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Regional and Global Climate Modeling Program

U.S. DEPARTMENT OF ENERGY Office of Science

Introduction to largescale ocean circulation - AMOC and its role in global climate

Aixue Hu

Thanks Prof. De-Zheng Sun for sharing his notes

TBI and AMV Summer School

The Abdus Salam International Centre for Theoretical Physics (ICTP)

WCRP World Climate Research Programme

CLIVAR

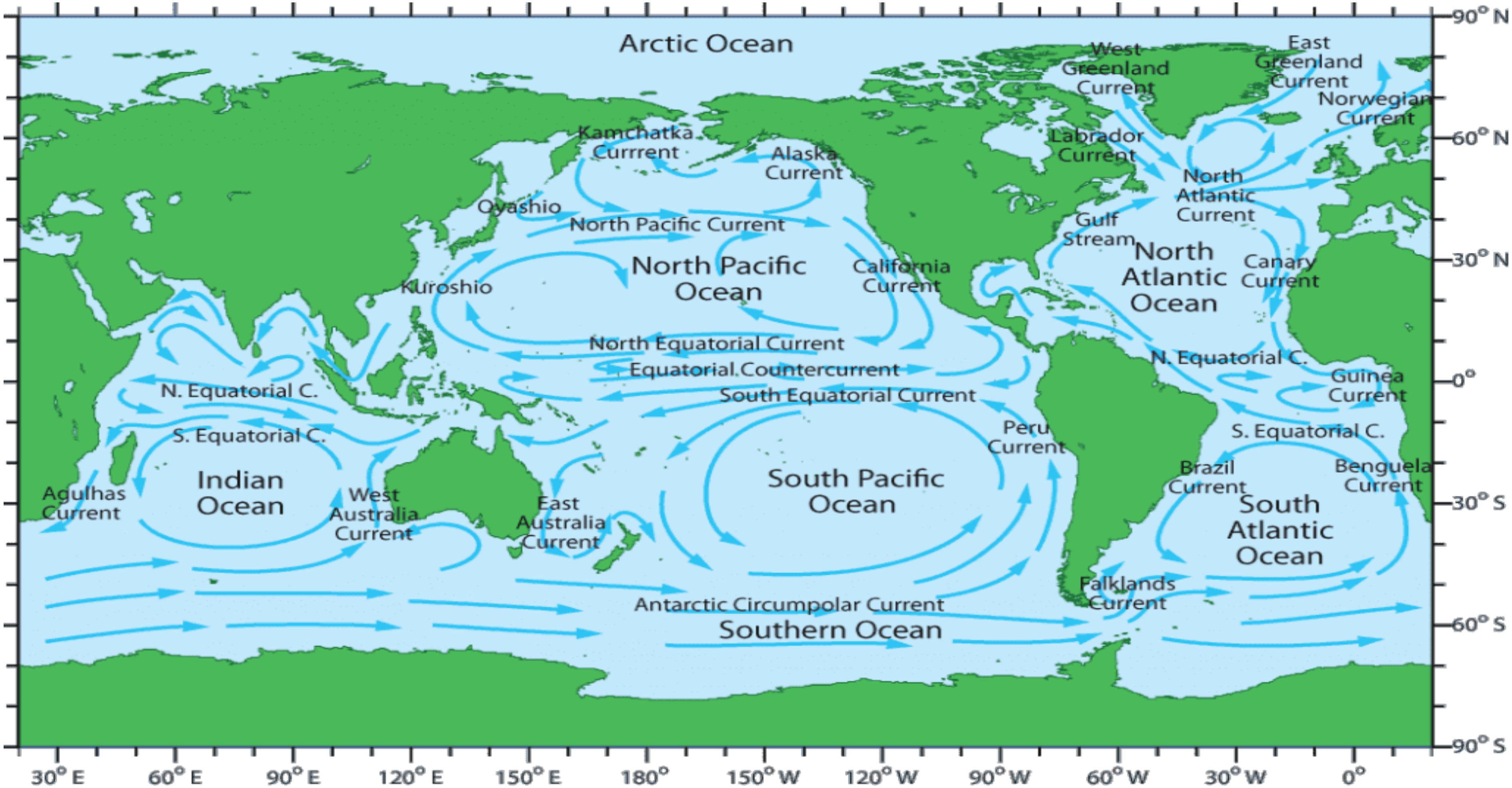
US CLIVAR

NASA

NOAA National Oceanic and Atmospheric Administration U.S. Department of Commerce

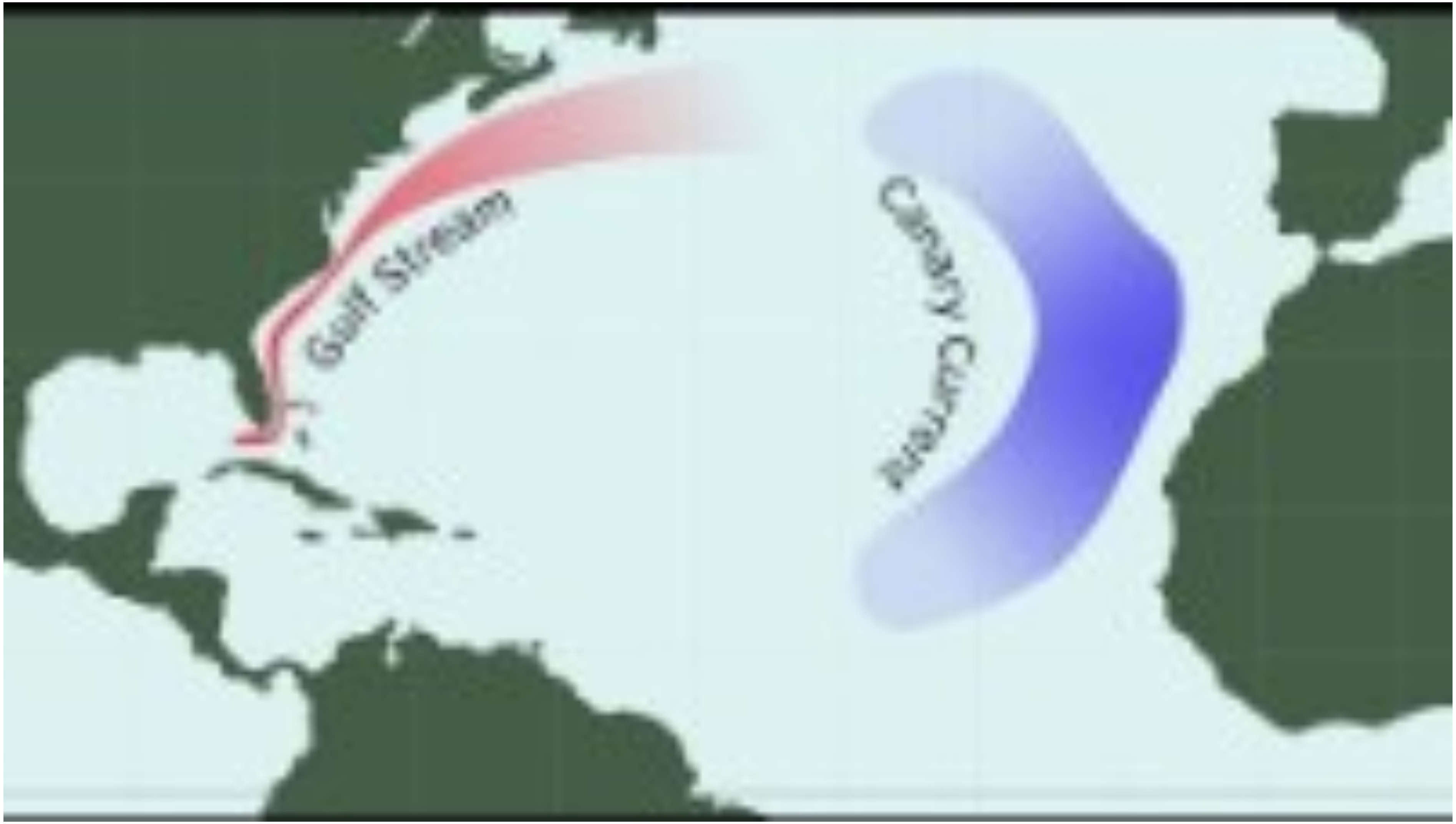
NSF

Wind driven ocean circulation

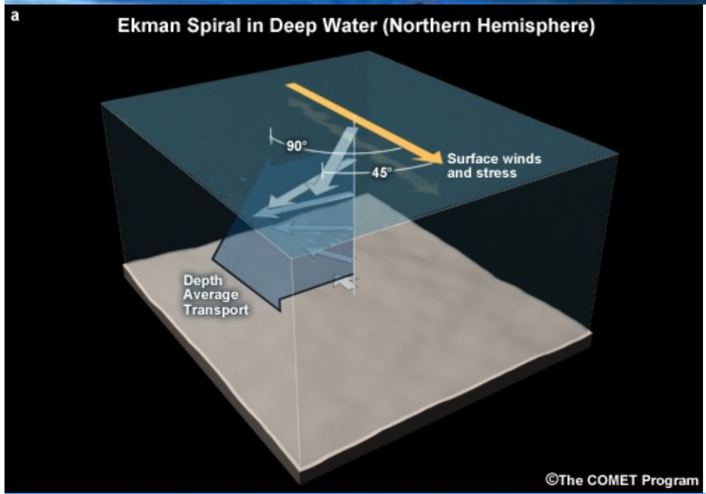


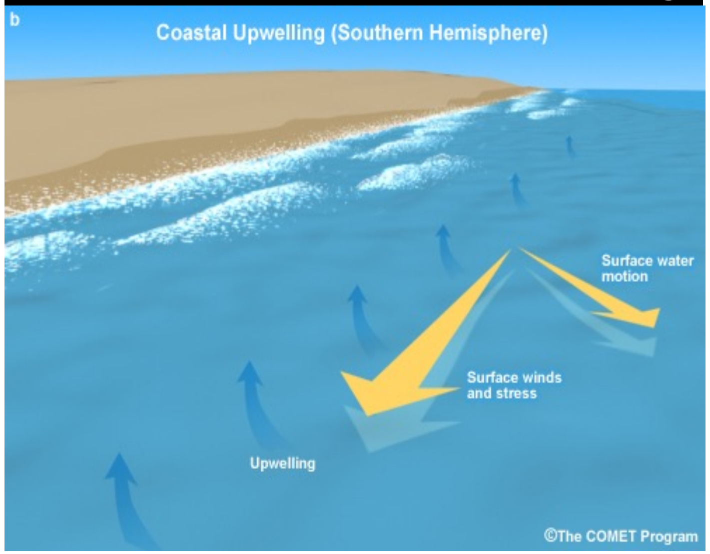
Ocean circulation and Ekman transport

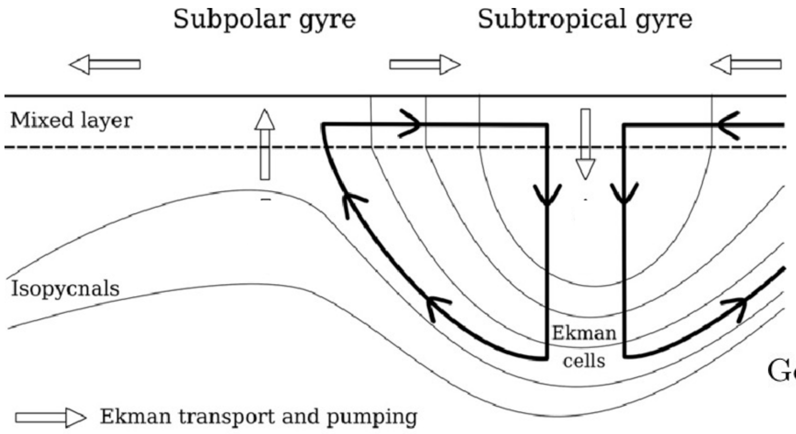
Formation of the gyre circulation

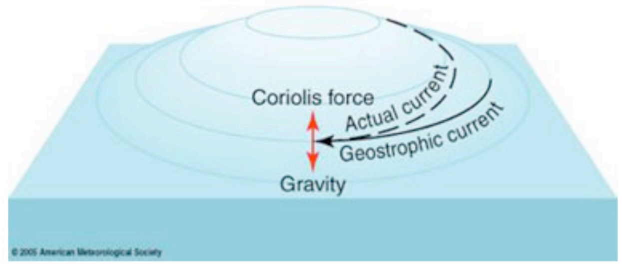


Formation of the wind driven ocean circulation



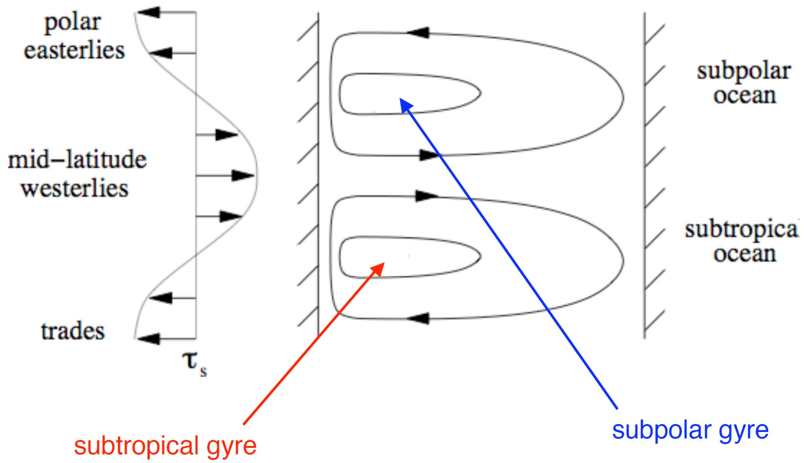




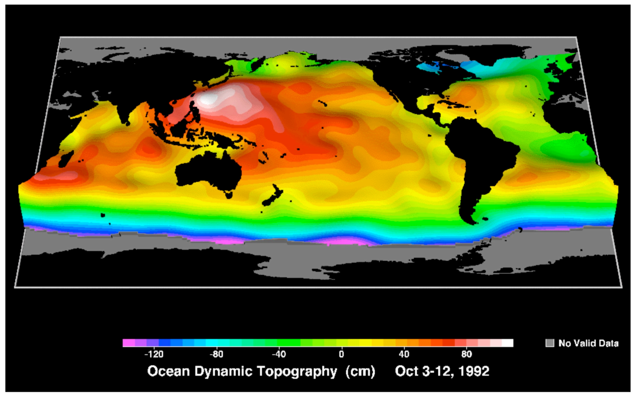


Geostrophic interior: $\beta V = f w_{\text{top}}$

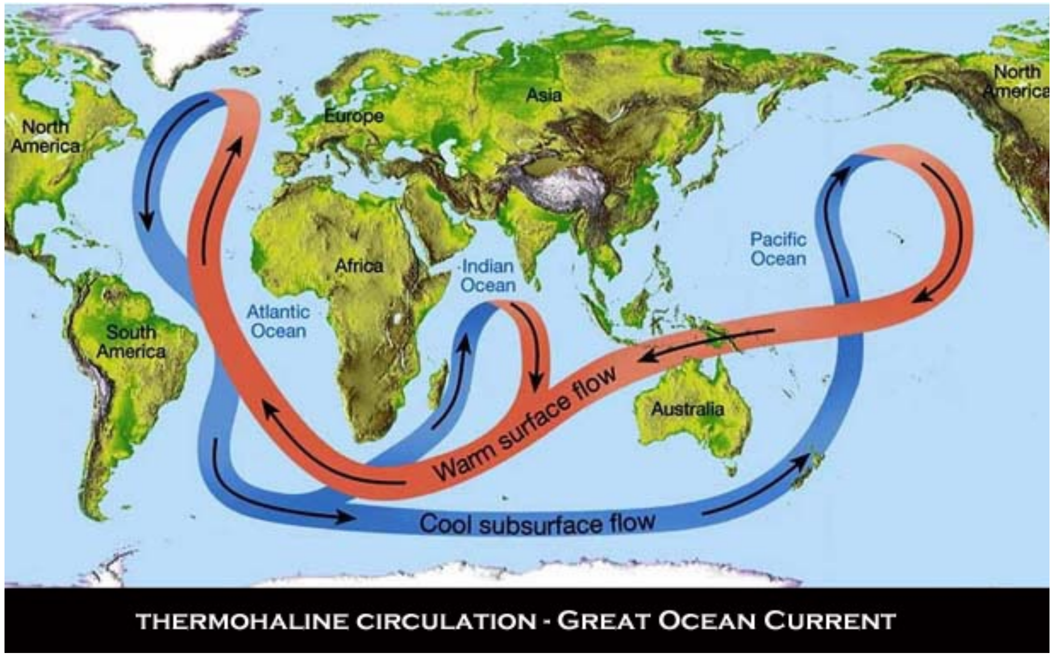
Ekman layer: $f w_{\text{Ek}} = \frac{1}{\rho}(\nabla \times \tau)$

