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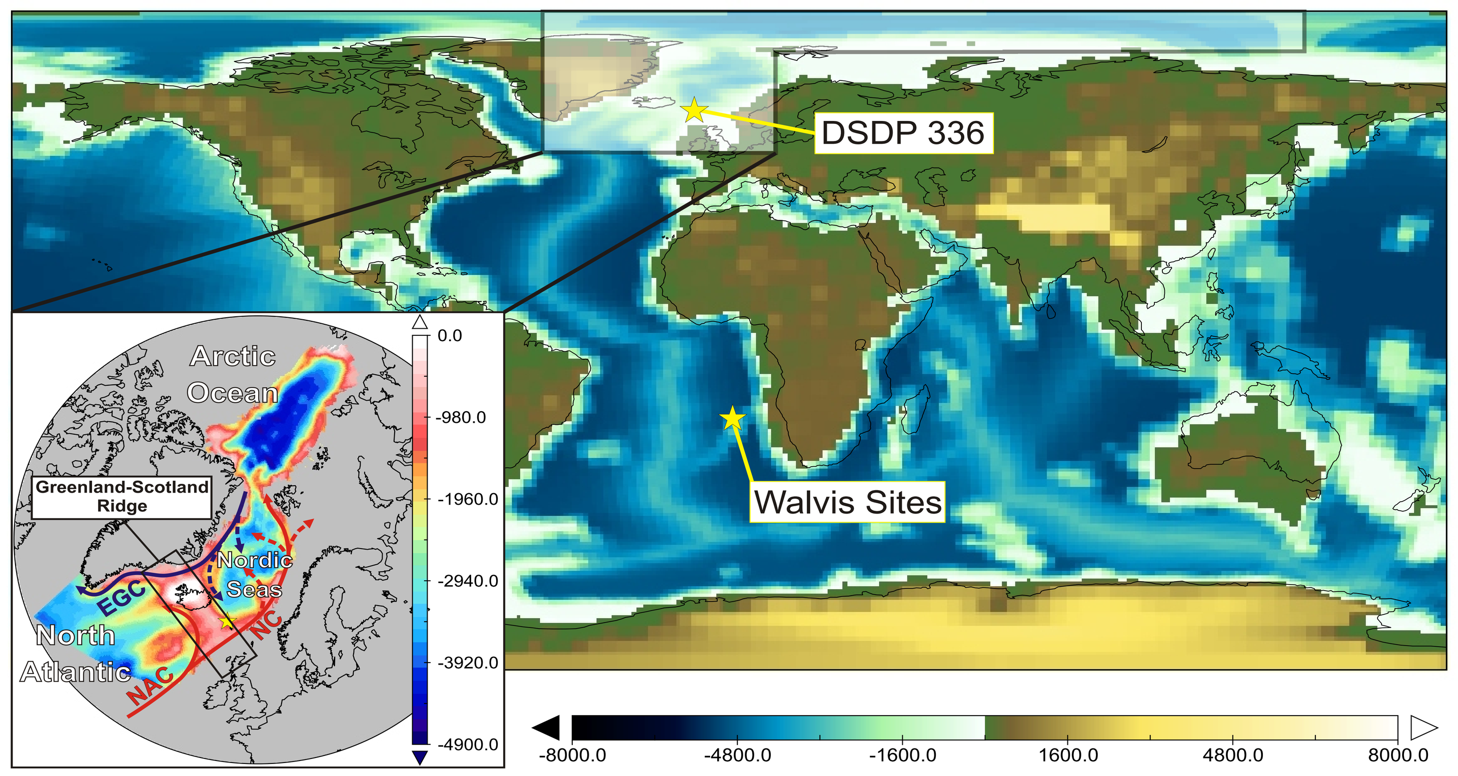
North Atlantic-Arctic circulation controlled by the subsidence history of the Greenland-Scotland Ridge

