Understanding oceans
Sustaining our future

May 2007

Enhanced storm activities triggered the North Pacific deep convection during the Younger Dryas event

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Haijun Yang, Zhengyu Liu, Ping Chang, Min-Te Chen…

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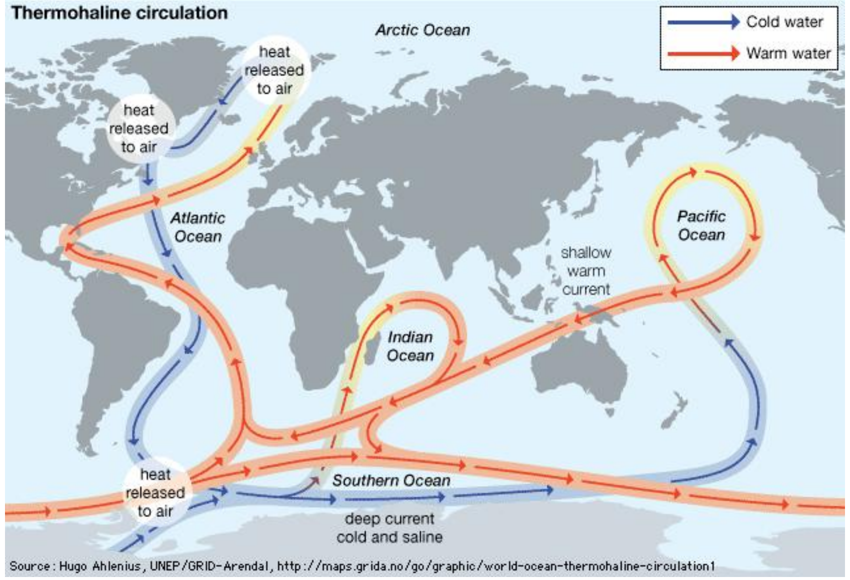
AMOC
Thermohaline Circulation



ftp://global.britannica.com/science/thermohalinecirculation

PMOC
Wind Driven Circulation

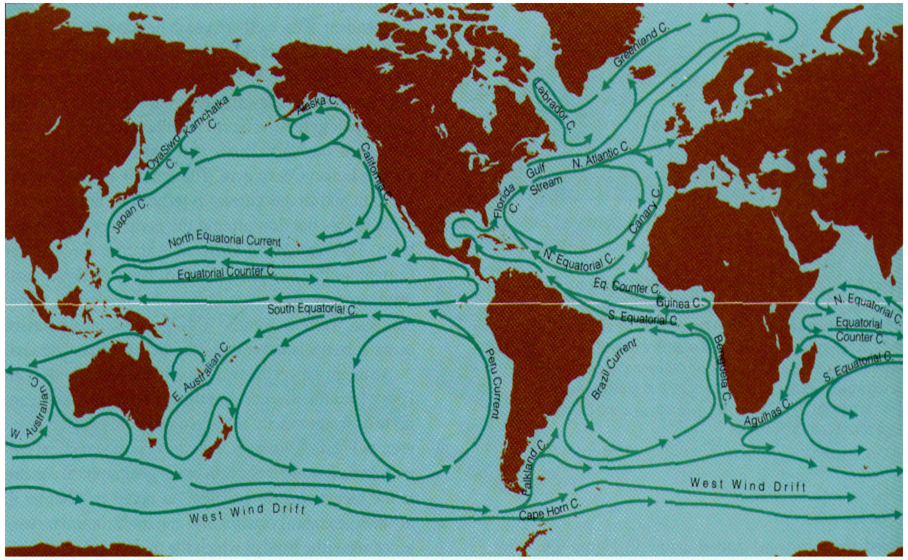
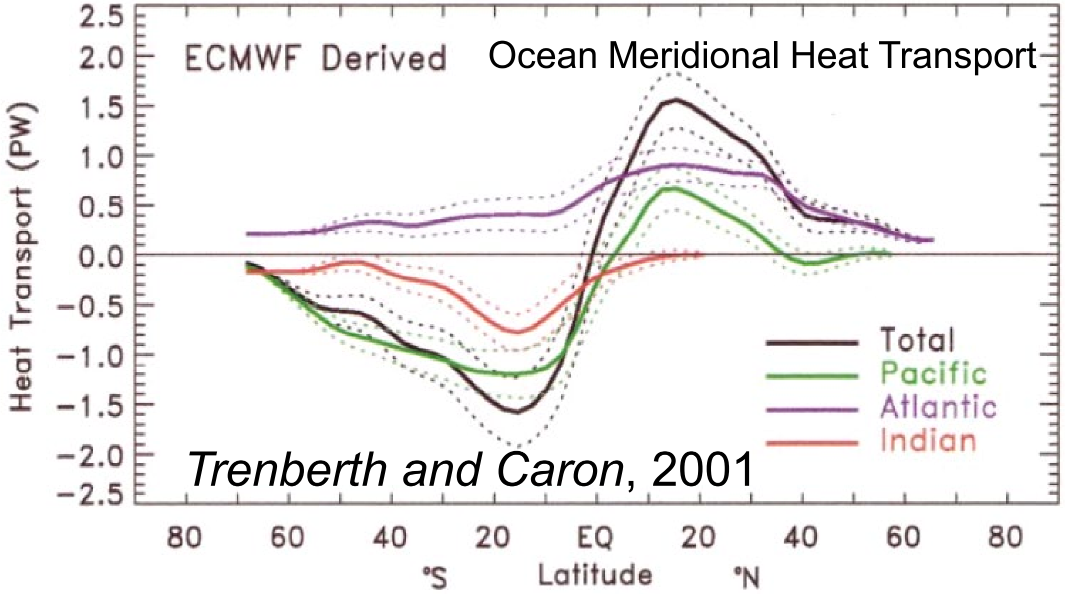


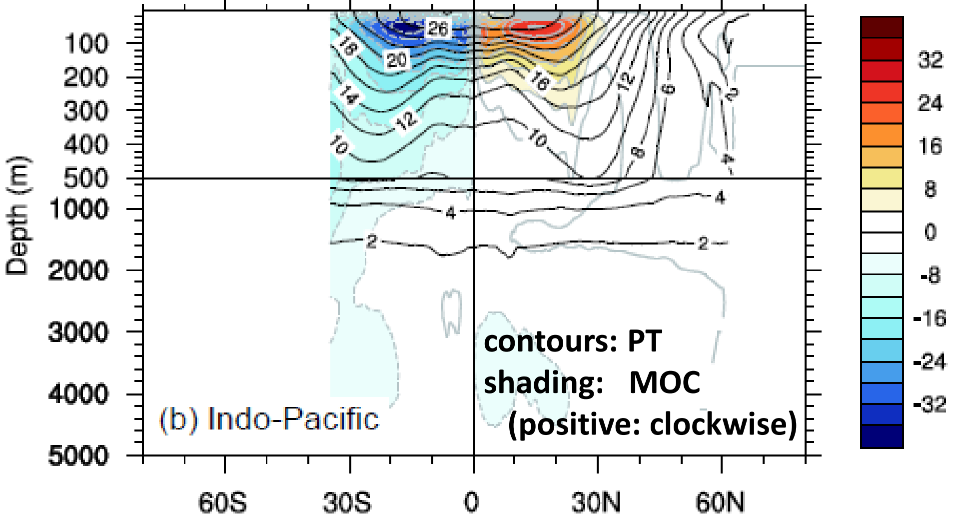
Figure 9.8 Major surface currents of the world ocean.

http://www4.ncsu.edu/eos/users/c/ceknowle/public/chapter07/part1.html

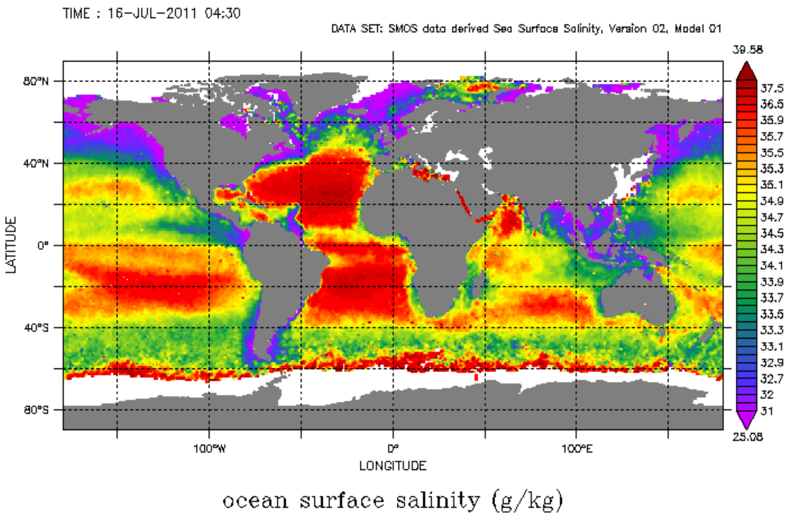


PMOC and AMOC under modern conditions

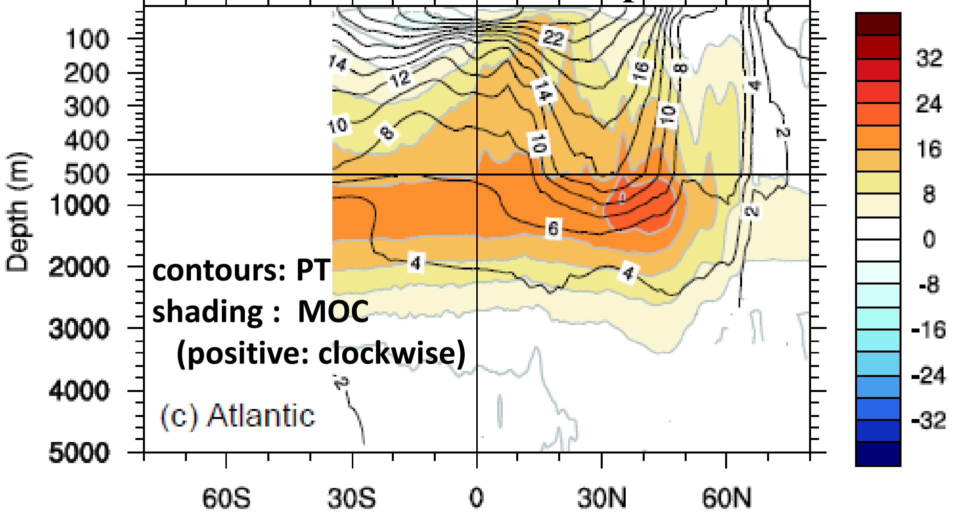
Indo-Pacific MOC and Potential Temperature



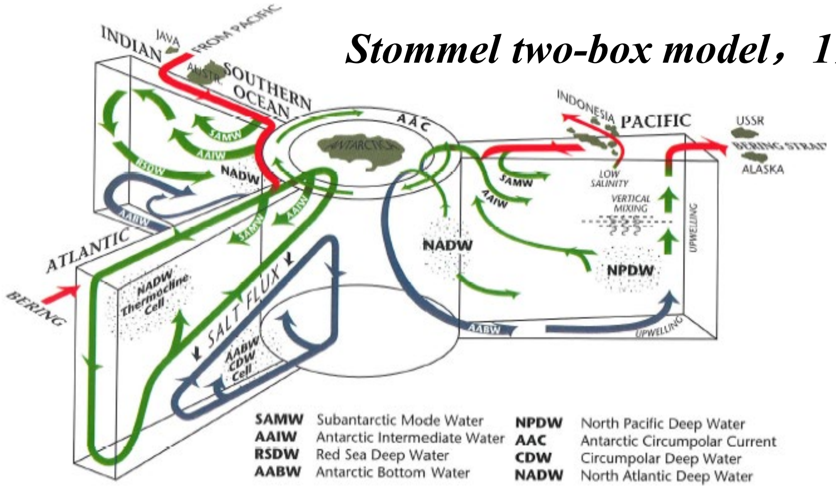
Sea Surface Salinity



AMOC and Potential Temperature



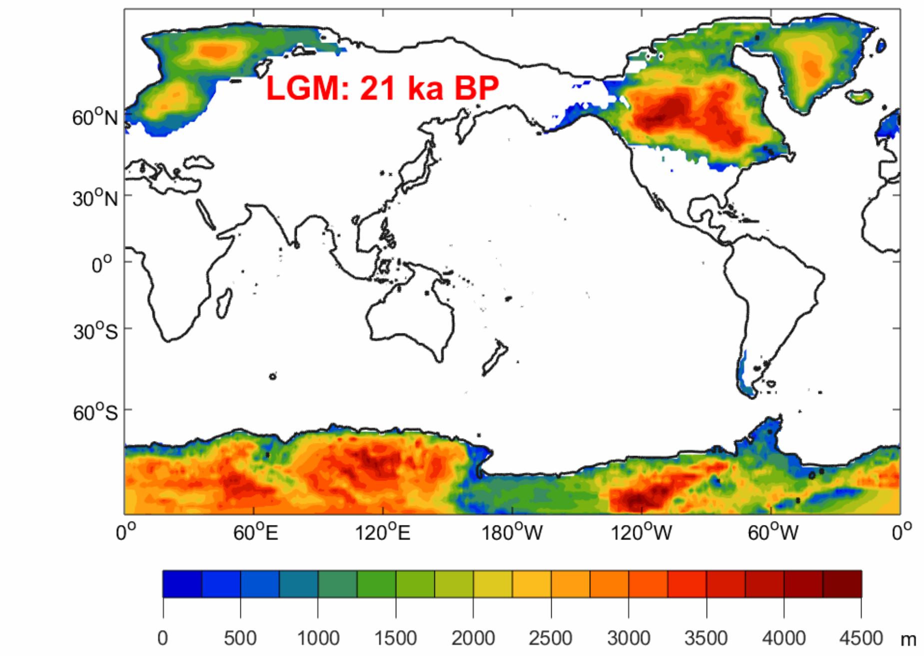
Stommel two-box model，1961



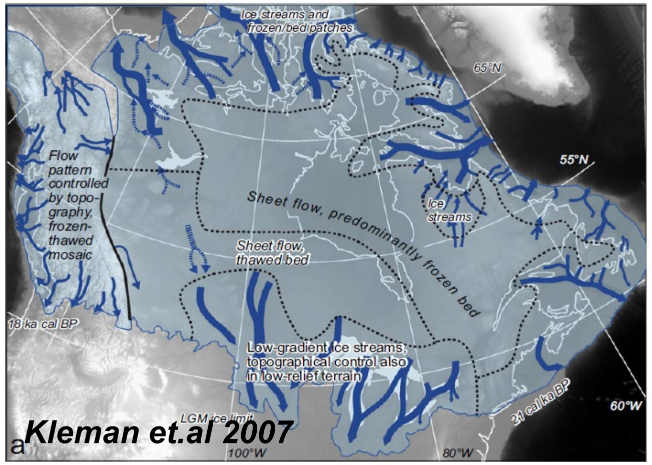
Yang et al. 2015

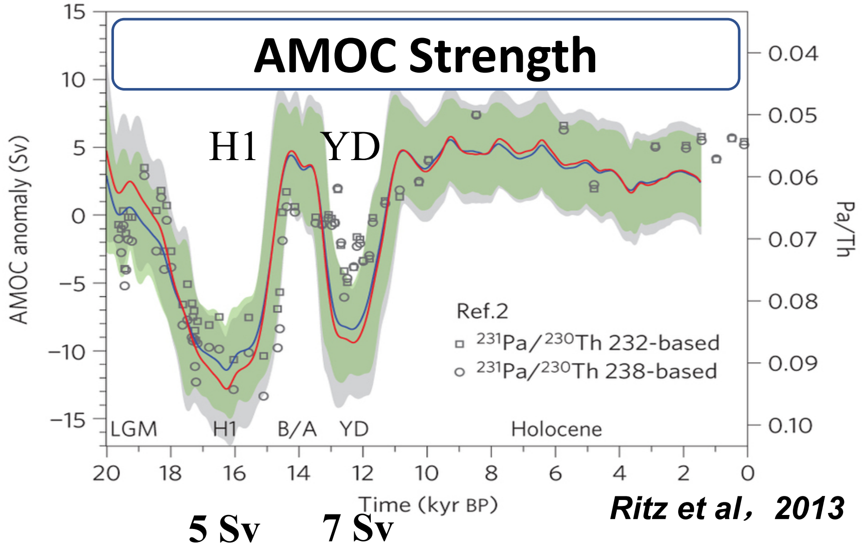
The modes of AMOC and PMOC might change during stadials in the last deglaciation.

