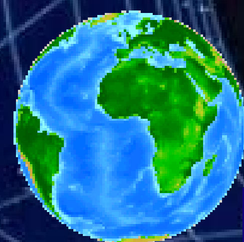
The warm deep–ocean conveyor during Cretaceous Period driven by surface salinity contrasts

Bernd J. Haupt & Dan Seidov



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Introduction

- Observations and ocean models suggest that ocean circulation during the warm Mesozoic-Cenozoic climate differed dramatically from its present-day pattern.
- Our goal is to explore the hypothesis that a warm deep ocean can coexist with a relatively cool subpolar/high latitude sea surface in one hemisphere and a warmer subpolar sea surface in another hemisphere.
- The warm deep water is usually associated with high-latitude deep-water sources. => The question is whether the warm deep-ocean water (direct geologic evidence) reflects a warm polar ocean surface.
- Note: Dedensification of surface waters shuts off the convection and thereby reduces the meridional overturning => Reduced overturning results in reduced poleward heat transport, and vice versa.

Stommel-Arons Ocean circulation (1958)

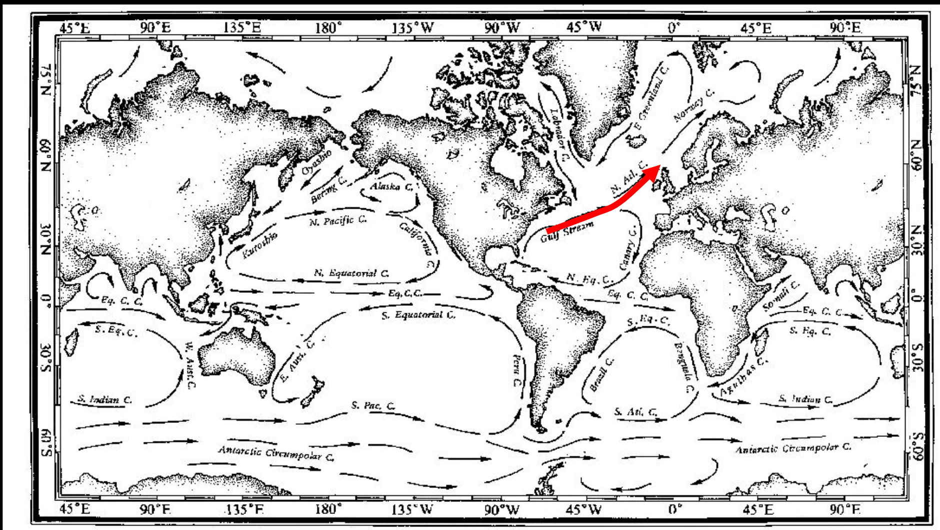


Fig. 2.17 The general surface circulation of the ocean in schematic form. The dominant features are the large, anticyclonic subtropical gyres in each ocean basin, the equatorial current systems, and the Antarctic Circumpolar Current.

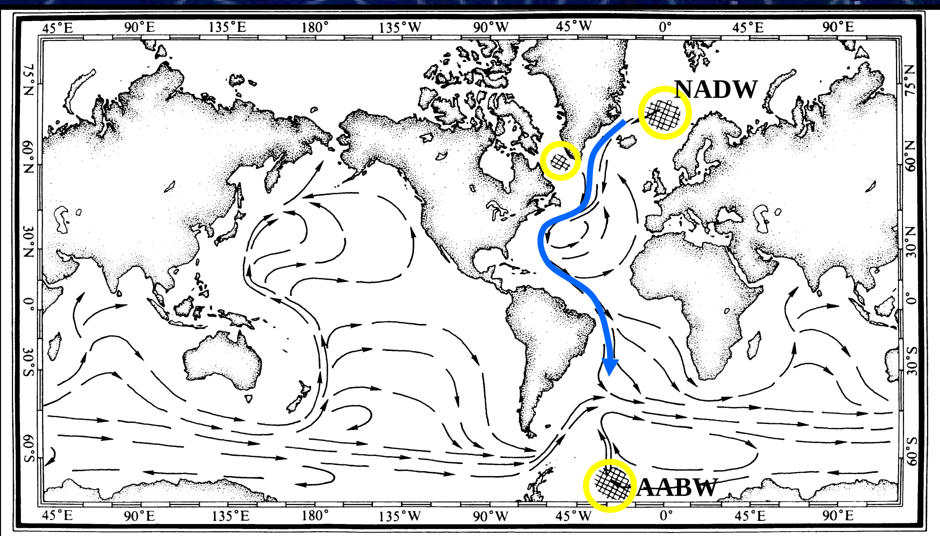


Fig. 2.23 Schematic flow lines for abyssal circulation. The cross-hatched areas indicate regions of production of bottom water. [Adapted from Stommel, H., *Deep Sea Research* (1958).]

- 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.

