# Notes on creating CESM ocean-only simulations forced by atmosphere & sea ice & river runoff fields specified from previous coupled simulations

This document describes the technical details of setting up the CESM ocean-only simulations presented in the following paper:

S. Sun, I. Eisenman, and A. Stewart (2016). **The influence of Southern Ocean surface buoyancy forcing on glacial-interglacial changes in the global deep ocean stratification.** *Geophys. Res. Lett.*, 43, doi:10.1002/2016GL070058.

This document is intended as a companion to the paper, and it is posted online along with model output used in the paper at `http://eisenman.ucsd.edu/code.html`.

# Contents

# 1 Introduction

These simulations were run on the NCAR Yellowstone supercomputer. This document and the related model setup files are available at http://eisenman.ucsd.edu/code.html. Other files, including the unprocessed simulation output, can be obtained by emailing the corresponding author: Shantong Sun (shantong@ucsd.edu).

A complication in creating these simulations was that although CESM supports a large number of different configurations with some components of the model replaced by data, it is setup for the fields in the inactive model components to be most readily specified from observational estimates rather than coupled model output. Furthermore, the ocean-only configuration (with specified sea ice), which we used for these simulations, is not widely used.

Note that the simulation names are different in this document from those in the paper. The runs called LGM, Test, and PI in the paper are referred to in this document as LGM.Control, LGM.test, and PI.Control, respectively.

In the sections below, setup details for each of the model components are described.

# 2 ATM

The relevant atmosphere fields are reported in CESM1/CCSM4 coupled runs by the coupler with a frequency of once every 3 hours. Three stream files need to be created under the case directory to allow for specification of shortwave forcing, precipitation, and other fields. These files are copied and modified from files under "$case/CaseDocs/".

## 2.1 offset in the 3 streamfiles

For '*coszen*' interpolation (usually for solar forcing), the time-stamps of the data should correspond to the beginning of the interval the data is measured for; for '*linear*' and '*nearest*' interpolation, the time-stamps of the data should correspond to the middle of the interval the data is measured for. However, the 3-hr data is placed at the end of the 3-hr period in the coupler history file (check variables *time* and *time_bounds* in the data file).

To fix this, offset within the stream files should be set -10800 for '*coszen*' and -5400 for the other interpolation method. This becomes an issue because the time-stamps for the 3-hr coupler history data can be different for different coupled runs. Typical patterns resulting from incorrect offset is presented in Fig. 1 in comparison to Fig. 2. It is seen that tracks of the diurnal cycle can be observed in the difference as in the third panel of Fig. 1, and the global-mean net shortwave forcing is considerably biased to give less shortwave forcing. Similar patterns of difference can also be observed if the albedo option is set incorrectly, as will be discussed in the next subsection.

## 2.2 albedo

By default, the albedo of ocean is set as a constant around 0.06 if CPL_ALBAV='true' (default) defined in 'env_run.xml'. In this case, 'coszen' interpolation cannot be used (a pattern similar to Fig. 1 will emerge and make the model crash). If 'linear' interpolation is applied in combination with the constant albedo, this will give a biase in the net shortwave forcing of around $-3\mathrm{W/m^2}$ (see Fig. 4). If CPL_ALBAV is turned off, the albedo should be consistent with that in the fully coupled