Change of ICE Sheet



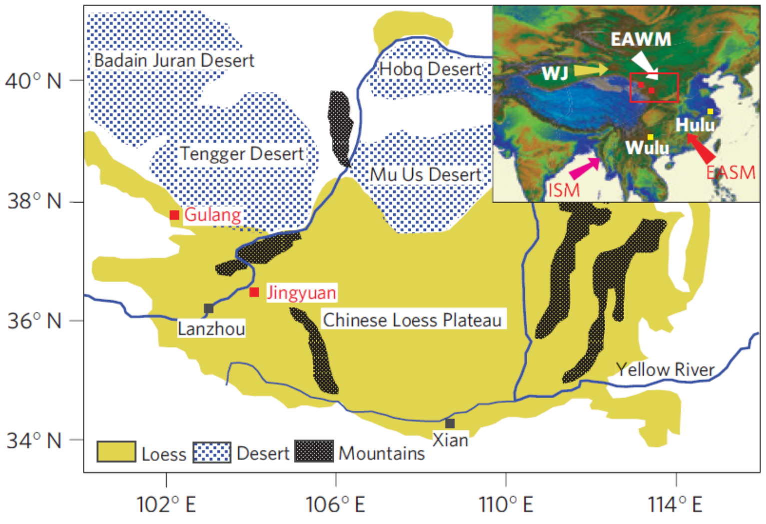
Data source ICE-6G

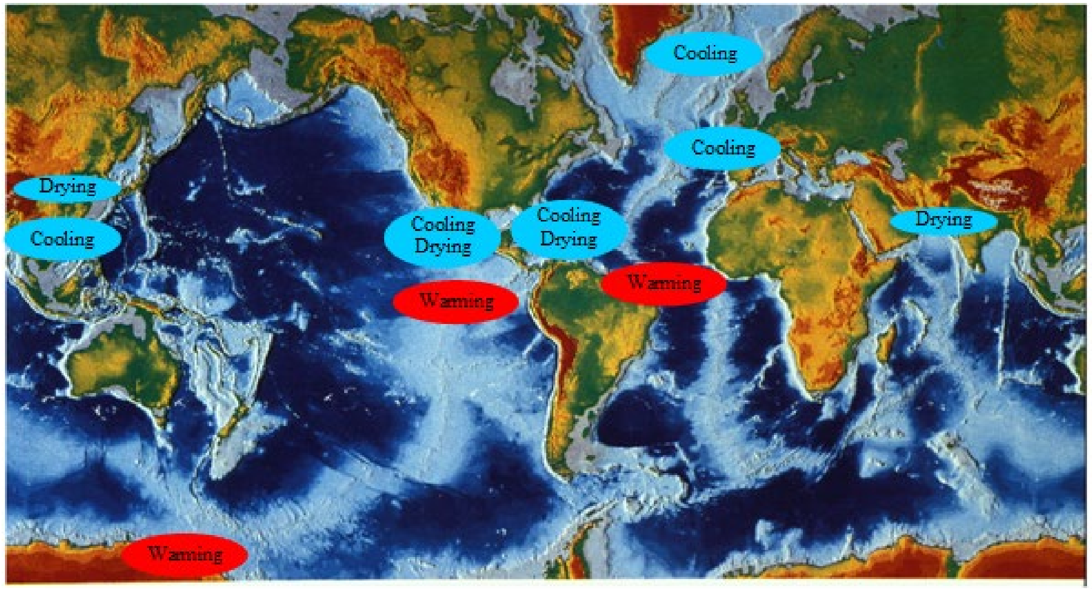


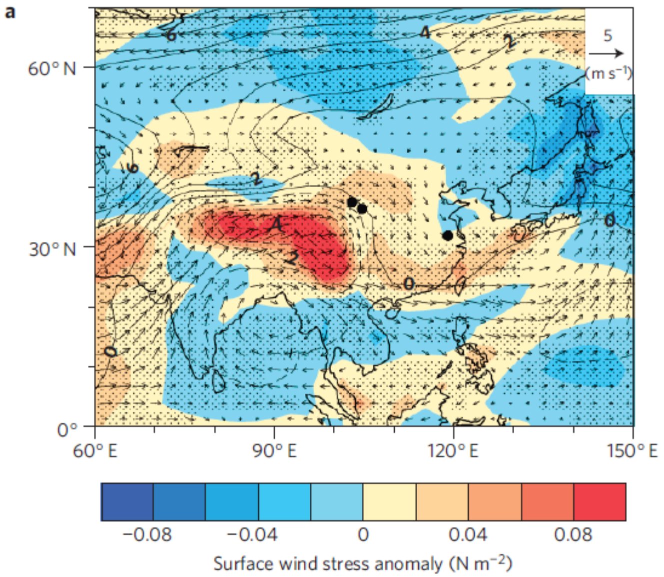


Most melt waters discharged into the

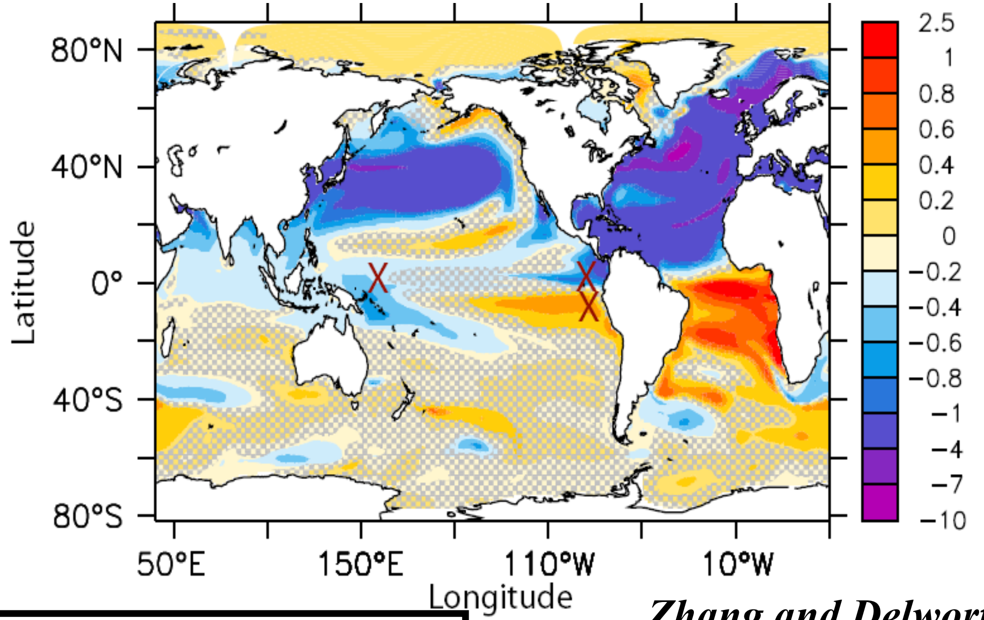
North Atlantic because of the topography







Sun…Lin et al., 2011, Nature Geoscience.*



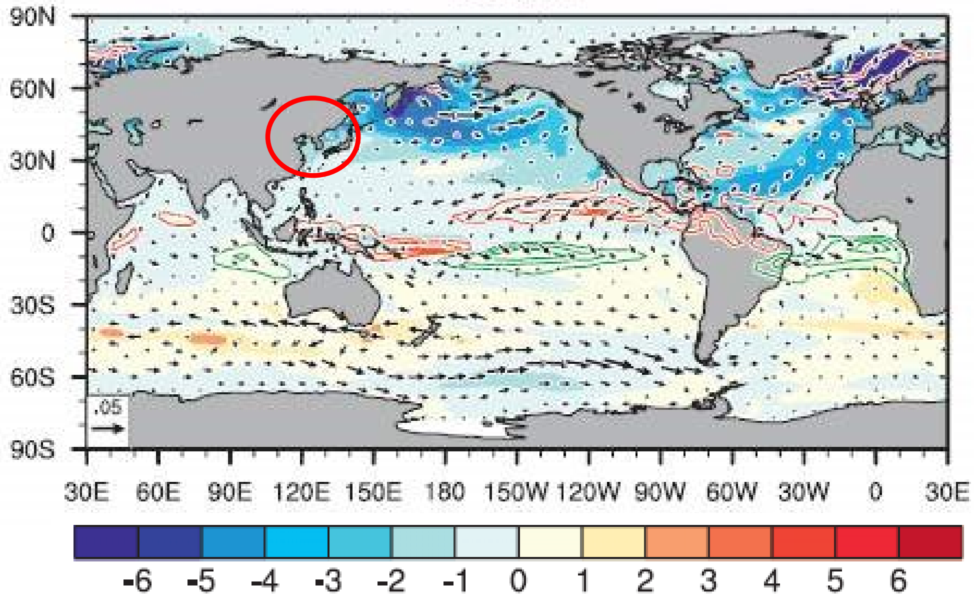
Zhang and Delworth, 2005, JC

Cold and Dry in the North Pacific

Stronger and southward shift Westerly

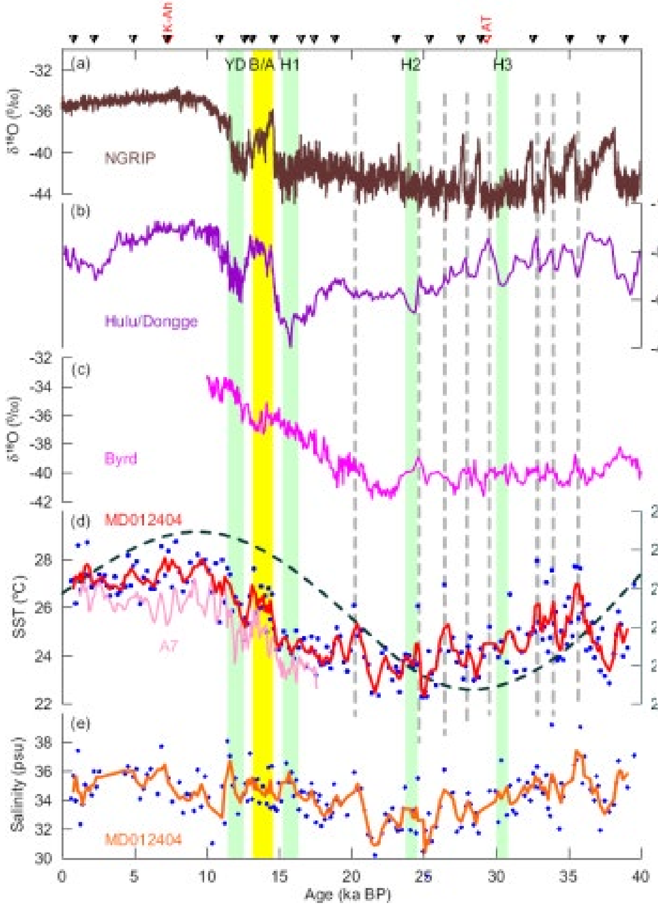
Implying a Sea Saw between AMOC and PMOC

