Persistent millennial-scale links between North Pacific intermediate-water ventilation and North Atlantic Climate during the deglaciation and last glaciation

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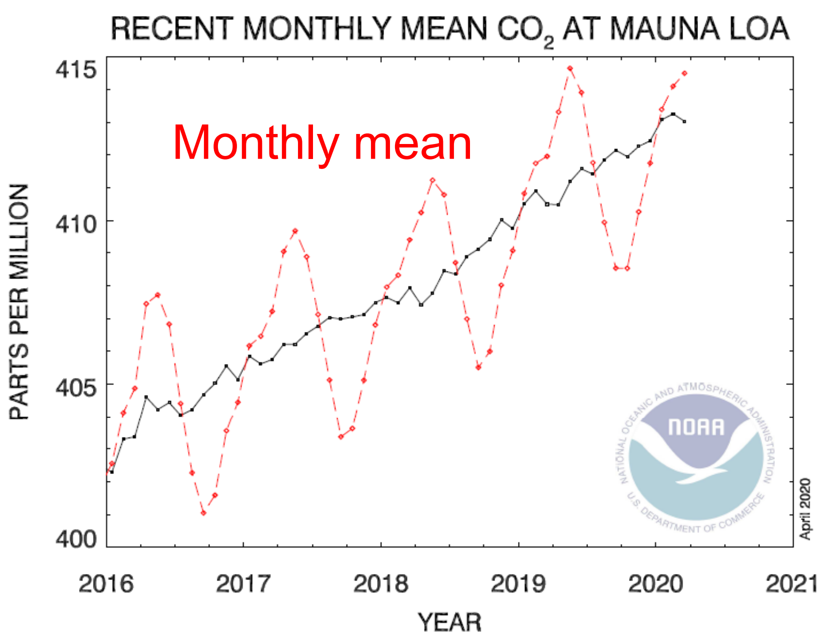
May, 2020 Vienna

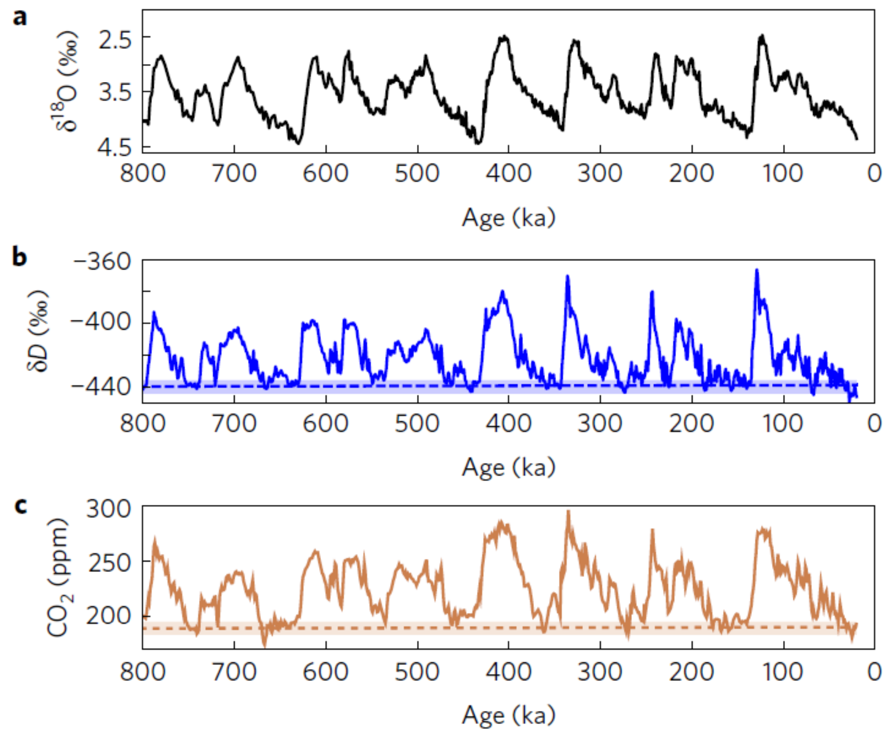
Changes in atmospheric CO_2 levels

March , 2020: 414.5 ppmv



Mauna Loa Atmosperic CO_2 Record

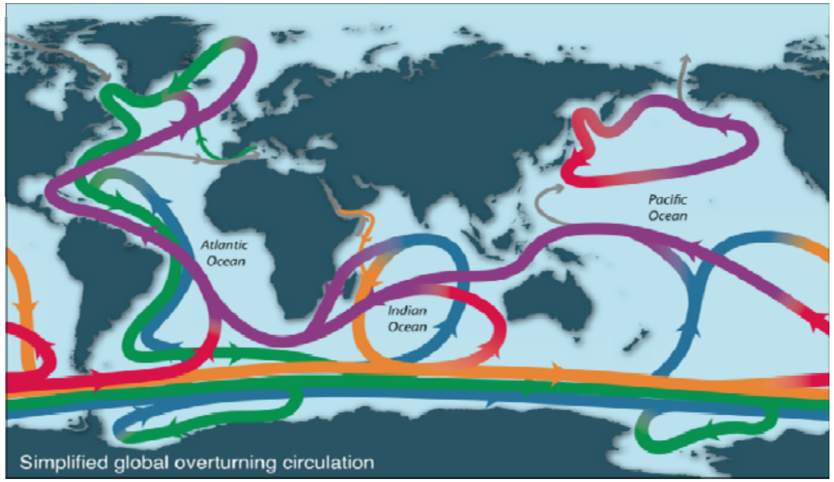
180-280 ppmv



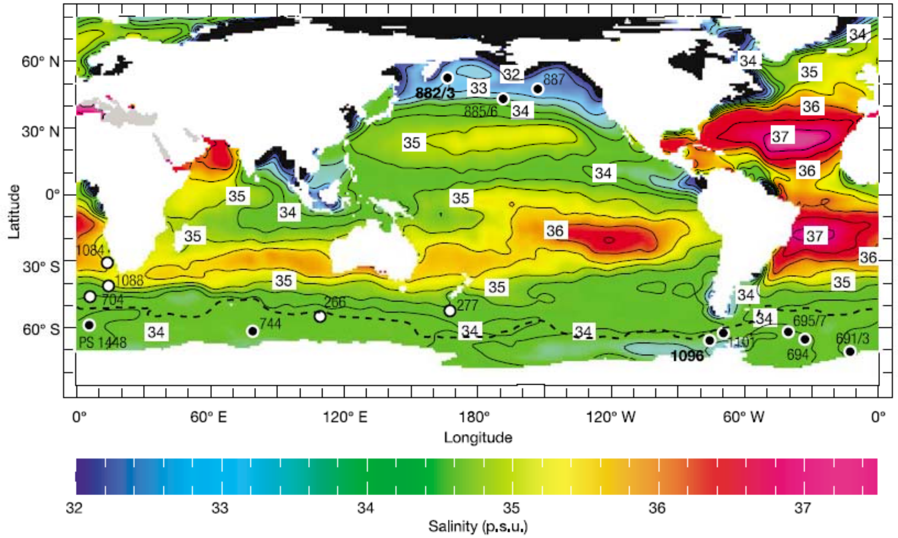
Galibraith 2017, NG

- Mechanisms for CO_2 variations: carbon sequestration, biological pump, silicate weathering, volcanic eruption, ...
- Coupling of sedimentary oxygenation and carbon sequestration

North Pacific Intermediate Water



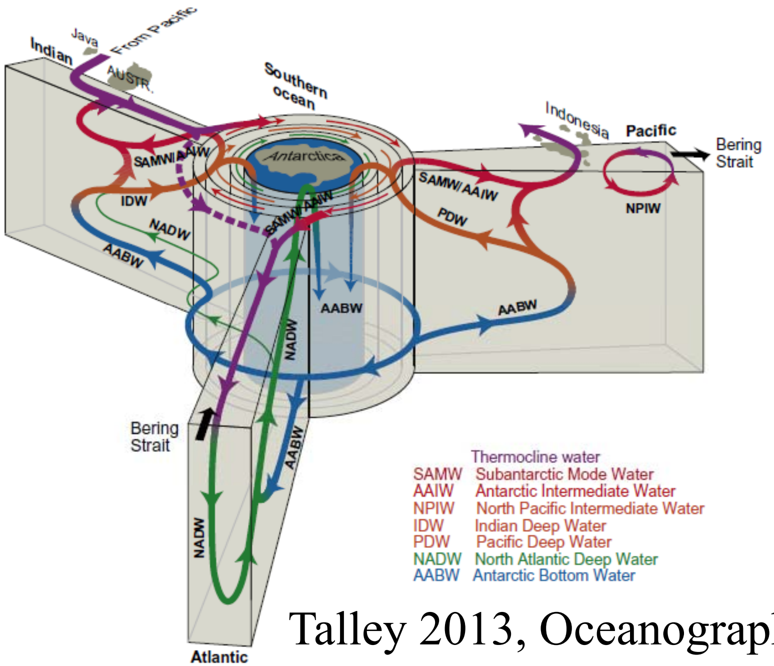
Talley 2013, Oceanography



Sigman et al. 2004, Science

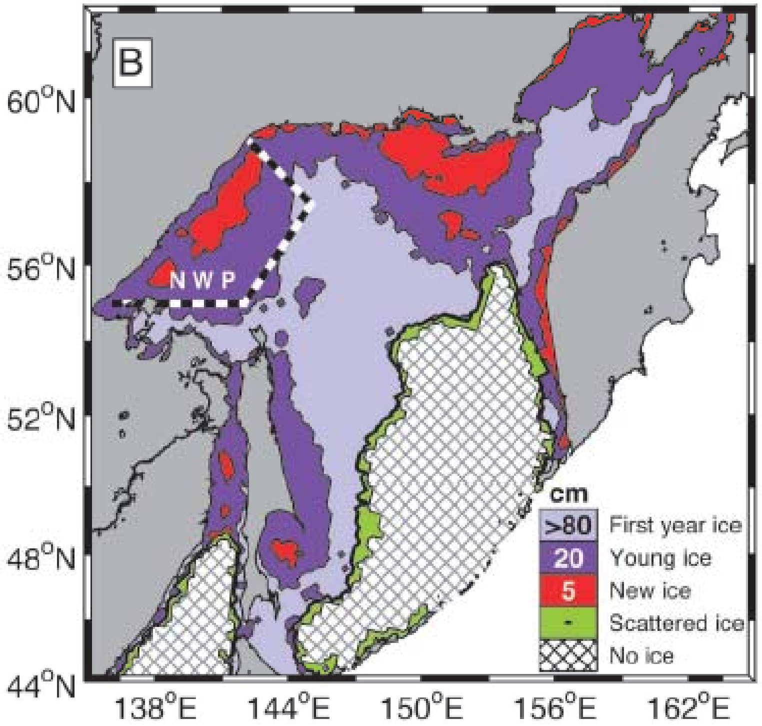
- ➢Formation: sea ice and brine rejection
- ➢Distribution: the subtropical gyre

- ☐ anthroprogenic CO_2 sink
- ☐ a total transport of about 2.7 Sv & low salinity;



Talley 2013, Oceanography

Direct observation of NPIW formation



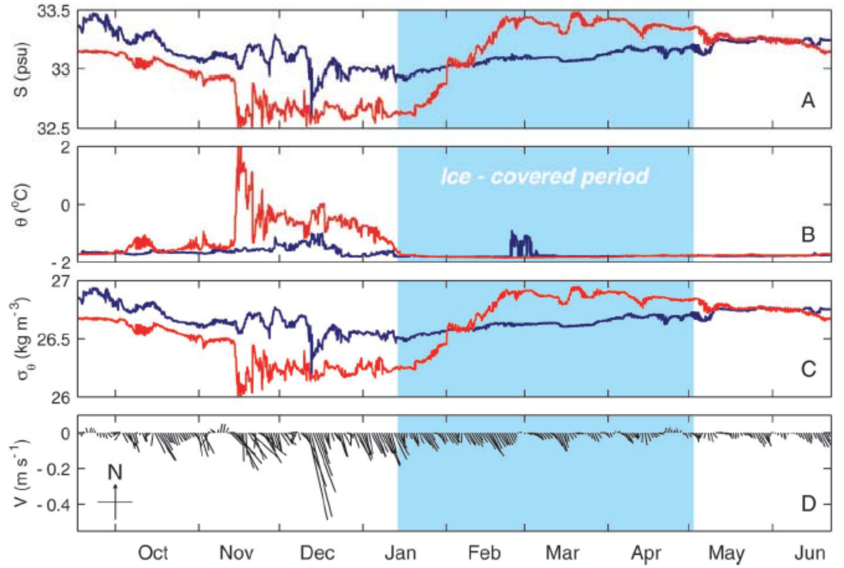


Fig. 3. Bottom water properties at the moorings. (**A**) Salinity, (**B**) potential temperature, and (**C**) potential density on the western (red line) and eastern (blue line) bottom moorings. (**D**) Mean horizontal velocity vector at the western bottom mooring low-passed with a 4-day Blackman filter. Blue shading indicates persistent ice cover over the western mooring, as detected by the mooring's Acoustic Doppler Current Profiler.

