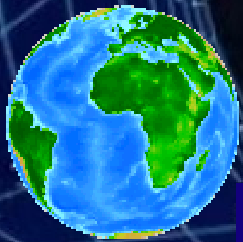
Changes in the deep ocean conveyor and eolian sediment transport caused by meltwater events in high latitudes

Bernd J. Haupt & Dan Seidov



PENNSTATE
1855

http://www.essc.psu.edu/~bjhaupt
http://www.essc.psu.edu/~dseidov

Global Ocean Conveyor

- Present-day ocean thermohaline circulation is driven by the deepwater sources in the Northern and Southern Hemisphere.
- During the geologic past and in the foreseeable future the balance of the sources can change, causing climate to differ dramatically from its present-day state.

Glacial Earth

Stommel-Arons Ocean circulation (1958)

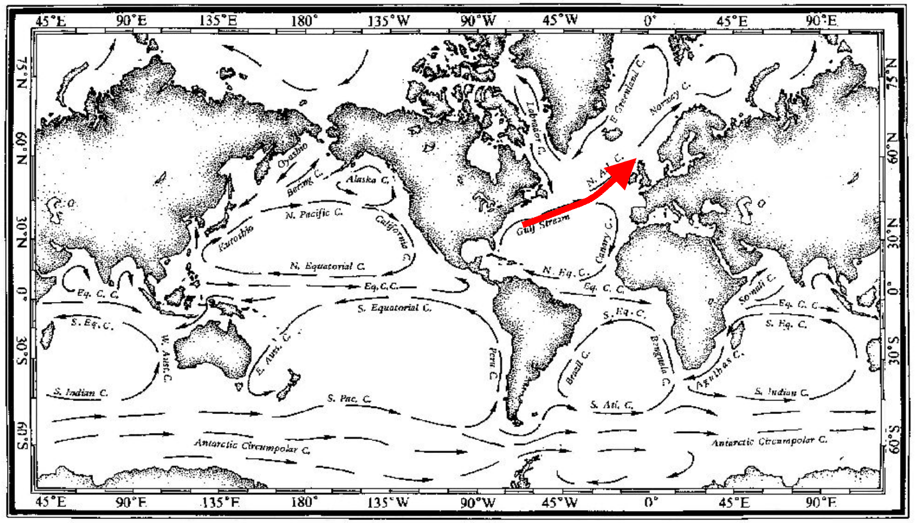


Fig. 2.17 The general surface circulation of the ocean in schematic form. The dominant features are the large, anticyclonic subtropical gyres in each ocean basin, the equatorial current systems, and the Antarctic Circumpolar Current.

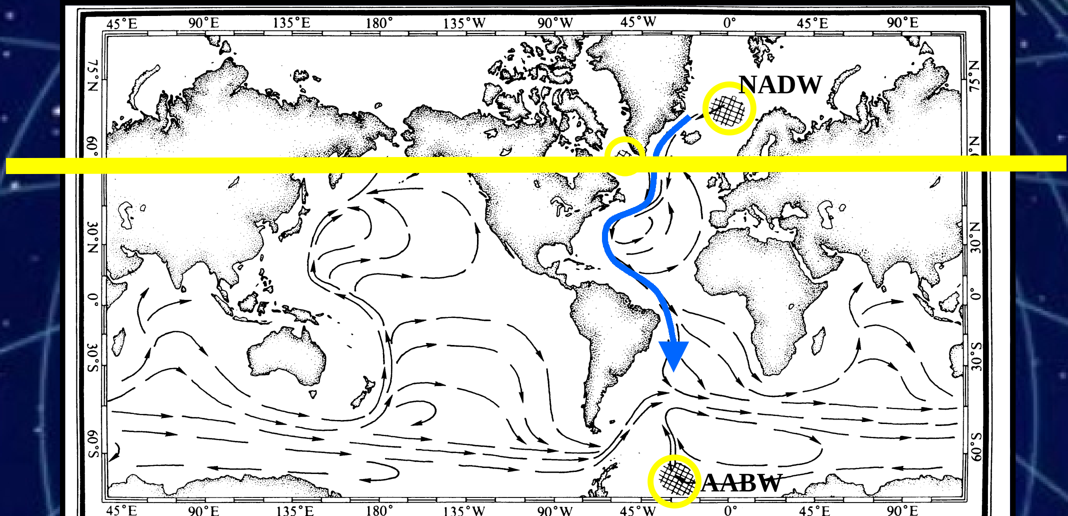
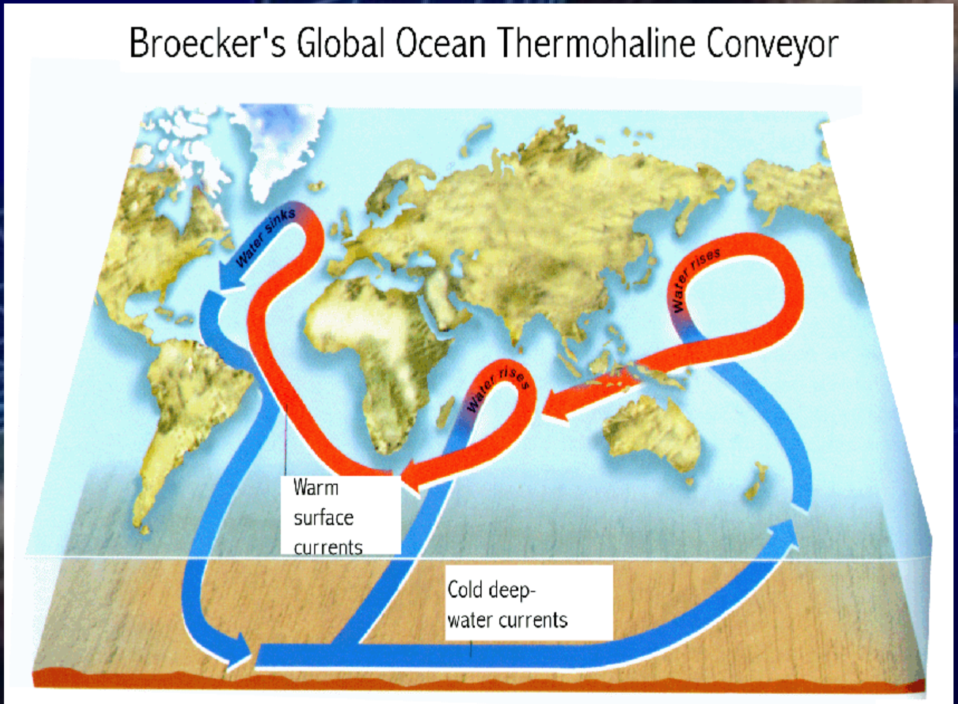


Fig. 2.23 Schematic flow lines for abyssal circulation. The cross-hatched areas indicate regions of production of bottom water. [Adapted from Stommel, H., *Deep Sea Research* (1958).]

- Meridional ocean circulation is responsible for poleward heat transport.
- Present-day ocean circulation is driven by deep-water sources in high latitudes.
- Geological past shows substantial differences in ocean circulation during warm and cold climates.
- Geological past shows that an imbalance between high latitudinal deep-water sources dramatically altered the climate.

Global Ocean (Salinity) Conveyor Belt

The concept of the global conveyor was put forward by W. Broecker in 1991 and has proved to be one of the most fruitful ideas in paleoceanography.



(after W. Burroughs, 1999)

Structure of presentation

- Problems/questions
  - What is the key to the large-scale ocean circulation?
  - What are the differences between southern and northern meltwater events?
  - Is a sea level rise possible without the meltdown of ice shields?
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- Experiments (1st set) and validation (past and present)
  - How does one test a model?
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  - What influences our climate pacemaker? (meltwater events and feedbacks)
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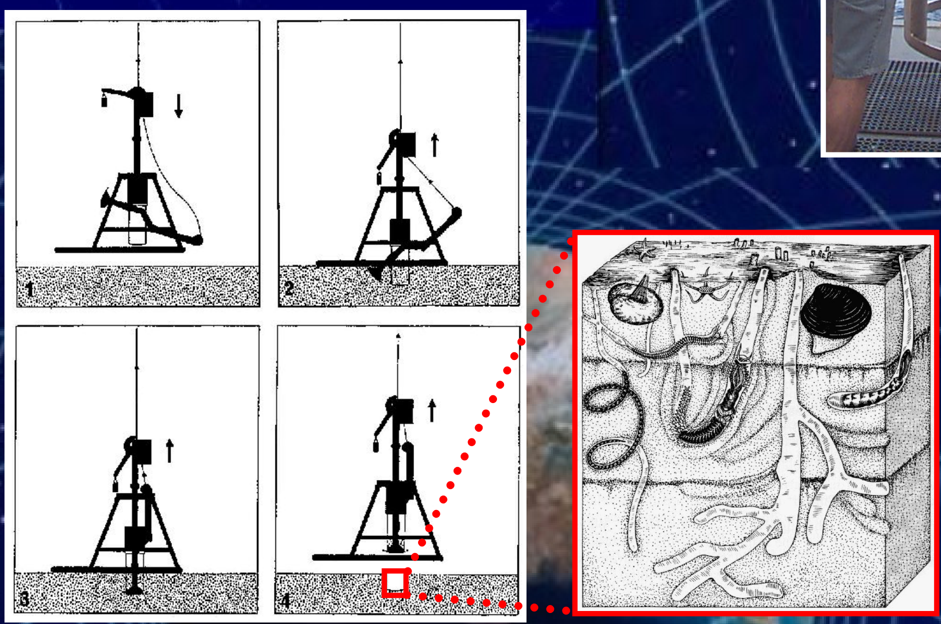
Requirements for climate studies

Data

- Observation
- Remote sensing (satellite, airplanes)
- Measurements from vessels and helicopters
- Platforms and moorings
- Sediment drillings at land and on sea

CTD (conductivity, temperature, and depth)



Box corer and sediment sample

Device from deep sea mooring

Experiment (1st set) and validation (past and present)

How does one test a model?

1st possibility: Predict future, including waiting to see whether forecast is proven to be true

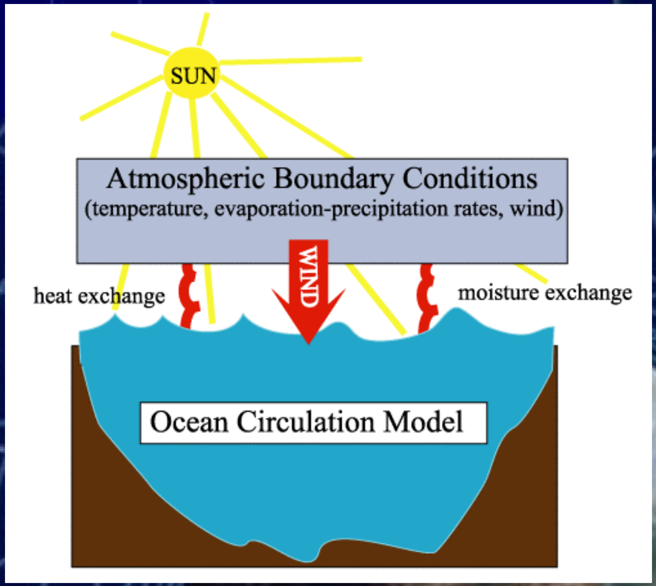
2nd possibility: Start model in the past and examine whether model "predicts" known facts (WITHOUT cheating!)

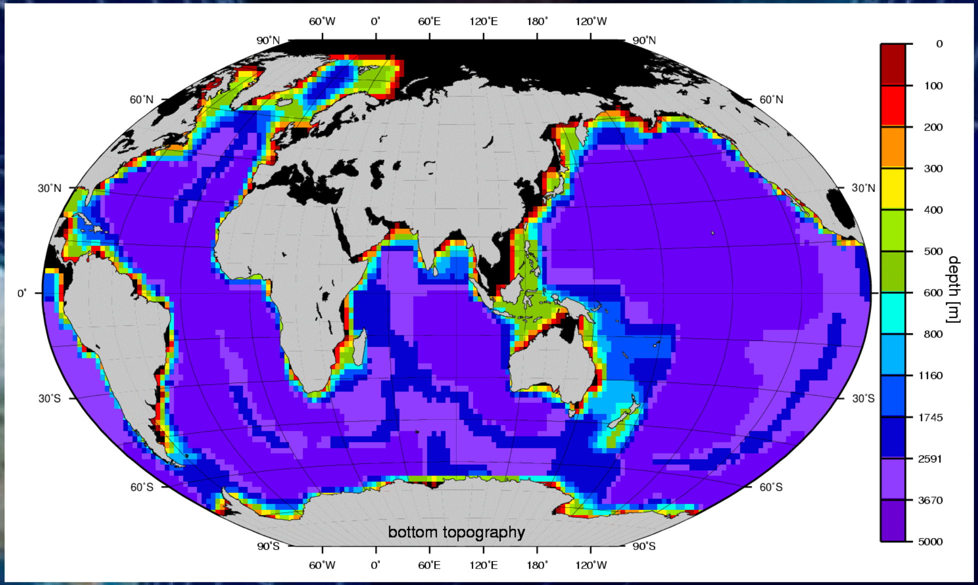
after R. Alley [2000]

For all those who question computer models: For example, computer models are used to develop cars, airplanes, houses, and bridges, and for some time have been used to create bombs and medicine. ⇔ Correctly used models are as great help in our daily life.