Atlantic water masses

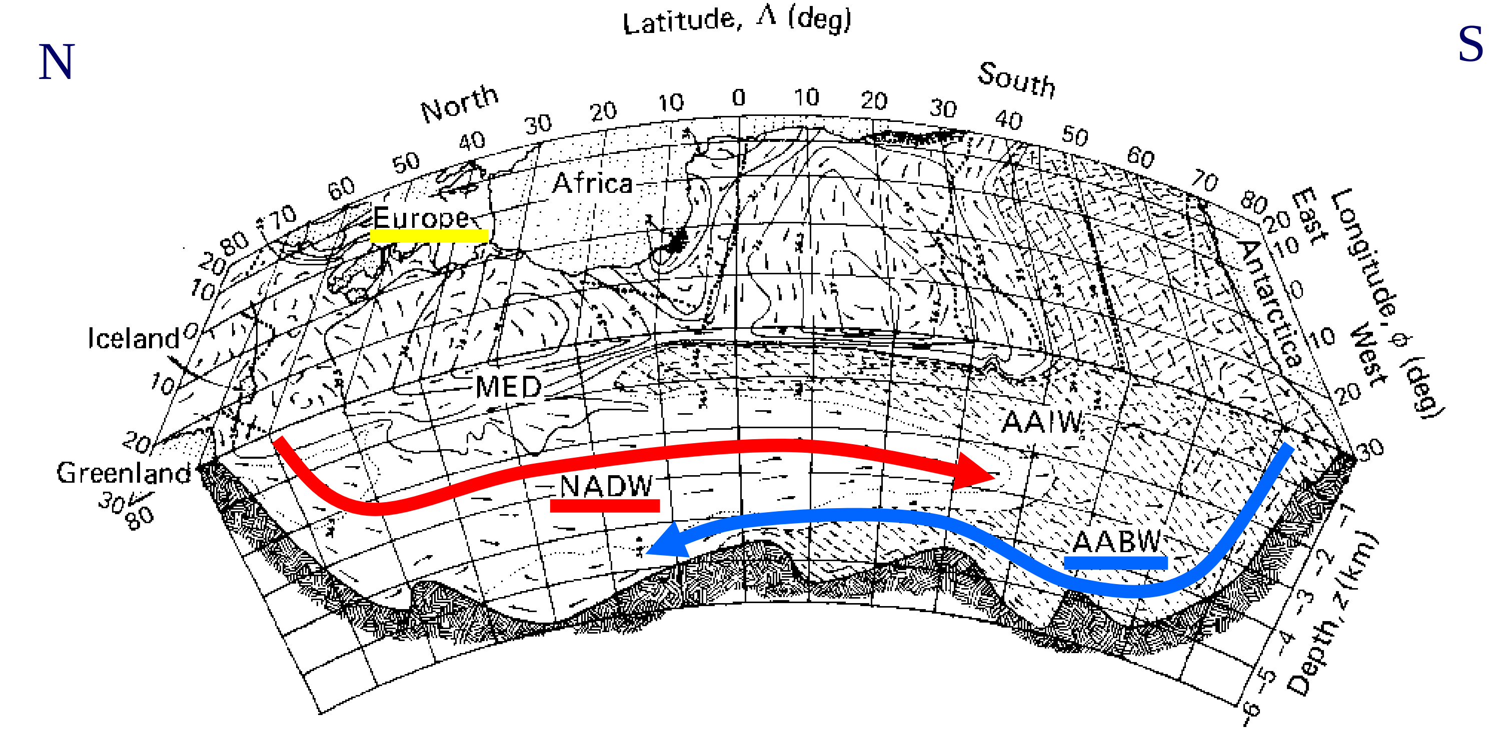
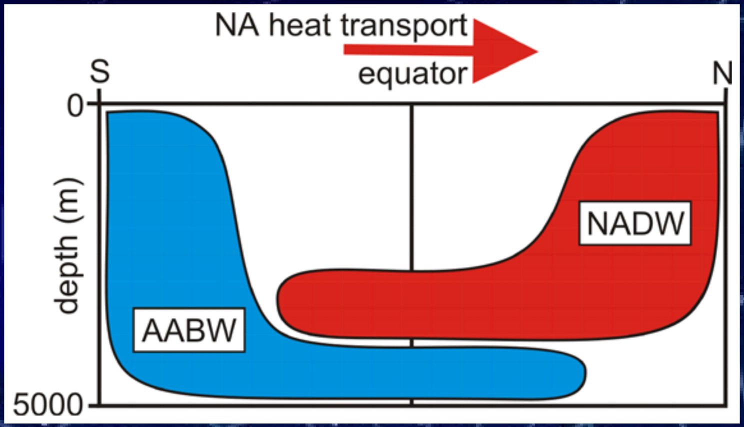


Fig. 2.22 Schematic cross section of surface and subsurface currents in the North and South Atlantic. [Adapted from Wüst, G., *Kieler Meeresforschungen* (1950).]

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

Bipolarity of deep-ocean dynamics (sketch)

present-day forward conveyor



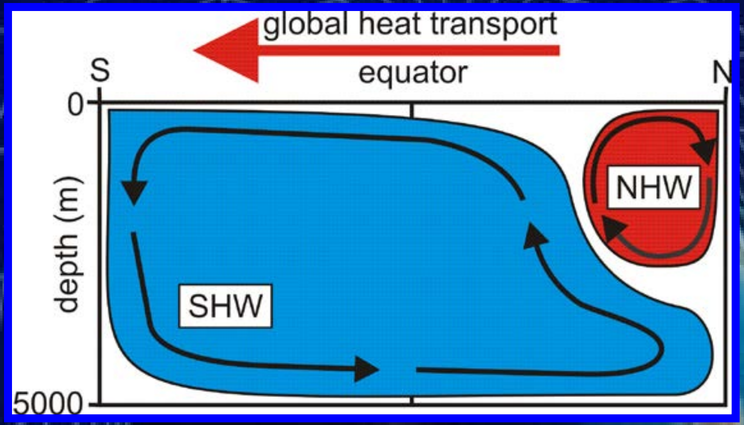
Idea of bipolar seasaw:

- Broecker, 1998 (*Paleoceanography*)
- Stocker, 1998 (*Science*)

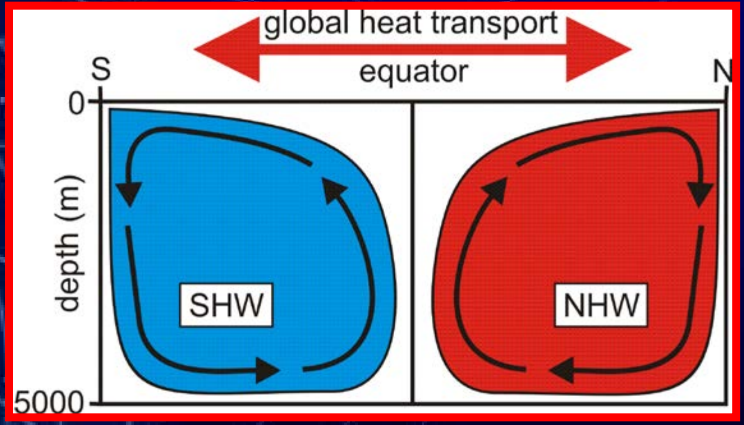
Ocean modeling of bipolar seasaw:

- Seidov & Maslin, 2001 (*J Quat Sci*)
- Haupt & Seidov, 2001 (*Geology*)

intermediate Cretaceous ocean



warm Cretaceous ocean

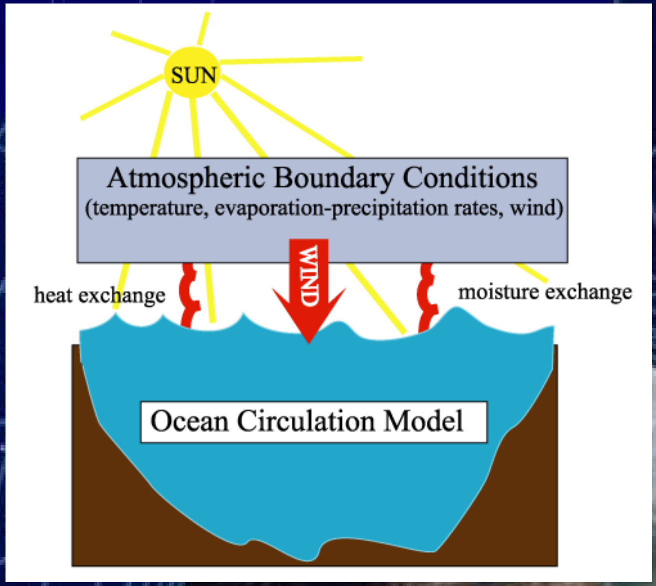


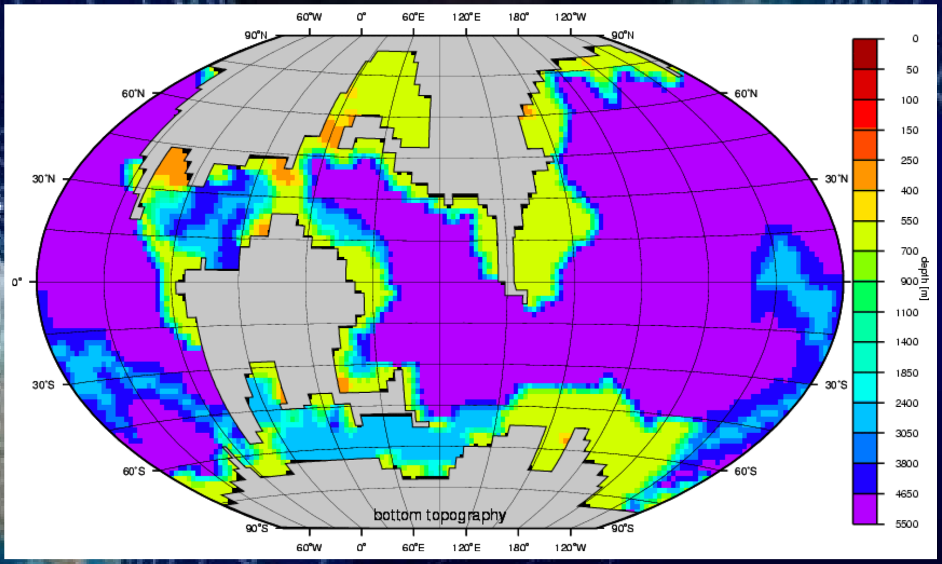
NADW = North Atlantic Deep Water
AABW = Antarctic Bottom Water

NHW = Northern Hemisphere Water
SHW = Southern Hemisphere Water

Global ocean circulation model

- MOM 2 (Modular ocean model version 2.2) from GFDL (Geophysical Fluid Dynamics Laboratory)
- Grid resolution: - horizontal: 4 x 4° (92 x 45 grid points)
  - vertical: 16 unevenly spaced layers