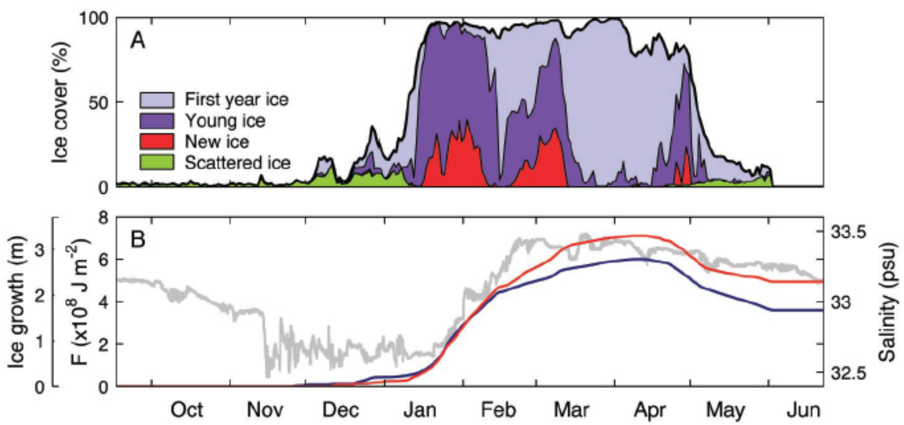


Fig. 4. Evolution of northwestern polynya. (**A**) Fractional ice cover over the northwestern shelf (within 50- to 200-m depth interval and the boundaries shown in Fig. 1B). (**B**) Cumulative heat loss through the ice above the western (red line) and eastern (blue line) mooring site. The leftmost scale shows the ice growth equivalent to this heat loss. Salinity at the western mooring (gray line) is shown for reference. The estimates of heat fluxes and ice classification are based on European Centre for Medium-Range Weather Forecasts reanalysis meteorology and National Snow and Ice Data Center ice data, respectively.

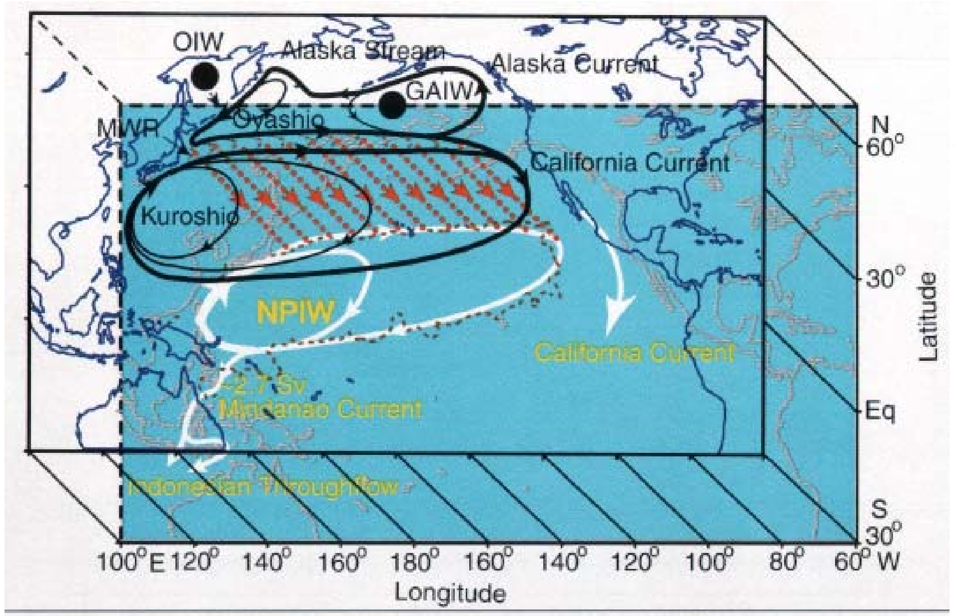
Source for low-salinity NPIW:

- Okhotsk Sea
- Gulf of Alaska;

Shcherbina et al. 2003 Science

Spread of NPIW toward subtropical North Pacific

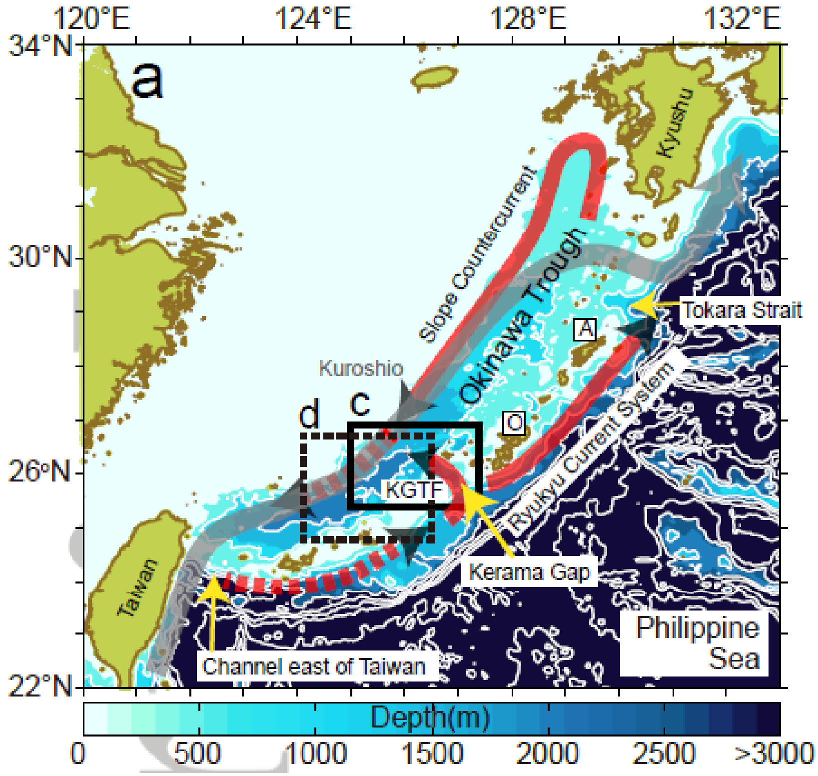
You 2005 EOS



- Cold/fresh Oyashio water meets the warm/salty Kuroshio water
- Mixing results in densification and sinking of water parcels

- Return back to the west Pacific and intrude into the SCS and OT

Kerama Gap

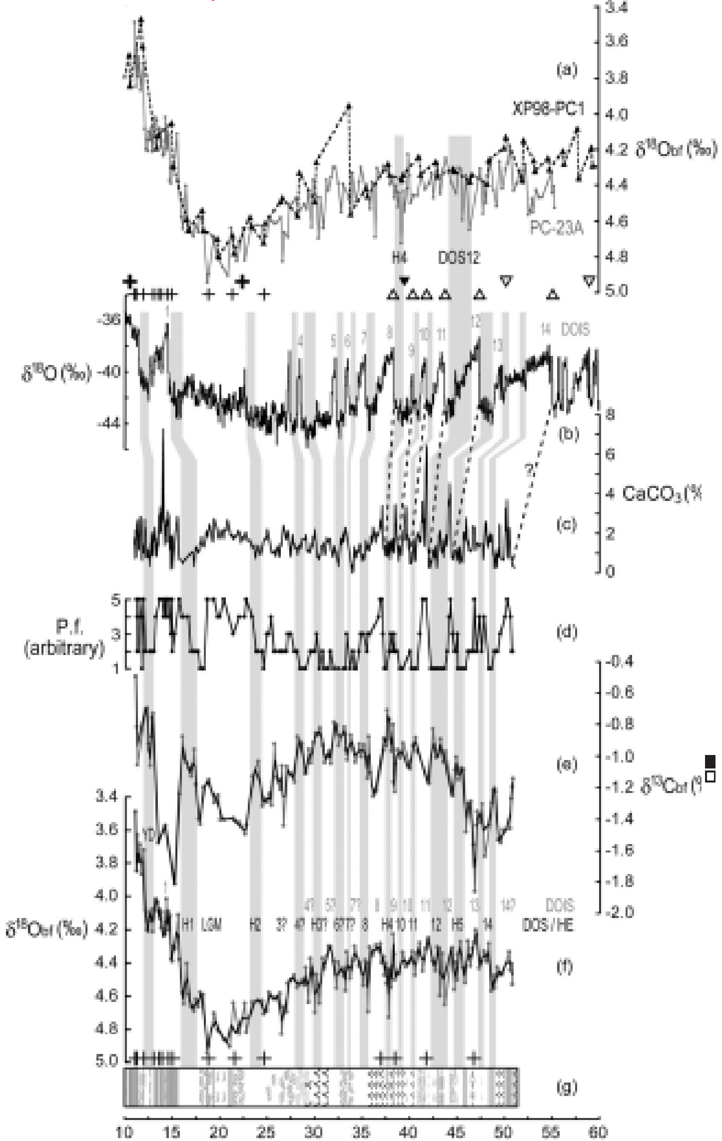


Nishina et al. 2016

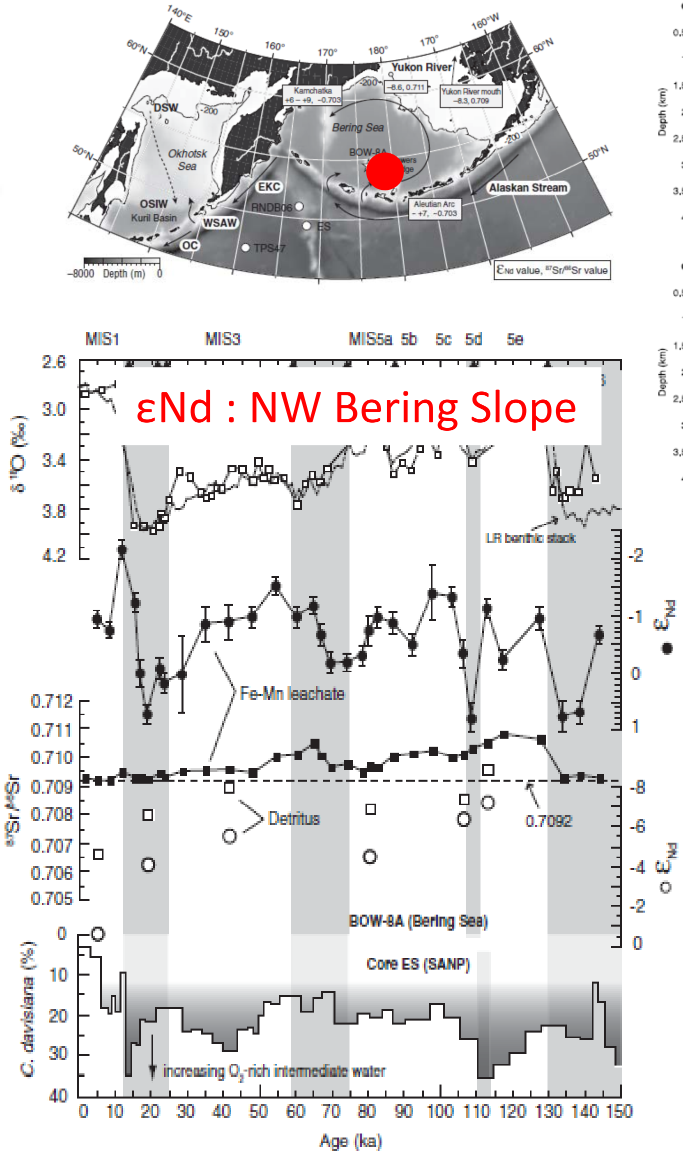
Last Glaciation: Ventilation and source variations in NPIW

