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Was the Arctic Ocean ice free during the Late Cretaceous? Sensitivity tests with different CO_2 levels and gateway configurations

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Towards the end of the Cretaceous the atmospheric CO_2 concentration declined, potentially enabling the formation of sea ice in the Arctic Ocean. This controversial scenario is still under discussion. Here, we investigate the effect of different atmospheric CO_2 levels and alterations in the gateway configurations between the North proto-Atlantic basin and the Arctic Ocean on the Late Cretaceous Arctic sea ice. In the experiments with 3xPI CO_2 level (PI = 280 ppm) central Arctic sea ice is observed in each gateway configuration from December to June, while for 4xPI CO_2 level only in one configuration from March to May. Therefore, the threshold for the formation of central Arctic sea ice is between these two CO_2 levels independent of gateway configuration.

For a 4xPI CO_2 level and closure of the Russian Platform Basin and Turgai Strait, we find freshwater conditions in the surface Arctic Ocean of $\sim$2 psu which facilitates sea ice formation. Additionally, a closure of the North American gateways creates a relatively large and continuous land area. During boreal polar-night northward winds provide cold air from North America to the ocean, triggering the formation of near coastal sea ice in November-December. Subsequently, the sea ice drifts northward and central Arctic sea ice is observed for March-May. A closure of the Asian gateways alone supports the establishment of freshwater conditions in the Arctic Ocean. However, coastal sea ice near America cannot form due to insufficient cooling in this region because relatively warm air is advected from the south. Therefore, near coastal sea ice is observed only in the Asian sector for March-May. A closure of the American gateways alone results in cooling of American near coastal regions, but sea ice built-up is inhibited by higher surface salinity ($\sim$8 psu). Therefore, the presence of sea ice near American and Asian coasts is limited to March-May.

In contrast to present day, seasonal sea ice melt in the experiments with 3xPI CO_2 under Cretaceous boundary conditions starts around the North Pole and sea ice retreats in southward direction. This is a consequence of the inflow of relatively warm air during the northern hemisphere polar day from the Late Cretaceous land masses close to the North Pole. Vice versa, seasonal sea ice advance is observed in northward direction from coastal North America towards the North Pole. Summarizing, our results indicate that changes in atmospheric CO_2 have a dominant effect on a sea ice formation compared to gateway alterations.