Impact of marine gateways on the Northern Hemisphere polar climate in the Late Cretaceous as simulated by an Earth System Model

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Maastrichtian, Late Cretaceous (70 Ma) set-up

Introduction

- **We simulate Maastrichtian (70 Ma) climate using state-of-the-art coupled atmosphere-ocean general circulation model (AOGCM) COSMOS.**
- **The paleogeogaphy is adjusted following Markwick and Valdes, (2004) to the AOGCM model (Figs 2 and 3a).**
- **Vegetation is prescribed (Fig. 3b) following Sewall et al. (2007).**
- **CO_2 level is set to the 1120 ppm level (4xpre-industrial) and additionally to 280 ppm (1xpre-industrial) for the sensitivity tests. CH_4 and N_2O levels are set to pre-industrial levels.**
- **Orbital parameters are set to present day and solar constant is reduced by 1% and is equal 1353.33 W/m^2.**

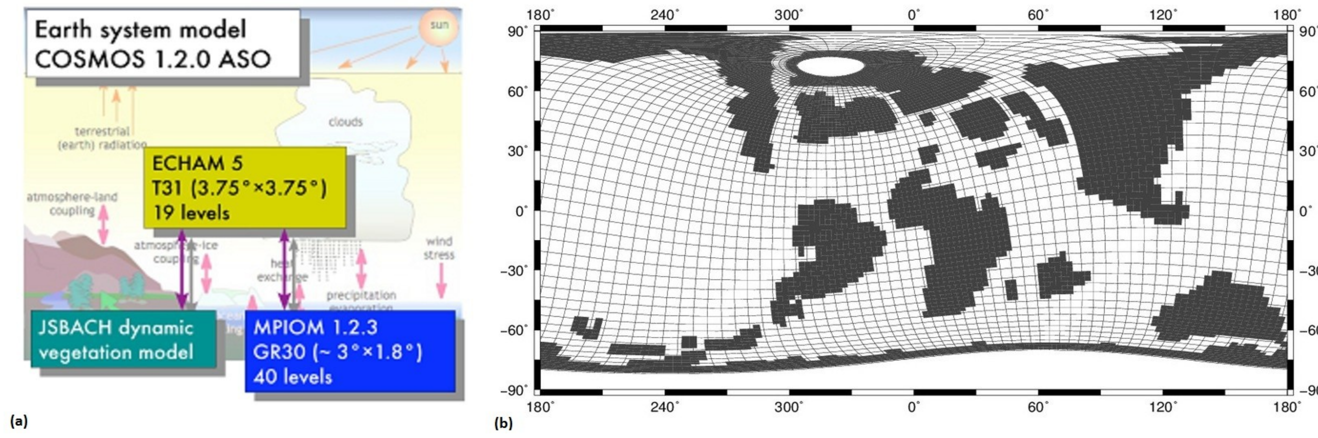

Fig. 1. (a) Schematic illustration of the comprehensive coupled model COSMOS (Community Earth System Model), including the atmosphere (ECHAM5), the ocean model (MPIOM) and the land surface scheme (JSBACH);
(b) Maastrichtian, Late Cretaceous (70 Ma) land sea mask (configuration on the oceanic curvilinear grid).

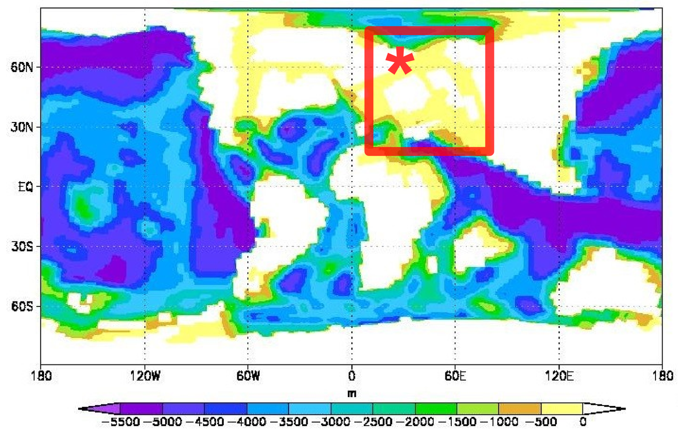

Fig. 2. Maastrichtian, Late Cretaceous (70 Ma) paleobathymetry [Markwick and Valdes, 2004] adjusted to COSMOS model. In frame - the area zoomed in (on Figs 7 and 13).