LGM: several sources
<1000m: well ventilated

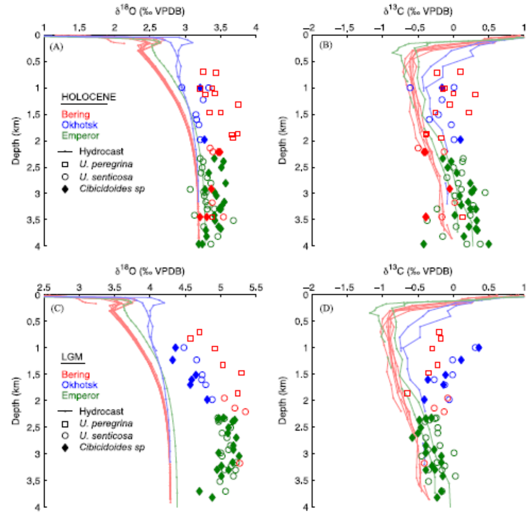
d18O, $d^{13}C$& radiolaria



Rella et al. 2012, Paleo



Horikawa et al. 2010 Geology

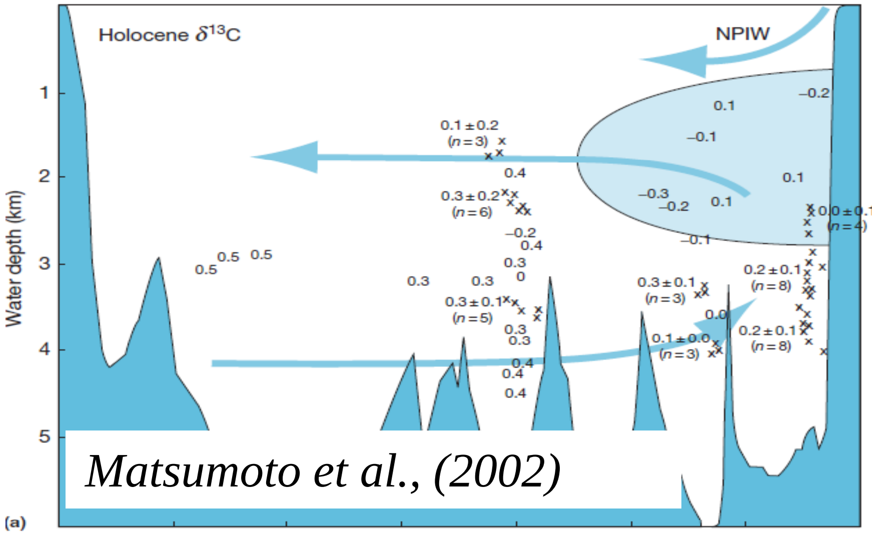


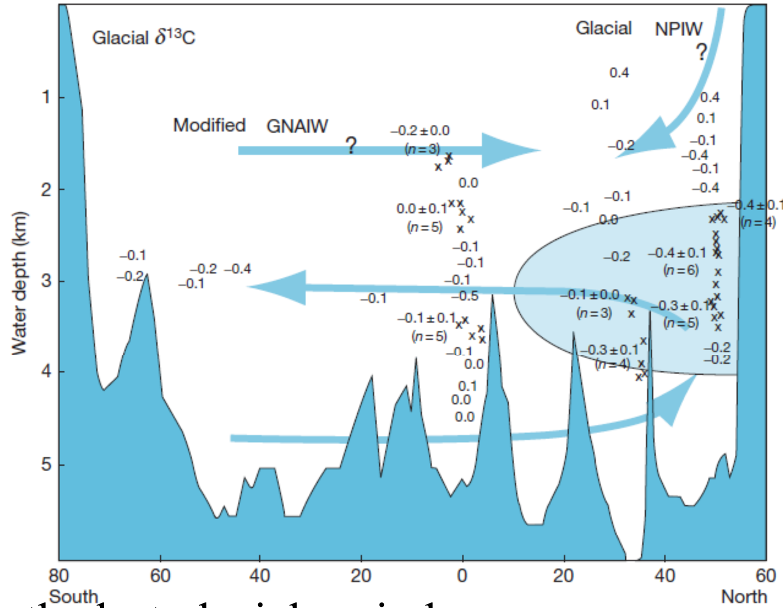
Cook et al. 2016, Paleo

$\delta^{18}O$, $\delta^{13}C$

LGM: Ventilation and source variations in GNPIW

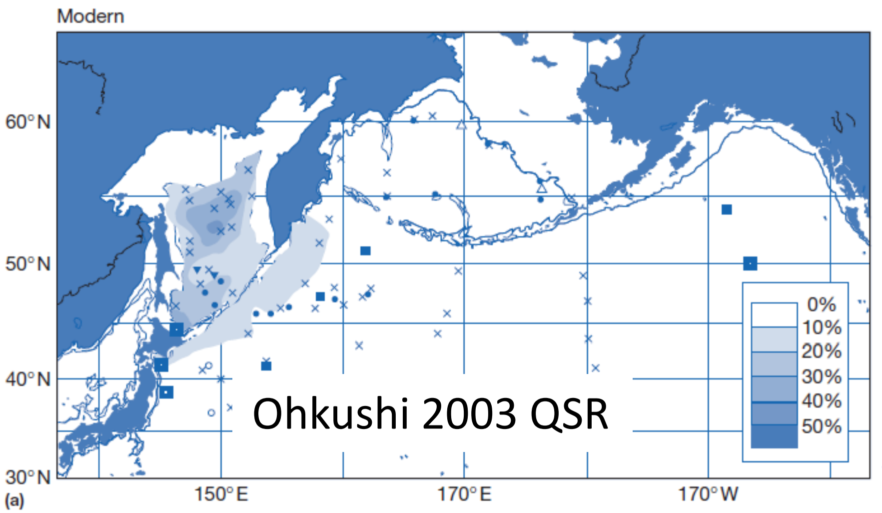
Benthic foraminiferal δ[13]C

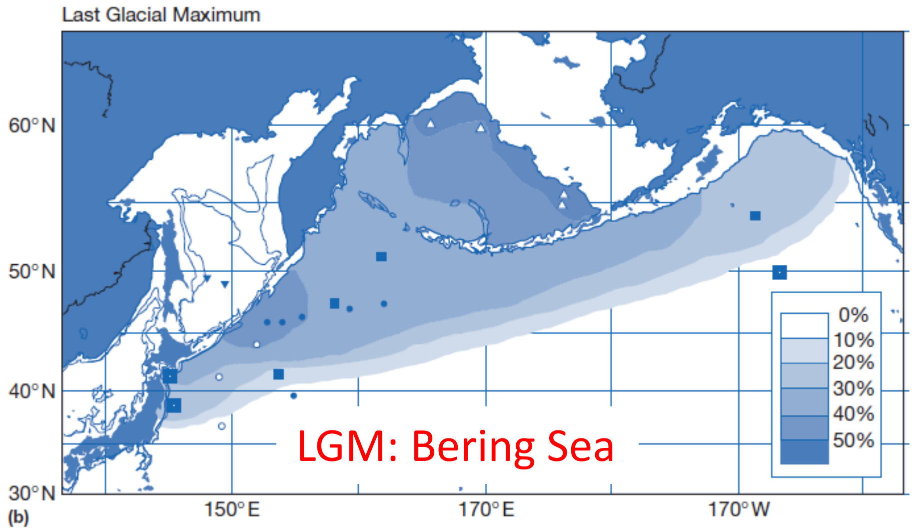




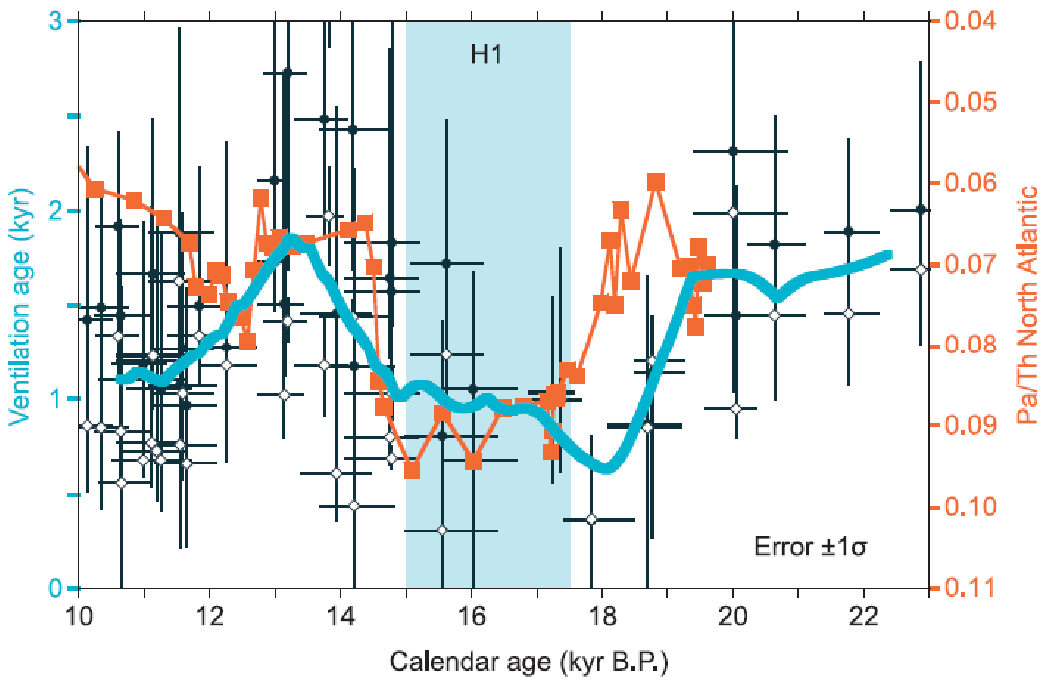
enhanced ventilation at water depth of < 2000 m during the last glacial period

Radiolarians

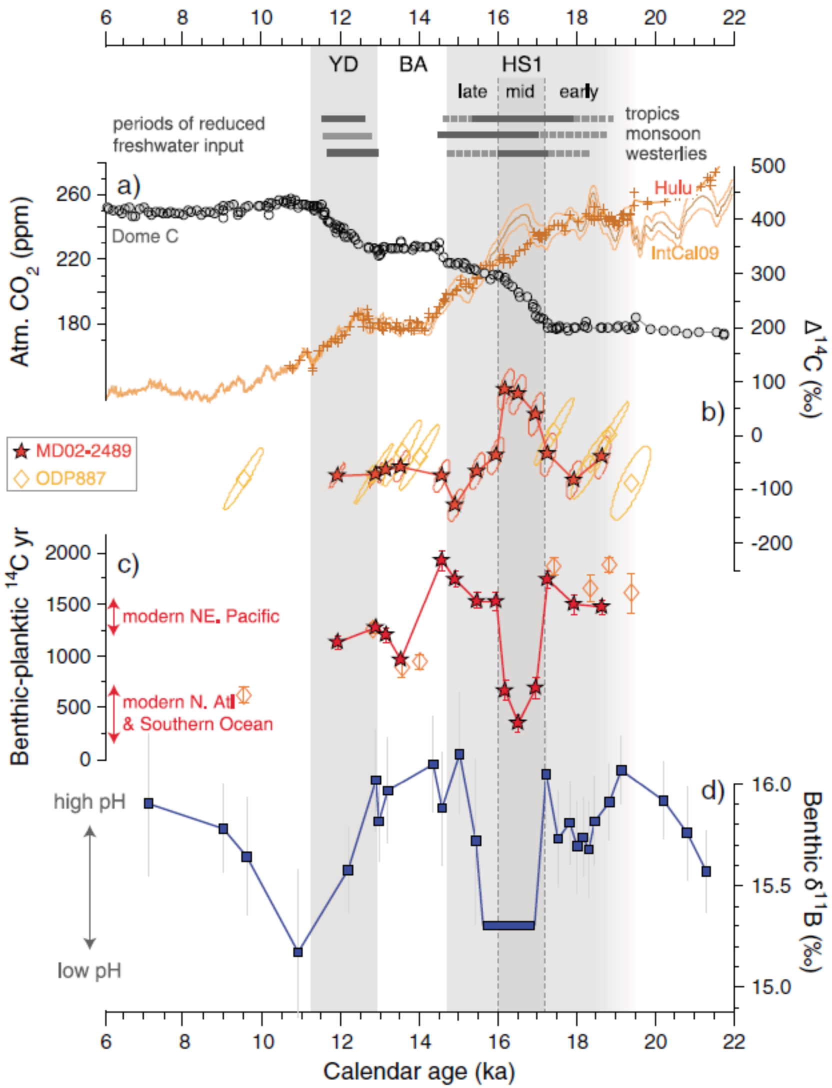




Early deglaciation: formation of NPDW



Okazaki et al. 2010 Science



- Penetrate to a depth of ~2500 to 3000 m
- Boron isotope & paired AMS 14C: 3640 m