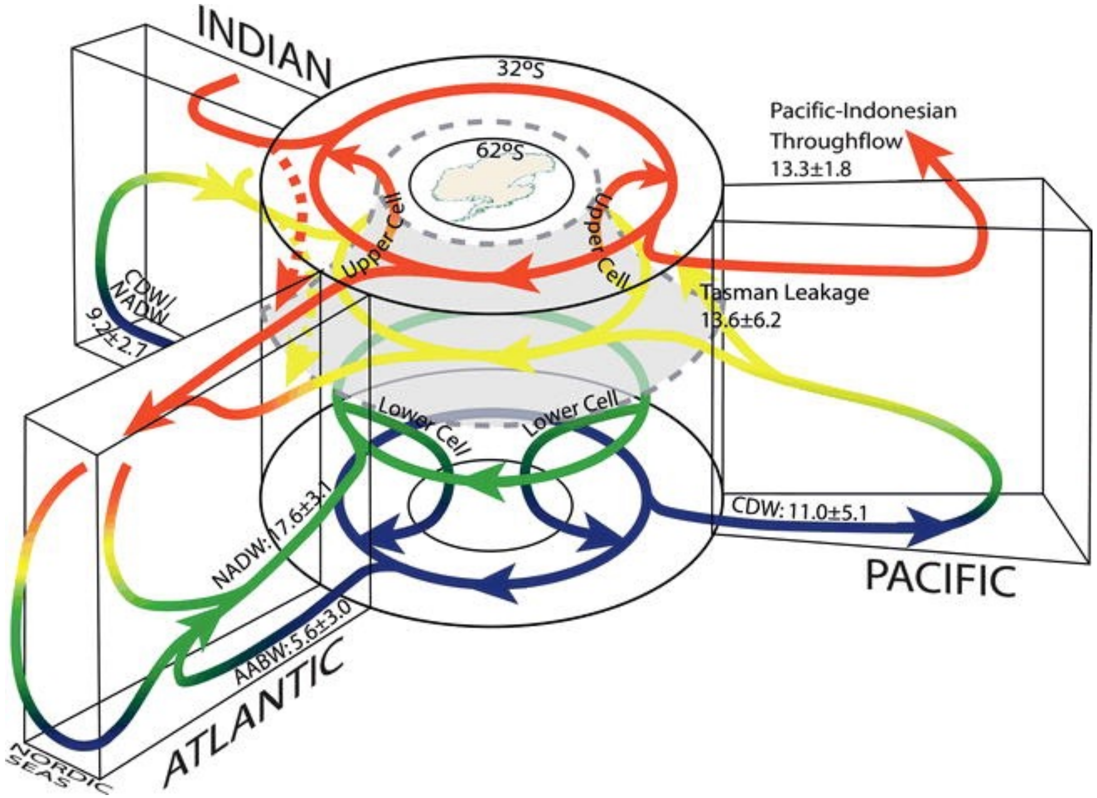


Sea surface height measured from space (satellite altimetry)



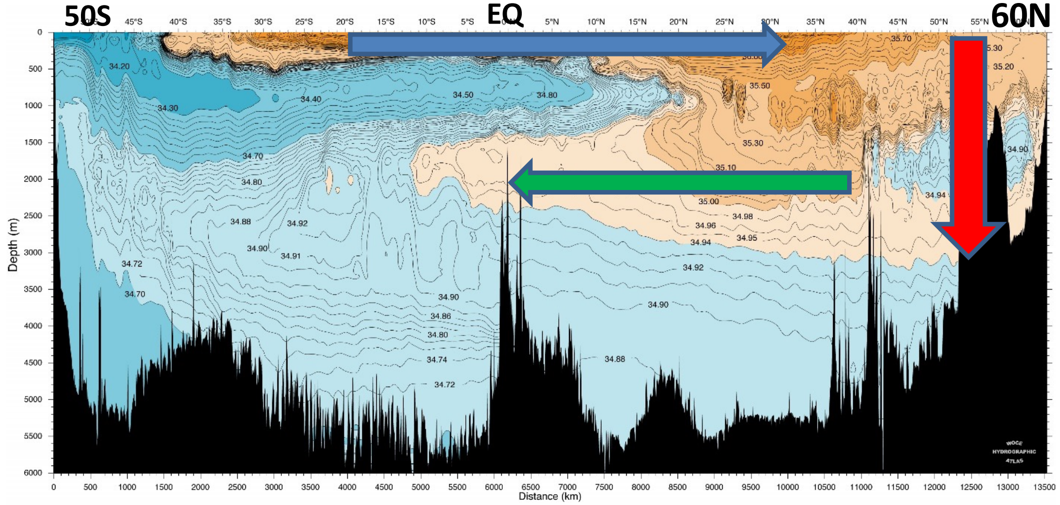
Atlantic Meridional Overturning Circulation (AMOC) or the thermohaline circulation (THC)



