ATM S 559 Homework 4: Ocean Analysis

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Ensemble mean output from the Large Ensemble shows SST increase everywhere but the northern North Atlantic for the epoc 2030-2049 relative to 1980-1999. This is likely the result of slowing oceanic circulation, and analyses of the meridional overturning circulation, the barotropic stream function, and northward heat transport back this conclusion.

Introduction and Overview

In the ensemble mean of the Large Ensemble Community Project (LE) with RCP8.5, the sea surface temperature (SST) increases from 1980-1999 to 2030-2045 everywhere except for the the North Atlantic, as exhibited in Figure 1.

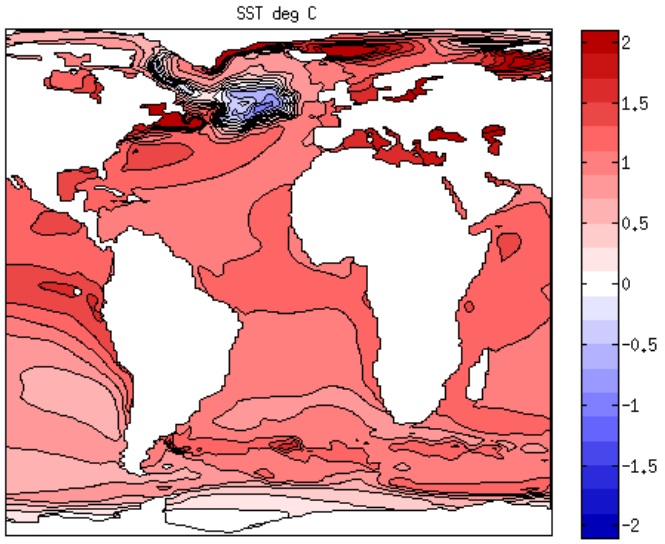

Figure 1: The sea surface temperature change in 2030-2049 versus 1980-1999.

Analysis of output from the 30 ensemble members in the LE attempts to explain why this is the case. Particularly, the meridional overturning circulation stream function (MOC), the barotropic stream function, and the northward heat transport are examined for different epocs.

Results

The MOC

First, it is useful to plot the MOC for the ensemble mean for the epocs of interest.

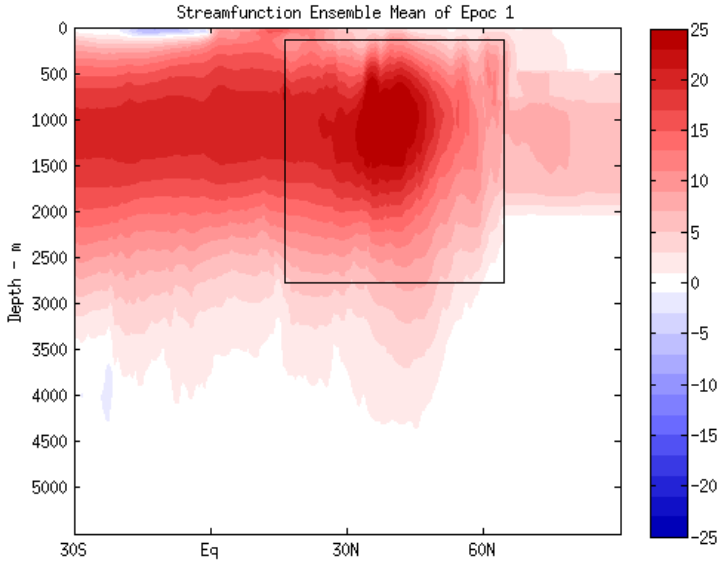

Figure 2: The MOC for the 1980-1999 ensemble mean. The boxed region highlights a large, downward mass transport in the North Atlantic.

Strong downward mass transport, deep water formation[1], is clear in the North Atlantic in Figures 2 and 3. However, subtracting the MOC for 1980-1999 from 2030-2049 reveals a decrease in the stream function. In the North Atlantic, that decrease is up to 10 Sv.