Rae et al. 2014 Paleoceanography

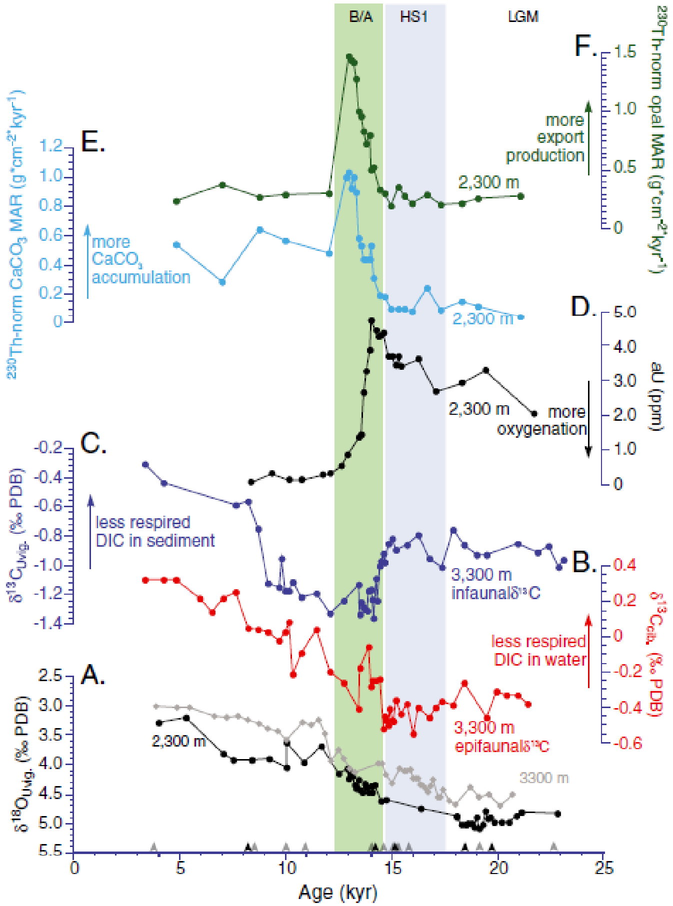
Early deglaciation: No formation of NPDW

GEOPHYSICAL RESEARCH LETTERS, VOL. 40, 199–203, doi:10.1029/2012GL054118, 2013

Direct ventilation of the North Pacific did not reach the deep ocean during the last deglaciation

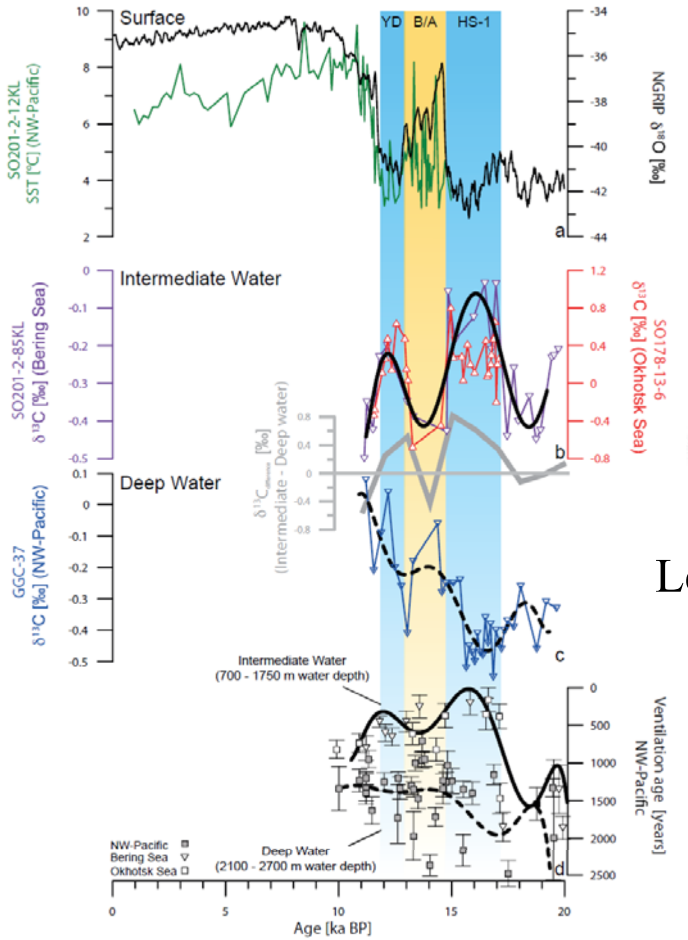
S. L. Jaccard[1] and E. D. Galbraith[2]

~2400m



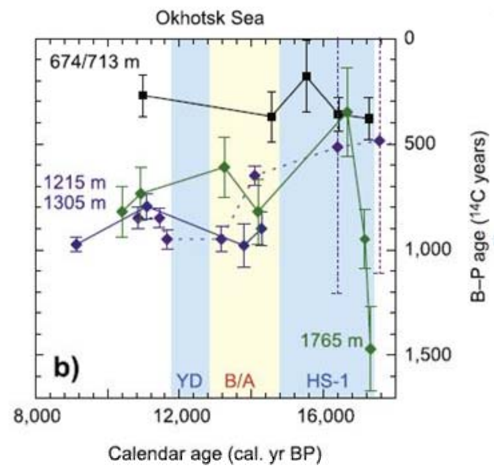
Jaccard & Galbraith 2013 GRL

2340m



Max et al. 2014 CP

1765 m



Lester et al. 2017 QSR

nature geoscience

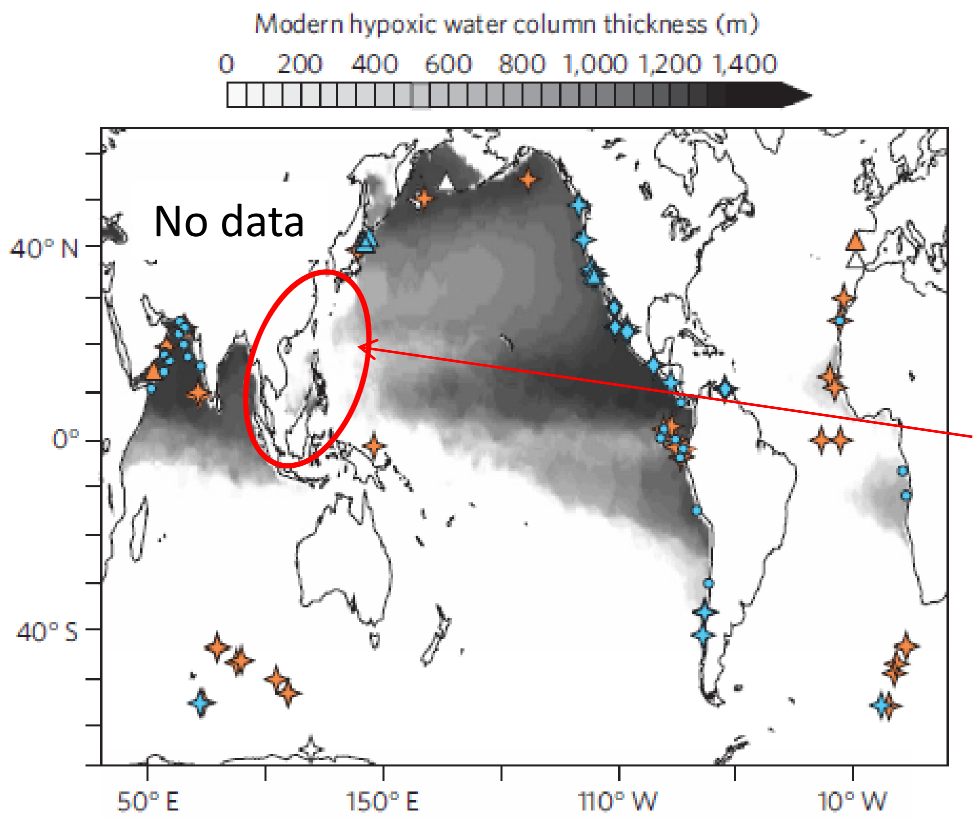
ARTICLES

PUBLISHED ONLINE: 18 DECEMBER 2011 | DOI: 10.1038/NGEO1352

Large climate-driven changes of oceanic oxygen concentrations during the last deglaciation

Samuel L. Jaccard[1]* and Eric D. Galbraith[2]*

During the last glacial termination, the solubility of gases in the ocean decreased as ocean temperatures rose. However, marine sediments have not unanimously recorded ocean deoxygenation throughout this time. Some records show increasing oxygenation since the Last Glacial Maximum, particularly in the deep sea, while many document abrupt oxygenation changes, often associated with apparent changes in the formation rate of North Atlantic Deep Water. Here we present a global compilation of marine sediment proxy records that reveals remarkable coherency between regional oxygenation changes throughout deglaciation. The upper ocean generally became less oxygenated, but this general trend included pauses and even reversals, reflecting changes in nutrient supply, respiration rates and ventilation. The most pronounced deoxygenation episode in the upper ocean occurred midway through the deglaciation, associated with a reinvigoration of North Atlantic Deep Water formation. At this time, the upper Indo-Pacific Ocean was less oxygenated than today. Meanwhile, the bulk of the deep ocean became more oxygenated over the deglaciation, reflecting a transfer of respired carbon to the atmosphere. The observed divergence from a simple solubility control emphasizes the degree to which oxygen consumption patterns can be altered by changes in ocean circulation and marine ecosystems.

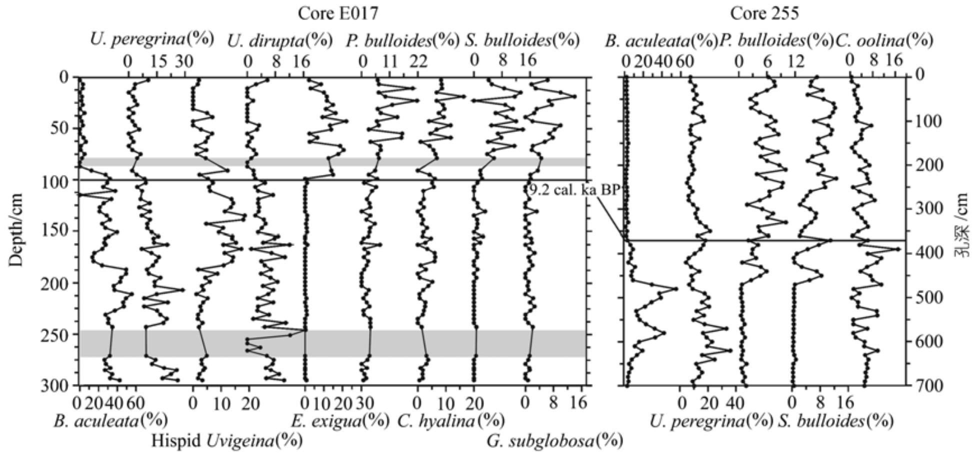


Deglacial DO distribution during the Deglaciation in the N Pacific

- Coherent oxygenation changes throughout deglaciation in the upper North Pacific and Indian ocean.
- No data available in the subtropical north Pacific!

