Project: **895**

Project title: **GFZ - RECOM**

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The project RECOM (Reconstruction of atmosphere-ocean circulation patterns for geological time slices by self-consistent coupled model simulations) is part of the DFG priority program SPP1375 SAMPLE (South Atlantic Margin Processes and Links with onshore Evolution) , which studies the mantle processes, lithospheric structures, sedimentary processes, topographic evolution and climatic consequences that formed the South Atlantic since its breakup in the Cretaceous. Within RECOM we investigated the links between plate tectonics and the evolution of climate. For this purpose, the three-dimensional atmospheric and oceanic circulation patterns were reconstructed with a self-consistent global coupled atmosphere-ocean model for time-slices relevant for the development of the South Atlantic, namely the Albian (ca. 110 million years ago, Ma), the Cenomanian-Turonian Boundary (ca. 93 Ma, CTB), the early Eocene (ca. 55 Ma), the Pliocene (ca. 5 Ma) and a pre-industrial control simulation (1850 AD).

The first goal of RECOM was to establish the three-dimensional ocean velocities since the opening of the South Atlantic and to compare these currents to reconstructed sedimentation rates and sediment thicknesses (cf., Uenzelmann-Neben et al. (2016)). In the shallow, narrow and enclosed South Atlantic of the Albian mainly wind-driven circulation was present. The opening of the South Atlantic to the North Atlantic in the Cenomanian started the influence of North Atlantic Intermediate Water and initiated strong intermediate currents. During the Palaeocene the Drake Passage closed, thus inhibiting a proto-Antarctic Circumpolar Current. This continued to affect the ocean circulation in the early Eocene. At this time, the thermohaline circulation was driven by intermediate water formation in the Weddell Sea and the Greenland Sea; deep water was not being formed and the deep ocean thus not ventilated. This changed until the beginning of the Pliocene, when deep water formation in the Greenland, Labrador and Weddell Seas led to a deep convection and ventilated the deep ocean. However, the Atlantic Meridional Overturning Circulation (AMOC) was weaker in the Pliocene than at present-day due to the open Central American Seaway. Only after the closing of the Central American Seaway in the early Pliocene, the AMOC strengthened and the Gulf Stream became as influential on European climate as it is today.

The second goal of RECOM was to identify the effects of changes in plate configurations and paleo-topographies on climate relevant feedback mechanisms on atmosphere-ocean dynamics. As case studies, the opening of the South American-African landbridge in the Cenomanian and the closing of the Central American Seaway in the Miocene/ Pliocene were simulated. The opening of the South Atlantic to the north increased deep water formation in the Southern Ocean and decreased deep water formation in the proto-Greenland Sea. Thereby the AMOC is increased in the southern hemisphere and decreased in the northern hemisphere (Figure 1). The opening increases surface temperatures by up to 2°C in the South Atlantic. At the Miocene/Pliocene boundary the closing of the CAS stopped the exchange of waters between the Pacific and the South Atlantic. A strengthening of the AMOC was the consequence. Thereby surface temperatures were increased by up to 5°C in the North Atlantic and Europe.