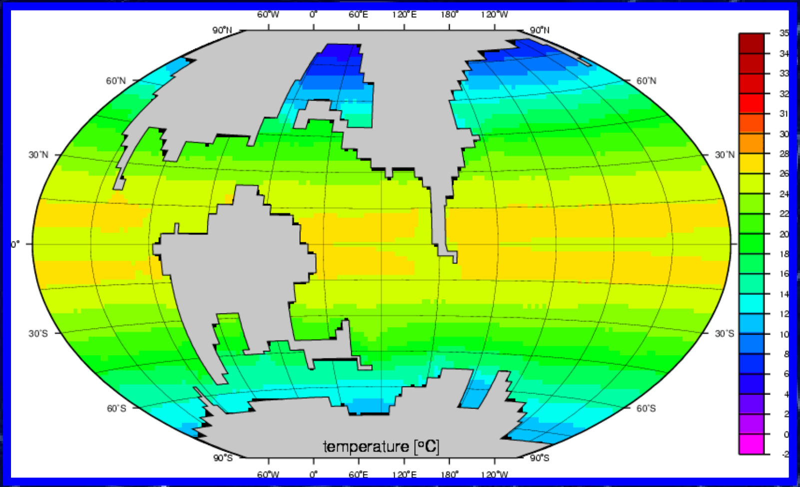




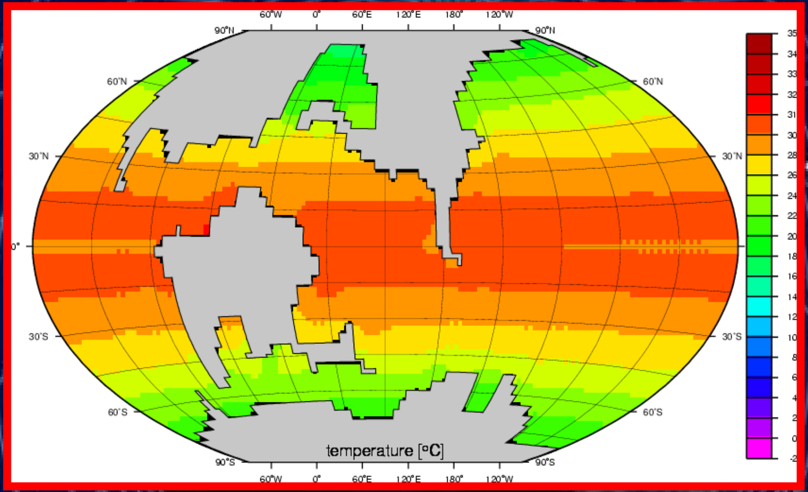
Bottom topography

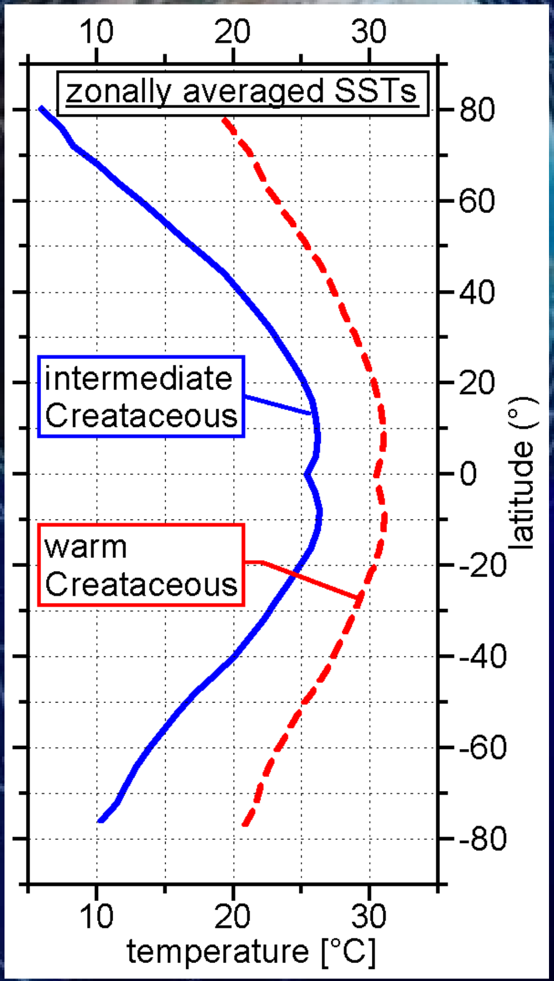
Sea surface temperatures

Intermediate Cretaceous



Warm Cretaceous

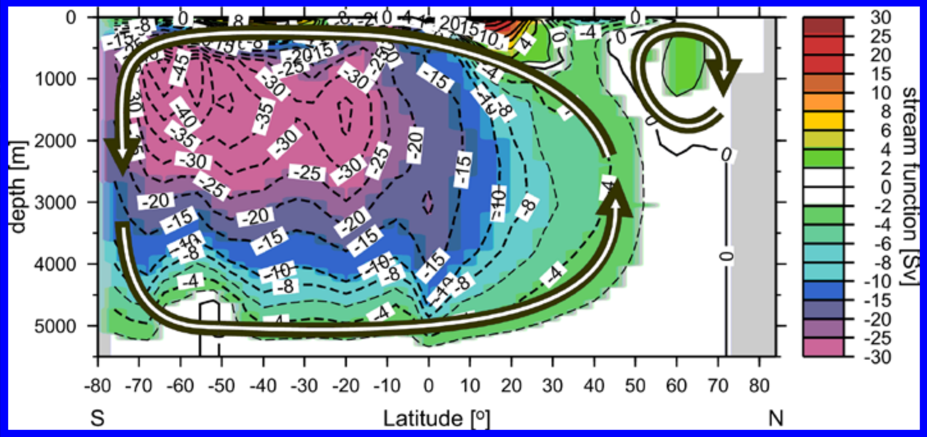




(Poulsen et al., 1999)

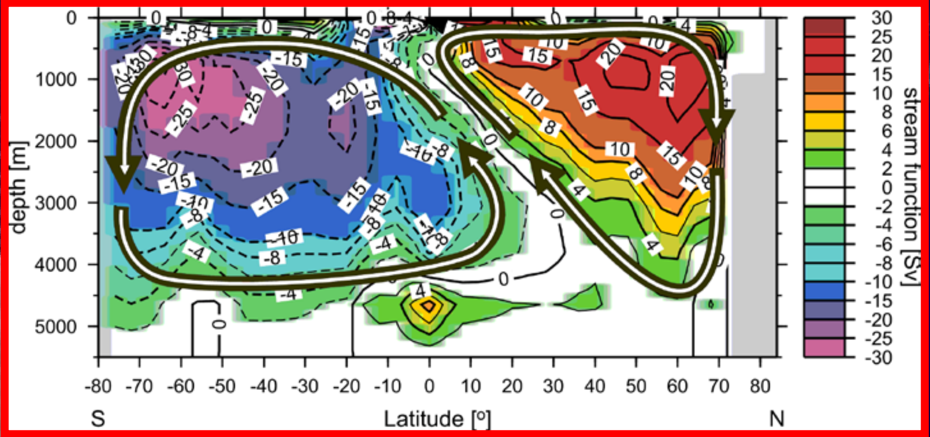
Meridional overturning for the global ocean in Sv