SST anomaly



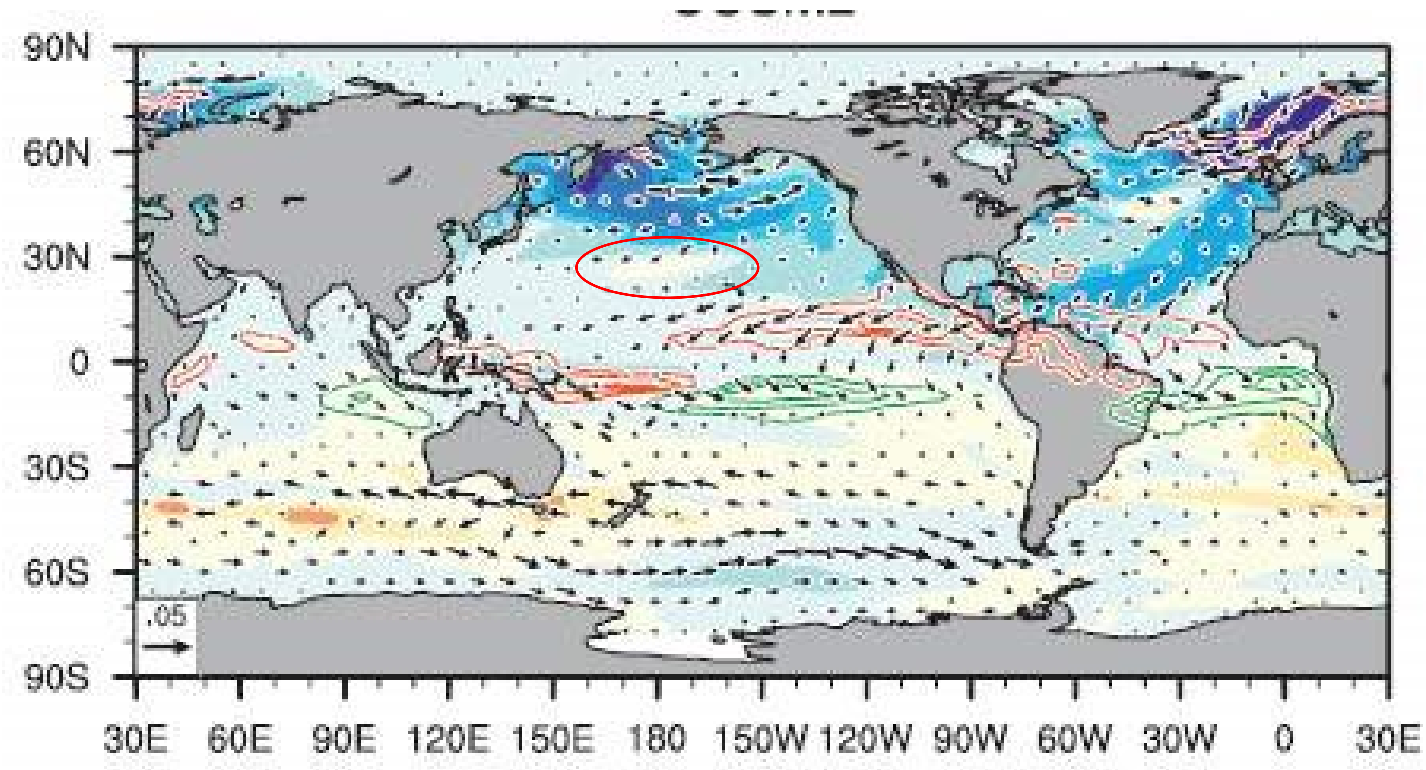
AMOC Shutdown

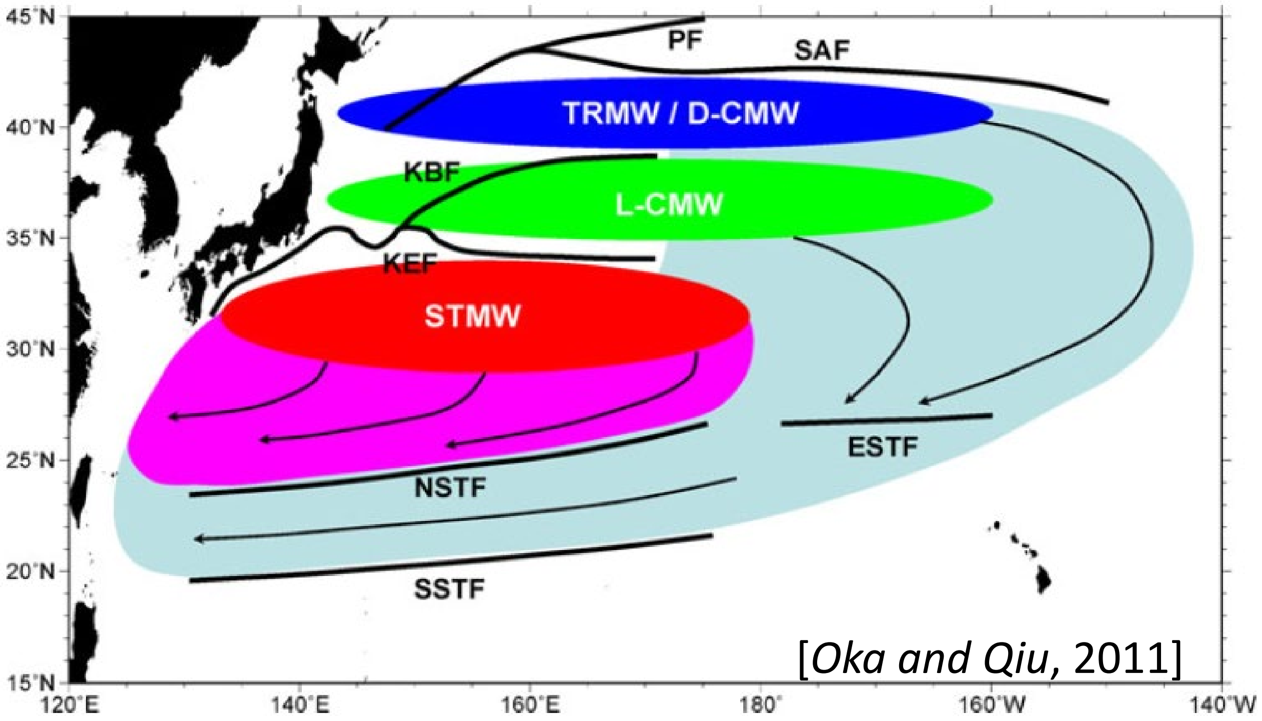
Kuroshio Increase

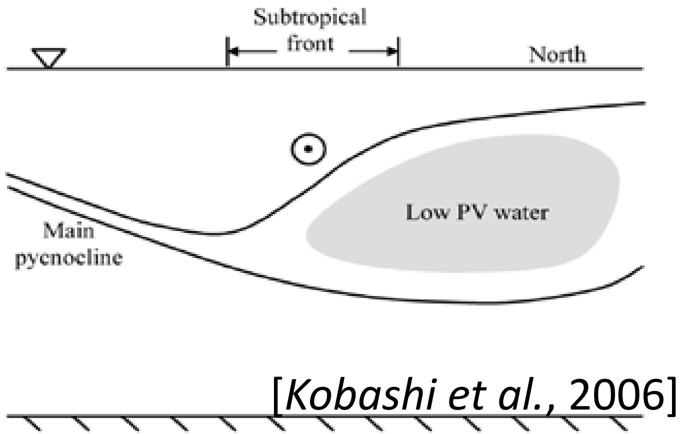


Chen & Lin et al., 2010, GRL*

Besides the Kuroshio, there is a warm belt in the central Pacific Subtropical Counter Current——Part of PMOC

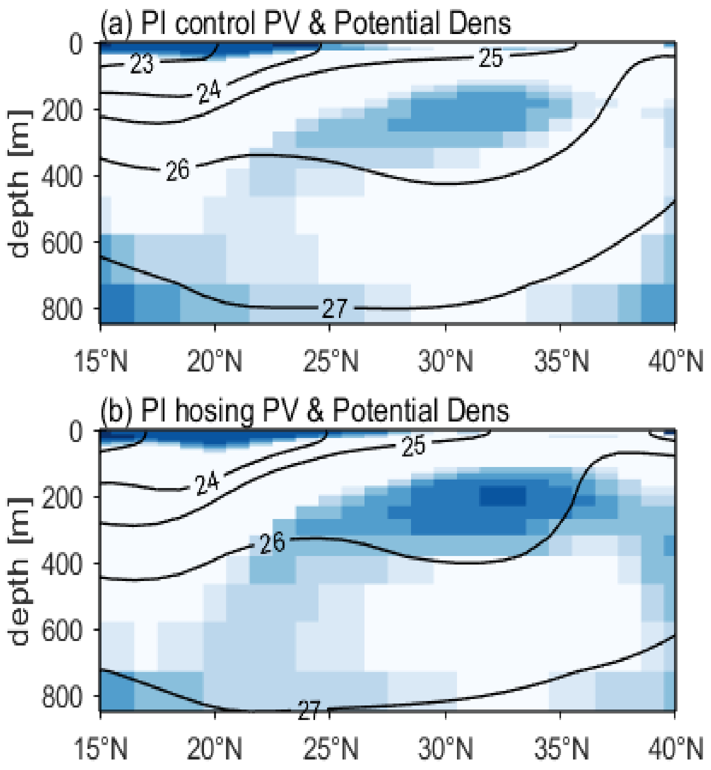


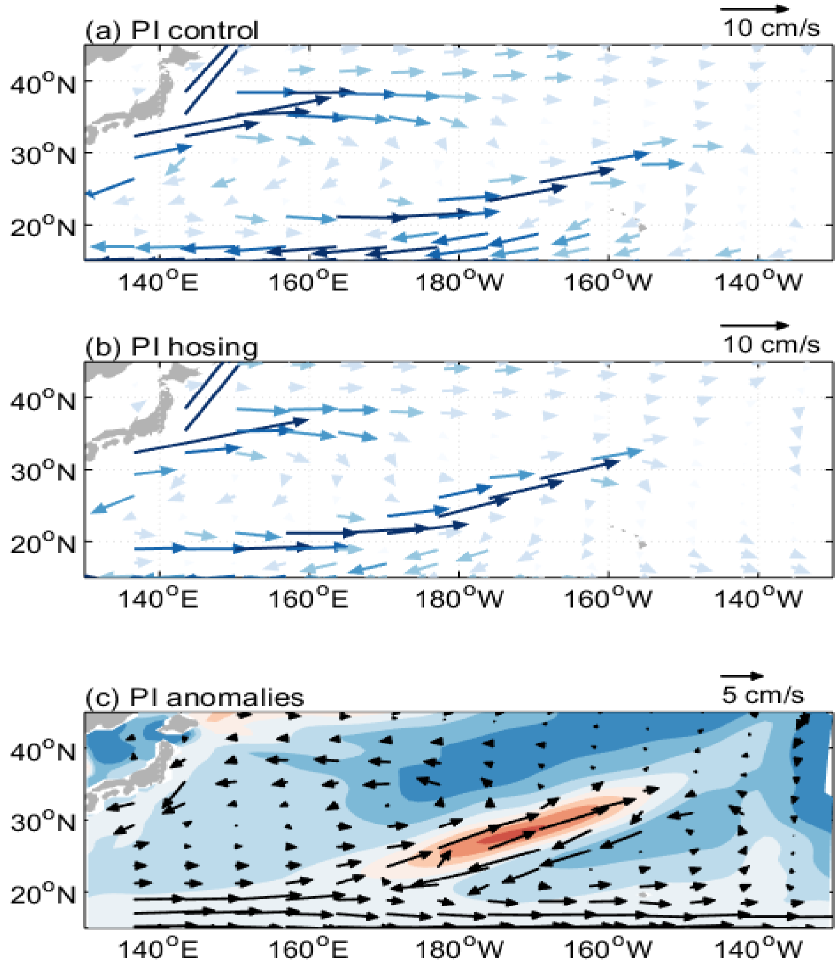




Mode Water——
Subtropical Counter Current

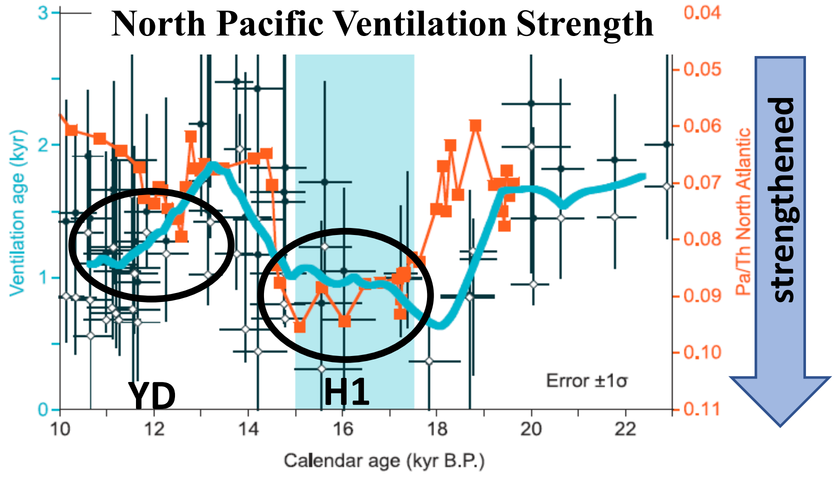
This warm belt is due to more mode water, stronger STCC by cold event and deep convection



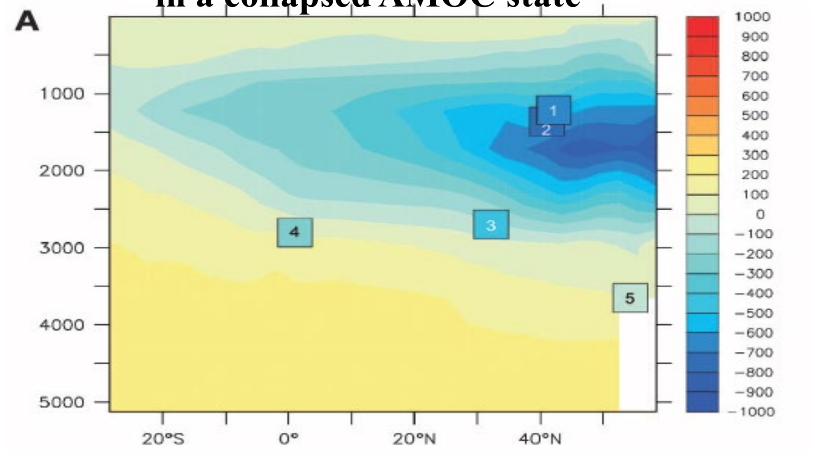


Zhang&Lin et al., 2018, CD

AMOC ⇓， PMOC ⇑， the seesaw of AMOC and PMOC



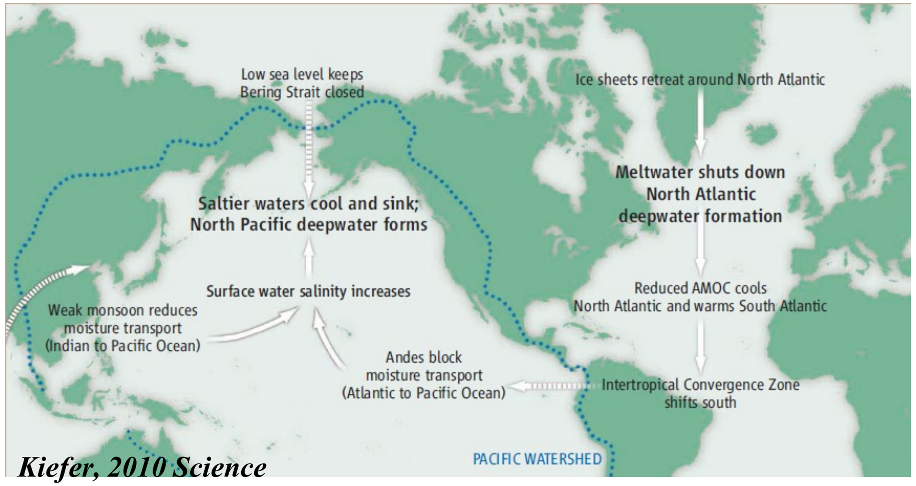
North Pacific water age anomalies in a collapsed AMOC state



Deep water extending 2500-3000 m was formed in the North Pacific during H1. (following articles prefer 2000 m).

