Southward Pathways of the Upper and Lower North Atlantic Deep Water and their Impact on Atlantic Meridional Heat Transport

Sang-Ki Lee[1] (Sang-Ki.Lee@noaa.gov), Marlos Goes[2,1], Hosmay Lopez[2,1], Shenfu Dong[1], Yanyun Liu[3], and Molly Baringer[1]

[1]Atlantic Oceanographic and Meteorological Laboratory, NOAA, Miami, FL, [2]Cooperative Institute for Marine and Atmospheric Studies, University of Miami, Miami, FL, [3]Climate Prediction Center, NOAA, College Park, MD

Summary

The climate models that participate the Coupled Model Intercomparison Project phase 5 (CMIP5) show a coherent spatial pattern of inter-hemispheric global sea surface temperature (SST) biases, which is closely linked to the strength of simulated AMOC **(Figure 1)**. The models with a weaker AMOC are associated with cold SST biases in the entire Northern Hemisphere, and vice versa for the models with a stronger AMOC **(Figure 2)**. In many of the CMIP5 models, however, the amplitudes of the AMOC agree very well with or are even larger than the observed value of about ~18 Sv at 26.5N; but they still show SST biases in the North Atlantic **(Figure 2)**.

This suggests that the sea surface temperature biases are not a reflection of underestimated AMOC strength and but is more related to an underestimated heat transport. A common symptom in these models is that the southward returning flow of the AMOC at depth is too shallow **(Figure 3)**. A shallow returning flow of the AMOC would carry relatively warmer water southward; thus the net northward heat transport by the AMOC would be weaker than the observed heat transport. Therefore, we hypothesize that the CMIP5 models produce too much upper North Atlantic Deep water (NADW) over the Labrador Sea, and too little lower NADW in the GIN Seas (the Greenland, Icelandic and Norwegian Seas).

To test the above hypothesis, we performed two ocean & sea-ice coupled model simulations using GFDL's Modular Ocean Model version 4.1. The first one is a global simulation forced with CORE2 surface flux fields. The second one is a regional model simulation for the North Atlantic with its temperature & salinity at the northern and southern boundaries relaxed to observations. The regional model simulation produces a more realistic southward return flow of the AMOC at 26.5N, although it is still too shallow compared to the observation **(Figures 4 and 5)**. The relationship between the AMOC strength and the meridional heat transport is also improved in the regional model run **(Figure 6)**.

Another modeling approach is to artificially decrease the upper NADW formation and increase the lower NADW formation, by increasing surface freshwater flux by *F* Sv over the Labrador Sea and decreasing it by -*F* Sv over the GIN Sea **(Figure 7)**. This model simulation using CESM1 is currently in progress.