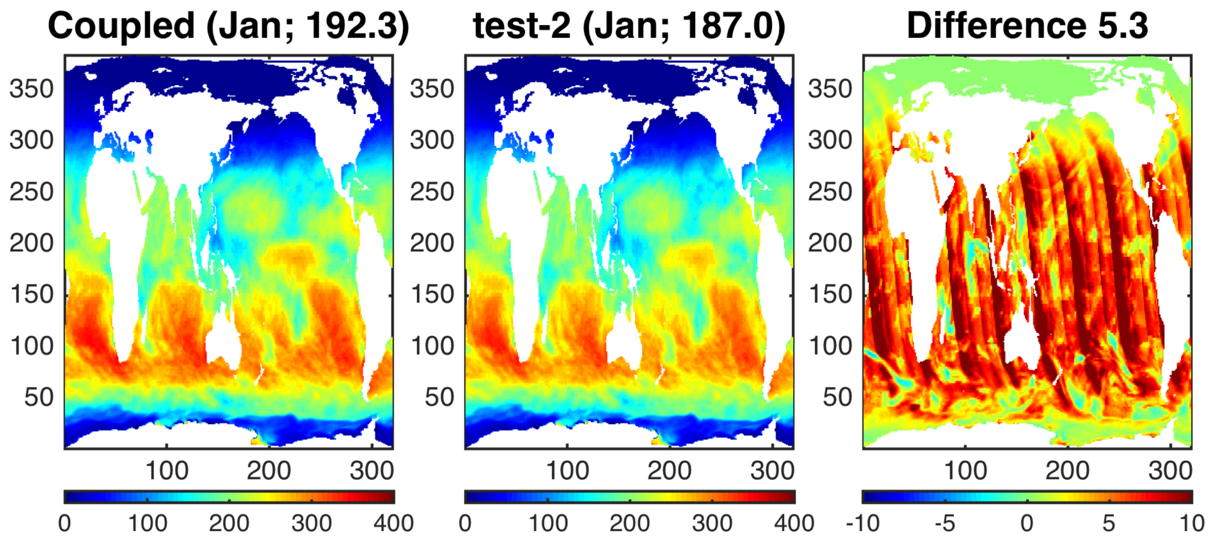


Figure 1: Comparison of net shortwave forcing (*SHF_QSW*) reported by POP between the coupled run (Pre-industrial) and POP-only run if the offset is set incorrectly; global-mean values are indicated above each panel in $W/m^2$.

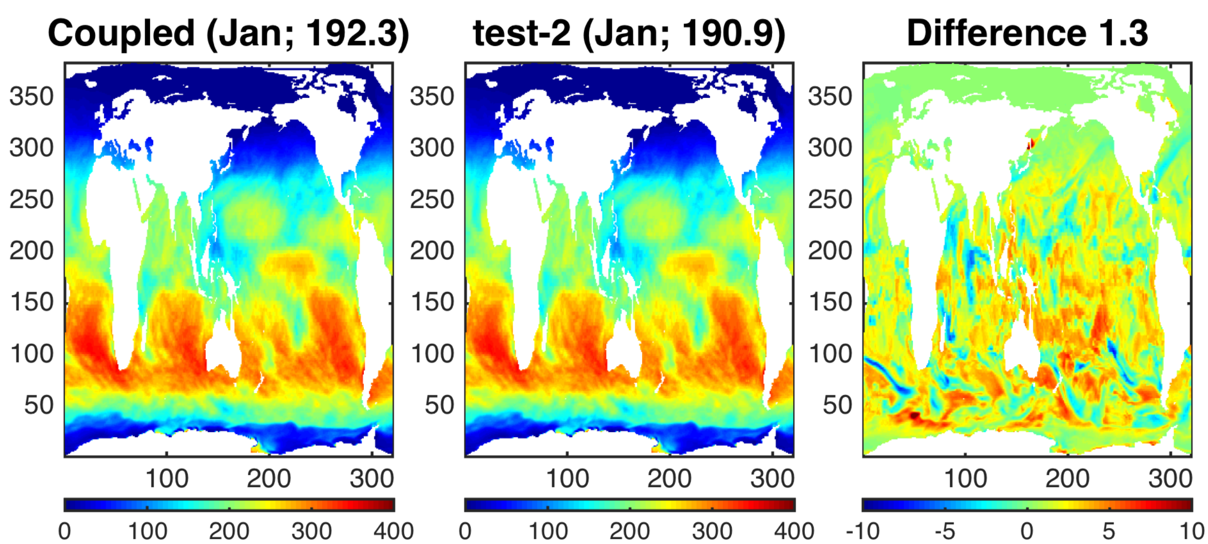


Figure 2: Comparison of net shortwave forcing (*SHF_QSW*) reported by POP between the coupled run (Pre-industrial) and POP-only run if the offset is set correctly; global-mean values are indicated above each panel in $W/m^2$.