Global ocean circulation model

- MOM 2 (Modular ocean model version 2.2) from GFDL (Geophysical Fluid Dynamics Laboratory)
- Grid resolution: - horizontal: 6 x 4° (62 x 45 grid points)
  - vertical: 12 unevenly spaced layers

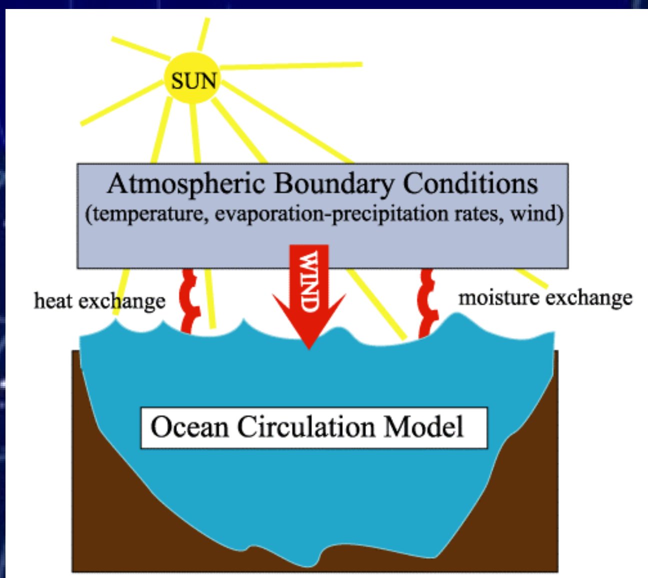


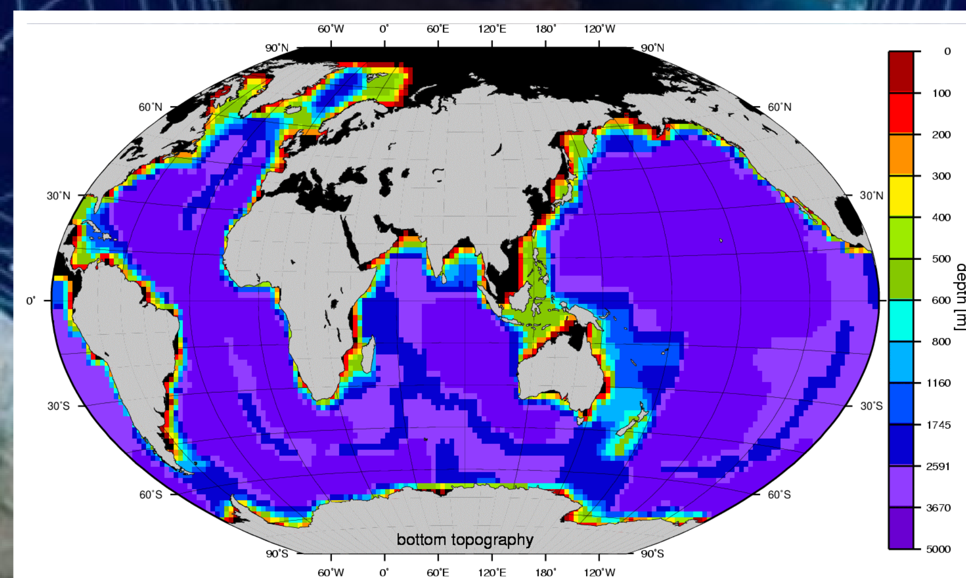


Bottom topography (ETOPO 5)

Global ocean circulation model

The numerical model MOM 2 (Modular ocean model version 2.2) developed at GFDL (Geophysical Fluid Dynamics Laboratory) has been used at Penn State to address past and possible future changes in the ocean global conveyor. The model equations are solved with different boundary conditions representing glacial, interglacial, and possible global warming scenarios.





Bottom topography (ETOPO 5)

Grid resolution:

- horizontal: 6 x 4° (62 x 45 grid points)
- vertical: 12 unevenly spaced layers

Experiment (1st set) and validation (past and present)

Exp.	SST	SSS
PD	*Levitus and Boyer* [1994]	*Levitus et al.* [1994]
MWE	*CLIMAP* [1981] is used everywhere except for the North Atlantic to the north of 50°N and east of 40°W, where the data from *Weinelt* [1993], summarized by Sarnthein et al. [1995] and processed by Seidov et al. [1996], replace the CLIMAP data.	The present-day SSS was globally increased by 1 psu according to Duplessy et al. [1991] (lower sea level); in the North Atlantic, to the north of 10°N, the data set is from Duplessy et al. [1991] and Weinelt [1993], and for the North Atlantic to the north of 50°N and east of 40°W, where the data from Weinelt [1993] are used. All data were summarized by Sarnthein et al. [1995] and processed by Seidov et al. [1996]

- PD = present-day
- MWE = meltwater event

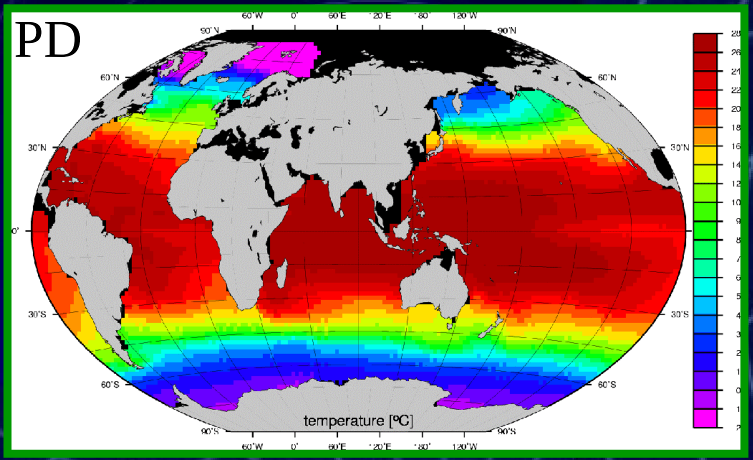
- SST = sea surface temperature
- SSS = sea surface salinity

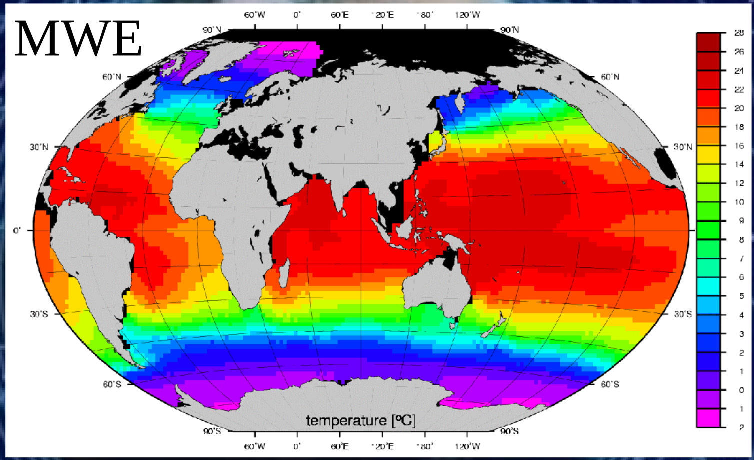
Sea surface boundary conditions

Control experiment

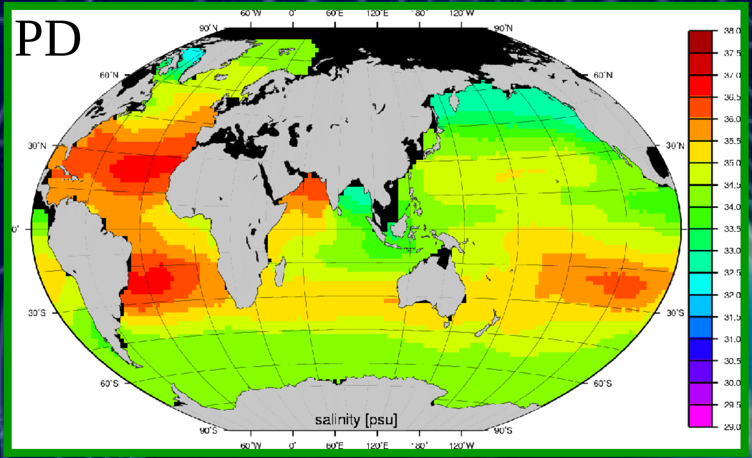
Northern meltwater experiment

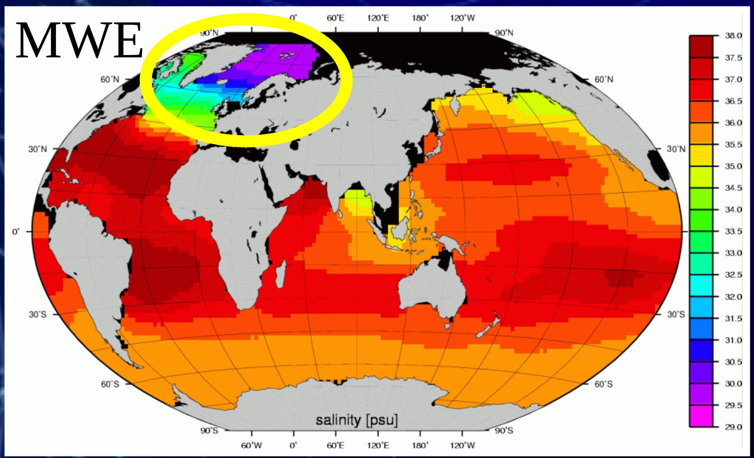
Temperature





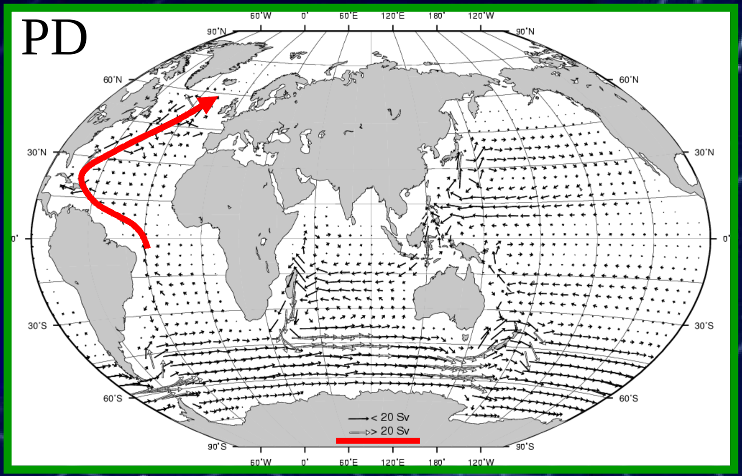
Salinity

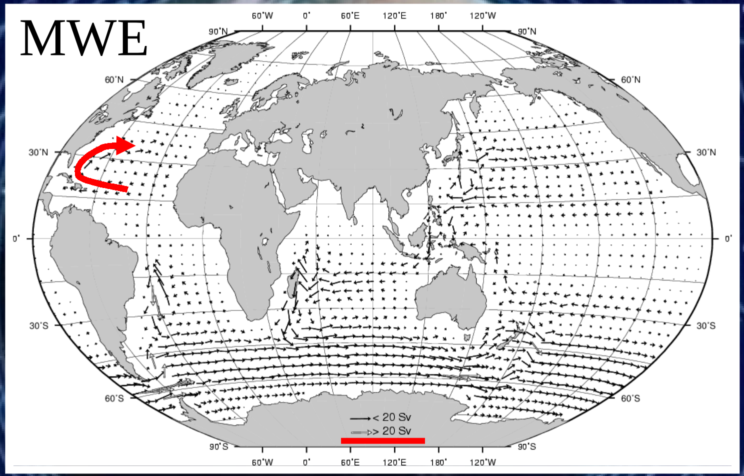




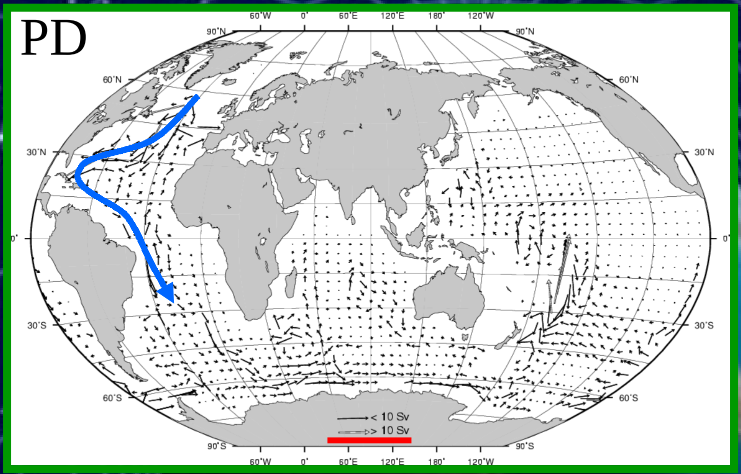
Water mass transport in Sverdrup

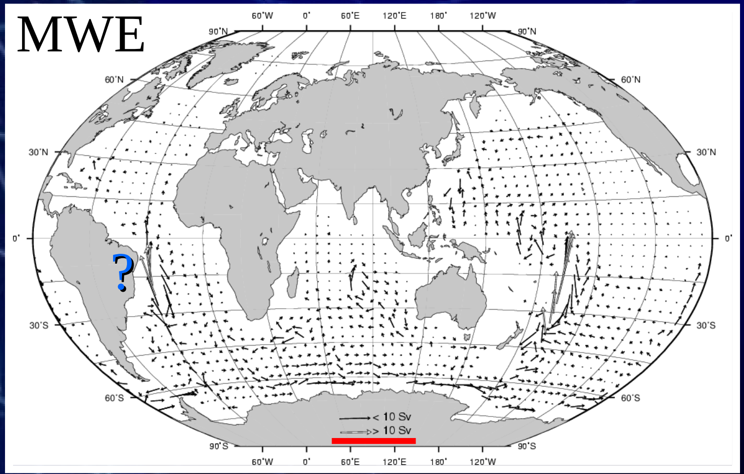
Vertical integrated transport above 1500 m





