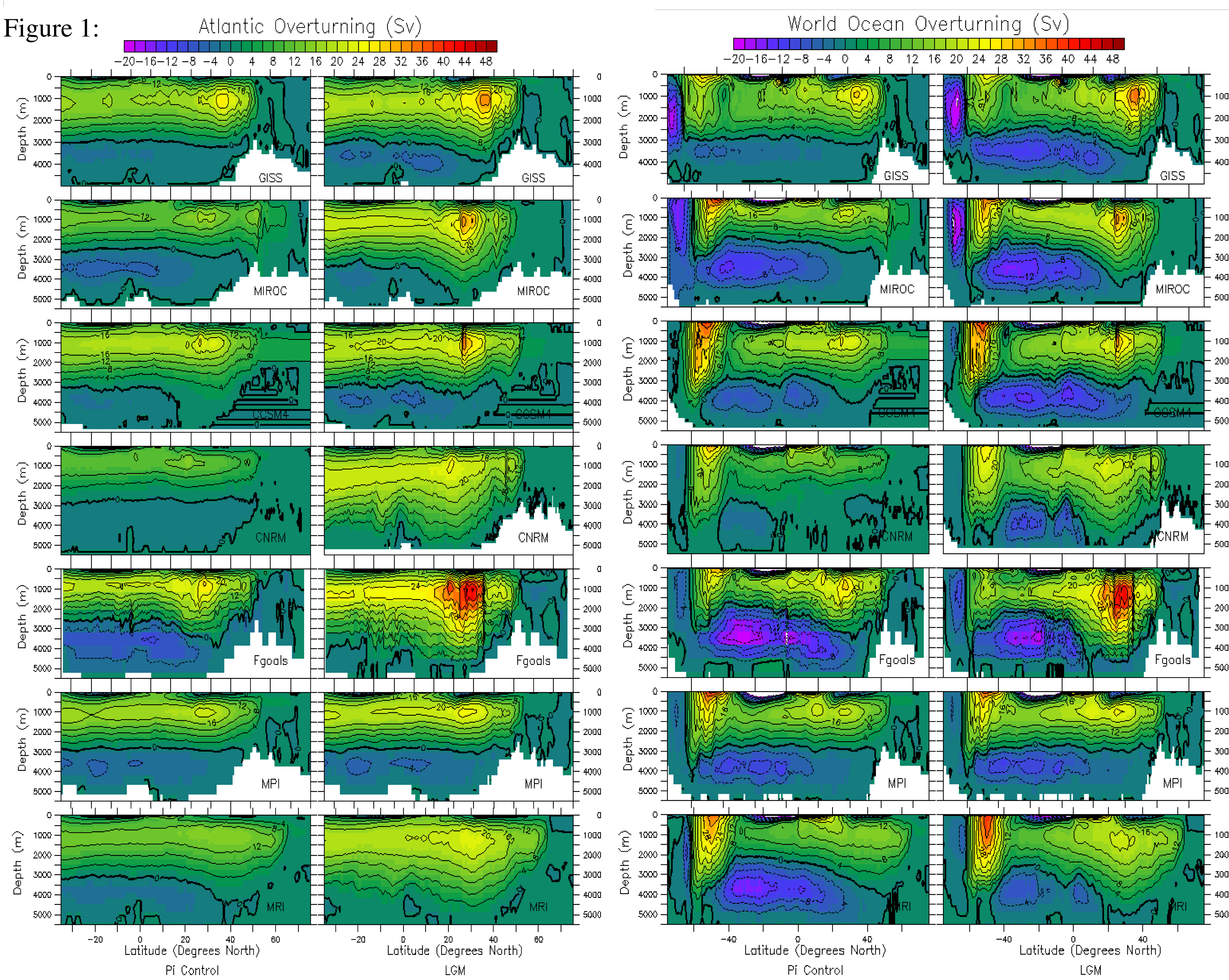
Ocean Circulation During the Last Glacial Maximum Simulated by PMIP3 Climate Models

Juan Muglia and Andreas Schmittner (College of Earth, Ocean, and Atmospheric Sciences, Oregon State University)

Meridional Streamfunction: Computer simulated meridional streamfunction data were obtained from several PMIP3 models, from the Last Glacial Maximum (LGM, ~20,000 years ago) and the pre-industrial Holocene. Meridional streamfunction has units of volume transport, and is a measure of the strength of the zonally-integrated meridional water flow in an ocean. We evaluated the difference between both time periods, by taking 50 year averages, and subtracting, for each model, the averaged values for the LGM and the pre-industrial Holocene streamfunction. Results can be seen in Figure 1. Positive Streamfunction values correspond to clockwise circulation.