Global SST bias and its relationship with the AMOC

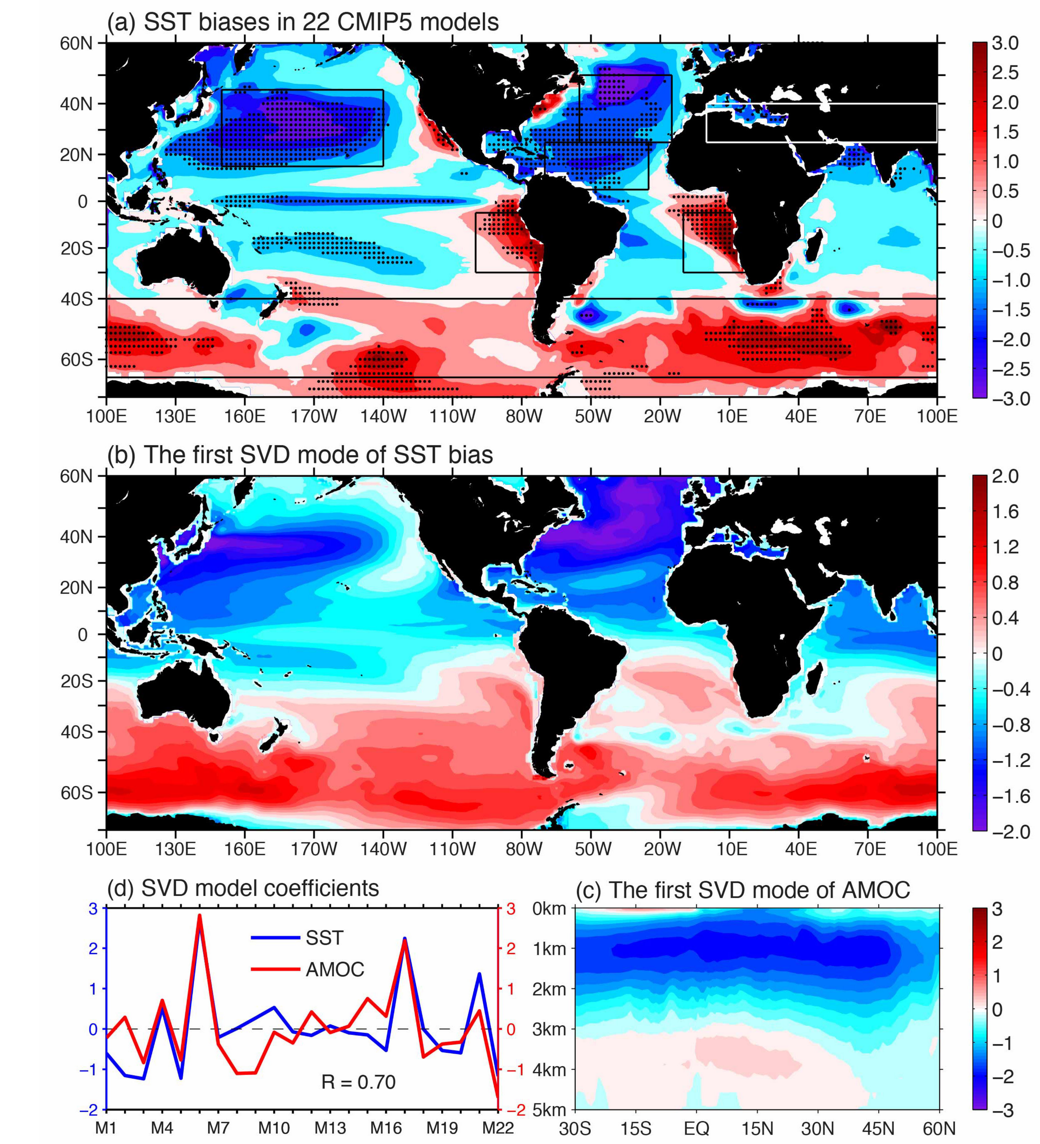

Figure 1. (a) The annual-mean SST bias averaged in 22 climate models. The SST bias is calculated by the SST difference between the model SST and extended reconstructed SST. The dots denote where at least 18 of 22 models (82%) have the same sign in the SST bias. The rectangles represent the focused regions. **(b,c)** Spatial maps of SST bias and the AMOC for the first inter-model SVD mode (accounting for 45% of total covariance). **(d)** Their corresponding coefficients. The x-axis in **d** represents different models. The coefficients were normalized by their own standard deviations (Reproduced from Wang et al. 2014)

Relationships of SST bias in the North Atlantic with the AMOC & SST bias in the North Pacific

