Homework 7

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1 Introduction

The Last Glacial Maximum is a period of interest for climate sciences. Compared to the Pre-Industrial Holocene (PI-H), it is was characterized by low atmospheric temperatures and CO_2 concentrations, and ice sheets covering large areas of Eurasia and North America. In the oceans, the North Atlantic overturning was stronger than it is today, suggesting a different regime for the whole Global Circulation. The driver of the strengthen of the overturning is still not well understood. Following the LGM, a major warming event took place, and information on this process can be extrapolated to help understand recent observations of global warming due to CO_2 emissions.

In this work we compare the simulation results for the overturning circulation of three models, both for the PI-H and the LGM. For this we study the meridional streamfunction ψ integrated over three different basins: The Atlantic Ocean, where sinking of dense water occurs in the north, the Indo-Pacific ocean, characterized by slow diffusive upwelling, and the World Ocean, which combines all the characteristics of the overturning circulation.

2 Theoretical background

The velocity field (u, v, w) in the ocean, where u, v and w are the zonal, meridional, and vertical velocities, respectively, is, at any specific instant, a function of (x, y, z). We can define the streamfunction ψ that describes dynamics in the yz plane, i.e., a meridional section of the ocean:

$$\frac{\partial \psi}{\partial z} = -V, \qquad \frac{\partial \psi}{\partial y} = W, \tag{1}$$

where V and W are the zonally integrated meridional and vertical transports, respectively.

The yz plane streamfunction describes the strength and direction of the overturning circulation. For a specific ocean basin it can be calculated from the meridional velocity v as

$$\psi(y, z) = -\int_z^0 V(y, z)dz = -\int_z^0 \int_0^{L(y)} v(x, y, z)dxdz, \tag{2}$$

where $L(y)$ is the width of the basin at each latitude, and the vertical integral is taken considering $z = 0$ to be the sea surface. It should be noted that a z-only dependent term has been omitted in this definition of ψ, but since we are looking at meridional currents across the oceans, we can disregard the effect of vertical velocities.

3 Methodology

Meridional velocity matrixes from the World's ocean were collected from the PCMDI data portal. Three different models were used: The NASA Goddard Institute for Space Studies (GISS-E2-H), the Max Planck Institute for Meteorology (MPI-ESM-HR) and the Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (MIROC-ESM). Each data set contains monthly values of v as a function of the discrete coordinate (x, y, z). Models have different griddings, and in the MPI case, a non rectangular grid is used. We downloaded data both for the pre-industrial (PI) and the last glacial maximum (LGM) simulations. To calculate the meridional streamfunction, we first transformed all the grids to a rectangular one (if necessary), and distinguished three ocean basins: Atlantic, Indo-Pacific, and World Ocean. Then, for the three basins we calculated the streamfunctions of each model by using equation (1), integrating with the tool provided by the NOAA Ferret software.

4 Results

Plots of the meridional streamfunction are shown, with colors and isolines indicating values for ψ. With this definition of the streamfunction, positive values indicate clockwise circulation.

4.1 Atlantic Ocean

4.1.1 Pre-Industrial

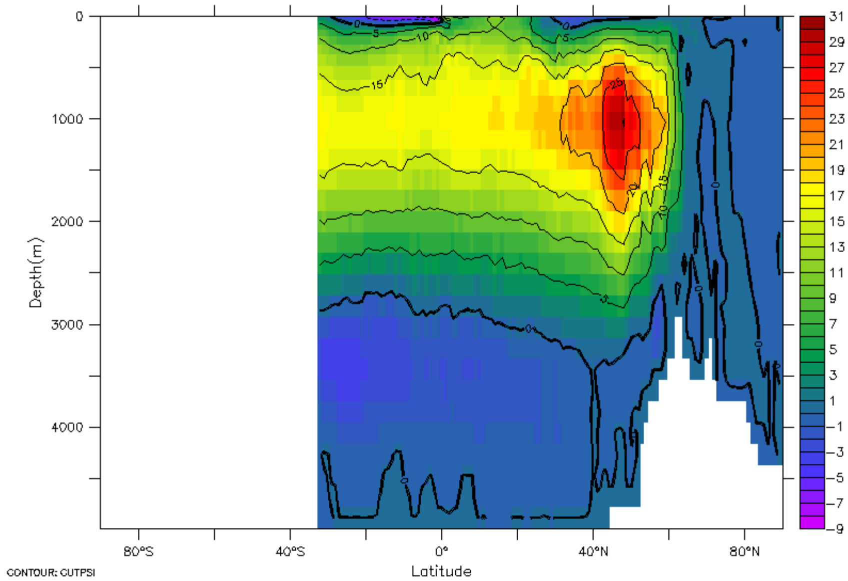

Figure 1: Meridional streamfunction for the Atlantic Ocean, obtained with the GISS Model.