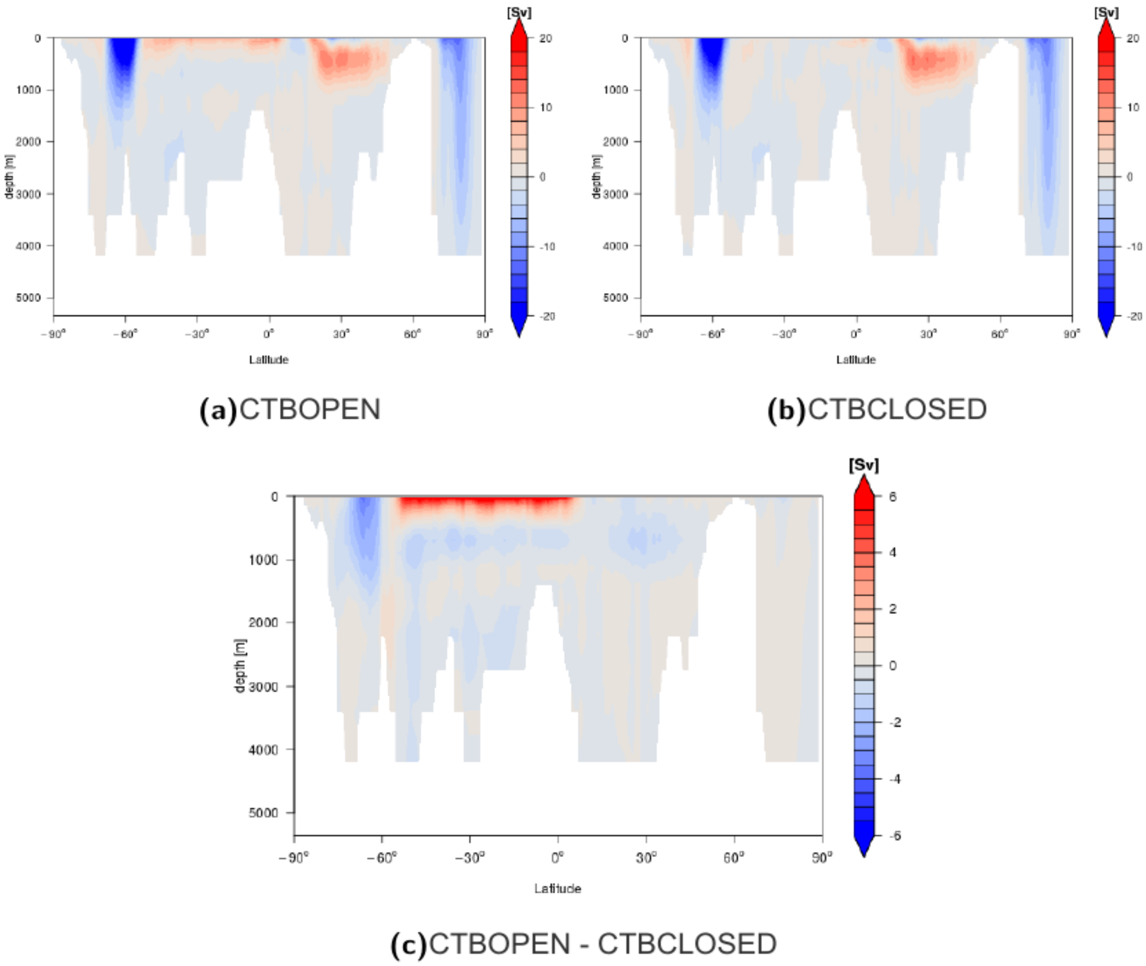

Figure 1*:* Multi-decadal mean Atlantic meridional overturning circulation for CTBOPEN (top left), CTBCLOSED (top right) and CTBOPEN - CTBCLOSED (bottom). Clockwise circulation is depicted red and positive, counter-clockwise circulation blue and negative. [From Köhler (2016)]

The third goal of RECOM was to investigate the effect of tidal forcing on the general ocean circulation for these five time-slices. For this purpose, the tidal module by Thomas et al. (2001) was included into MPIOM and the effect of tidal dynamics on ocean and atmosphere circulation was studied for the early Albian, the CTB, the early Eocene, the Pliocene and the pre-industrial period (cf., Weber (2016)). In the early Albian, tidal forcing causes a reduction of the Global Meridional Overturning Circulation. For the CTB, local temperature changes range from -3.4°C in the Southern Ocean to 4.6°C off the north coast of proto-South America and Australia. Reasons for these modifications are shifted pathways of ocean currents or changed current strengths and the ensuing alteration of temperature advection (Köhler (2016)). In the early Eocene, horizontal velocities in the deep ocean are severely enhanced and are increased to 400% the original values in 25% of the deep ocean. This leads to the onset of an overturning circulation in the deep ocean and doubles the strength of the GMOC. In the Pliocene and the pre-industrial period, the influence of tidal forcing on ocean currents is small compared to the early Albian and the early Eocene. However, sea ice concentration is decreased by up to 25% in the Weddell Sea. Thereby the heat flux from the ocean to the atmosphere is increased, which causes a raise of the atmospheric 2m-temperature by up to 4°C (Figure 2).