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



Intermediate Cretaceous

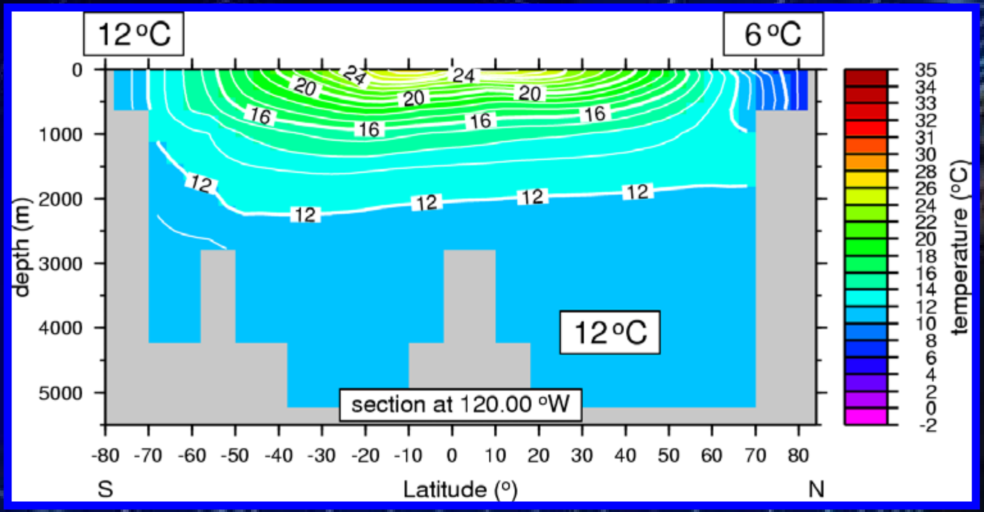
Warm Cretaceous



The positive values depict clock-wise motion while negative values depict counterclockwise motion.

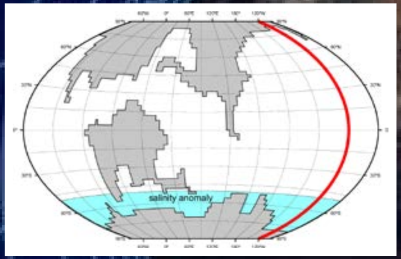
Haupt & Seidov, 2001 (*Geology*)