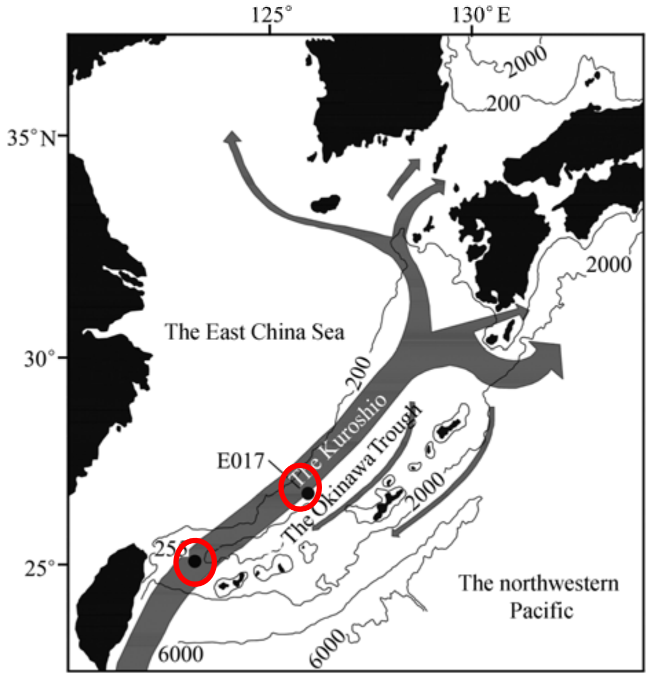
Question: What and how does the ventilation vary in the western subtropical North Pacific since the last glaciation?

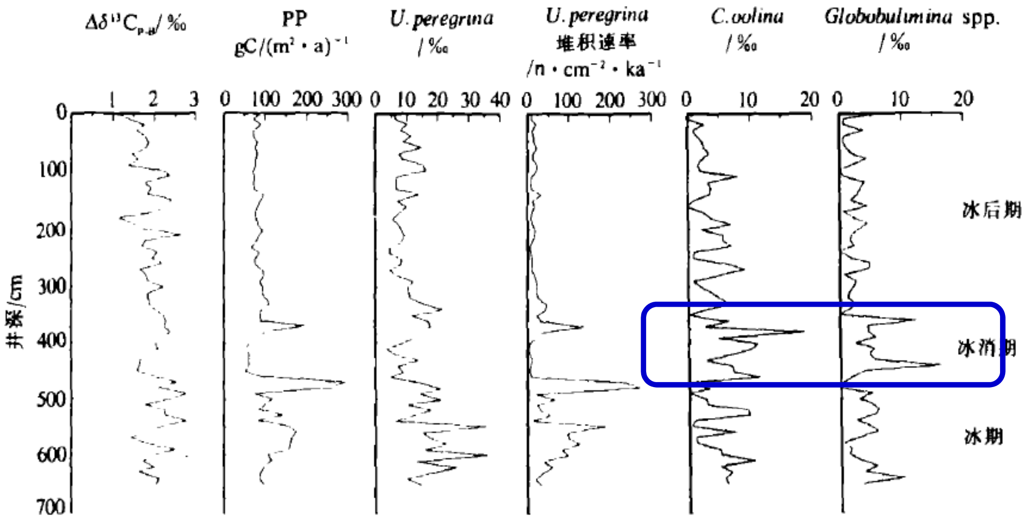
Benthic foraminifera: Evidence for oxygenation variations



Li et al. 2005

Hypoxia was prevailing during the deglaciation.





Jian et al. 1996

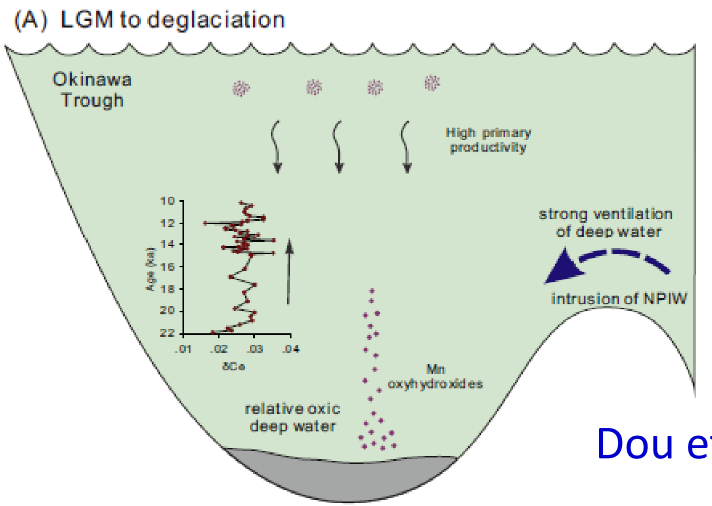
Post deglaciation

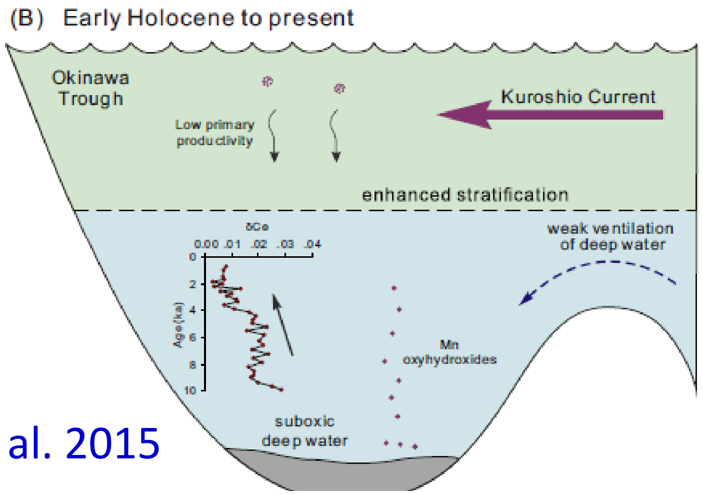
oxygen depletion - like BF species

deglaciation

glaciation

Different ventilation patterns





Dou et al. 2015

Strong Ventilation: intrusion of NPIW

Weak Ventilation and suboxic environment

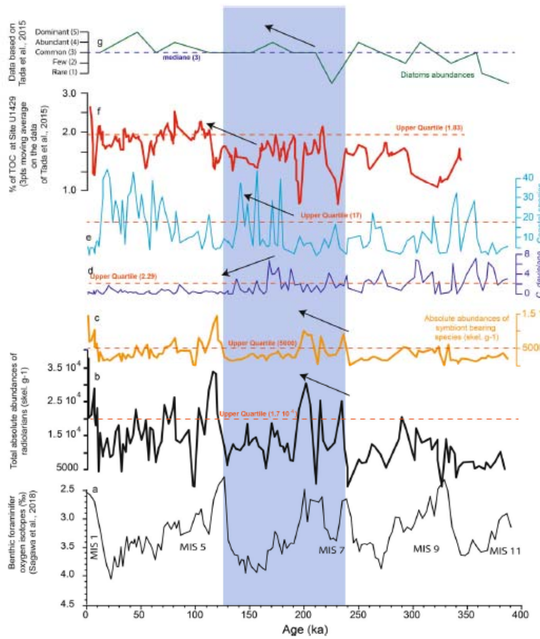
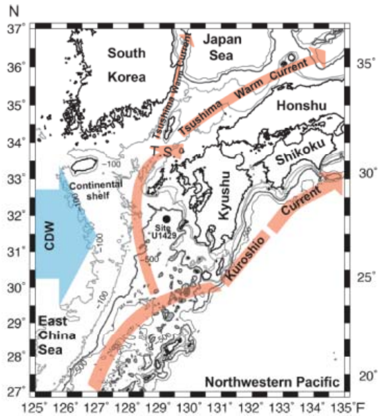
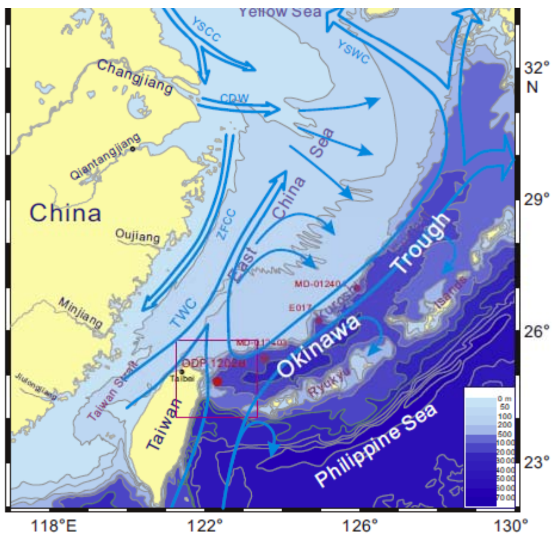


Fig. 9 Temporal fluctuation of the local primary productivity. **a** benthic foraminifera isotope curve of Sagawa et al. (2018), **b** radiolarian absolute abundance, **c** radiolarian absolute abundance of species bearing algal symbiosis based on Zhang et al. 2018 (*A. vinculata, B. scutum, L. hispida, P. obeliscus, P. praetextum, P. clausus, A. lappacea/spinosa, D. tetrathalamus, D. muelleri, P. pylonium* group, *S. resurgens, S. streptacantha, Tetrapyle circularis/fruticosa* group, *L. reticulata, Heliodiscus* spp., *D. elegans*), **d** *C. davisiana* (%), **e** continental shelf species (%), **f** total organic carbon (TOC) (%), and **g** diatom abundances