Background information

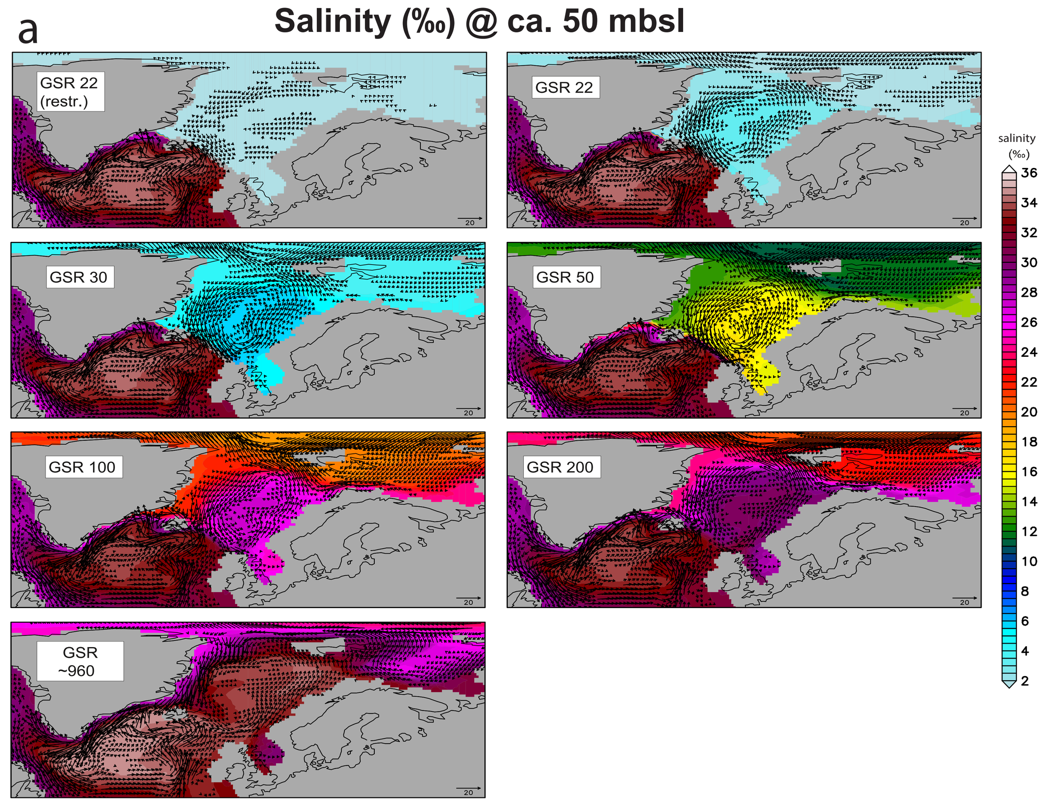
During the Eocene/Oligocene interval (42–24 Ma), the subsidence of the Greenland-Scotland Ridge (GSR) from subaerial conditions towards a submarine rise constitutes an active ocean gateway control of North Atlantic-Arctic water exchange. Although the long-term evolution of such ocean gateway development on adjacent ocean water mass characteristics is generally accepted to induce basin-scale reorganizations, the climatic impacts, as well as the associated mechanisms of climate changes remain largely elusive. Here, we investigate the effect of the GSR subsidence with the aid of a fully coupled Earth System Model (ESM) COSMOS (Jungclaus et al., 2006):



Geographical settings of Miocene topography (20–15 Myrs). Global compilation of Miocene geography (elevation and depth in metres; modified data from Herold et al., 2008) embedding a high resolution (0.5°) bathymetric dataset comprising the northern North Atlantic, Nordic Seas and the Eurasian Basin in the Arctic Ocean (Ehlers and Jokat, 2013). The schematic circulation shows pathways of the North Atlantic Current (NAC), the Norwegian Current (NC) and the East Greenland Current (EGC). The yellow star reflects the location of DSDP site 336 (Clift et al., 1996; Talwani et al., 1976) at the northern flank of the GSR.

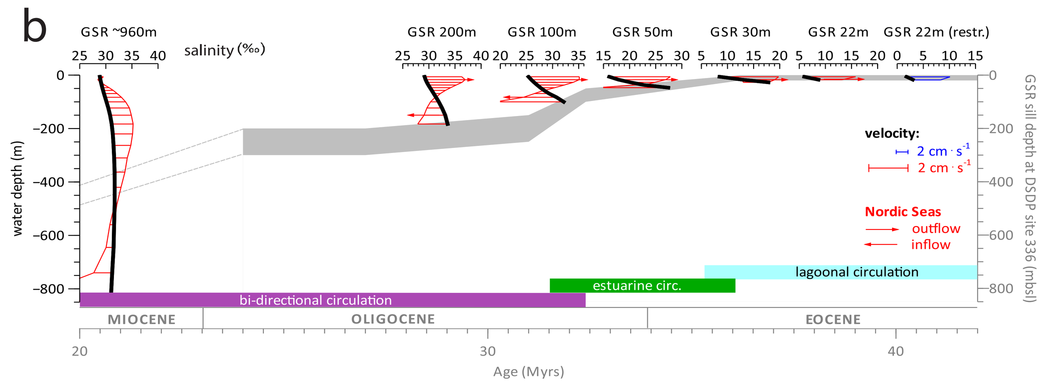
Results

Sill depth controls on the Arctic salinity regime



Seaway opening evolution in context of the Greenland-Scotland Ridge (GSR) subsidence history. A threshold regime, characterized by semi-enclosed estuarine circulation is identified at ca. 30-80 m of GSR sill depth.