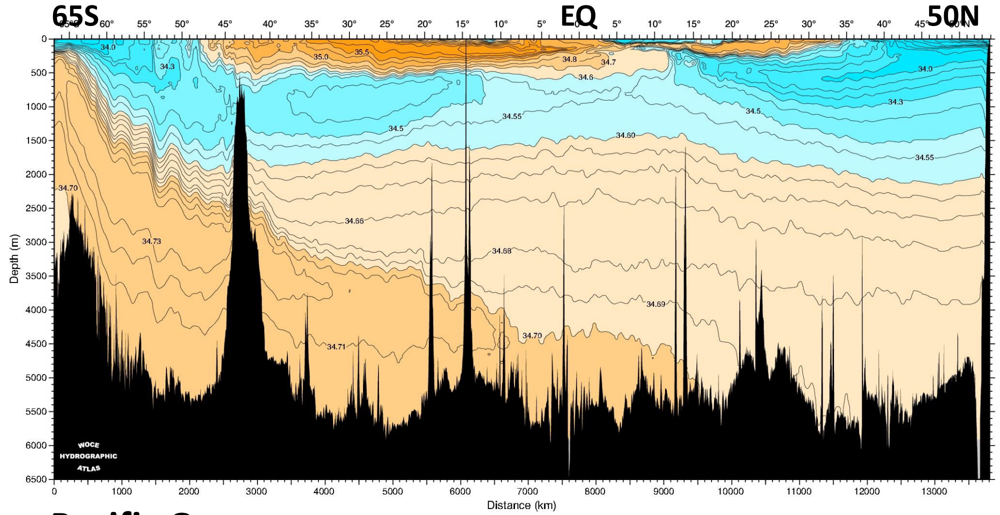


Is there an AMOC

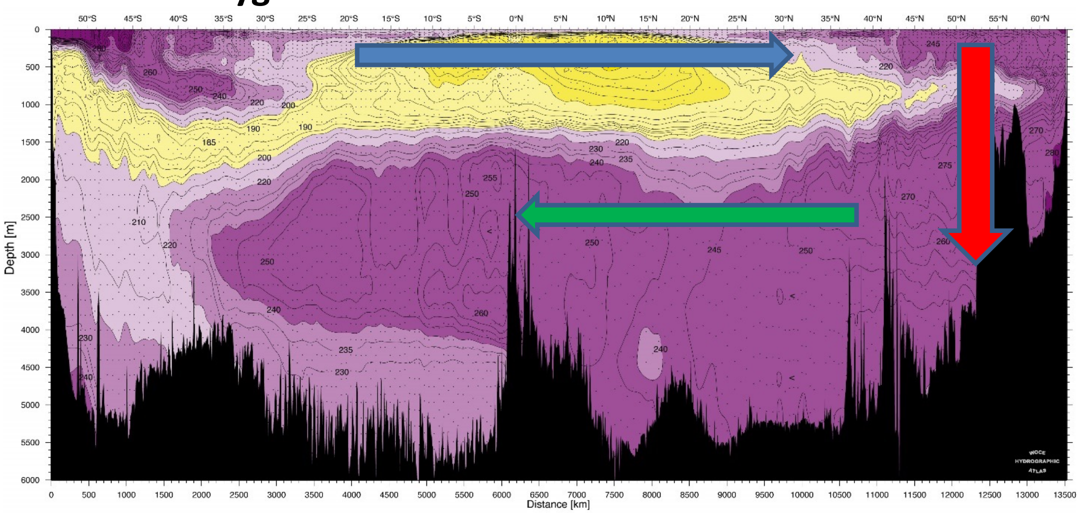
Atlantic Salinity A16



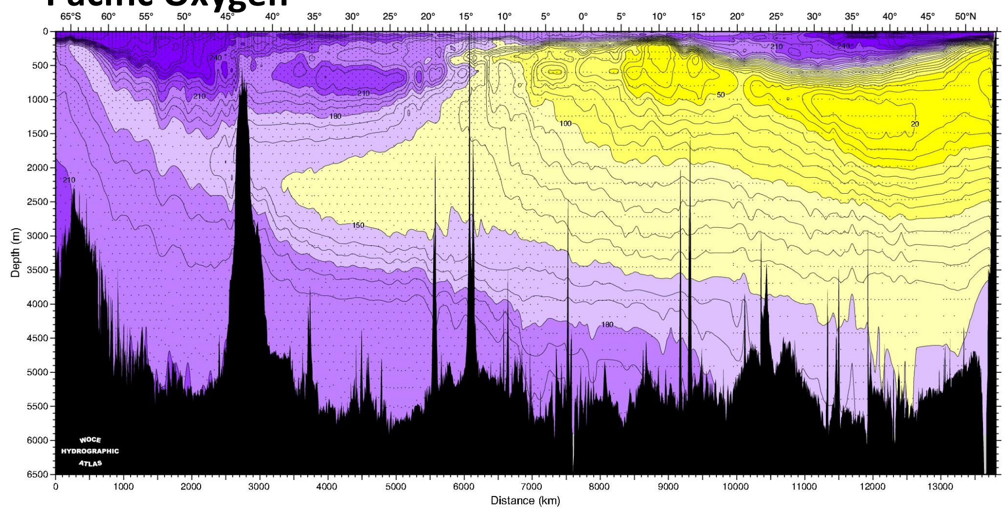
Pacific Salinity P15



Atlantic Oxygen

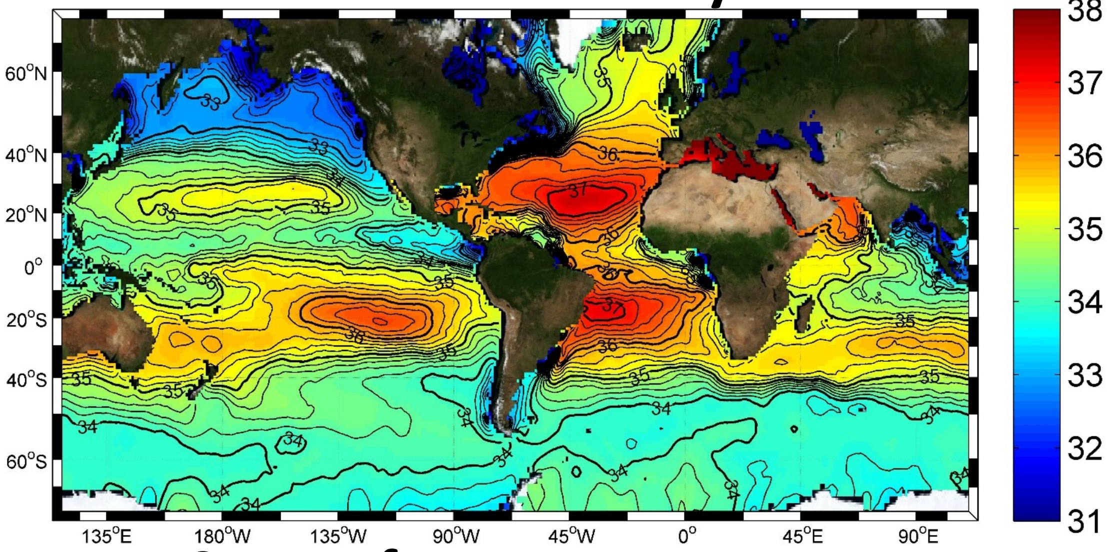


Pacific Oxygen

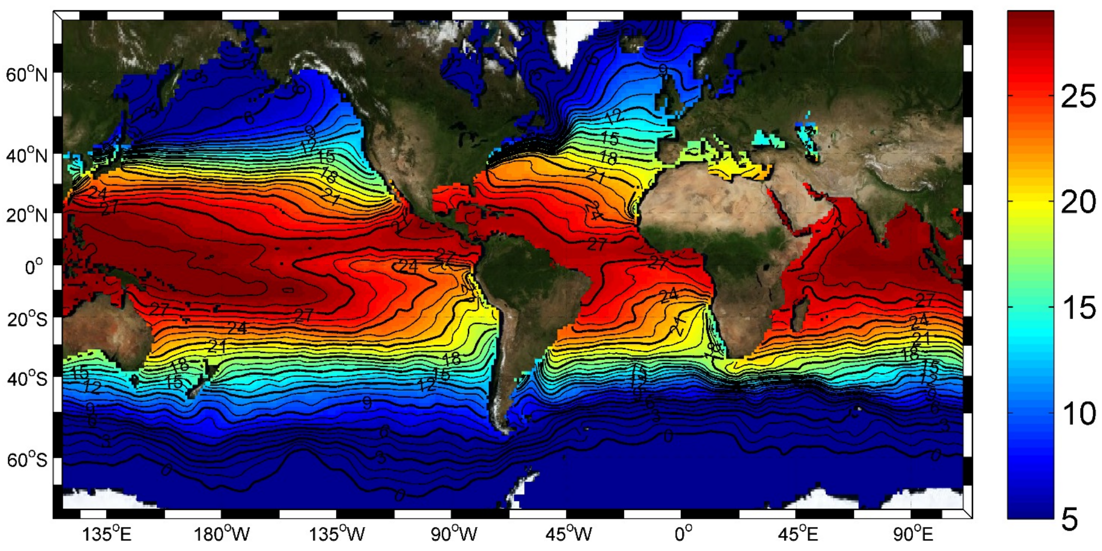


http://woceatlas.ucsd.edu/index.html

Sea surface salinity

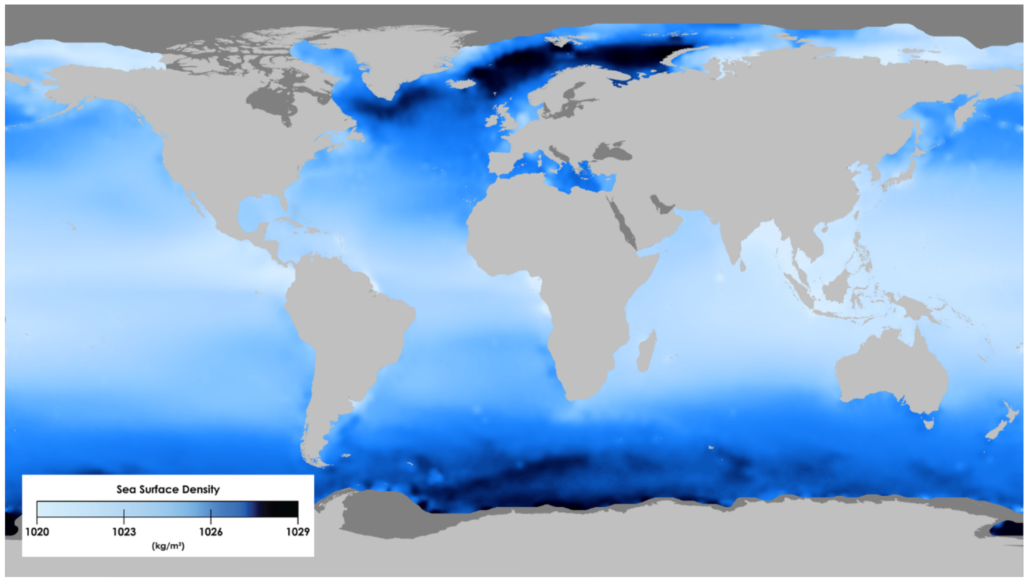


Sea surface temperature



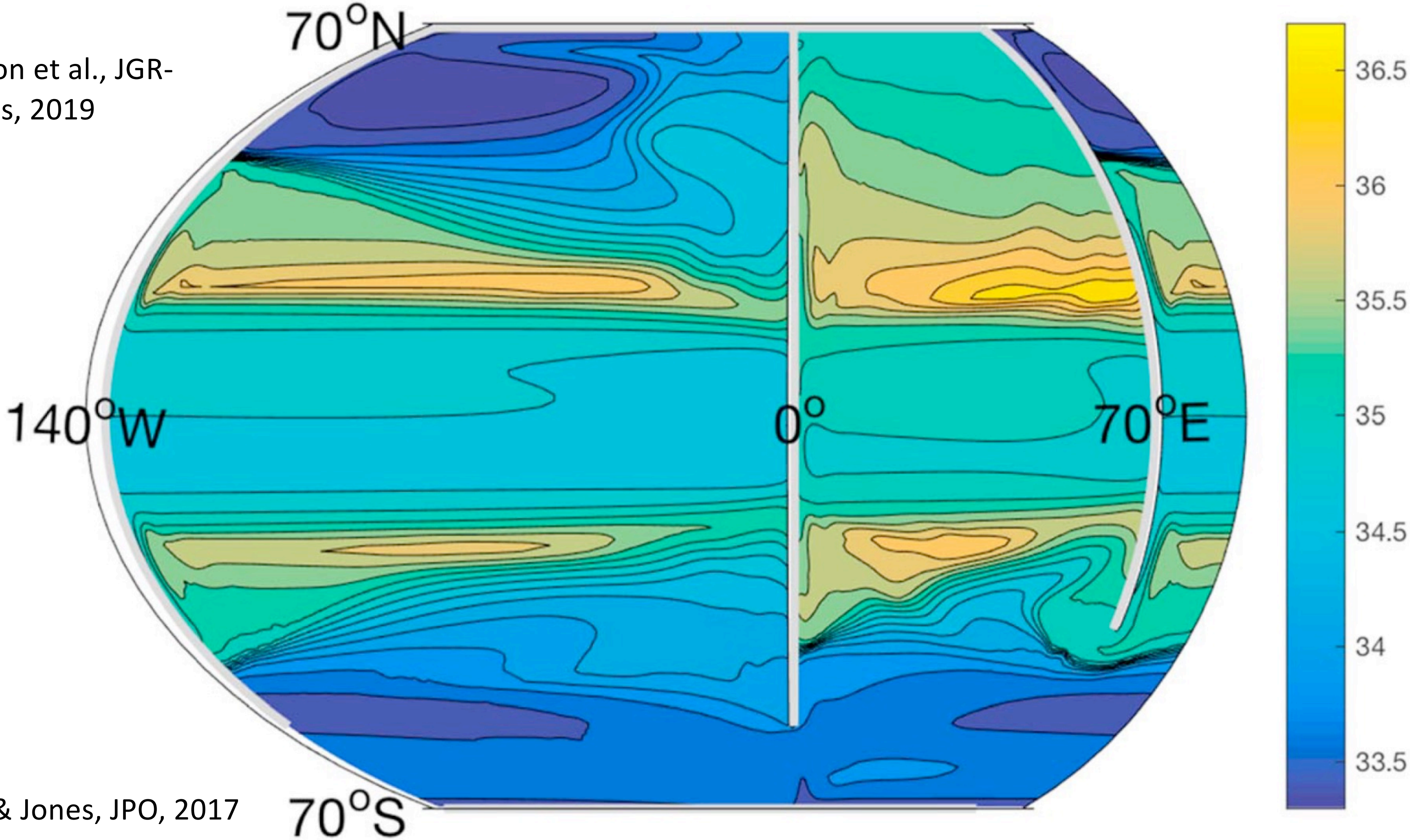
Linear equation of sea water state

$$\rho = \rho_0 - \alpha(T - T_0) + \beta(S - S_0)$$



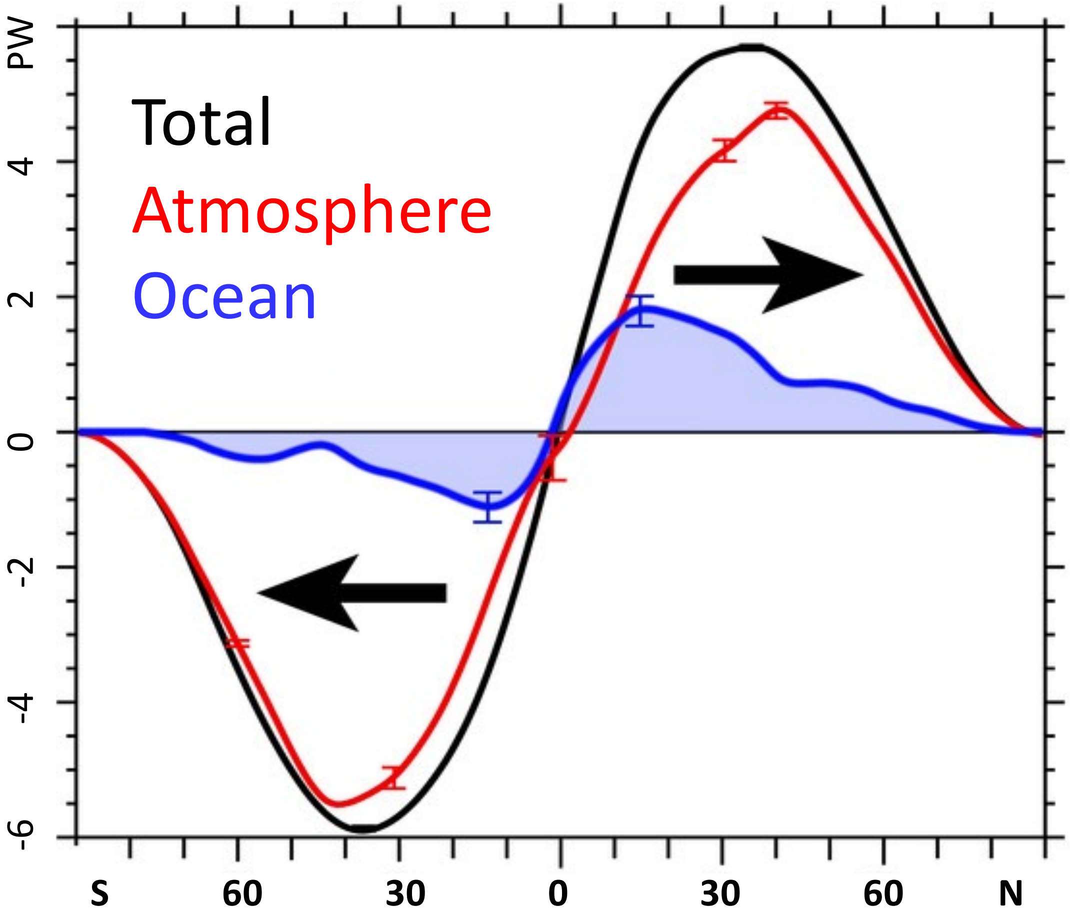
Reasons for a saltier Atlantic under present day climate