Vertical integrated transport below 1500 m





1 Sverdrup (Sv) = $10^6\ m^3s^{-1}$

Atlantic water masses

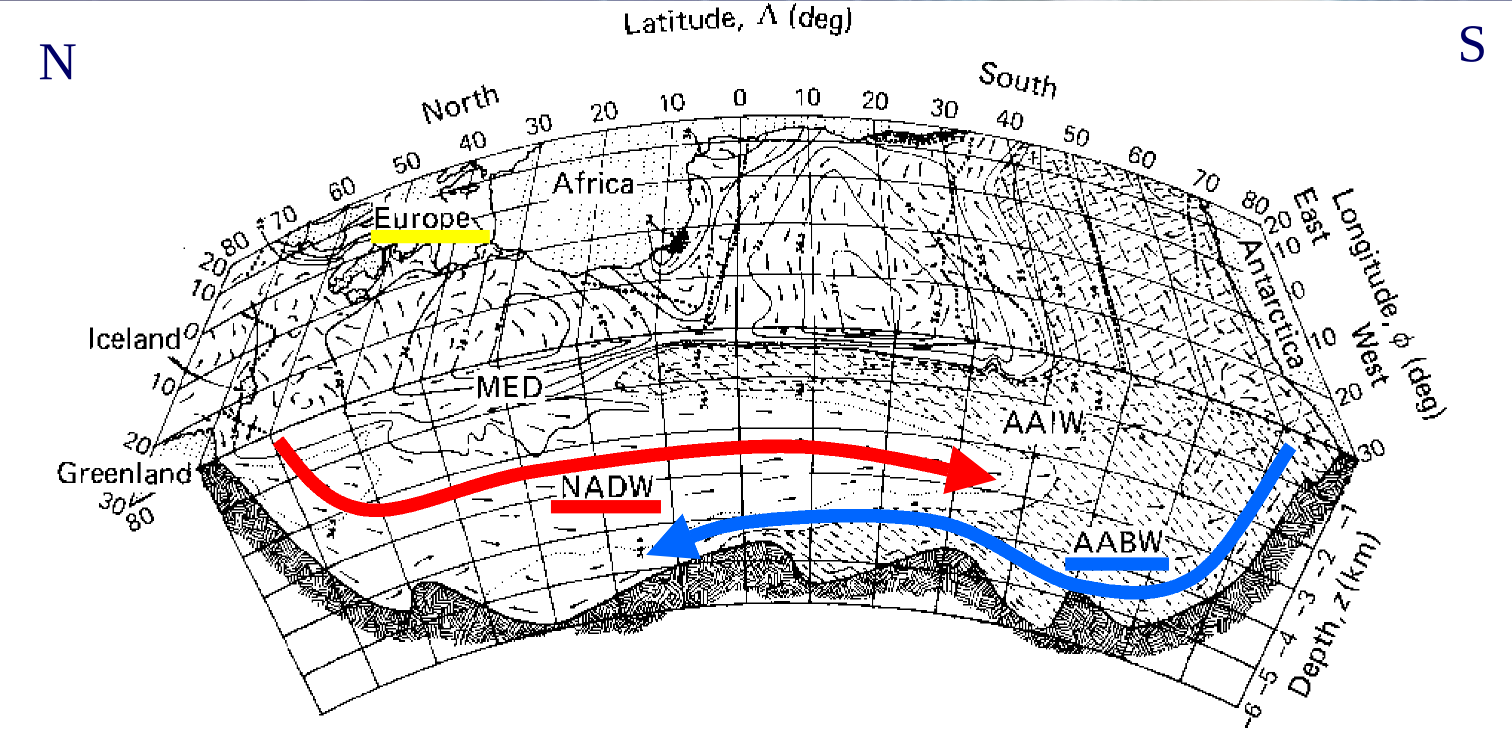
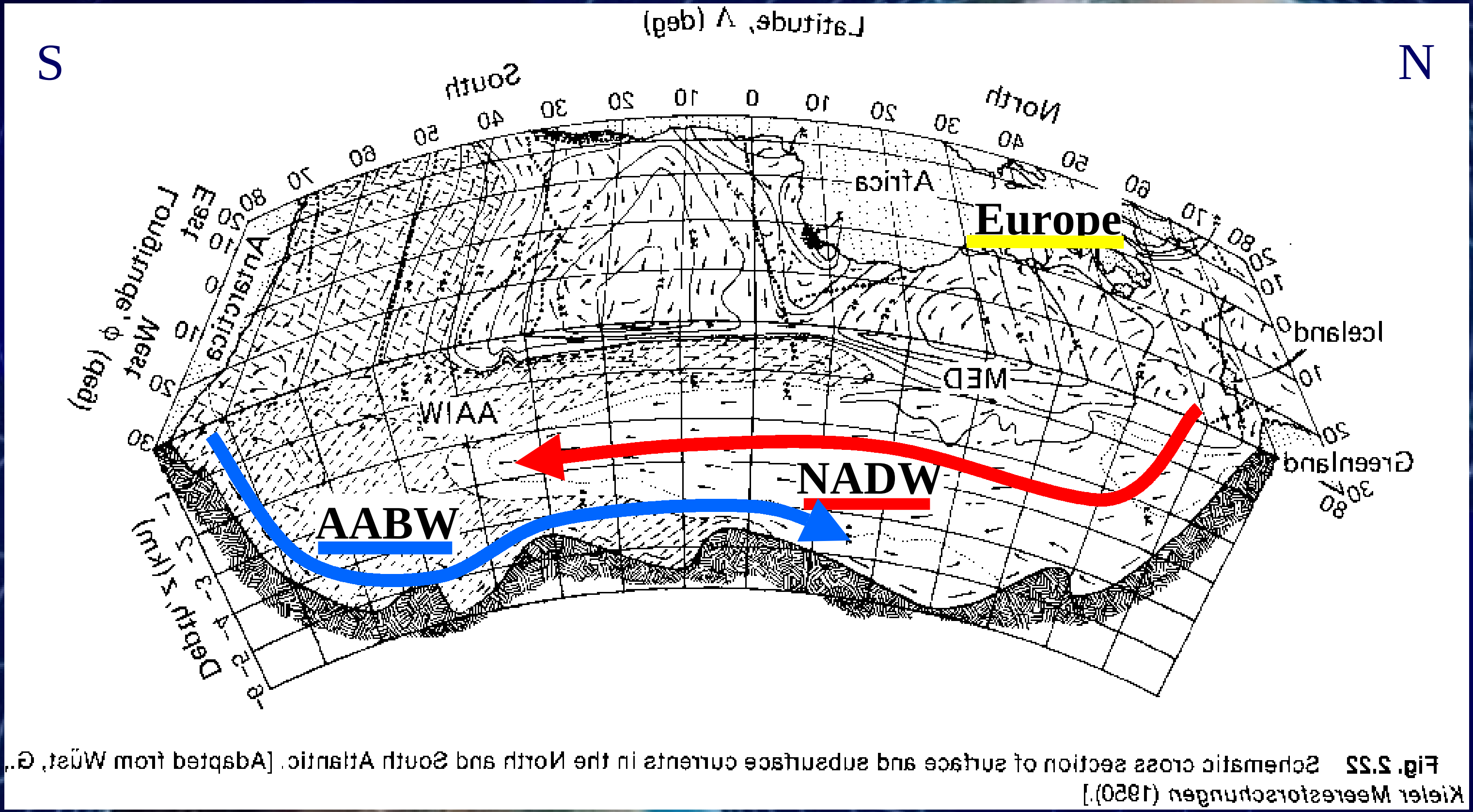


Fig. 2.22 Schematic cross section of surface and subsurface currents in the North and South Atlantic. [Adapted from Wüst, G., *Kieler Meeresforschungen* (1950).]

- NADW = North Atlantic Deep Water
- AABW = Antarctic Bottom Water

Atlantic water masses (mirror image)



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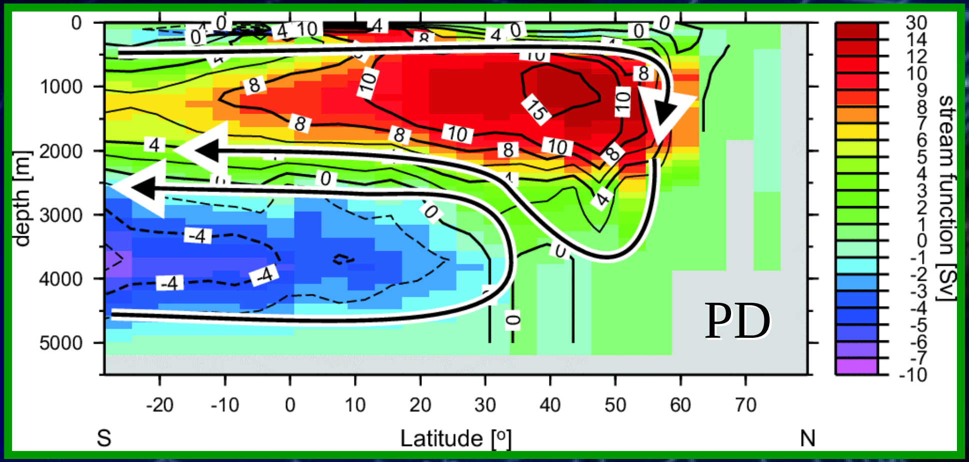
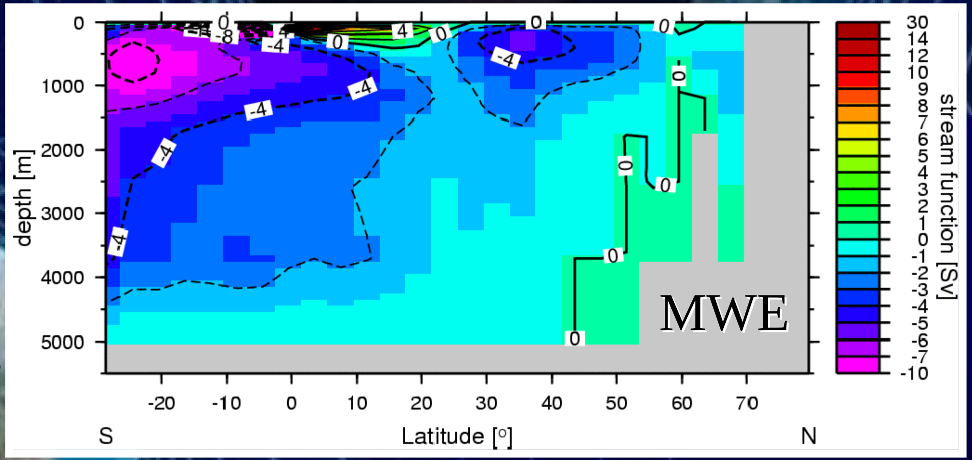
Meridional overturning in the Atlantic Ocean in Sv

1 Sverdrup (Sv) = $10^6\ m^3 s^{-1}$

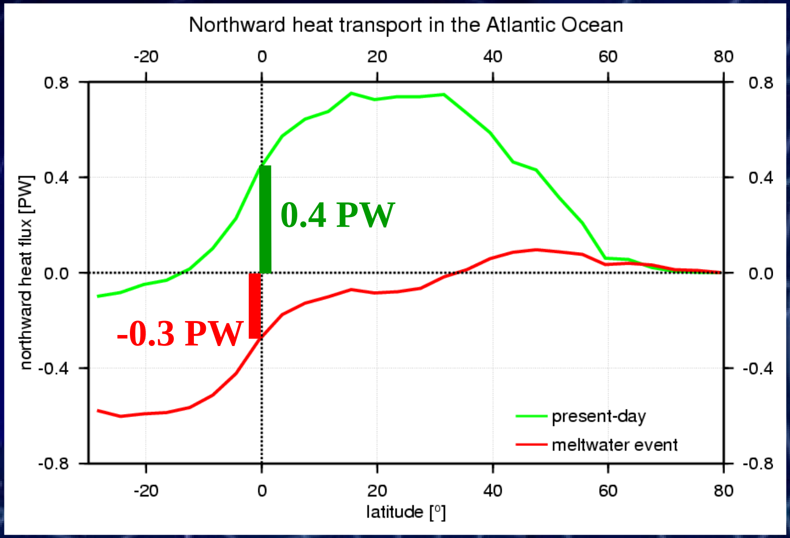


present-day forward conveyor



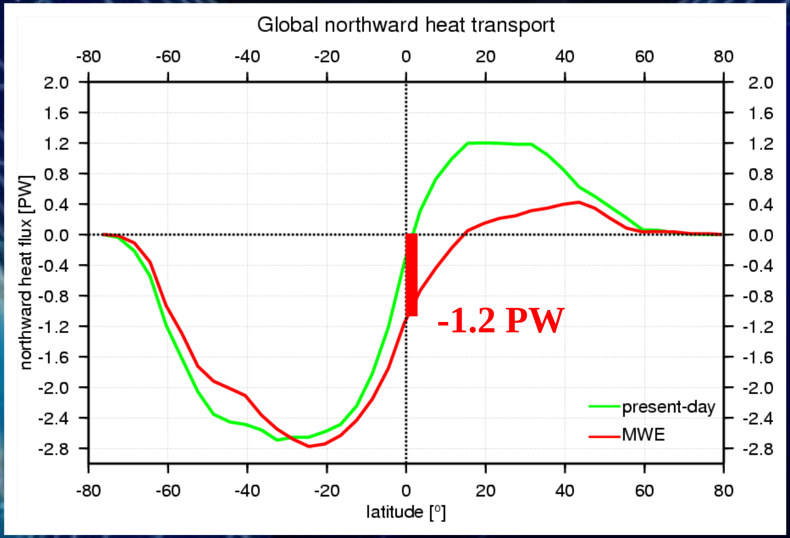
The positive values depict clock-wise motion while negative values depict counterclockwise motion. The Atlantic's overturning is valid only within this ocean's geographical boundary (with meridional walls at both sides; therefore, the area south of 30°S is not shown).