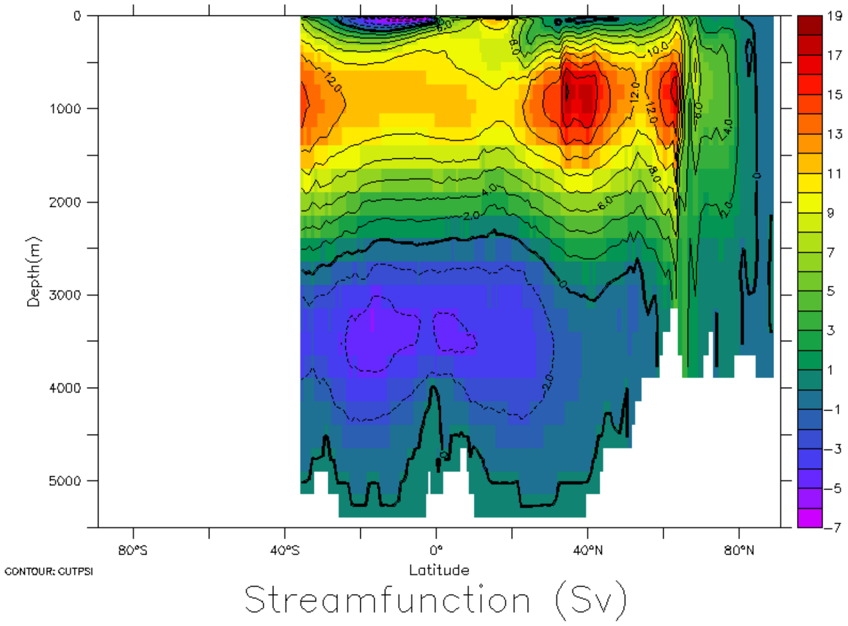

Figure 2: Meridional streamfunction for the Atlantic Ocean, obtained with the MIROC Model.

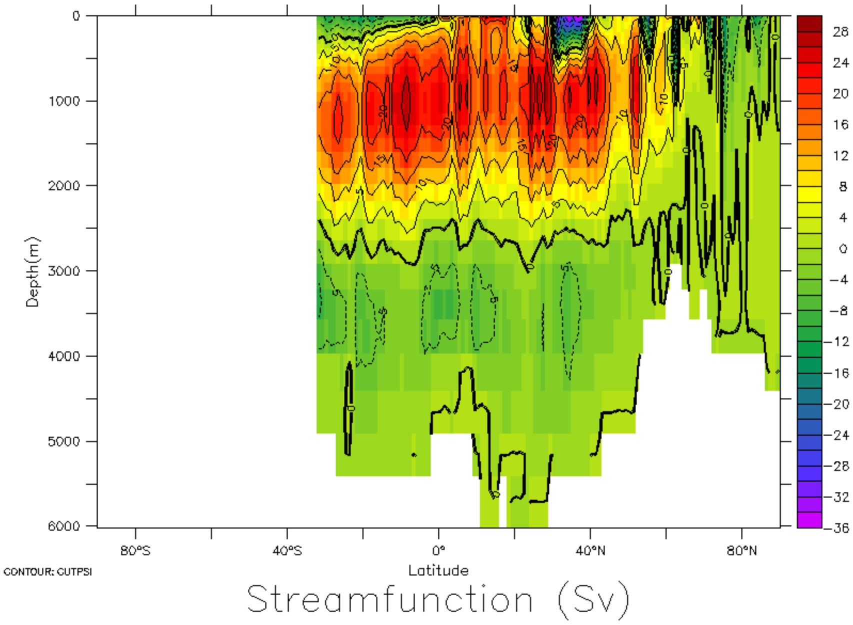

Figure 3: Meridional streamfunction for the Atlantic Ocean, obtained with the MPI Model.

