Ocean modelling with varying topographic boundaries

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Introduction

For long-term simulations of past and future climate, it is important to include an interactive land-sea mask into Earth System Models (ESMs). As ice sheets melt or grow, the volume of freshwater in the ocean changes and the bedrock adjusts through isostatic adjustment. This leads to significant changes in the oceanic boundaries and bottom topography (Figure 1). Hence, it is necessary to consider these changes, particularly for paleoclimate studies.

The generation of a new ocean model bathymetry implies several levels of manual corrections. Therefore it is one of the main challenges for simulating a complete glacial cycle. We present a tool to allow for automatic computation of bathymetry changes in the Max Planck Institute Ocean Model (MPIOM).

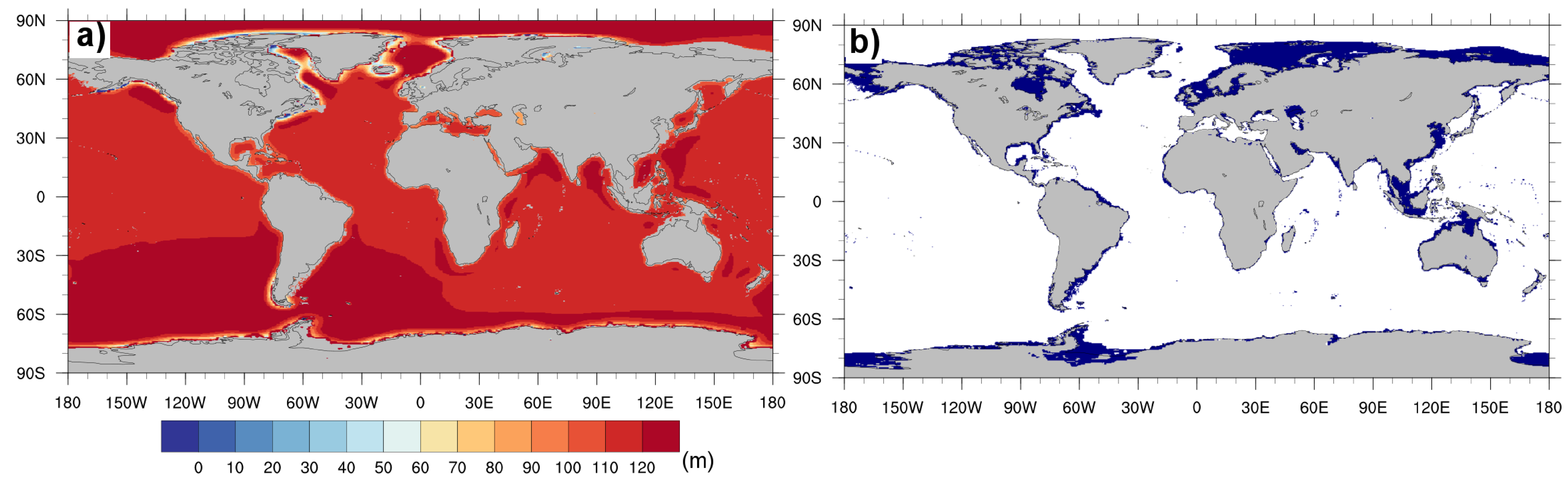

Figure 1: Difference in a) ocean bathymetry (m) and b) land-sea mask between present day conditions and 21 kyrs BP from the reconstruction of ICE-6G_C.

Methodology and results

This work can technically be split into two parts: the generation of the bathymetry file and the modification of the restart file.

Generation of bathymetry file

The aim is to automatically generate a Coarse Resolution (CR) bathymetry to run MPIOM from a high resolution (10‘x10‘) bathymetry. Our approach consists of the following steps:

1. Remapping a high resolution bathymetry to the CR MPIOM grid.
2. Calculation of a CR land-sea mask and modification of it by considering:
   - That ocean areas are connected to avoid isolated lakes.
   - Key straits and peninsulas. If they are open (closed) in the high resolution data, they will be open (closed) in the CR land-sea mask.
3. Modification of the interpolated CR bathymetry to provide sufficient through-flow depths (TFD) at key straits by:
   - Obtaining first the TFD in the high resolution bathymetry. Some examples are Gibraltar, Denmark and Nares straits, North-West Passage, Bab-el-Mandeb and Bosphorus between others.
   - Modifying the TFD in the CR bathymetry according to the values found in the high resolution data.
4. Sequences of artificial rapid flooding/drying events on a shelf are avoided by applying an inertia term.

An example of how the algorithm works for a) 21 kyrs BP and b) present day conditions is shown in Figure 2.