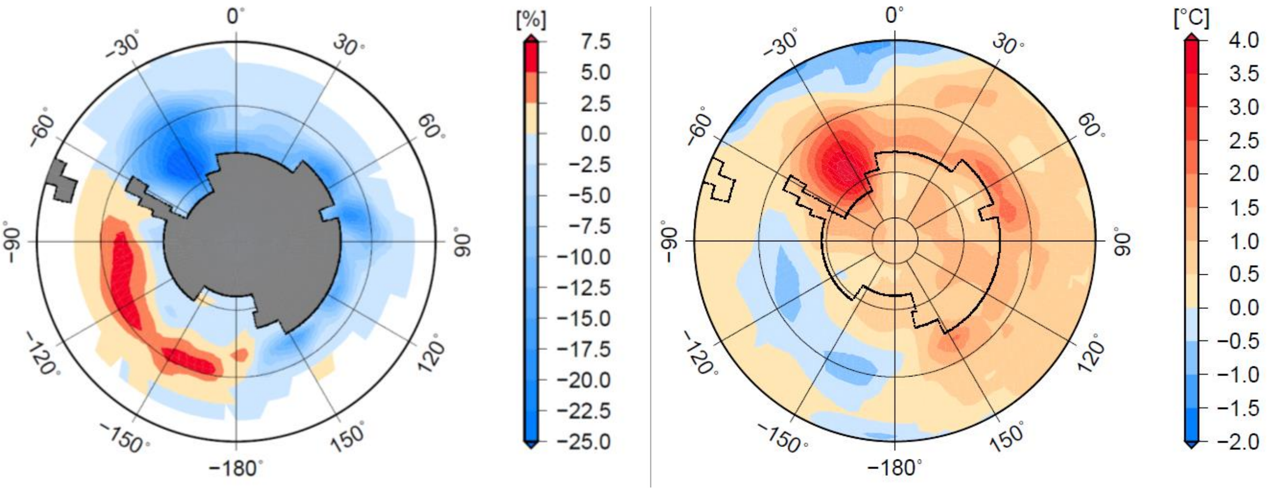

Figure 2: Difference PITIDE-PICTRL of multi-decadal mean sea ice concentration (left) and atmospheric 2m-temperature (right). Positive values indicate an increase in sea ice concentration or 2m-temperature, respectively, when tidal forcing is included into the ocean model. Marked latitudes are 45°, 60°, 75° and 85°.

The fourth goal of RECOM was to determine the influence of orbital re-configuration of celestial bodies over paleo-time slices on tidal dynamics and henceforth on ocean circulation and climate. As a case study, the ocean of the CTB was simulated with tidal forcing generated by different reconstructions of celestial constellations (Figure 3). The distance between Earth and Moon, eccentricity and obliquity are the dominant sources of uncertainty in reconstructing past tidal systems. While uncertainties in the reconstruction of the first two have negligible effects (less than 0.1% uncertainty in the global mean squared amplitude of M2), the latter is responsible for an uncertainty of up to 2.3% (Köhler (2016)). On paleo-time scales, the distance Earth-Moon varies steadily over time and has therefore an impact on tidal amplitudes. The global mean squared amplitudes of M2 are thereby increased by 6.0% in the Albian and 4.2% in the early Eocene (Weber (2016)). At the CTB the global mean squared amplitudes were increased by the combination of eccentricity, obliquity and distance Earth-Moon by up to 4.8% (Köhler (2016)).