4.1.2 LGM

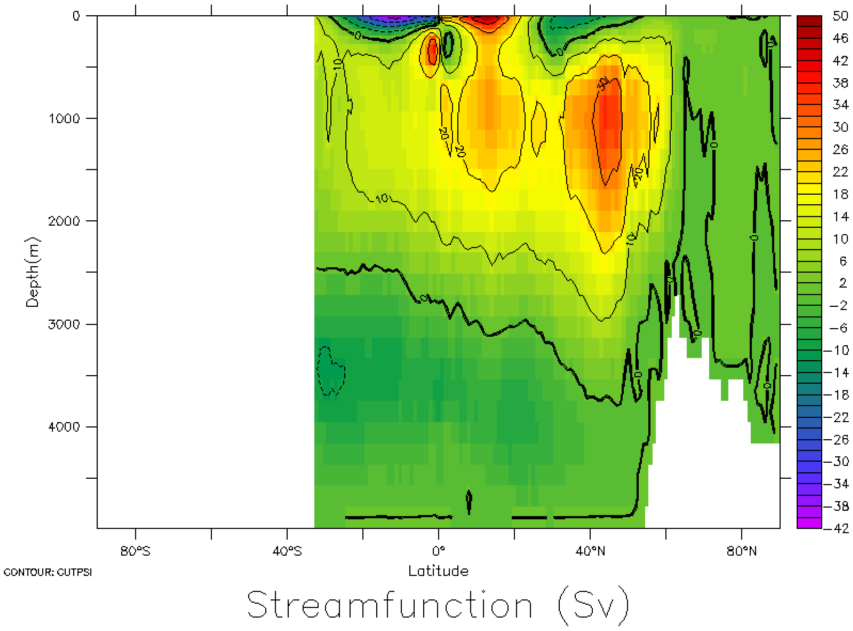

Figure 4: Meridional streamfunction for the Atlantic Ocean, obtained with the GISS Model.

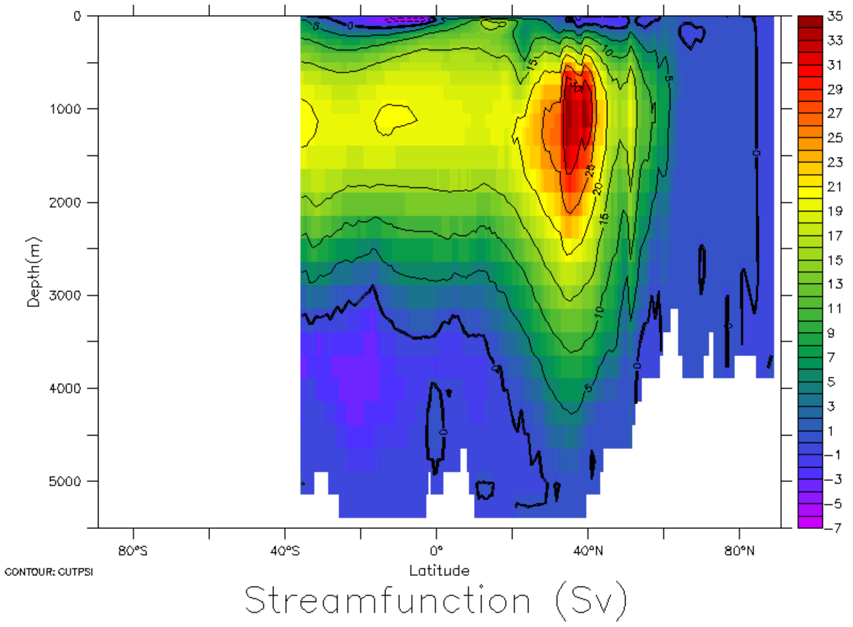

Figure 5: Meridional streamfunction for the Atlantic Ocean, obtained with the MIROC Model.

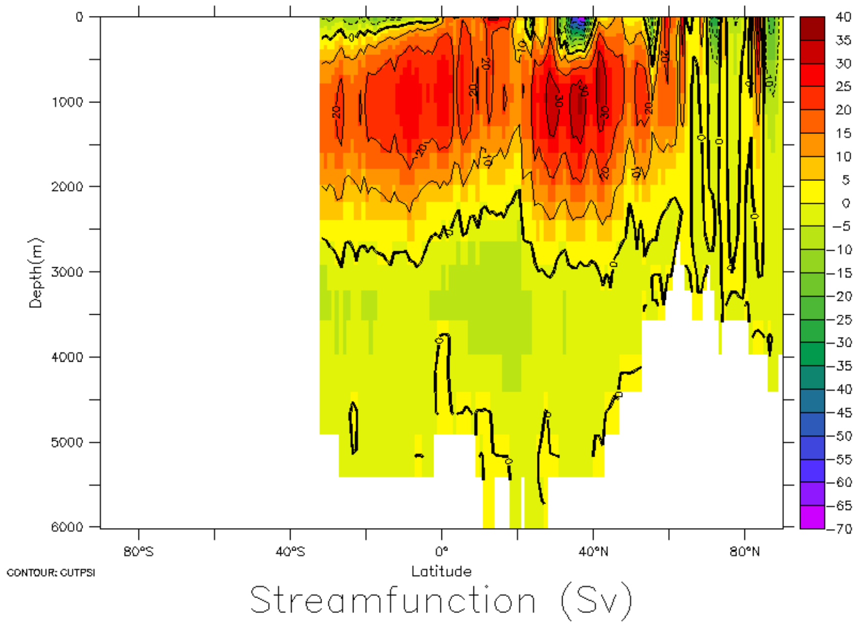

Figure 6: Meridional streamfunction for the Atlantic Ocean, obtained with the MPI Model.