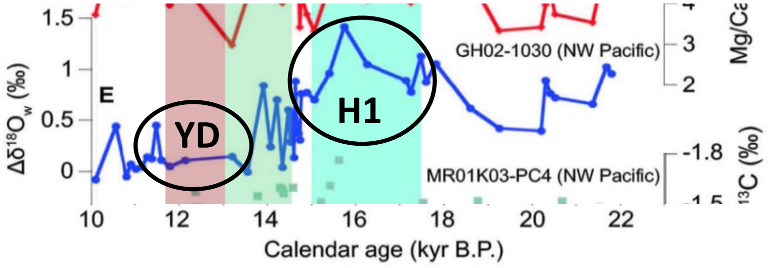
Previous explanations：

saltier surface North Pacific



Kiefer, 2010 Science

North Pacific salinity proxy

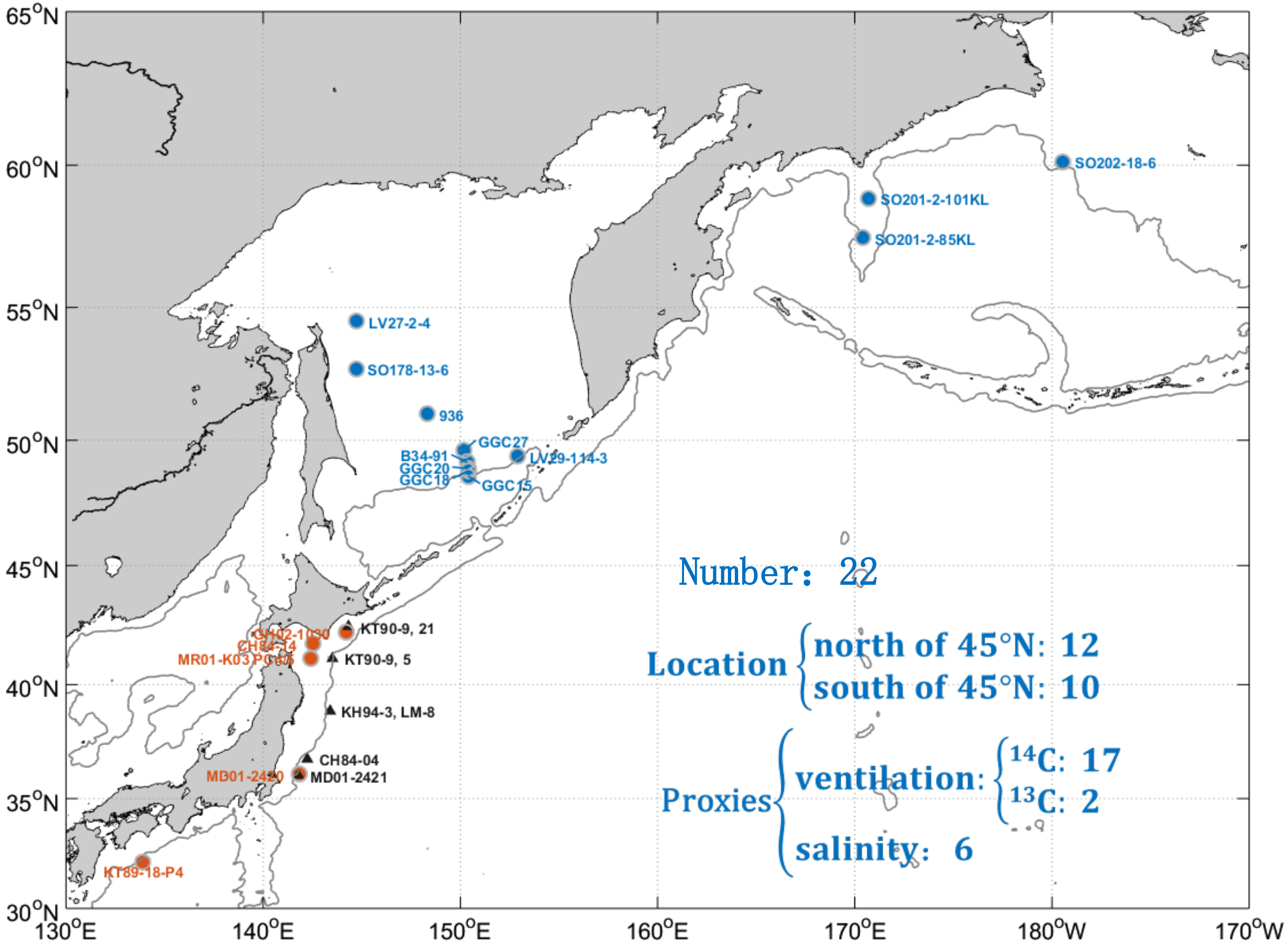


Okazaki et,al 2010 Science

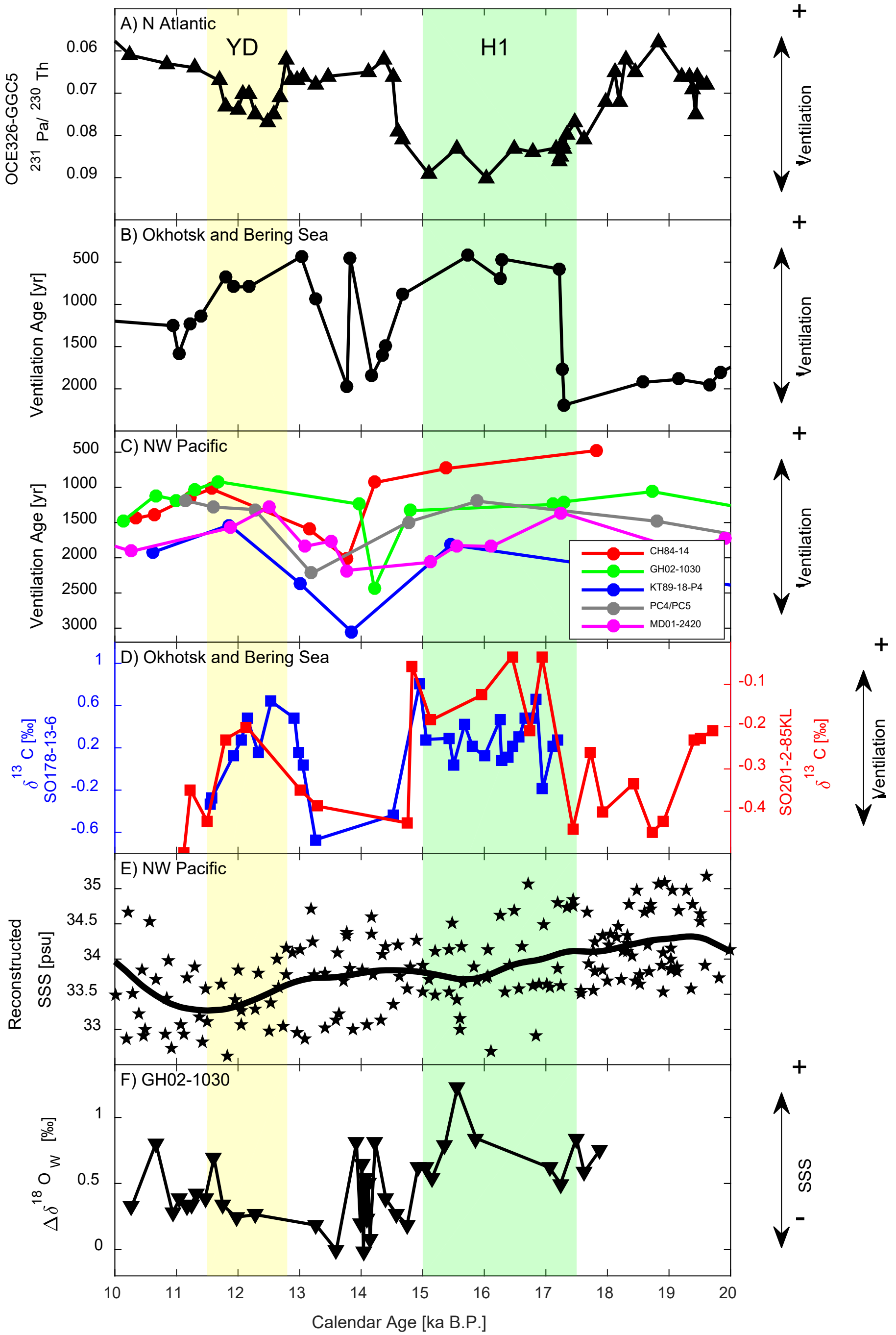
Limits：

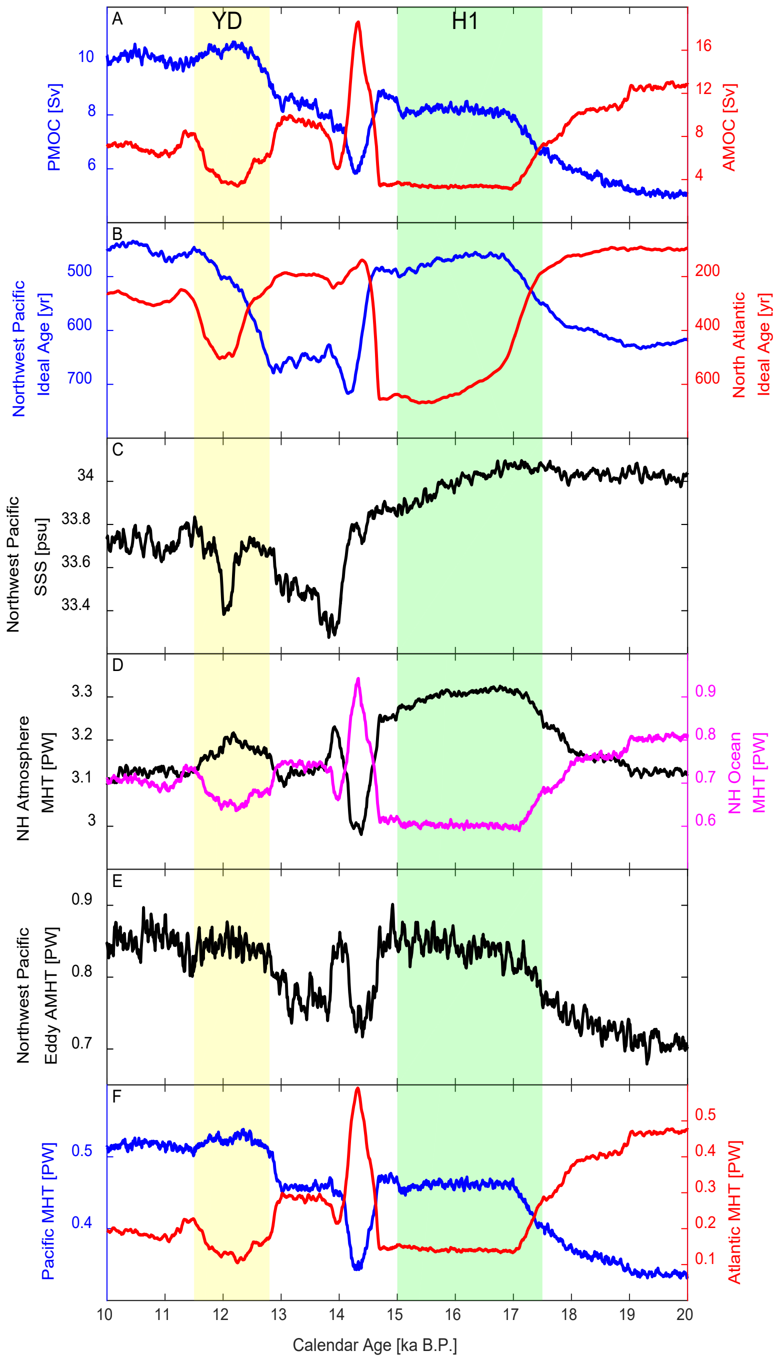
- Salinity proxy： only one core in the western subtropical gyre.
- Applied to H1， but not to YD.

Locations of paleo records：



Paleo Record





21K CCSM3 Simulation Liu et al., 2013

What affects deep convection besides salinity?

Observed deep convection in the North Atlantic

is related to storm activities in the westerly

1-d MLD model（PWP model）

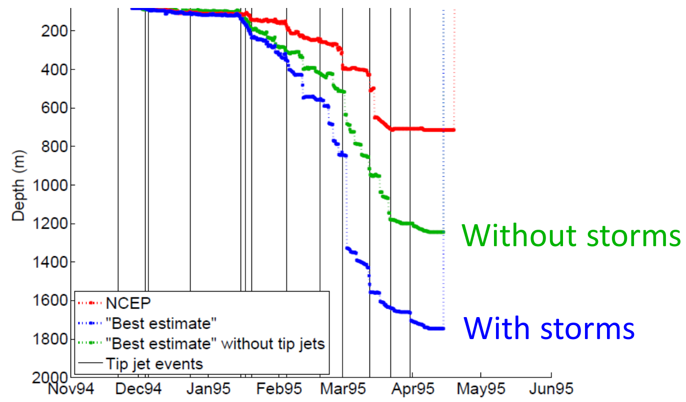
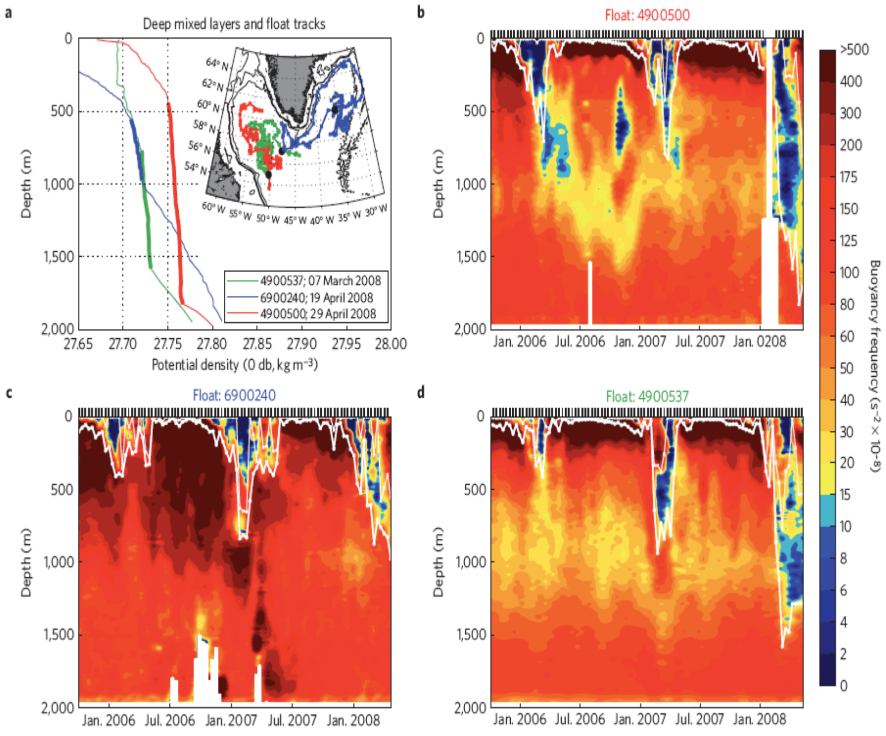
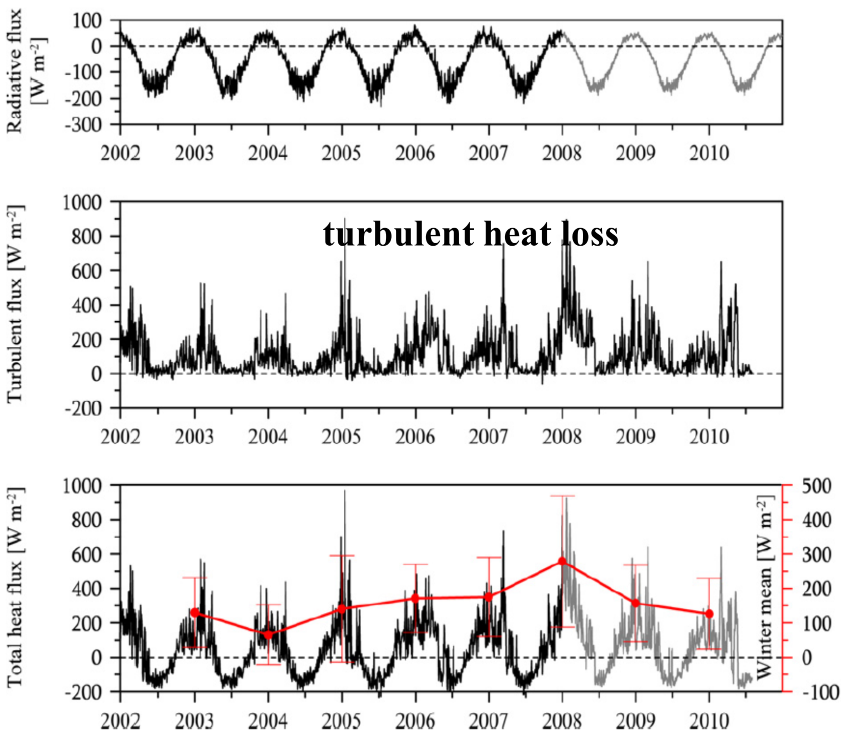


Figure 7: PWP results for winter 1994-5.