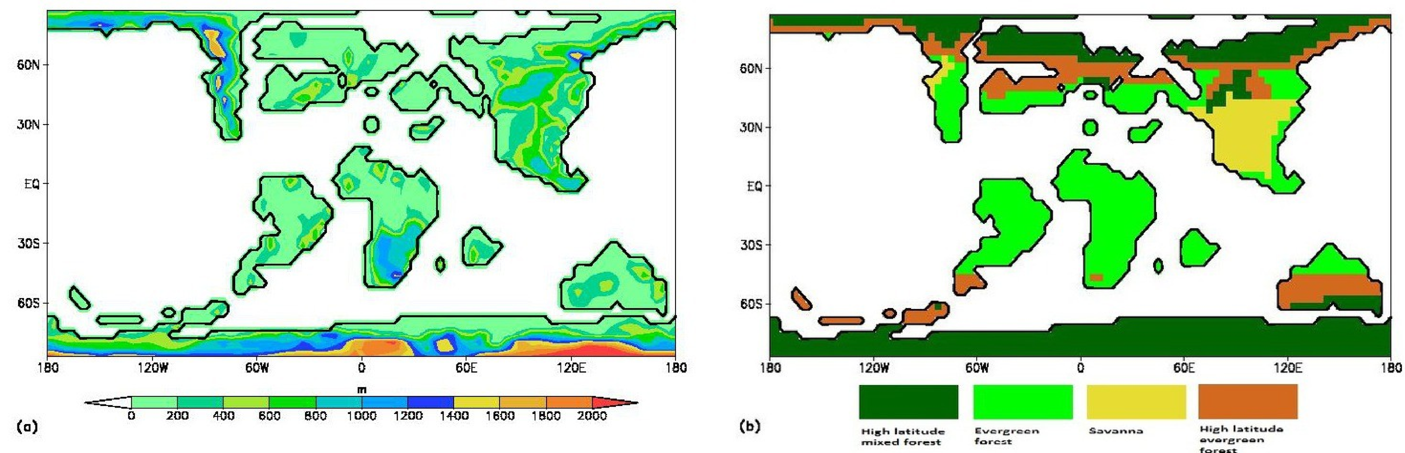

Fig. 3. (a) Maastrichtian, Late Cretaceous (70 Ma) paleogeography [Markwick and Valdes, 2004] adjusted to COSMOS model;
(b) Maastrichtian, Late Cretaceous (70 Ma) plant functional types following Sewall, et al. (2007).

Results with standard paleobathymetry and 4xpre-industrial CO_2 level as simulated by AOGCM

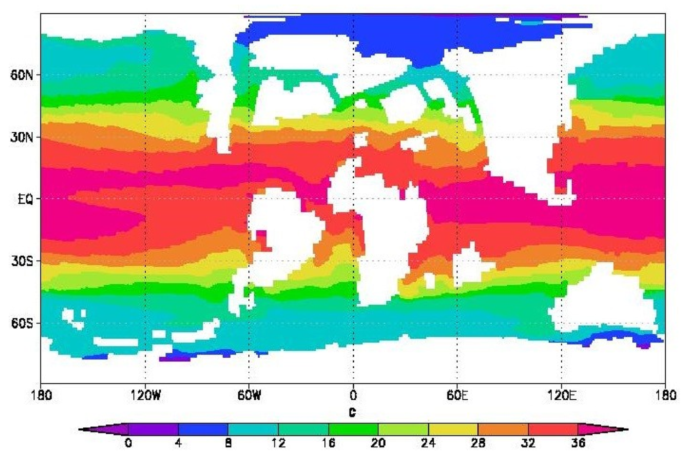

Fig. 4. Maastrichtian mean annual sea surface temperature.