4.2 Indo-Pacific

4.2.1 Pre-Industrial

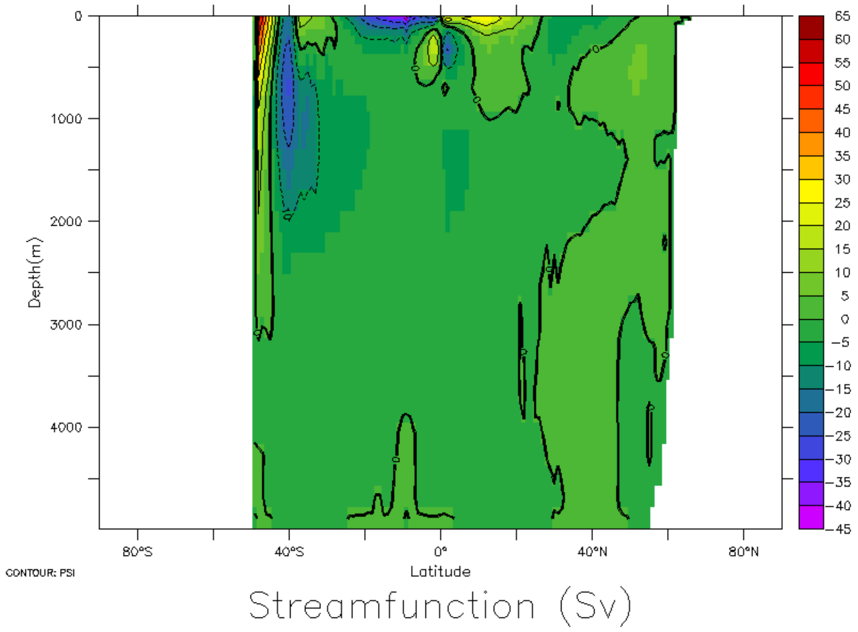

Figure 7: Meridional streamfunction for the Atlantic Ocean, obtained with the GISS Model.

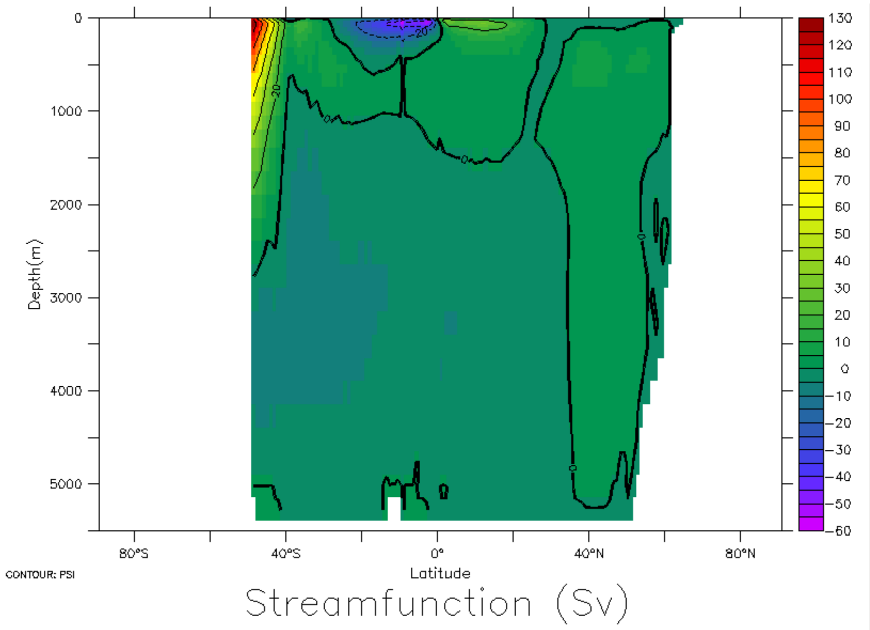

Figure 8: Meridional streamfunction for the Atlantic Ocean, obtained with the MIROC Model.