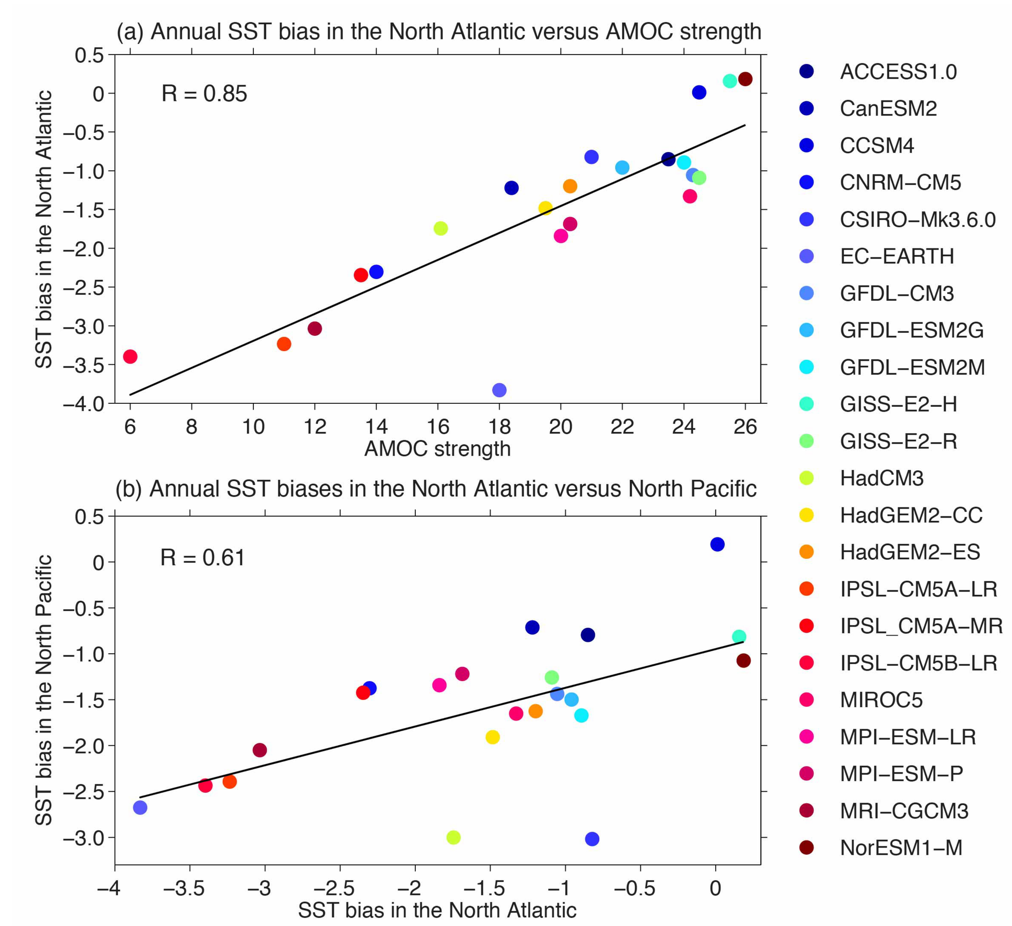

Figure 2. (a) Scatter plot of annual-mean SST bias in the North Atlantic (55°W-15°W, 25°N-50°N) versus AMOC strength. **(b)** Scatter plot of annual-mean SST bias in the North Pacific (150°E-140°W, 15°N-45°N) versus the annual-mean SST bias in the North Atlantic. The inter-model correlation R is shown in the left-upper side of each panel (Reproduced from Wang et al. 2014).

Long-term mean AMOC streamfunction in CMIP5 historical simulations.