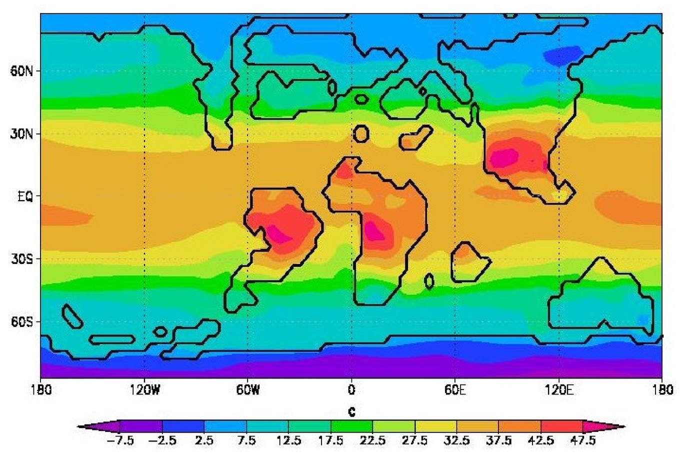

Fig. 5. Maastrichtian mean annual surface temperature.

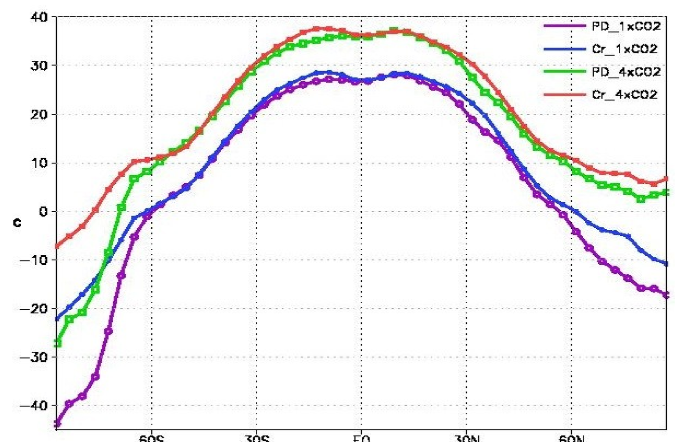

Fig. 6. Zonal annual mean surface temperature for Maastrichtian and Present Day world with pre-industrial (280 ppm) and 4xpre-industrial (1120 ppm) CO_2 level.

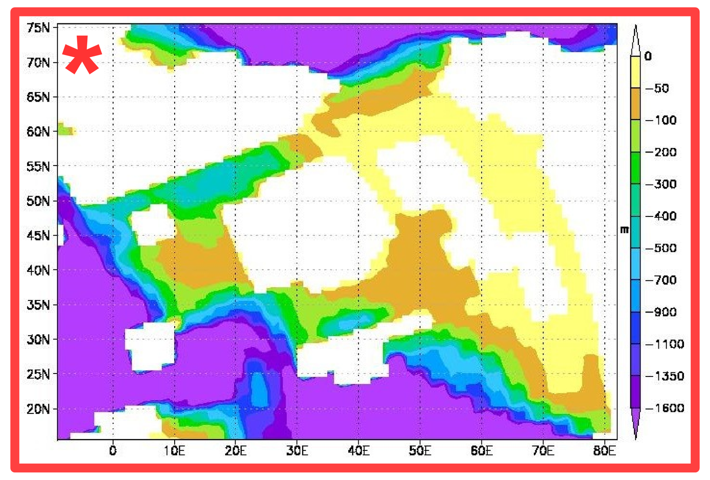

Fig. 7. Maastrichtian paleobathymetry in a Norwegian-Greenland Sea for a standard model.