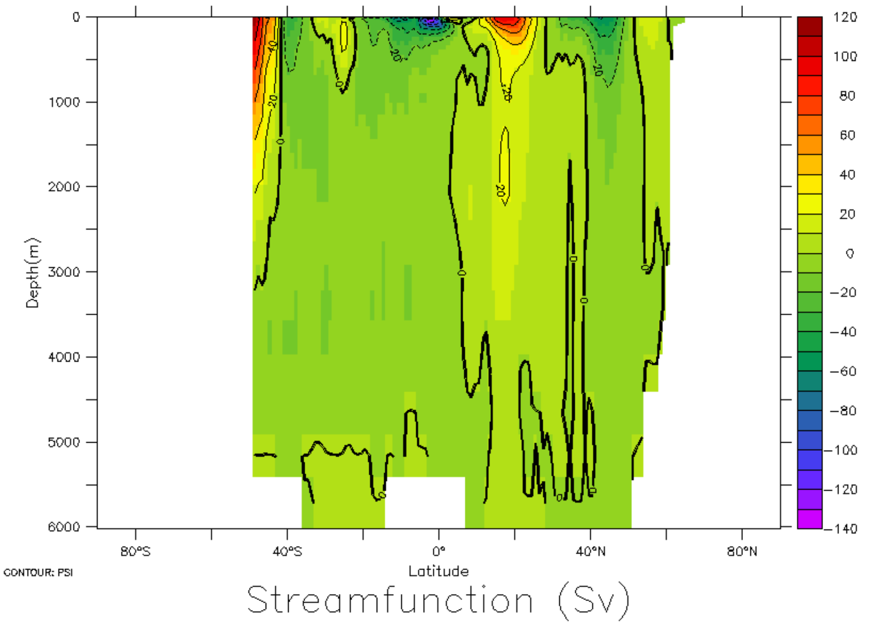

Figure 9: Meridional streamfunction for the Atlantic Ocean, obtained with the MPI Model.

4.2.2 LGM

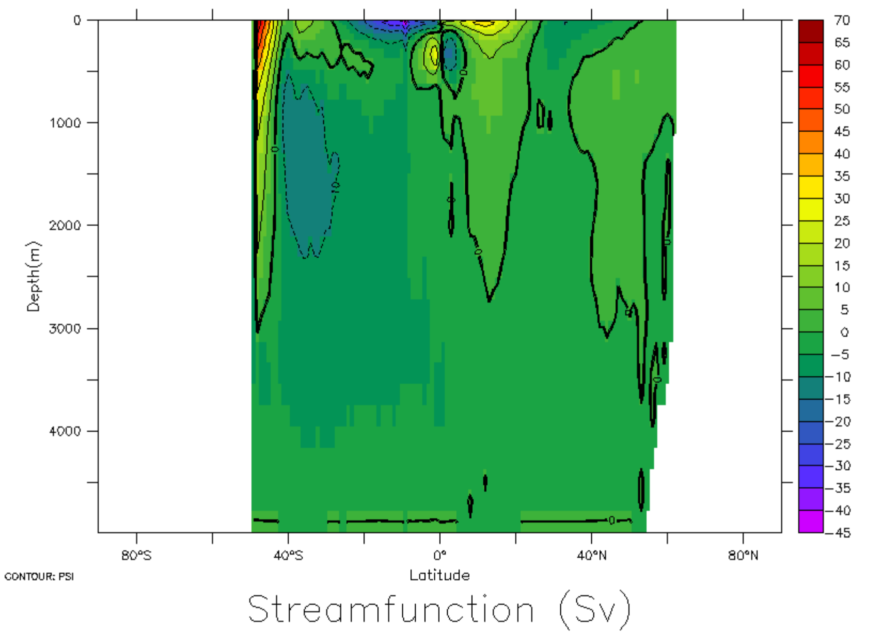

Figure 10: Meridional streamfunction for the Atlantic Ocean, obtained with the GISS Model.

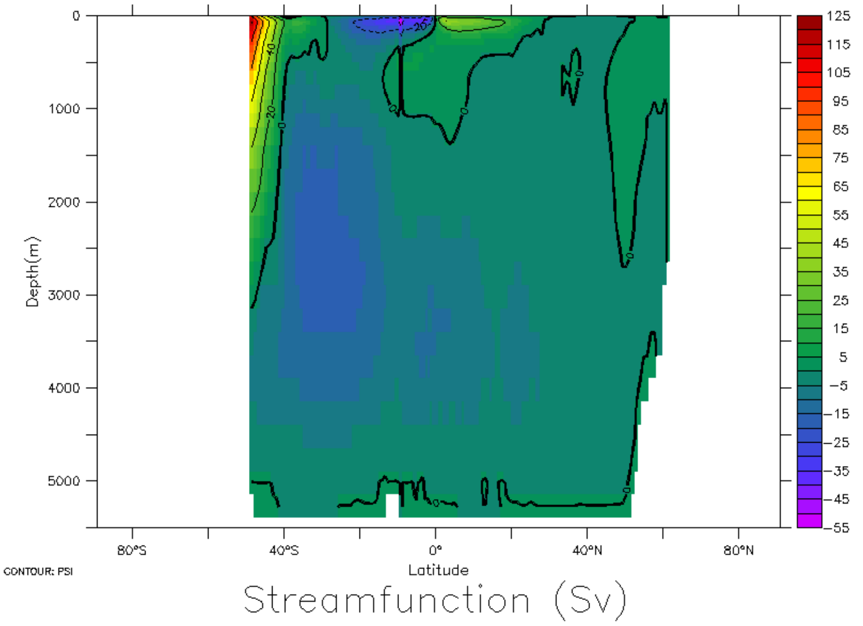

Figure 11: Meridional streamfunction for the Atlantic Ocean, obtained with the MIROC Model.