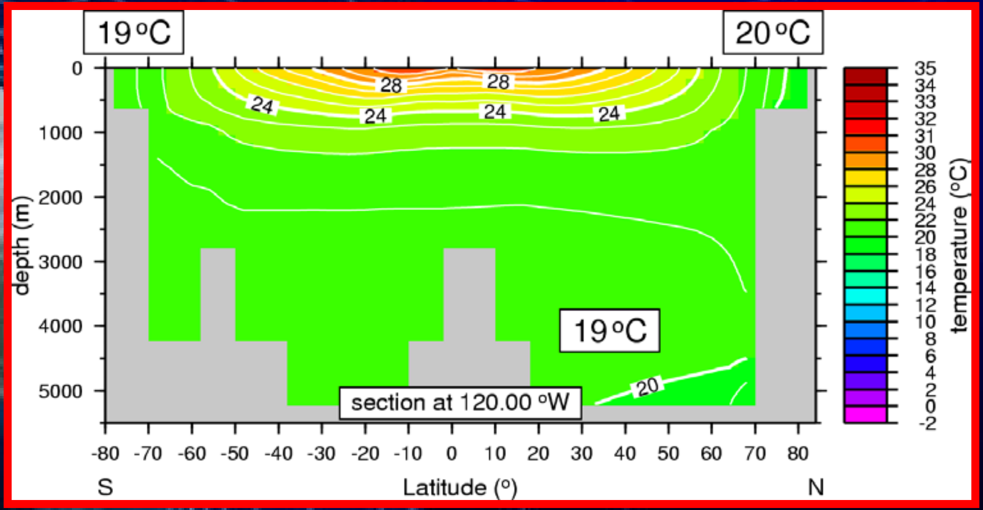
Meridional temperature sections



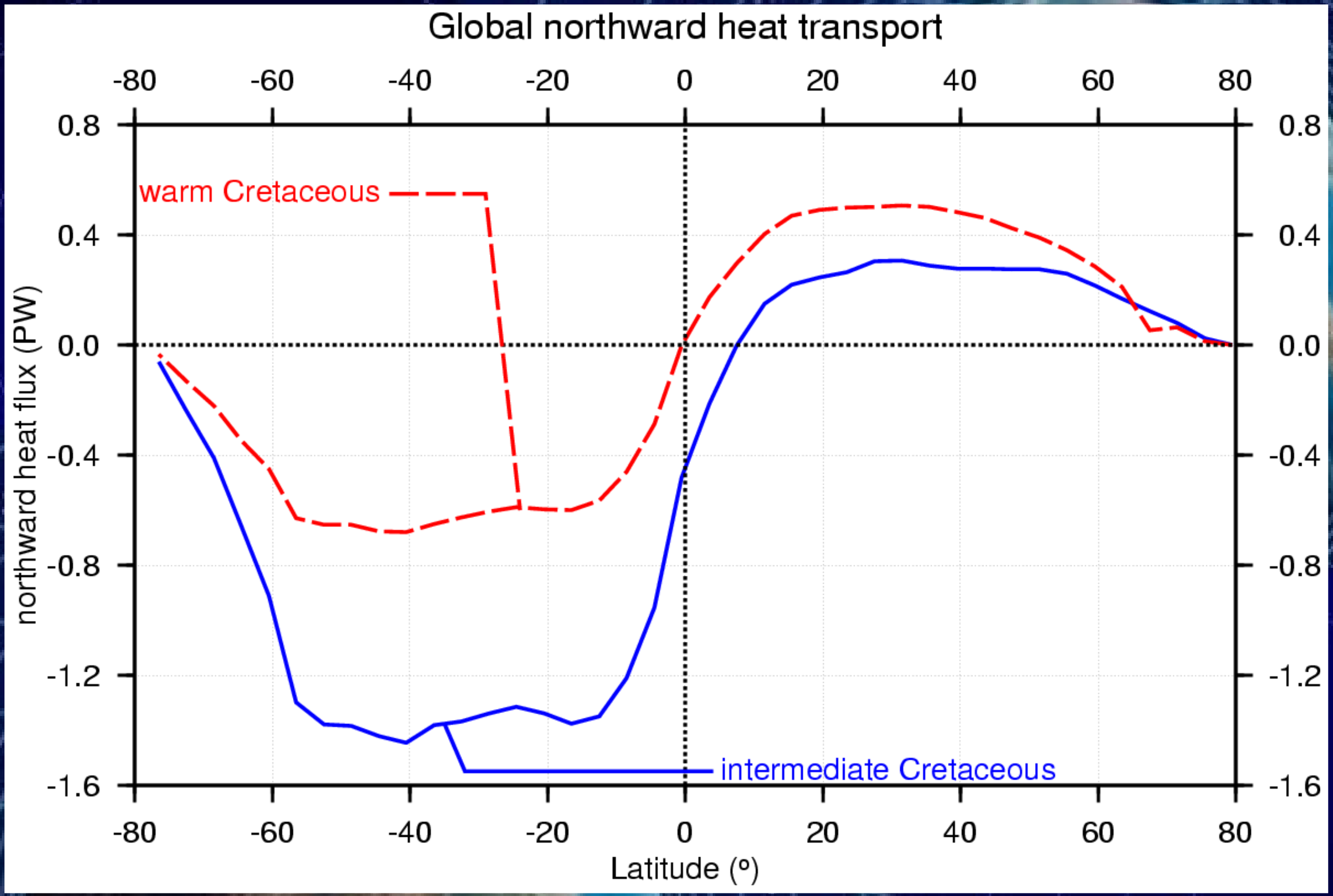
Intermediate Cretaceous

Warm Cretaceous





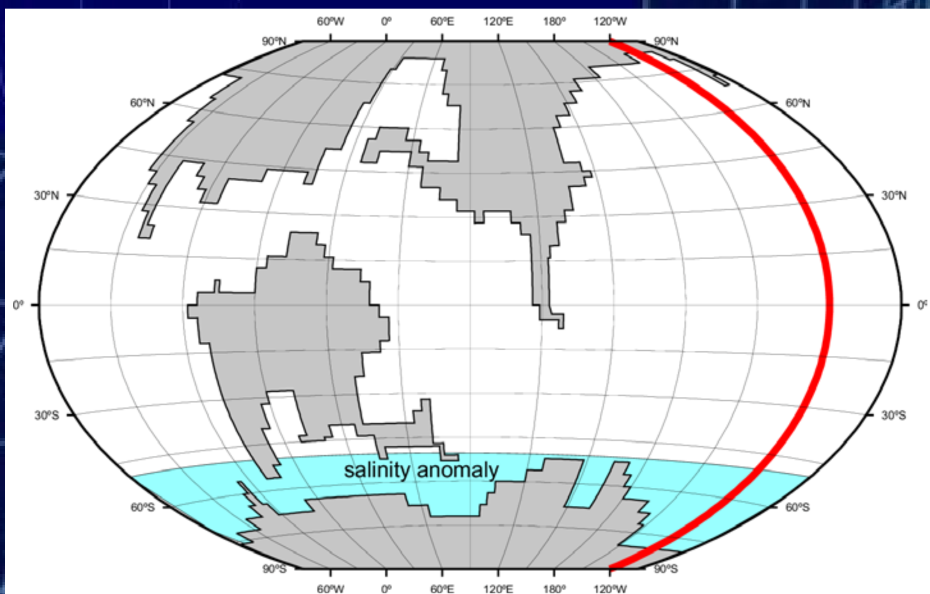
Global northward heat transport in PW



(1 PW = 10^{15}W)

SSS anomalies and the thermohaline conveyor

- Our goal is to test whether the Cretaceous ocean is sensitive to perturbation of the high-latitude sea surface density.
- Density changes in high latitudes are known to be the strongest regulator of the ocean global thermohaline circulation.



Salinity anomaly

Seidov, Barron & Haupt, 2001
(Global Planetary Change)

- SSTs are kept unchanged and therefore SSS is to be the variable controlling the density
- Rule of thumb: A salinity change of -1 psu is equivalent to a 5°C temperature change.

Exp.	SO
#1	–
#2	–
#3	-1
#4	-1

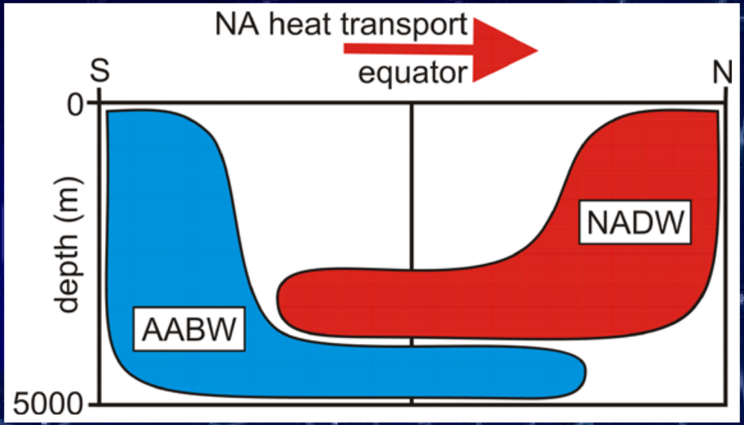
Intermediate Cretaceous
Warm Cretaceous

SO = Southern Ocean salinity anomaly

(psu = practical salinity unit)