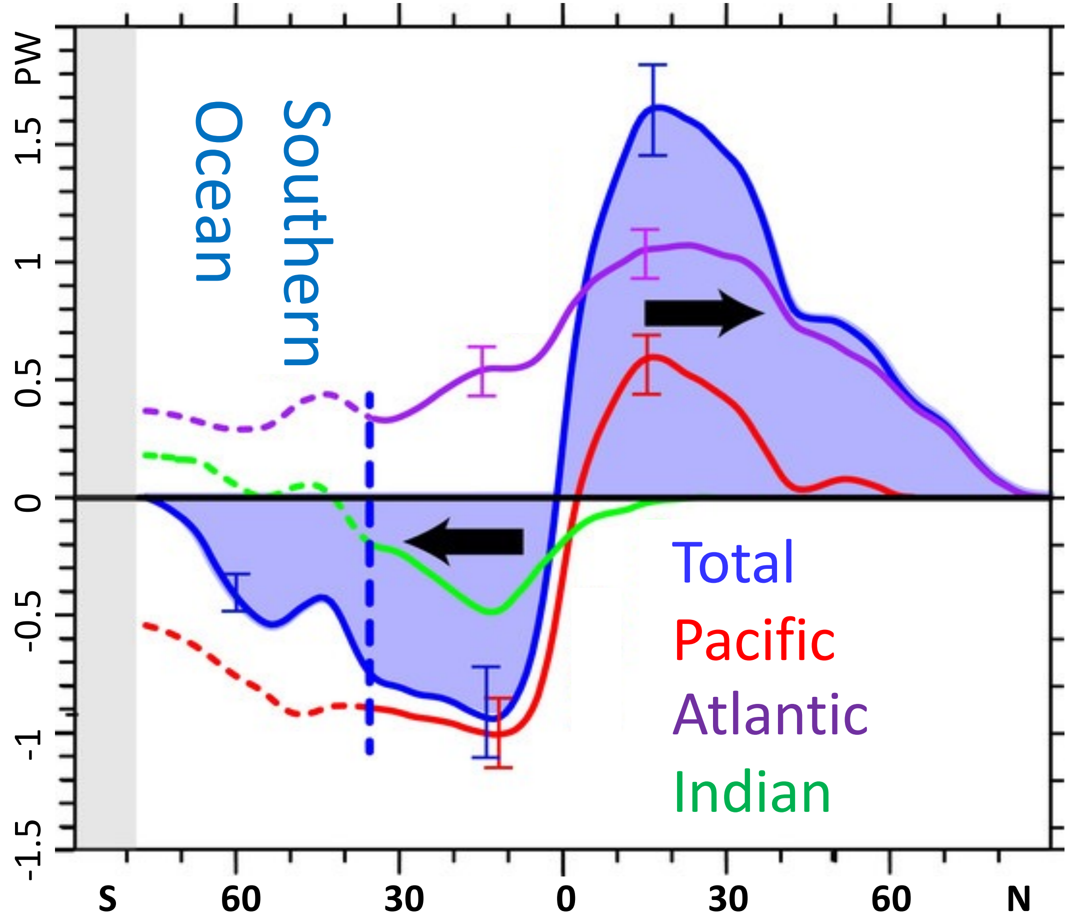
Johnson et al., JGR-Oceans, 2019



Cessi & Jones, JPO, 2017

Meridional heat transport by air and ocean

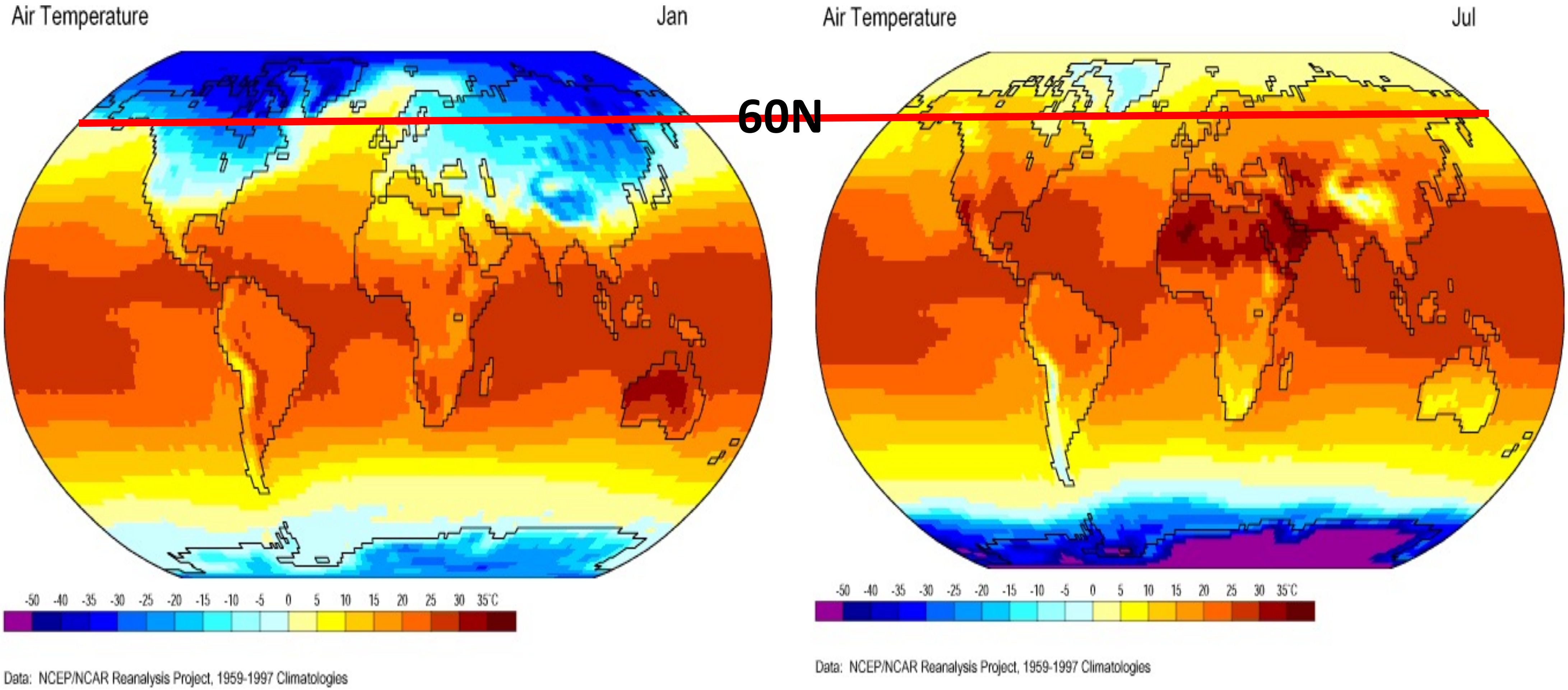




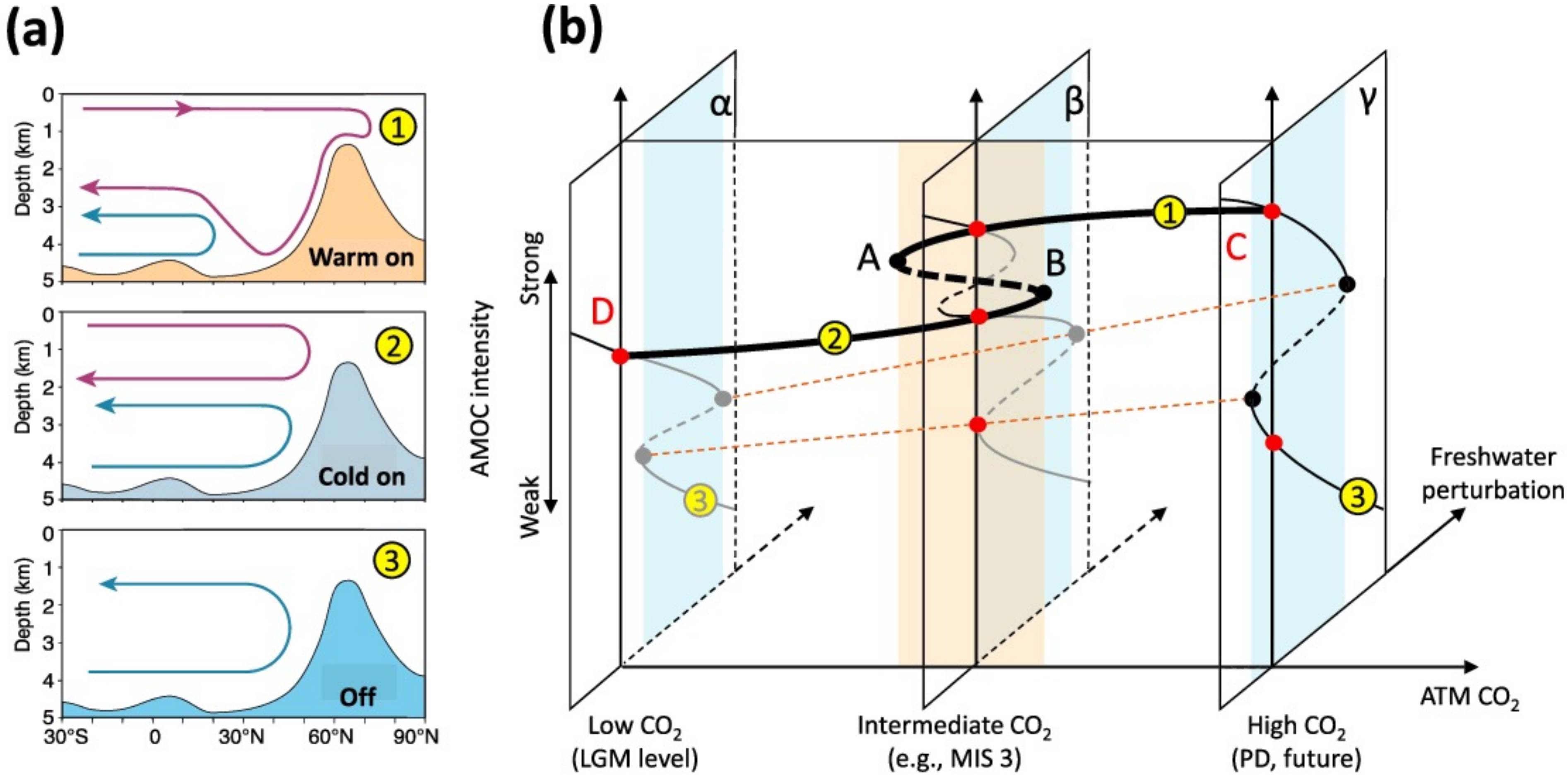
PW = 10^{15}W

Trenberth et al., J. Climate, 2019

AMOC and its influence on regional mean climate

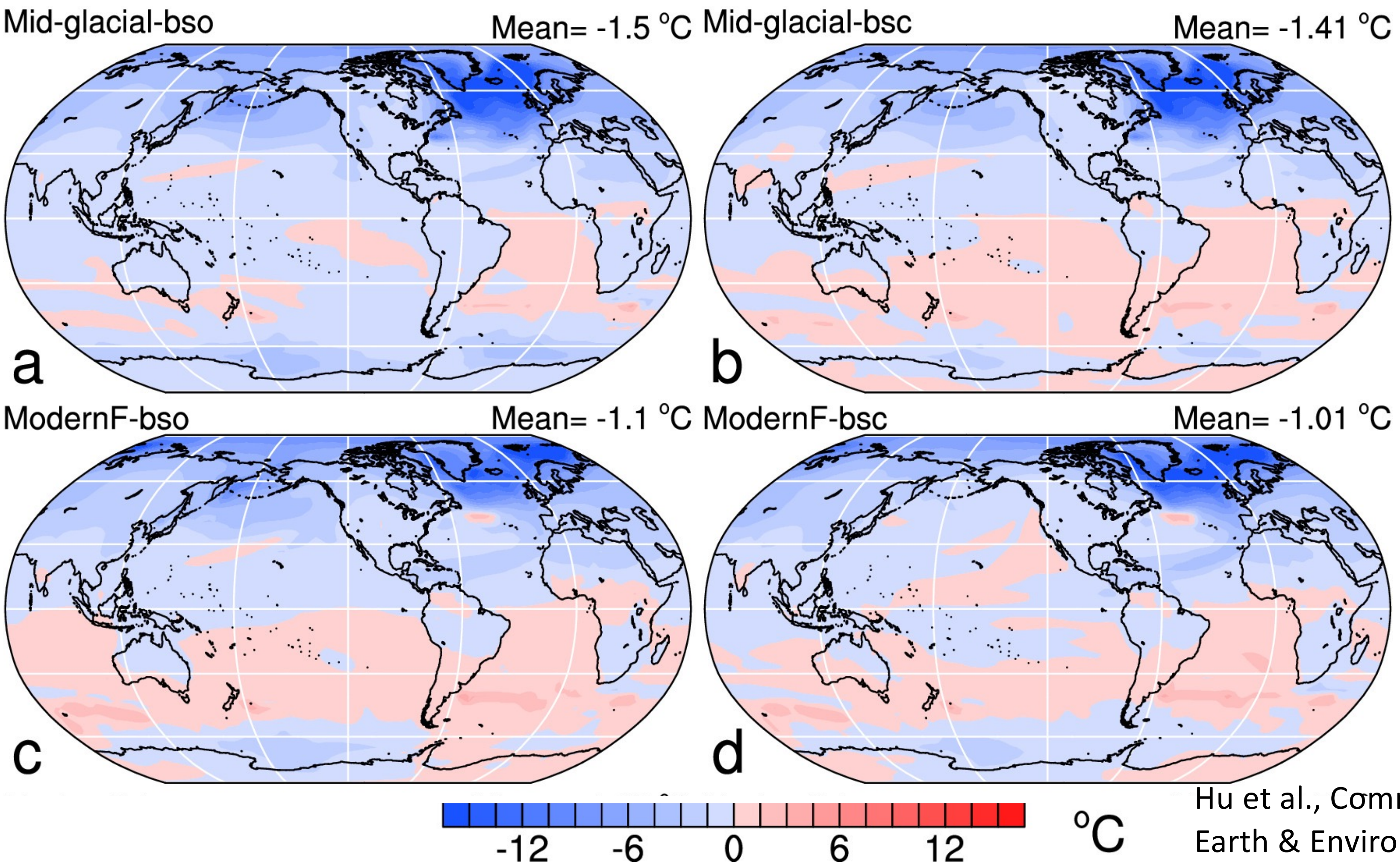


AMOC hysteresis and abrupt climate change



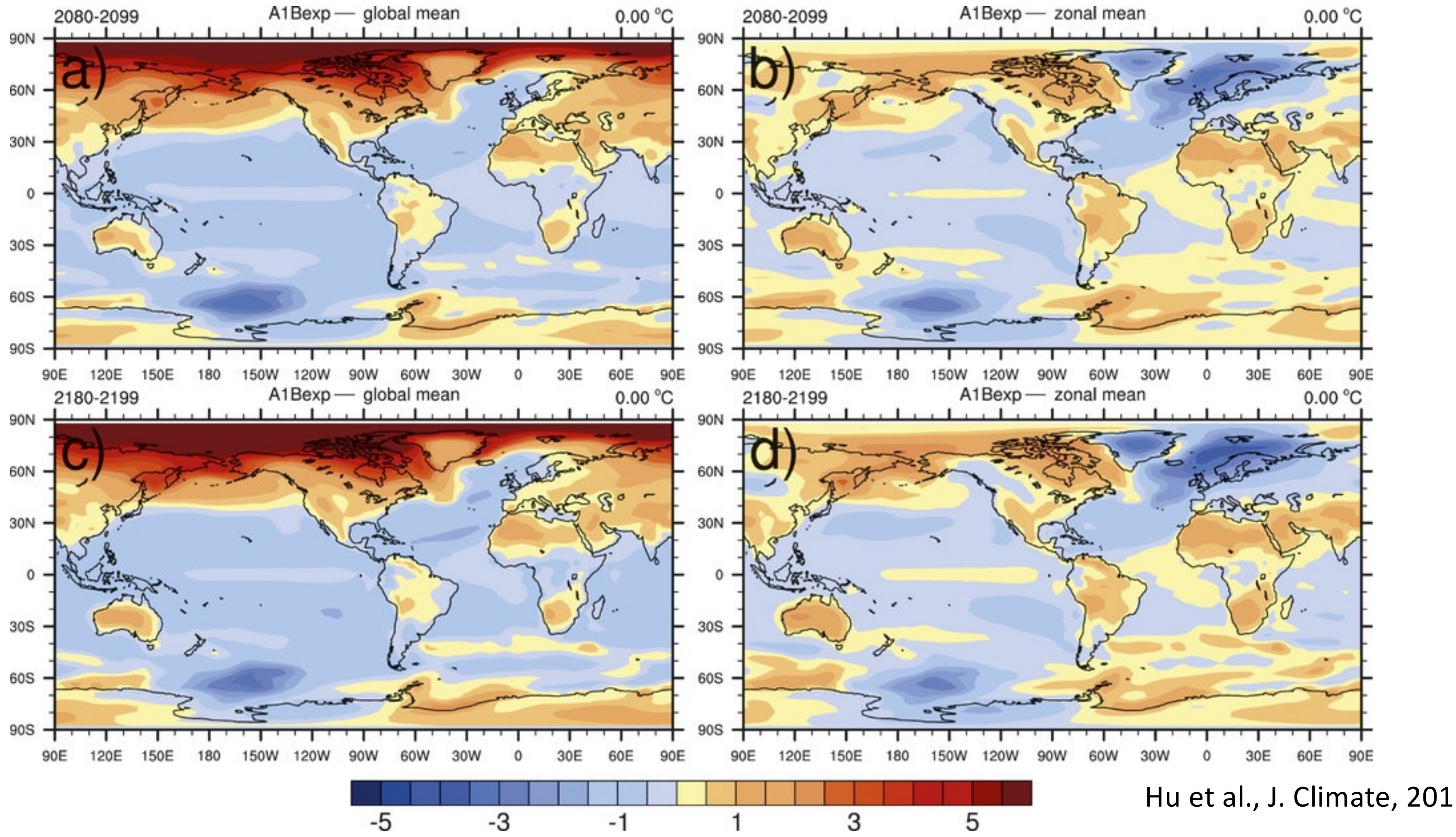
Weijer et al., JGR-ocean, 2019

Impact of a collapsed AMOC on regional climate



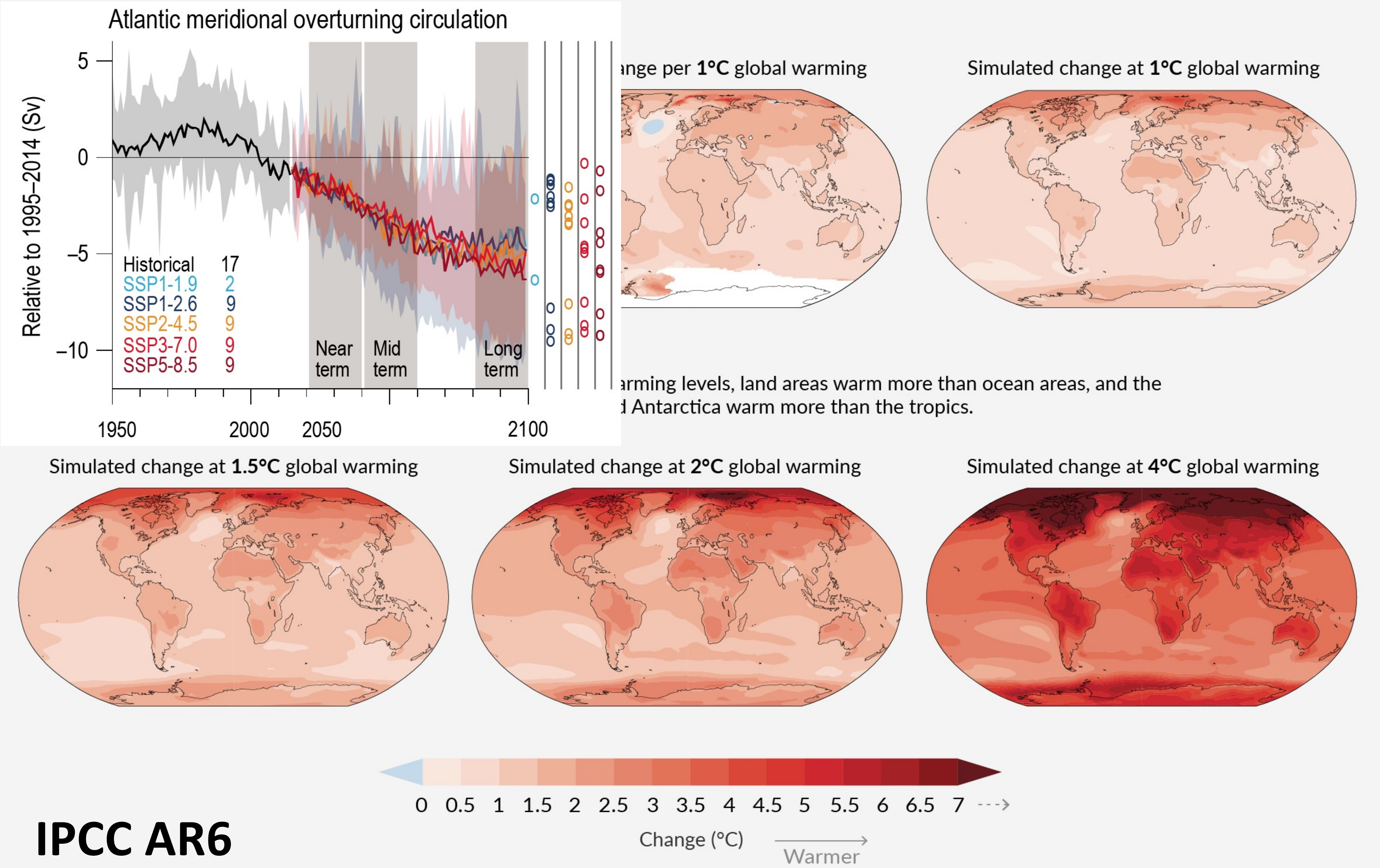
Hu et al., Communications Earth & Environment, 2023

Influence of AMOC on regional climate under global warming



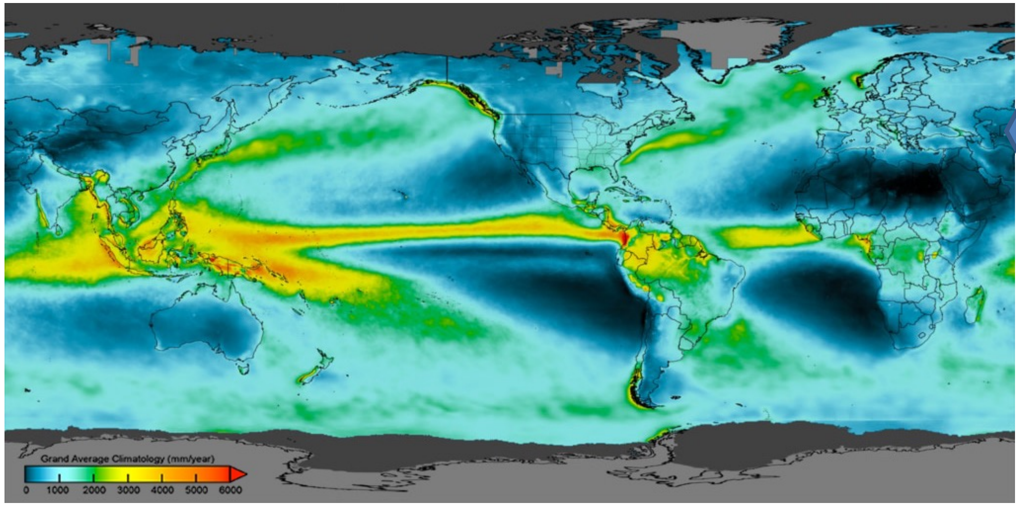
Hu et al., J. Climate, 2012

Evidence of AMOC- s impact on regional warming

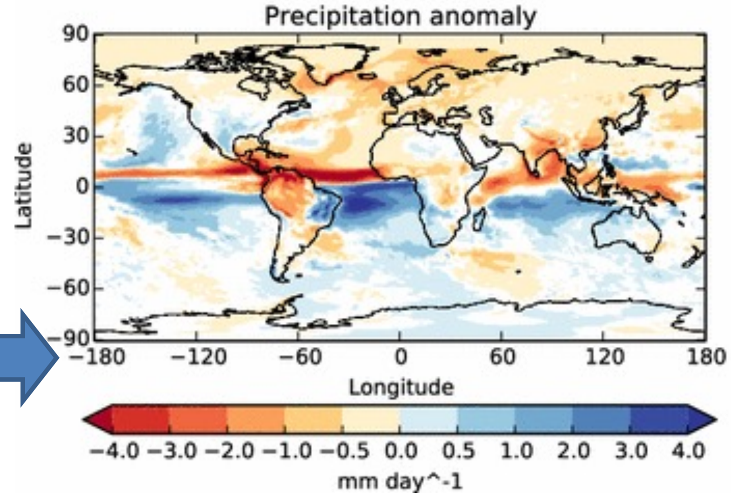


IPCC AR6

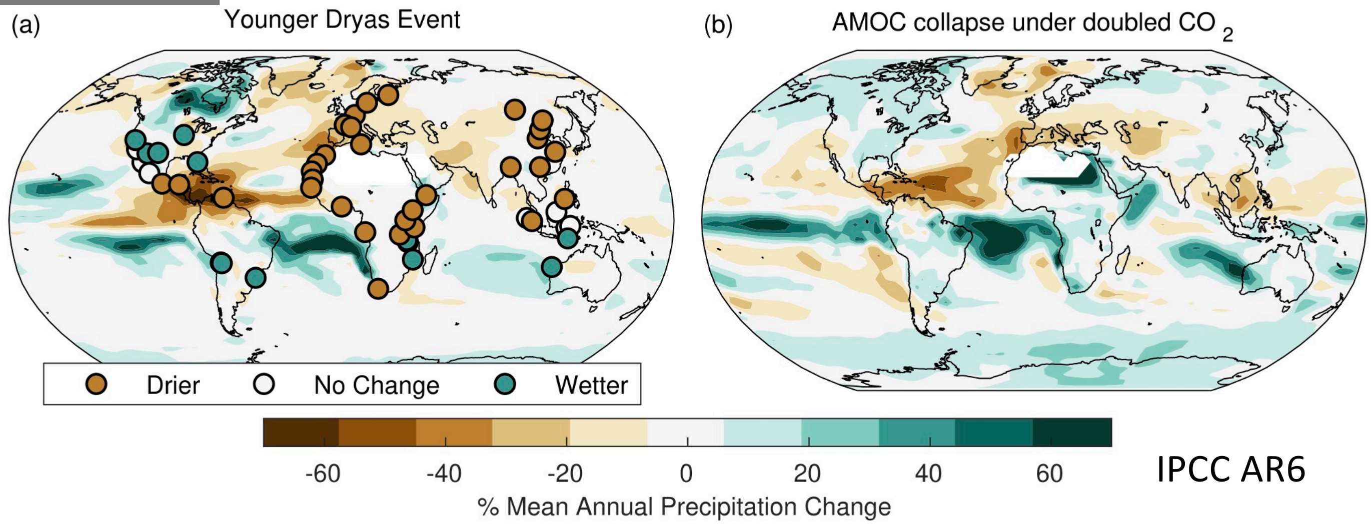
AMOC and its influence on regional precipitation



