

Evolution of ocean circulation and climate during the Miocene: Results from GCM simulations

M. Butzin, G. Lohmann, T. Bickert and K. Grosfeld
 University of Bremen, Department of Geosciences
 P.O. Box 330 440, D-28334 Bremen, Germany (contact: mbutzin@marum.de)

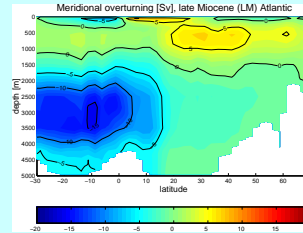
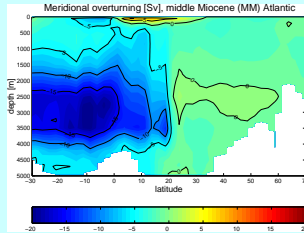
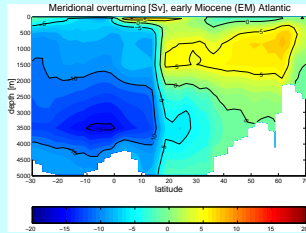
We investigate the ocean circulation and its impact on climate during the transition from the early to the late Miocene (~ 24 - 5 Ma BP) with a series of simulations using three-dimensional general circulation models of the ocean and the atmosphere.

Model scenarios:

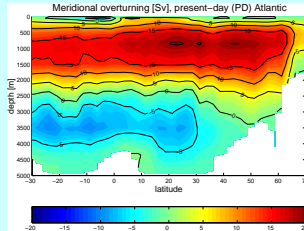
- EM: Early Miocene (24 - 15 Ma BP), open Panamanian gateway (depth = 3000 m) and wide Tethys (depth = 1000 m), closed Bering Strait, no sea ice
- MM: Middle Miocene (15 - 11 Ma BP), open Panamanian and narrow Tethys gateways (depth = 1000 m each), closed Bering Strait, no arctic sea ice
- LM: Late Miocene (11 - 5 Ma BP), open Panamanian gateway (depth = 500 m), open Bering Strait, arctic sea ice
- PD: Present-day control run

The ocean model is based on the Large Scale Geostrophic model LSG and includes a simple thermodynamic sea ice model, a new advection scheme for temperature, salinity, $\Delta^{18}\text{O}$, numerical 'age' and 'dye' tracers, as well as a parameterization of overflow. The horizontal resolution is 3.5° with 11 levels in the vertical. The ocean model is forced with monthly fields of wind stress, surface air temperature and freshwater flux taken from simulations with the atmospheric general circulation model ECHAM3/T42.

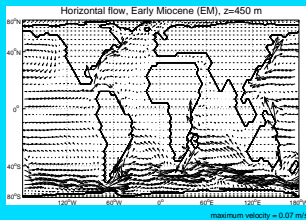
In the first step of modeling, we employ a hybrid coupled modeling approach, which allows an adjustment of sea surface temperatures and salinity to changes in the ocean circulation, based on an atmospheric energy balance model.



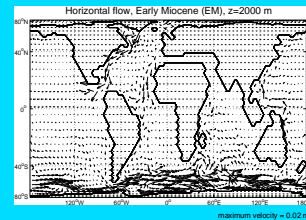
Compared with the control run (PD) the Miocene experiments reveal significant changes in the ocean circulation pattern. Deep water formation in the North Atlantic is strongly reduced (EM, LM) or even absent (MM) when the Isthmus of Panama is open. In the South Atlantic we find a strong northward flow (in the order of $15 \cdot 10^6 \text{ m}^3/\text{s} = 15 \text{ Sv}$) of bottom water from the Antarctic (AABW). The strength of the AABW overturning cell increases with the depth of the Panamanian gateway.



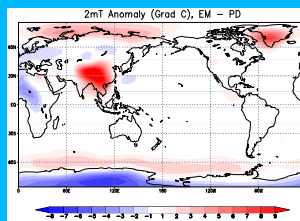
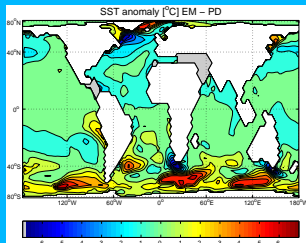
Deep and bottom water formation also depend on the distribution of sea ice. If only antarctic sea ice is present (model experiment MM), we find maximum strength of AABW flow and virtually no production of NADW. The latter is due to sea surface warming in the Arctic Sea together with impeded brine release. If sea ice is allowed to exist at both hemispheres (scenario LM), we find some potential for NADW formation in connection with a shallow Panamanian gateway. If sea ice is globally removed (experiment EM), the global ocean becomes warmer and a shallow and weak overturning circulation in the North Atlantic establishes. This circulation regime exists even in presence of a deep Central American gateway.



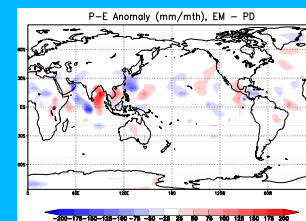
The horizontal flow patterns show export of surface and deep water from the Atlantic to the Pacific Ocean but import of thermocline and intermediate layer water from the Pacific to the Atlantic Ocean. The latter is responsible for a reversal of the Northeast Brazil Current. The net flux of Pacific water through the Panamanian gateway into the Atlantic amounts to 1-3 Sv and increases with the gateway depth. A weak upper level Gulf Stream circulation and the relatively low-salinity thermocline water suppress deep water formation in the North Atlantic.



In a second step, sea surface temperature (SST) anomalies are taken as an input for the atmospheric circulation model PUMA, which belongs to models of intermediate complexity (resolution: horizontal T21-spacing of approximately 5.6° and five unevenly spaced, terrain following levels in the vertical). Motivated by geological evidences, the orography of Greenland and of the Himalaya are lowered to 10% and to 50% of their present-day values, respectively.



For the early Miocene, our experiments yield warming of surface air above the Himalaya, Asia, Greenland, in the high latitudes of Russia, and over the subantarctic Southern Ocean. Colder surface air temperatures are found over Antarctica and parts of Africa.



Precipitation anomalies display increased rainfall for South and Southeast Asia (which may be the result of an intensified Monsoon circulation) but drier conditions for the Northwest Indian Ocean, Greenland and parts of Africa.

Conclusions:

- If the Central American Gateway is open, NADW flows into the Pacific. The export is compensated by an influx of low-salinity Pacific Intermediate water entering the Caribbean with a maximum strength of about 3 Sv at a depth of about 500 m.
- In a model scenario of the early Miocene assuming additionally no sea-ice coverage in the southern hemisphere, we find intensified subantarctic deep water production but only modest formation of NADW. This is consistent with very low $\delta^{13}\text{C}$ gradients between the North Atlantic and Southern Ocean.
- Model experiments related to the middle Miocene build-up of a permanent Antarctic ice sheet yield maximum production of Sub-Antarctic deep water while NADW formation is suppressed. This scenario is corroborated by the convergence of Atlantic and Pacific benthic $\delta^{13}\text{C}$ values between 15 and 11 Ma.
- Our model experiments predict the re-establishment of the formation of NADW in the late Miocene and the evolution of the modern ocean conveyor assuming further shoaling of the Central American Gateway and evolution of sea-ice in the Arctic Ocean.
- First atmospheric experiments suggest warming of surface air above the Himalaya and in the high latitudes of the Northern Hemisphere, but colder conditions in parts of Africa. Maximum (positive and negative) precipitation anomalies are found above the tropical Indian Ocean and in the southern regions of the Asian continent.