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Mid-Cretaceous Ocean Circulation in the Kiel Climate Model

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The Mid-Cretaceous ($\sim$ 100 Ma) was one of the warmest climate episodes during the Phanerozoic. During the Mid-Cretaceous, Earth received about 1% less solar radiation compared to the present and the atmospheric carbon dioxide concentration was in the range of 800-2000 ppm. Proxy data suggest global mean temperatures of more than 20°C, a reduced meridional surface temperature gradient, and an enhanced hydrological cycle. The Atlantic Ocean was still to evolve and instead the giant Proto-Pacific and the Tethys Seaway in the low latitudes allowed a circum-tropical oceanic flow. Although continental configuration and radiative forcing were different from the modern, the mid-Cretaceous climate has been widely used as an example for a potential future high-pCO_2 world. Furthermore, proxy information about Oceanic Anoxic Events (OAE) raised the question of how the ocean circulation and the enhanced runoff from land might have supported the formation of OAEs.

We present a Mid-Cretaceous simulation with the Kiel Climate Model (KCM), a fully coupled atmosphere-ocean general circulation model (CGCM) with a horizontal resolution of 2.8° in the atmosphere (ECHAM5) and 2° in the ocean (NEMO, with enhanced resolution in the tropics). Here, we describe the horizontal surface flow and meridional overturning circulation. Regions of formation of intermediate and/or deep waters were identified. Finally, regions characterized by strong stratification were analyzed and suggestions are made about where anoxic conditions might have evolved.

Both hemispheres showed clear sub-polar gyres in the Pacific basin during the Mid-Cretaceous. The Antarctic circum-polar circulation was prohibited by the rather narrow passage south of South America and Africa. Intermediate transports in and out of the Arctic basin and strong freshwater runoff from the northern continents generated an isolated and strongly stratified ocean there. In low latitudes, a circum-tropical westward flow is simulated in the Pacific and the Tethys, yielding a strong longitudinal water mass exchange. The meridional overturning circulation was very weak. No significant deep water formation could be found. However, strong tropical and subtropical cells are simulated and two types of intermediate water masses were formed: in subtropical regions with high evaporation, warm and saline water was subducted to depths of 1000 m, and in the high latitudes of the Pacific basin, cold and rather fresh intermediate water was formed which penetrated towards the equator at levels between 500 and 1000 m depth. The Arctic basin did not allow convection and served as a environment for anoxic conditions. Our results support the theory of a rather weak thermohaline circulation during strong greenhouse climates such as the Mid-Cretaceous and confirm an ocean potentially allowing for vast anoxic regimes.