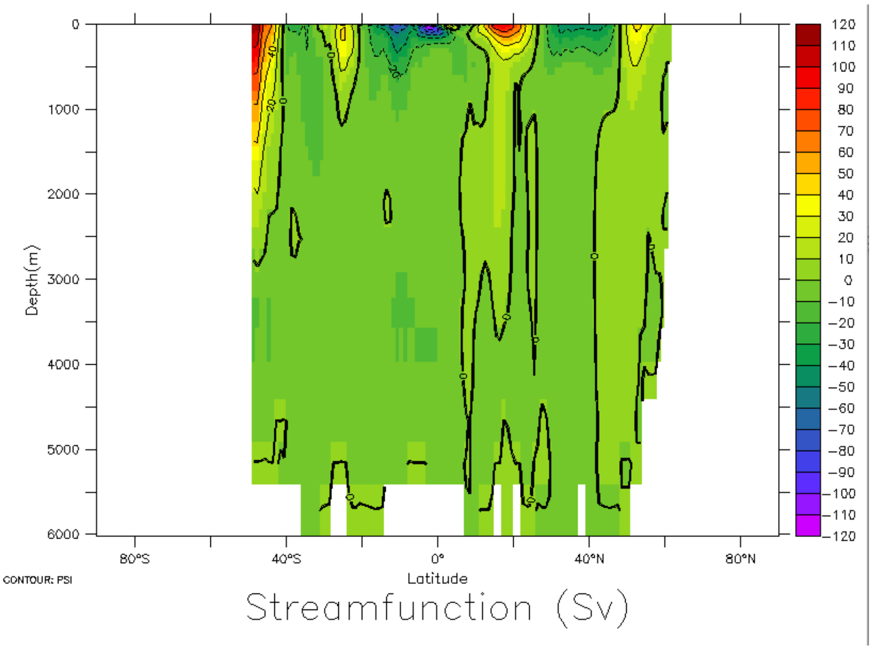

Figure 12: Meridional streamfunction for the Atlantic Ocean, obtained with the MPI Model.

4.3 World Ocean

4.3.1 Pre-Industrial

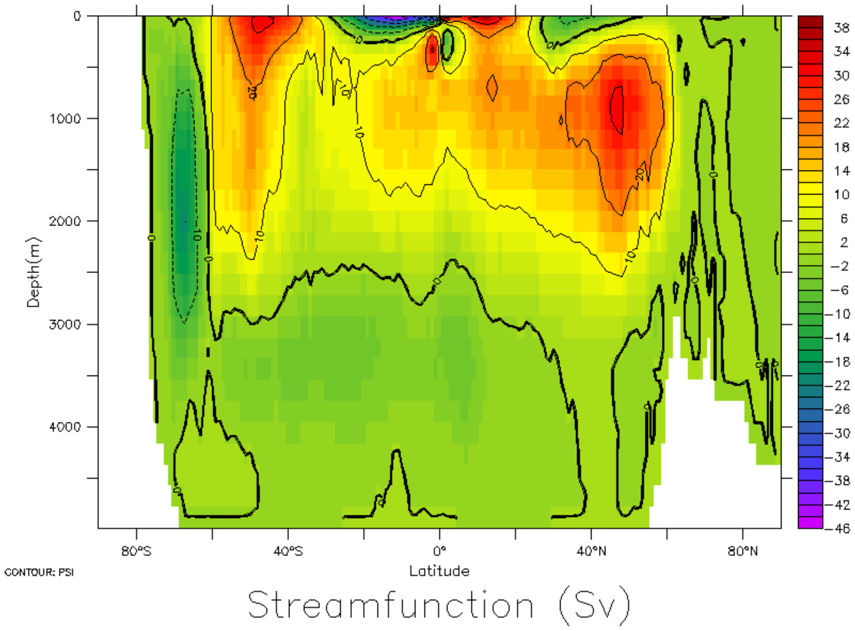

Figure 13: Meridional streamfunction for the Atlantic Ocean, obtained with the GISS Model.