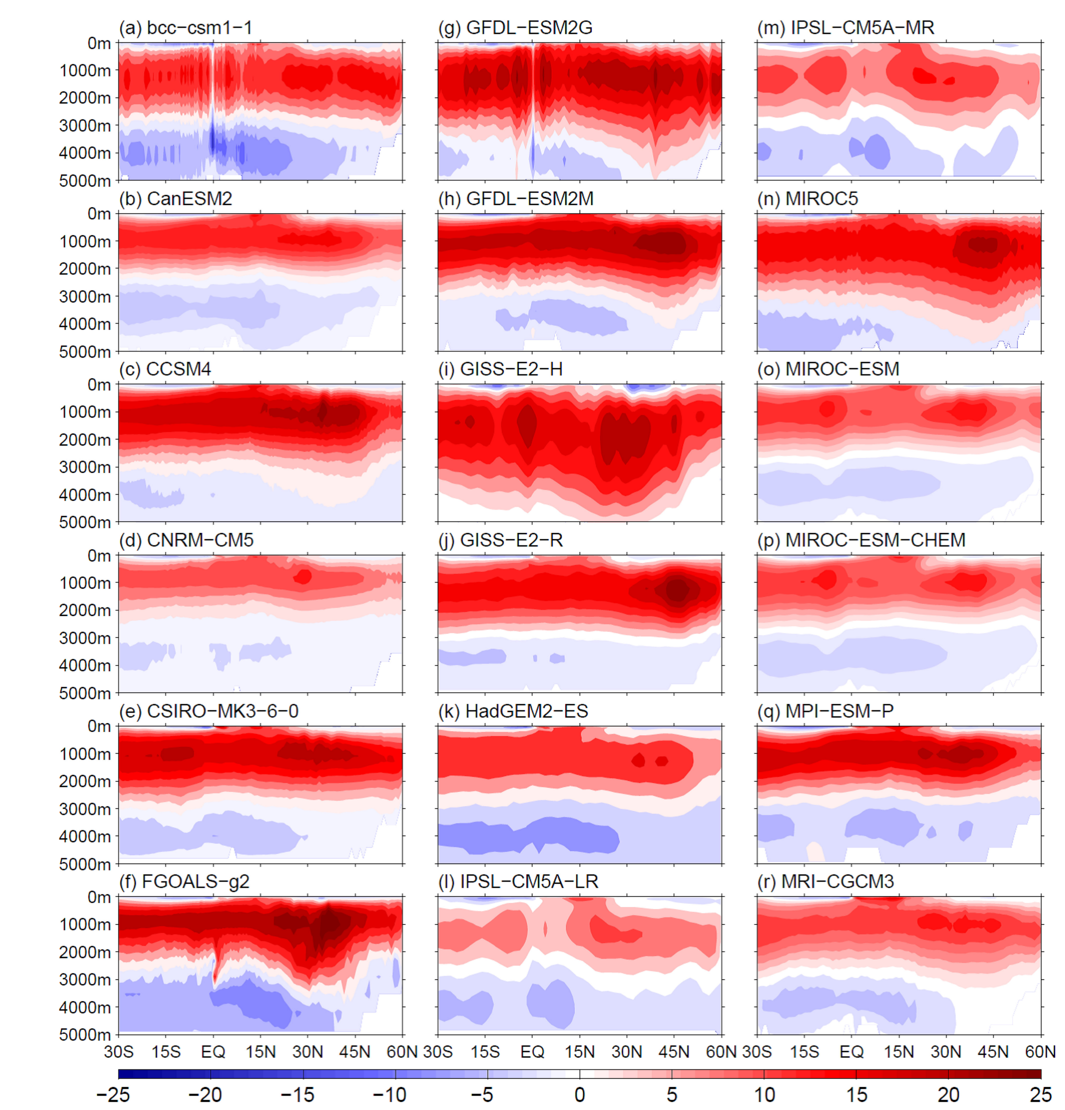

Figure 3. Long-term mean AMOC streamfunction in CMIP5 historical simulations. Units are in Sv (Reproduced from Zhang and Wang et al. 2013).