Models used are GISS (Goddard Institute for Space Studies, USA), MIROC (Model for Interdisciplinary Research on Climate, Japan), CCSM4 (Community Climate System Model 4, USA), CNRM (National Centre for Meteorological Research, France), Fgoals (Flexible Global Ocean-Atmosphere-Land System Model, China), MPI (Max Planck Institute, Germany) and MRI (Meteorological Research Institute, Japan).

Figure 1:

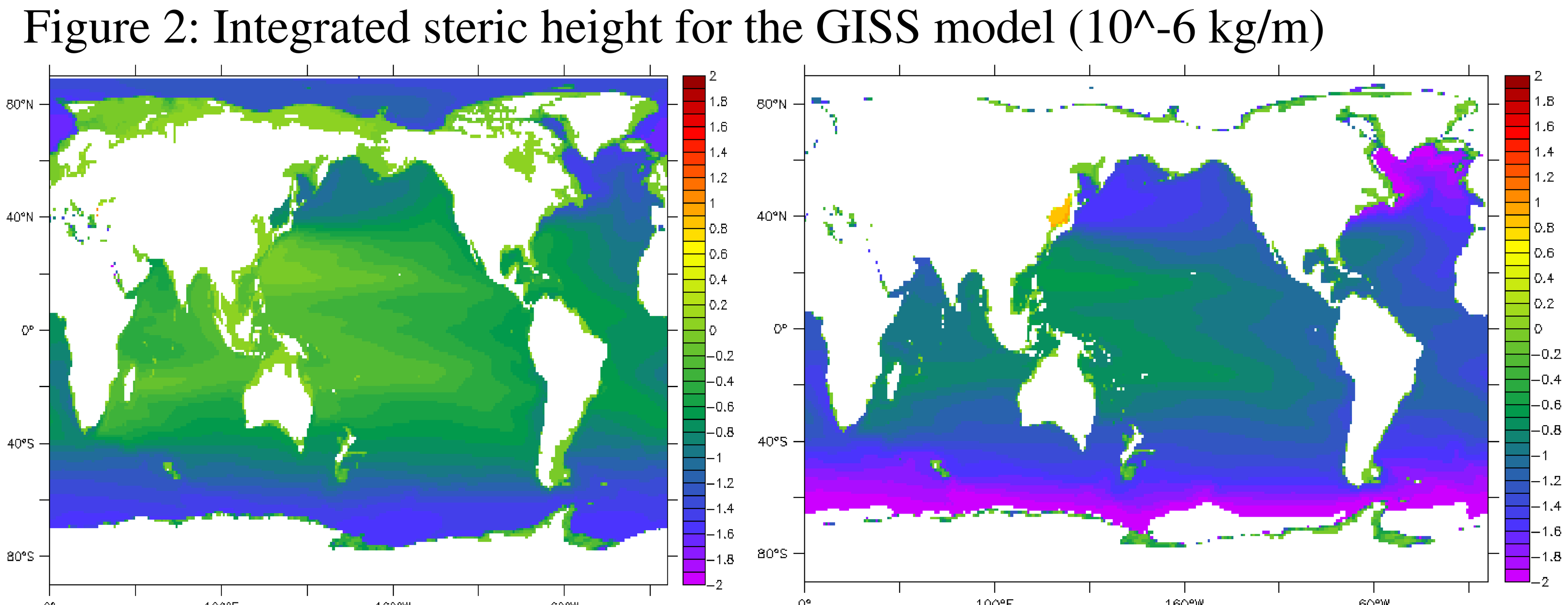


We observe an increase in the intensity of the Atlantic Overturning Circulation (distinguished by the local maximum at approximately 30º N in both sets of plots) between the PI control and the LGM. To quantify this increment, we obtained the maximum value of positive overturning at 25º N, and for each model calculated the difference between the LGM and the PI control values. The percentage of increase, averaged over all models, is 40 %.

In the plot corresponding to the World Ocean Circulation, an increase in the Deep Circulation, associated with the Antarctic Bottom Water, can be observed for the GISS, MIROC, CNRM, CCSM4 and MPI models. On the contrary, in the Fgoals and MRI cases a decrease occurs. The Atlantic Ocean shows a weak increase in the deep circulation, with higher values in the LGM for the GISS, CCSM4 and MPI models.

Integrated Steric Height: From potential density data, we integrated zonally-averaged densities over the top 1000 m of the water column, as explained in Godfrey[1], to obtain the *depth integrated steric height,* P. This dynamical quantity is related to meridional transport by the thermal wind relation (Talley [2]), which balances water transport with the integrated geostrophic pressure gradient.

