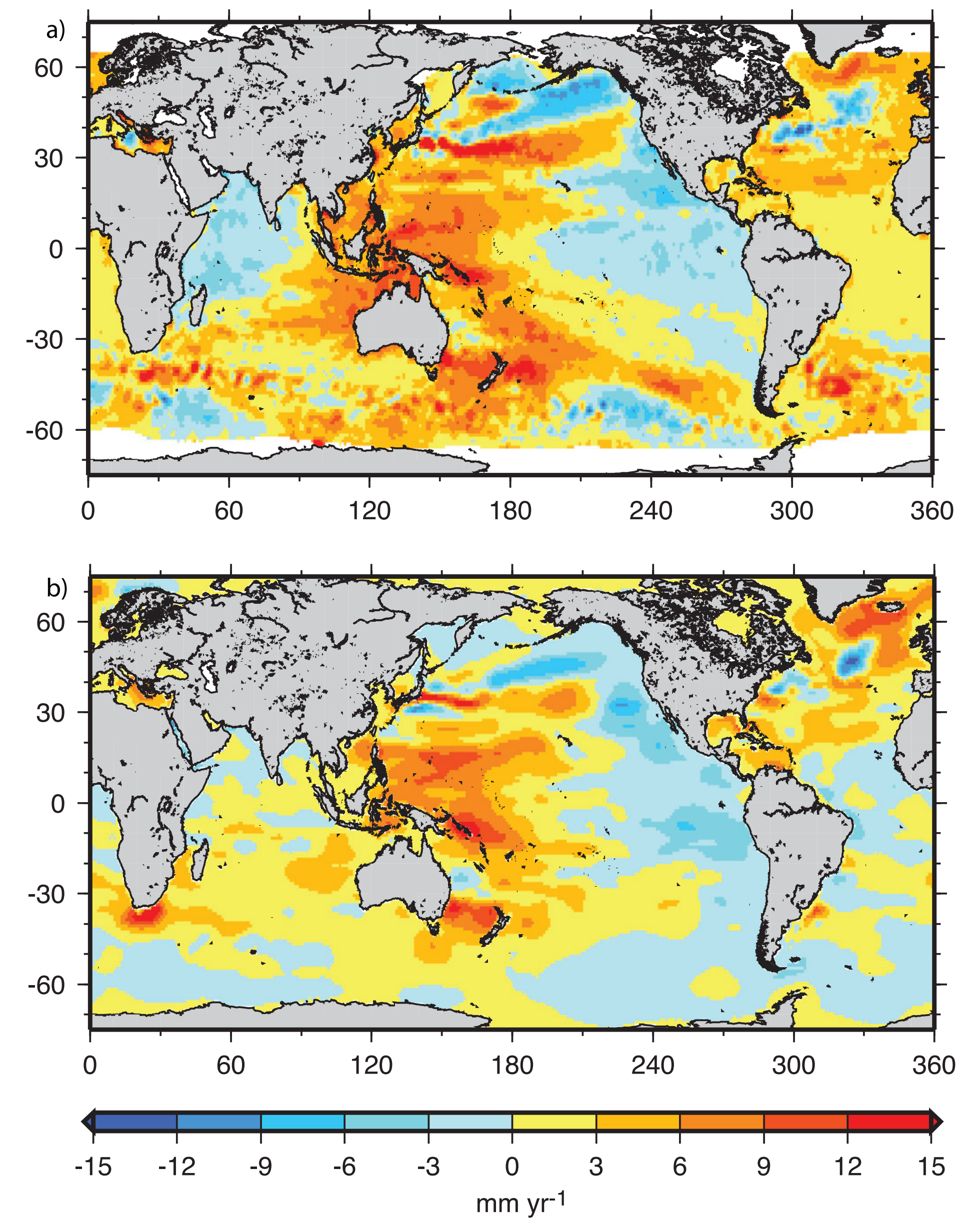


Figure 5.15. *(a) Geographic distribution of short-term linear trends in mean sea level (mm yr^{-1}) for 1993 to 2003 based on TOPEX/Poseidon satellite altimetry (updated from Cazenave and Nerem, 2004) and (b) geographic distribution of linear trends in thermal expansion (mm yr^{-1}) for 1993 to 2003 (based on temperature data down to 700 m from Ishii et al., 2006).*

“Uncertainties”

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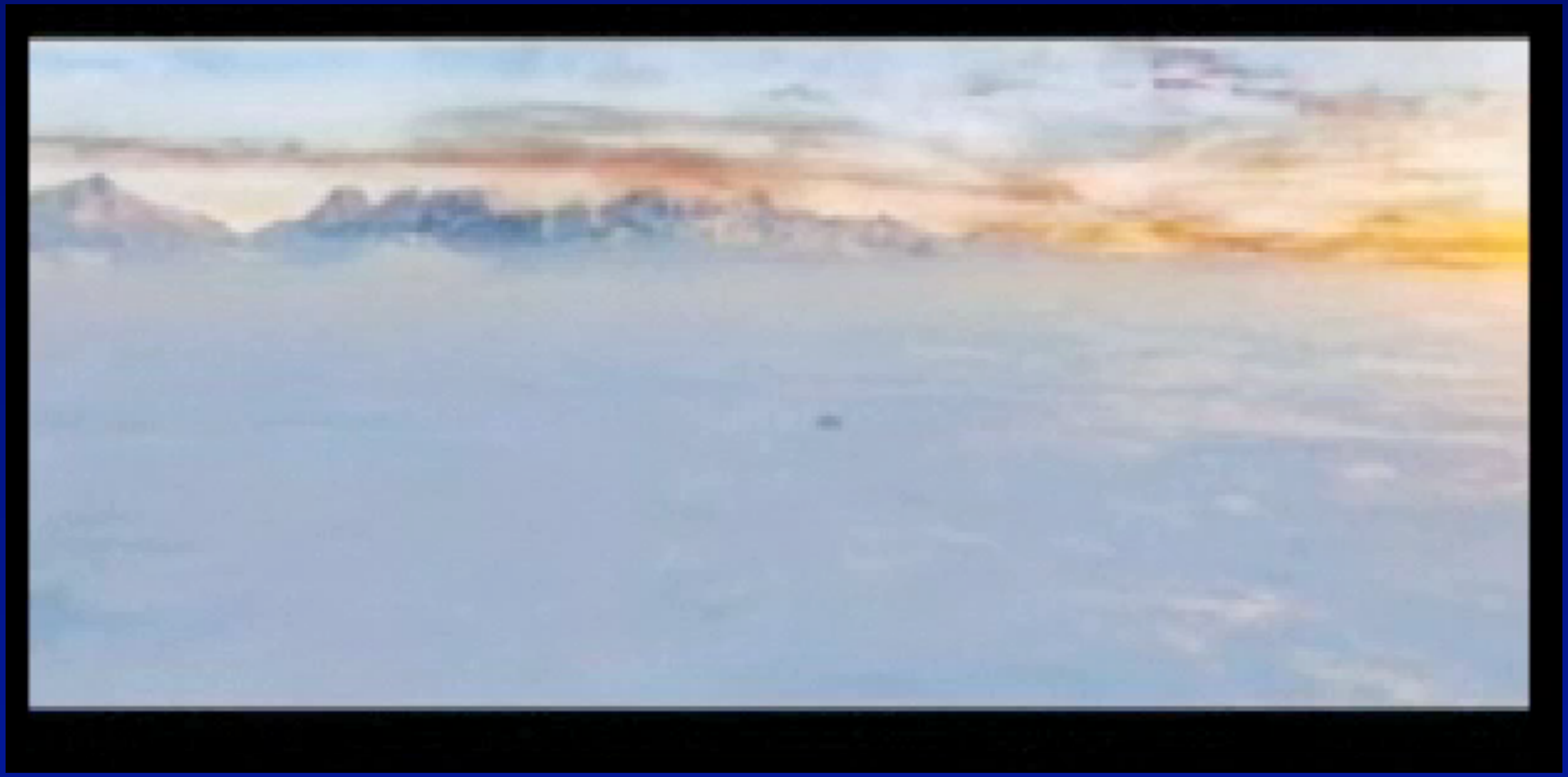
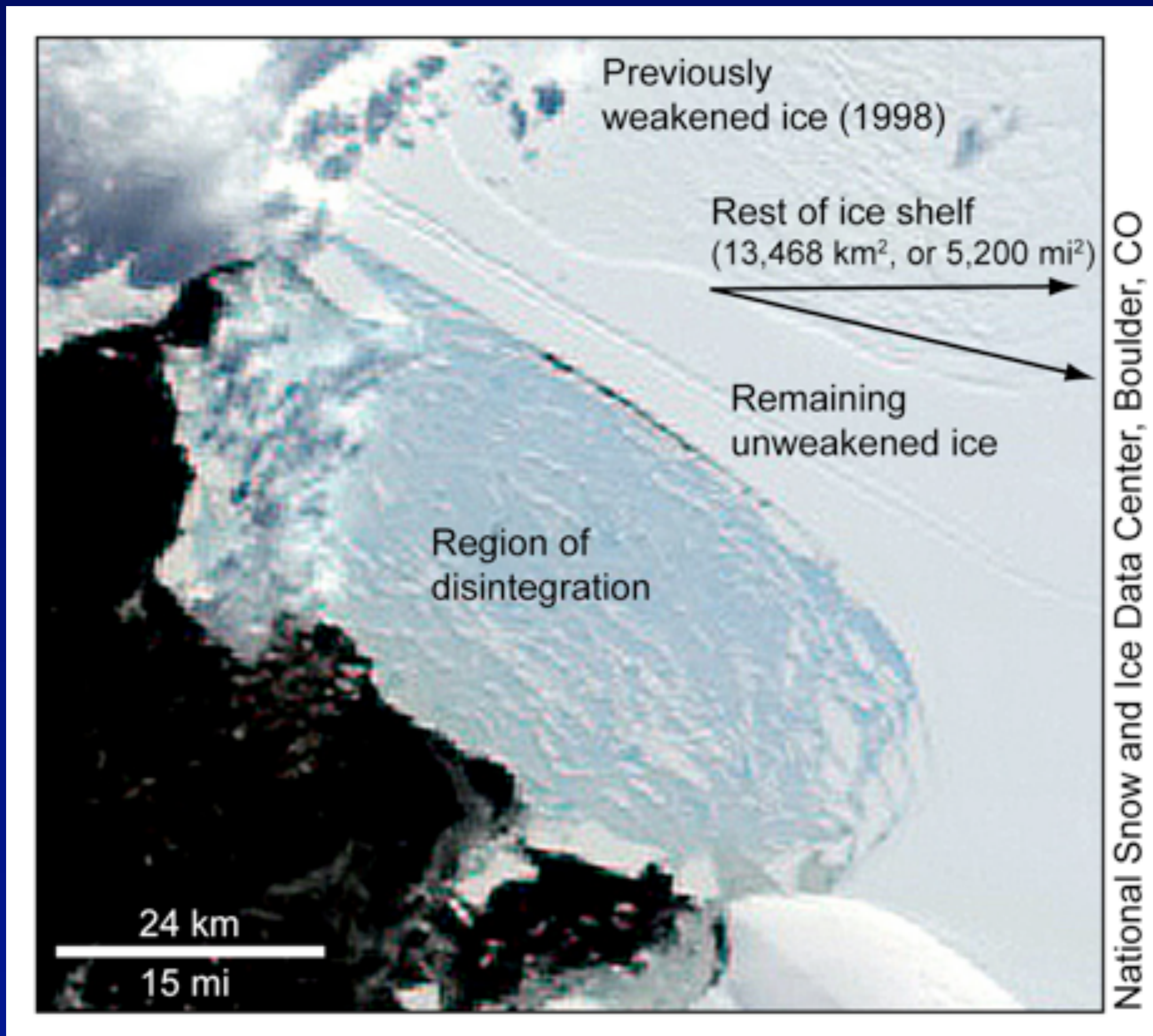
-