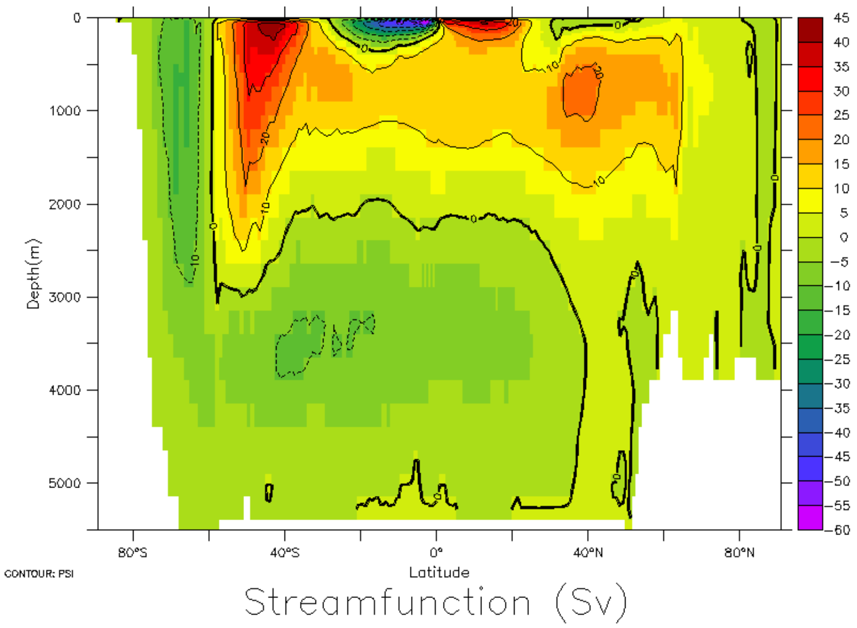

Figure 14: Meridional streamfunction for the Atlantic Ocean, obtained with the MIROC Model.

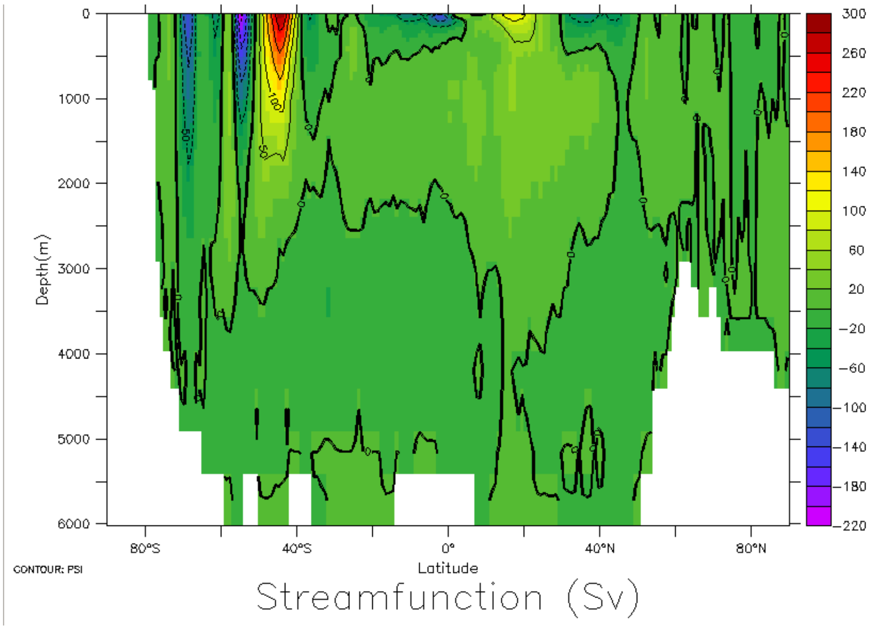

Figure 15: Meridional streamfunction for the Atlantic Ocean, obtained with the MPI Model.

4.3.2 LGM

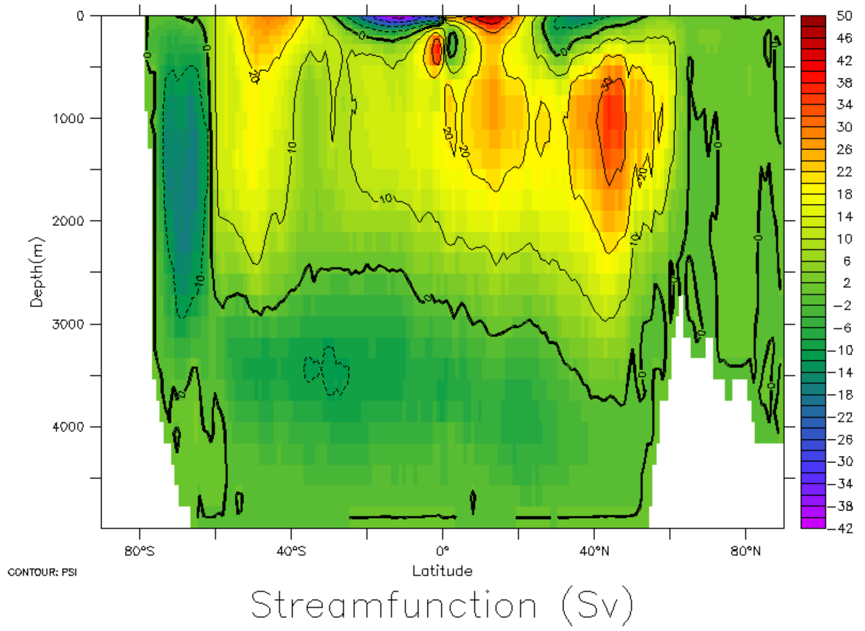

Figure 16: Meridional streamfunction for the Atlantic Ocean, obtained with the GISS Model.