Satellite observed precipitation (2000-2019) by NASA



Jackson et al., Climate Dynamics, 2015

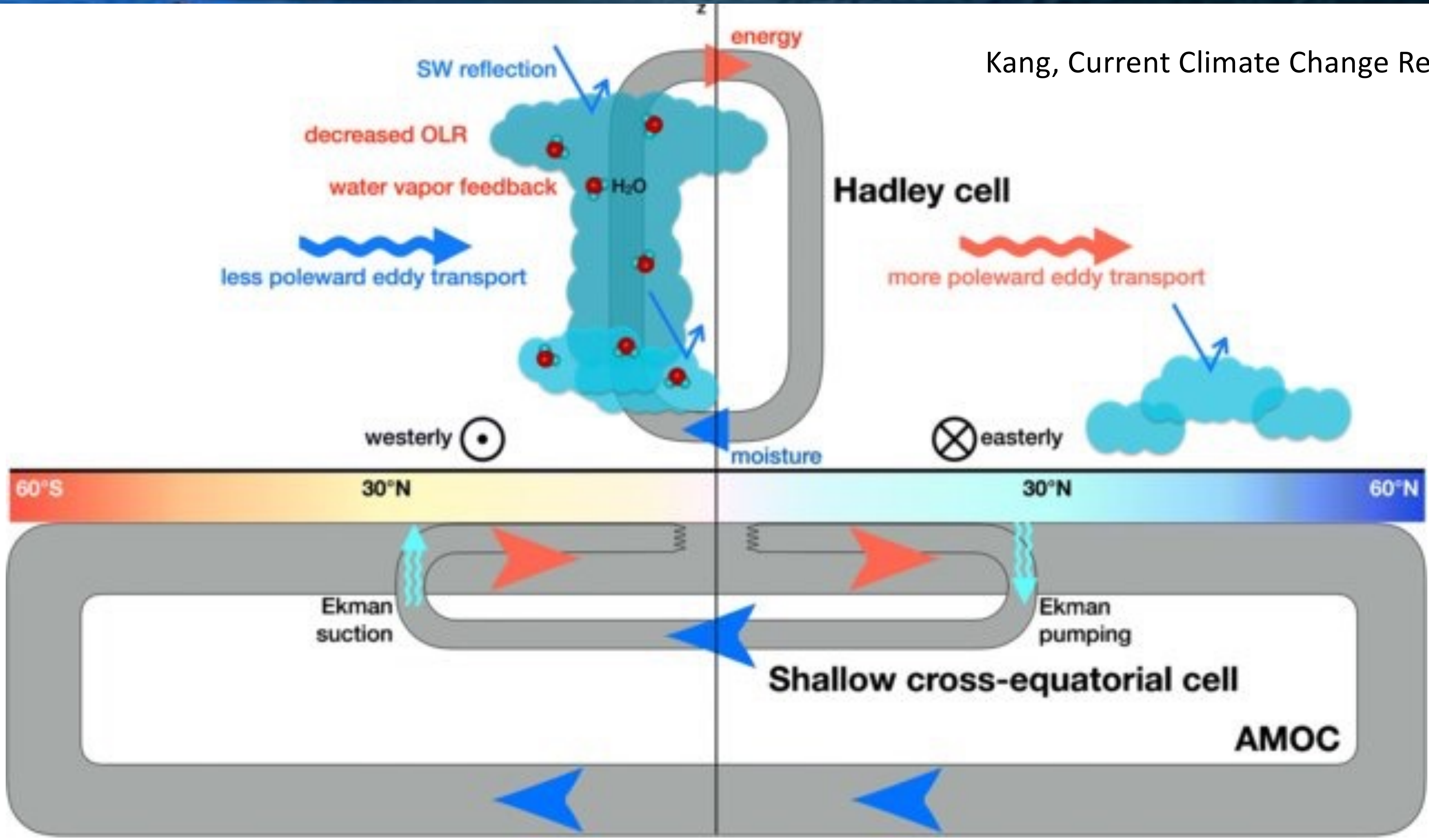


IPCC AR6

Younger Dryas: 12,900 – 11,700 yrs BP

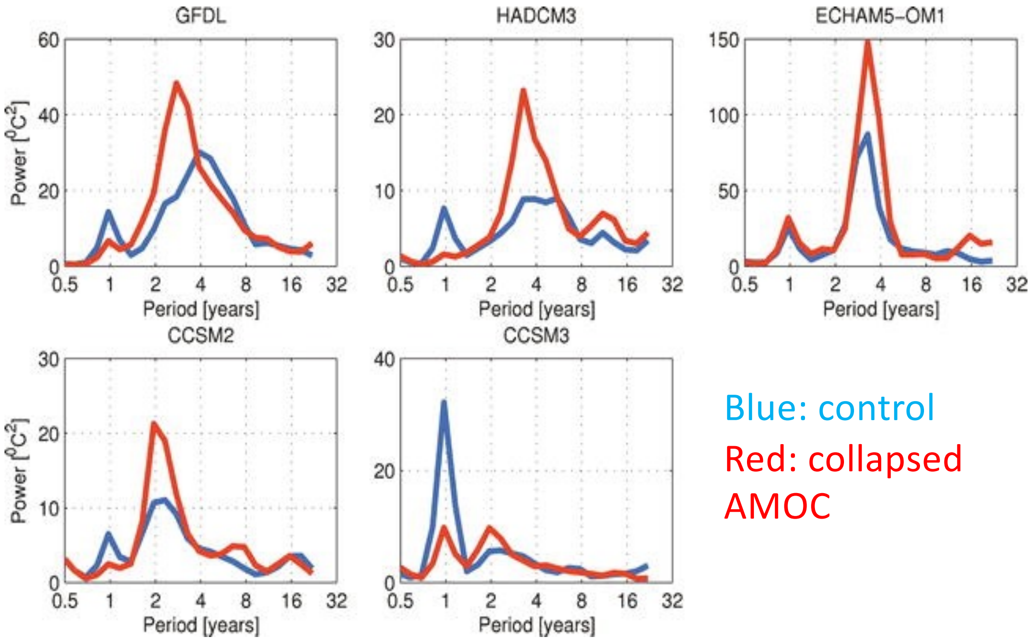
Influence of AMOC on ITCZ

Kang, Current Climate Change Reports, 2020



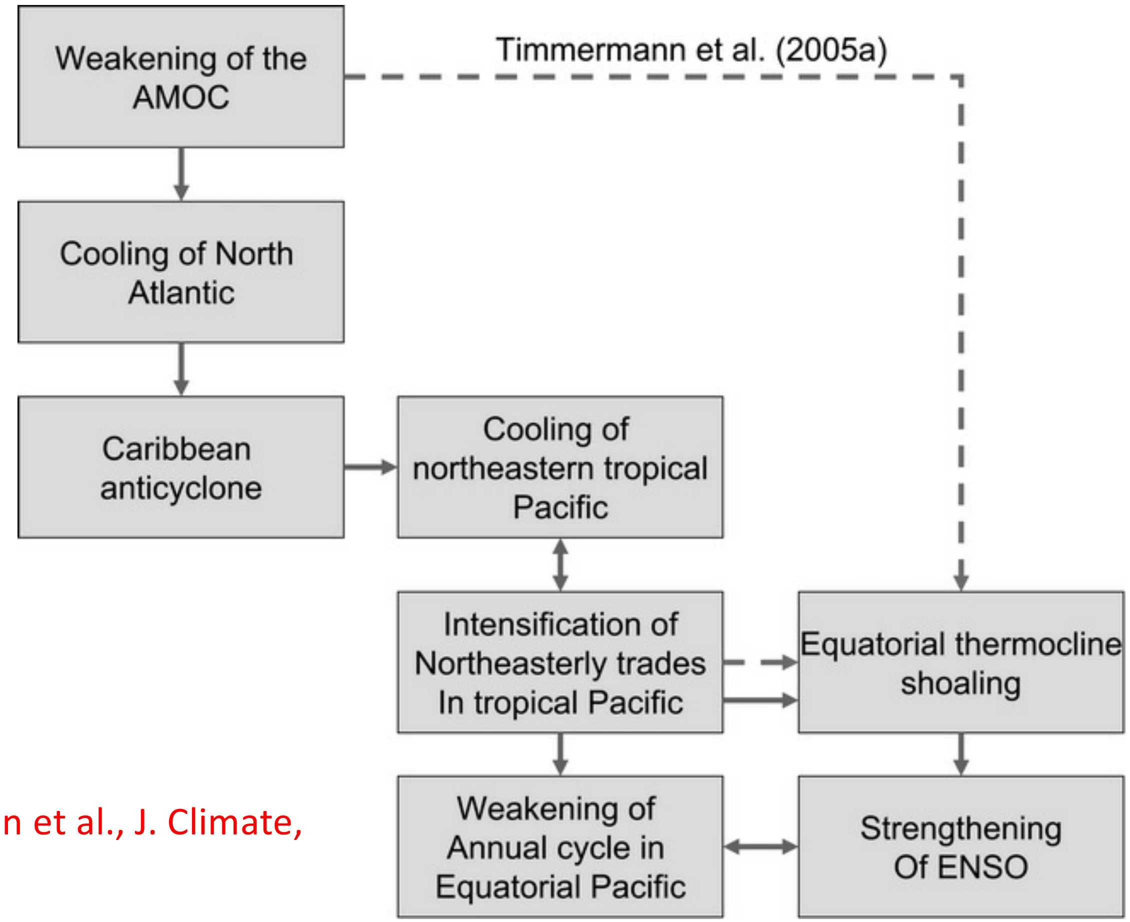
Influence of a collapsed AMOC on ENSO

Nino 3 power spectrum



Blue: control
Red: collapsed AMOC

Schematic diagram

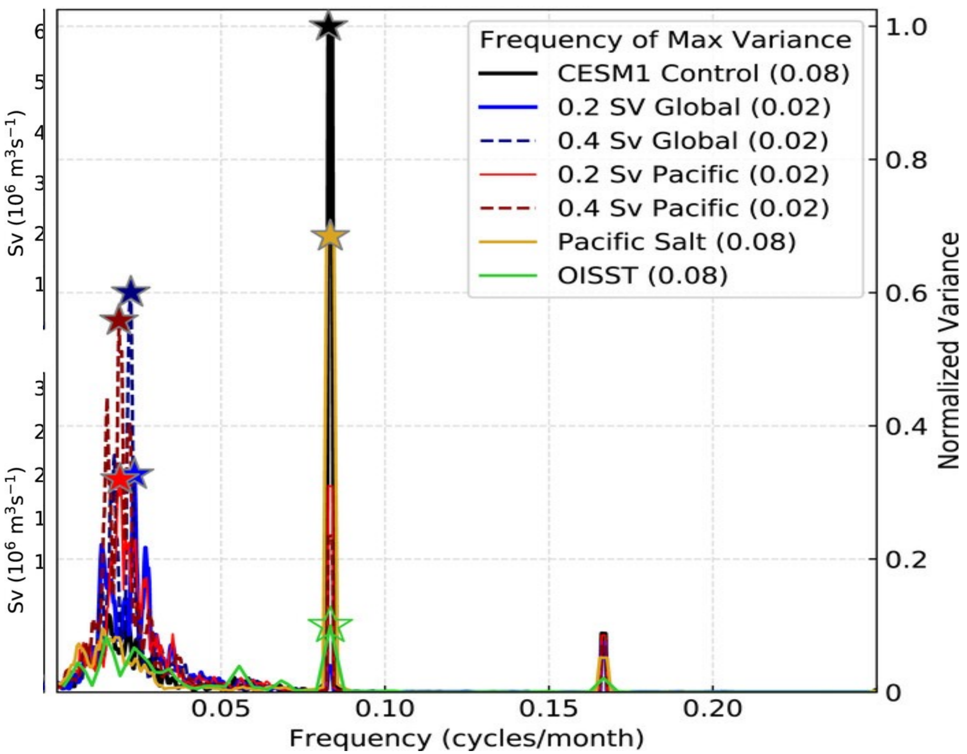


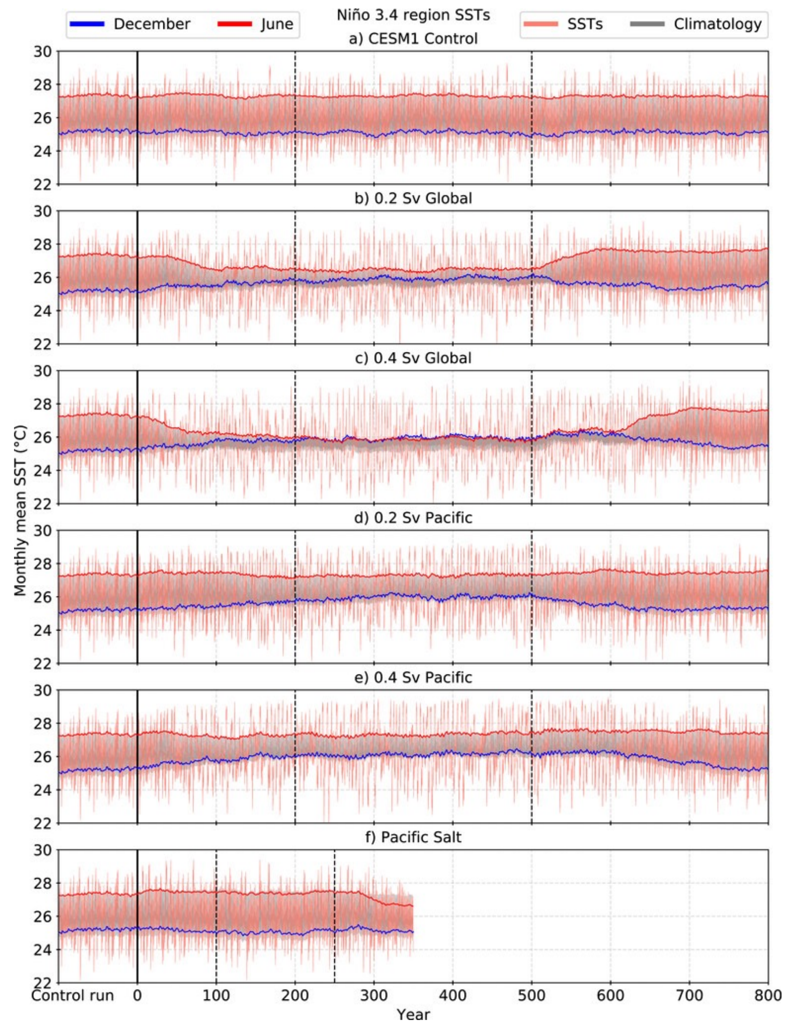
1. Southward movement of ITCZ
2. Reduced annual cycle
3. Strengthened ENSO

Timmerman et al., J. Climate, 2007

Influence of a collapsed AMOC on ENSO

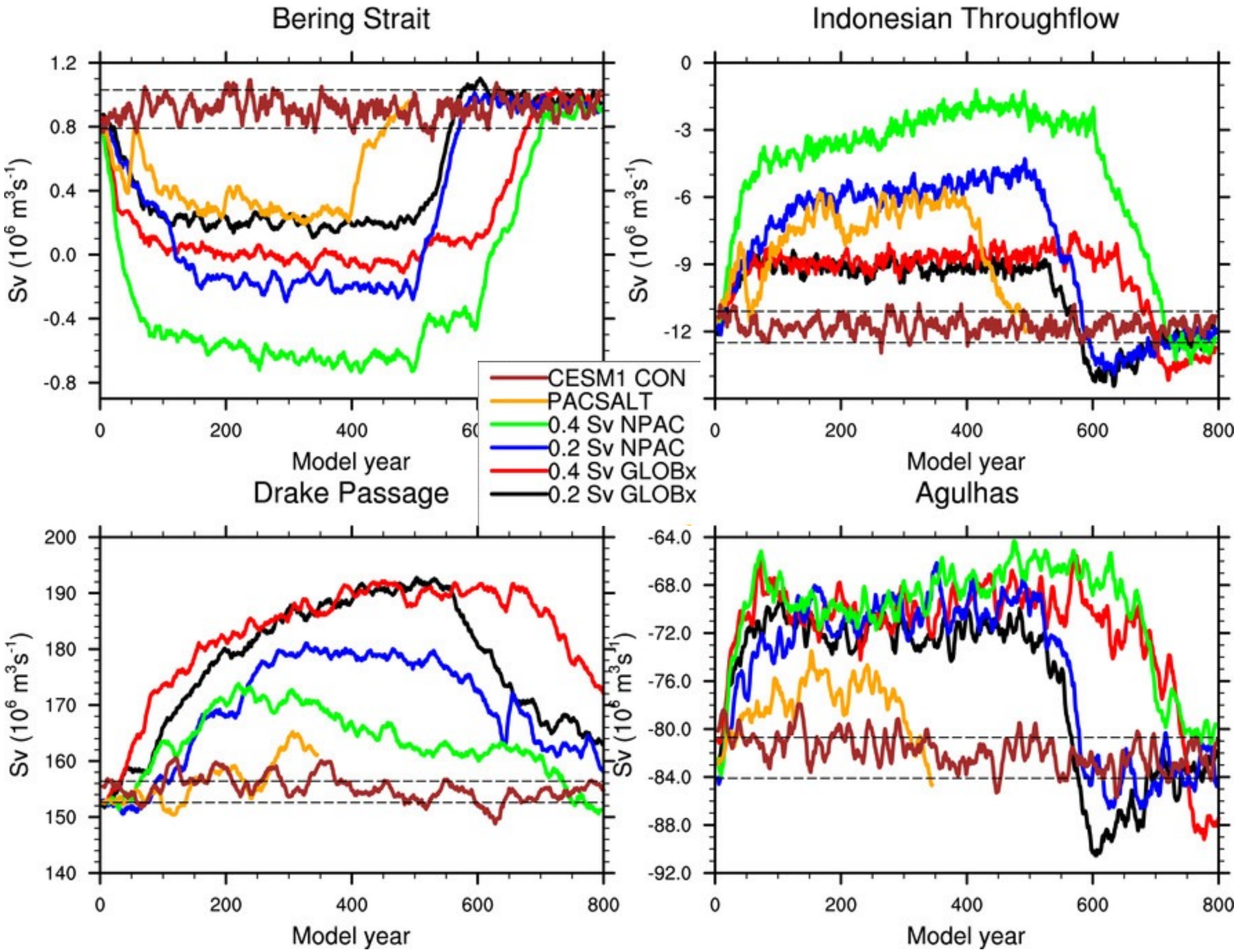
Community Earth System Model version 1
1850 control, 0.2 or 0.4 Sv freshwater added into subpolar North Atlantic, compensation global or North Pacific