Bipolarity of deep-ocean dynamics (sketch)

present-day forward conveyor



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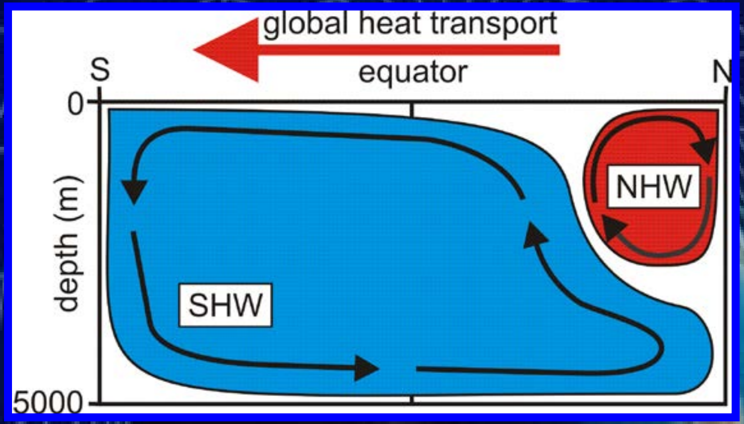
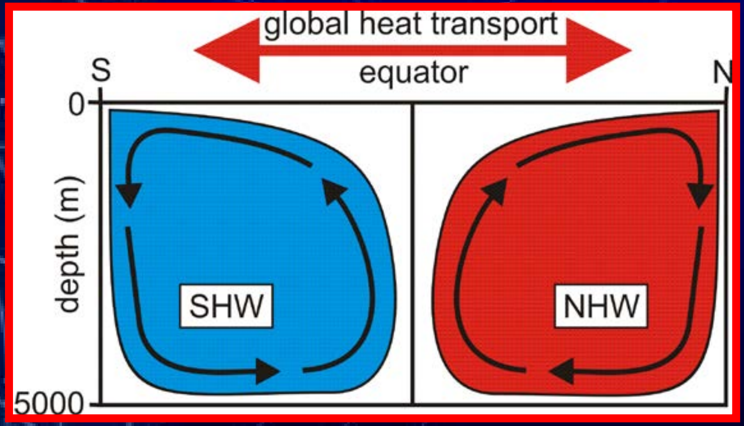


warm Cretaceous ocean



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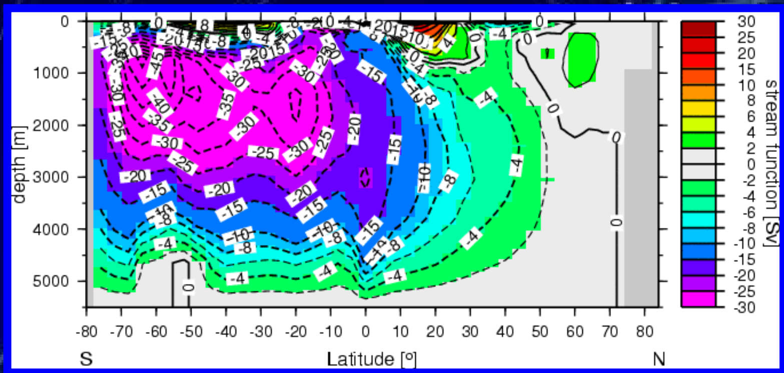
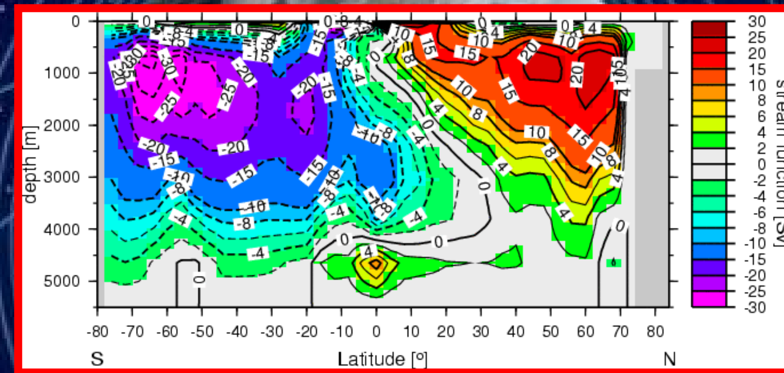
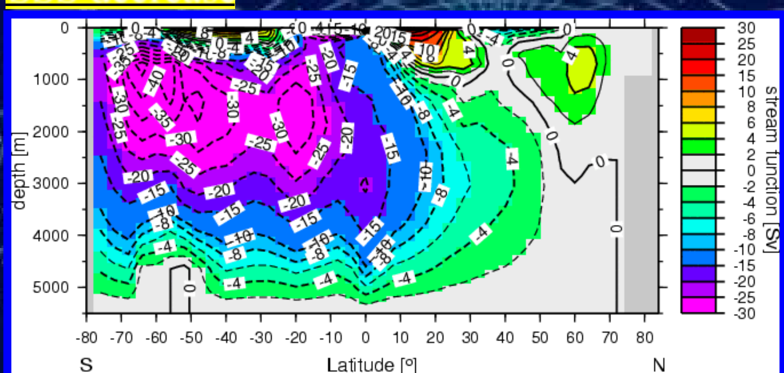