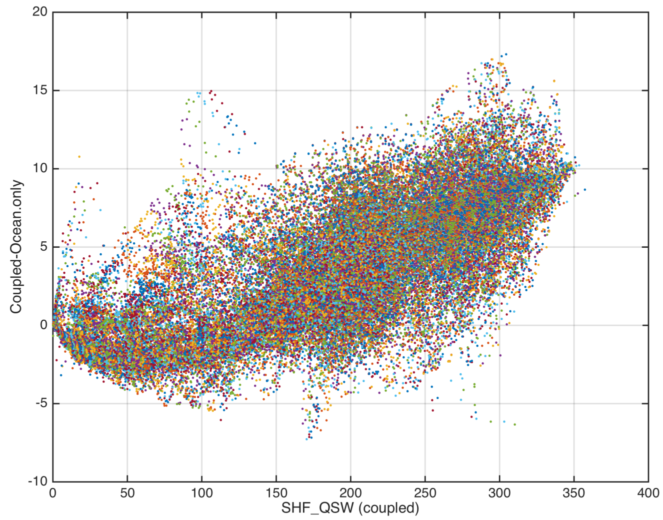


Figure 3: Scatter plot of the difference of shortwave forcing (coupled minus ocean-only) against the shortwave forcing reported by the coupled run.

run, which depends on the solar zenith angle and latitude. An incorrect albedo option can lead to errors as indicated in Fig. 3, where the plot of the shortwave forcing difference between coupled & pop-only runs against the shortwave forcing presents a somewhat linear relationship. Fig. 4 is a plot of the global mean net shortwave forcing over the ocean before and after the albedo & offset issues are fixed. It can be seen that the model can give considerably biased shortwave forcing if the issue is not fixed. The remaining difference could possibly result from our specification using 3-hr average data.

## 2.3 Atmosphere forcing for LGM.Control and LGM.test simulation

Because of the expansion of ice sheets on the continent and lowering of the sea level at the LGM, the surface geopotential has been changed substantially. Before applying LGM ATM forcing to the present ocean in our LGM.control ocean-only simulation, the change of surface height needs to be accounted for. The bottom cell temperature and potential temperature (referenced to the surface pressure; so there is only a slight difference between *tbot* and *ptem*) is adjusted by assuming a lapse rate of -6.5K/km. The surface pressure is modified based on an exponential decay of pressure with height, *i.e.* $p = \exp(-z/H)$, where the scale height $H$ is taken to be 7.6km.

## 2.4 Others namelist variables in DATM

ATM_NCPL is set to 48 in 'env_run.xml'. This defines the coupling frequency between DATM and the coupler.

We set DATM to use no prescribed aerosol forcing.

The namelist variable iradsw specifies the frequency at which the radiation is calculated. In our simulations, it is set as 1.