Deep convection in 2008

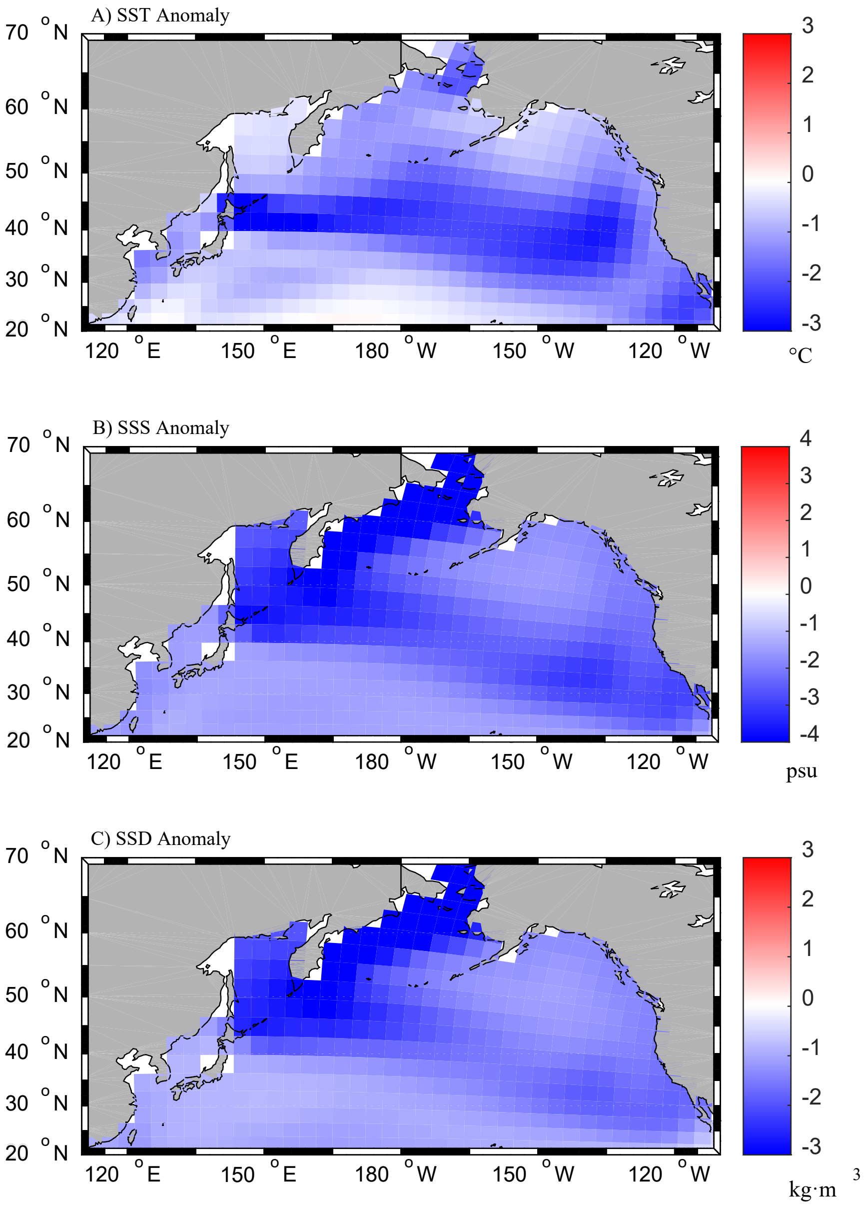


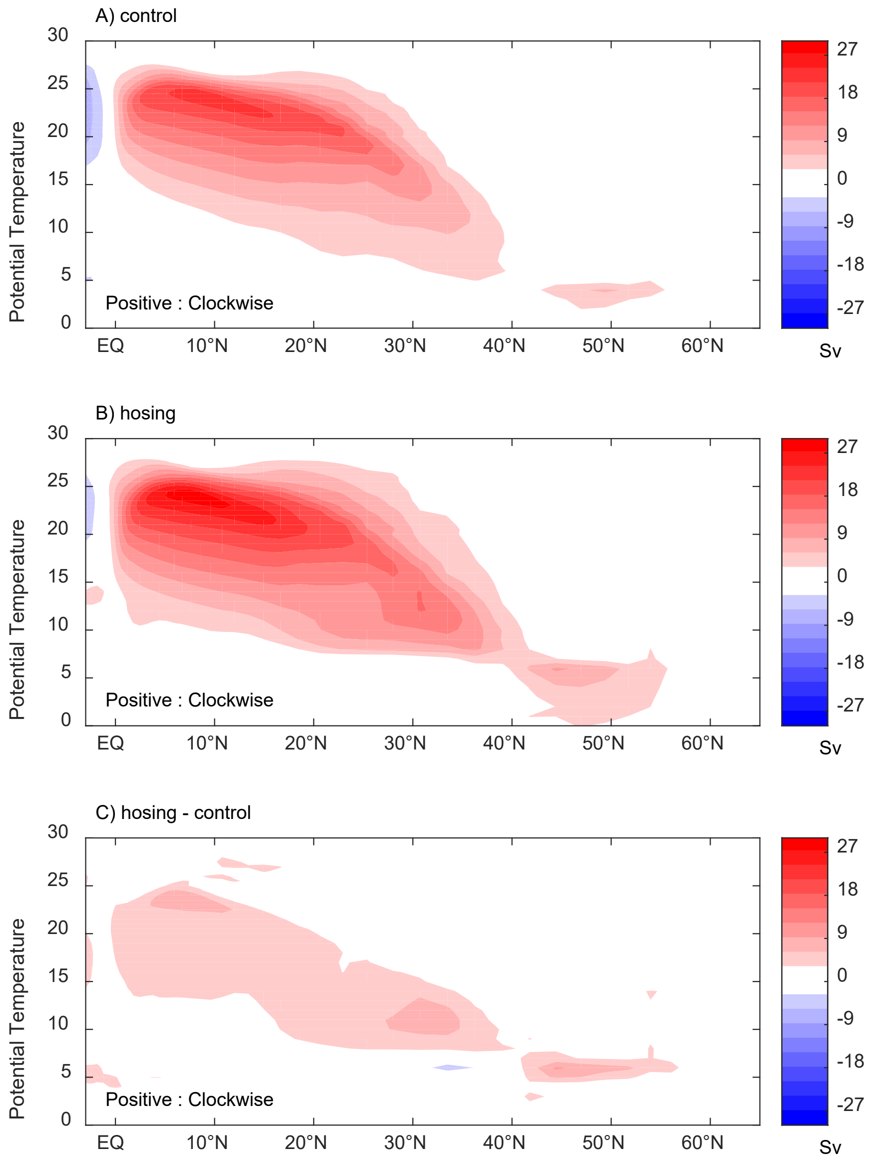
Vage et al., 2009, Nature Geoscience



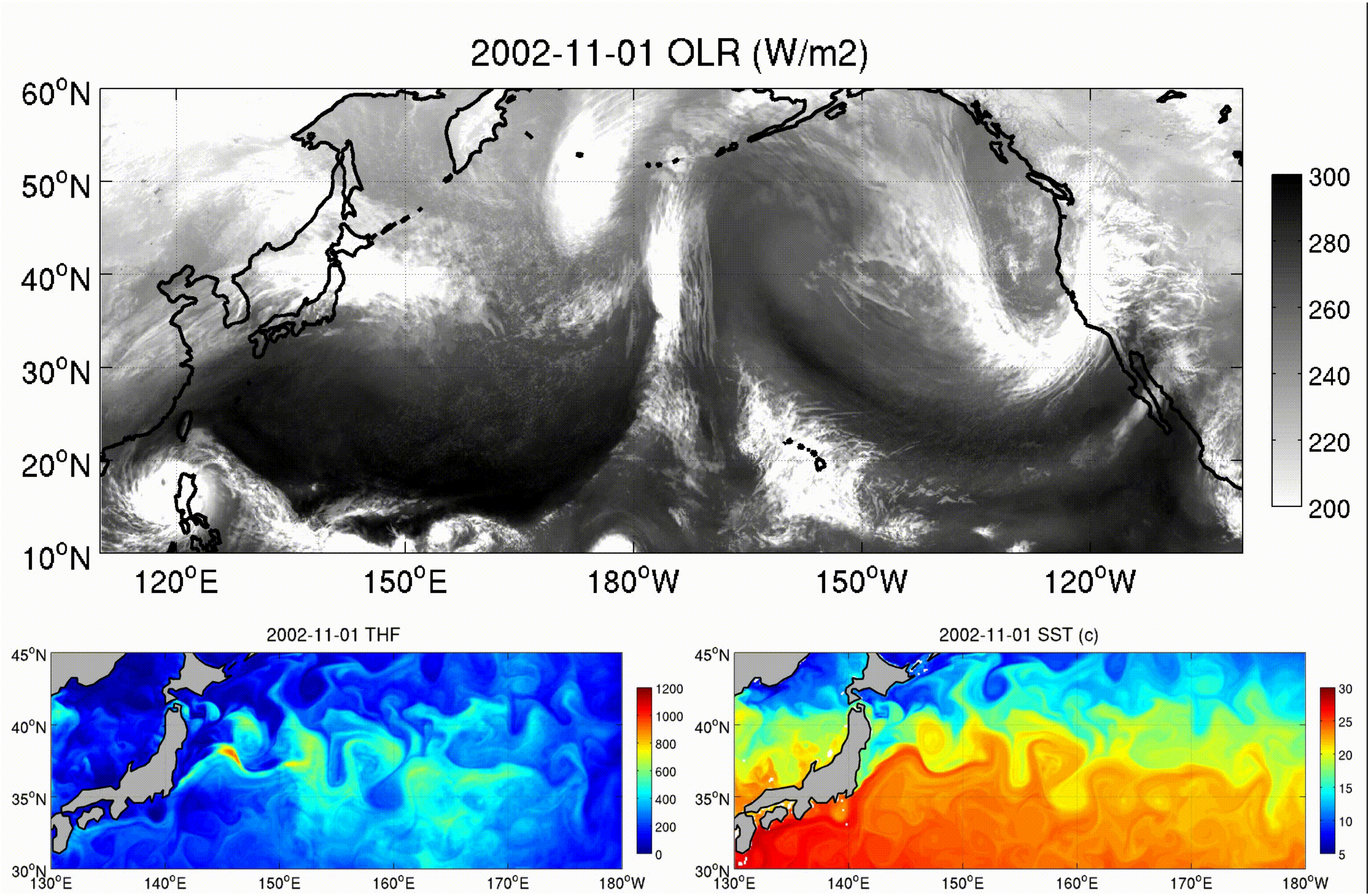
M. Femke de Jong,2012,JC

CESM Water Hosing Experiments： Fresh water input in the North Atlantic and shutdown the AMOC





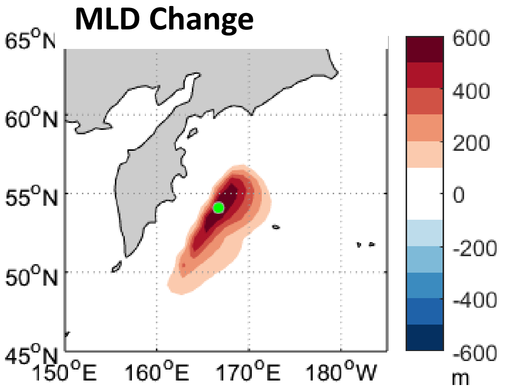
Storm is dominant for the ocean heat loss and SST change