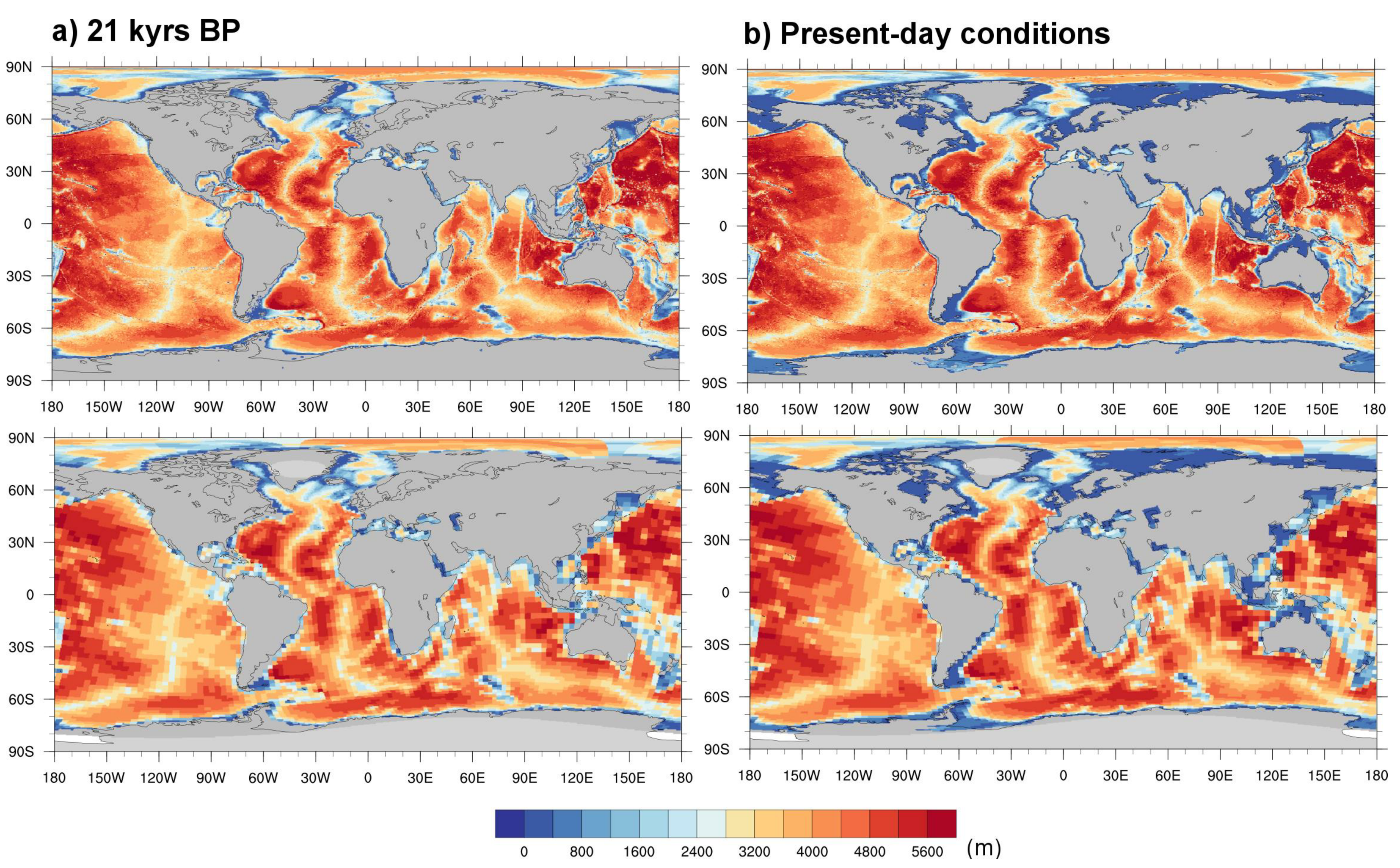

Figure 2: Global ocean bathymetry on a 10'x10' resolution grid and the associated remapped field on the MPIOM CR grid for a) 21 kyr BP and b) present day conditions.

Modification of restart file

The aim is to automatically modify the restart file by redistributing mass and water properties when the bathymetry and land-sea mask change. The challenge is to conserve them not only at global but also at regional scales. Our approach consists of the following steps:

1. Vertically redistribution of water and tracers when the depth changes. Fields of sea surface height, temperature and salinity are vertically adapted to the new bathymetry.
2. Smoothing of the fields to avoid large gradients in sea level height that can be artificially introduced trough the previous step. Special attention is given to the conservation of volume and tracers when a parcel of water is moved.
3. Horizontally redistribution of water, tracers, ice and snow when the land-sea mask changes. The necessary amount of water and tracers to fill new ocean grid points are taken from adjacent ocean boxes in order to conserve properties at global and regional scales.
4. Smoothing of the fields to avoid large gradients in sea level height that can be artificially introduced trough the previous step.