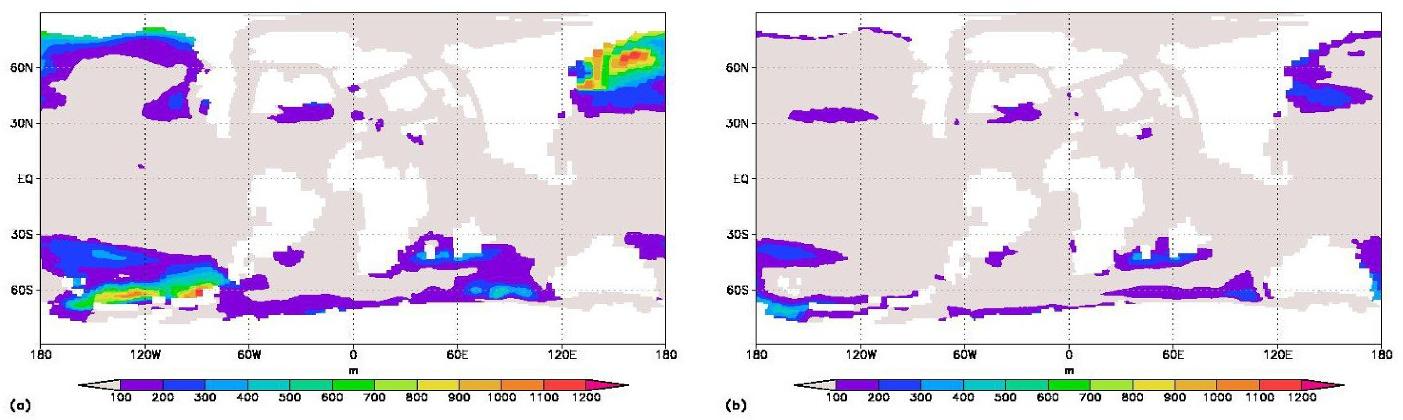

Fig. 8. Maastrichtian mean annual mixed layer depth for pre-industrial (a) and 4xpre-industrial (b) CO_2 concentration.

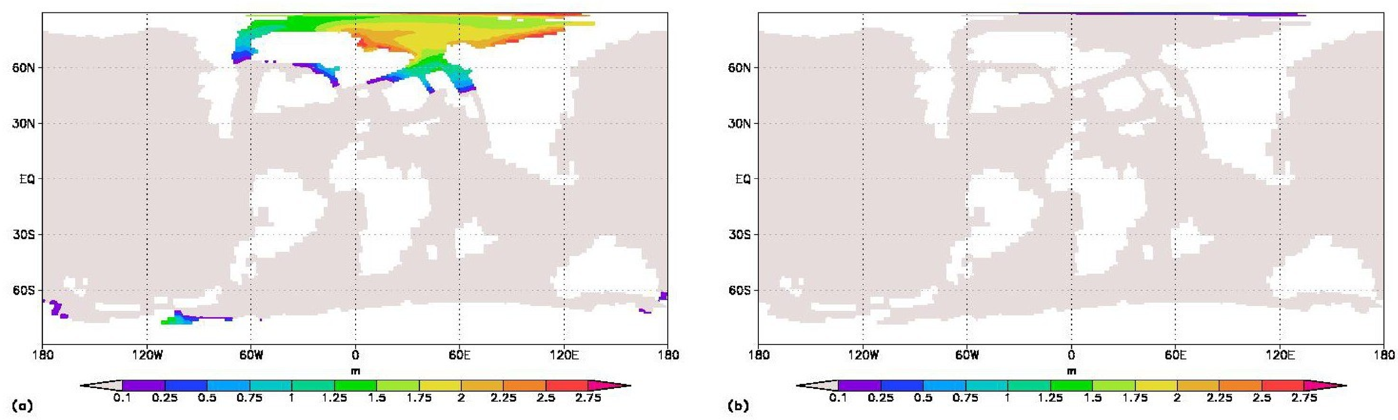

Fig. 9. Maastrichtian mean sea ice thickness in February and March for pre-industrial (a) and 4xpre-industrial (b) CO_2 concentration.

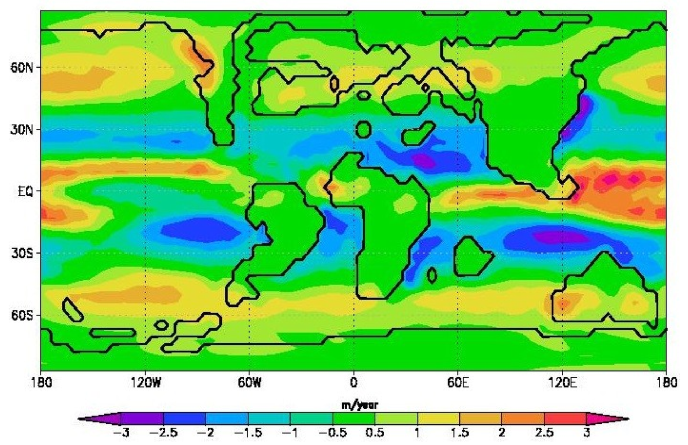

Fig. 10. Maastrichtian mean annual precipitation-evaporation values.

