The Effect of Bathymetry Changes on Meridional Overturning Currents

Marte Voorneveld
5911591

May 15, 2020

Abstract

1 Introduction

The geometry and resulting bathymetry of our planet is an ever changing phenomenon. In the last 120 Ma the earth moved from having one major oceanic system in the Pacific with a single large continent to the current 3 ocean system (Besse and Courtillot 2002). The Bathymetry changes that occurred in this time period are characterized by the opening and closing of certain passages through which exchange of water between the oceanic basins is observed. The exact timing of passage openings is a topic of rigorous debate in literature (Scher and Martin 2006, Schmidt 2007).

One of the changes on which there is general consensus, is the inception and expansion of the Atlantic ocean and the resulting decrease in size of the Pacific basin. The creation of the Atlantic basin has had major effects on the earth's climate, especially resulting in massive localized changes such as the temperate European climate, due to the north Atlantic meridional overturning current (AMOC). This creates the current Northern sinking oceanic throughflow in the Atlantic. However it is unknown when exactly this northern sinking started. With the past non-existance of the Atlantic it must have started some time in the last 40Ma with the advent of a larger Atlantic (Abelson and Erez 2017).

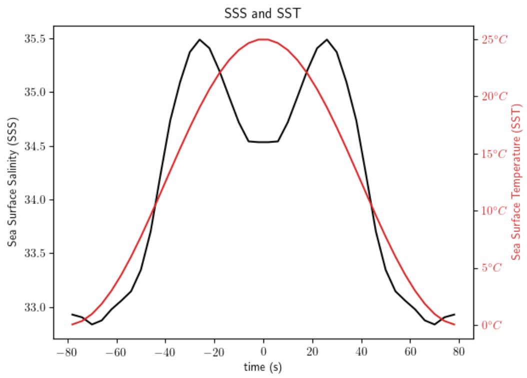
The result of these bathymetry changes on the oceanic stream function and the resulting overturning currents is something that has been previously studied by Mulder et al. 2017. They however found that using a Jacobian matrix for continuation in each of the model years fails to simulate the onset of the Northern sinking AMOC that is physically observed. Here we instead propose to use a general circulation ocean model with only a changing bathymetry keeping the same initial forcing for each time step. This eliminates the need for a continuation using the Jacobian matrix method proposed in Mulder et al. 2017.

This paper will focus solely on changes in bathymetry using simplified zonally averaged global forcings. The results of the model will be used to estimate global changes in oceanic through flow at the critical passages. Furthermore the strength of the meridional overturning currents (MOC) will be studied.

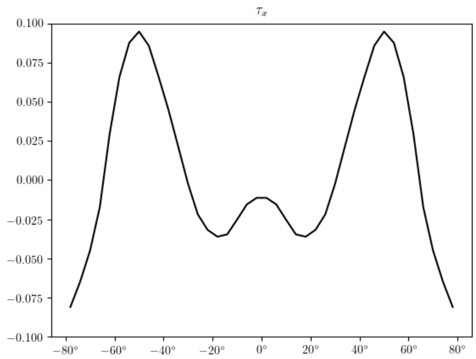
2 Methods

2.1 Simplified Forcings

The domain chosen is bounded by longitudes $\phi_E = -180^\circ$ and $\phi_W = -180^\circ$ and latitudes $\theta_N = 80^\circ$ and $\theta_S = -80^\circ$ with periodic boundary conditions in the zonal direction. Furthermore the model uses restoring boundary conditions first proposed by Haney 1971. Restoring the boundary at the surface of the oceanic basin to be a certain value based of a forcing field for Sea Surface Temperature (SST), Sea Surface Salinity (SSS), and wind stresses (τ). The depth profile has 15 layers with grid stretching. There are 90×40 grid points to make a $4^\circ \times 4^\circ$ resolution model. The forcings are prescribed as in Mulder et al. 2017 by highly idealized zonally averaged forcings using current day values. The SST and Zonal wind stress are chosen as the analytical model in Bryan 1987. While SSS is chosen as a zonal average of current day values (from ECMWF but not sure how to cite). The meridional wind stress is set to zero. The maximum ocean depth is 5000m. The model also requires initial conditions for salinity and temperature, for this zonally averaged present day values are again used.



