Implementation of hosing in CESM experiments to study AMOC stability at IMAU

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1 Introduction

The Atlantic meridional overturning circulation (AMOC) is an important part of our climate system. The AMOC is predicted to weaken under climate change and there are theories that it may have a tipping point beyond which recovery is difficult. A common way to study this is by doing so called hosing experiments with a global climate model in which additional freshwater is added to a specific region in the North Atlantic.

At IMAU we work with the Community Earth System Model (CESM) and we use it for two types of hosing experiments: one in which we apply freshwater around the coasts of Greenland and one in which we apply freshwater uniformly in a specific region (e.g. the region north of 50°N in the Atlantic to the Bering Strait at 66°N)

The next section describes how we implement the hosing in CESM as well as two actual hosing experiments (greenland and uniform) that we did at IMAU.

2 Hosing in CESM

In Earth System Models, adding freshwater to the ocean can be done by:

1. NBC (the Natural Boundary Condition), i.e. the freshwater flux is represented as a mass or volume flux across the ocean boundary.
2. VSF (the Virtual Salt Flux), i.e. a representation of the dilution effect of added freshwater on salinity but with no change in ocean volume.

While 1. Is a more realistic representation of the physics than 2. the impact on the difference in formulation on the large-scale circulation have generally been found to be small [1] (see here)

CESM uses the VSF formulation. In the original CESM ocean (POP) code there is no "out-of-the-box" option to support hosing experiments. NCAR however published a general guidance for modellers who are interested in doing hosing experiments on their own (see here).

Without getting too technical it is a matter of adding the extra "hosing" virtual salt fluxes to a certain segment in the code in proper units.

Somehow the model needs to read in these extra fluxes. At IMAU we decided to modify the code such that there is an extra subnamelist called `forcing_imau_nml` in the `pop_in` namelist which looks like this:

```
forcing_imau_nml
imau_blanking = .true.
imau_data_type = 'monthly'
imau_filename = '$HOME/FWForcing/grl_fw_prace_f05_t12/FW_GrIS_AIS_2226.nc'
imau_filename_blanking = '$HOME/FWforcing/blanking_mask/tx0.1v2_blk_mask.nc'.
imau_filename_next = '$HOME/FWforcing/grl_fw_prace_f05_t12/FW_GrIS_AIS_2227.nc'
imau_filename_prev = '$HOME/FWforcing/grl_fw_prace_f05_t12/FW_GrIS_AIS_2225.nc'
```

This particular subnamelist was used for the Greenland hosing experiment described in section 2.1.

With the namelist the user provides freshwater fluxes in 12-monthly files. The fluxes are read by POP and inserted (added) at every timestep. Interpolation is applied when appropriate. As the forcing files are given for each calendar year, 3 files are needed in total: the fluxes for the current model year, the fluxes of previous year (needed for interpolation in early January) and the fluxes of next year (needed for interpolation in late December). The simulation needs to be restarted at every new calendar year to update these file pointers. For uniform hosing experiments all 3 files are the same and the simulation does not have to be restarted every year. Variable names for the liquid and solid fluxes are FW_liquid and FW_solid, respectively. These are hardcoded. The liquid flux is added to POP field ROFF_F (river runoff flux) and the solid flux to IOFF_F (ice runoff flux due to land-model snow capping.

Optionally blanking is applied just before the freshwater fluxes are inserted. The fields ROFF_F and IOFF_F are set to zero on a user-defined mask. In this way flux-replacement designs may be achieved. Cells are blanked where mask > 0.0. The mask variable name in the input file is hard-coded to BLK_MASK. In our own experiments we used blanking for our Greenland hosing simulation (see section 2.1). Here we knew exactly how much freshwater we wanted to 'dump' along the coastal gridpoints of Greenland and put this in the 3 forcing files. You then do not want to add the original freshwater fluxes that the model calculates. The mask option allows you to set the original freshwater fluxes to zero in the masked gridpoints.

For our uniform hosing experiments we simply add extra freshwater to the original freshwater fluxes so blanking is not necessary.

For users who want to implement the hosing in CESM1 themselves, the code and explanation about how to implement it can be found here. The code for CESM2 is slightly different, a github link to this code will be available soon.