[1] Hugues Goosse, PY Barriat, W Lefebvre, MF Loutre, and V Zunz. *Introduction Climate Dynamics and Climate Modelling*. Université catholique de Louvain, 2008

The MOC Index

Next we look at the MOC index, shown in Figure 5. This index is built by taking the maximum of the stream function in the boxed region in the previous figures. Again, we see the MOC decreasing over time, and the spread of the ensemble members decreases after 2000, indicated by the standard deviation of the index[2]. Just looking at the index, the ensemble members seem to become independent of the initial condition sometime near 1940[3].

[2] I am not sure how to know if the spread is not altered by anthropogenic forcing. Would that require subtracting an ensemble control run (say 1850 CO_2 levels) to determine?

[3] This seems far into the simulation to be influenced by the initialization. I could be wrong. It does seem like comparing 1980-1999 to 2030-2049 is still safe.

Statistical Significance

Another way to see the change in the MOC index is to compare the ensemble means for three epocs (1940-1959, 1980-1999, and 2030-

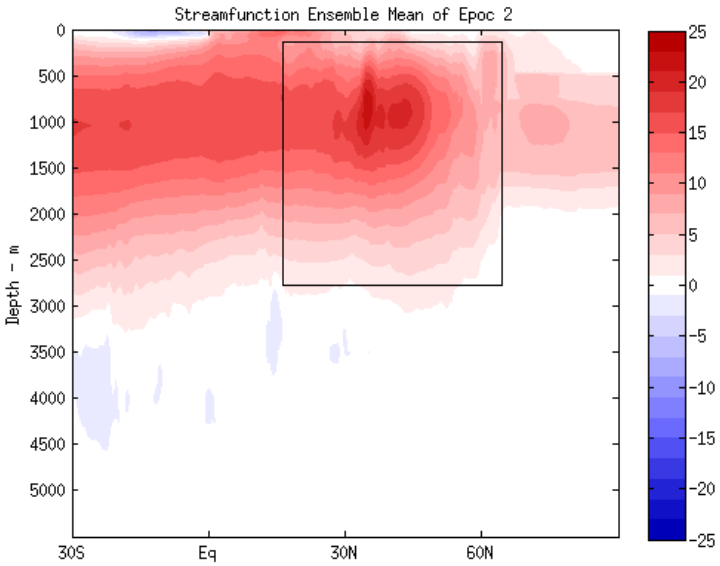

Figure 3: The MOC for the 2030-2049 ensemble mean. The boxed region highlights a large, downward mass transport in the North Atlantic.

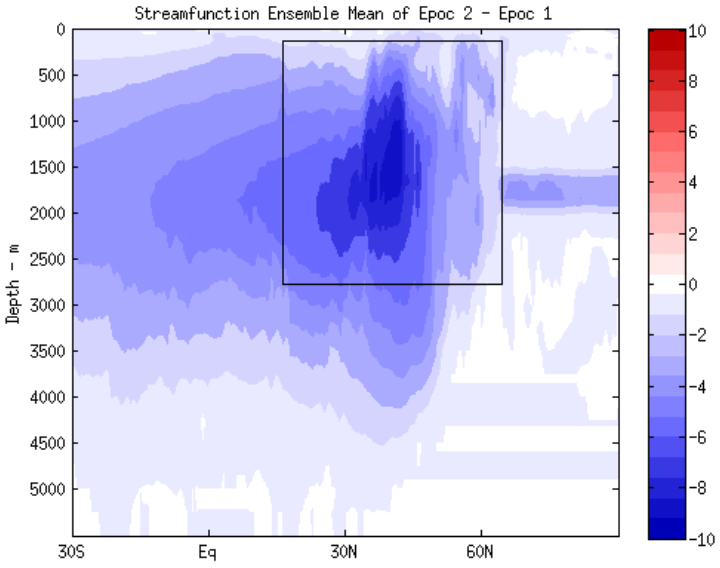

Figure 4: The difference the the MOC for the ensemble means between the 2030-2049 and 1980-1999 epocs.