An example of how the algorithm works regarding the horizontal redistribution of water is shown in Figure 3.

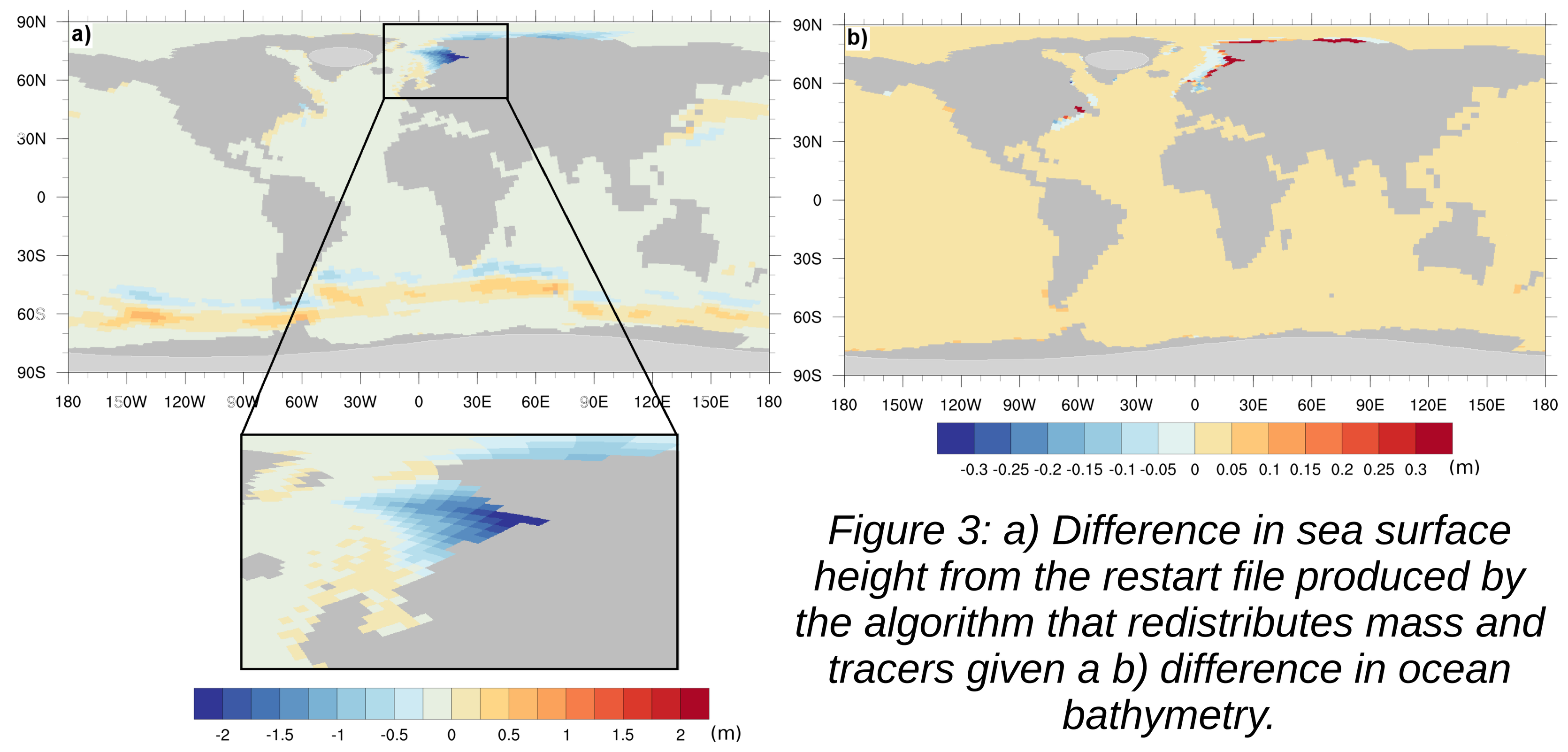

Figure 3: a) Difference in sea surface height from the restart file produced by the algorithm that redistributes mass and tracers given a b) difference in ocean bathymetry.

Current status

We are currently testing the module within MPI-ESM in order to ensure a reliable behaviour of the algorithms under a wide range of conditions, including both the glaciation and deglaciation.

Once tested thoroughly the module can be used for transient simulations of the last terminations, allowing for interactive land-sea mask and bathymetry.

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GEFÖRDERT VOM Bundesministerium für Bildung und Forschung

PALMOD GERMAN CLIMATE MODELING INITIATIVE

MAX-PLANCK-GESELLSCHAFT