Northward heat transport in PW (1 PW = 10^{15}W)

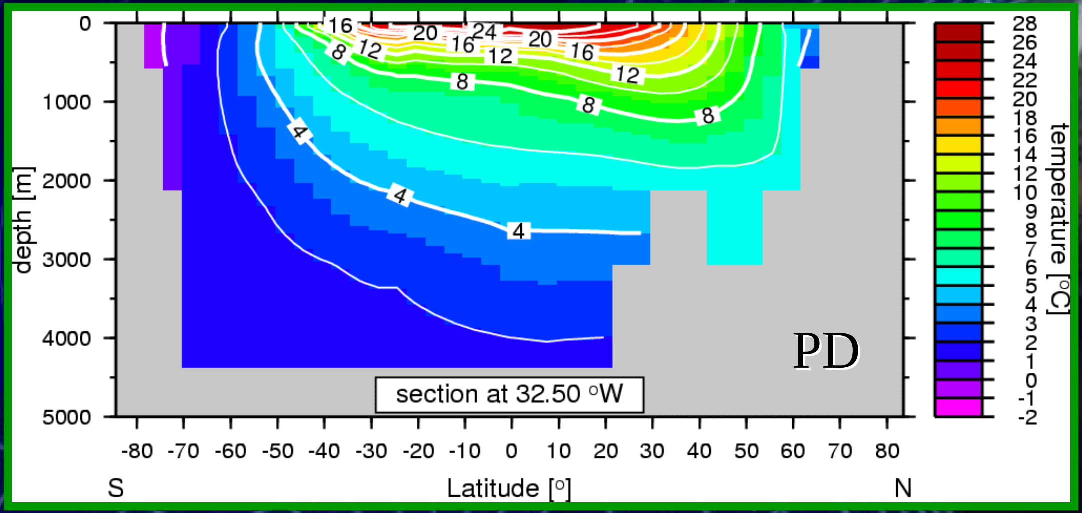


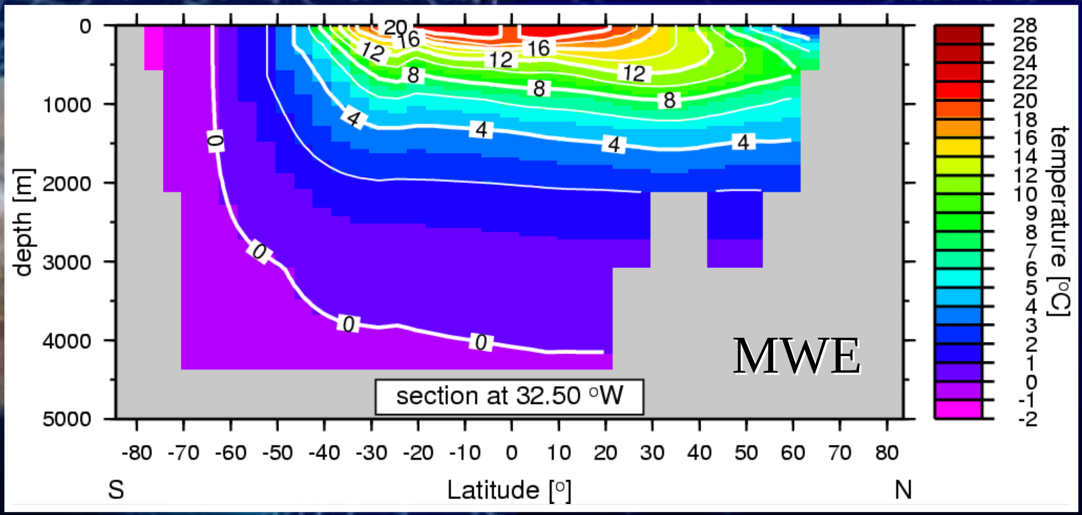
"northward heat piracy"

"southward heat piracy"



Meridional temperature section in the North Atlantic



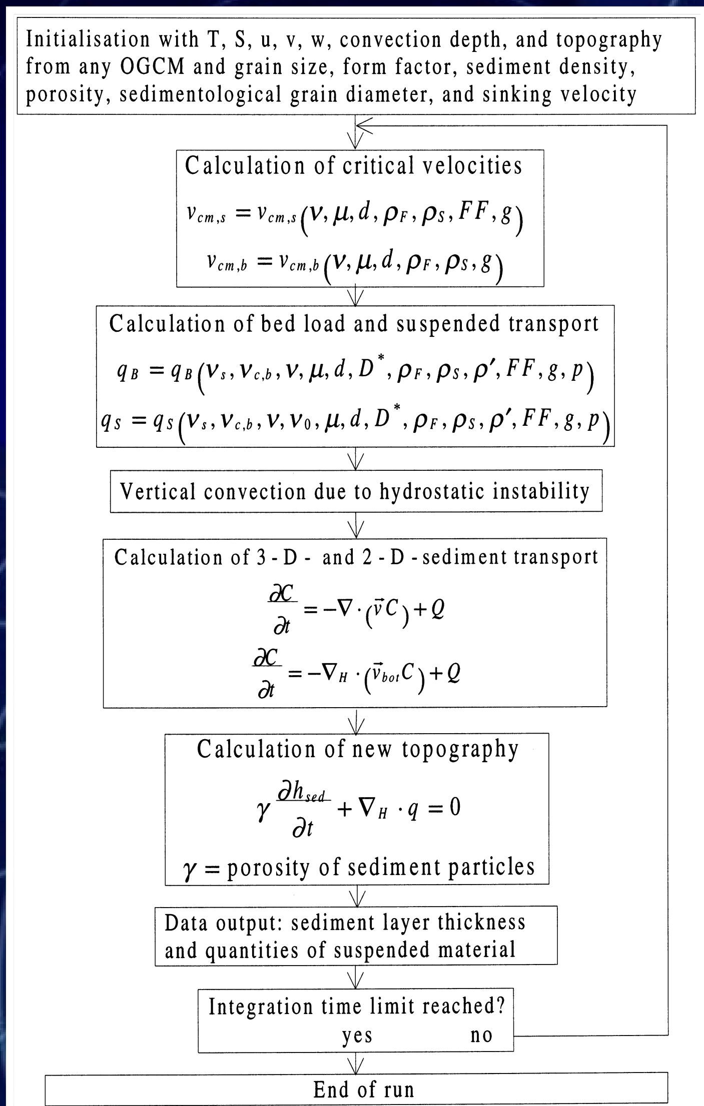


Experiment (1st set) and validation (past and present)

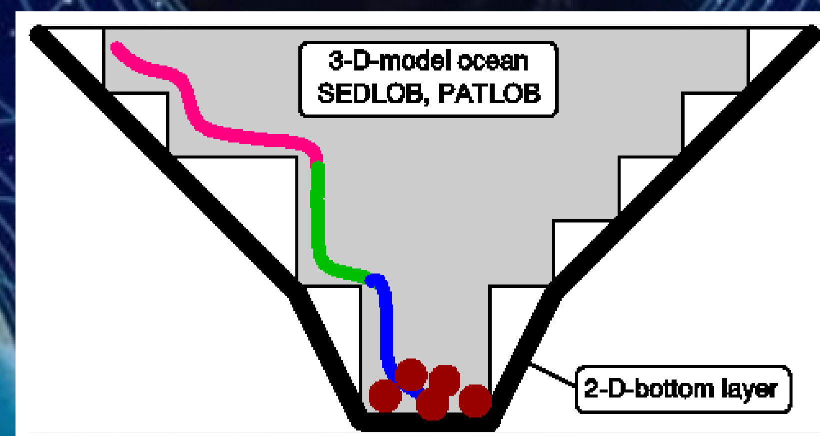
- Validation of present-day circulation through comparison with observation and measurements ("trivial").
- In the geological past, neither observations nor direct measurements exist.
- Search for an indirect procedure => the circulation leaves a *direct* and distinct sediment pattern at the sea floor.
- Idea: Modeling of the large-scale sediment transport and comparison with the geologic record.

Sediment transport model SEDLOB

(SEDimentation in Large Ocean Basins)