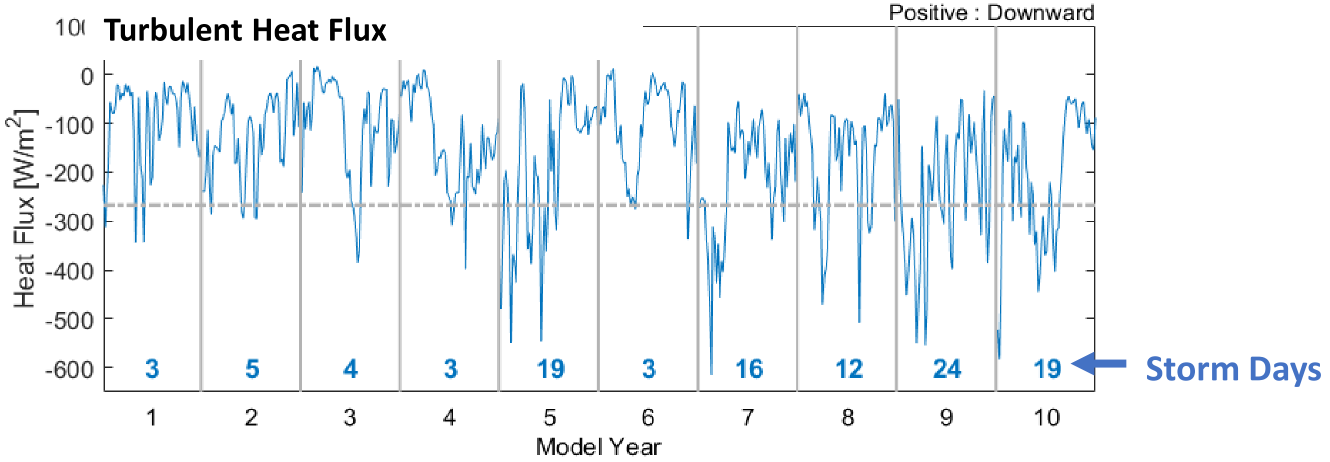


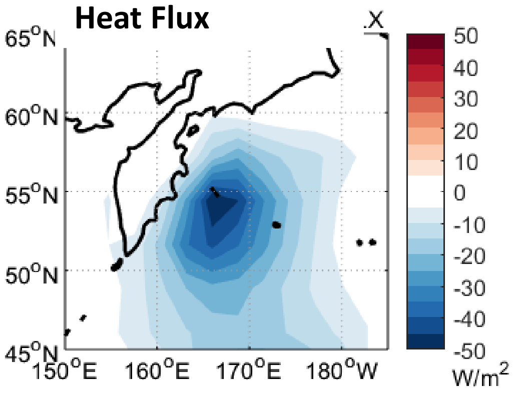
Ma et al., 2015, Sci. Rep

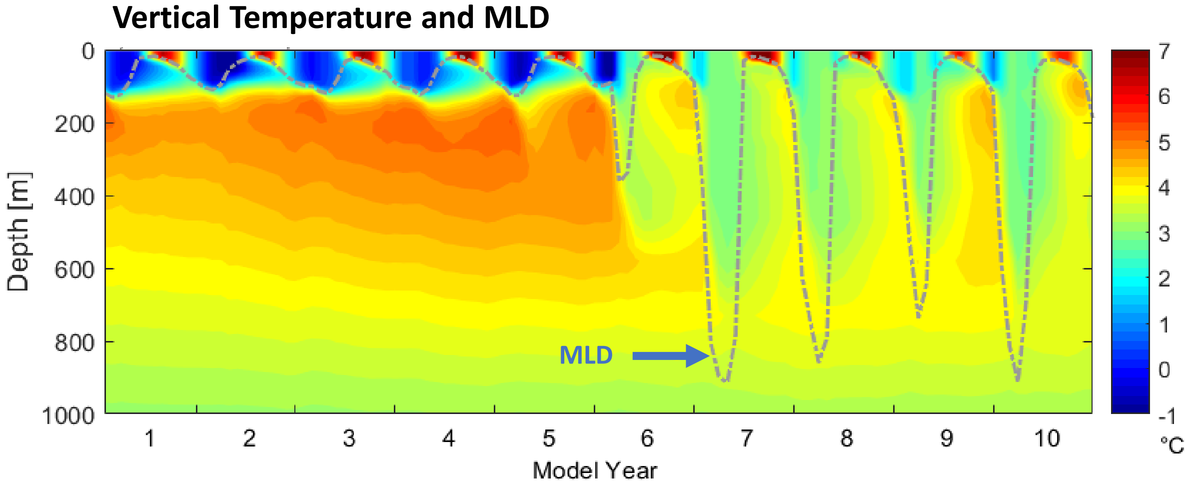
Water Hosing Experiment-YD simulation：

Strong Westerly, Strong Storm, Increased Convection, Strong PMOC

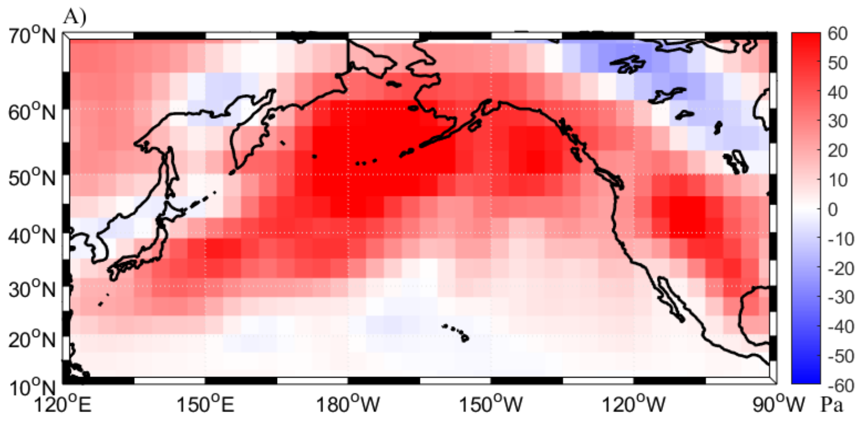








Shutdown of AMOC-Cold SST in North Atlantic-Atmospheric Teleconnection
Strong, Southward Westerly and Storm-Deep Convection-Strong PMOC



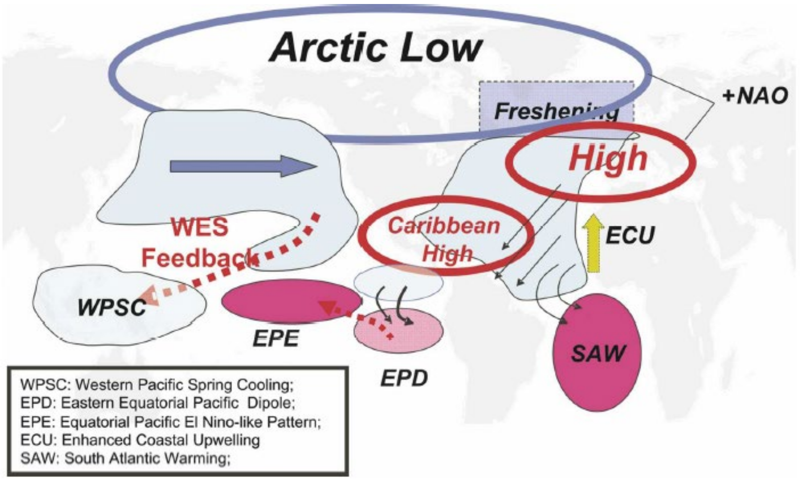
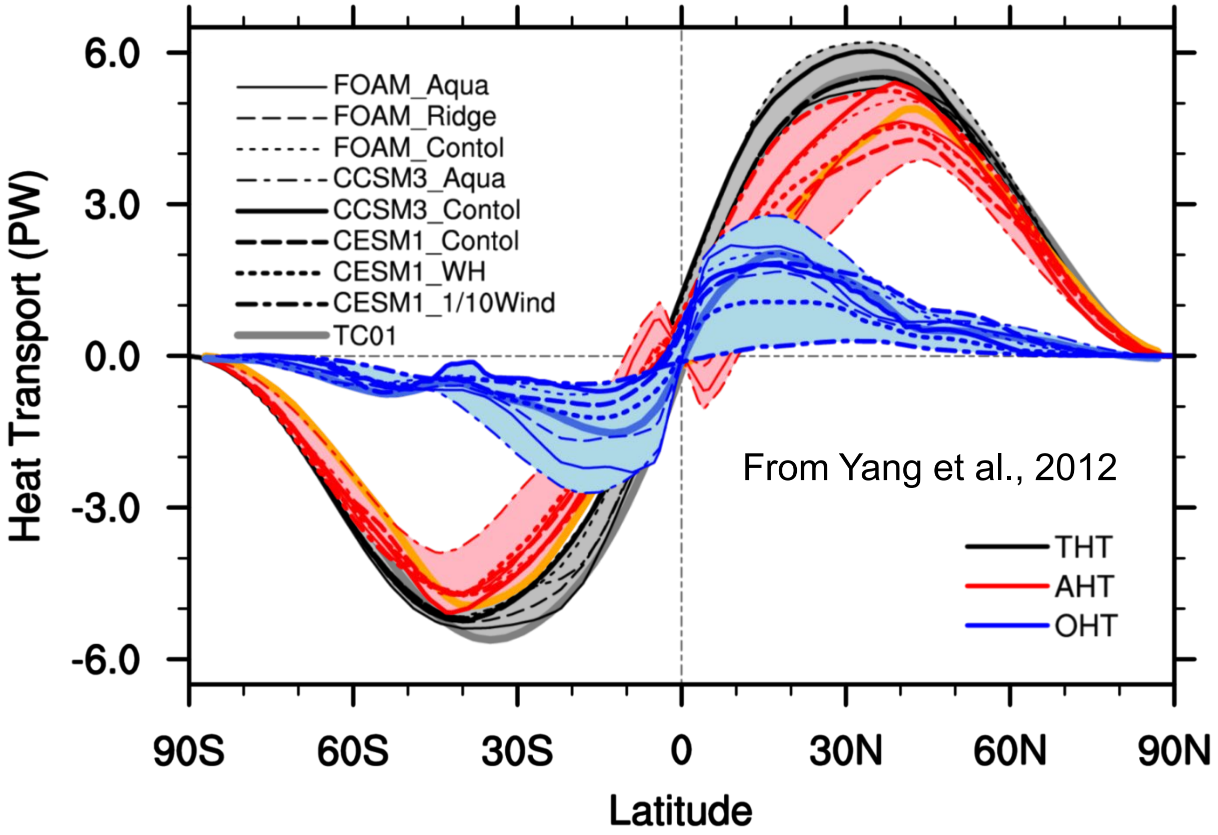


FIG. 13. Schematic diagram of global teleconnections in response to AMOC shutdown.

Storm Change after AMOC Shutdown

Wu et al., 2008,JC

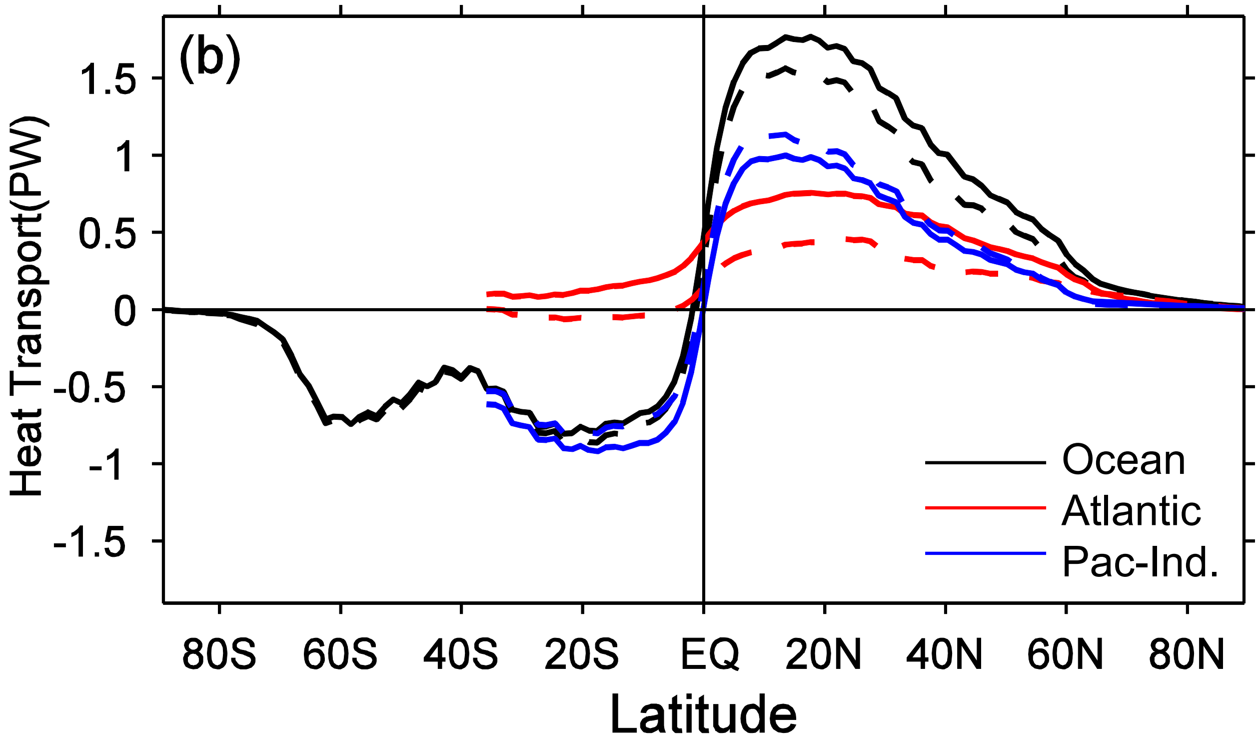
Why AMOC Shutdown Increase Westerly and Strom?