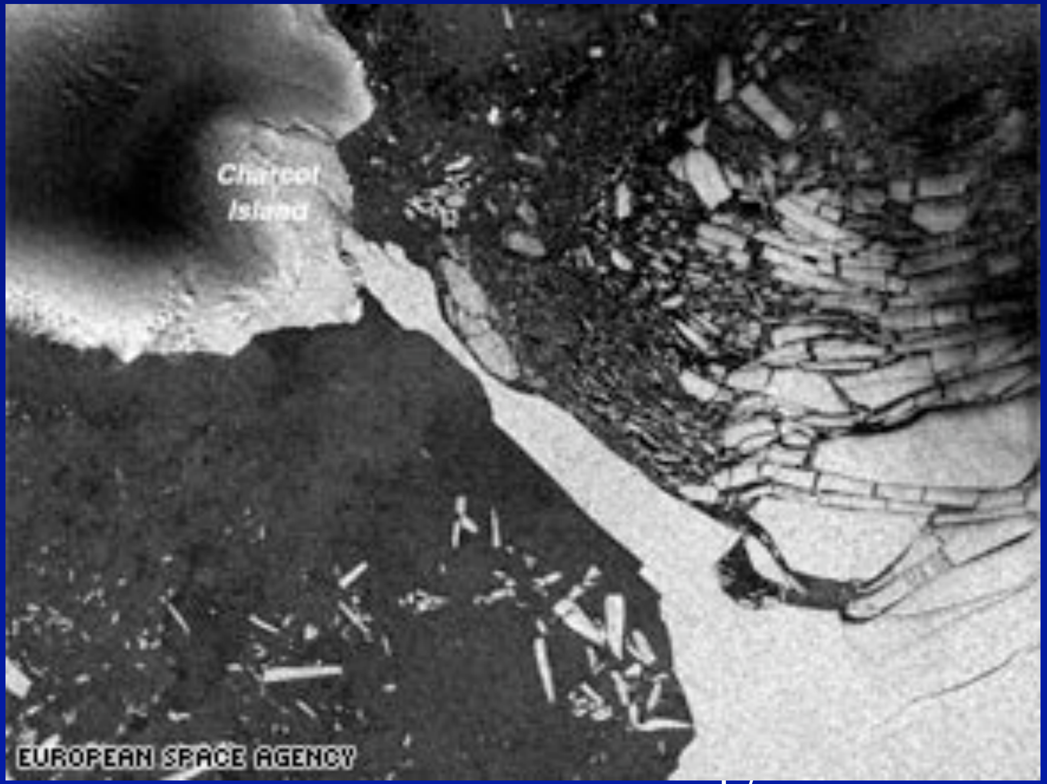


Wilkins Ice Sheet (size of Connecticut)



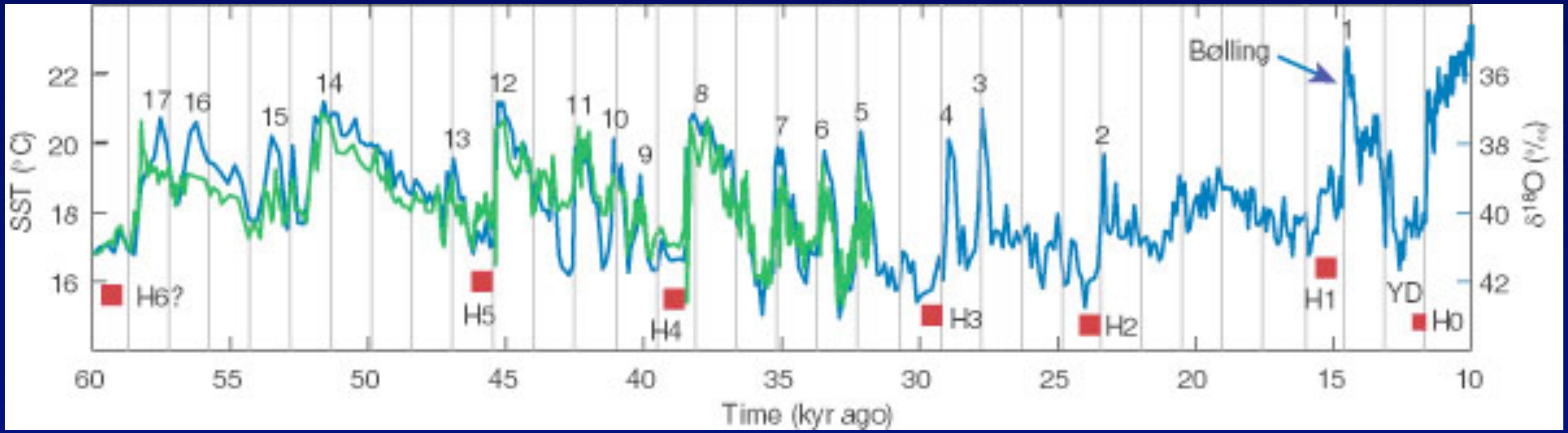
April 2008

April April 2009

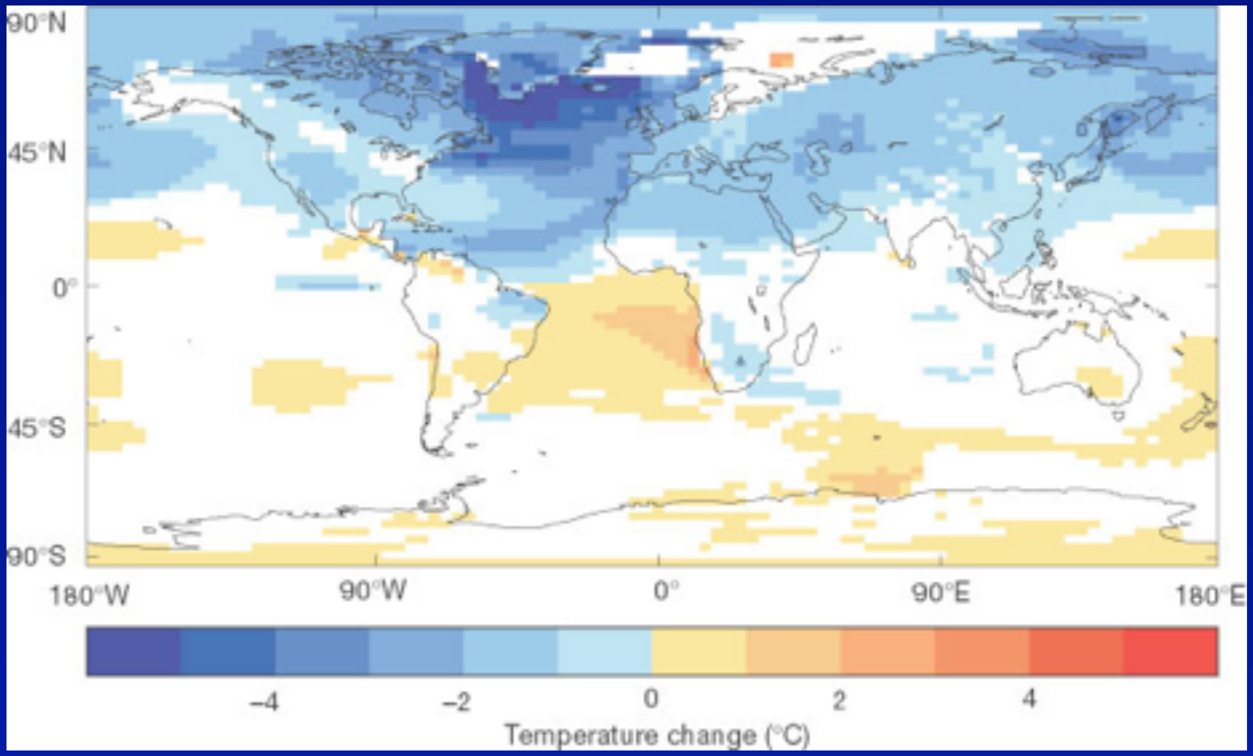


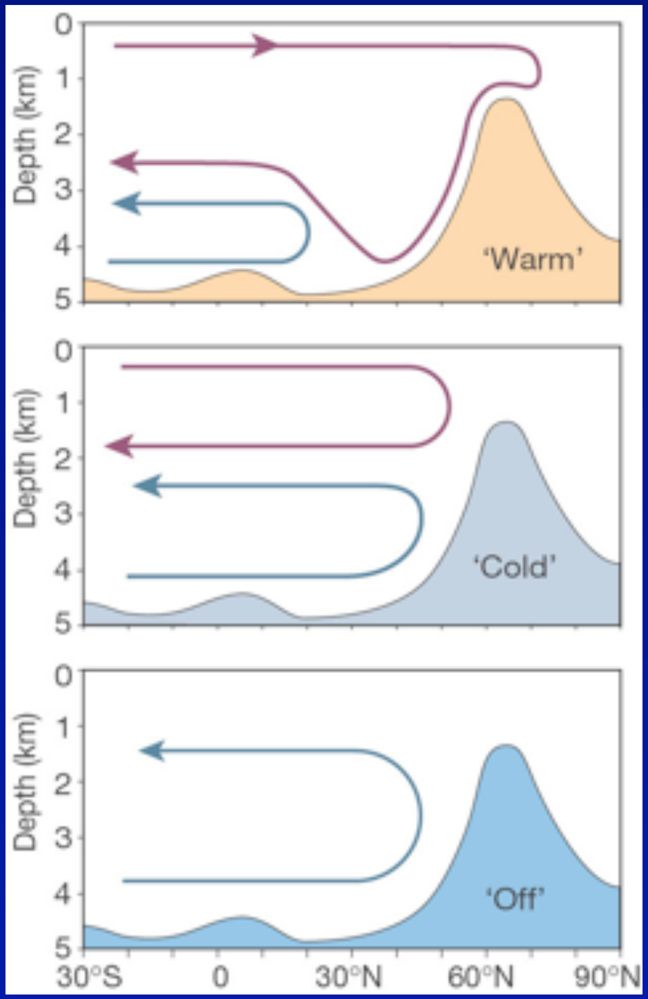
“Abrupt” climate change?

Historical record of temperature in mid-atlantic(green) and Greenland (blue)



Pattern of ‘cold phase’





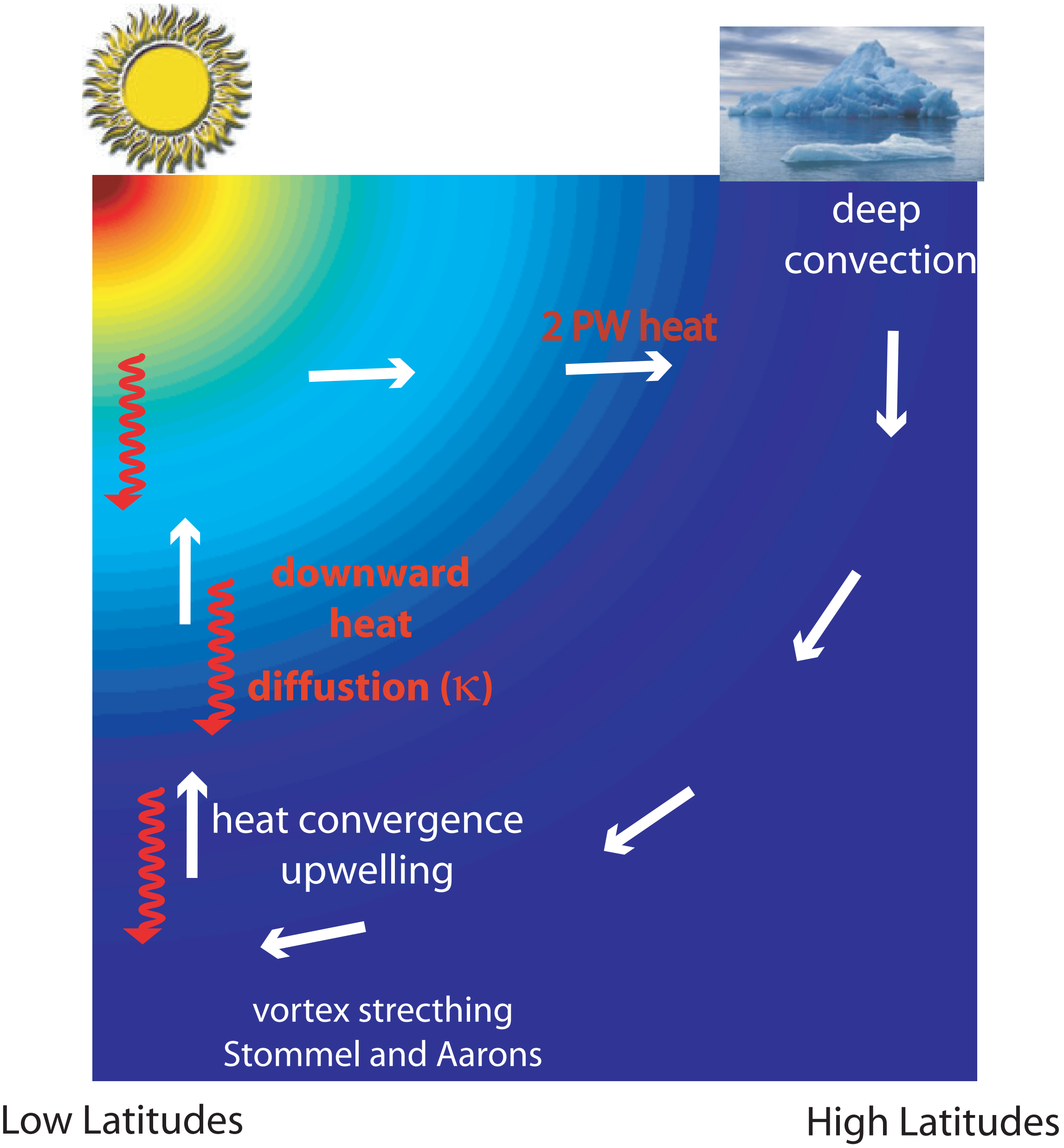
Rahmstorf, Nature, 2002

"Uncertainties"

- While C02 rise and overall warming are NOT in doubt, some of the specific consequences are. Why? Because they depend on details of circulation.