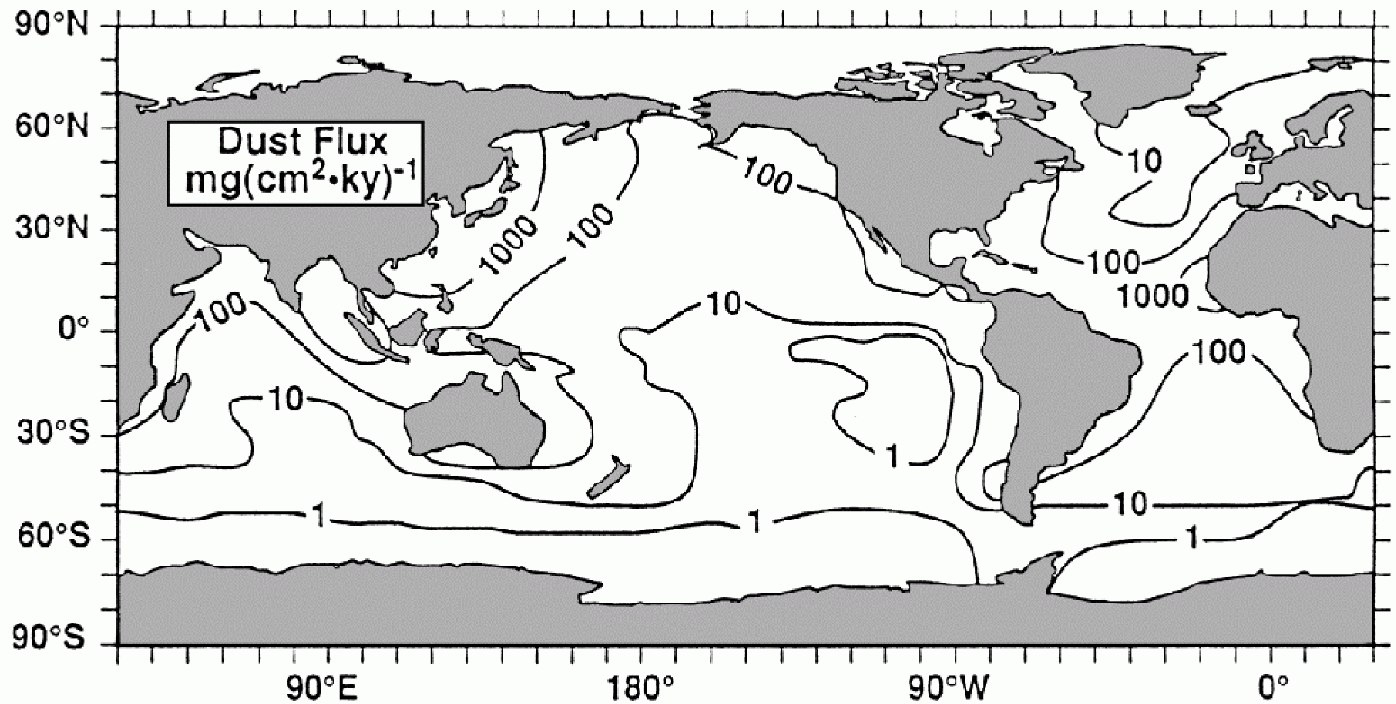


Flux diagram SEDLOB



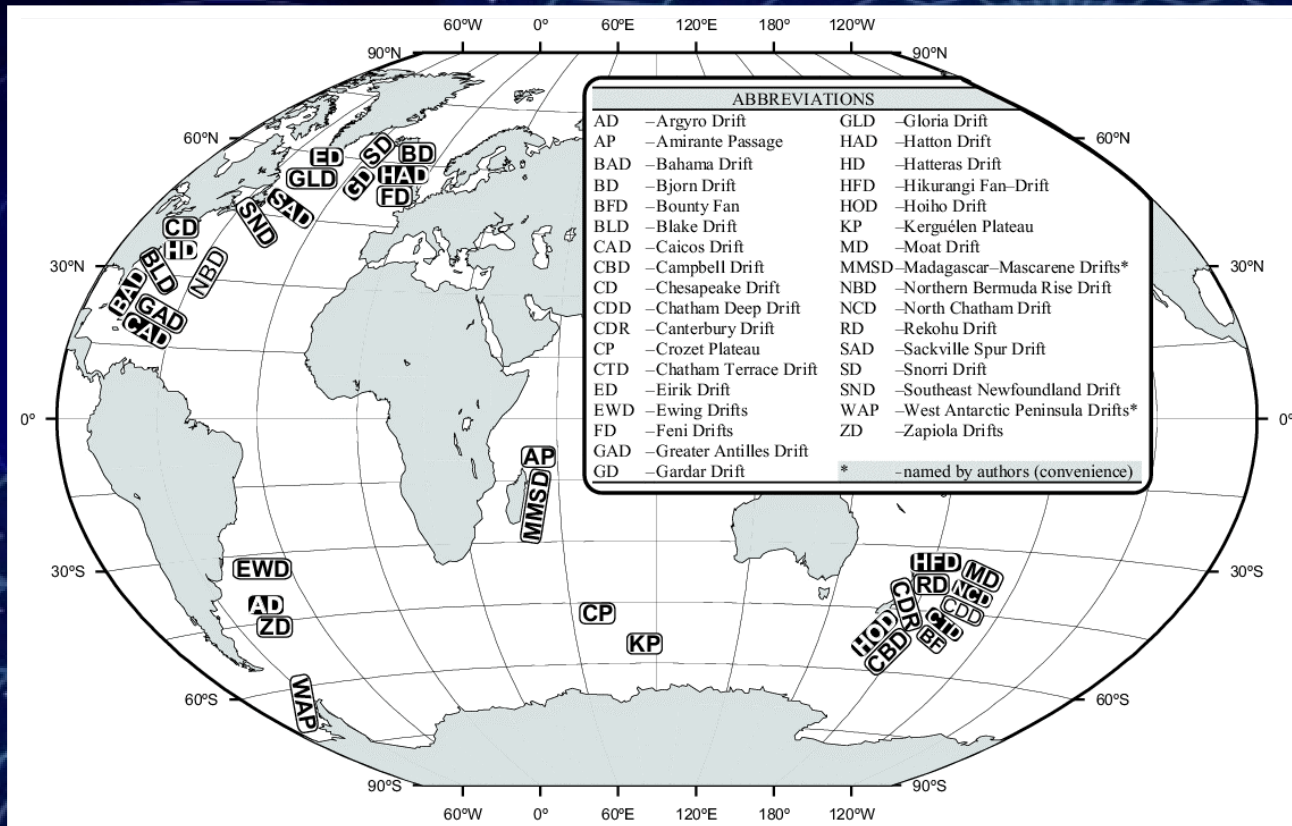
coupling of 2-D and 3-D model

Present-day eolian dust distribution



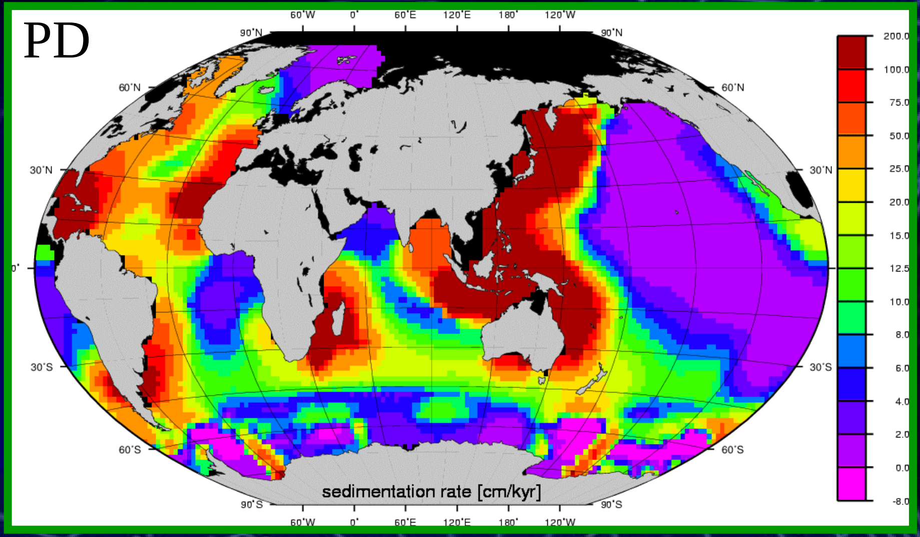
reproduced from *Rea* [1994], after *Duce et al.* [1991]

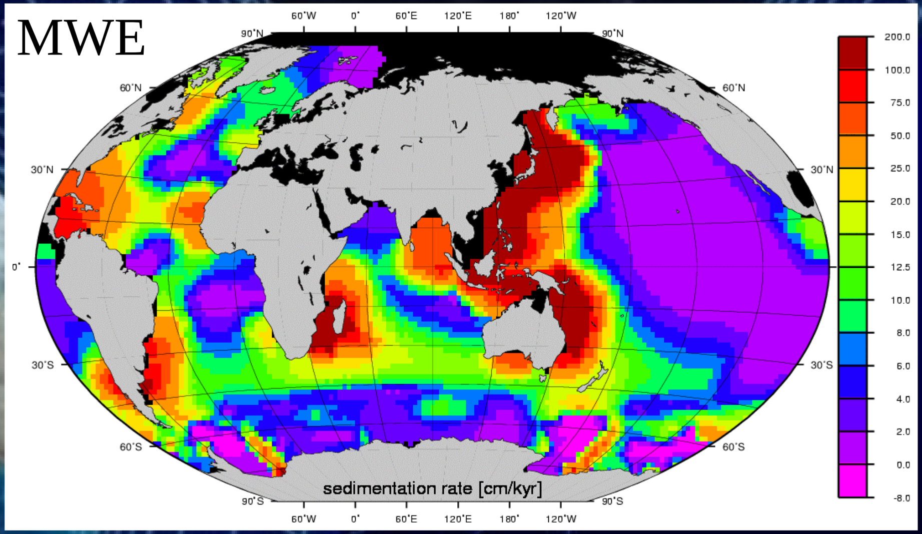
Known sediment drifts



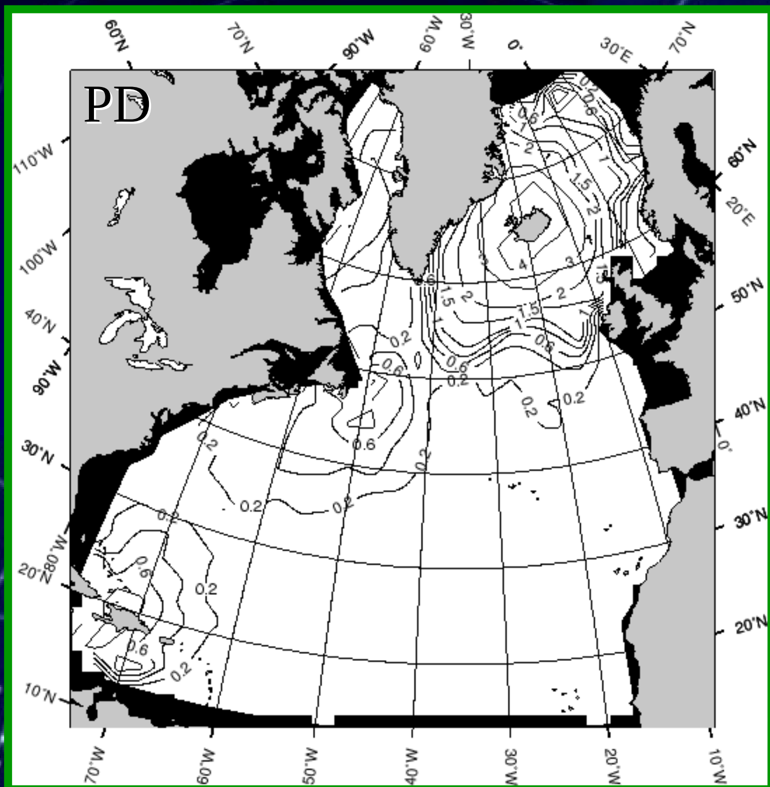
- Sediment drifts reflect development times from tens to hundreds of thousands of years.
- Drifts are formed along the deep western boundary currents.
- Drifts reflect a long–term response to environmental conditions rather than a short-term response to discrete events [Flood and Shor, 1988].

Modeled sediment drifts

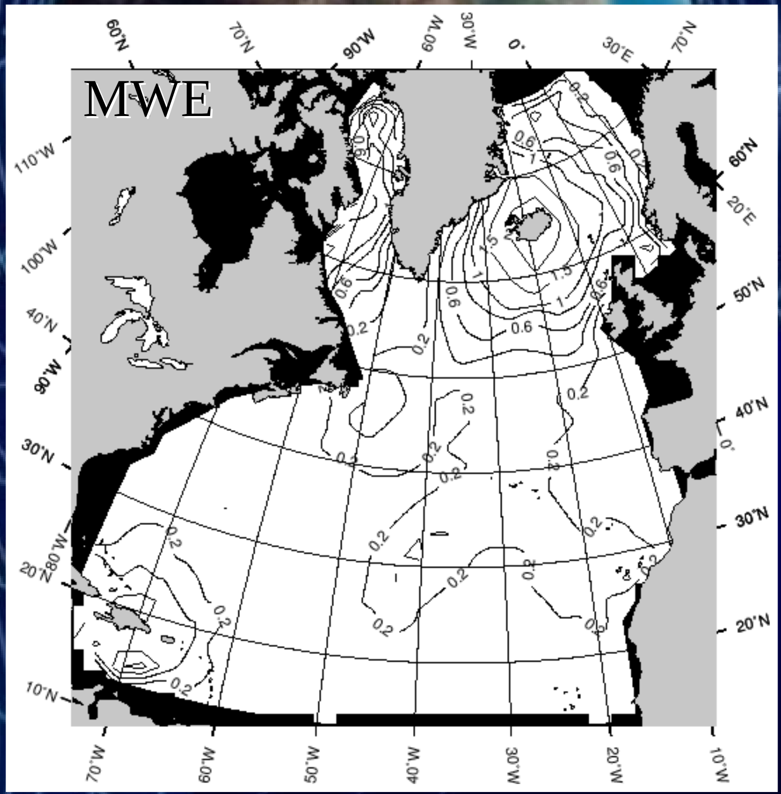




Modeled sediment drifts (North Atlantic model)



2°x2°; 12 layers; homogeneous eolian sediment input



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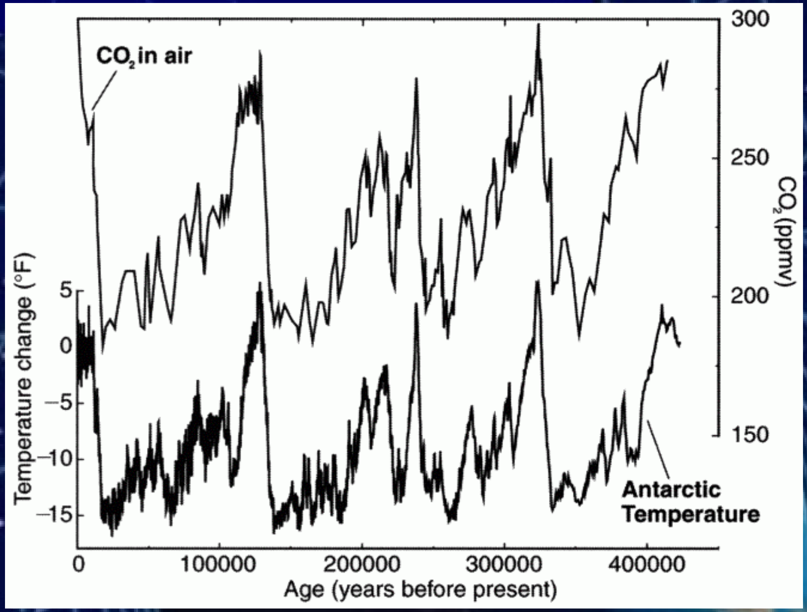
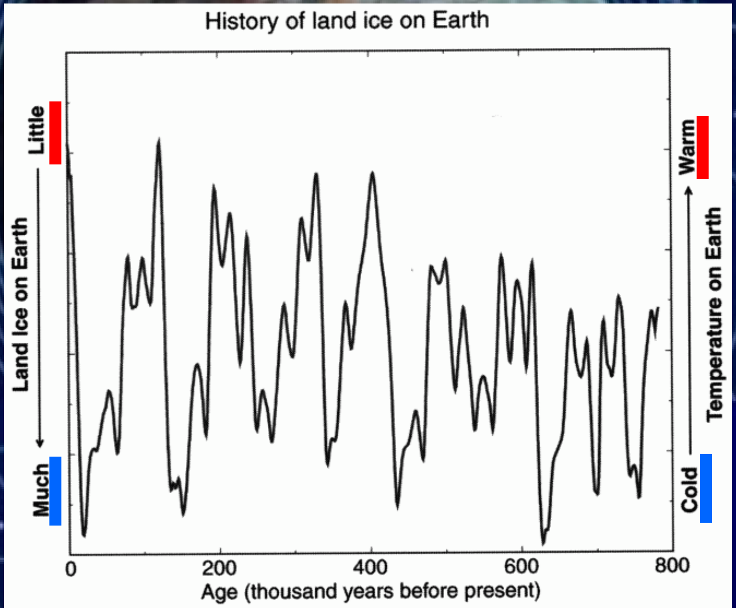
Experiment (2nd set)
(past, present, and future)

Geologic record shows a direct correlation between CO_2–content in air and temperature.