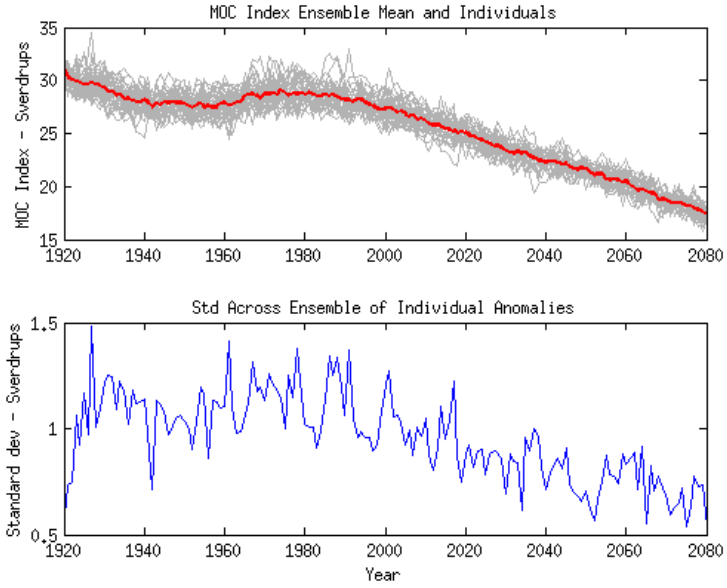

Figure 5: The index of the MOC for the ensemble between the 1920 and 2080 and the standard deviation of the index.

	Standard Error	Threshold	N_{min}
1940-1959 vs. 1980-1999	0.4010	0.3714	50
1980-1999 vs. 2030-2049	-1.5705	0.3714	4

Table 1: Comparison of standard error, threshold, and N_{min} between epocs.

2049). Figure 6 emphasizes the decrease in MOC index for the epoc 2030-2049 relative to the other two epocs.

Further, a significance test can show whether the ensemble means for two epocs are different. If the standard error (SE) of the difference in means is below a threshold value, then the ensemble means (X) are different, where SE $= |X|/\sigma$, and the threshold $= 2/\sqrt{N-1}$, N being the number of ensemble members. Table 1 summarizes the significance tests and indicates the minimum number of ensemble members (N_{min}) needed to reject the null hypothesis if the result is significant. As expected from looking at the histogram, the epoc means of 1940-1959 and 1980-1999 are not different, but the mean from 2030-2049 is significantly different.

Barotropic Stream Function

The barotropic stream function (BSF) for the North Atlantic gives another clue about our anomalous SST. Figures 7 and 8 show the direction of flow for the BSF in the North Atlantic for 1980-1999 and 2030-2049, respectively. In the 2030-2049 epoc, we see the boxed region slowing relative to the 1980-1999 epoc (as does the North Atlantic Gyre). Subtracting the two BSFs from each other verifies that

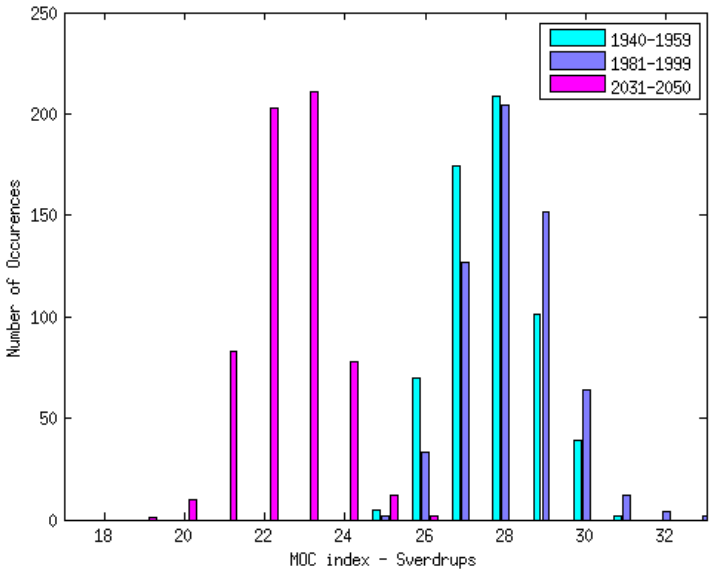

Figure 6: The index of the MOC for the ensemble between the 1920 and 2080 and the standard deviation of the index.

our region of interest has slowed.

Plotting the index of the BSF minimum stream function for the sub polar gyre (Figure 10) shows the sub polar gyre weakening.