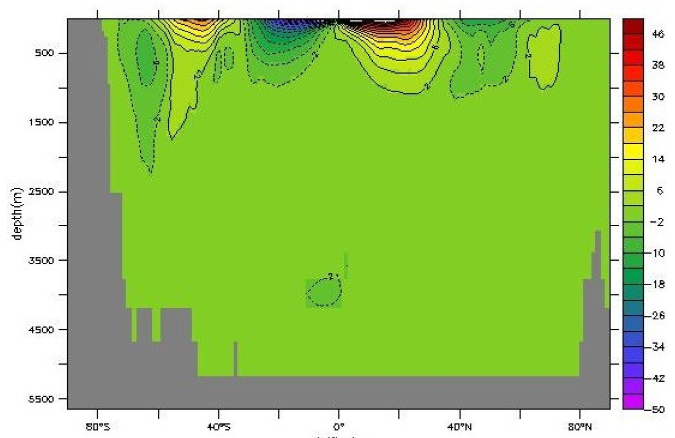

Fig. 11. Maastrichtian mean annual global overturning circulation.

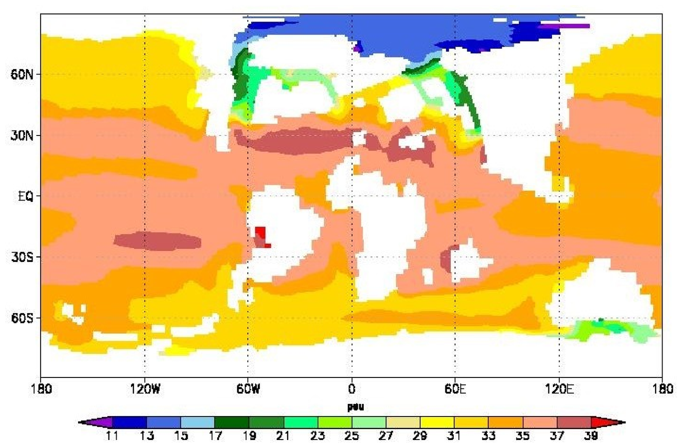

Fig. 12. Maastrichtian mean annual sea surface salinity.