2.1 Greenland hosing

In the first experiment in 2014 we ran a high resolution (0.1° ocean, 0.5° atmosphere) present day case with CESM1.0.4 and applied a realistic (approximately 0.1Sv) freshwater flux around the coasts of Greenland. We forced the run with year 2000 greenhousegases (CO_2, CH_4 , N_2O and CFKs). Overflows and tidal mixing are on.

The freshwater forcing was calculated by collegue Jan Lenaerts who made an estimate of freshwater fluxes coming from Greenland (and Antarctica) from now until the 23th century. For our 75 year run we used Jan's Freshwater forcing files of years 2225 until 2300. This way we implemented artificial dumping of freshwater around Greenland (and Antarctica) but also spatial and seasonal as well as inter-annual variation in the forcing. In these last 75 years of Jan's 23 century forcing files the total contribution of freshwater from Greenland is about 3500 Gt per year which is indeed about 0.1 Sv.

Figure 1 shows a ncview screenshot of one of the forcing files (year 2226), mentioned in the previous section. It contains the two fields FW_liquid and FW_solid. Figure 2 shows a screenshot of the used blanking file. It contains the field BLK_MASK containing all the gridpoints in which the original freshwater fluxes that the model calculates are set to zero (green and red ones).

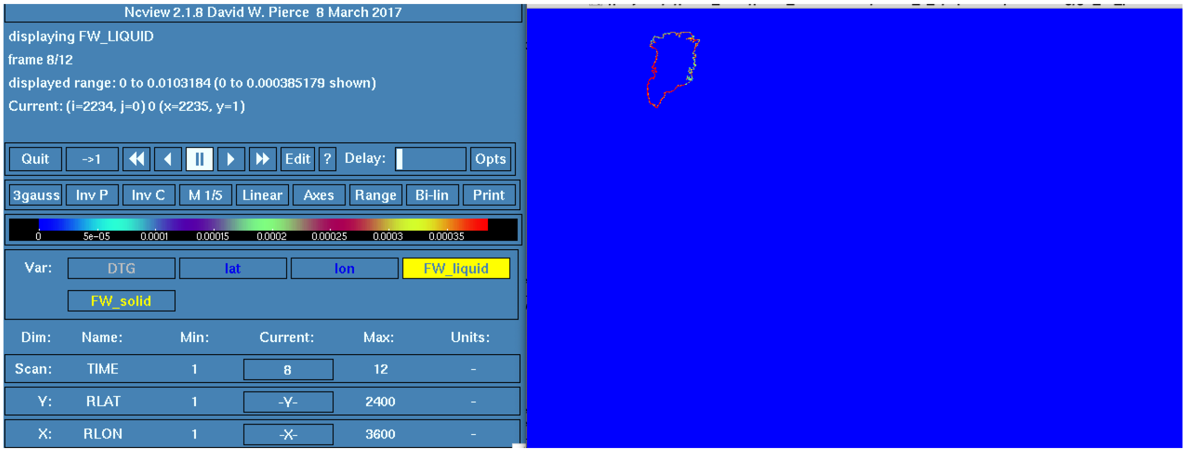

Figure 1: ncview screenshot of greenland hosing file

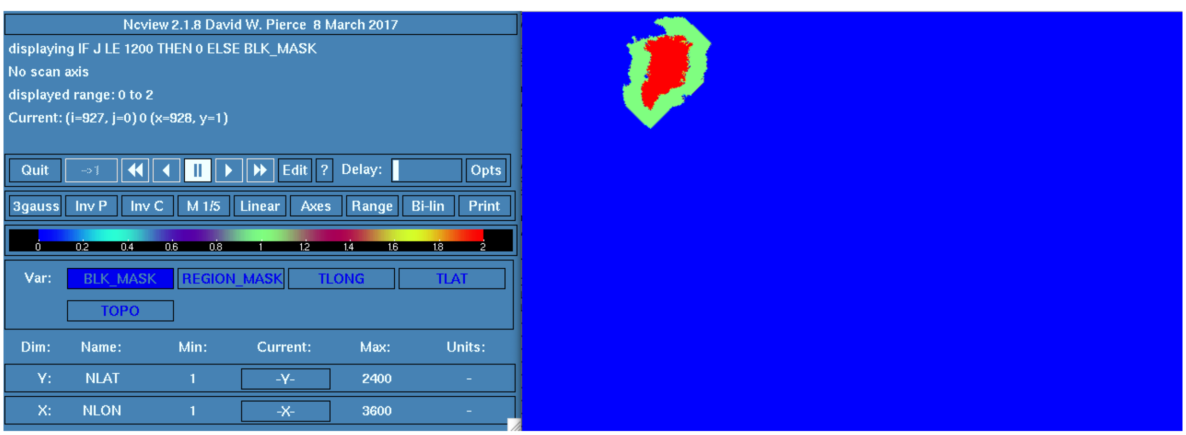

Figure 2: ncview screenshot of greenland blanking file

2.2 Uniform hosing