- One of the most common consequences in the press is a slowdown of the global overturning circulation

Turbulent mixing makes the ocean go round



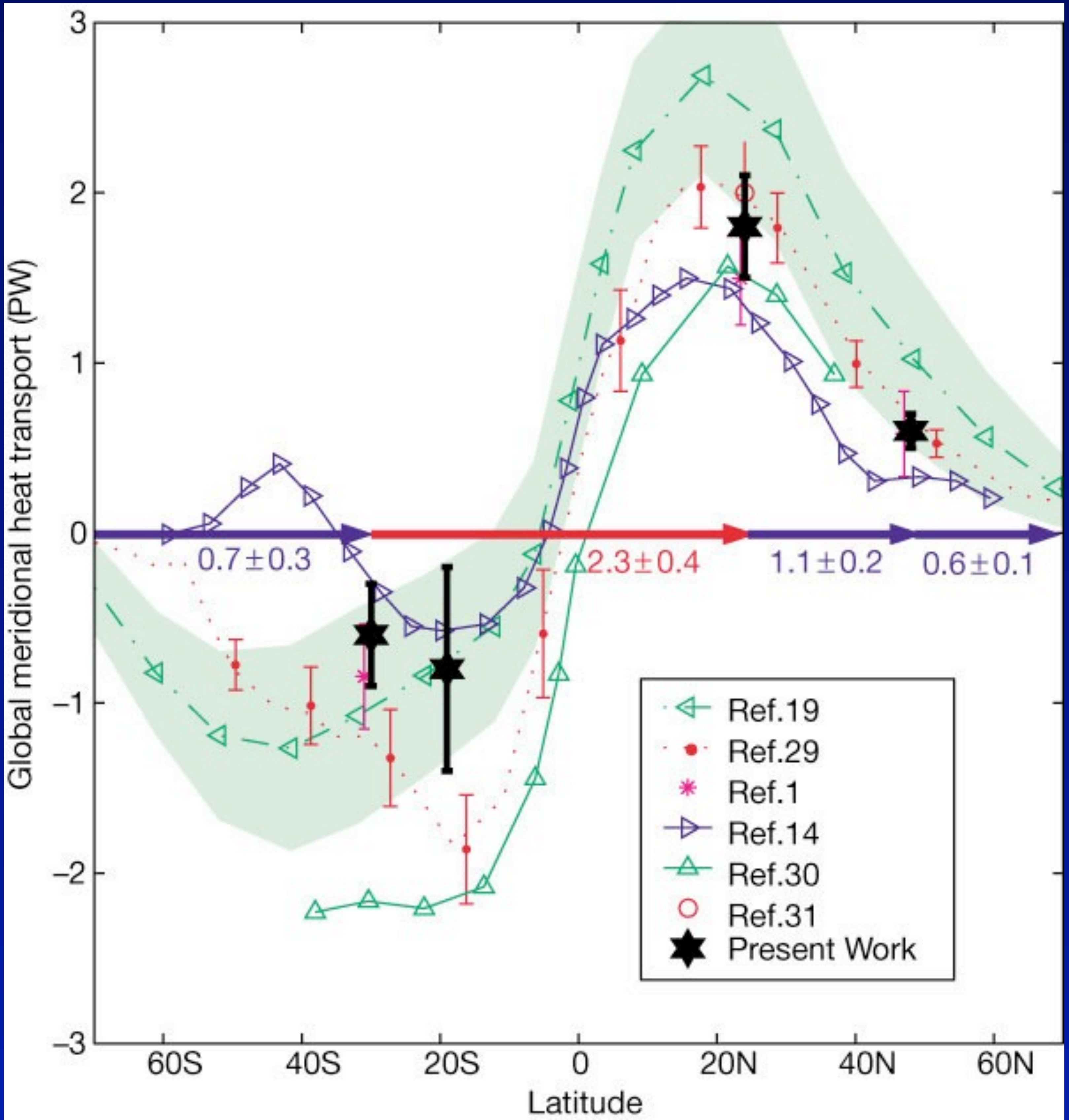
- Turbulence occurs at small scales: cm to m
- Determines large scale vertical transport of heat, C02, nutrients, etc.
- Drives meridional overturning circulation by creating potential energy.


nature (may 2007)

Churn, churn, churn

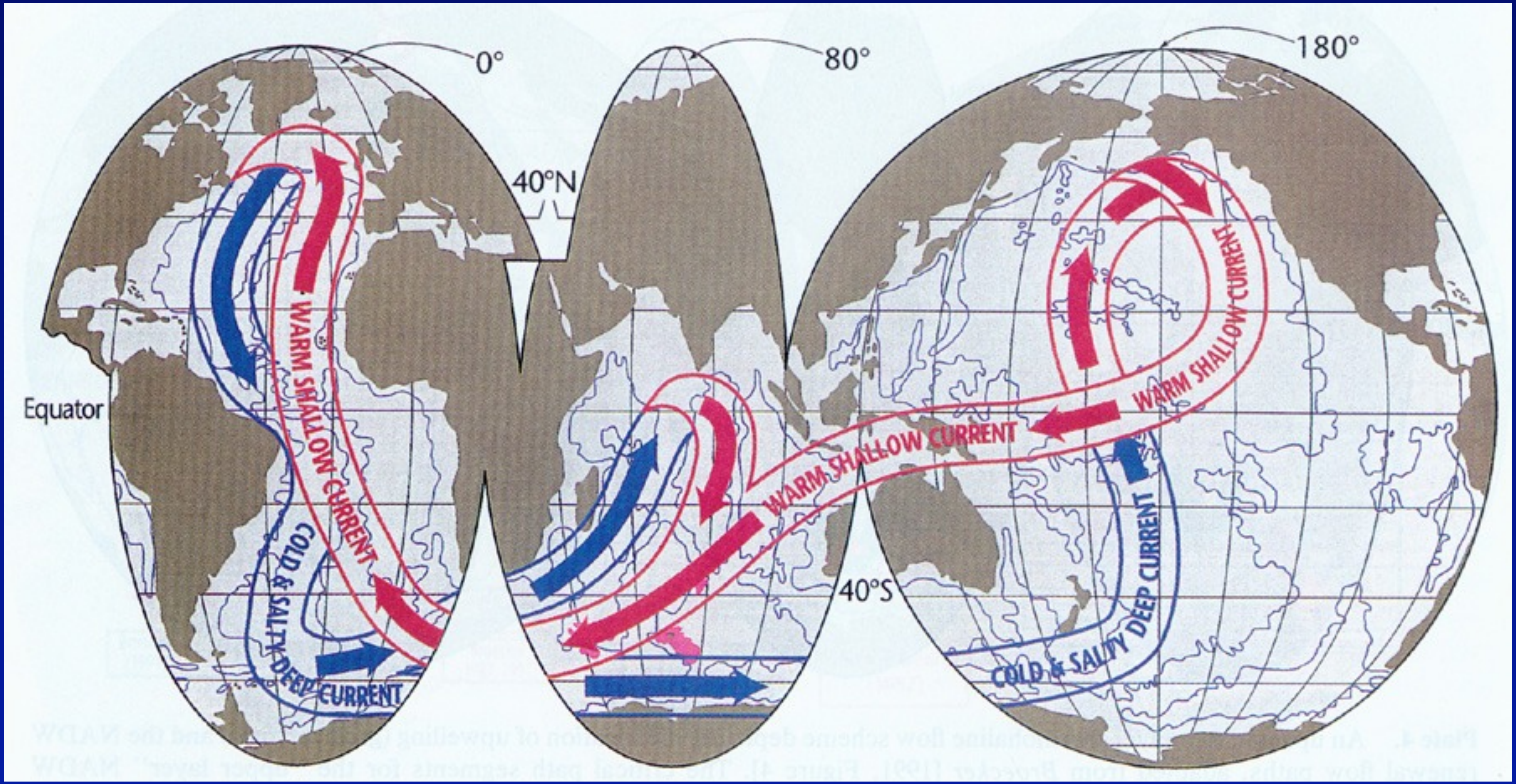
How the oceans mix their waters is key to understanding future climate change. Yet scientists have a long way to go to unravel the mysteries of the deep.

Global heat transport
(Ganachaud and Wunsch, 2000)

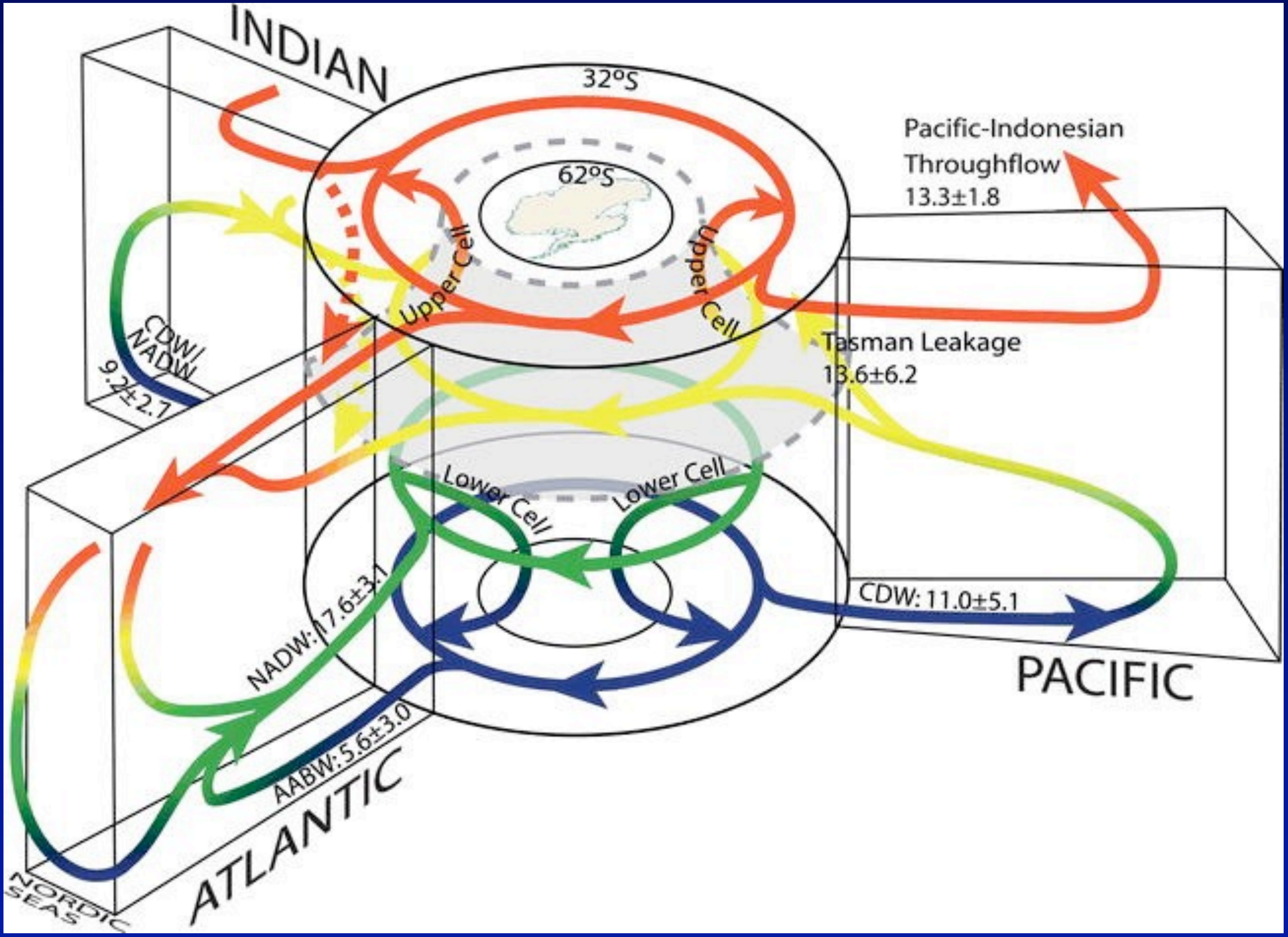


Very simplified version of this: “Ocean Conveyor Belt”, but of course deeper circulation is more complex than this (Broecker, 1981)