Geologic record shows a direct correlation between temperature und ice volume.

“Antarctic Meltdown”

There is a concern about the stability of the West Antarctic Ice Sheet, which may collapse if global warming continues.

However, our model predicts that freshening of the sea surface in the high latitudes due to the southern cryosphere melting can speed up the North Atlantic conveyor and lead to climate changes that are genrally not expected in a warming climate trend.

(Seidov, D., E.J. Barron, and B.J. Haupt, *Meltwater and the global ocean conveyor: Northern versus southern connections*. Global and Planetary Change, 30/3, 2001)

February 2000

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subtitle:
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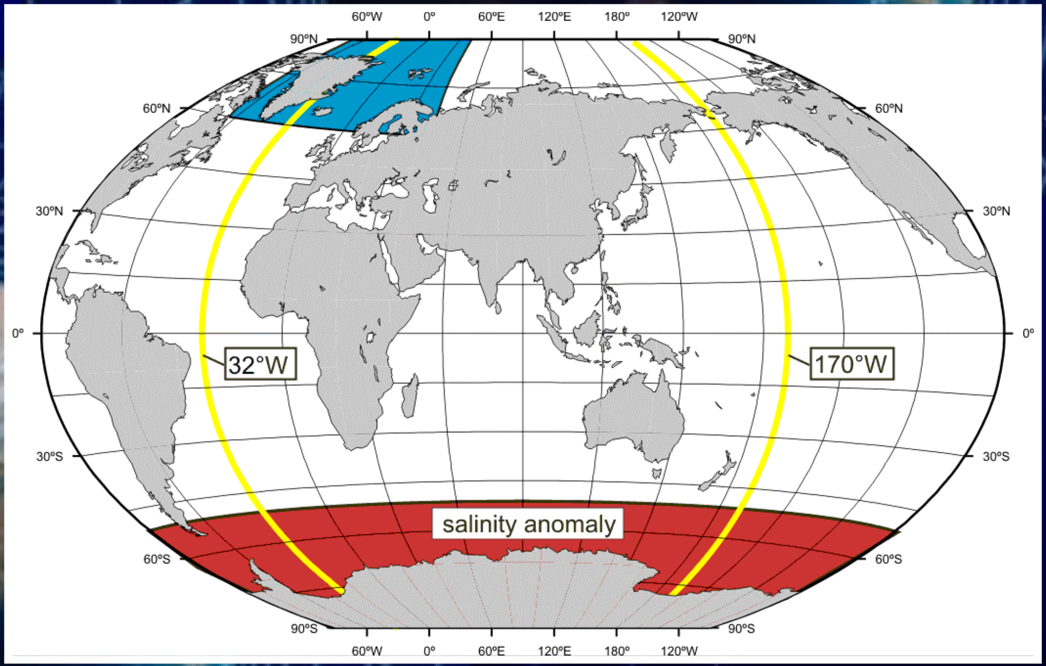
February 2000

Salinity anomaly in psu

Exp.	NA	SO
#1 (PD)	–	–
#2	-3	–
#3	–	-1
#4	–	+1

PD = Present-day
NA = North Atlantic
SO = Southern Ocean

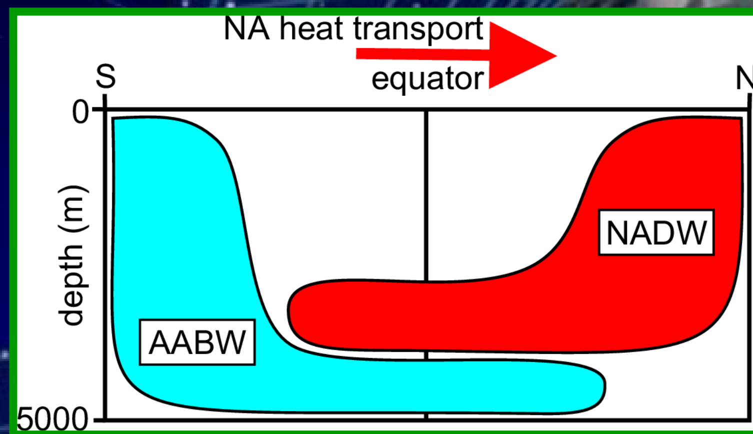
Rule-of-thumb:
A salinity change of -1 psu is equivalent to a 5°C temperature change.



(psu = practical salinity unit)

North Atlantic water masses (sketch)

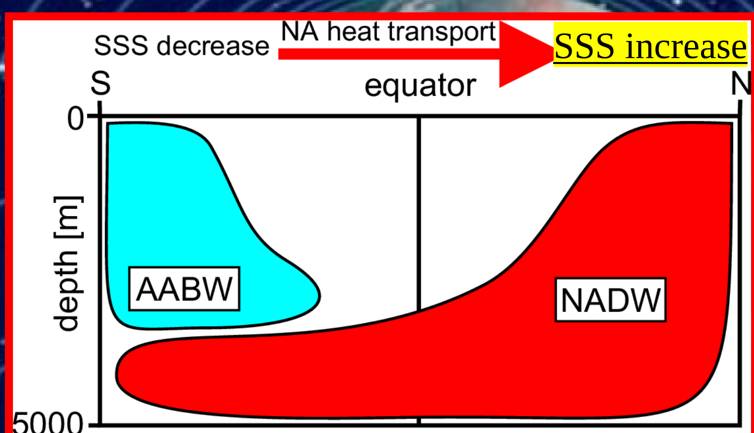
present-day forward conveyor



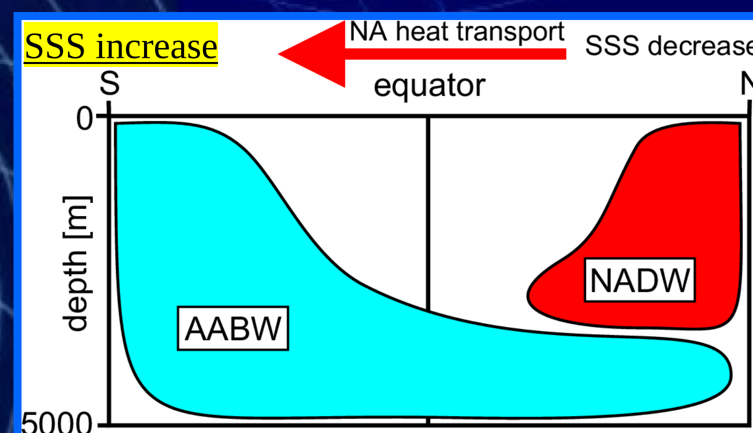
negative feedback

negative feedback

southern meltwater event

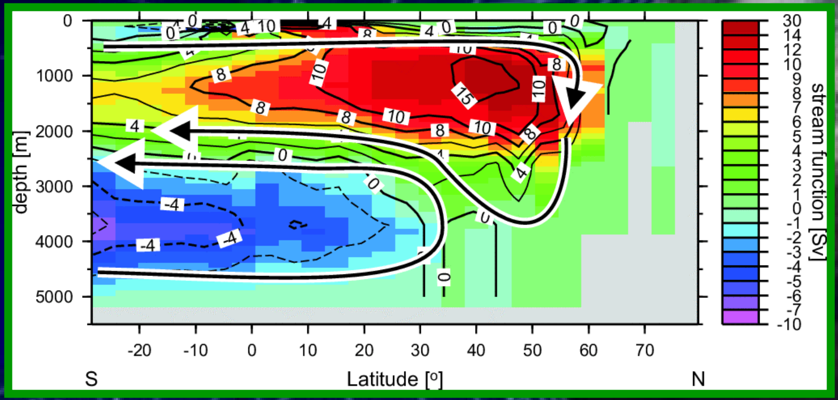


northern meltwater event

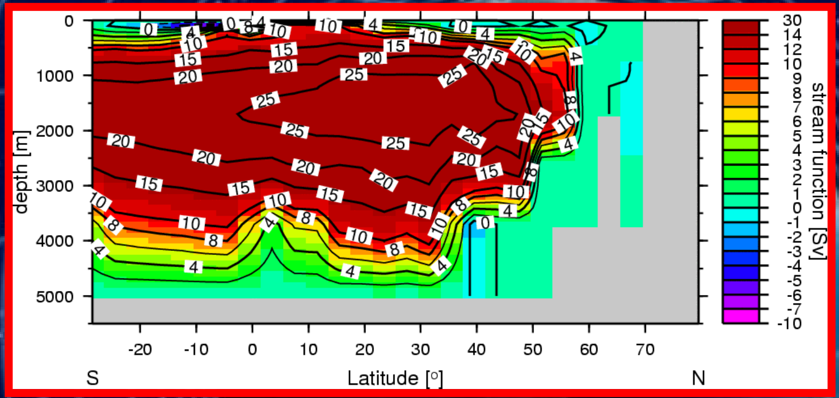


Meridional overturning in the North Atlantic (Sv)

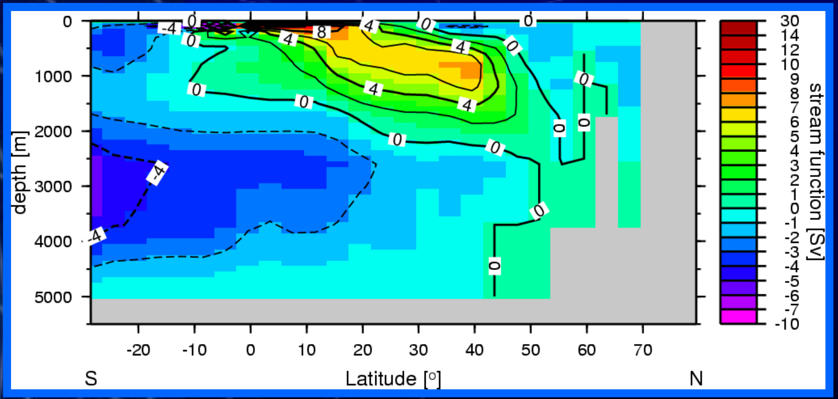
present-day forward conveyor



southern meltwater event (-1 psu)



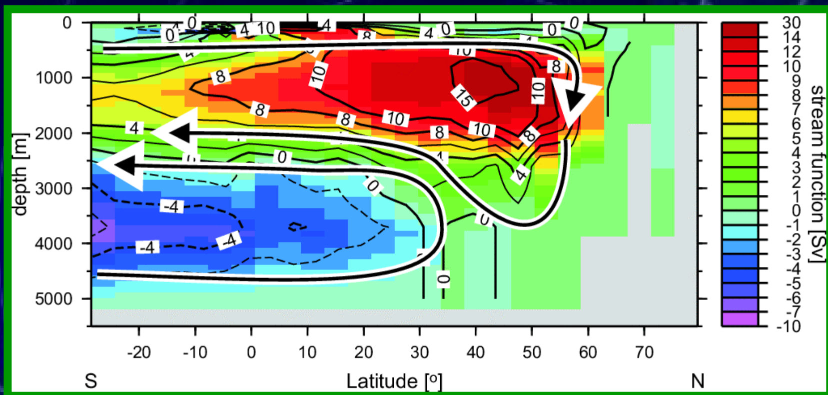
northern meltwater event (-3 psu)



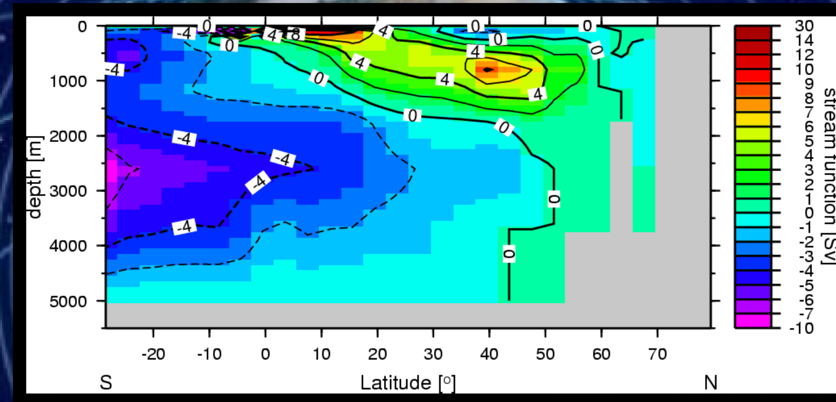
(1 Sv = 10^6 m^3s^{-1})