The second experiment was done in 2018. Here we ran a low resolution (1° ocean, 2° atmosphere) palaeo case (30Ma, Oligocene) with CESM1.0.5 and applied uniform hosing of 0.5 Sv of freshwater, for our case study not in the North Atlantic but in the North Pacific above 45°N in order to try to get the MOC in another state. The same amount of freshwater is added in every ocean in the rest of the world below 45°N to make sure the salt budget is closed. This was done for years 1800-1925. After that the run was continued with the normal freshwater forcing. We forced the run with 2x pre industrial concentrations (2pic) of CO2 and CH4 (and 1pic N2O and CFKs).

To create a hosing field h we first define the region $R1$. For a given hosing of H (in m3/s), a hosing field can then be created:

$$h(i,j) = \frac{H}{\int_{R1} dxdy}.$$

where dx, dy are the zonal and meridional grid spacings, and i and j are the zonal and meridional grid coordinates. Hence

$$\int_{global} hdxdy = H.$$

In our case $H = 0.5Sv$.

Figure 3 shows a ncview screenshot of the hosing file used for this run. The 0.5 Sv is divided over the blue area and has a negative sign because it will be added to the virtual salinity flux. This way the water becomes less salty, representing addition of freshwater. We also divided 0.5 Sv over the red area and here the values have a positive sign. This way the salt budget is closed. The yellow area (all value 0) represents land or gridpoints where no virtual salinity flux is added (everything above 45°N)

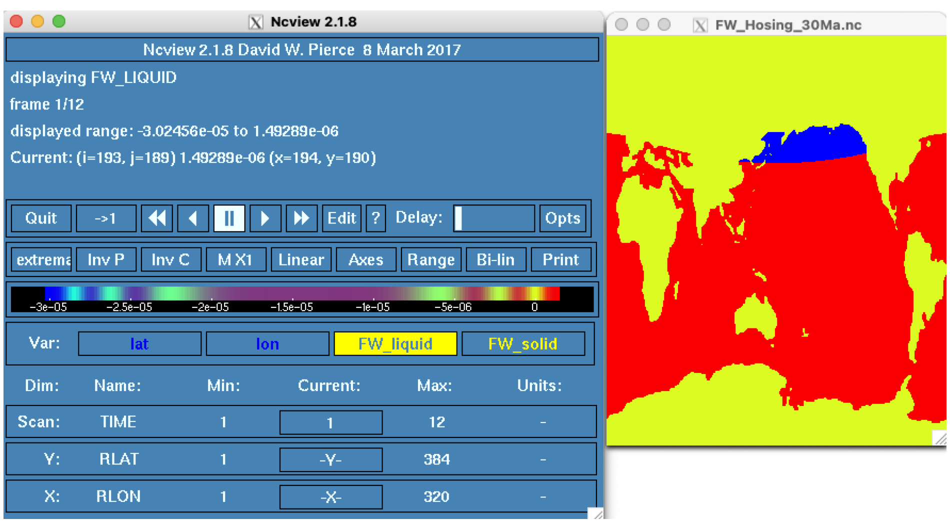

Figure 3: ncview screenshot of uniform hosing file

References

[1] Yu-heng Tseng, Frank O. Bryan, Michael M. Whitney, "Impacts of the representation of riverine freshwater input in the community earth system model", *Ocean Modelling*, pp. 71-86, September 2016.