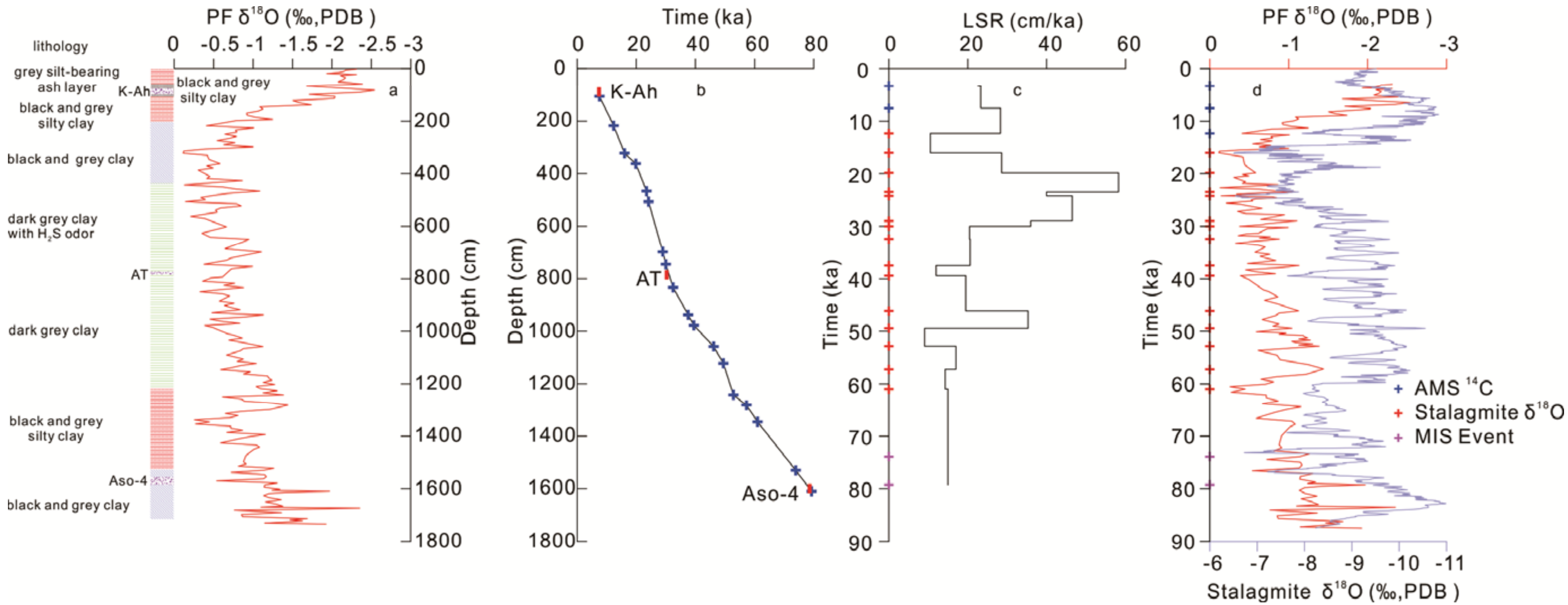


after mid-MIS 6: oxygen-poor condition
mid-MIS 6 and MIS 11: oxygen-rich

Matsuzaki 2019, Progress in Earth Science

Millennial-scale ventilation during the last deglaciation

Lithology



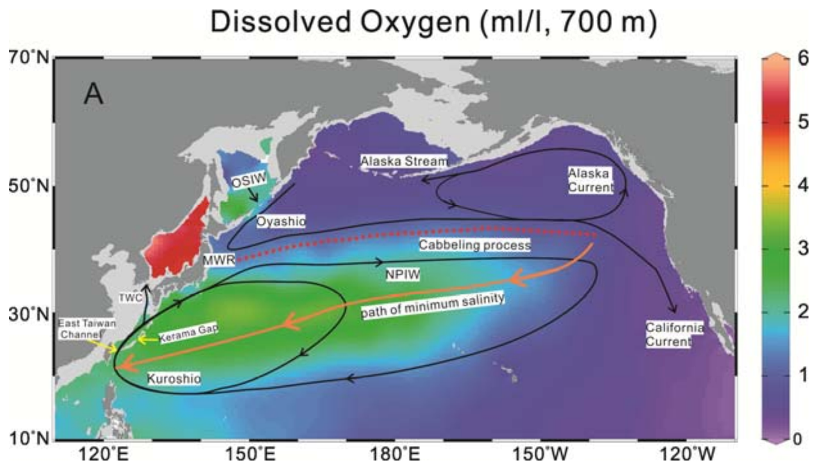
Water depth: 703m

Age model: correlation with stalagmite $\delta^{18}O$

Bottom age: ~88 ka

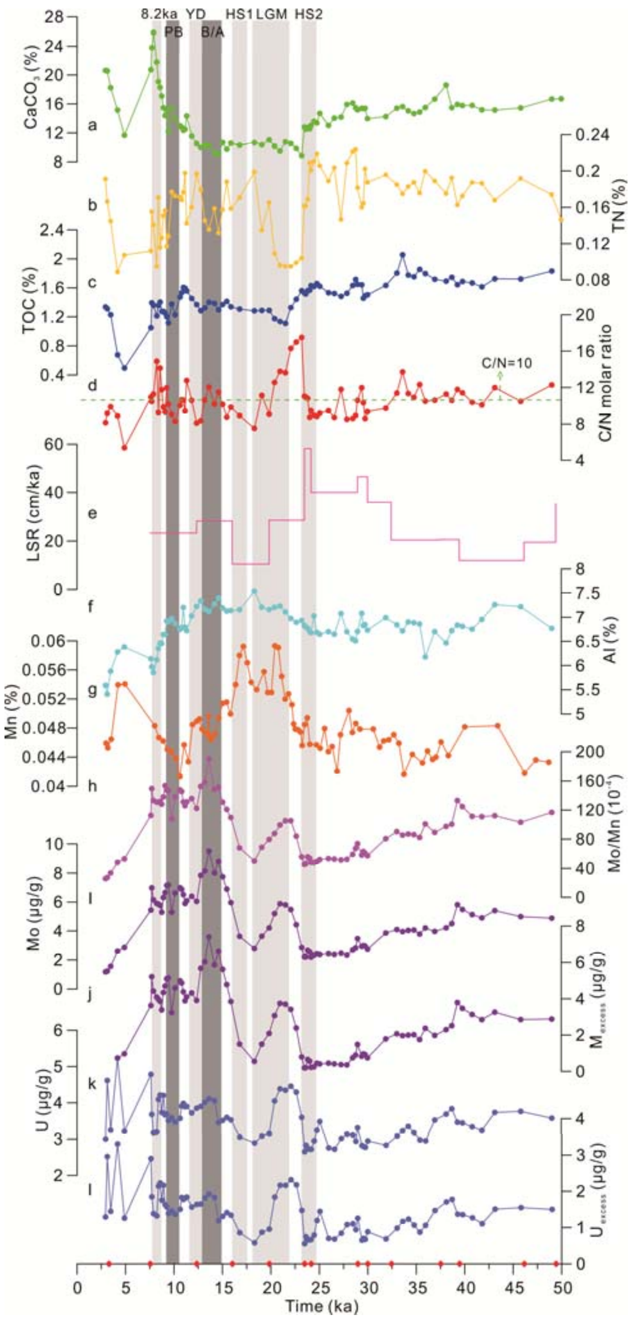
Resolution: 240 yr/sample

LSR: 10 - 60 cm/ka;



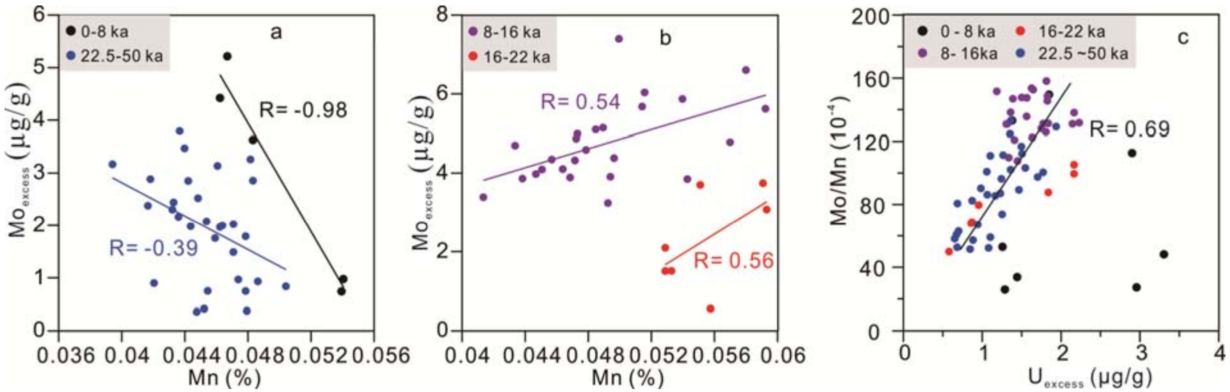
Zou et al. 2020, CP

Sedimentary oxygenation variation in the northern OT



Contrasting geochemical behavior

- Mn: enriched under oxic condition
  depleted in suboxic and anoxic condition
- Mo and U: enriched in oxygen-depleted water.
- Mo: also enriched in oxic sediments due to its adsorption on the surface of manganese oxide.

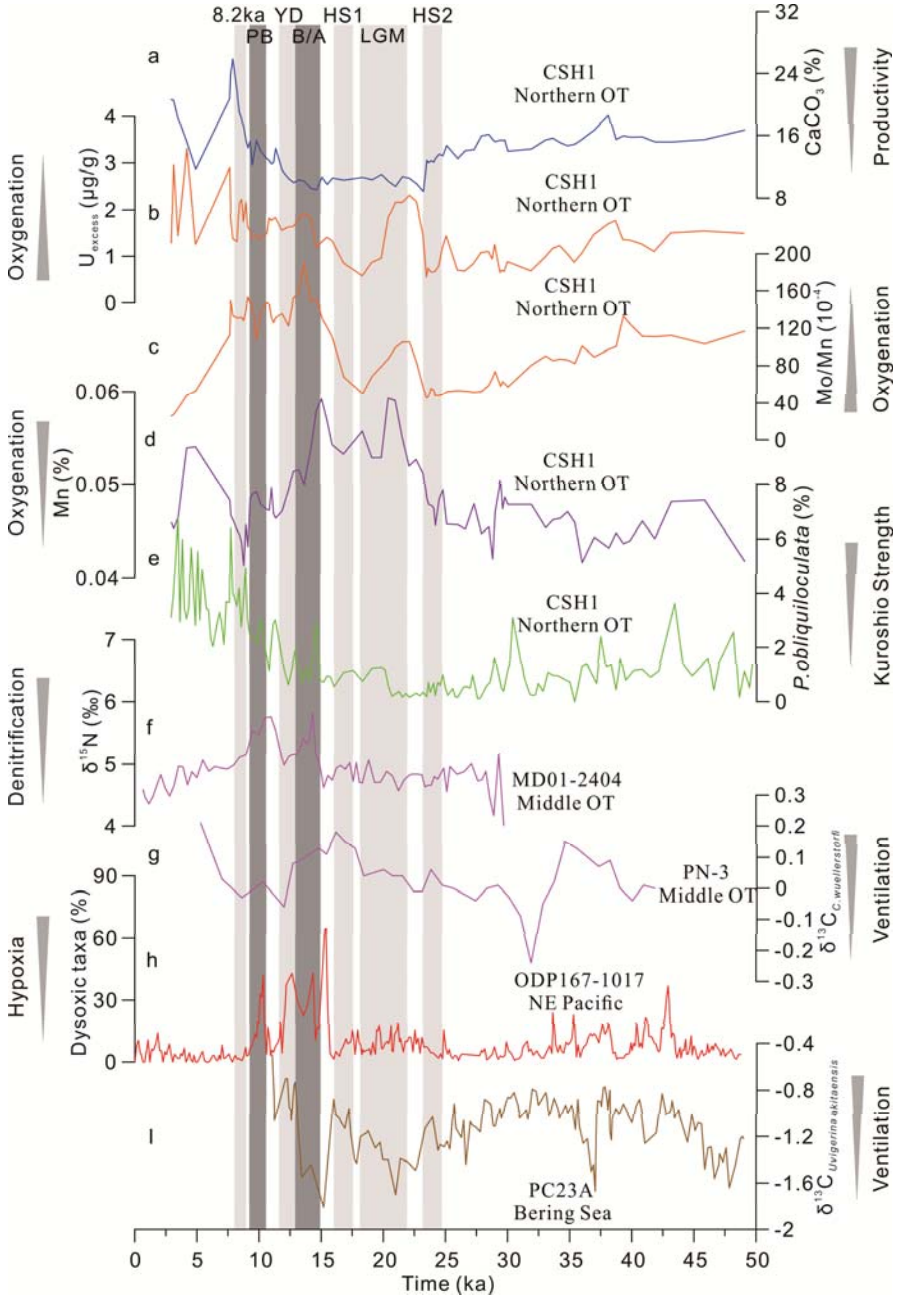


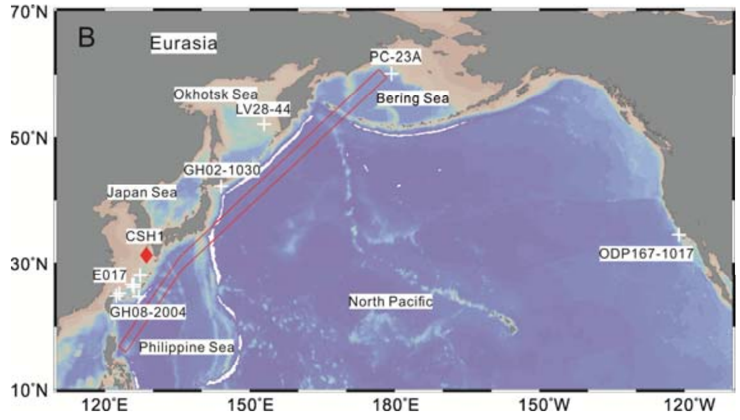
MIS3 & LGM & HS1&HS2: oxic condition
B-A: suboxic condition
YD &PB: suboxic condition

Oxic : enhanced intrusion of NPIW
Suboxic: decreased NPIW and enhanced productivity export

Zou et al. 2020, CP

Coherent variations in deglacial sedimentary oxygenation





- consistent pattern of oxygen change with the ones at high norhtern latitudes and eastern Pacific