Sensitivity tests with varying depth of Norwegian-Greenland Sea

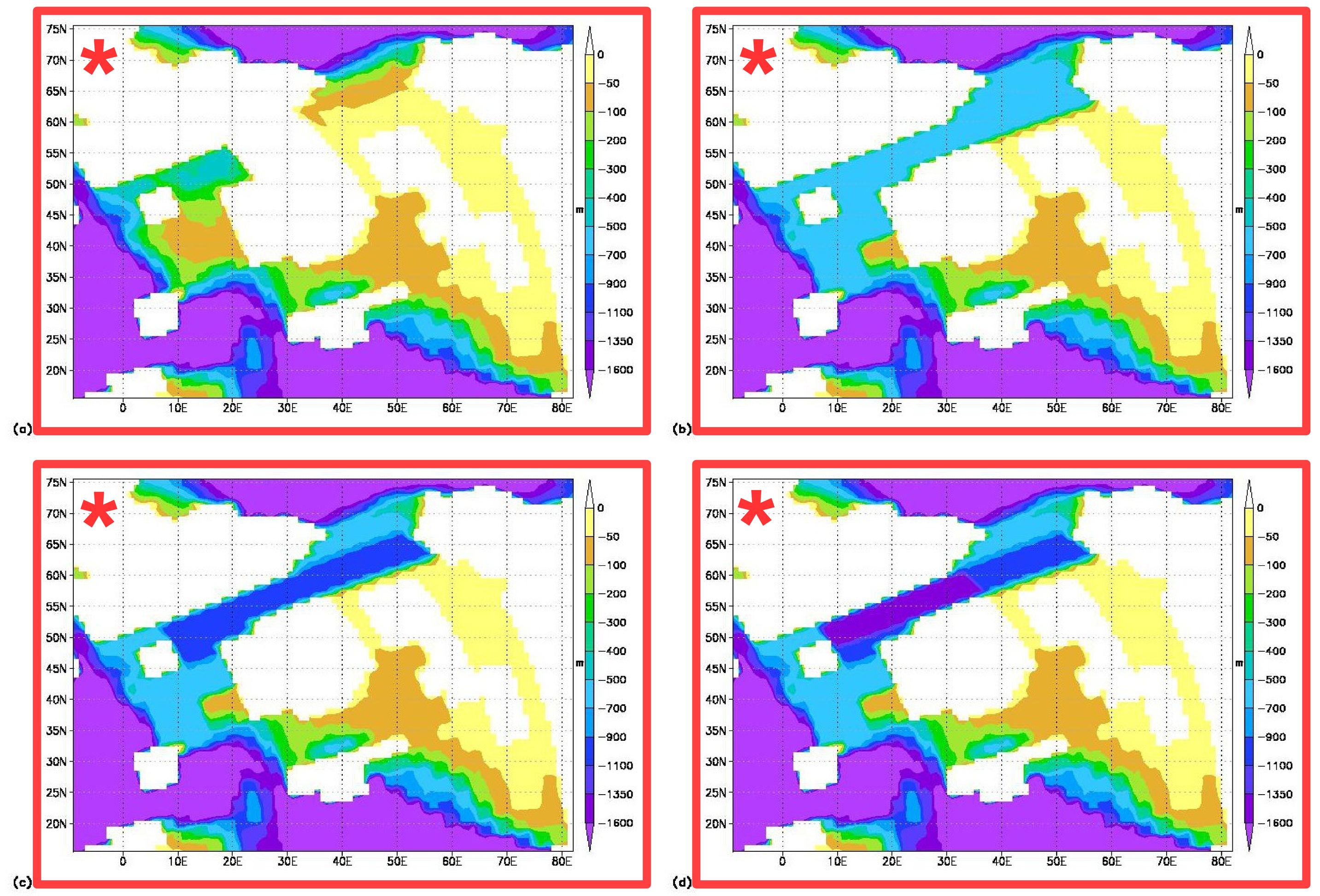

Fig. 13. Paleobathymetry in the Norwegian-Greenland Sea as used for sensitivity tests. Paleodepth varies from (a) entirely closed; (b) -666 meters; (c) -1000 meters and (d) -1500 meters.

Sensitivity tests

We set the depth of the Norwegian-Greenland seaway from the -1500 m to being entirely closed for different experiments. The paleo-depth range follows realistic inter-pretations based on the sedimentary record and microfossil proxies, including foraminifers and dinoflagellate cysts.

Experiments reveal that the depth of the seaway has no impact on temperature in the Arctic Ocean nor on the precipitation-evaporation values in high latitudes. It changes however surface salinity in the Arctic Ocean which varies from around 7 psu (closed seaway) to around 24 psu (deep seaway).