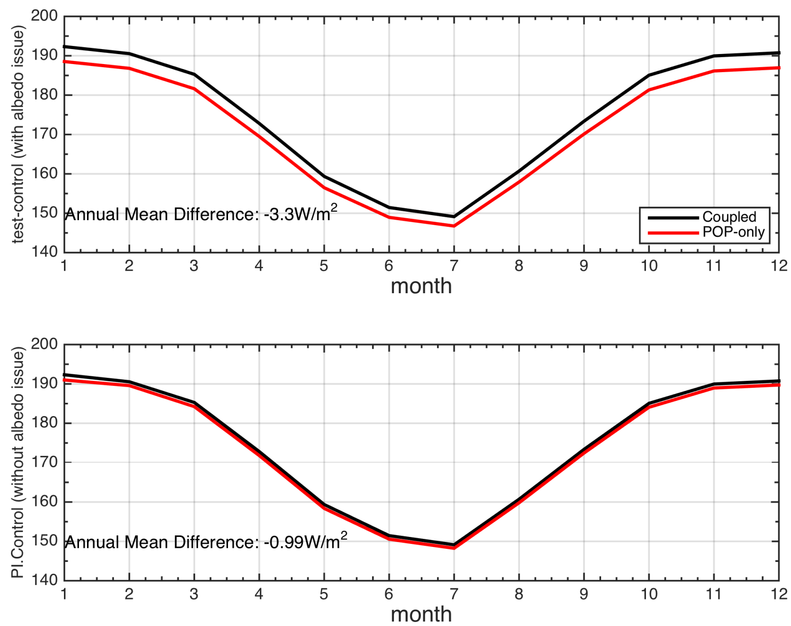


Figure 4: Global mean net shortwave forcing over the ocean before (upper) and after (lower; corresponding to Fig. 2) the albedo & offset issues are fixed.

# 3 ICE

In order to specify the ice forcing, the code, data, and stream files all need to be edited.

## 3.1 Variables to be specified

Six variables need to be specified in DICE (the inactive sea ice model): *melth, meltw, salt, ifrac, taux, and tauy*. For *melth* and *ifrac*, we use daily-mean data reported by the CCSM4 sea ice model (CICE). For the other ice-related forcing, daily output is not available for the coupled runs so we use monthly data instead. To allow for specification of all these variables, a new stream file needs to be created besides the one that can be copied from "$case/CaseDocs/" because we have two different source data frequencies (monthly and daily). This new stream file must be copied to the run directory.

By default, only ifrac can be specified directly. To allow the specification of the other variables, the code file 'dice_comp_mod.F90' needs to be modified. In the default setup of DICE, the salt flux and freshwater flux are both set zero. To compensate for this, a climatological ice/ocean flux is introduced in POP2, the data of which is read from a file defined by sfwf_filename in the POP stream file. If all these variables are specified, the climatological ice/ocean flux should be turned off in 'forcing_sfwf.F90' (this can only be done by modifying the code).

Variables weighted by ice area are preferred instead of the non-weighted variable to avoid the introduction of Reynold averaging effects (i.e., terms like $\overline{c'S'}$): for example, *fhocn_ai* is preferrable instead of *fhocn*. Note that *fhocn* in DICE is equivalent to *melth* reported in the CICE history files. To do this, 'mrg_mod.f90' needs to be modified to allow the specification of variables weighted by

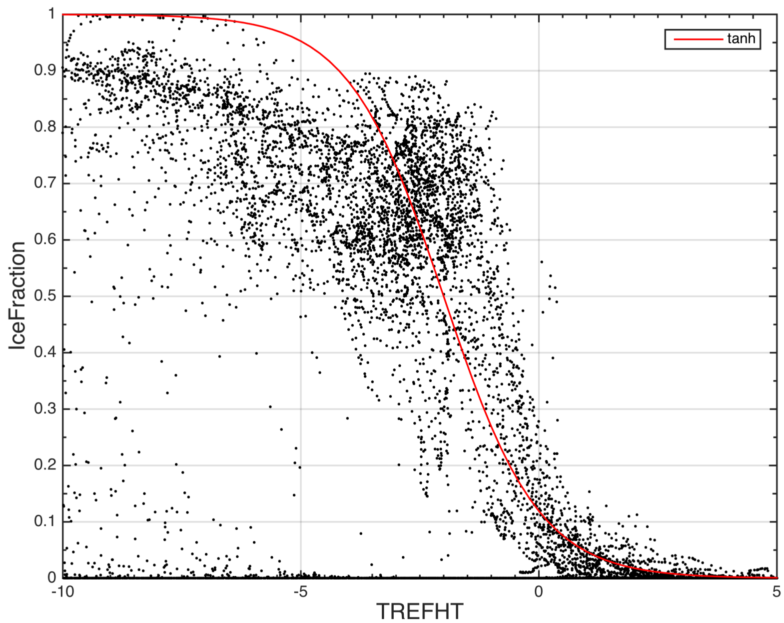


Figure 5: Scatter plot of monthly mean ice concentration vs. surface air temperature at the reference height, both reported in the ATM history files. The red line indicates the functional form that we adopt to generate ice concentration based on surface air temperature in locations that are ocean in the LGM.test run but not in the LGM coupled run.

the ice area.