Huge climate impact via meridional heat transport

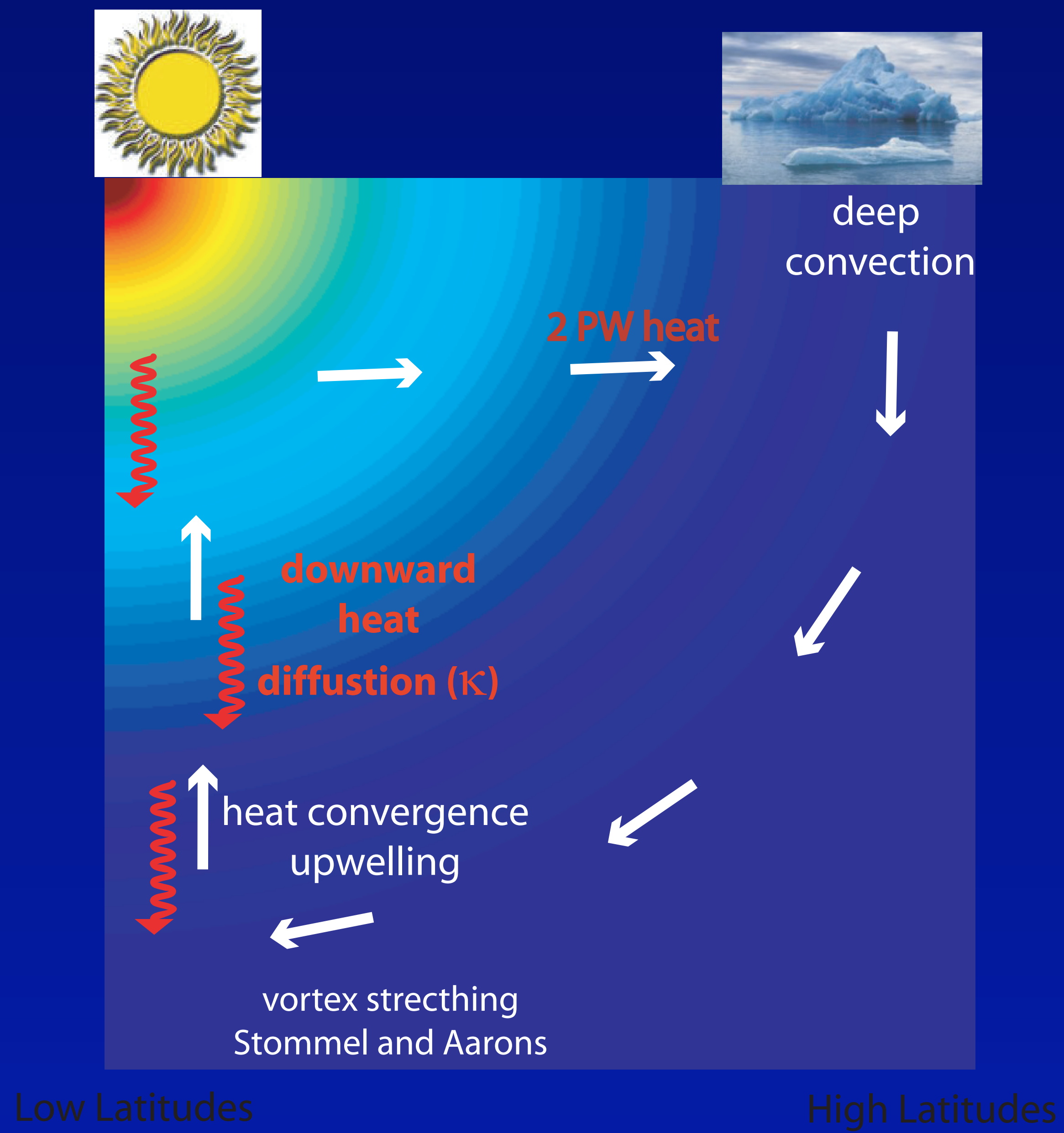


Lumpkin and Speer (2007) version



North Atlantic thermohaline circulation variations - millenial time scales and abrupt climate change

What happens if melting ice makes the North Atlantic too fresh/ light for deep convection?



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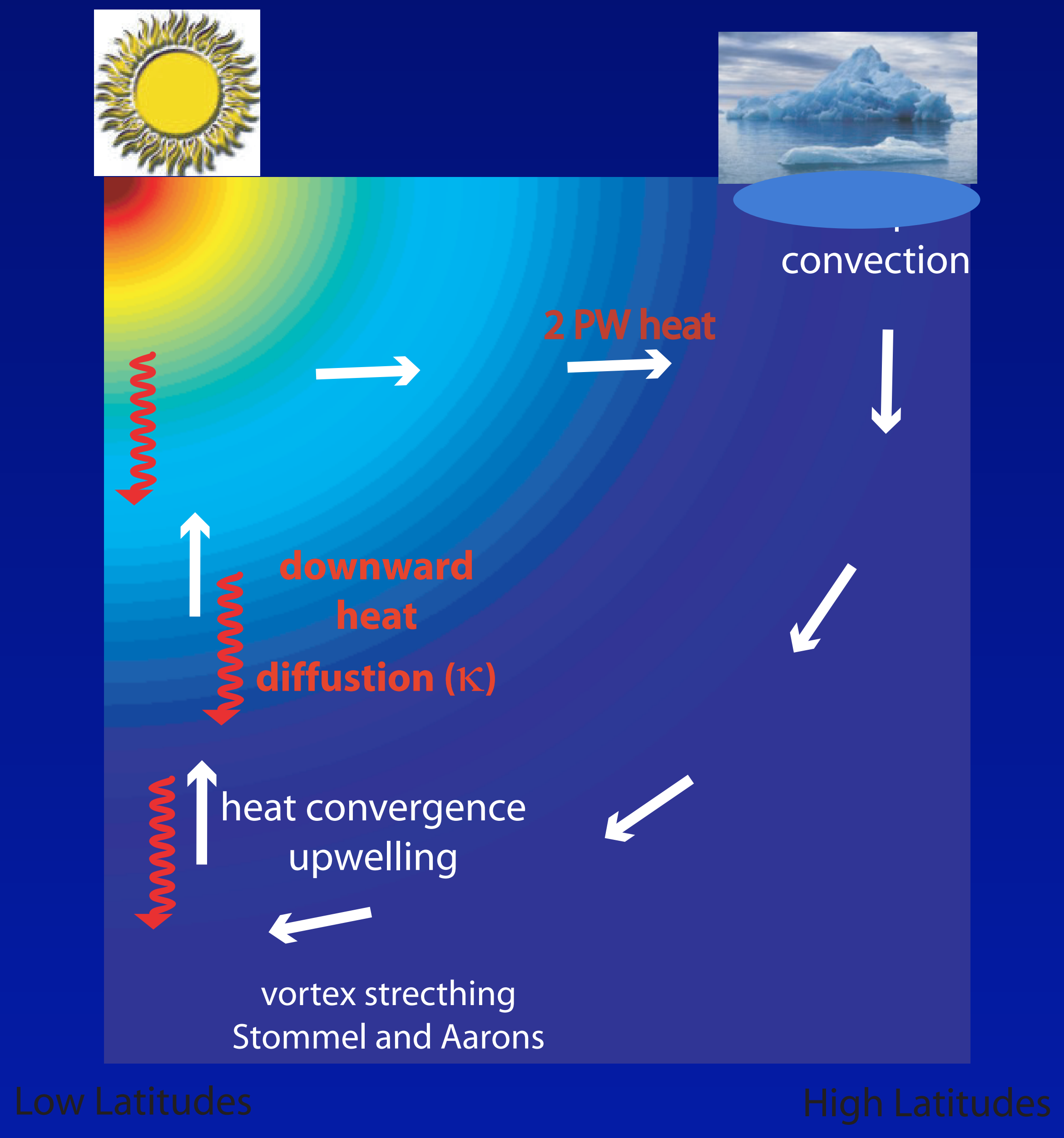
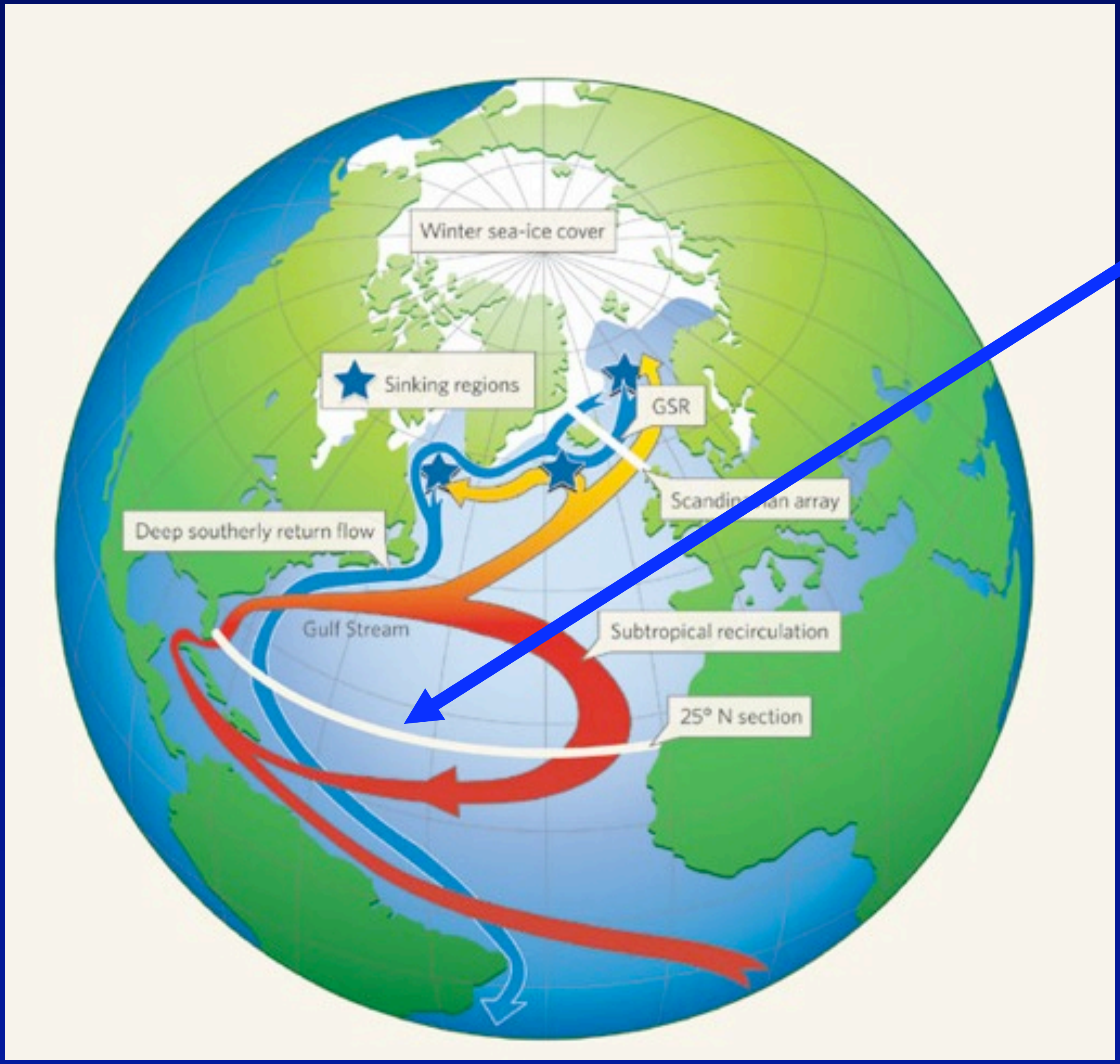