Meridional Heat Transport: Total, Atmosphere and Ocean

Bjerknes Compensation $\Delta HT_{total} = \Delta AHT + \Delta OHT = 0$

Sea Saw of AMOC and PMOC

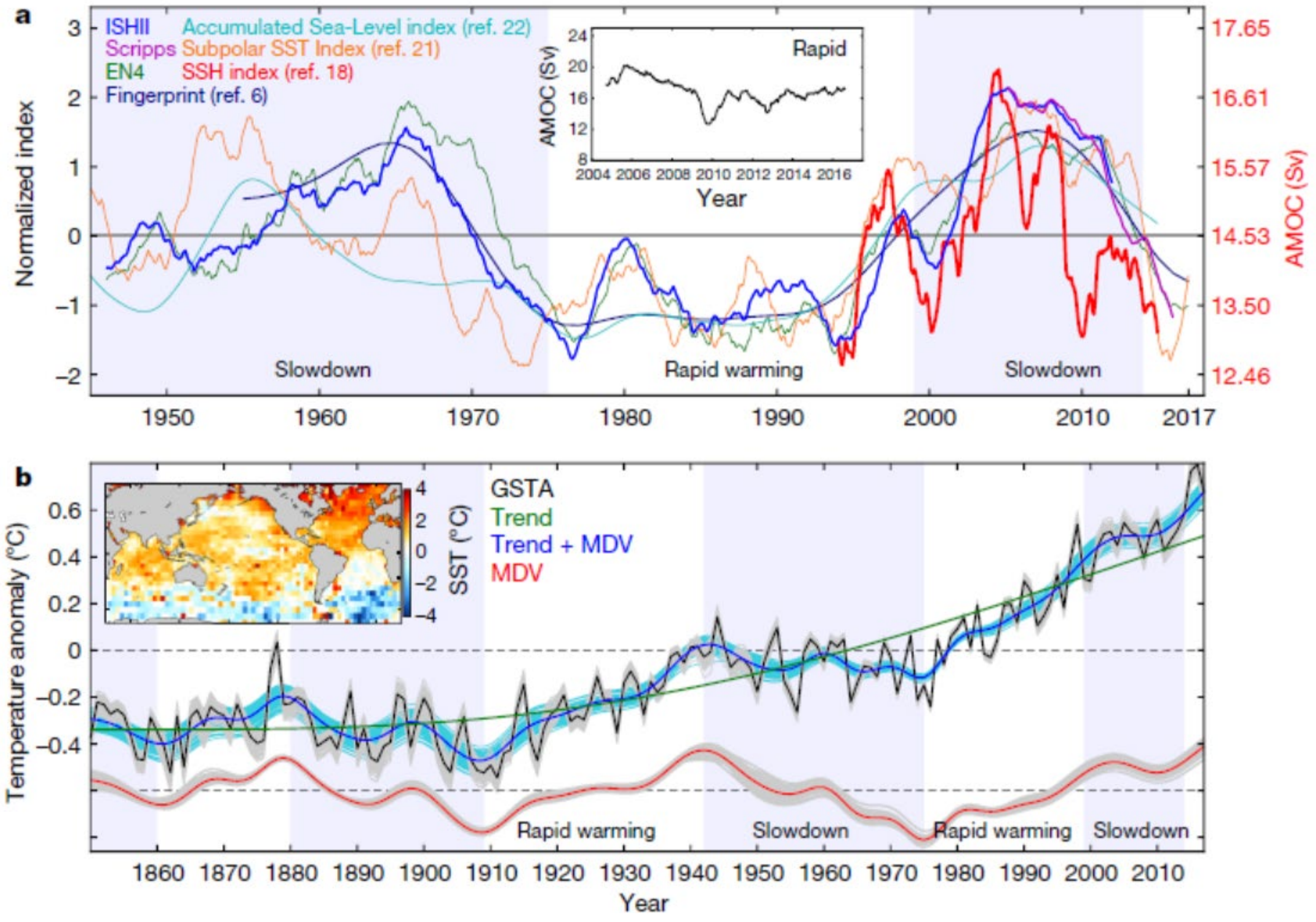


Total OHT ⇓ 0.2 PW

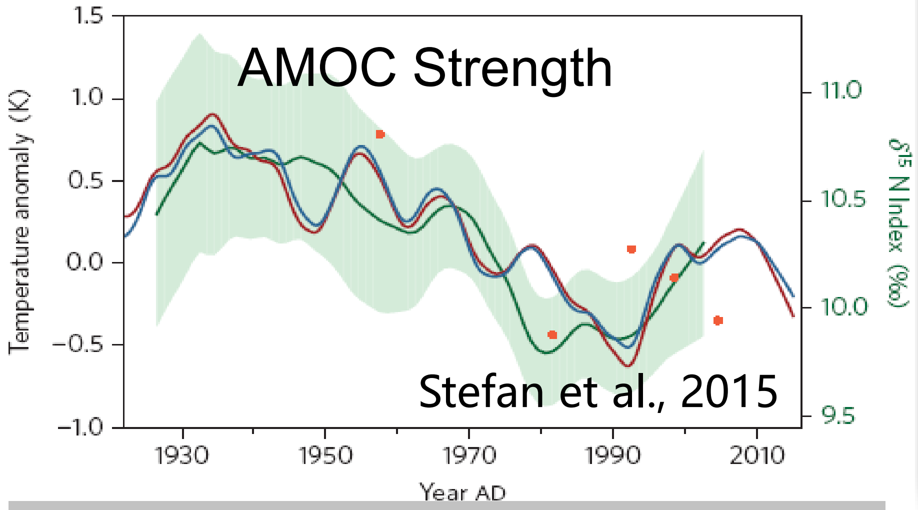
Atlantic OHT ⇓ 0.3 PW, Pacific-Indian OHT ⇑ 0.1 PW

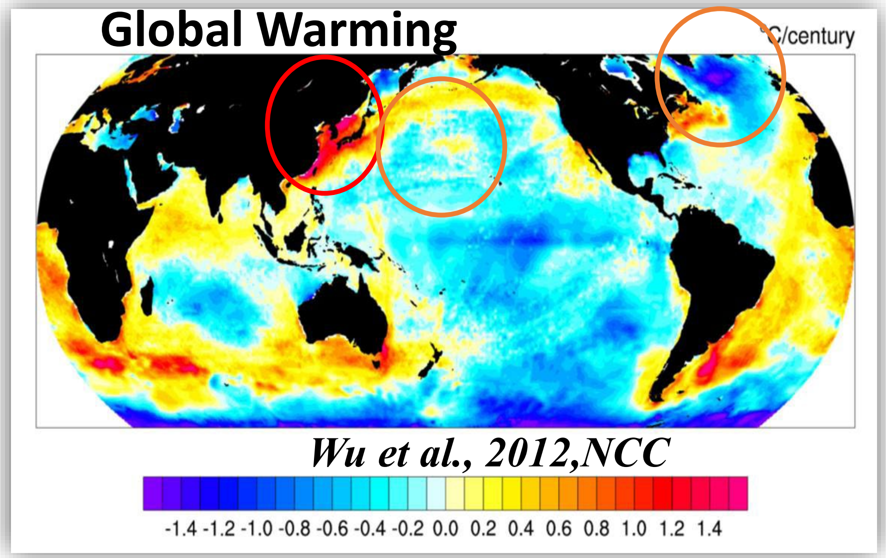
AMOC+ More Convection More Heat Down Global Hiatus

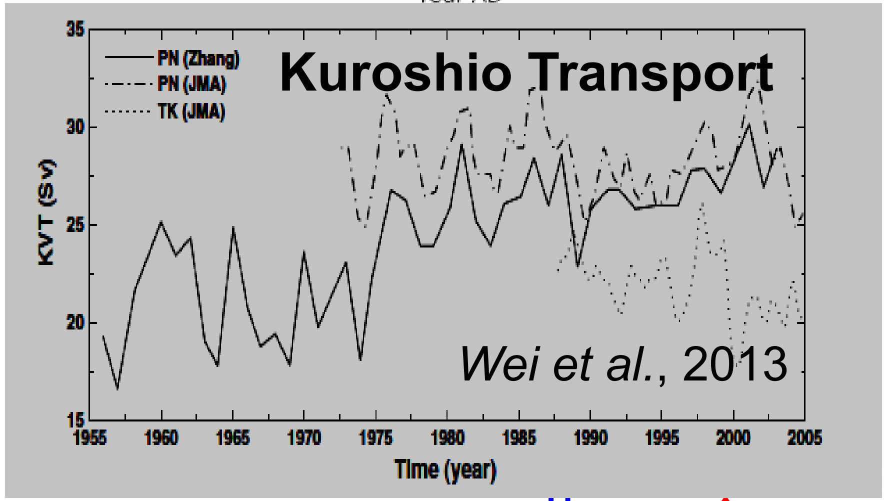
Chen & Tung, 2018, Nature

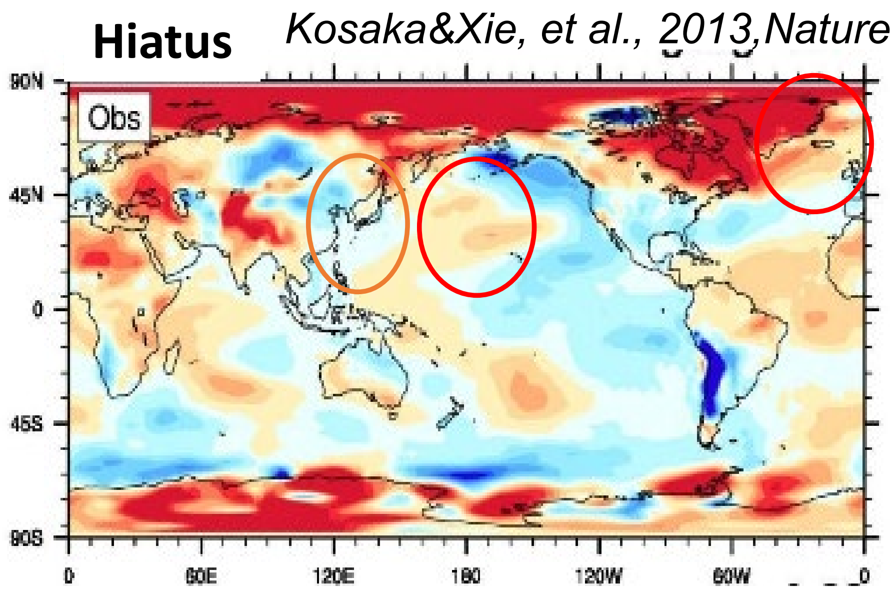


AMOC-PMOC Sea Saw in modern climate





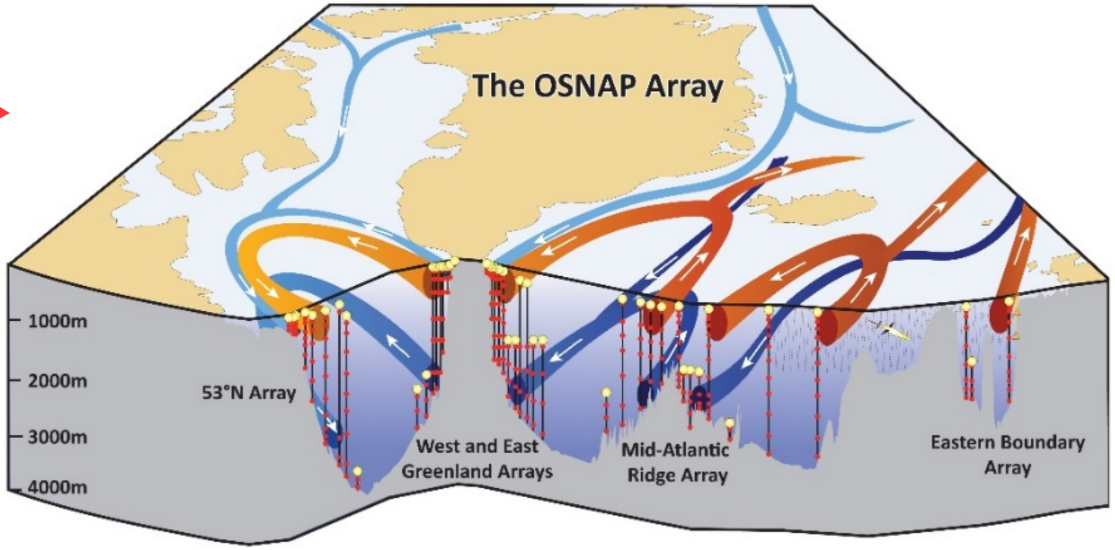




Warming Period： AMOC ⇓ , KC ⇑

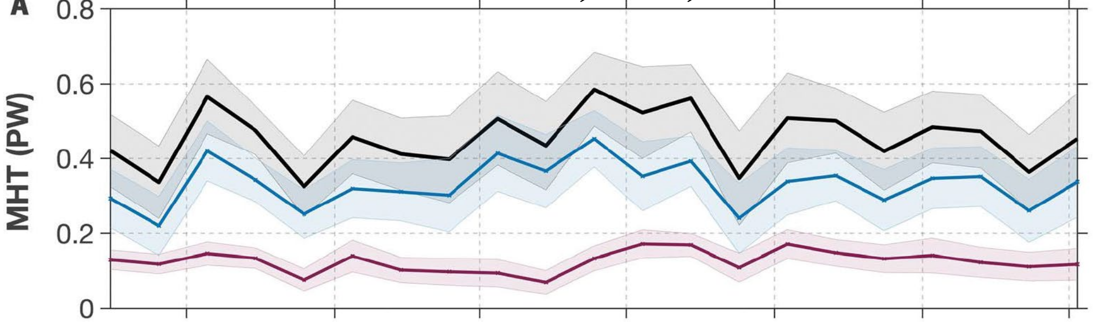
Hiatus Period： AMOC ⇑, KC ⇓

Deep Convection in Labrador Sea is not important
Overflow between Subpolar Atlantic and Nordic Sea is Dominant