Meridional overturning in the North Atlantic (Sv)

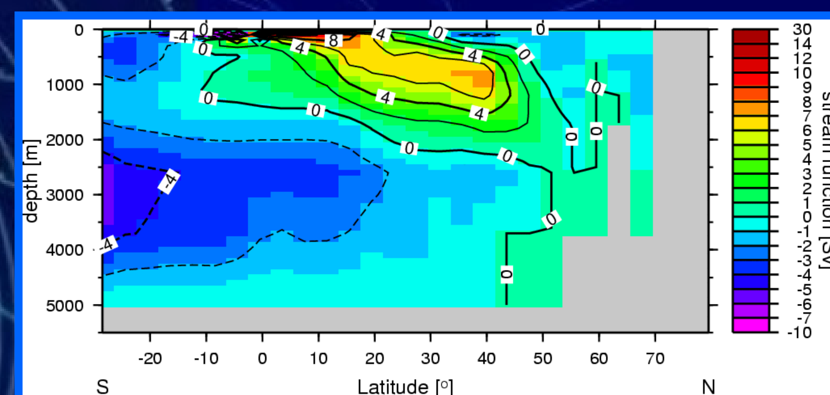
present-day forward conveyor



southern salinity increase (+1 psu)



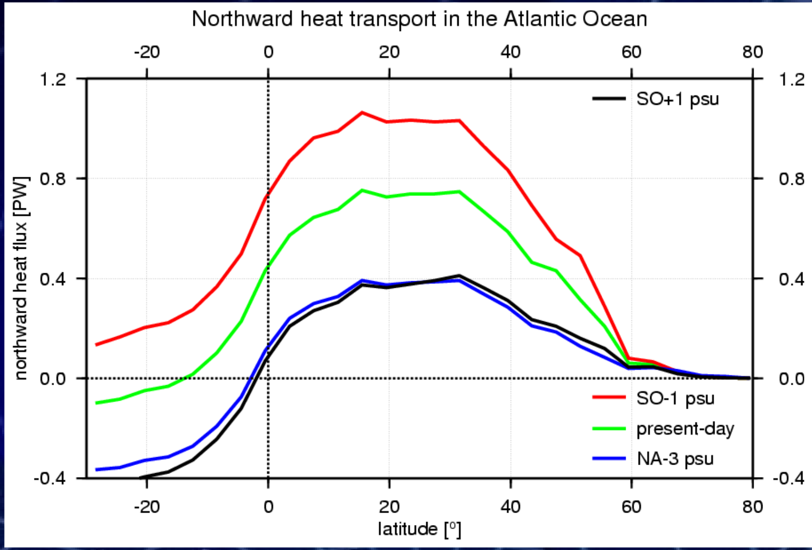
northern meltwater event (-3 psu)



(1 Sv = 10^6 m^3s^{-1})

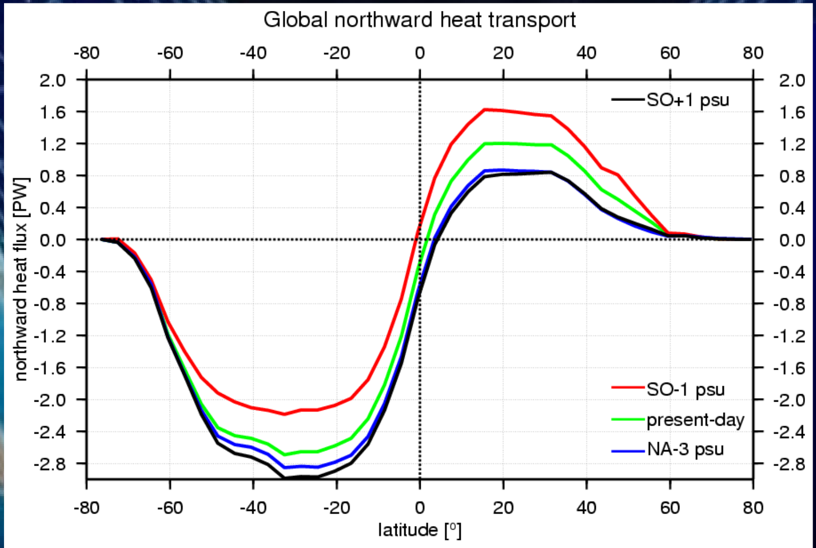
Meridional northward ocean heat transport (PW)

(1 PW = 10^{15} W)



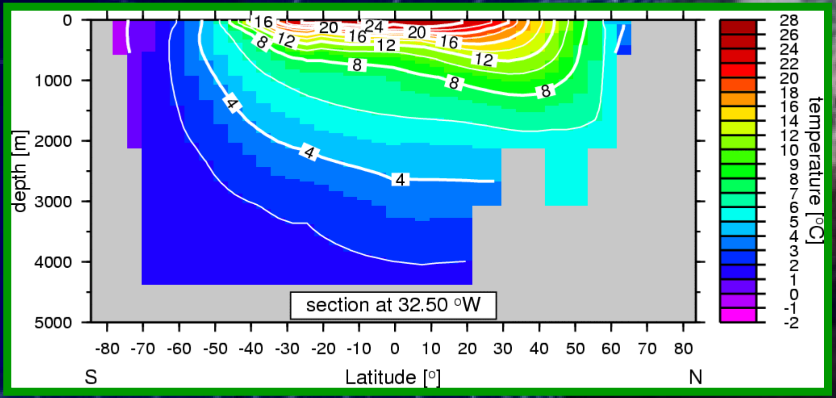
- Southern meltwater events accelerate the global conveyor and increase the northward ocean heat transport.

- Northern meltwater events slow down the global conveyor and decrease the northward oceanic heat transport.

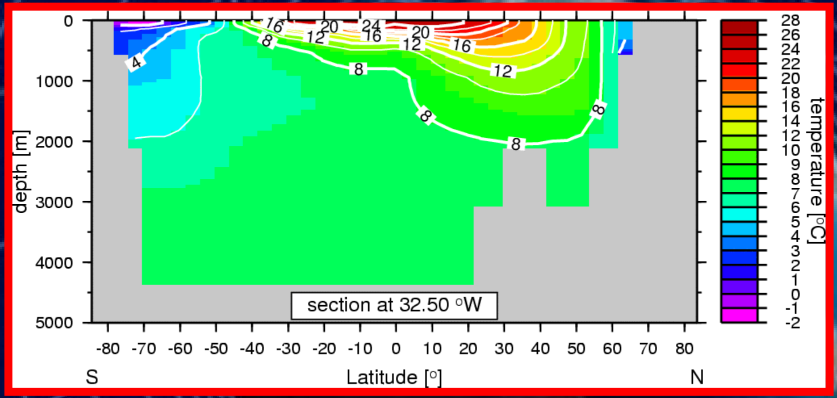


Meridional temperature section in the Atlantic Ocean

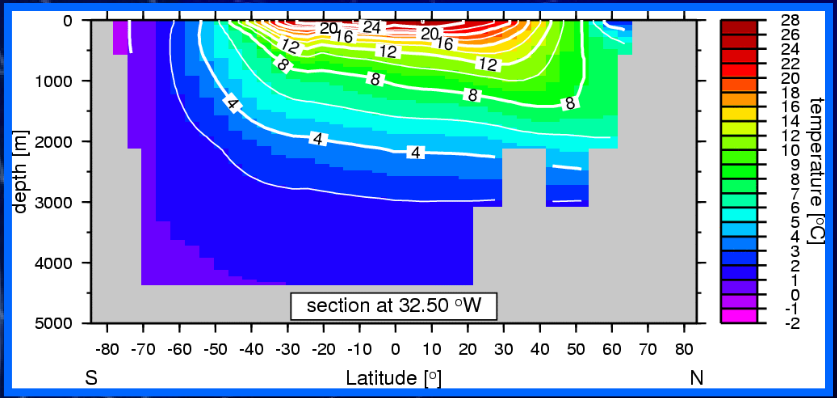
Present-day forward conveyor



southern meltwater event (-1 psu)

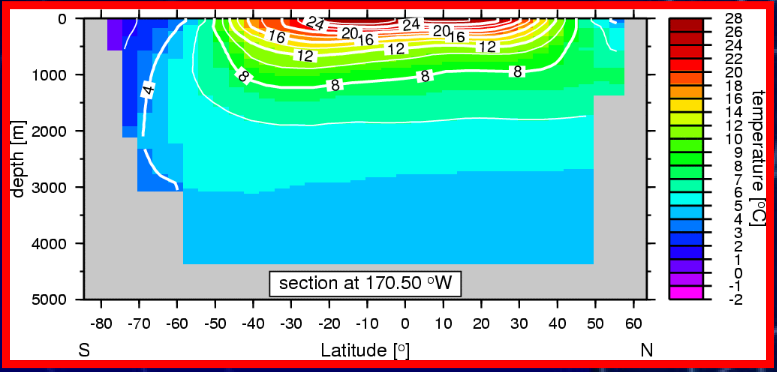


northern meltwater event (-3 psu)

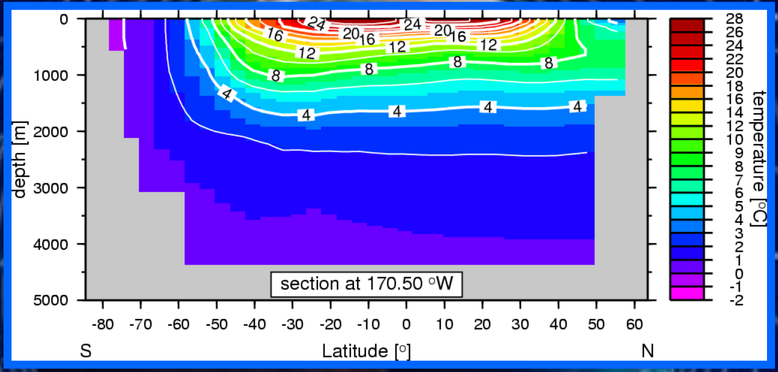


Northern versus southern meltwater event

southern meltwater event (-1 psu)

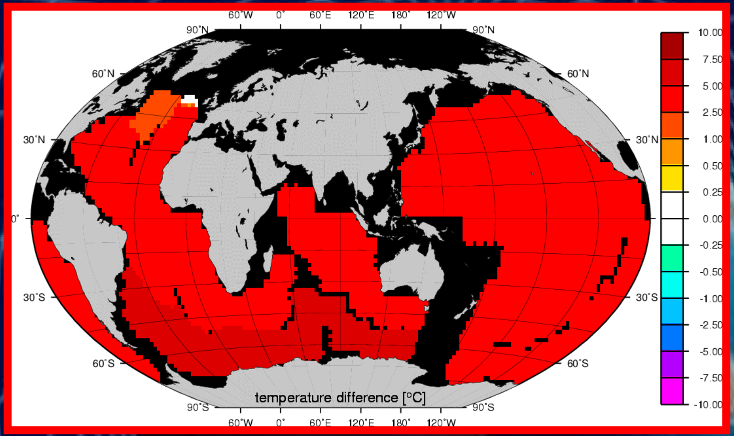


northern meltwater event (-3 psu)



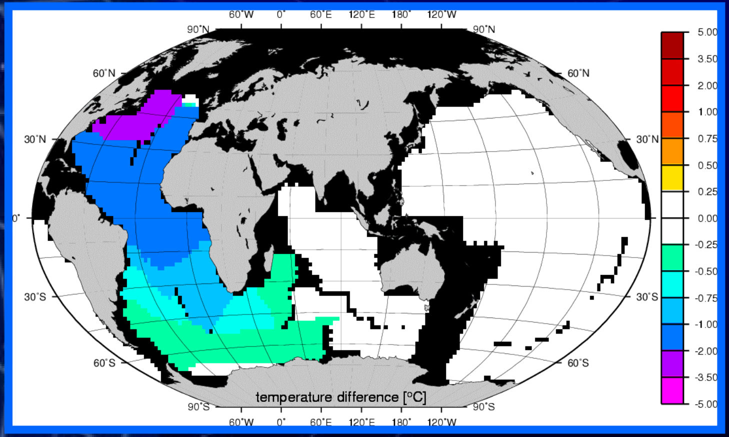
Temperature difference between meltwater and PD control experiment

southern meltwater event (-1 psu)