Similar to the 3-hr coupler history file, the time-stamps of the daily/monthly ice forcing data are placed at the end of the interval. Rather than using offset to address this, we modified the variable called *time* in the netcdf data file so that it was at the middle of *time_bounds*.

## 3.2 Ice forcing for LGM.test and LGM.control runs

The ice forcing for the LGM.test run follows the same method as the atmospheric forcing for LGM.test. For the LGM.Control run, there is an issue regarding specifying ice forcing from the LGM coupled run because of the change in ocean domain between the LGM and PI coupled runs: there are locations that are ocean in the PI coupled run and land in the LGM coupled run, whereas the ocean-only simulations (including LGM.test) all use the PI ocean basin configuration. This raises the question what sea ice cover should be used in locations that are ocean in the LGM.test ocean-only simulation but land in the LGM coupled simulation from which the sea ice forcing is specified. To resolve this issue, we set the ice concentration in the unspecified locations based on the surface air temperature. Fig. 5 shows the dependence of ice concentration on surface air temperature that we adopt, which is a hyperbolic tangent function, next to the scatter of ice fraction and surface air temperature (at the reference height), both reported by the ATM component of the model. Other ice-related forcing variables including the ice-ocean freshwater flux and ice-ocean heat flux are set as zero at those locations that are land in the LGM coupled run.

# 4 Run-off

River and ice run-off are specified from the coupled runs. Monthly mean values are reported by the land component in the LGM and PI coupled runs (the fields are named *QCHOCNR* and *QCHOCNR_ICE*). To specify the run-off, 'diddling' is applied to the coupled model output (see ICE section above), and we edited the code to perform the necessary unit conversions.

# 5 POP

By default, the ocean component of the model (POP2) communicates with the coupler once per day, receiving daily-mean values of relevant fields.

## 5.1 Weak restoring for salinity

To avoid the spurious presence of AMOC bistability in the ocean-only simulations due to the temperature and salinity mixed boundary conditions at the surface (Griffins *et al*. 2007), "weak restoring" of the sea surface salinity (SSS) should be turned on in the namelist file. There is an issue regarding what the SSS field should be restored to, since we are simulating PI and LGM climates as well as the LGM.Test simulation that includes forcing from both coupled runs.

In the default settings, the ocean is restored to annual data defined by sfwf_filename in the POP streamfile, which is created from "version1 forcing for coordinated ocean-ice reference experiment (core)" (`http://data1.gfdl.noaa.gov/nomads/forms/core/COREv1/support_data_v1.html`) based on the Levitus 98 and PH2 observationally-based monthly data sets. To be consistent in our simulations, we use the 30-year mean seasonal cycle in monthly-mean SSS values from the coupled simulations that were used to produce the forcing fields at each location.

The weak restoring does not cause the volume-averaged global salinity to drift, because the global-mean value of the SSS tendency due to weak restoring is subtracted in the model. Therefore, the weak restoring effect only causes a tendency for the model to evolve toward a specified SSS pattern, rather than a specified salinity value. In the ocean-only simulations, the model calculates a field called the *precipitation_factor* which scales the precipitation based on the change in annual-mean global-mean sea surface height and volume-averaged global salinity in order to avoid the salinity from drifting from its initial value due to the interactive evaporation not necessarily balancing the specified precipitation (this is controlled by the variable *ladjust_precip*).

## 5.2 Other setup factors

To make sure that the salinity in marginal seas does not blow up, we turned on lms_balance. In the coupled run, by default the model includes a strong restoring effect in the marginal seas for both temperature (shf_strong_restore_ms) and salinity (sfwf_restore_ms). We turned off both of these namelist variables in the ocean-only simulations in order to get better consistency between the PI coupled run and our PI ocean-only control run (PI.Control).

For LGM runs, at times we needed to change the ocean time step to ensure numerical stability. We did this by modifying dt_count in the POP code and then rebuilding the model.