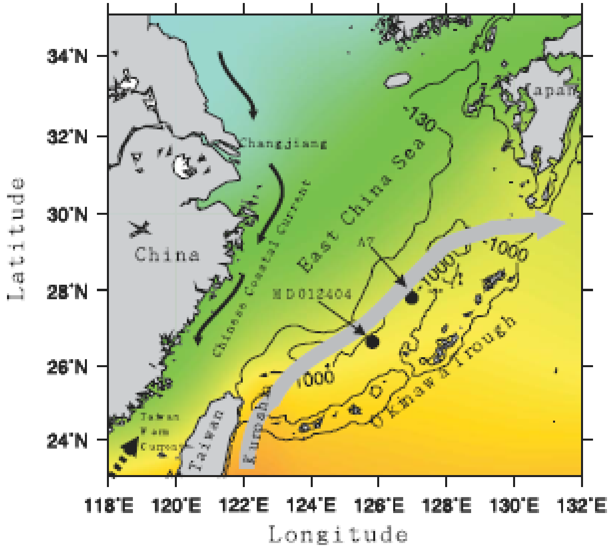
  LGM &HS1: enhanced ventilation

  B/A:weakened ventilation

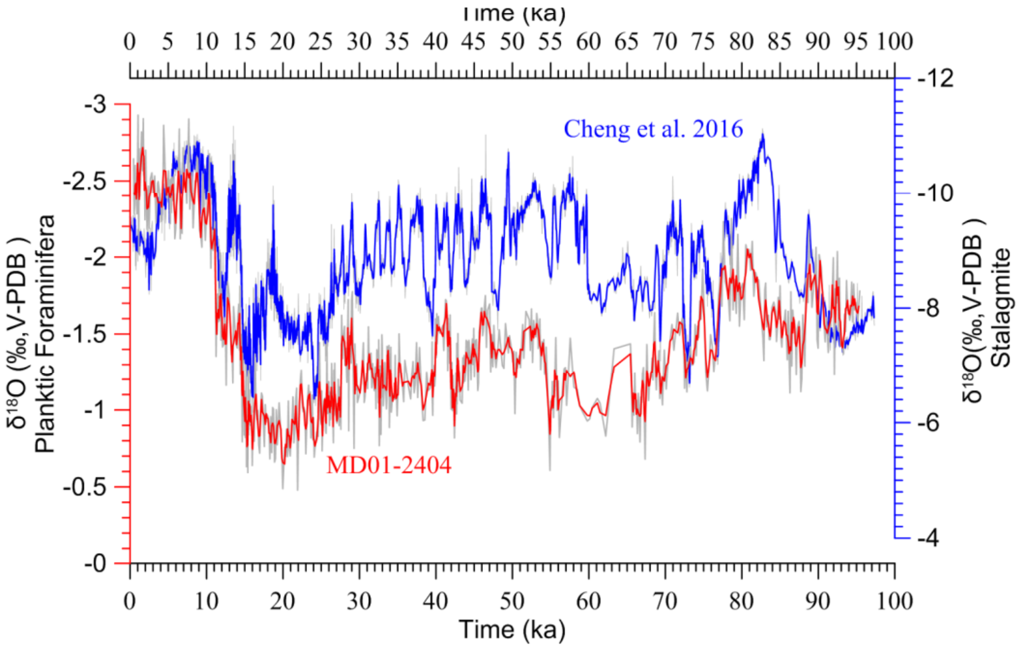
- NPIW: the main mechanism in regulating deep ventilation and sedimentary oxygen variation in the N Pacific.

Zou et al. 2020, CP

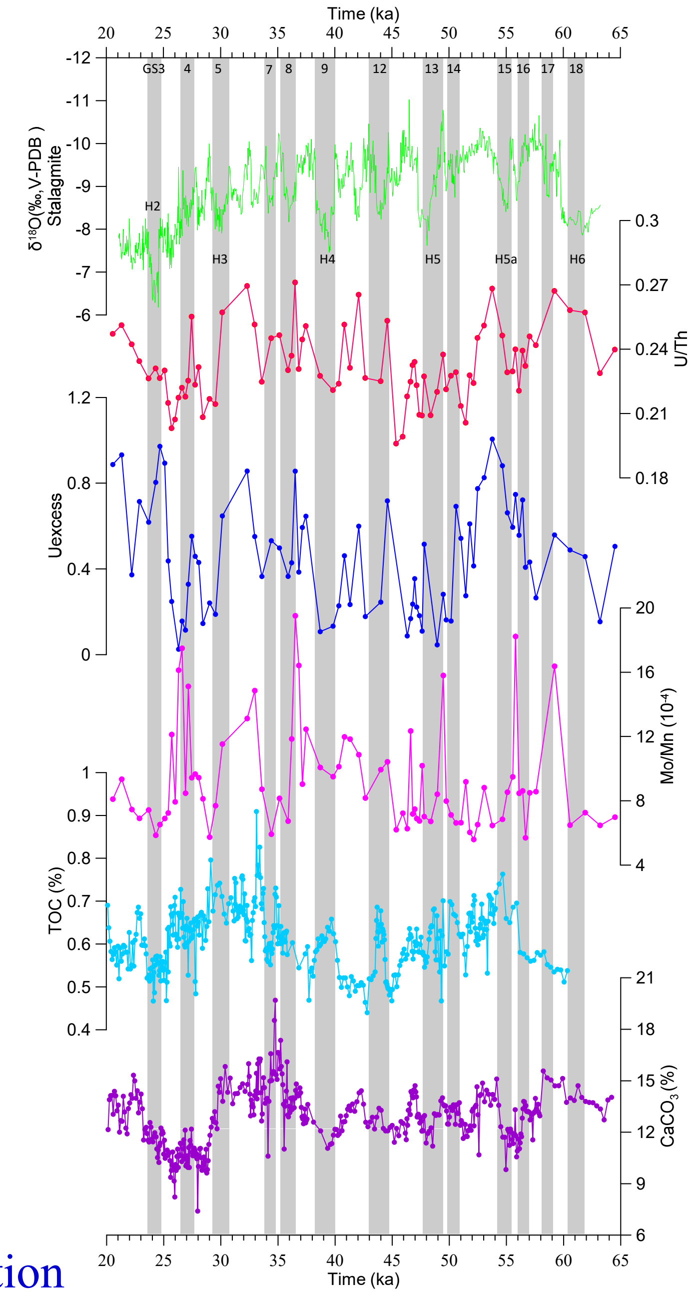
Millennial-scale subtropical ventilation during MIS3



Greenland stadials & Heinrich Events:
Enhanced ventilation

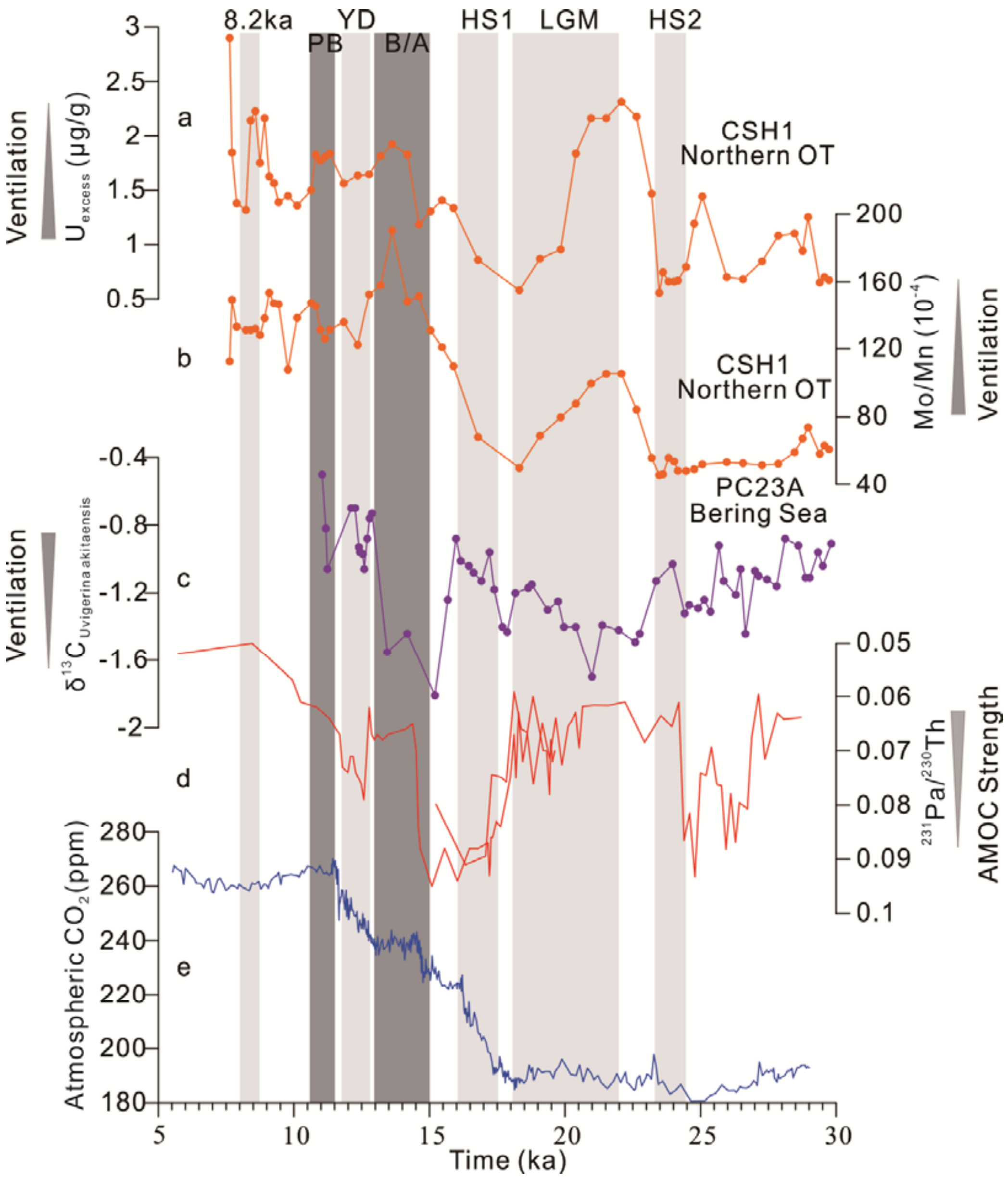


Correlation between $\delta^{18}O_{pf}$ and $\delta^{18}O_{cave}$



Zou et al. in preparation

Subtropical ventilation links to NADW



HS1, 2 & YD:

weak AMOC vs strong NPIW;

Enhanced north Pacific oceanic interior stratification;

Reduced CO2 outgassing;

B/A:

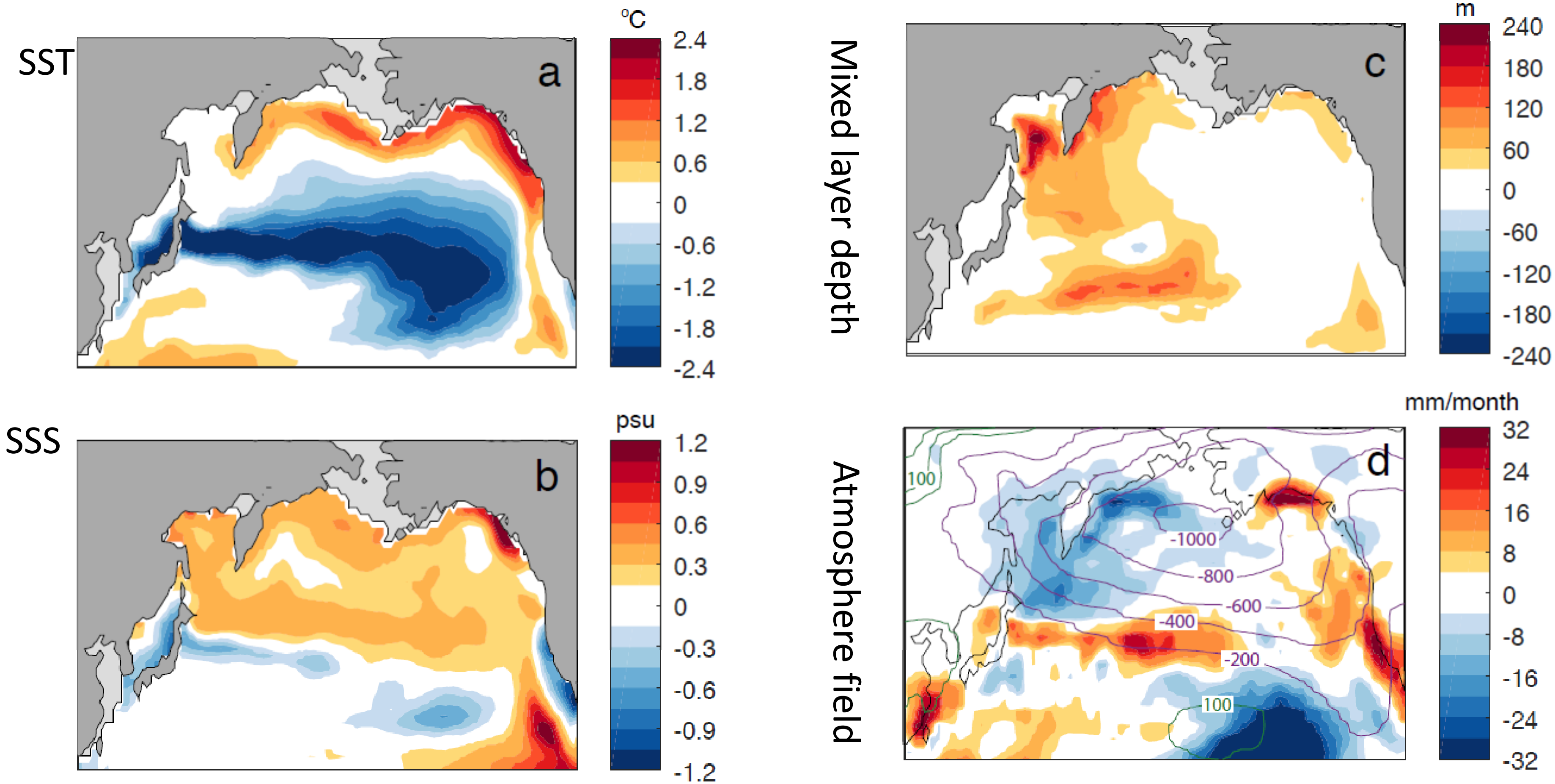
strong AMOC & weak NPIW formation;

Enhanced upwelling of aged PDW

Enhanced storage of respired CO_2 at mid-depth water.