Is the N. Atlantic “conveyor” changing?

e.g. Bryden et al., Nature (2005)

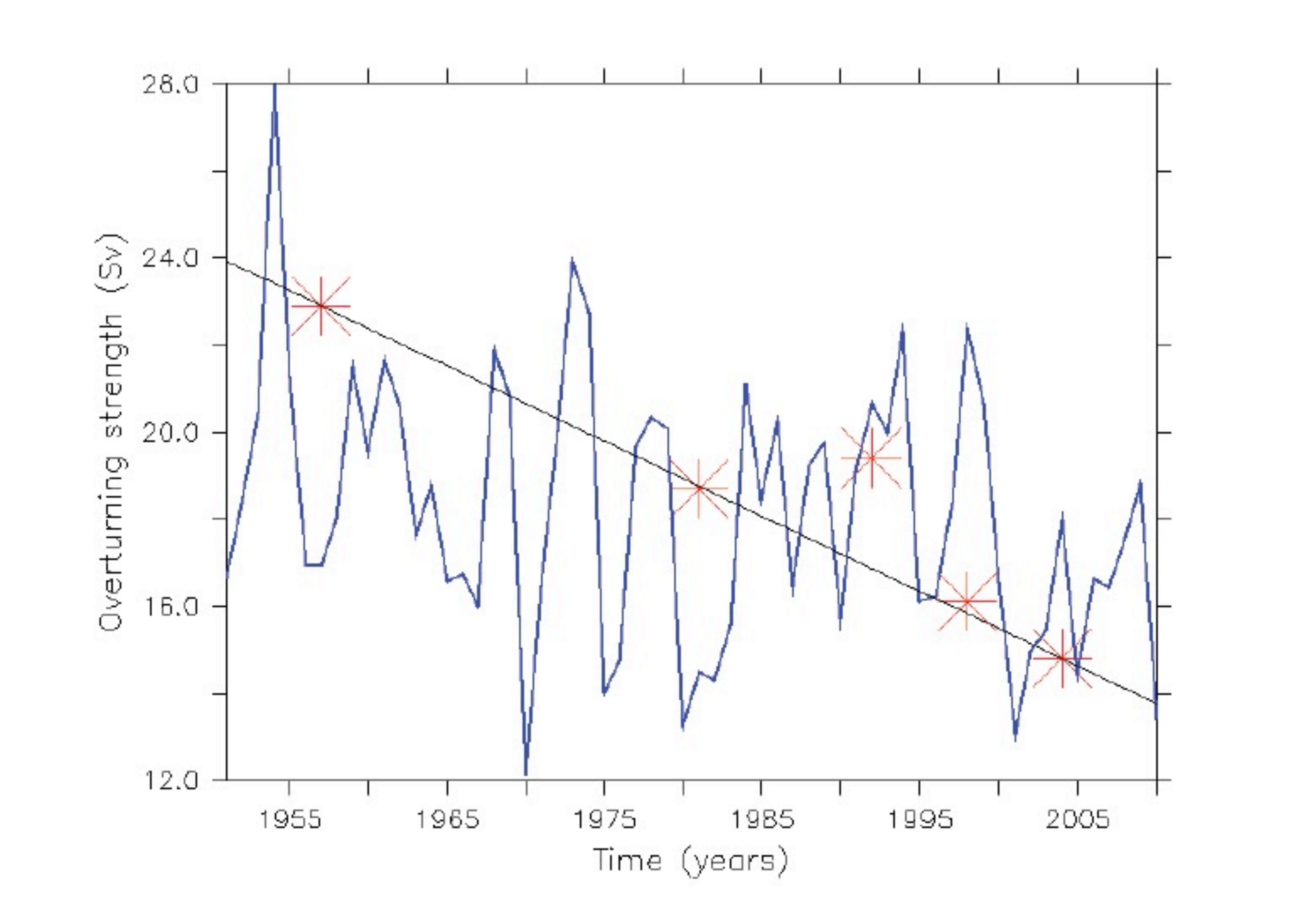


Bryden et al. measurements at 25°N suggested a slowdown.

Cartoon of “conveyor” and measurement arrays in place from Quadfasel (Nature, 2005)

Is the overturning circulation changing (decreasing) ??

Model data from Drijfhout & Hazeleger, 5 observations points from Bryden et al 2005



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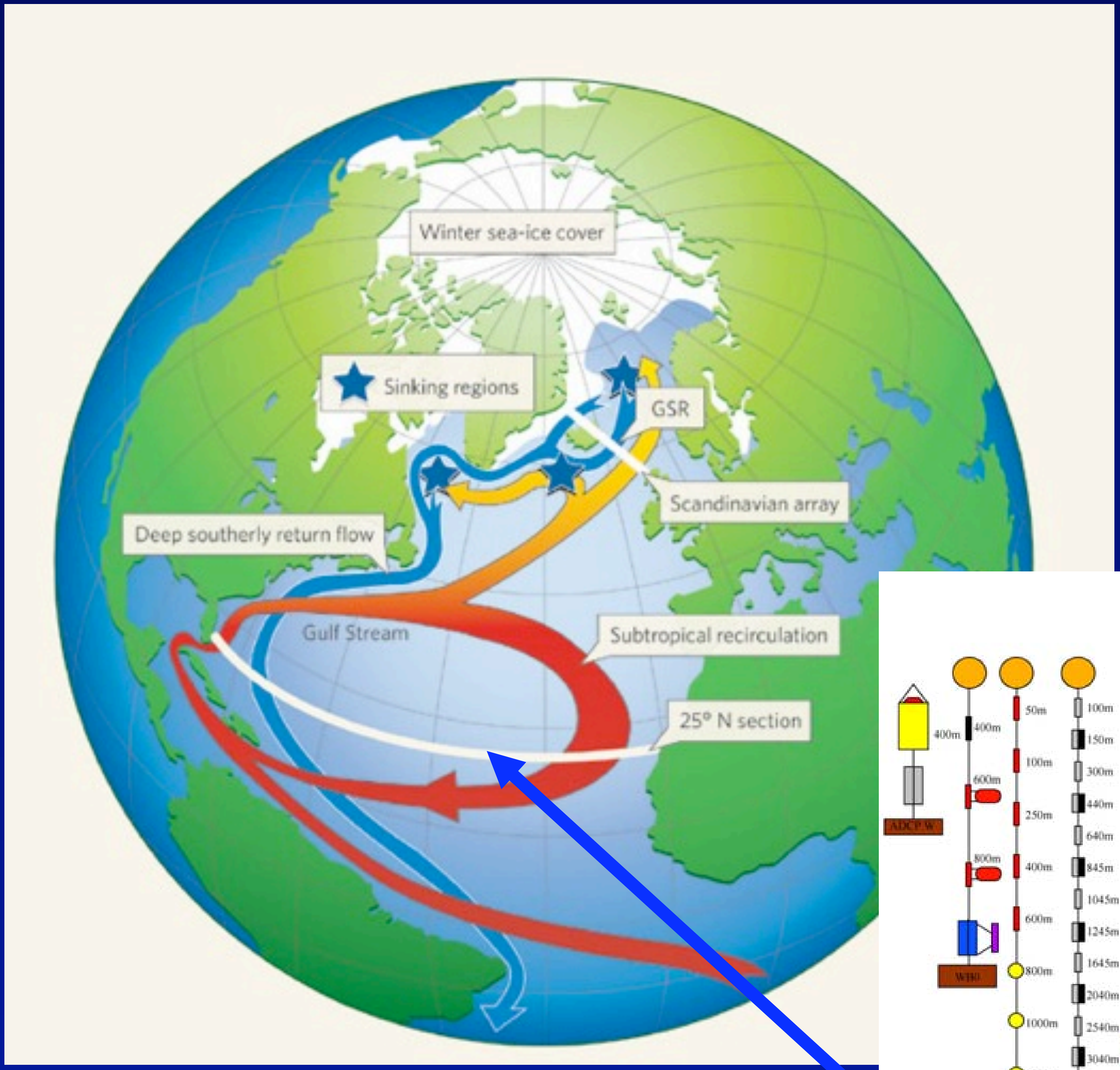
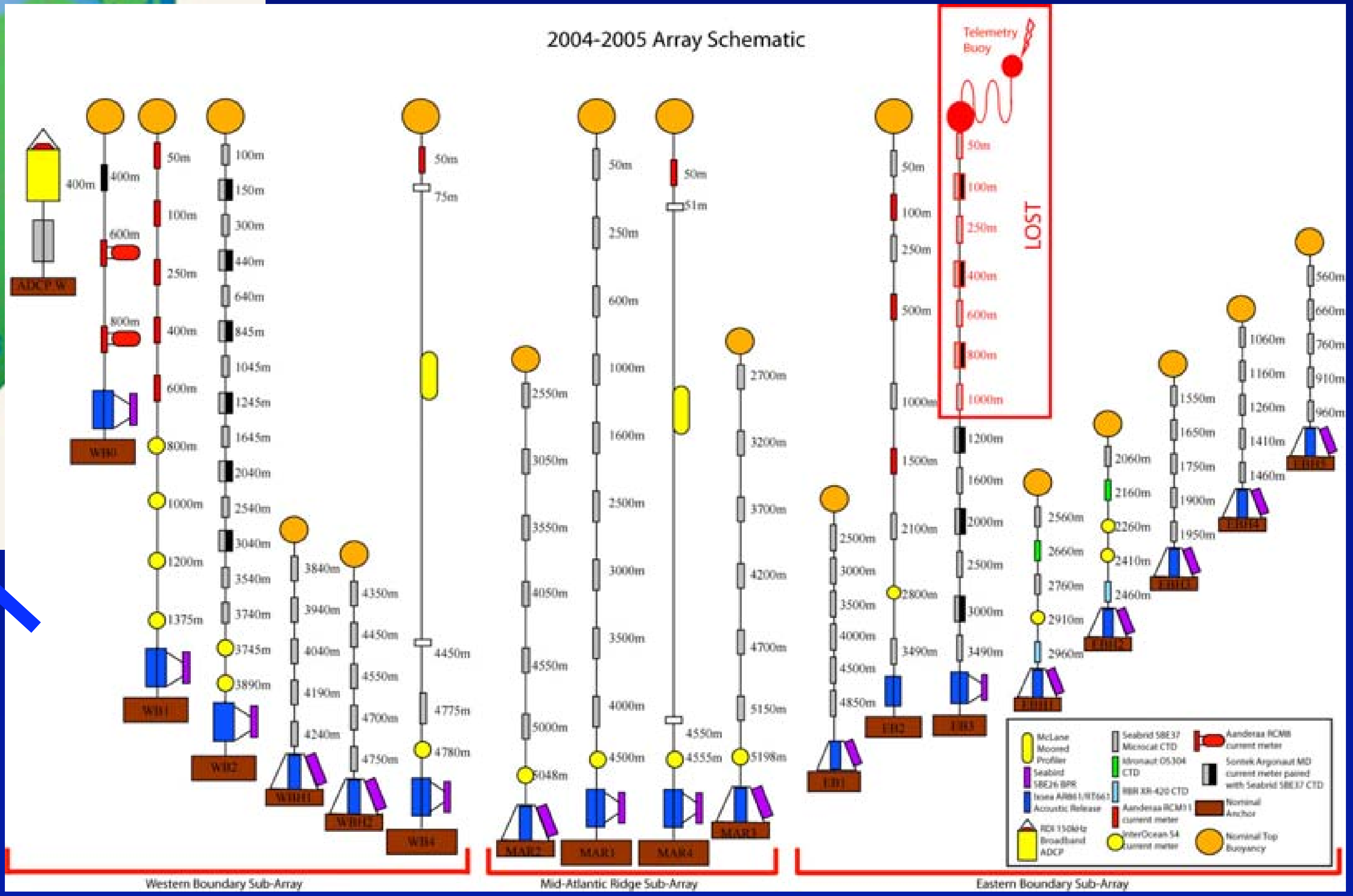
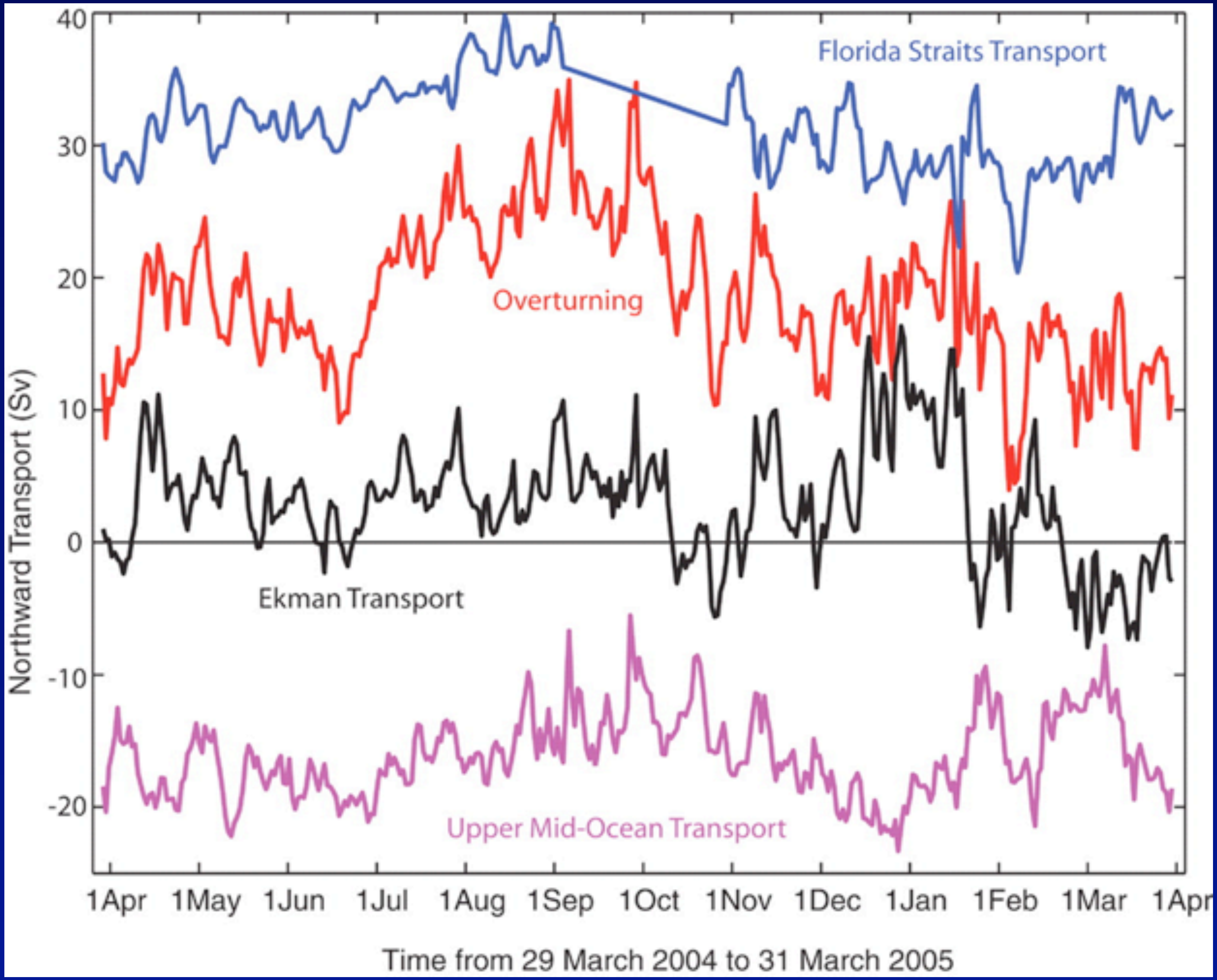