Atlantic Northward Heat Transport

Lastly we look at northward heat transport for the Atlantic. The top panel in Figure 11 indicates a decrease in northward heat flux between the 1980-1999 and 2030-2049 epocs. The middle panel shows a decrease in northward heat flux at 39.4 N, and the bottom panel shows an increase in northward heat flux at 76.8 N–both are additional indicators of slowed North Atlantic Currents.

Summary and Conclusions

So why has the rest of the ocean warmed in the LE while the North Atlantic cooled? It seems to be the result of slowed oceanic currents. Ensemble means of both the MOC and BSF show a decrease in the volume of warm water being delivered to the North Atlantic. Analysis of northward heat flux in the Atlantic corroborates this finding, and the warm water that is not transported downward in our region of interest is remaining near the surface and staying warm.

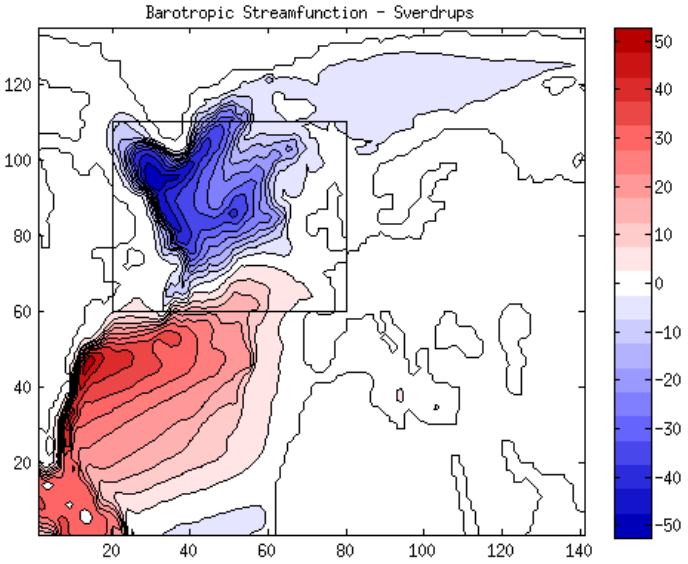

Figure 7: The BSF for the North Atlantic for 1980-1999. Blue indicates counterclockwise flow.

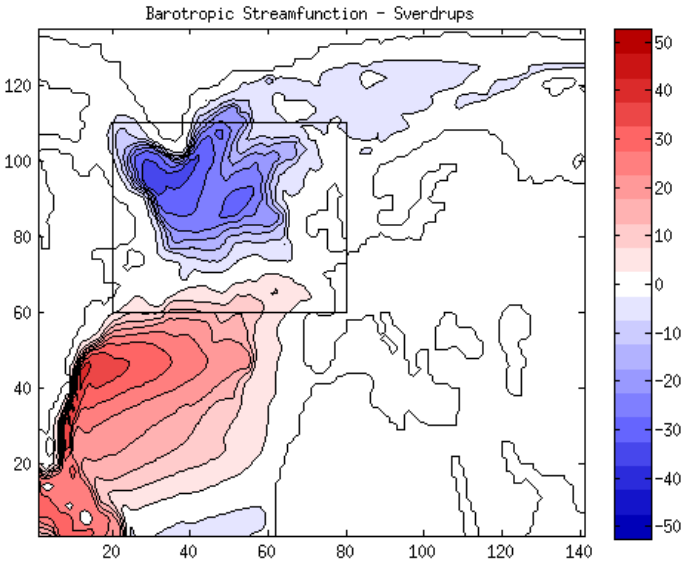

Figure 8: The BSF for the North Atlantic for 2030-2049. Blue indicates counterclockwise flow.