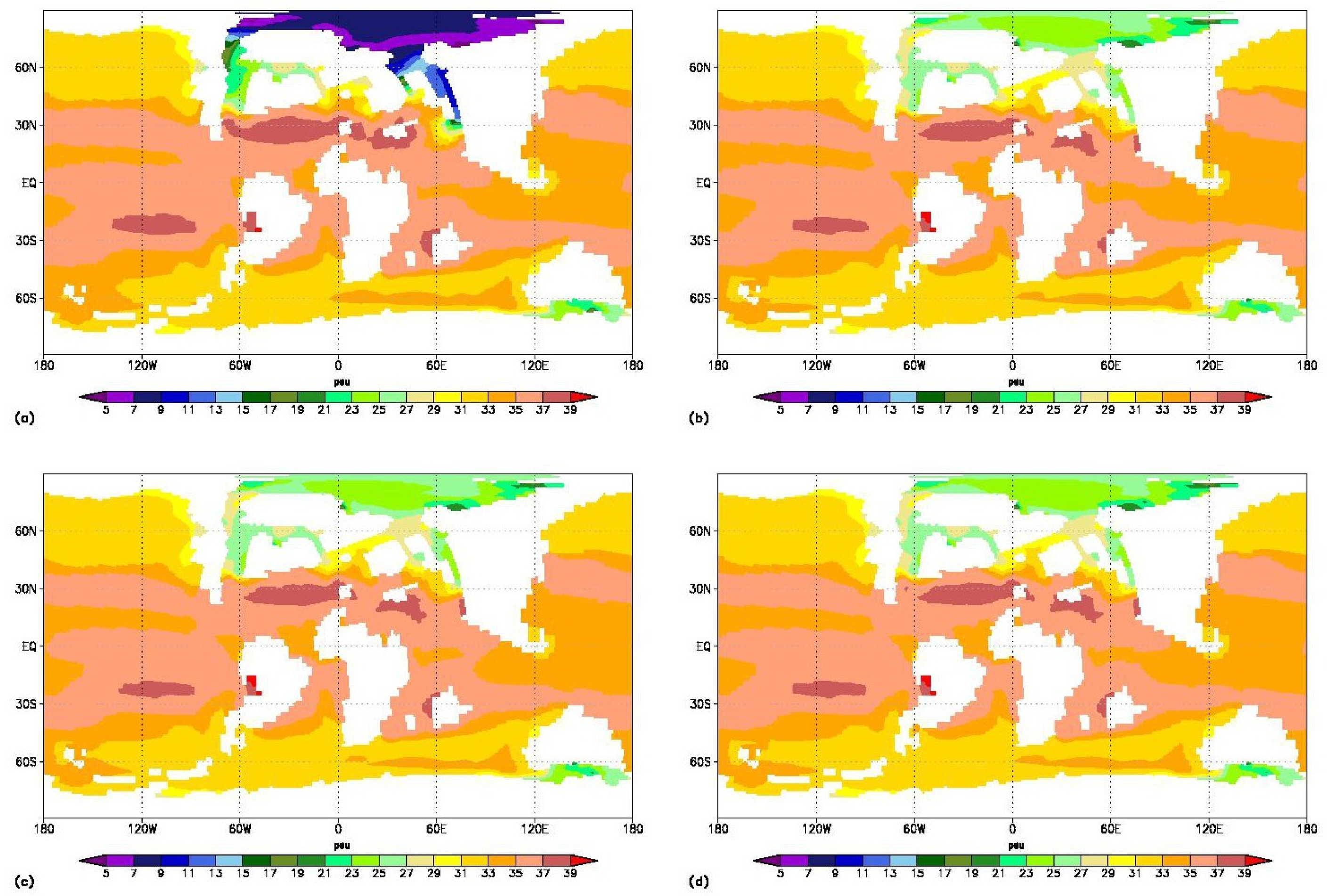

Fig. 14. Maastrichtian mean annual sea surface salinity where Norwegian-Greenland Sea is (a) entirely closed; (b) -666 meters; (c) -1000 meters and (d) -1500 meters deep.