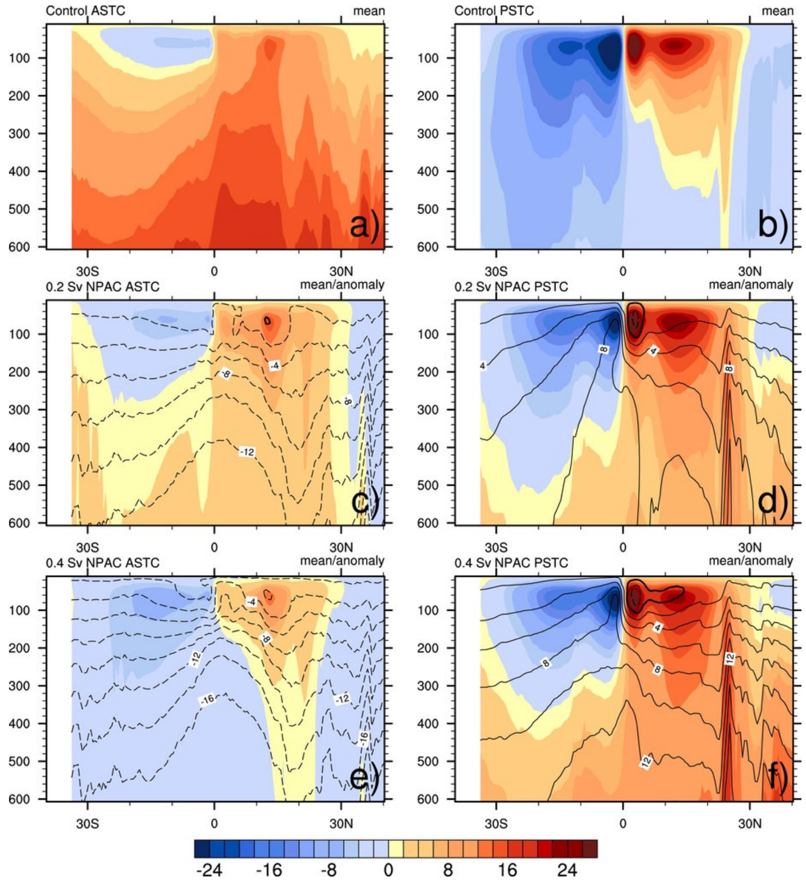




Molina et al., J. Climate, 2022

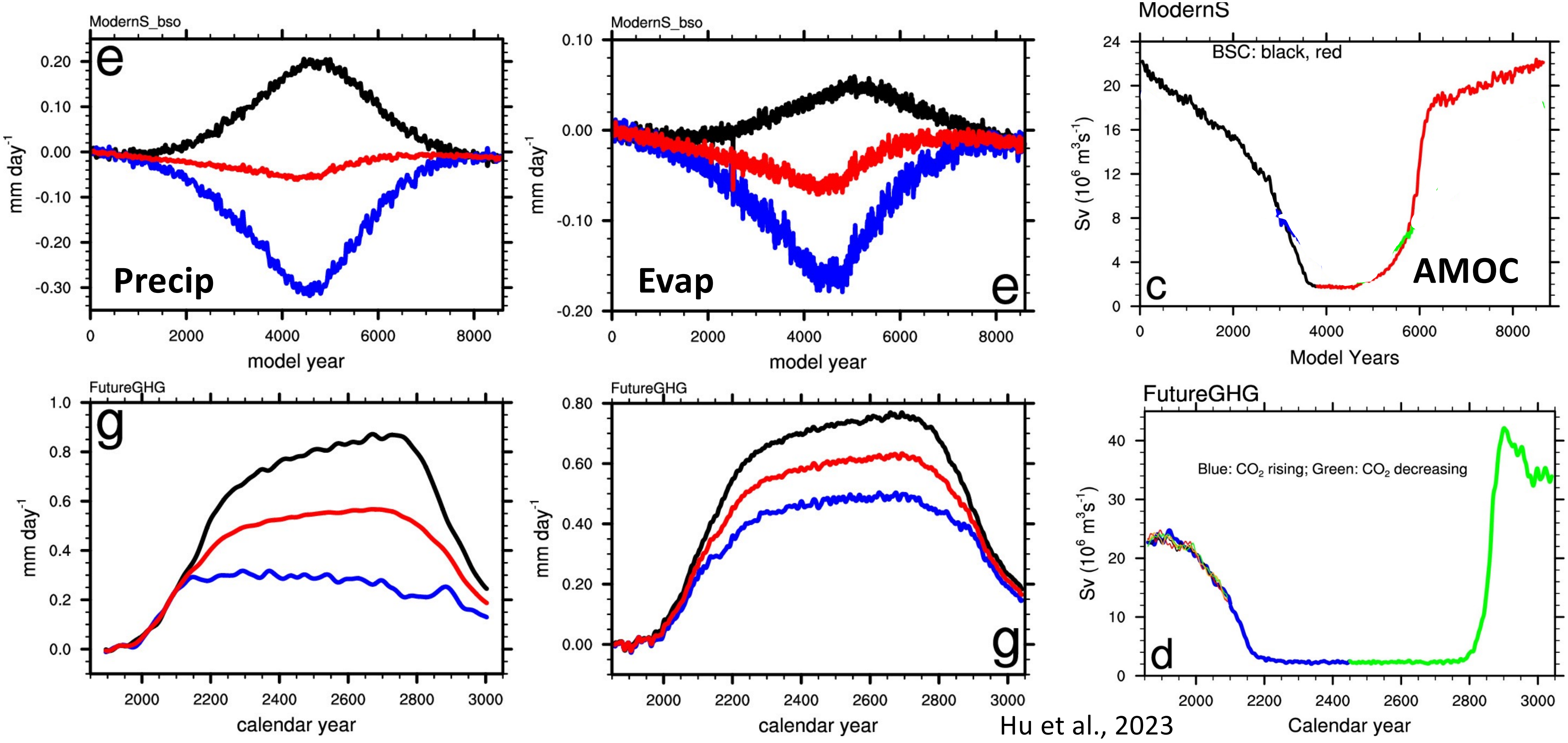
Influence of Collapsed AMOC on ocean circulation





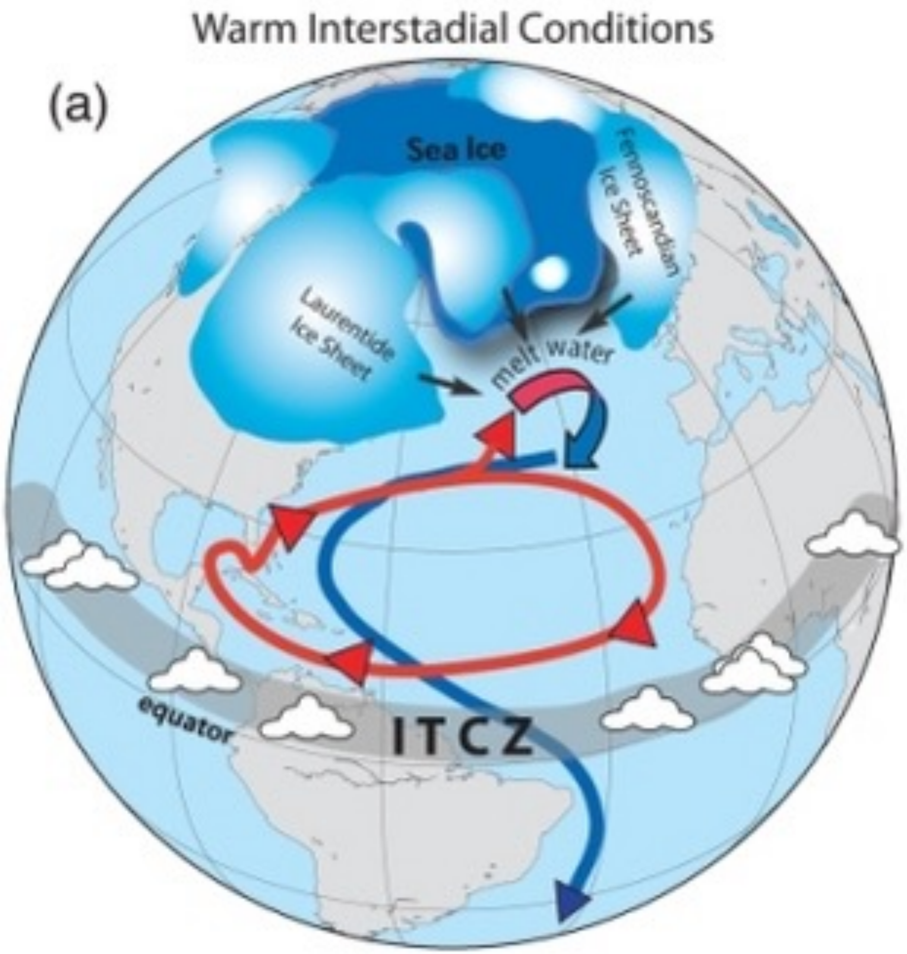
Hu et al., J. Climate, 2021

Influence of AMOC on precipitation and evaporation



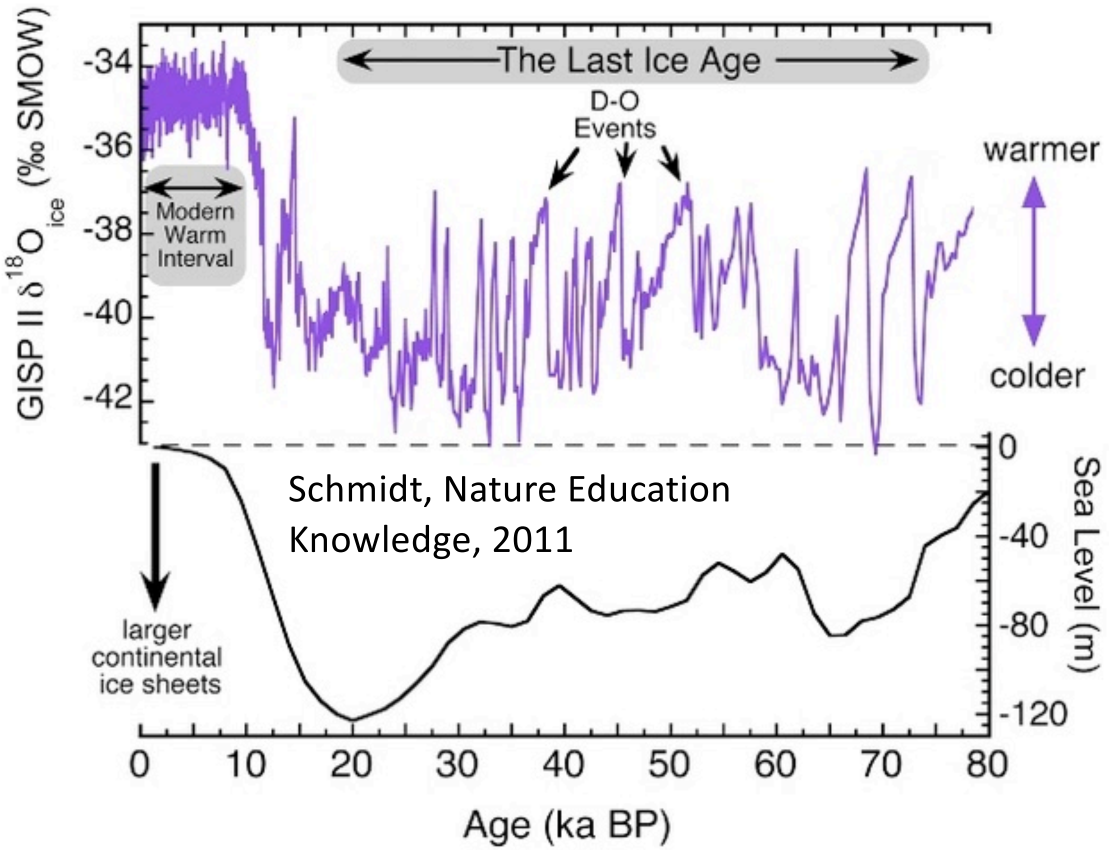
Hu et al., 2023

AMOC, ITCZ and Ice Sheet under glacial conditions

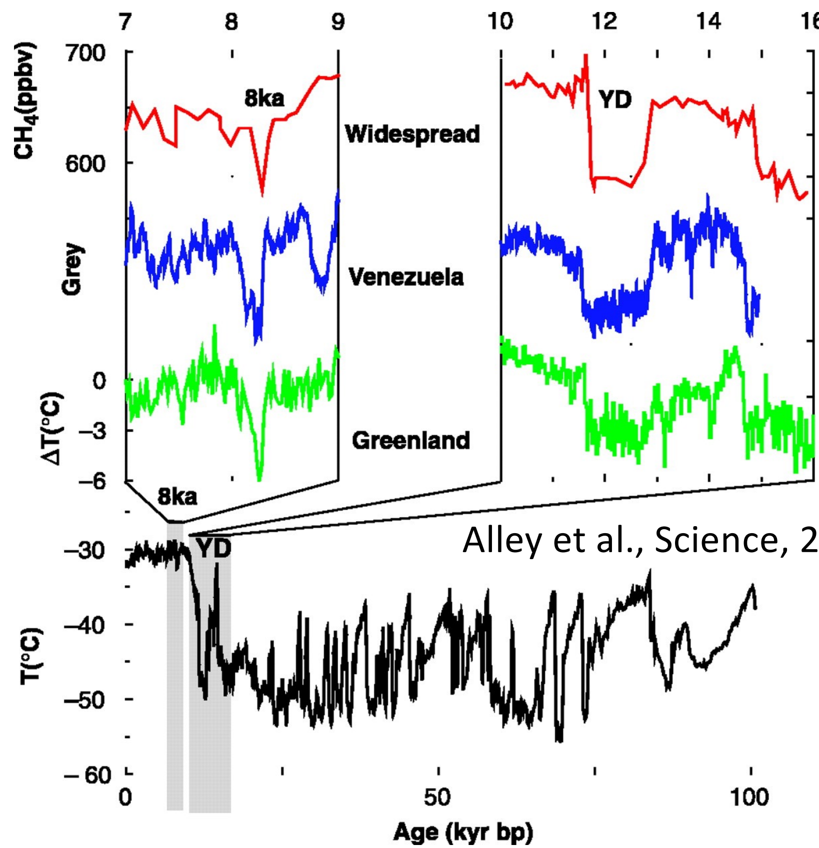


Schmidt, Nature Education Knowledge, 2011

Abrupt climate change events during last glacial period



Schmidt, Nature Education Knowledge, 2011

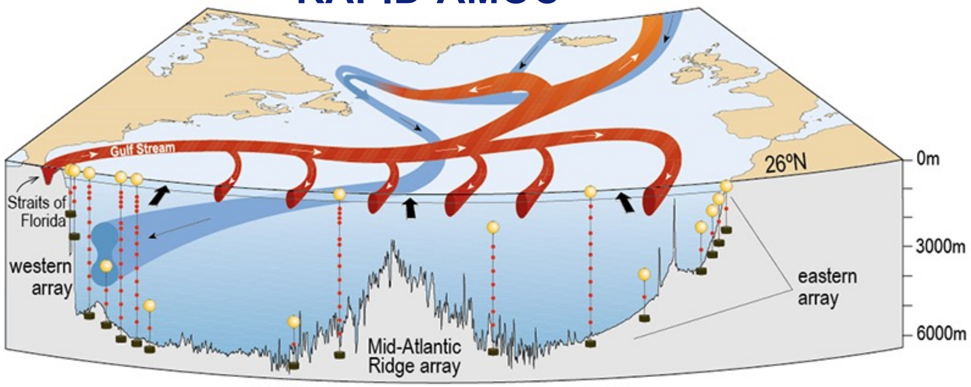


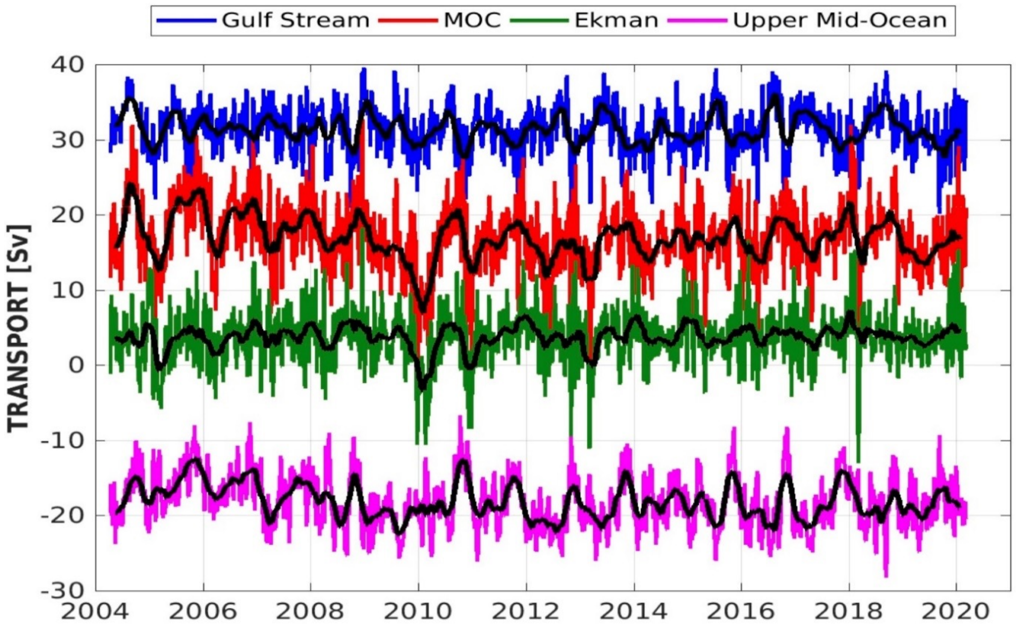
Alley et al., Science, 2003

Dansgaard–Oeschger events (D-O events): ~1500 yrs
Heinrich events (ice rafted debris): H1-H6
Younger Dryas: 12,900 – 11,700 yrs BP