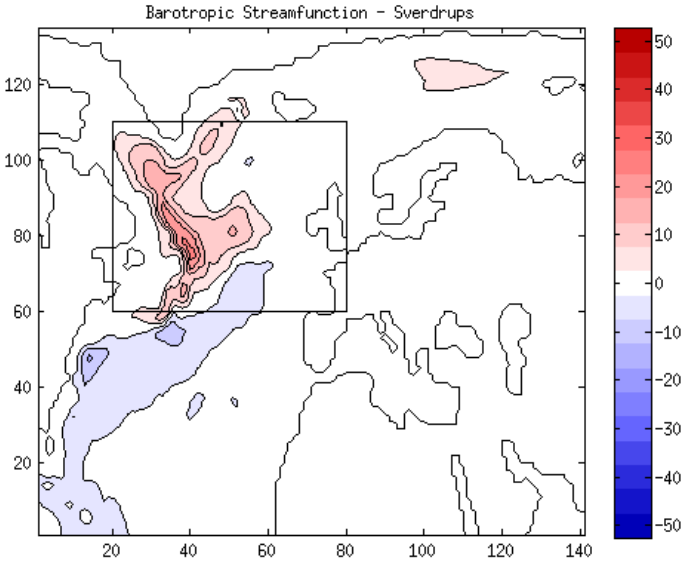

Figure 9: The difference in BSF for the North Atlantic between 1980-1999 and 2030-2049. Blue indicates counterclockwise flow.

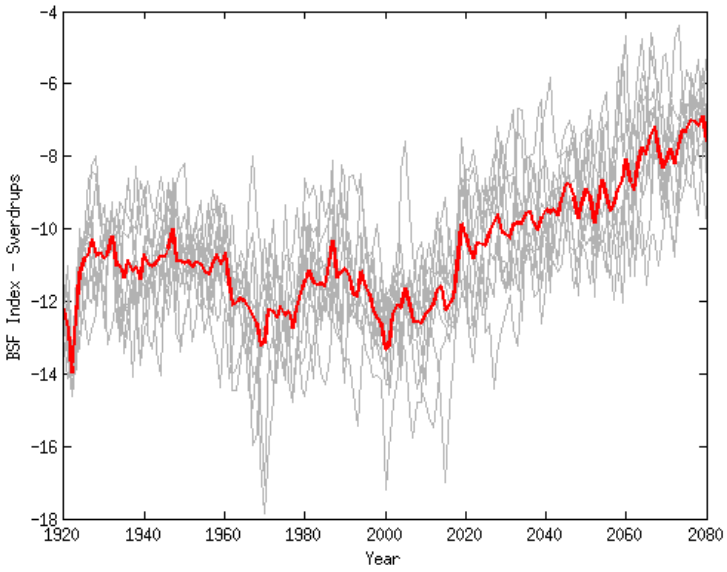

Figure 10: BSF minimum stream function index, indicating a weakening sub ploar gyre.

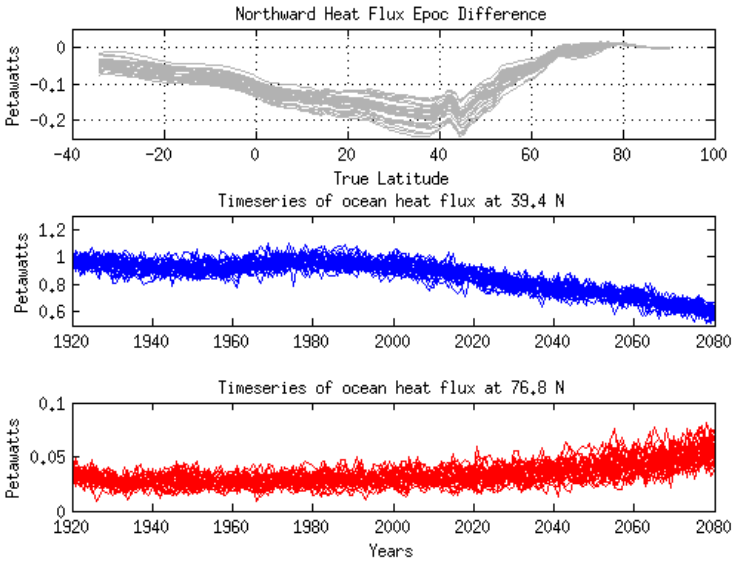

Figure 11: Top: The difference in northward heat flux between the 1980-1999 and 2030-2049 epocs, Middle: Ocean heat flux at 39.4 N over time, Bottom: Ocean heat flux at 76.8 N.

References

[1] Hugues Goosse, PY Barriat, W Lefebvre, MF Loutre, and V Zunz. *Introduction Climate Dynamics and Climate Modelling*. Université catholique de Louvain, 2008.