Figure 2: Integrated steric height for the GISS model (10^-6 kg/m)

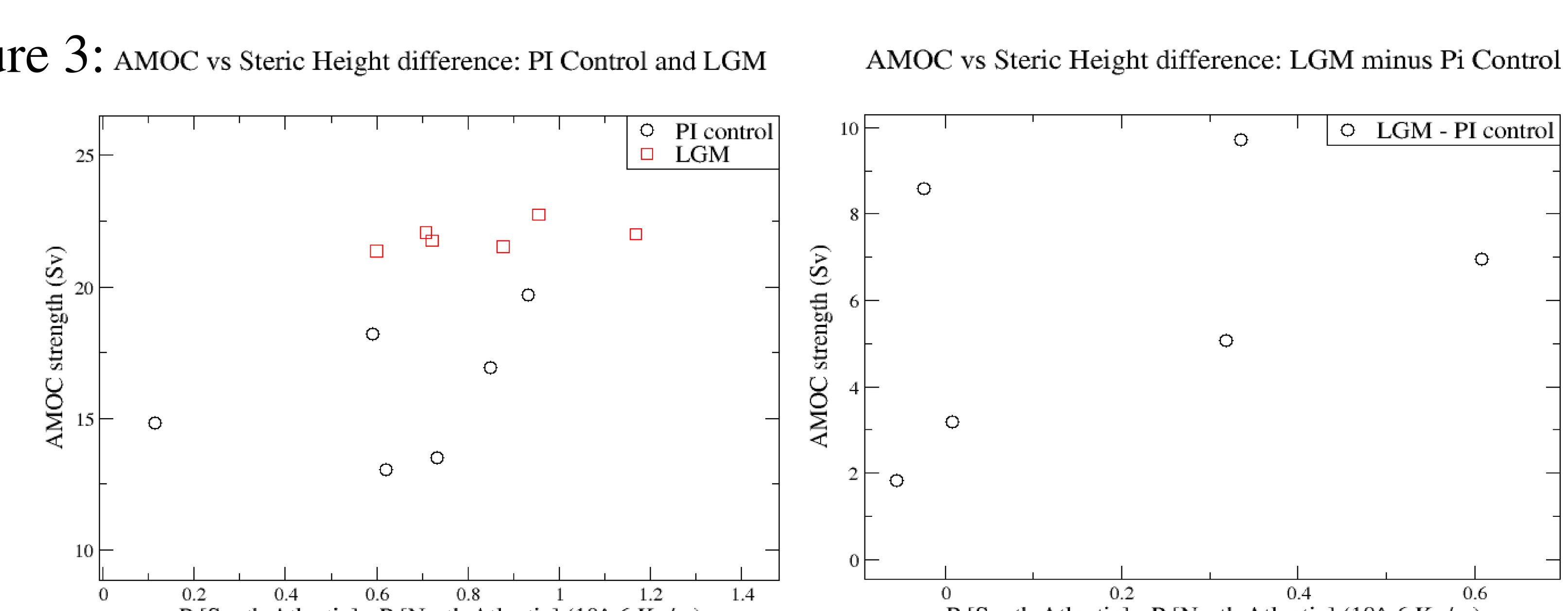


PI control LGM

A decrease in the integrated height accounts for the lower sea level in the LGM.

Models with a stronger AMOC present a stronger difference between the southern and northern Atlantic values (Figure 3, left panel). This difference increases by 20% (averaged over all models) in the LGM, although we do not find a correlation between this and the AMOC changes (Figure 3, right panel). To obtain the integrated steric height differences between S. and N. Atlantic, we used the method explained in Hughes et al. [3]

Figure 3:



Conclusions: We observe a strengthen of the AMOC in the LGM, although more physical variables are needed to be studied to find the physical processes governing this difference. In the future we will study horizontal gradients of the integrated steric height, and differences between densities of the water masses as well as the impact on ocean carbon storage.

References: [1] Godfrey J. S., Geophysics. Astrophysics. Fluid Dynamics, Vol. 45, pp. 89-112 (1988).
[2] Talley L. D., Pickard G. L., Emery W. J. and Swift L. H., *Descriptive Physical Oceanography* (sixth ed.), Elsevier (2012).
[3] Hughes T. and Weaver A., Journal of Physical Oceanography, Vol. 24, pp. 619-637 (1994).

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CEOAS
College of Earth, Ocean, and Atmospheric Sciences

OSU Oregon State University