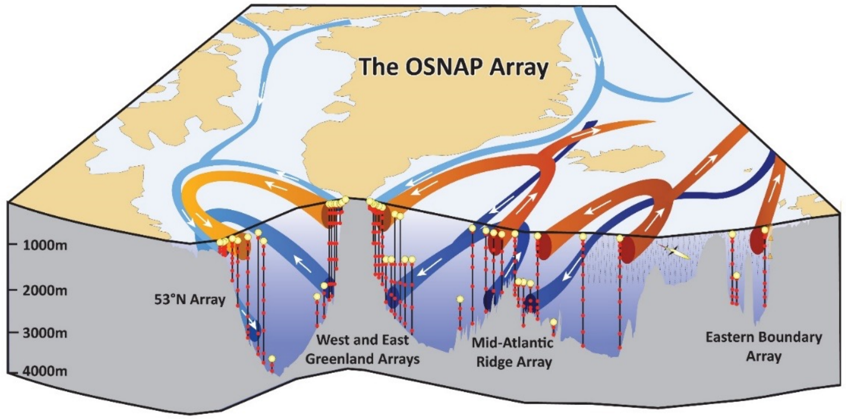
Modern AMOC observations

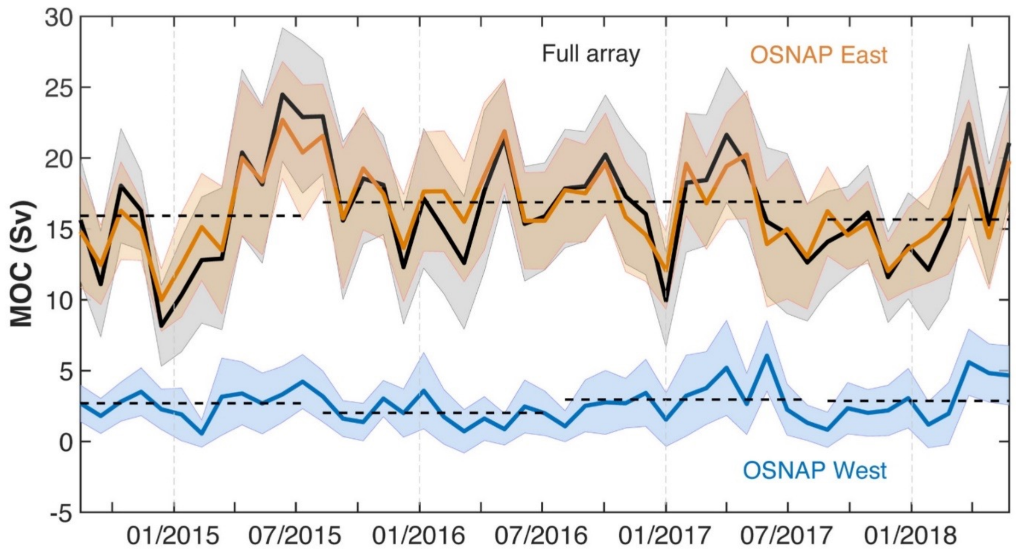
RAPID-AMOC



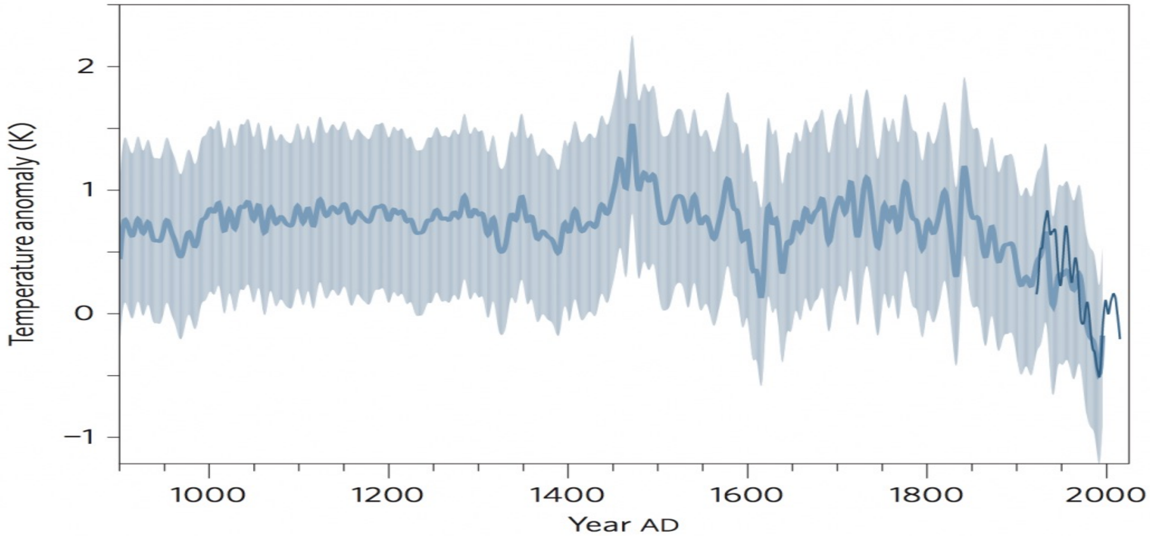


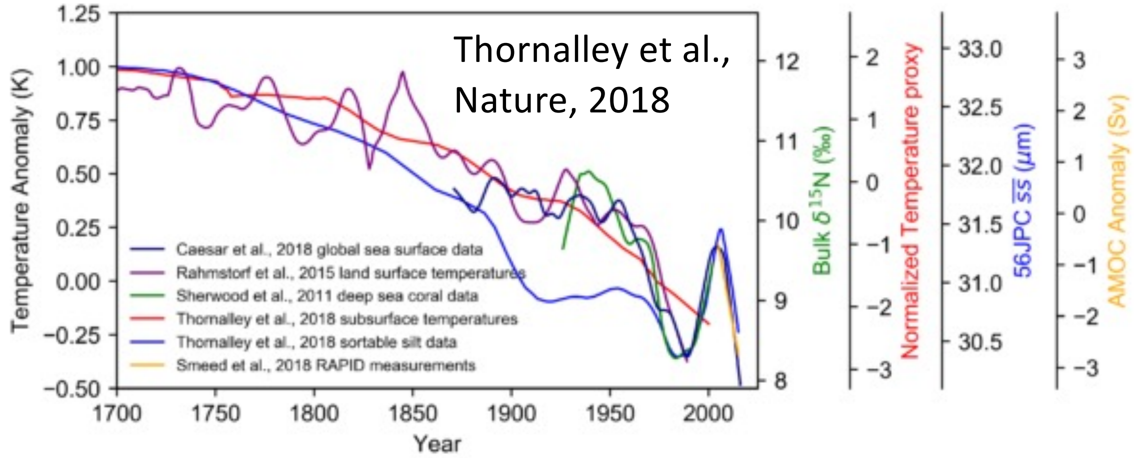
Overturning in the Subpolar North Atlantic Program

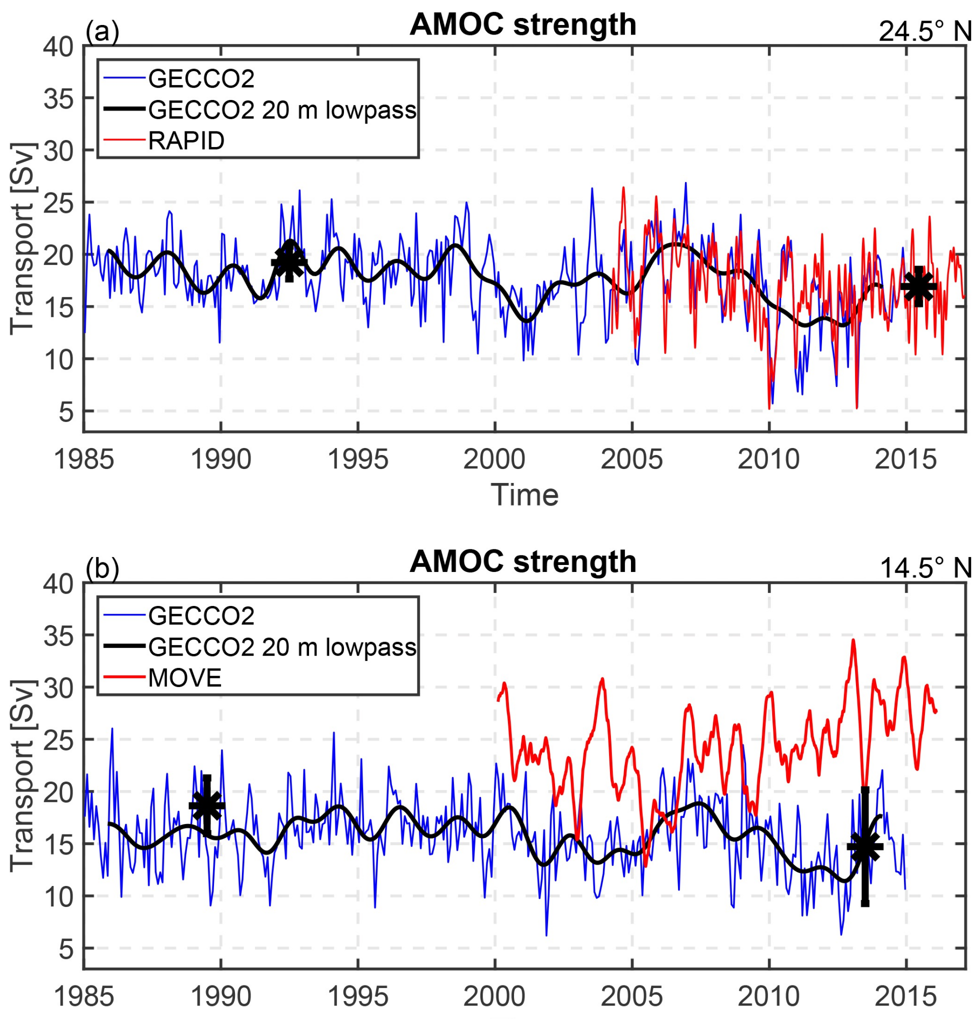




IS AMOC CHANGING OR WHETHER THE AMOC IS SLOWING DOWN?







Fu et al., 2018

Summary

- The ocean circulations include the wind-driven circulation and the buoyancy-driven thermohaline driven circulation (THC, or is called the Atlantic Meridional Overturning Circulation (AMOC).
- AMOC is a global scale ocean circulation which transports upper ocean warmer and saltier water into the subpolar North Atlantic where it cools and sinks to depth and flows southward.
- Changes in AMOC can significantly affect the regional and global climate, and the response of the climate system to external forcing.

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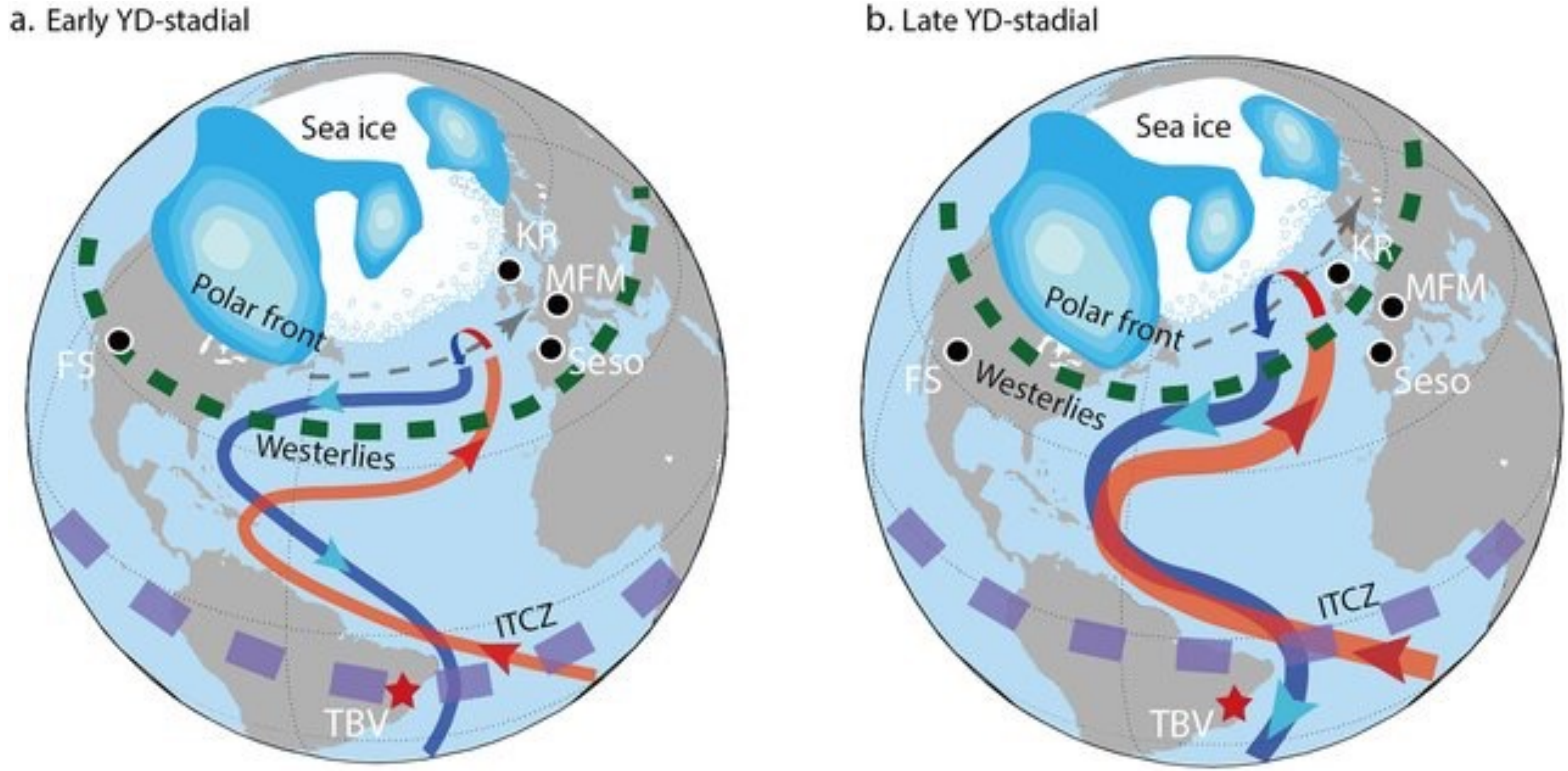
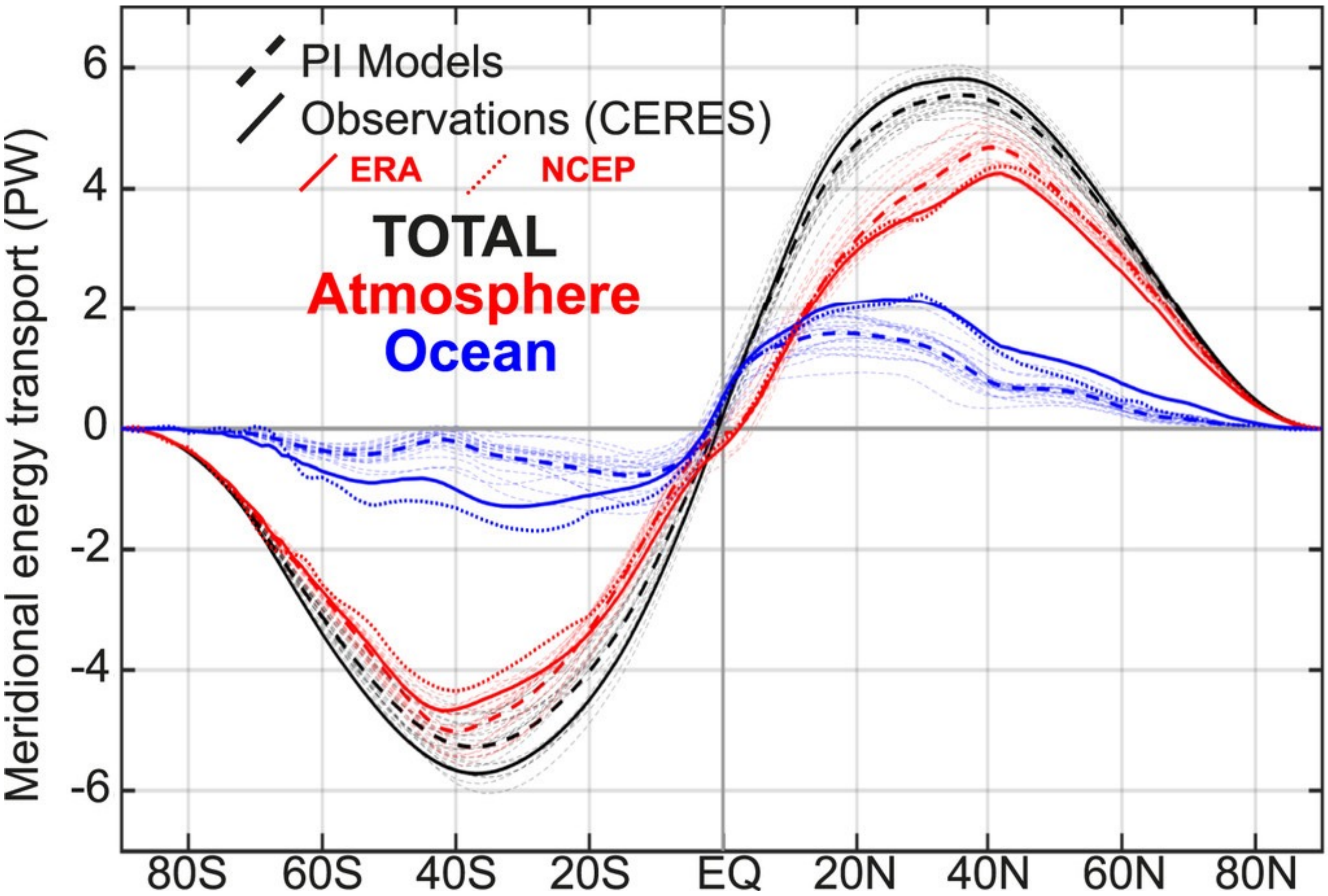
THANK YOU!

QUESTIONS?