Zou et al. 2020, CP

Model evidence for enhanced ventilation during HS1

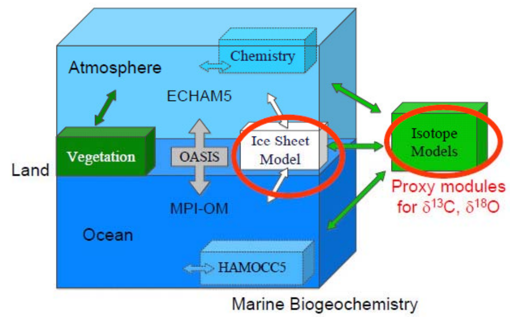


Xun et al. 2019

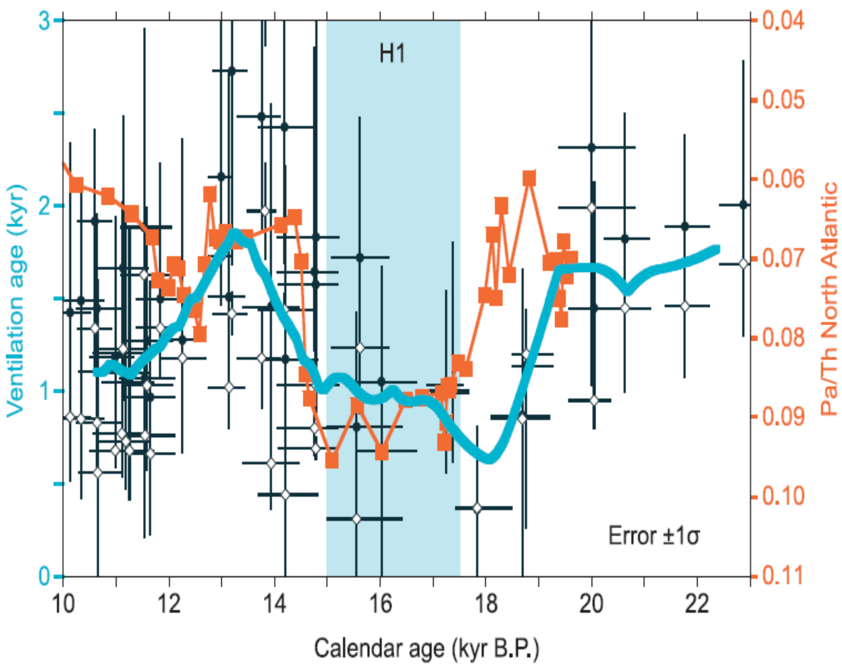
Decreased temperature
Increased salinity
Enhanced mixture layer
weakened precipitation

Favoring the formation of NPIW

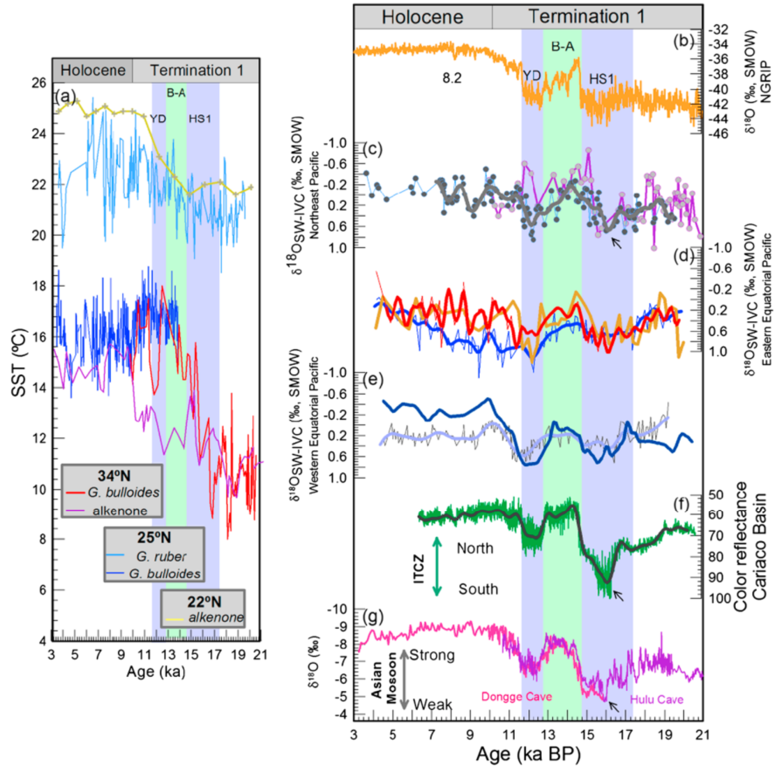
New developments within the ESM COSMOS:



Oceanic teleconnection

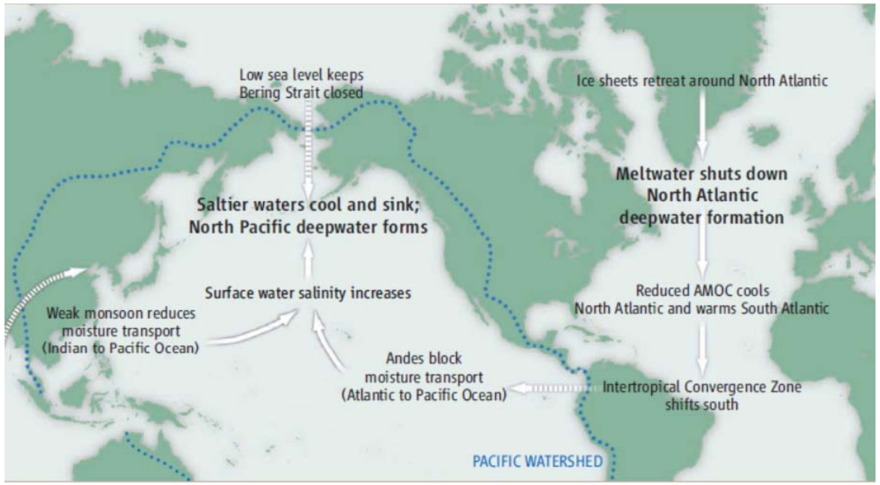


Okazaki et al. 2010 Science



Rodríguez-Sanz et al. 2013

- Cooling Northern Hemisphere
- enhanced sea ice cover
- ITCZ southward shift
- decreased summer Asian Monsoon
- decreased moisture transport
- increased SSS in the subtropic Pacific
- high saline water transported by PMOC
- enhanced formation and ventilation of NPIW



Atmospheric teleconnection

Cavalieri et al. 1987

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 92, NO. C7, PAGES 7141–7162, JUNE 30, 1987

Deepening of winter AL

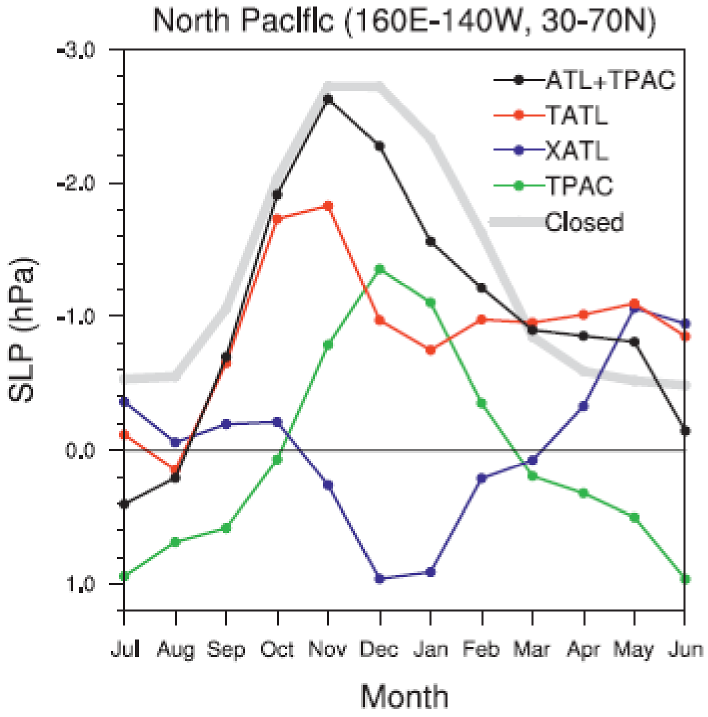


FIG. 12. Sea level pressure anomalies (hPa) averaged over the Aleutian low region (30°–70°N, 160°E–140°W) as a function of calendar month: CCSM2 closed Bering Strait experiment (thick gray) and CAM2 experiments forced with the CCSM2 SST/sea ice anomalies over the Atlantic and tropical Pacific (black), tropical Atlantic (red), extratropical North Atlantic (blue), and tropical Pacific (green, estimated by taking the difference between the Atlantic + tropical Pacific and Atlantic runs).

Okumura et al. 2009

On the Relationship Between Atmospheric Circulation and the Fluctuations in the Sea Ice Extents of the Bering and Okhotsk Seas

D. J. CAVALIERI AND C. L. PARKINSON

Laboratory for Oceans, NASA Goddard Space Flight Center, Greenbelt, Maryland

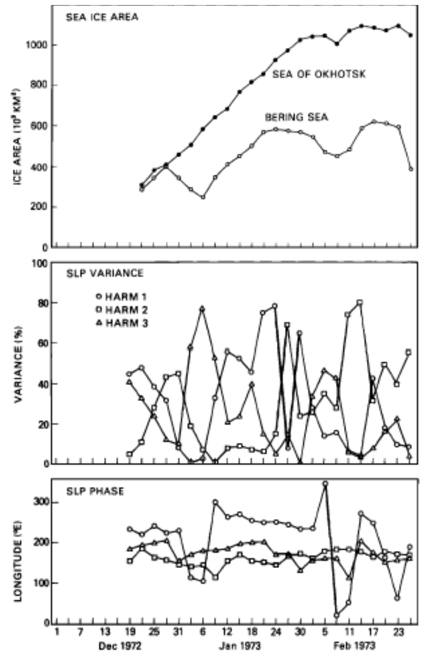


Fig. 8. Time series of the Bering Sea and Sea of Okhotsk ice cover areas, the percent variance, and phase of the sea level pressure, all for the winter of 1972–1973. The phase of each harmonic corresponds to the position of minimum amplitude or low pressure.

- Intensification and eastward shift of AL
- increased sea ice cover
- Active formation of NPIW
- Increased ventilation and oxic condition in the OT

Summary

- Drastic variations in ventilation and sedimentary oxygenation occurred in the subtropical North Pacific during the last glaciation.
- The North Pacific Intermediate Water is responsible for the variations in sedimentary oxygenation in the northern Okinawa Trough during the last deglacial and the glacial periods at millennial timescales.
- Persistent linkages between Atlantic Meridional Overturning Circulation and the ventilation of North Pacific Intermediate occurred at millennial timescales via atmospheric and oceanic teleconnections.

Thanks for your attention !