Lozier…Lin et al., 2017, BAMS

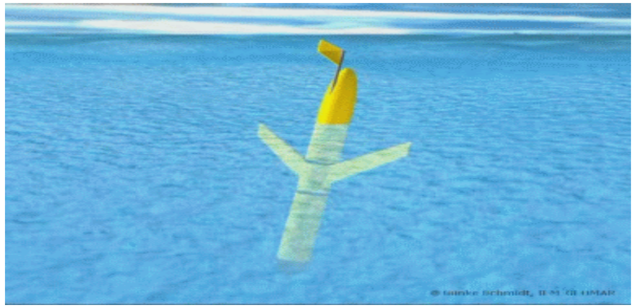
Lozier…Lin et al., 2019, Science*

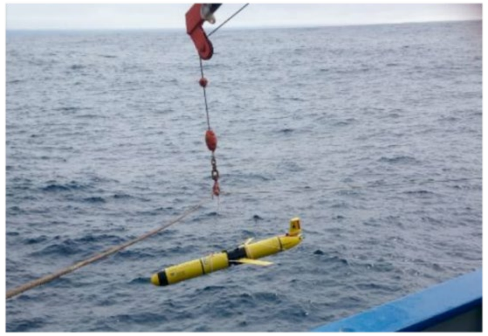


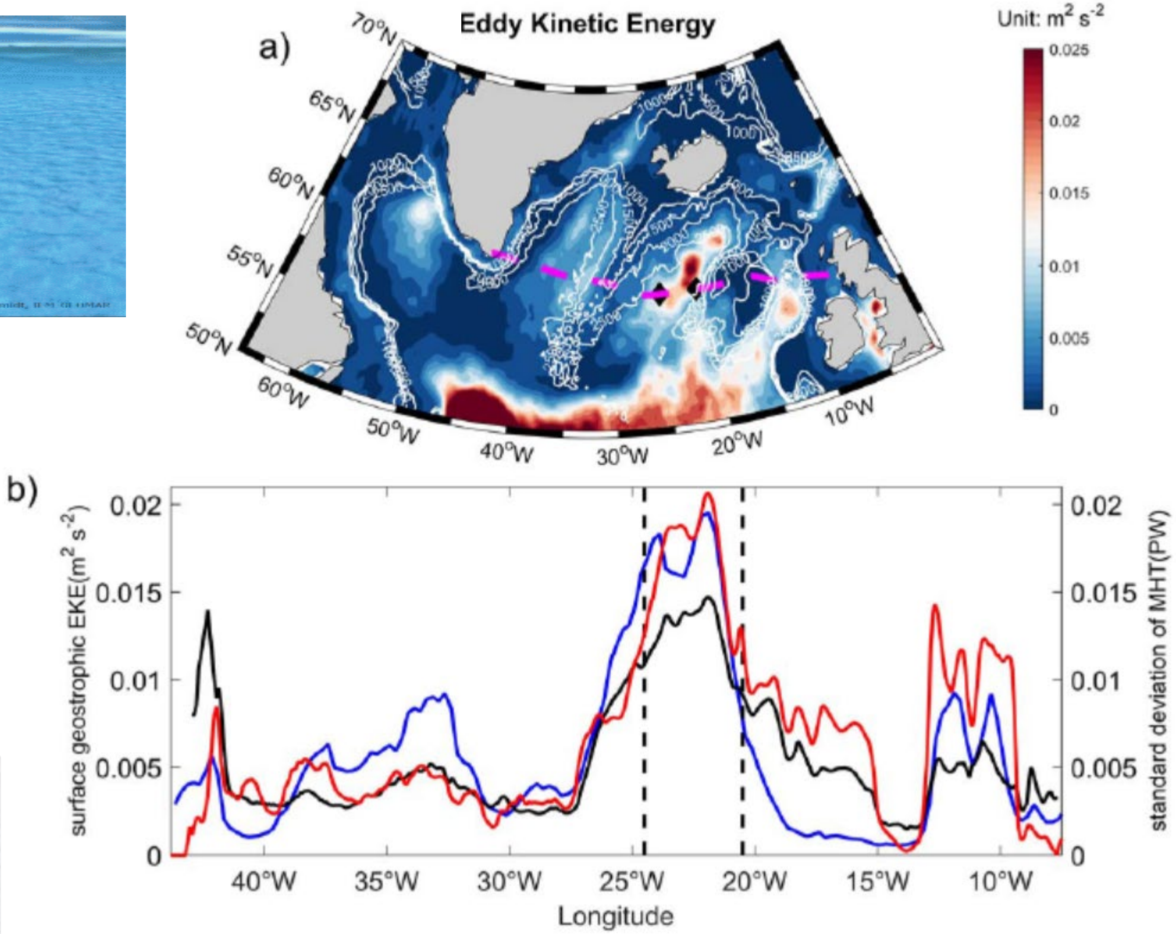
AMOC from Nordic Sea

AMOC from Labrador Sea

Mesoscale Eddies contribute a lot to AMOC



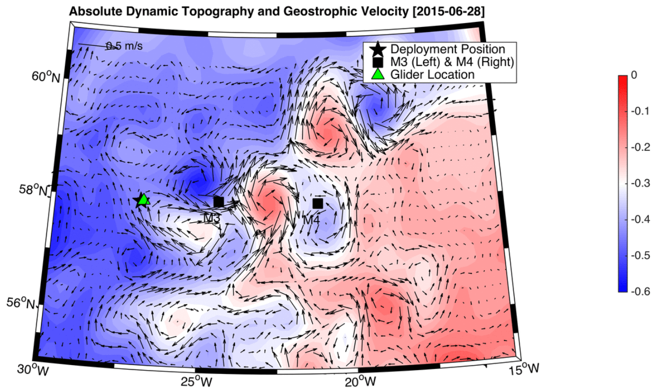


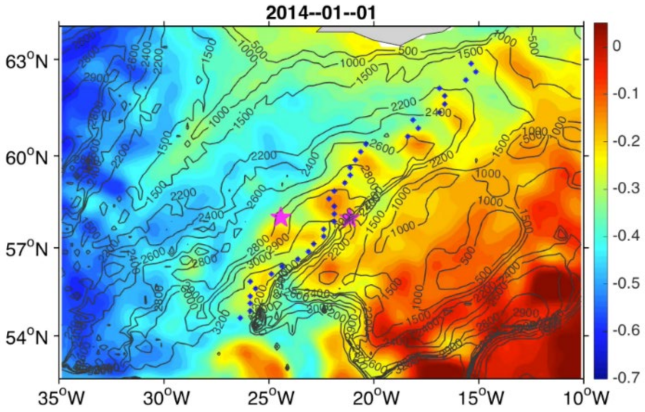


Meridional Heat Transport By Eddies

Zhao…Lin* et al., 2018, Nature Communications*

Zhao…Lin* et al., 2018, JGR*





Summary

- There is a Sea-Saw between AMOC and PMOC.
- Besides salinity, the storm induced deep-convection is also important to explain the observed Sea-Saw, especially in the YD event.
- The modern observation imply that the deep-convection may be not important for the formation and change of AMOC, but eddies play some roles on the AMOC variability.

Thank You!

Ventilation Age: Compare ^{14}C age difference between planktonic and benthic foraminifers to estimate the age of bottom waters. Affected by: Ventilation strength + Water depth

Convection depth in the Okhotsk Sea and Bering sea:

Select: <2000-m depth only

- 1400-2400 m during the H1. By *Jaccard and Galbraith* [*2013*]
- 1750-2100 m during the H1 and YD. By *Max et al.,* [*2014*]

Adapted

Core ID	Longitude	Latitude	Water Depth (m)	Area	Used in Figure	Reference
B34-91	150.34°E	49.14°N	1227	Okhotsk Sea	Fig. 2-3.B	Keigwin (2002), Okazaki et al. (2010), Cook et al. (2015)
GGC27	150.18°E	49.60°N	995	Okhotsk Sea	Fig. 2-3.B	Keigwin (2002), Okazaki et al. (2010), Okazaki et al. (2010), Cook et al. (2015)
LV27-2-4	144.75°E	54.50°N	1305	Okhotsk Sea	Fig. 2-3.B	Gorbarenko et al. (2010), Okazaki et al. (2014)
936	148.31°E	51.02°N	1305	Okhotsk Sea	Fig. 2-3.B	Gorbarenko et al. (2004), Okazaki et al. (2014)
GGC15	150.4°E	48.6°N	1980	Okhotsk Sea	Fig. 2-3.B	Keigwin (2002), Okazaki et al. (2010)
GGC18	150.4°E	48.8°N	1700	Okhotsk Sea	Fig. 2-3.B	Keigwin (2002), Okazaki et al. (2010)
GGC20	150.4°E	48.9°N	1510	Okhotsk Sea	Fig. 2-3.B	Keigwin (2002), Okazaki et al. (2010)
SO178-13-6	144.70°E	52.72°N	713	Okhotsk Sea	Fig. 2-3.B; Fig. 2-3.D	Max, L et al. (2014)
LV29-114-3	152.88°E	49.37°N	1765	Okhotsk Sea	Fig. 2-3.B	Max, L et al. (2014)
SO201-2-101KL	170.68°E	58.87°N	630	Bering Sea	Fig. 2-3.B	Max, L et al. (2014)
SO201-2-85KL	170.40°E	57.50°N	968	Bering Sea	Fig. 2-3.B; Fig. 2-3.D	Max, L et al. (2014)
SO202-18-6	179.43°W	60.12°N	1100	Bering Sea	Fig. 2-3.B	Max, L et al. (2014)

Abandoned

Core ID	Longitude	Latitude	Water Depth (m)	Area	Reference	
MD01-2416	167.73°E	51.27°N	2317	Emperor Seamounts	Sarnthein el al. (2006), Okazaki et al. (2010)	> 2000 m
ODP883	167.77°E	51.20°N	2385	Emperor Seamounts	Sarnthein el al. (2006), Okazaki et al. (2010)	> 2000 m
SO201-2-12KL	162.37°E	53.98°N	2145	Bering Sea	Max, L et al. (2014)	> 2000 m
SO201-2-77KL	170.68°E	56.32°N	2135	Bering Sea	Max, L et al. (2014)	> 2000 m
RNDB 10PC	167.665°E	51.296°N	2364	Emperor Seamounts	Keigwin et al. (2015)	> 2000 m
RNDB 11PC	167.975°E	51.073°N	3225	Emperor Seamounts	Keigwin et al. (2015)	> 2000 m
V34-98	153.20°E	50.11°N	1175	Okhotsk Sea	Gorbarenko et al. (2002), Okazaki et al. (2014)	No data during 10-20 Ka

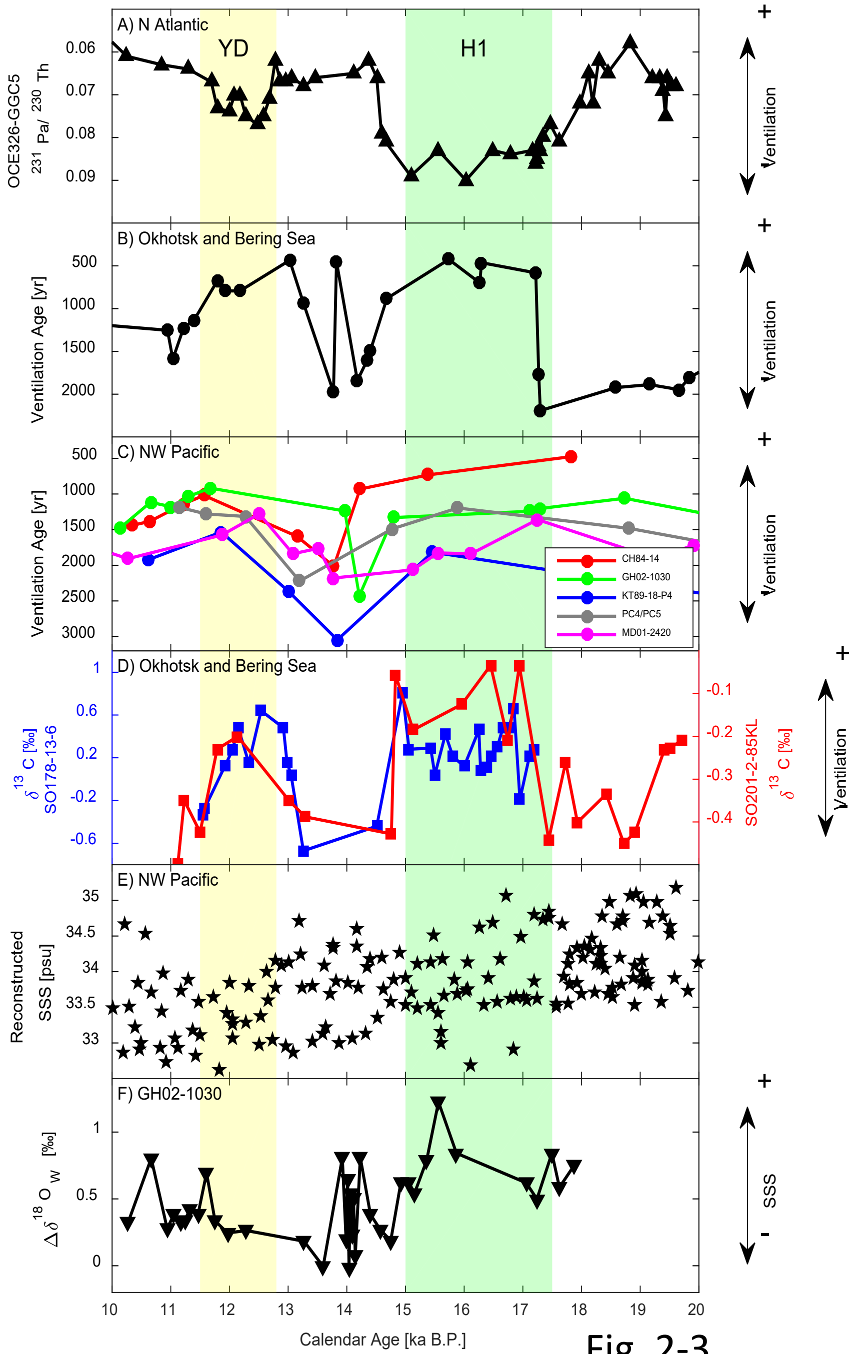


Fig. 2-3

AMOC strength

Based on: ^{31}Pa/^{230}Th ratio

Ventilation Age for the Okhotsk Sea and Bering Sea based on ^{14}C

Select: < 2000 m depth only

Ventilation Age for the western North Pacific subtropical gyre based on ^{14}C

Select: At least one value for the H1 and YD period

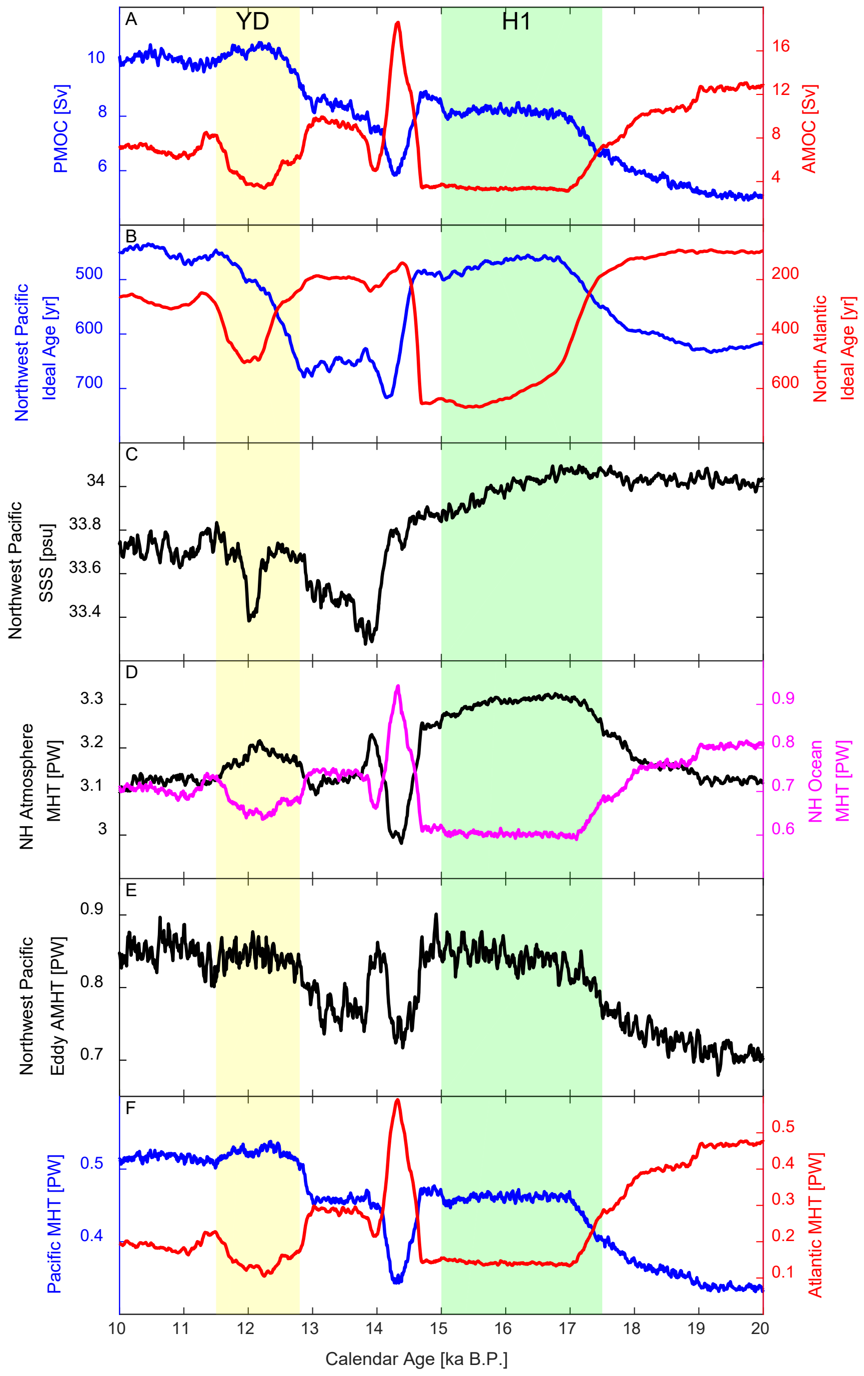
Ventilation Strength for the Okhotsk Sea and Bering Sea based on benthic foraminifers δ^{13}C

Reconstructed SSS

Cores: KT90-9, 21; KT90-9, 5; KH94-3,LM-8; MD01-2421; CH84-04

SSS proxy

Core: GH02-1030



Seesaw of AMOC and PMOC

MOC definition:

Max streamfunction between 20°N-60°N, below 500-m

Water Age at 1000-m for NA and NW P

North Atlantic : north of 30°N

Northwest Pacific : 30°N- 60°N, 140°E-180°E

Northwest Pacific SSS

Area: 30°N- 60°N, 140°E-180°E

Atmospheric and Oceanic MHT in the northern hemisphere

Bjerknes Compensation

Storm induced atmospheric MHT in the Northwest Pacific

Area: 30°N- 60°N, 140°E-180°E

Pacific and Atlantic MHT in the northern hemisphere

21K CCSM3 Simulation, Liu et al., 2013