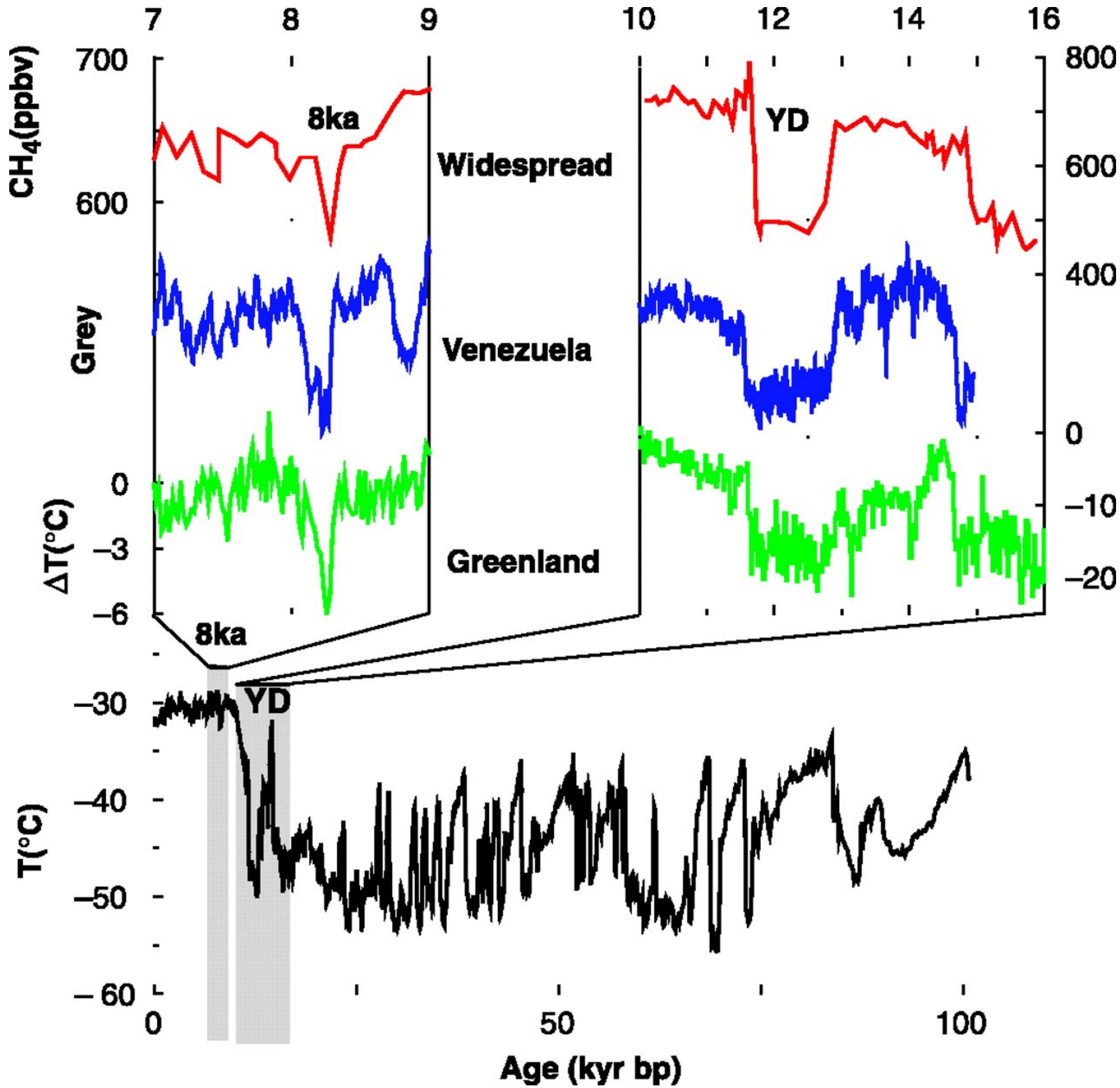
CONTACT: AHU@UCAR.EDU



Zhang et al., GRL, 2021

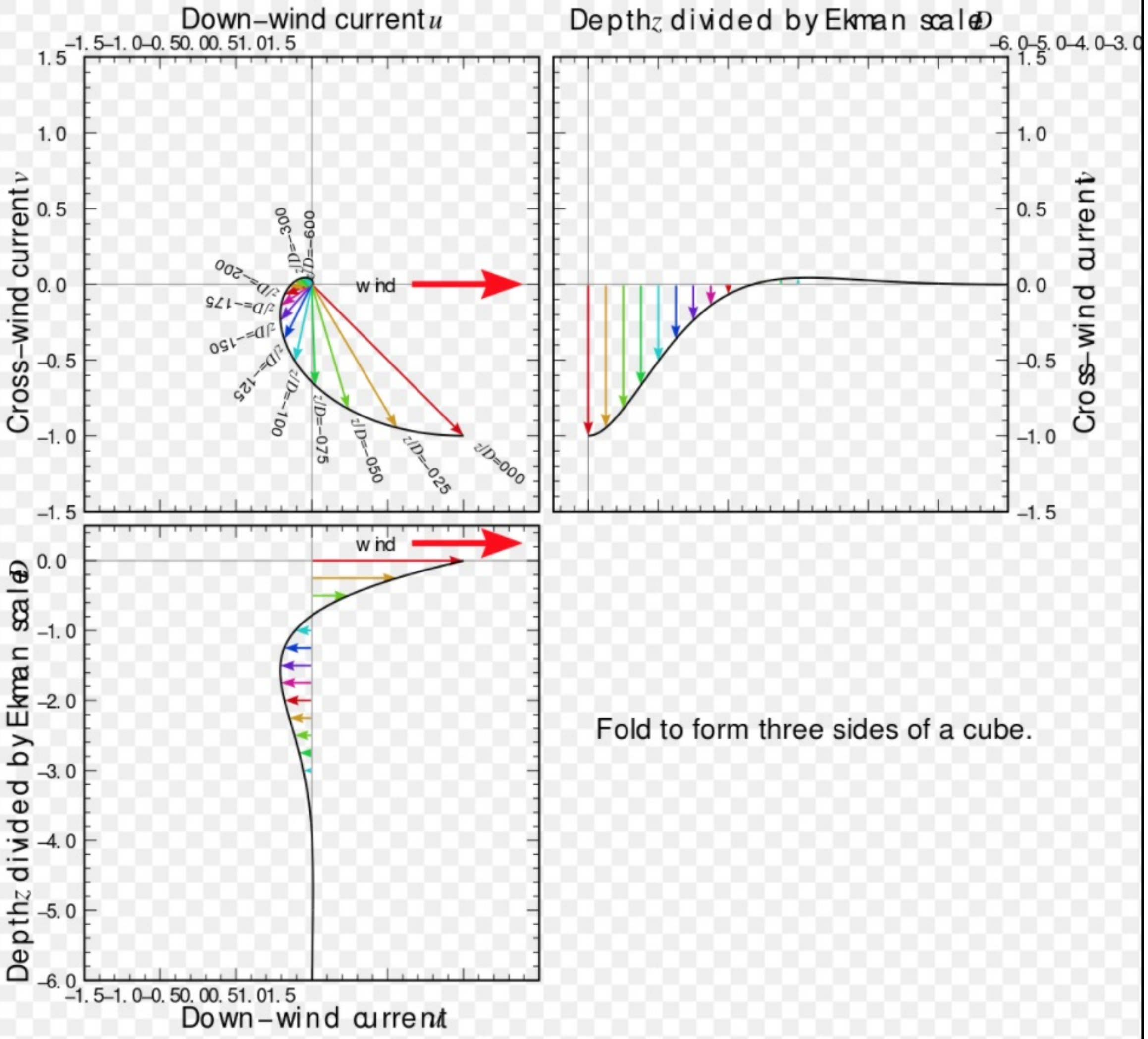


Donohoe et al., J. Climate, 2020

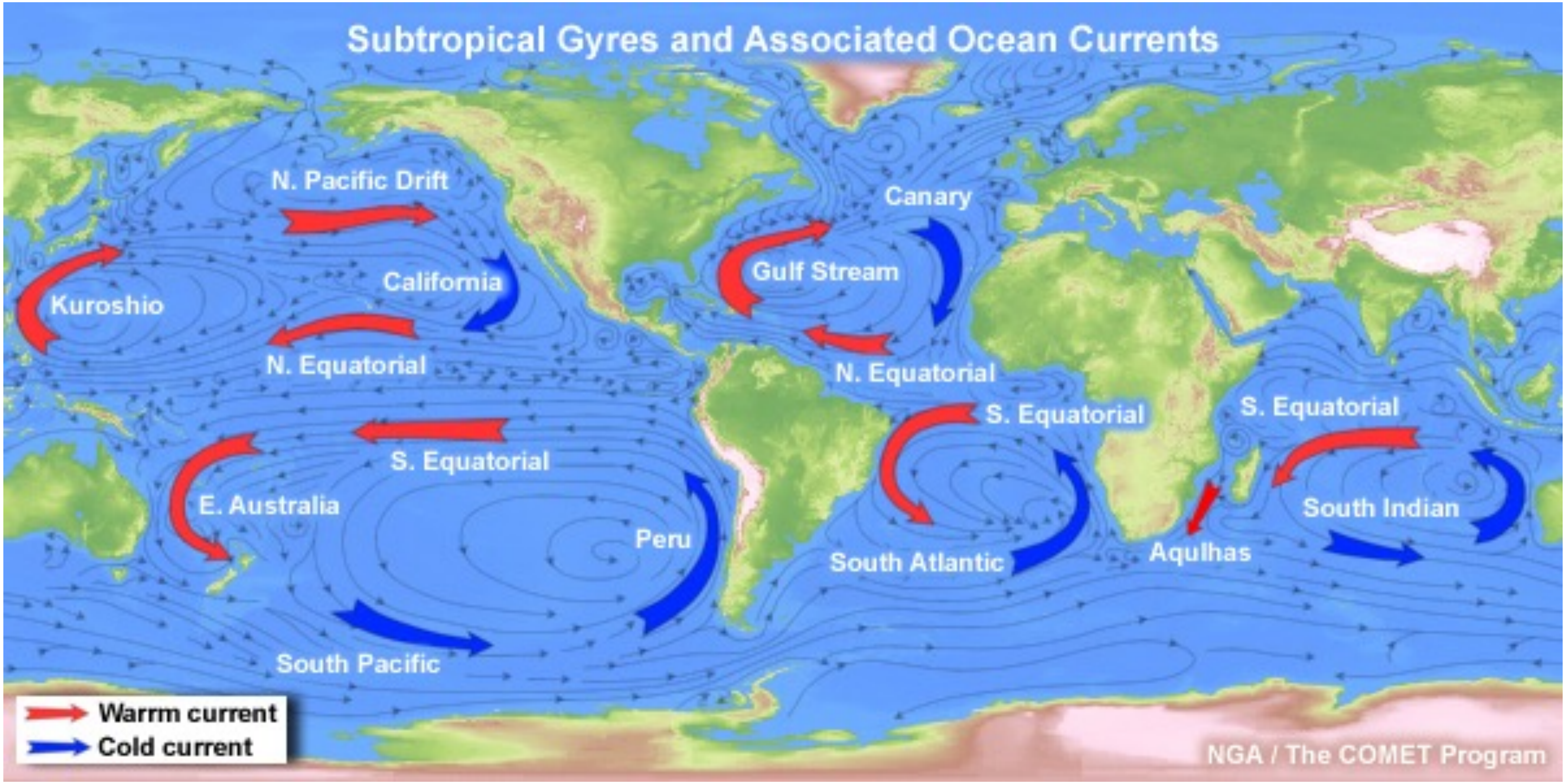


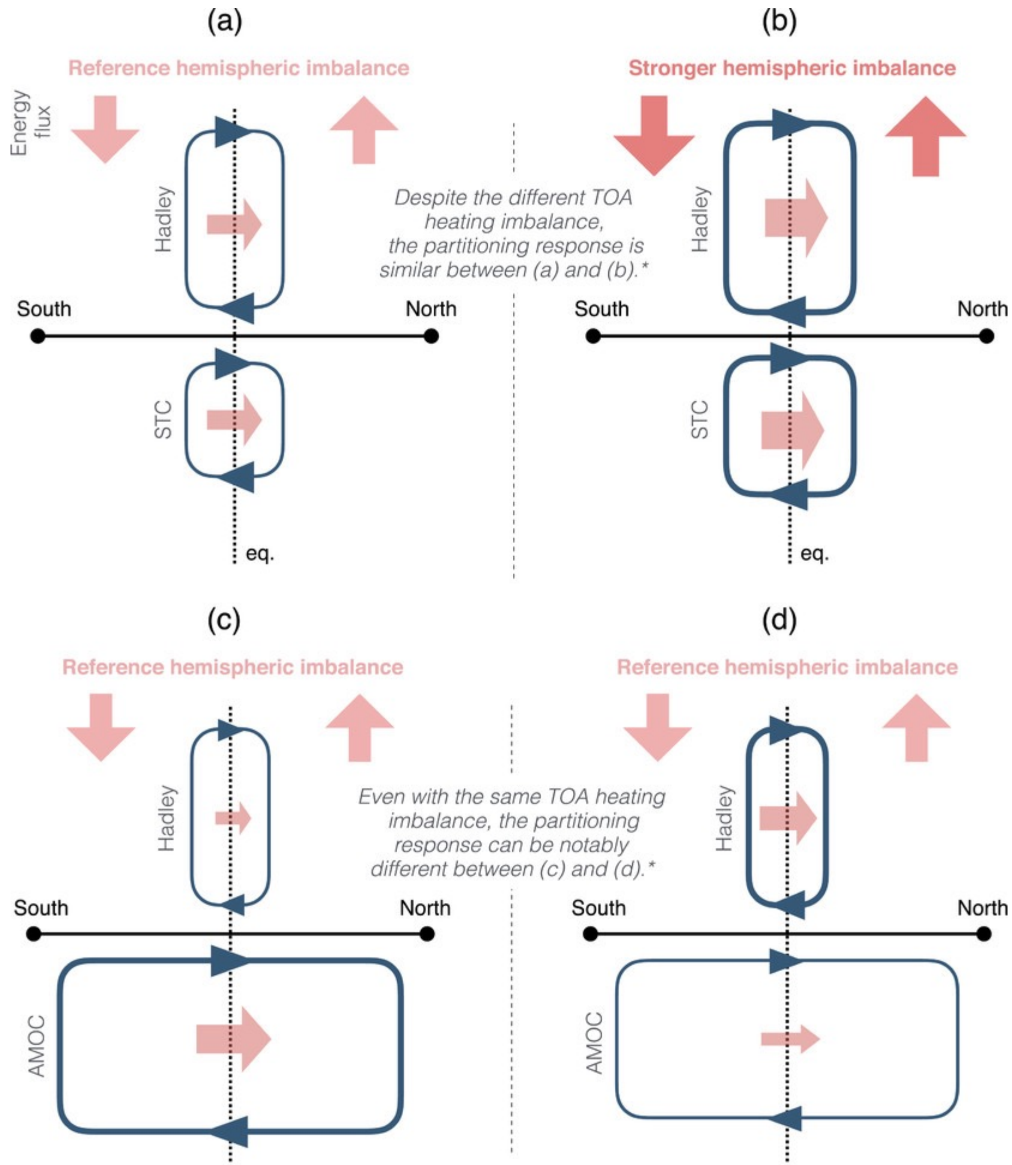
Alley et al.,
Science, 2003

Three views of an Ekman Spiral (Northern Hemisphere)

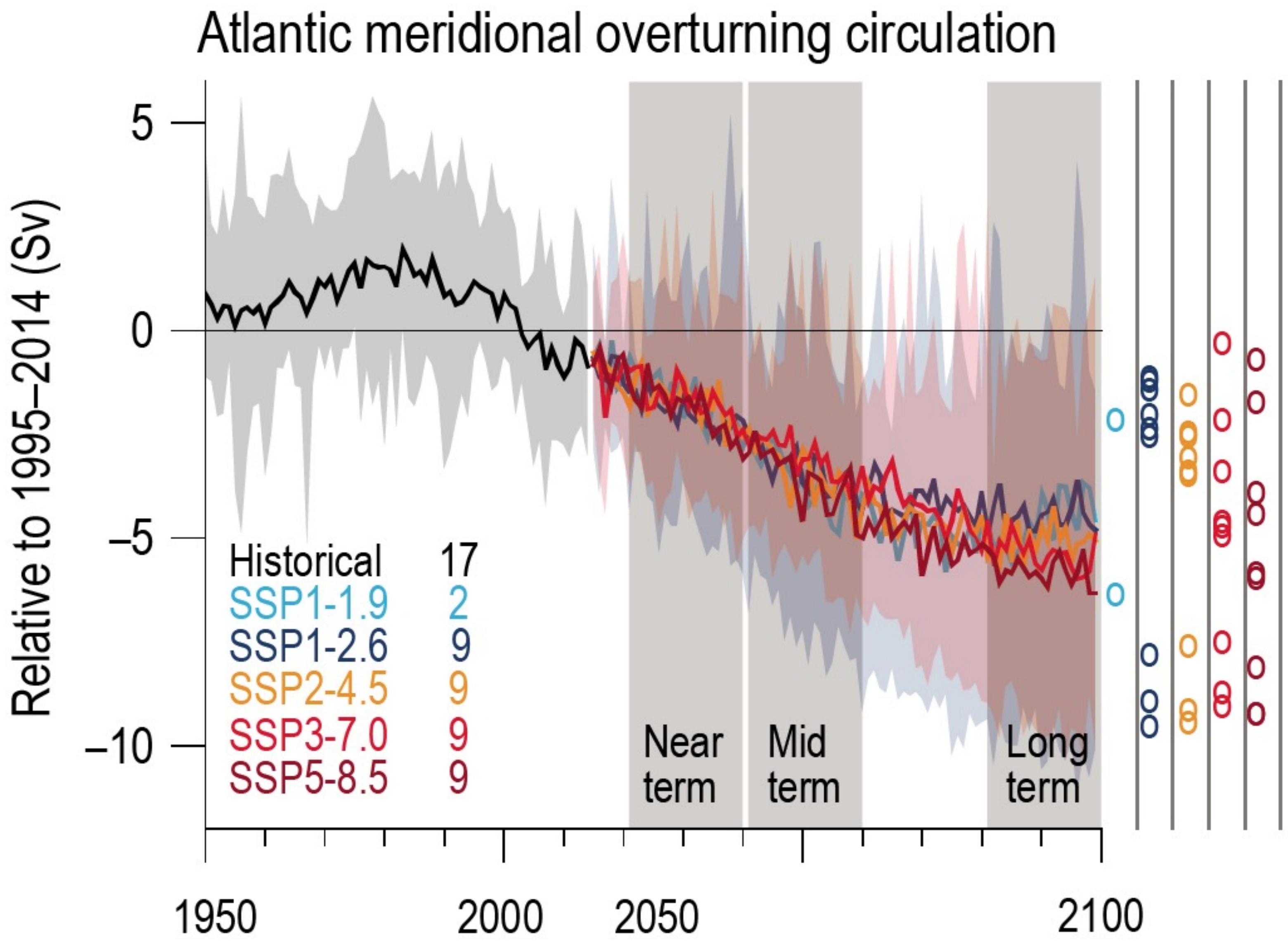


Fold to form three sides of a cube.


Subtropical Gyres and Associated Ocean Currents
N. Pacific Drift
Canary
California
Gulf Stream
Kuroshio
N. Equatorial
N. Equatorial
S. Equatorial
S. Equatorial
S. Equatorial
E. Australia
Peru
South Atlantic
Aqulhas
South Indian
South Pacific
Warrm current
Cold current
NGA / The COMET Program



*: Assumes that gross atmospheric stability and gross oceanic stability changes are negligible and that eddy heat transport responses are secondary.



Atlantic meridional overturning circulation
Relative to 1995–2014 (Sv)
5
0
−5
−10
Historical 17
SSP1-1.9 2
SSP1-2.6 9
SSP2-4.5 9
SSP3-7.0 9
SSP5-8.5 9
Near term
Mid term
Long term
1950
2000
2050
2100