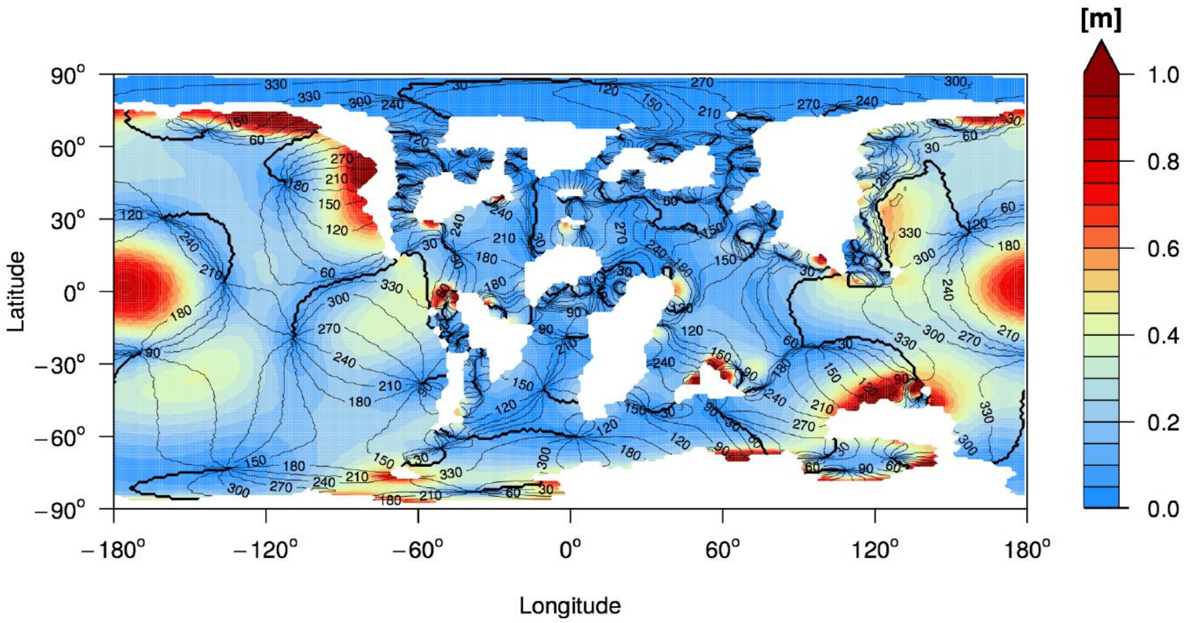

***Figure 3*:** Amplitude (colored contours) and phase (numbered cotidal lines in °) of the partial tide M2 of CTBTIDE. The 0° cotidal line is printed bold. Phase is relative to the Greenwich Moon transfer. Amplitudes higher than 1 m are marked as dark red. [From Köhler (2016)]

Within the project RECOM so far one PhD thesis (T. Weber), one Master thesis (R. Köhler) and a study about the oceanic circulation in the South Atlantic from the Cretaceous (110 Ma) to present day (Uenzelmann-Neben et al. (2016)) were published:

Köhler, R. 2016. Climate system of the Cenomanian-Turonian boundary and how it is influences by ocean tides. Master thesis, Department of Earth Sciences, Freie Universität Berlin, (2016).

Uenzelmann-Neben, G., Weber, T., Gruetzner, J. & Thomas, M., in press. Transition from the Cretaceous ocean to Cenozoic circulation in the western South Atlantic — A twofold reconstruction. Tectonophysics. doi:10.1016/j.tecto.2016.05.036

Weber, T., 2016. Impact of ocean tides on the climate system during the pre-industrial period, the early Eocene, and the Albian. PhD thesis, Department of Earth Sciences, Freie Universität Berlin, (2016).