Bryden et al. measurements at 25°N suggested a slowdown. They have since withdrawn this conclusion - answer is very uncertain.

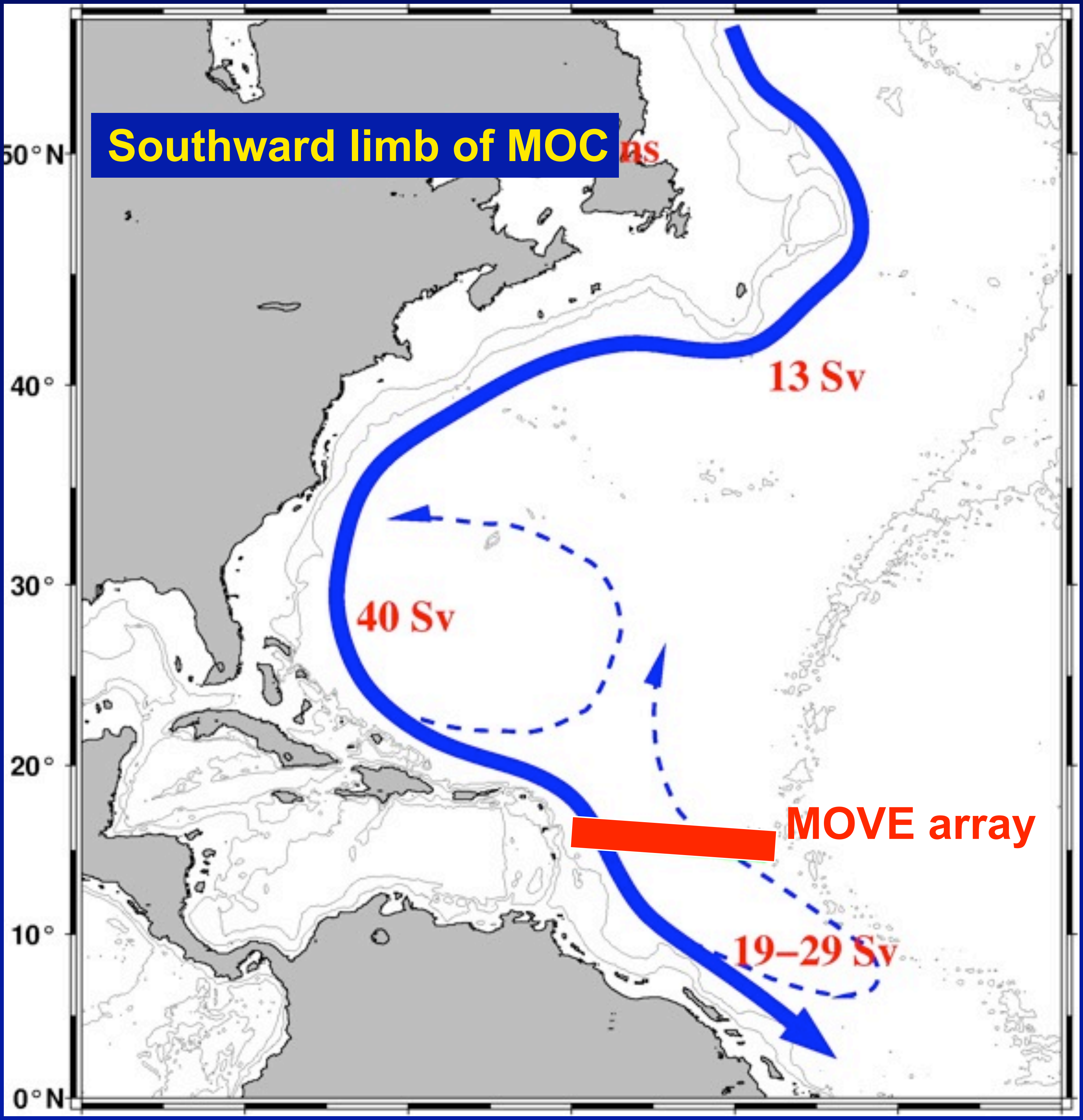




Net overturning (red) varies enormously during a single year, makes it hard to see a trend yet

MOVE (Meridional Overturning Variability Experiment):

Cost-effective concept to monitor transport of southward NADW between western boundary and Mid-Atlantic Ridge

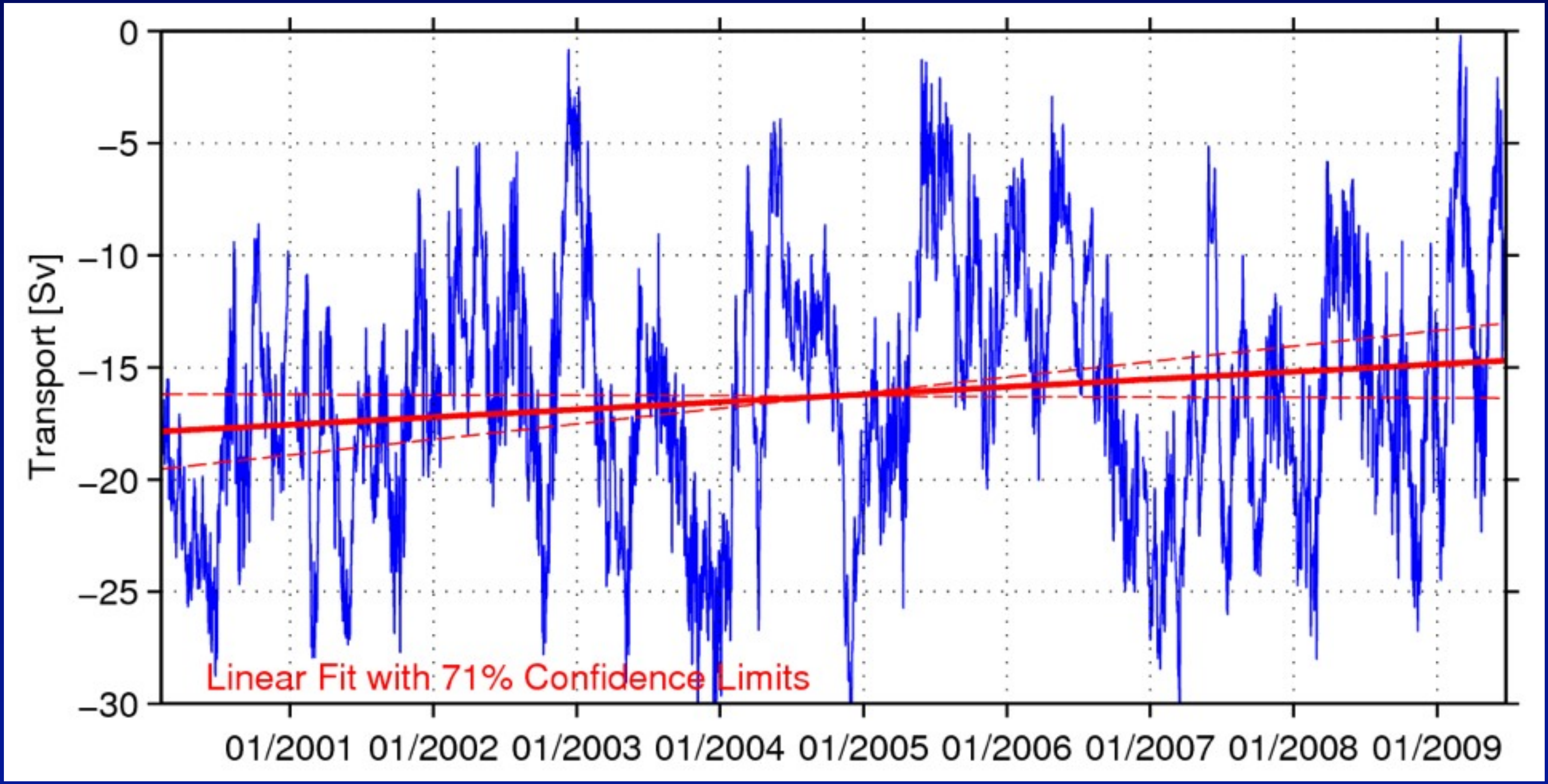


Assumptions:

1) **Balances northward thermocline transport** (mass balance)