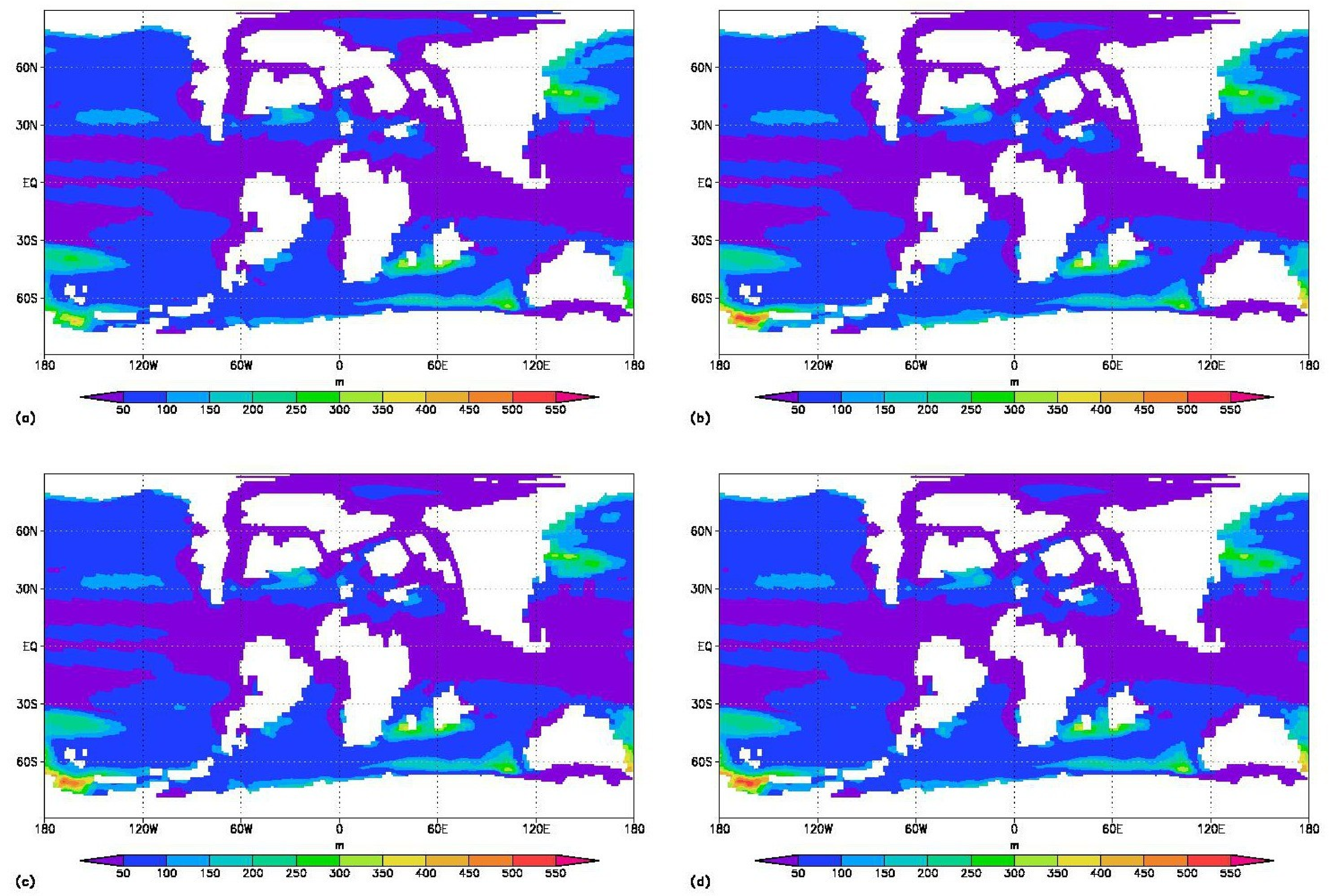

Fig. 15. Maastrichtian mean annual mixed layer depth where Norwegian-Greenland Sea is (a) entirely closed; (b) -666 meters; (c) -1000 meters and (d) -1500 meters deep.

Conclusions

- **4 times higher than pre-industrial CO_2 level is a sufficient factor to maintain Maastrichtian greenhouse world with warm northern polar region (Figs 1-3) and without existence of even seasonal sea ice (Fig. 9).**
- **Mixed layer depth is shallow on both hemispheres under high CO_2 level and overturning circulation is sluggish, so the latter can not be regarded as a dominant transporter of heat from low to high latitudes.**
- **Depth of mixed layer is controlled by CO_2 level and by the bathymetry (Figs 8 and 15).**
- **Arctic Ocean in the Late Cretaceous is brackish, the salinity in the ocean is controlled i.e. by the depth of the gateways between Arctic and Atlantic Oceans (Figs 13-14).**

Markwick, P. J. and Valdes, P. J.: Palaeo-digital elevation models for use as boundary conditions in coupled ocean–atmosphere GCM experiments: a Maastrichtian (late Cretaceous) example, Palaeogeography, Palaeoclimatology, Palaeoecology 213, 37 – 63, 2004.
Sewall, JO, van de Wal, RSW, van der Zwan, K, van Oosterhout, C, Dijkstra, HA, and Scotese, CR: Climate model boundary conditions for four Cretaceous time slices, Climate of the Past, p. 647 – 657, 2007.

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