Early Cretaceous South Atlantic opening - modelling the effects of geography, bathymetry and radiative forcing

S. STEINIG[1], W. DUMMANN[2], S. FLÖGEL[1], W. PARK[1], T. WAGNER[3], J.O. HERRLE[4,5], P. HOFMANN[2]

[1]GEOMAR Helmholtz Centre for Ocean Research Kiel, Wischhofstr. 1-3, D-24148 Kiel, Germany
[2]Institute of Geology and Mineralogy, University of Cologne, Zülpicher Str. 49a, D-50674 Cologne, Germany
[3]Sir Charles Lyell Centre, School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University, Edinburgh, EH14 4AS, UK
[4]Institute of Geosciences, Goethe-University Frankfurt, Altenhöferallee 1, D-60438 Frankfurt am Main, Germany
[5]Biodiversity and Climate Research Centre (BIK-F), Senckenberganlage 25, D-60325 Frankfurt am Main, Germany

Paleoceanographic data indicate large-scale perturbations of the Early Cretaceous (i.e. Aptian-Albian) global climate system associated with severe changes of the marine carbon cycle (Jenkyns, 2010). At the same time, the ongoing break-up of Gondwana and the related opening of the South Atlantic and Southern Ocean led to the emergence of young ocean basins, characterised by vast shelf areas and limited circulation (Pérez-Díaz and Eagles, 2017). Several studies relate these evolving basins and their restricted environments to periods of increased black shale formation and carbon burial (Trabucho-Alexandre et al., 2012) with a particular importance of the developing South Atlantic (McAnena et al., 2013).

Within this project, we target the question whether increased carbon burial in the early Cretaceous South Atlantic influenced or even triggered global climate perturbations. We further test the hypothesis that the development and destruction of regional marine carbon sinks in the South Atlantic are primarily controlled by the progressive opening of several key oceanic gateways. For this purpose we tightly combine a new stratigraphical framework for several sites across the South Atlantic and the Southern Ocean (see abstract of Dummann et al.) with a joint physical and biogeochemical modelling approach. The model simulations are designed to test hypotheses generated from sea water-derived neodymium (Nd) isotope signatures and to assess possible influences of regional circulation changes on the marine carbon cycle.

In a first step we employ a global atmosphere-ocean general circulation model, the Kiel Climate Model (KCM), under Early Aptian (120 Ma) boundary conditions and evaluate the simulated large-scale dynamics and mean climatic conditions of the reference simulation. Land topography and ocean bathymetry are based on reconstructions from Müller et al. (2008) and Blakey (2008). Surface freshwater routing strictly follows the model topography (Hagemann and Dümenil, 1998). We apply a zonal mean, climatic zone dependent surface vegetation with no continental ice and glaciers (Ando et al., 2009). The solar constant is reduced by 1% and three different atmospheric pCO_2 concentrations of 300, 600 and 1200ppm are used to reflect the large range of available reconstructions (Jing and Bainian, 2017). Additional experiments with different ocean bathymetries representing key stages of the South Atlantic opening are used to assess the sensitivity of the regional oceanic circulation to changes in geography and bathymetry. Varying levels of atmospheric pCO_2 are applied to distinguish between signals caused by local tectonic or global radiative processes.

Simulated sea surface temperatures at pCO_2 leveles of 1200ppm show highest agreement with available proxy data. Corresponding steady state global mean surface air temperatures in the control simulation are elevated by nearly 10°C compared to pre-industrial and reach 23.5°C. The surface warming is mainly radiatively driven by the higher atmospheric pCO_2 levels (~70% of the warming) and a surface albedo reduction (~30% of the warming). High-latitude surface albedo changes reduce the global meridional surface temperature gradient (MTG) by 15°C. Cloud feedbacks partly compensate the polar amplification and strengthen the MTG by up to 4°C compared to a pre-industrial reference simulation.

High atmospheric pCO2 levels lead to an enhanced hydrological cycle with amplified evaporation over the coastal shelf areas and a subsequent halokinetic circulation with warm and saline intermediate and bottom waters in the South Atlantic. We find a high sensitivity of the South Atlantic and Southern Ocean circulation and water mass stratification to the local basin geometry and gateway depths. A sufficient northward extension of the young South Atlantic strengthens the evaporatively driven intermediate water production and therefore also the basin wide meridional overturning circulation. Higher rates of rainfall and river runoff in the northern Angola Basin potentially suppress the local formation of intermediate water at lower pCO2 levels and reverse the sign of the meridional circulation. The opening of the Georgia Basin gateway leads to a net export of the dense, saline bottom waters produced in the South Atlantic into the Southern Ocean. These scenarios can be matched to distinctively different paleoenvironments found in the proxy data. Ongoing geochemical modelling aims to transfer these circulation changes into responses of key biogeochemical cycles and carbon burial variations.

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