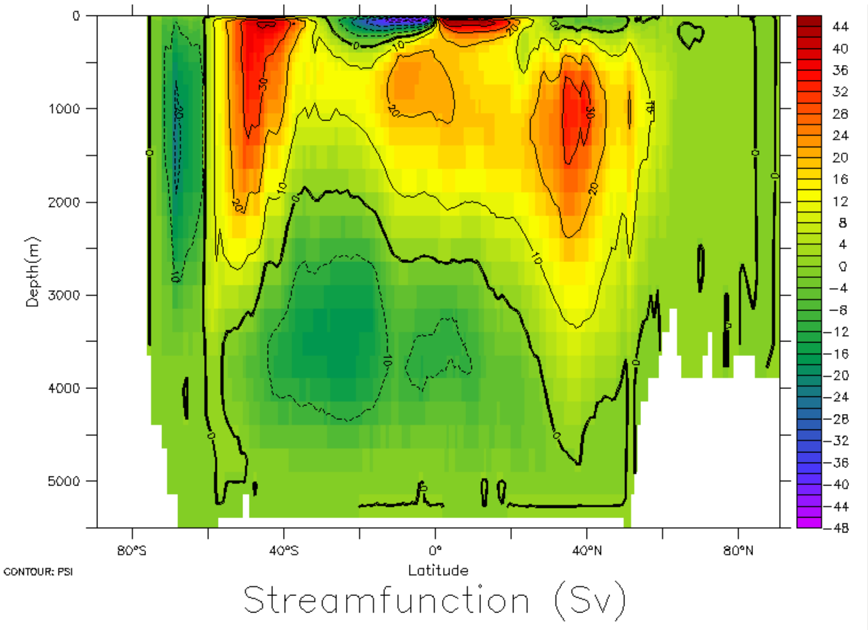

Figure 17: Meridional streamfunction for the Atlantic Ocean, obtained with the MIROC Model.

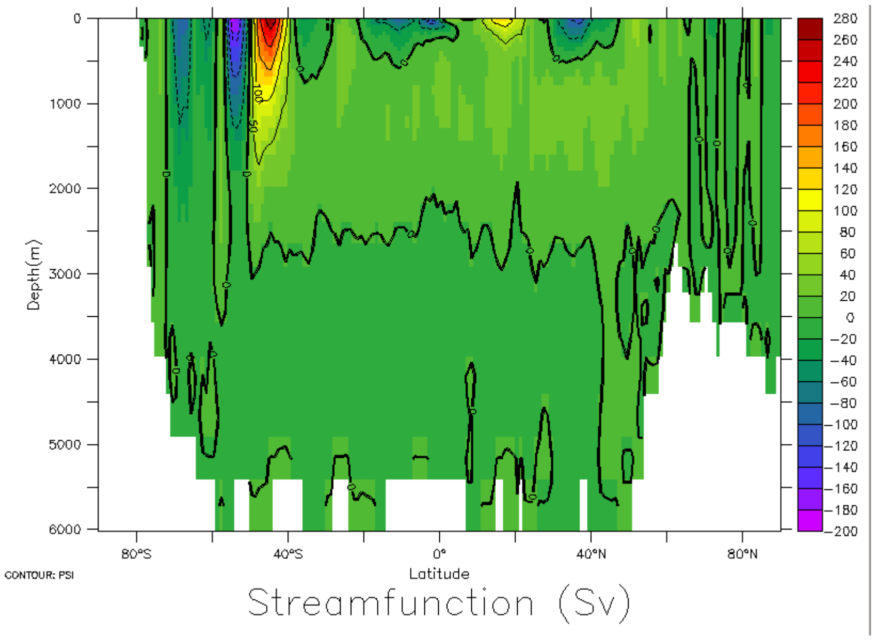

Figure 18: Meridional streamfunction for the Atlantic Ocean, obtained with the MPI Model.

The North Atlantic overturning is clearly visible in the Atlantic plots as a red spot at 40^o N, $500-2000$ m of depth. For the three models, the streamfunction at that location has values approximately 50% larger in the LGM than in the PI-H. In the MPI case, high values for the streamfunction appear at all latitudes south of 40^o N, not just at the North Atlantic.

The Indo-Pacific Ocean has much lower currents than the Atlantic, although we can see an equatorial circulation which is stronger in the LGM. MPI shows a surface circulation at 30^o N, but this is not repeated in the other models.

For the World Ocean, we can see many features combined. The Atlantic overturning is distinctive at 40^o N, with a more spread pattern in the PI-H. There are poleward circulation cells at the surface equatorial region, which could be associated with mid-latitude gyres such as the Brazil Current, the Gulf Current or the Kuroshio Current. The 10 Sv cell in the southern ocean could be associated with the Antarctic Circumpolar Current.

5 Conclusions

We observe stronger current patterns in the LGM than in the PI-H, indicating that the characteristics of the atmosphere and cryosphere at that period had a visible influence in the ocean circulation.