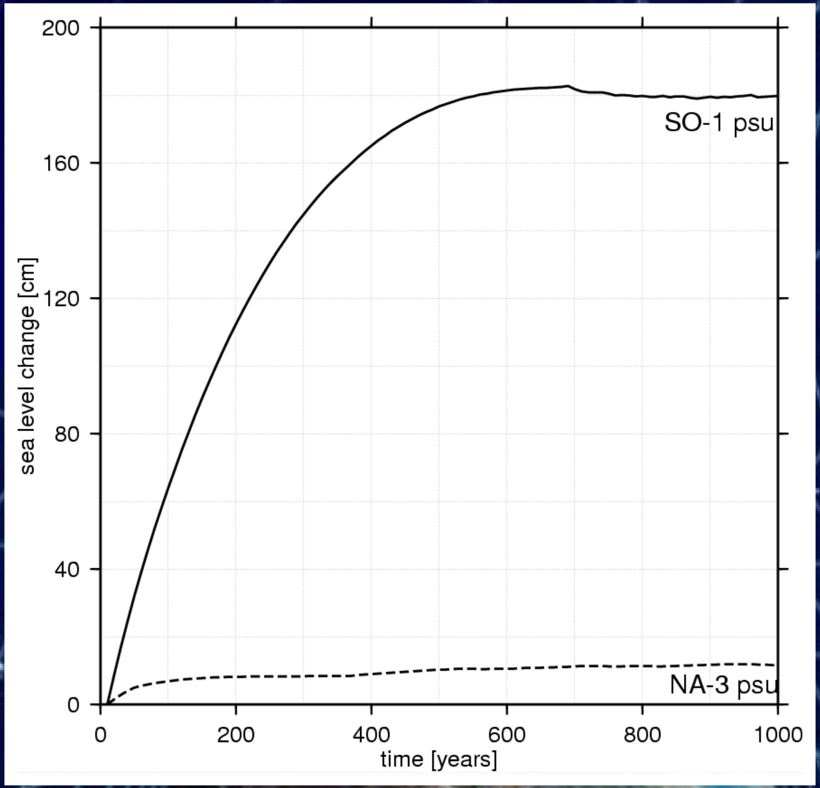
3000 m

northern meltwater event (-3 psu)



3000 m

Sea level rise caused by thermal expansion



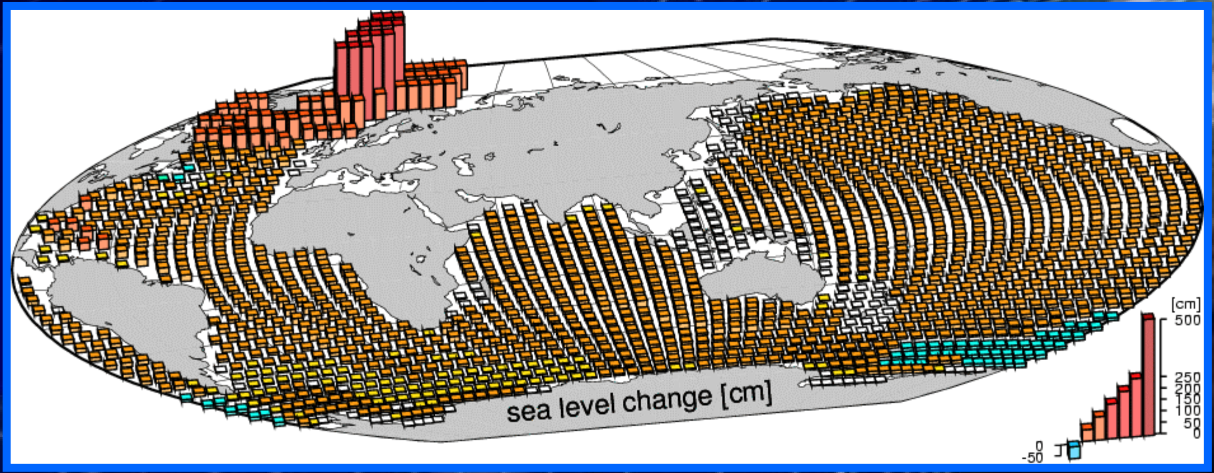
Sea level rise without melting of ice sheets

Location	Volume [km³]	Potential sea-level rise [m]
East Antarctic ice sheet	26,039,200	64,80
West Antarctic ice sheet	3,262,000	8,06
Antartic Peninsula	227,100	0,46
Greenland	2,620,000	6,55
All other ice caps, ice fields, and glaciers	180,000	0,45
Total	32,328,300	80,32

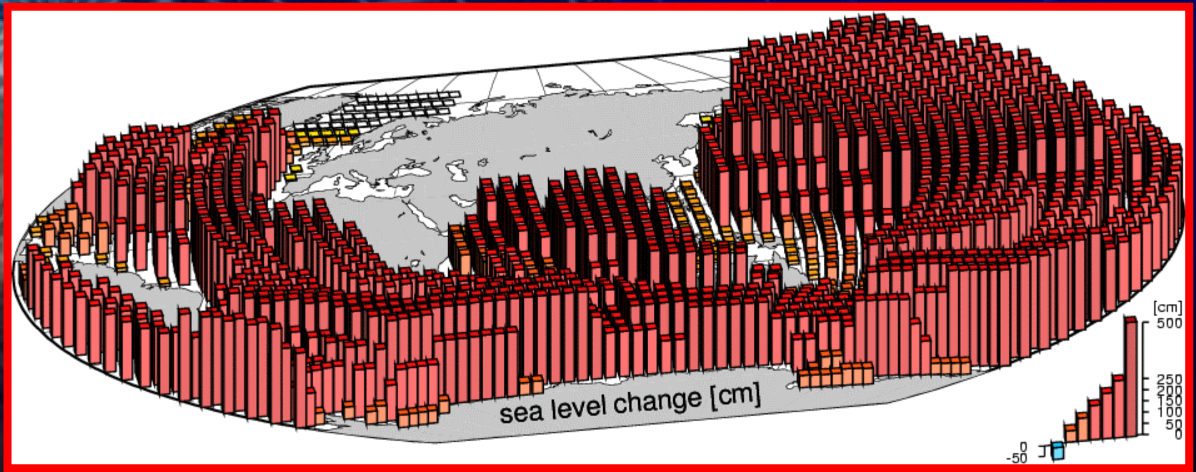
Modified from Williams and Hall, 1993

Sea level rise caused by thermal expansion

northern meltwater event (-3 psu)



southern meltwater event (-1 psu)



Conclusions

- Water mass motion can be traced in ocean models, and changes in ocean circulation can be seen in ocean sediment. Therefore, the sediment transport model SEDLOB can be used to validate ocean circulation.
- The key for global thermohaline circulation lies in the high latitudes of both hemispheres. The global conveyor reacts more sensitively to a southern meltwater event than to a northern meltwater event.
- Northern meltwater events slow down the global conveyor, decrease the northward oceanic heat transport, and cause a cooling of the deep ocean.
- Southern meltwater events accelerate the global conveyor, increase the northward ocean heat transport, and cause a warming of the deep ocean.
- A salinity reduction in one hemisphere is equivalent to a salinity increase in the opposite hemisphere.
- A sea level rise is possible without an extreme melting of ice shields.
- Even a “global cooling” event can lead to a sea level rise!
- Will Washington/Cancun be flooded?

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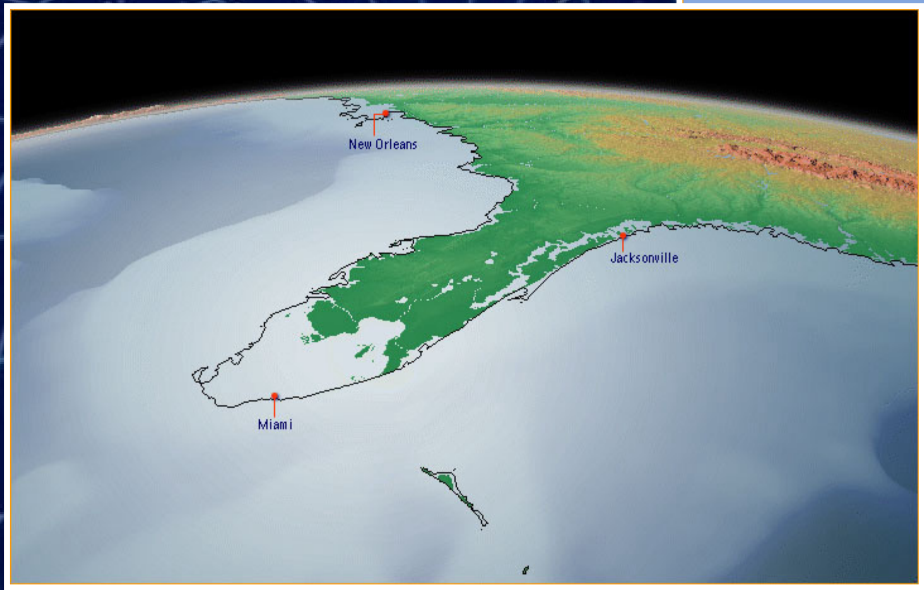
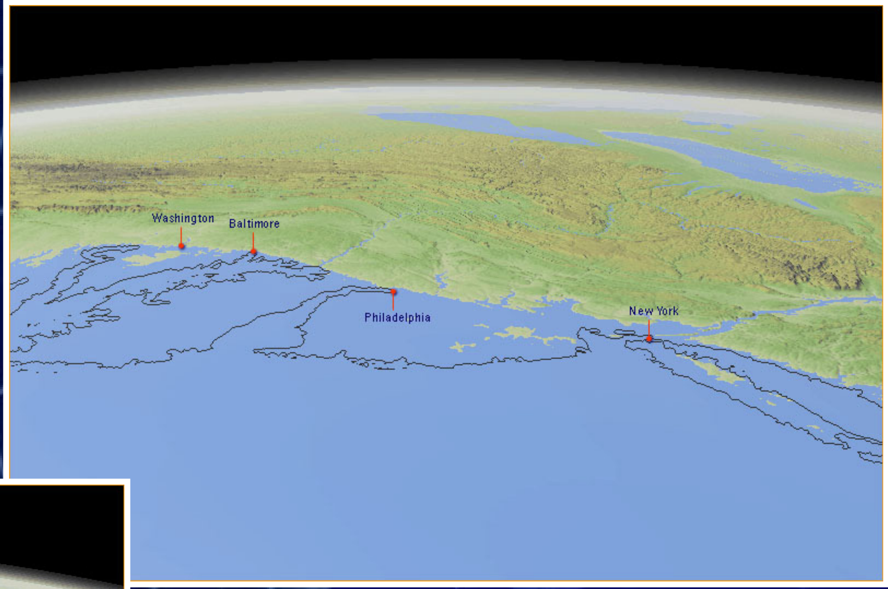
Will Washington/Cancun be flooded?

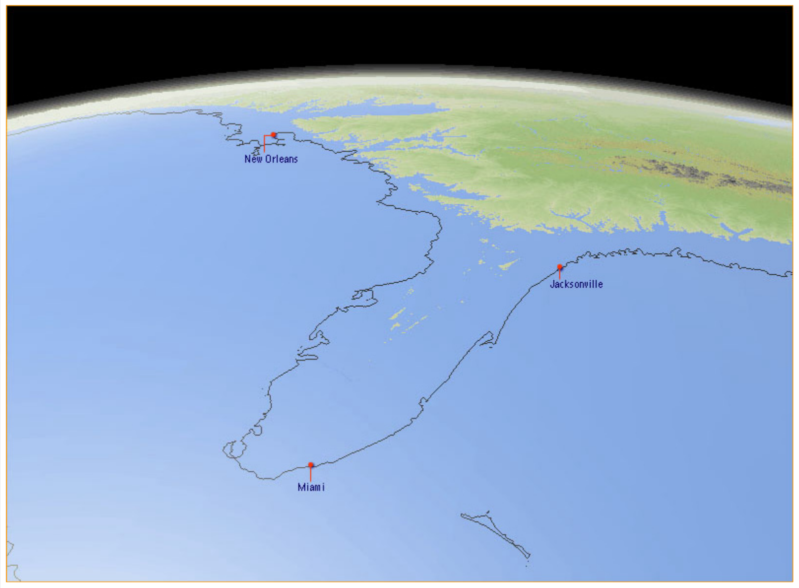
5 m sea level rise



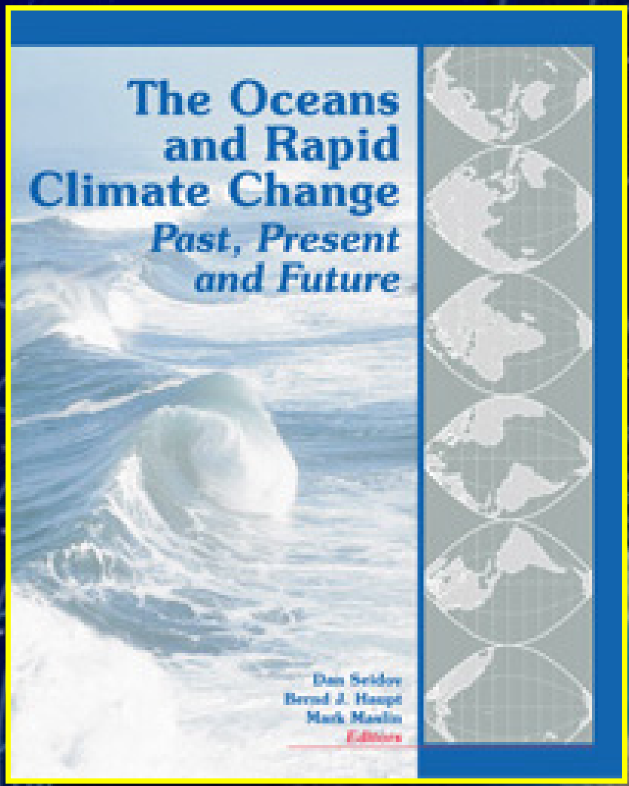
Will Washington/Cancun be flooded?

50 m sea level rise





THE END



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