Time-averaged AMOC in global and regional MOM4p1 simulations

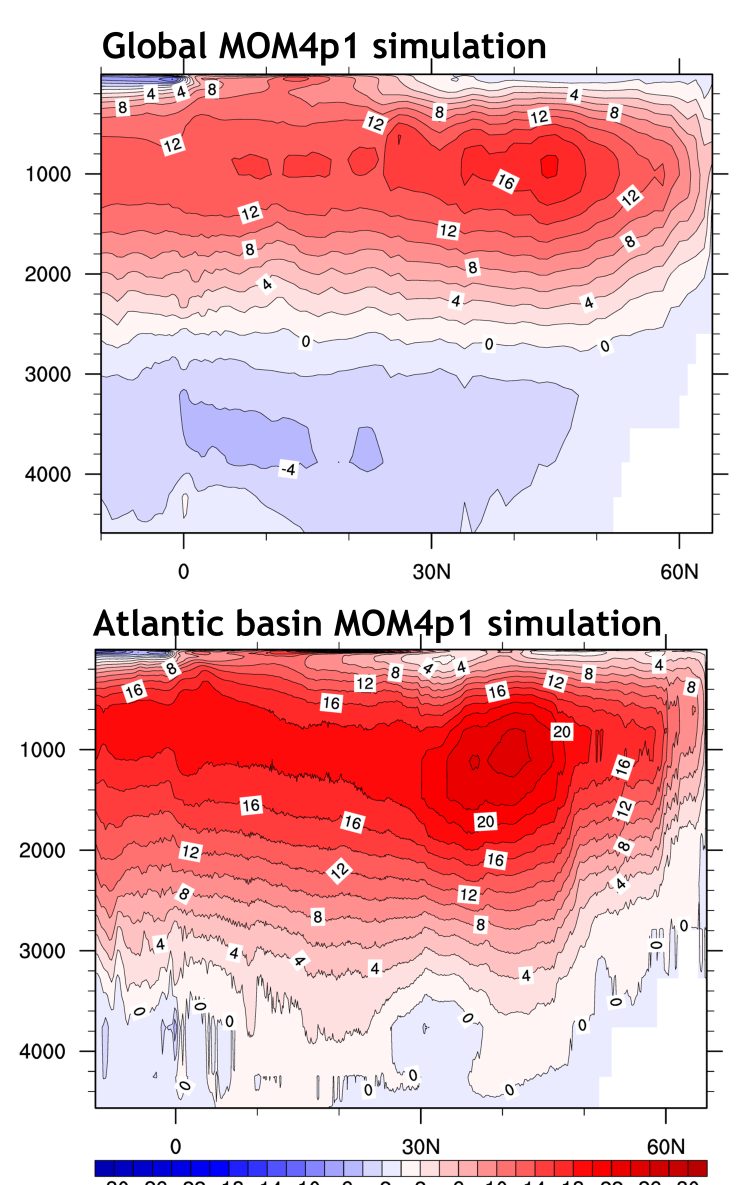

Figure 4. Time-averaged AMOC in the late 20th century obtained from surface-forced MOM4p1 simulations. The upper panel is based on a global model simulation, while the lower panel is based on a Atlantic basin model simulation with the model's temperature and salinity in the Labrador Sea and GIN Seas relaxed to long-term mean observations (Reproduced from Liu et al., 2015).