(a) SSS and SST



(b) Zonal wind stress (τ_x) profile

Figure 1: Idealized forcing profiles

2.2 Creating Bathymetries

To facilitate the model a set of 14 bathymetries were created in 5Ma time steps. From 65Ma to present. These were reconstructed from bathymetries gained in Baatsen et al. 2016. These bathymetrys were subsequently scaled to a 4 degree model and changed to address passage openings in the 4 degree case. Due to the low resolution of the model, choices have to be made with respect to the opening of certain passages. One of the choices that was made is that the Arctic sea is closed of in all of the bathymetrys. This is mainly due to the fact that 4 degree models do not have enough resolution to facilitate this. The main events that shape the oceanic passages can be devided into time periods. These time periods are defined as follows in this paper. This deviates from their definitions in literature but serves only as a means of applying a name to the time steps.

	From	Until
Paleocene	65Ma	55Ma
Eocene	50Ma	35Ma
Oligocene	30Ma	20Ma
Miocene	20Ma	Present

In the paleocene a vast Pacific exists almost serving as a single basin. This period is largely characterized by the growth and development of a larger atlantic basin. Serving to decrease the size of the pacific basin.

The Eocene in contrast to the Paleocene is distinguished by The opening of certain passages connecting oceanic basins. These effects are often studied extensively for each individual passage. Choosing the exact timing for opening the passages is done manually by looking at often active research taking into account big uncertainties in the exact timing of the openings. The first of such passage changes that occurs is the Indian continent colliding with the Eurasian continent. This has the effect of closing the deep water formations between the Thetys sea and the Pacific ocean. Next the Tasman passage is opened as a shallow passage slowly growing in size(Lawver and Gahagan 2003). The Tasman passage opening is believed to have had a large impact on the onset of the ACC. The Total circulation of water around the antartic basin is finalized by the opening of the shallow Drake passage at around 30Ma. 30Ma is specifically chosen to differentiate between the opening of the drake and Tasman passages. Especially since there is still some debate on the exact timing of drake passage opening (Scher and Martin 2006).

The next time period is the Oligocene Which is largely characterized by the deepening of the Tasman and drake passage and further expansion of the atlantic basin.

The Miocene is Characterized by Some more passage closures. Starting with the closure of the Thetys Seaway at 15Ma(Hamon et al. 2013). The Thetys seaway had been decreasing in size in the previous 20Ma. Also the Indonesian passage is significantly decreasing in size due to the onset of multiple islands making the passages more narrow. Further more the Tethys ocean is finally closed at 15Ma, Making northern flow over Africa between the Atlantic and Indian oceans impossible from this point onward. Then another major change occurs with the closure of the central American seaway (Molnar 2008; Pindell et al. 1988). Stopping the mid latitude throughflow between the Atlantic and Pacific basins.