Warm Cretaceous



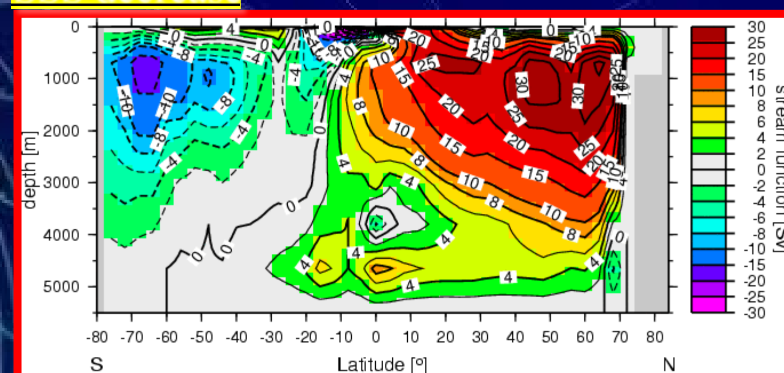
Intermediate Cretaceous –1 psu

SSS decrease



Warm Cretaceous –1 psu

SSS decrease



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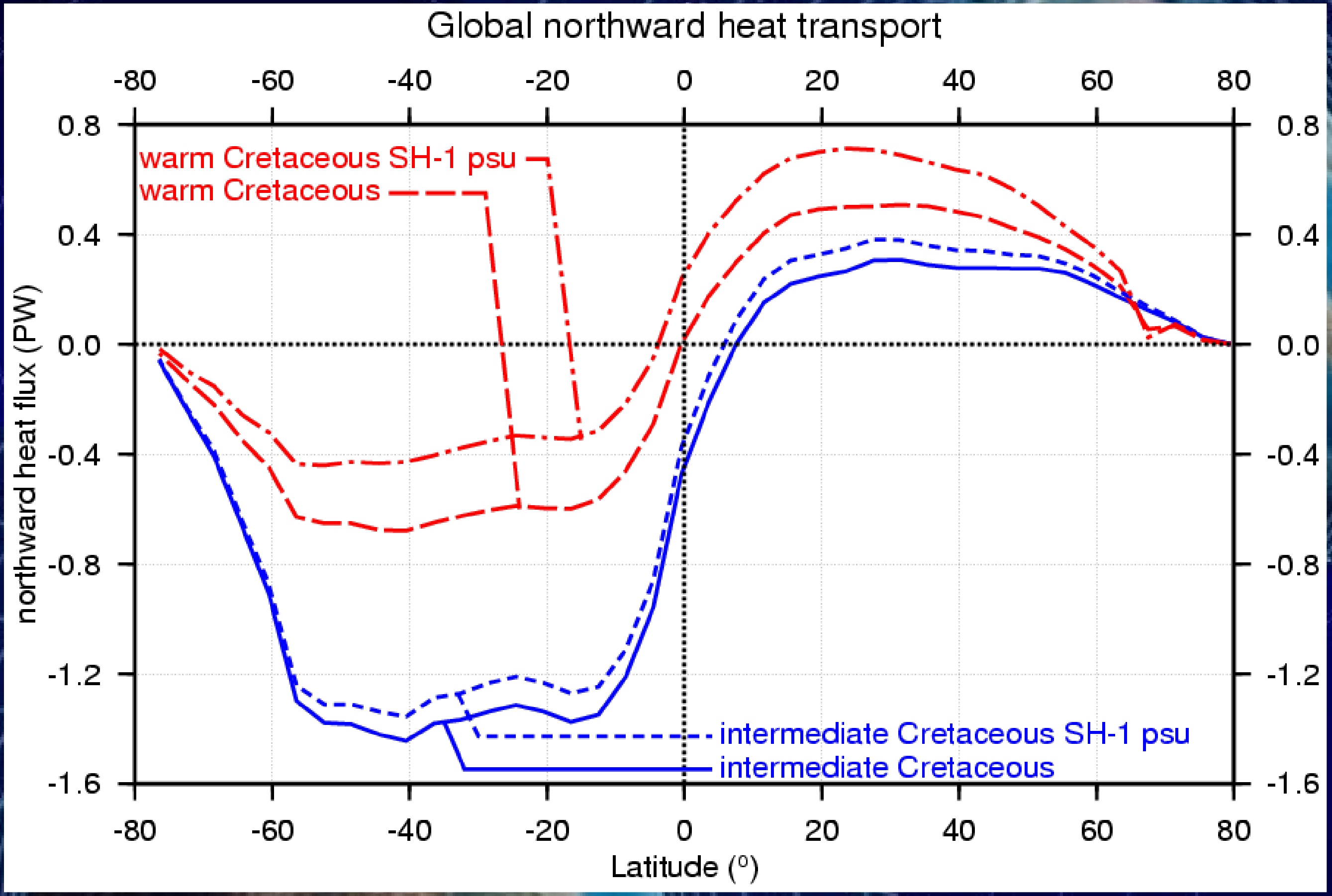

(1 PW = 10^{15}W)

Conclusions

Our experiments show that:

- Within a reasonable range of sea surface salinity the deep ocean circulation pattern in the intermediate Cretaceous scenario is very robust and cannot be changed easily.
- The circulation in the warm scenario is extremely sensitive to small surface freshwater impacts; we consider this scenario less realistic because of this super-sensitivity in ocean overturning.
- The Cretaceous ocean operated similarly to the present-day Atlantic Ocean branch of the conveyor, showing the same sensitivity to high-latitudinal freshwater impacts. Thus, a warm deep ocean can coexist with a relatively cool subpolar ocean, at least in one hemisphere.

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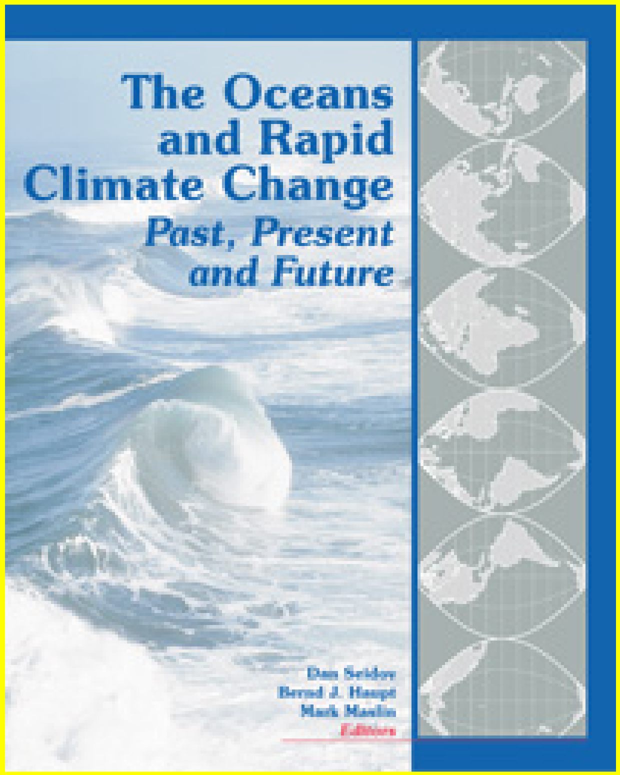

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