AMOC Streamfunction at 26.5°N

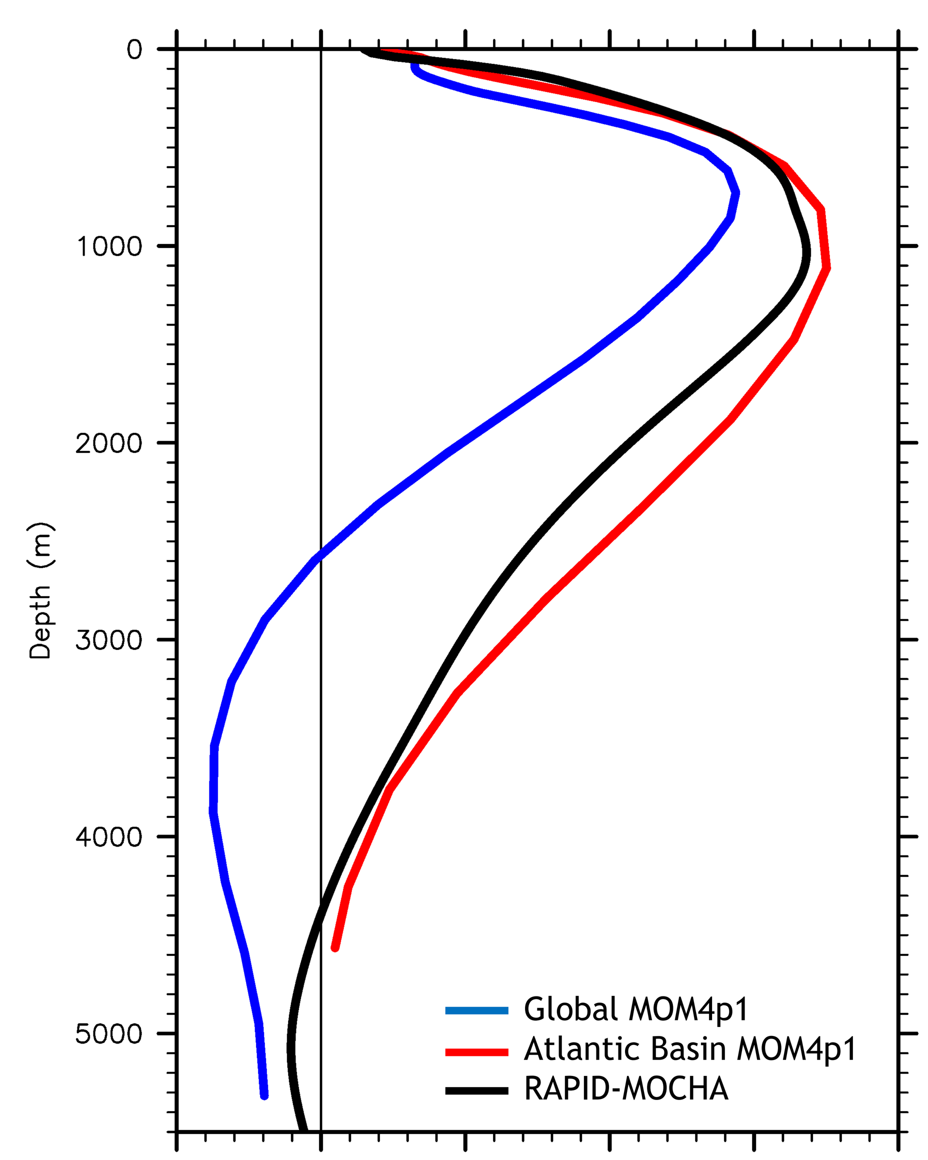

Figure 5. AMOC streamfunction at 26.5°N obtained from the 10-year averaged (April 2004 - March 2014) RAPID-MOCHA array data and from the global and regional MOM4p1 simulations.

Maximum AMOC transport against meridional heat transport evaluated at 26.5°N

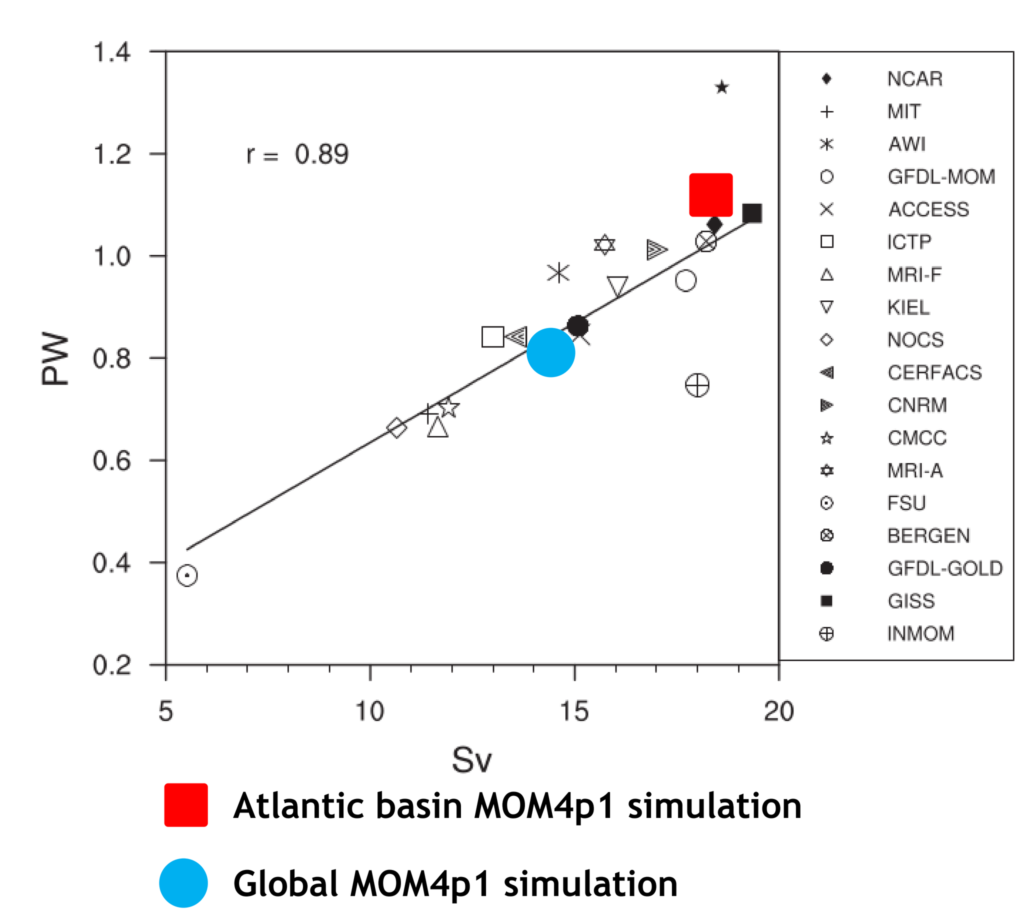

Figure 6. Scatter plot of the maximum AMOC transport against meridional heat transport (MHT), both evaluated at 26.5°N obtained from the 18 models participating CORE2. The model data are for the time-mean. The solid star denotes the observational AMOC and MHT estimates from the RAPID-MOCHA array data. The red box is from the Atlantic basin MOM4p1 simulation, while the blue circle is from the global MOM4p1 simulation. The regression line and correlation coefficient are also shown. (Reproduced from Danabasoglu et al., 2014).