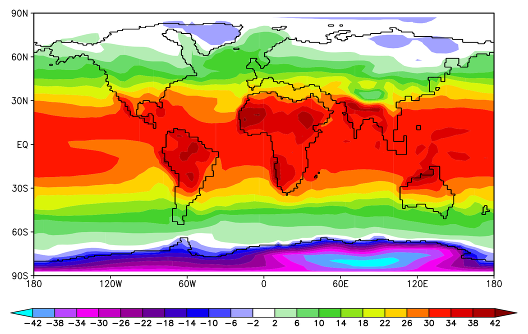
a Subsurface **salinity** (‰) and **ocean velocity** maps (cm•s-1; velocities <0.5 cm•s-1 are not shown) maps for the Eocene/Oligocene scenarios at different sill depths of the GSR.



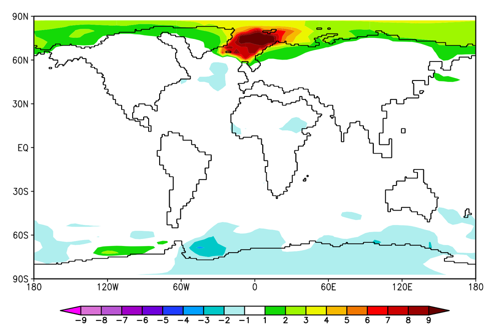
b Modelled **salinity (black)** and **velocity (blue/red) profiles** across the GSR section for the Eocene/Oligocene GSR sill depths are displayed in context of the subsidence evolution as derived from DSDP site 336 (Clift et al., 1995). Between 30-80 m of sill depth a semi-enclosed estuarine circulation establishes across the seaway.

Effect of Arctic seaway opening on the climate

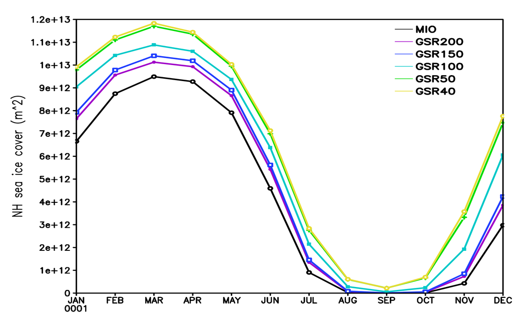
Impact of the Greenland-Scotland Ridge seaway opening on the surface air temperatures (°C, middle panel) and the seasonal cycle of the sea ice in the Northern hemisphere with respect to the mean climate state (left panel). The GSR seaway opening induces a pronounced warming in the high northern latitudes as well as the removal of perennial sea ice in the Arctic Ocean (right panel).



Mean climate state of absolute surface air temperatures (°C)