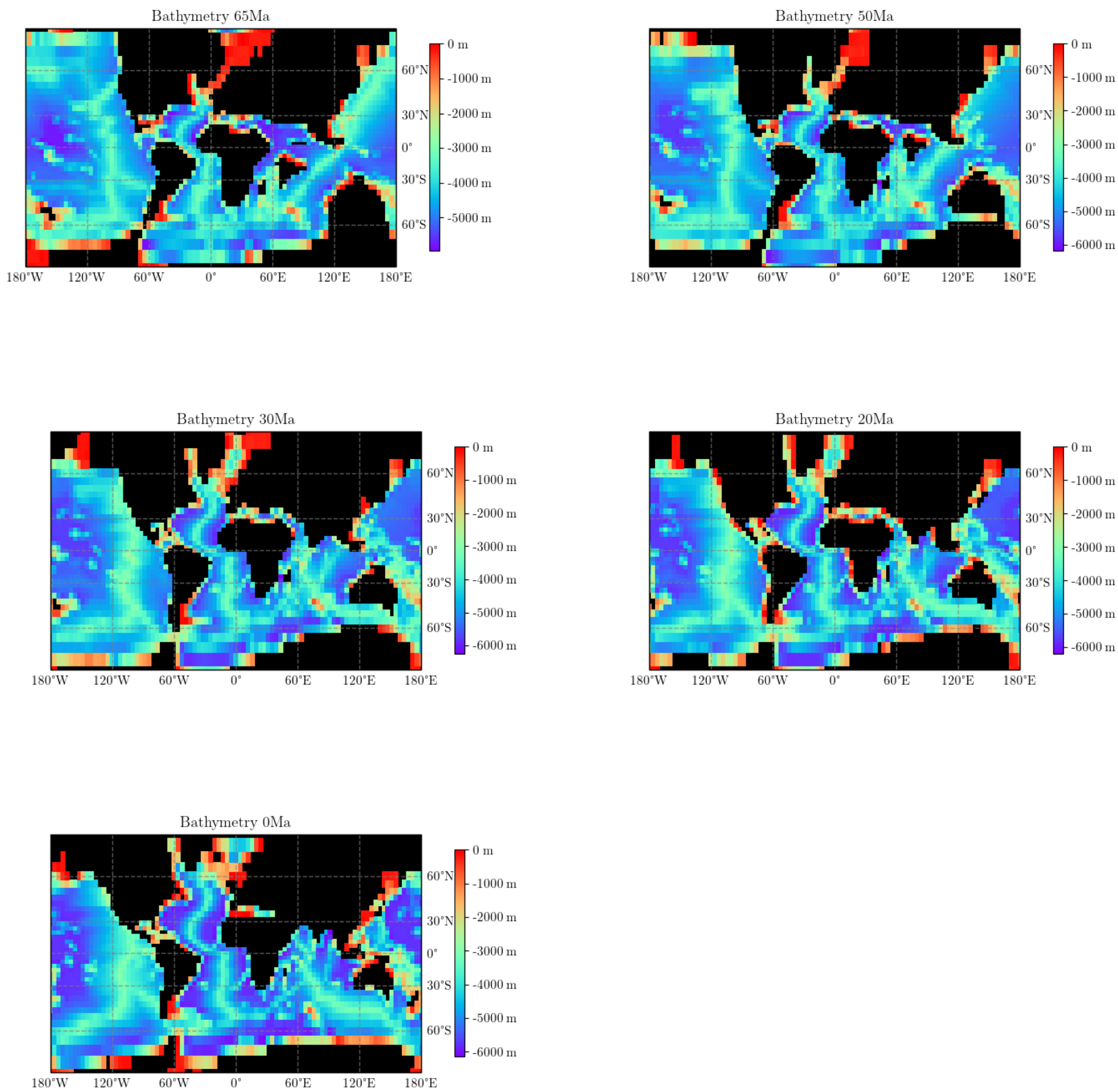


Figure 2: Paleocene Begin and End

2.3 Veros and Runtime

Ocean modeling has been an area of continued progress. The resolutions of the models have been steadily increasing since the inception of the first computerized ocean models. However, due to the age of some of these models and the continued adaptation of often old legacy Fortran code, many models have become enormous hurdles to get started with often resulting in frustration. The Veros ocean model project is trying to tackle this problem with a totally new code base written entirely in Python (**Hafner2018Aug**). Veros is a General Circulation Ocean model based on the successful PyOm2 model. It was designed from the ground up with flexibility in mind. This flexibility cuts valuable time spent on figuring out the often cumbersome Fortran models of the past. Veros is specifically well suited for researching the effect of changes in both forcings and bathymetrys. They can be easily edited using Python. These features in particular are heavily used in this paper. One of the most extensively used features for example is the fact that any bathymetry can, without further manual specifications of islands be used for stream function calculation.

In this case the models used in this paper were run on a 8 core (16 threads) machine using an MPI CPU configuration of 1 node. The Bohrium GPU possibilities of Veros were also tried but failed to result in much improvement in speed. Figure (figure on speed) shows the model speed of the integration. The total time needed to run all of the models was approximately one week.

3 Results

3.1 Stabilizing of the models

(Section on when the integration was stopped. How good it is etc.) 60/100 done

3.2 Passage throughflow

For each of the afforementioned passages the throughflow was computed. This is done using a simple integration to calculate the volumetric flux through each passage.

$$Q = \int \int_A \vec{u} \cdot d\vec{A} \tag{1}$$

For each passage a suitible location was chosen such that there are no boundaries next to the passageways. Then the u component of the flow is used to compute the total flow. This method is the same for each of the passages and thus we can study the effect of changes in bathymetry to on the relative strenght of the flow. However, it should be noted that these values may not represent real physical values. As the passages are often only a few gridcells wide and, the nature of the 4 degree model. Resulting in discepencies due to boundary conditions. The passageways have been labeled in figure (figure of these) and results are plotted in figure (figure of these).

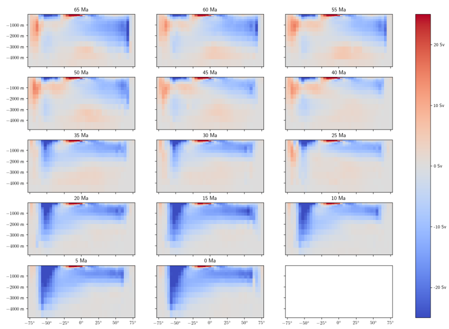


Figure 3: test caption

3.3 Stream function

(Section on the Long-Lat stream function and vertical zonnally integrated streamfunction) 60/100 done

4 Summary

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5 Discussion

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