Proposed CESM1 Experiments

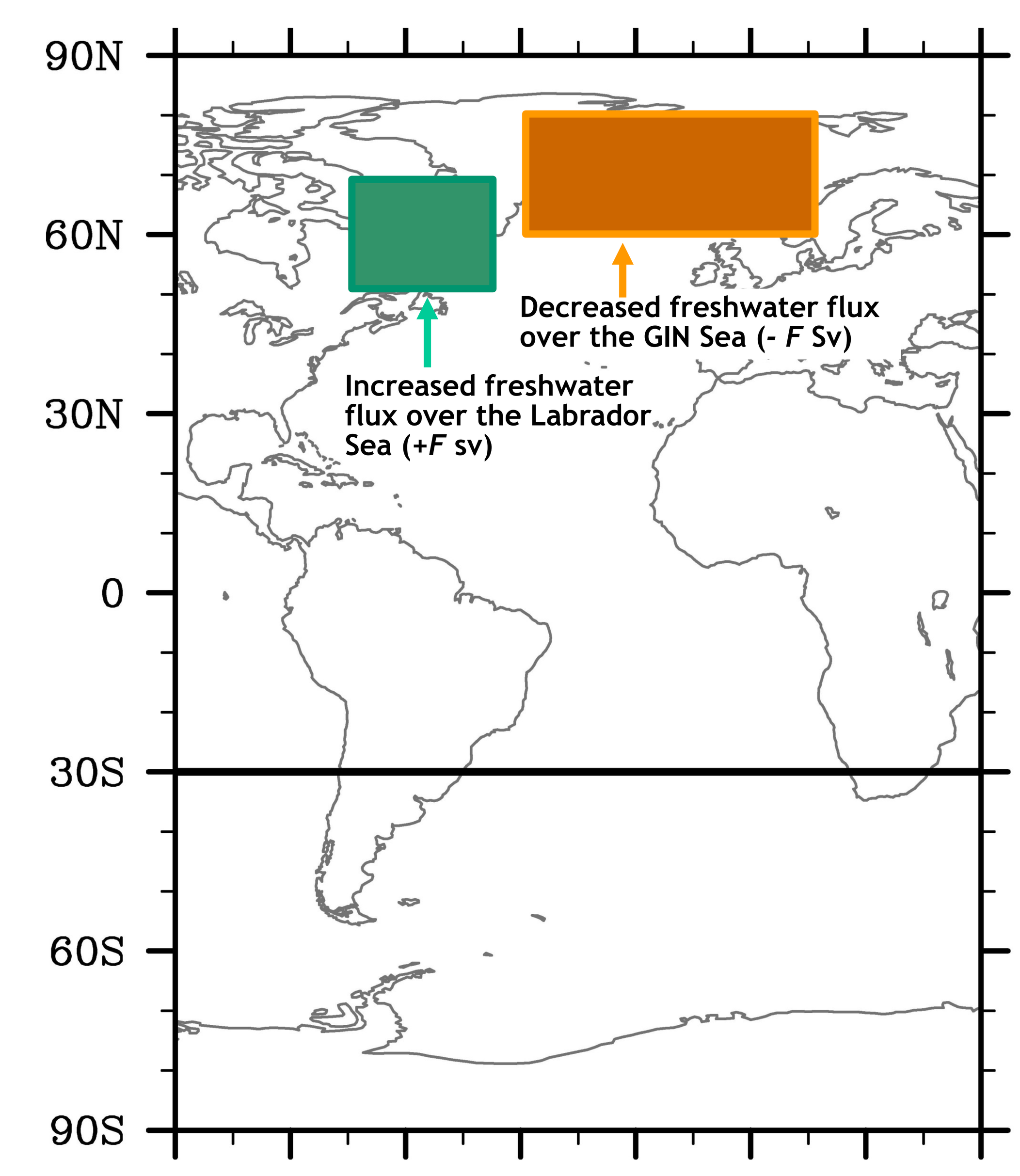

Figure 7. Proposed CESM1 experiment. In this ocean & sea-ice coupled model experiment, we want to artificially decrease the upper NADW formation and increase the lower NADW formation by increasing surface freshwater flux by *F* Sv over the Labrador Sea and decreasing it by -*F* Sv over the GIN Sea.