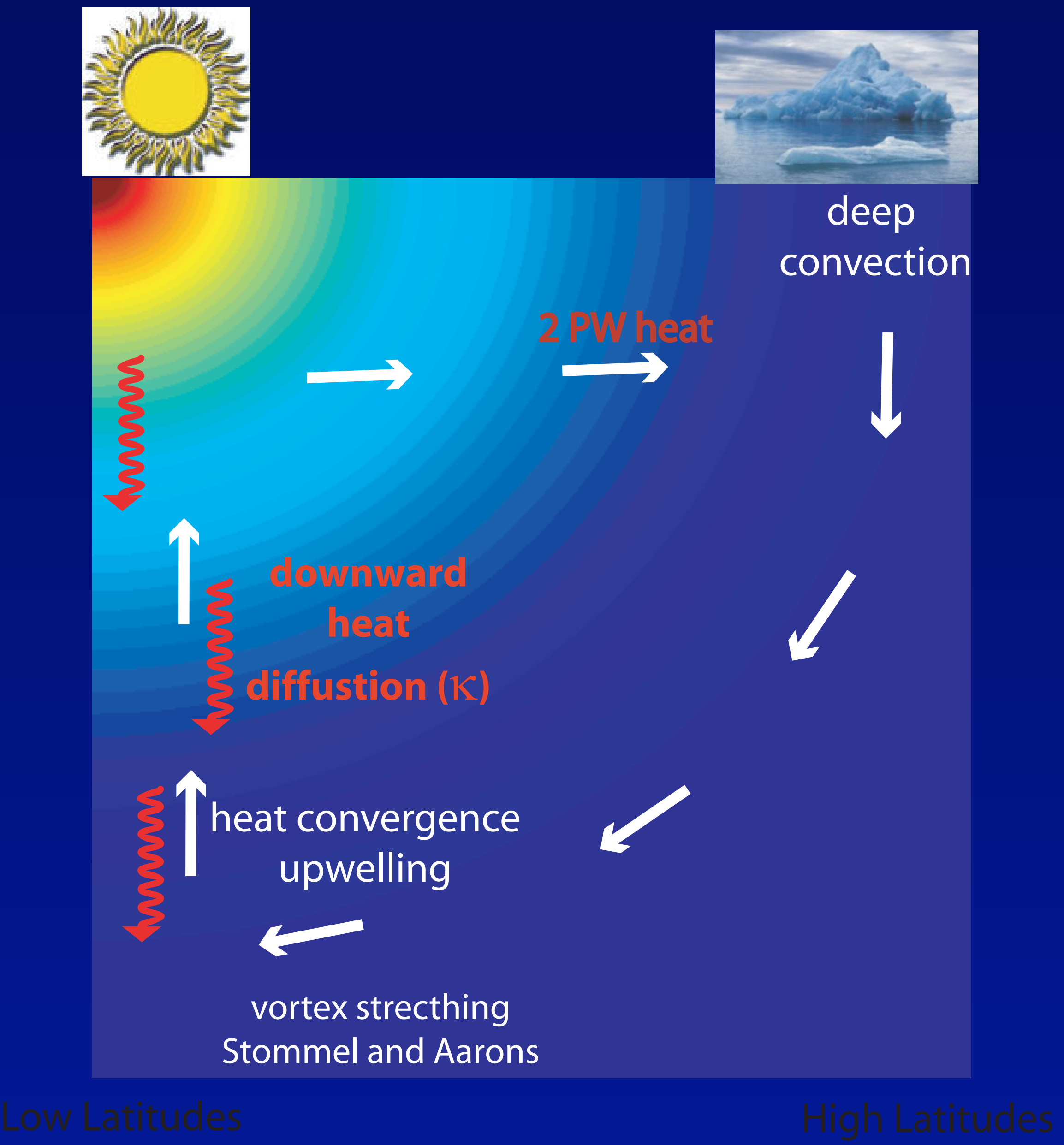
2) **Little transport east of MAR** (reasonable based on CFC and model data, since 2006 full-basin coverage with German mooring in east)

Internal transport rel 4700db plus boundary transport:



- Trend = +0.35 Sv/a → MOC decrease of 3Sv over measurement period
- 85% certain trend > 0
- 45 degrees of freedom

what if mixing strength changes?



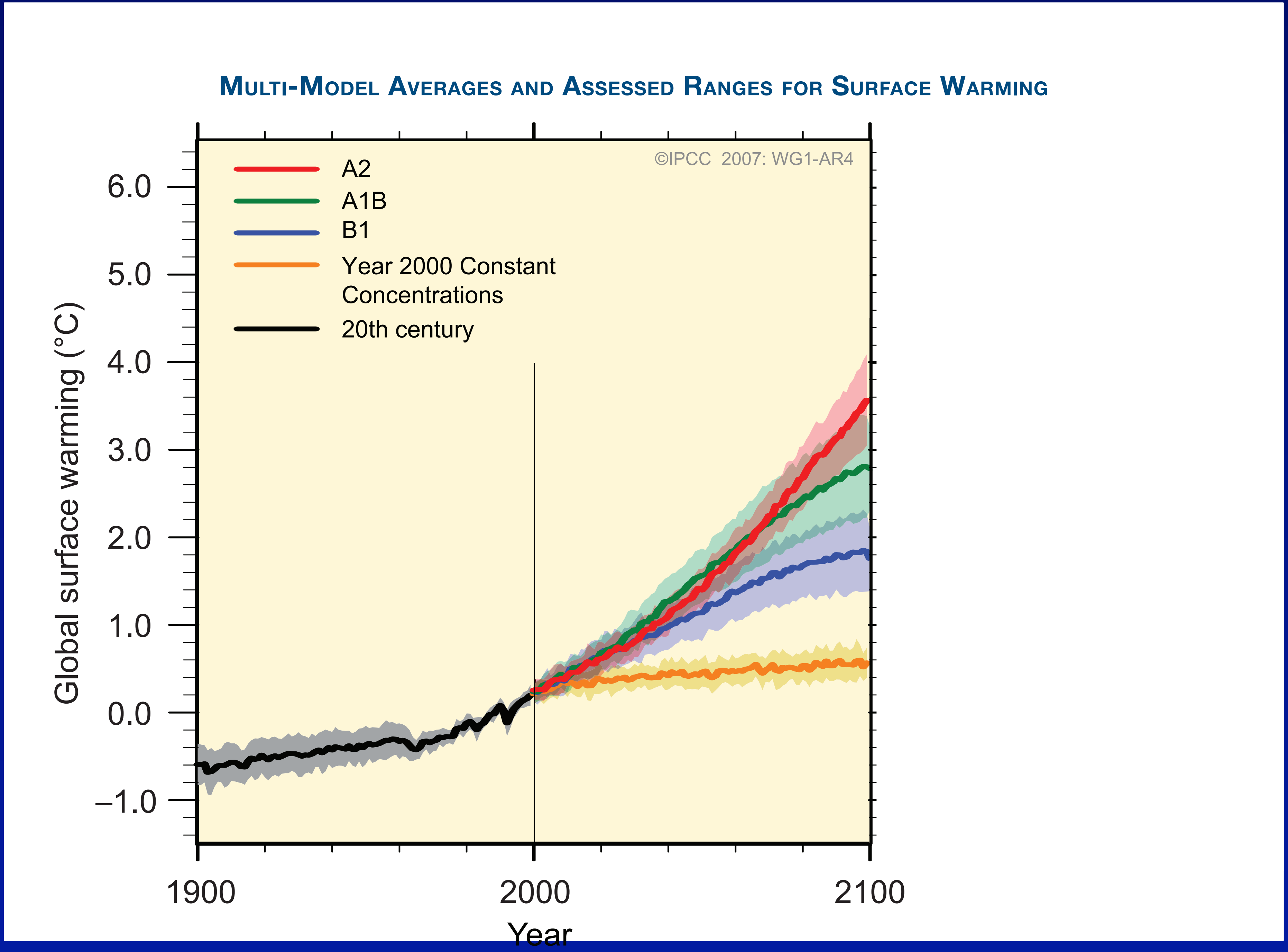
In a windier world, more mixing could 'compensate' for changes in surface gradients, so overturning could either slow down or speed up (Schmitt et al, 2009).

“Uncertainties”

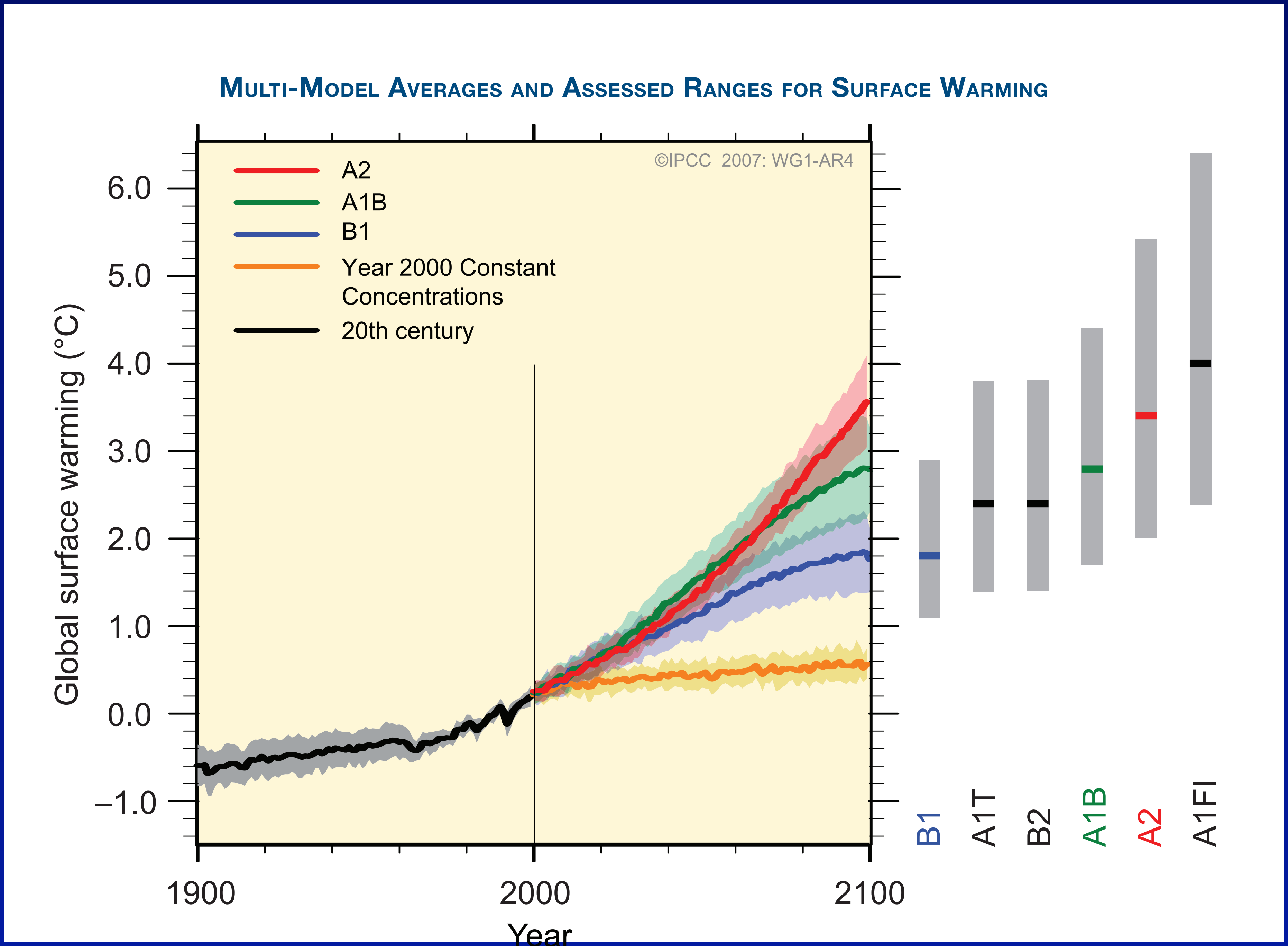
- While C02 rise and overall warming are NOT in doubt, some of the specific consequences are. Why? Because they depend on details of circulation.

- What happens in a future climate is also somewhat uncertain. Why?