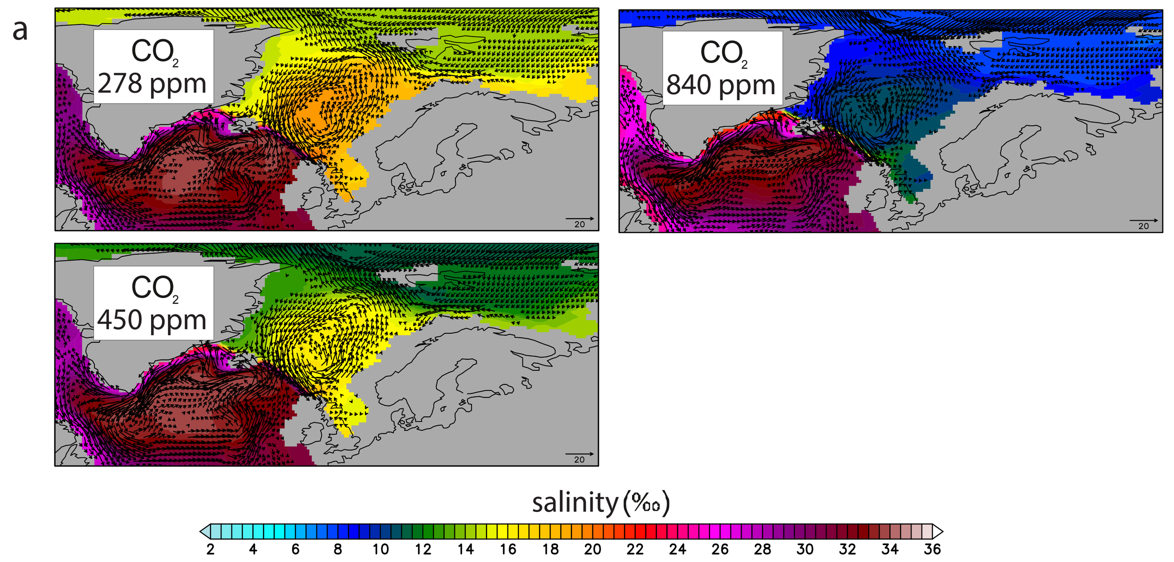


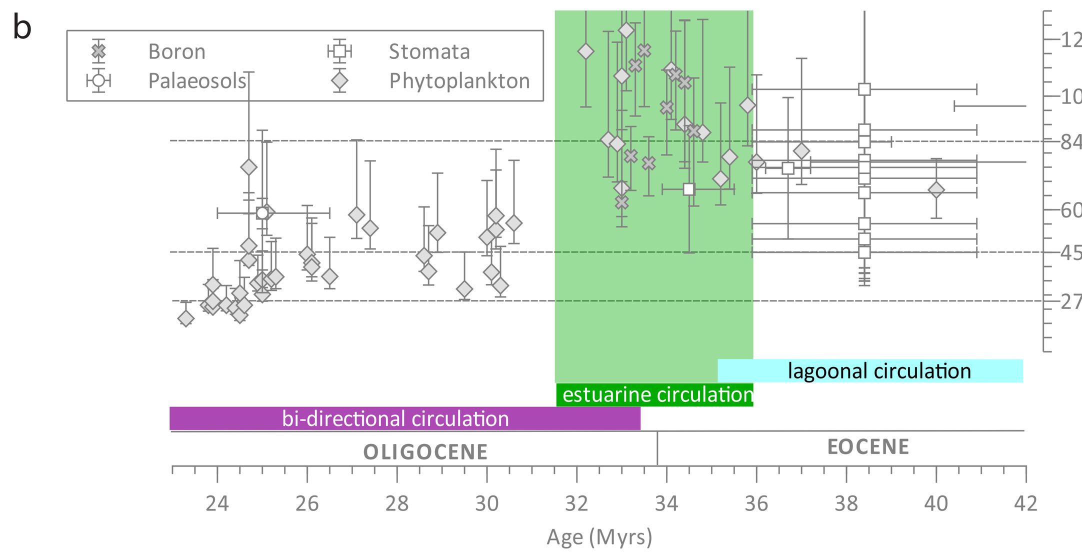
Surface air temperature anomaly (°C) induced by the seaway opening.



Effect of GSR sill depth changes on the seasonal cycle of the Arctic sea ice extent (m^2).

CO_2 controls on the Arctic salinity regime





North Atlantic-Arctic circulation and salinity regime modulated by CO_2 levels at sensitive GSR sill depths for ~36–31.5 Myrs.

a Modelled salinity (‰) and ocean velocity maps (cm•s-1; velocities <0.5 cm•s-1 are not shown) in the subsurface for E/O scenarios at sensitive GSR sill depths and different CO_2 levels in the atmosphere.

b Evolution of seaway circulation regimes across the GSR set into context of reconstructed CO_2 proxy history (Pagani et al., 2005; 2011).

Conclusions

We find a critical GSR sill depth regime between ca. 30-80 mbsl that forces major reorganizations in the North Atlantic-Arctic circulation associated with extreme salinity, temperature and sea ice changes in the Arctic Ocean. At critical GSR sill depths, atmospheric CO_2 changes also affect the brackish Arctic salinity and circulation regime. Taking uncertainties in timing into account this suggests that after tectonic preconditioning between ca. 36-31.5 Myrs ago, contemporary CO_2 changes modulated the climate and circulation regime in the Arctic Ocean on much shorter millenial timescales towards the establishment of a fully ventilated bidirectional seaway circulation ca. 31.5 Myrs ago.

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