Variability in climate models



Variability in climate models



Forcing (coupling) with no feedback

- Cause and effect: example of negative coupling
  - Volcano causes aerosols
  - Causes cooling and decrease in temperature

Volcano eruption

Negative coupling

Reduction in sunlight

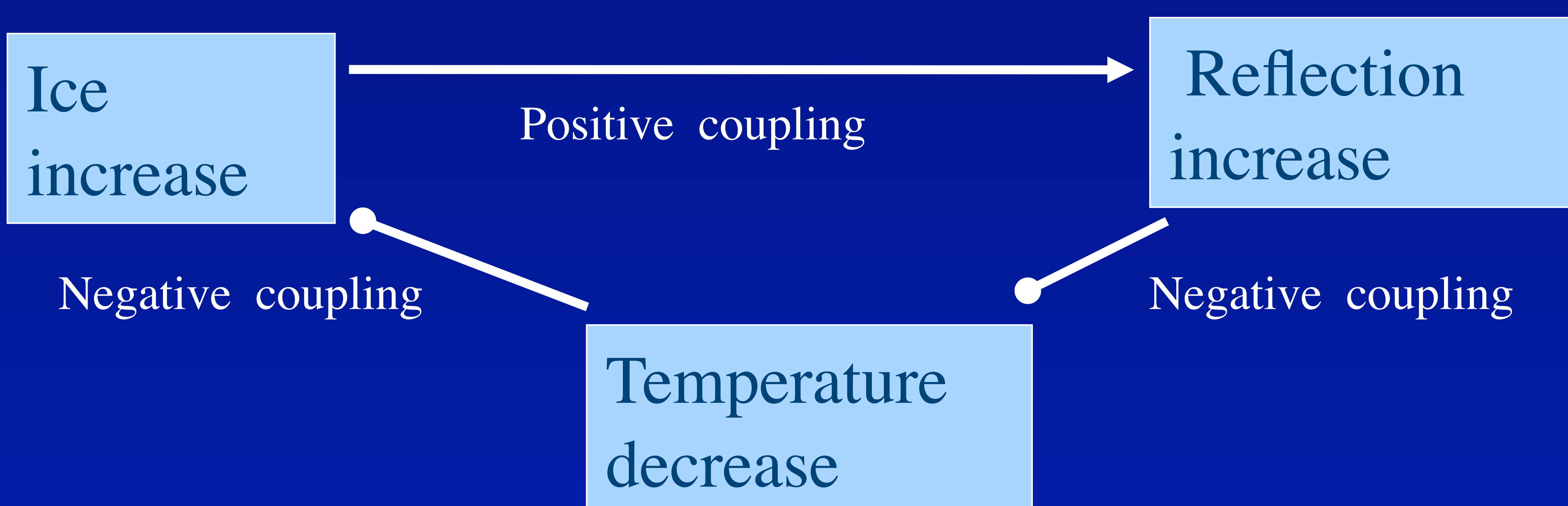
Temperature decrease

Feedback? None since air temperature does not change incidence of volcanoes

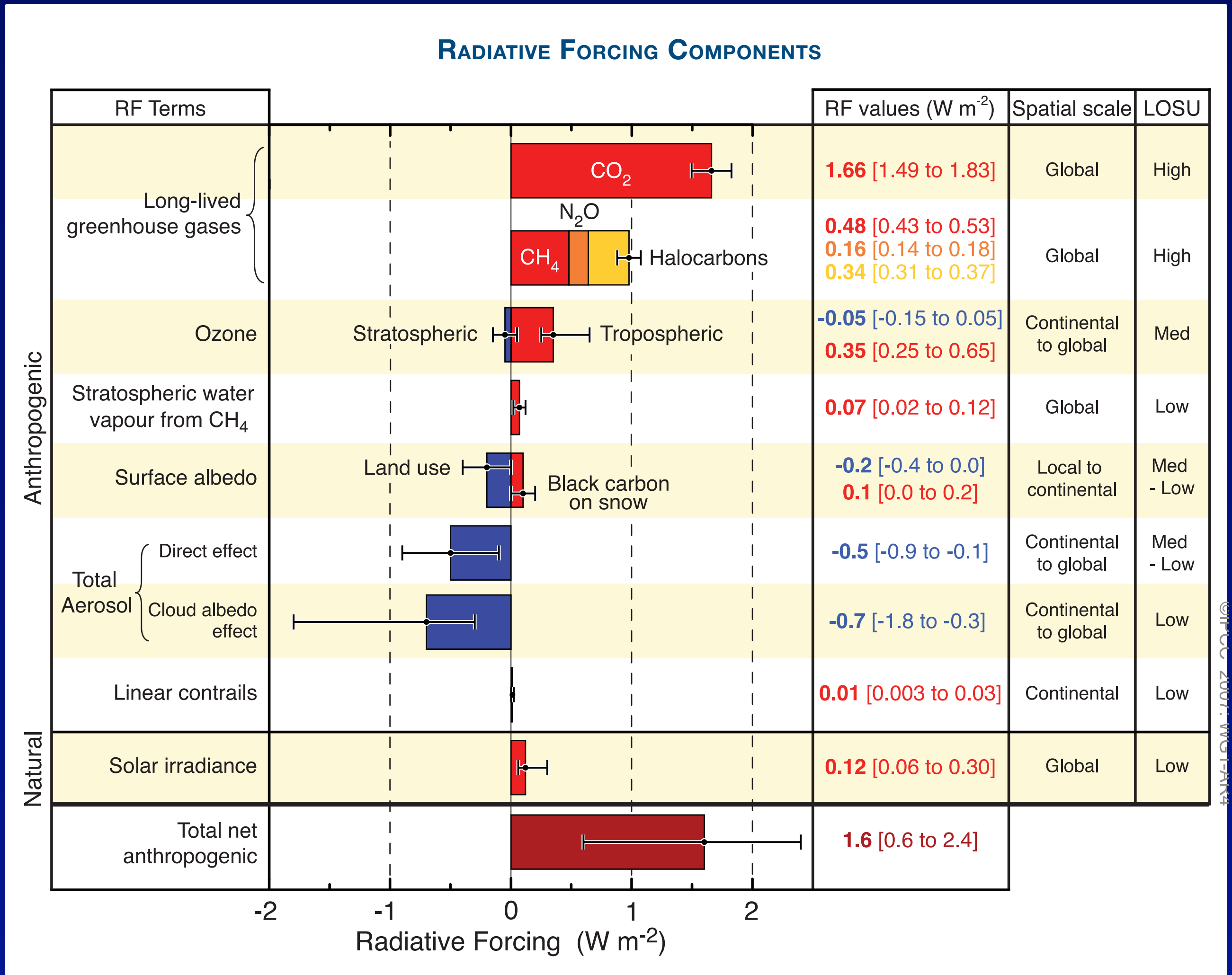
Positive feedbacks

Albedo = reflectivity, scale of 0-1 with 0 = no reflection, 1 = all reflected

- Example: ice-albedo feedback
  - Increased ice and snow cover increases albedo
    - (Positive coupling, denoted by arrow)
  - Increased albedo decreases temperature of atmos.
    - (negative coupling, denoted by circle)
  - Decreased temperature of atmos. Causes ice increase
    - (negative coupling, denoted by circle)
  - Two negatives cancel to make positive; net is positive feedback ("runaway", unstable)



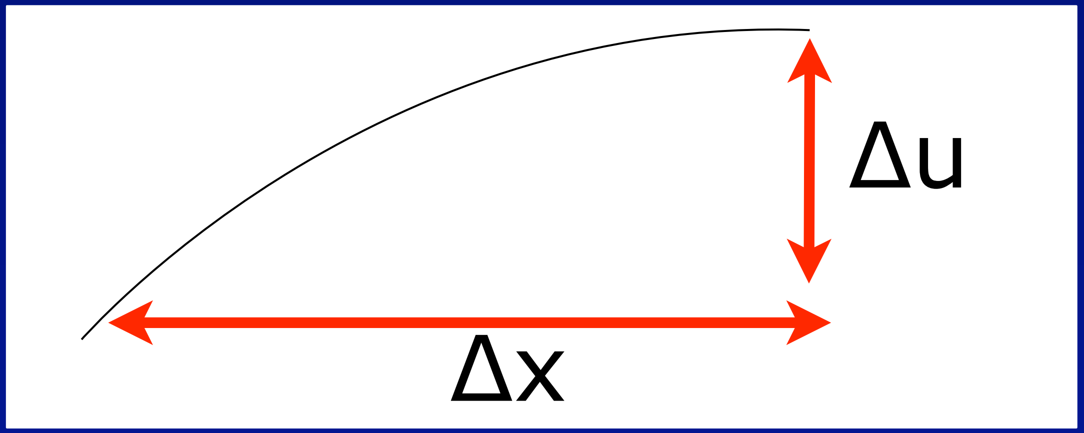
Albedo effect



Estimates from 2005. Relative roles in a future climate less clear. [IPCC summary 2007]

Other model uncertainties.

- Unresolved sub-grid-scale processes: turbulence, eddies, clouds, rain.
- Don’t include much detail in shallow water, which can be particularly important for biological effects (carbon uptake, etc).
- Discretization errors ($du/dx \sim \Delta u / \Delta x$)



- hard to represent steep/complex topography
- Physics/biology interactions (e.g. phytoplankton density controls depth of light/heat penetration)
- Iceberg calving (very nonlinear)

modeled flow in the southern ocean

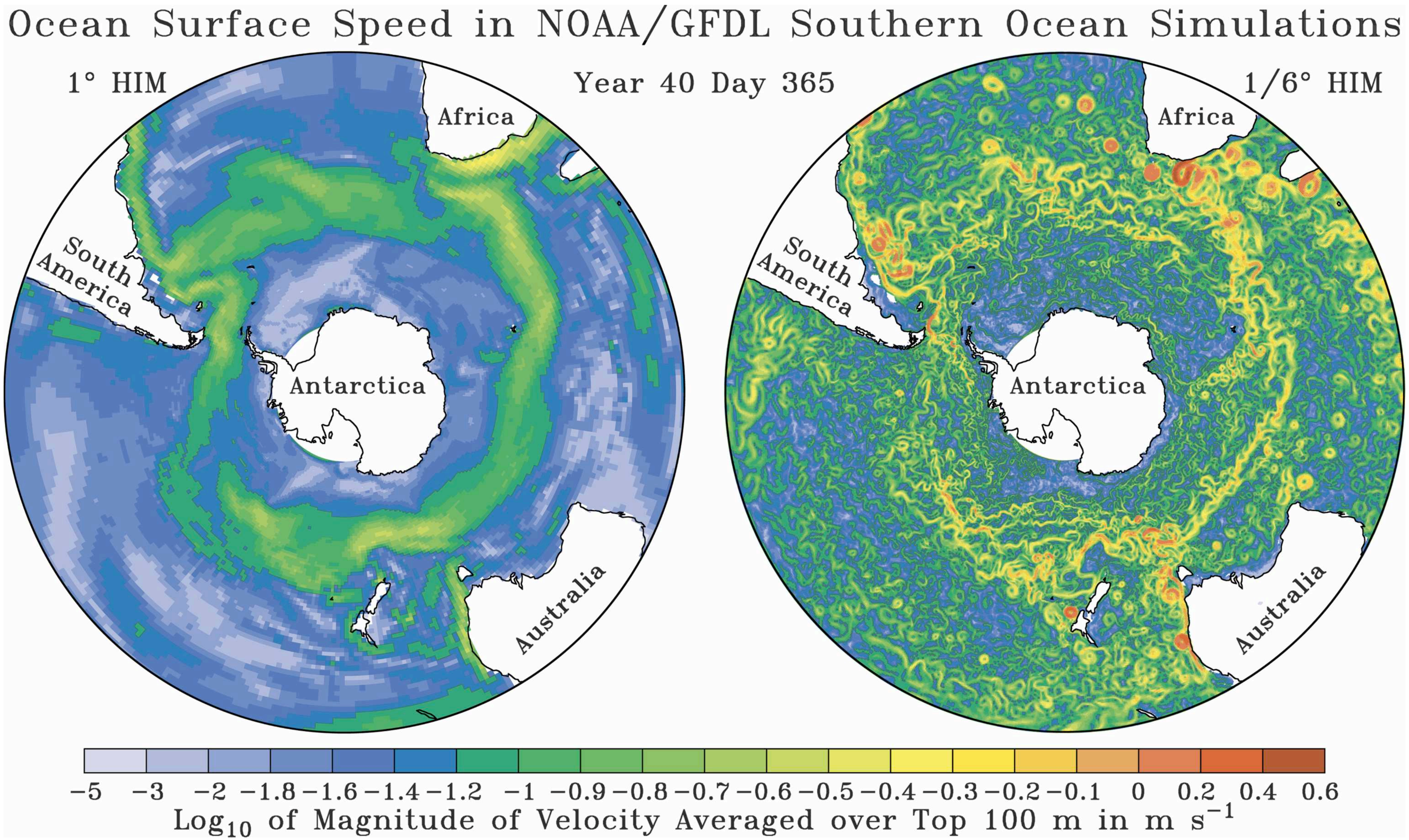


FIG. 6. Instantaneous surface speed in 1° and ⅙° models after 40 yr. Note that the large-scale structure of the 1° model is quite similar to the ⅙° model (the currents have similar locations and have similar horizontal extents). The main difference is in the presence of intense jets and eddies in the ⅙° model.