In this exercise, you will use CESM to compute the surface mass balance of the Greenland ice sheet. You will make a simple code modification to perform a crude global warming or cooling experiment.

Create a case

You will create a case that consists of an active land component (CLM, the Community Land Model), an active ice-sheet component (CISM, the Community Ice Sheet Model), an active river component (RTM, the River Transport Model), a data atmosphere component, and stub ocean and sea ice components. The data atmosphere component is from an NCEP reanalysis at T62 (~1.5 deg) resolution. The land model will (among many other things) compute a surface mass balance that is used to force the ice sheet model.

```
> cd /glade/p/cesm/tutorial/cesm1_2_2.tutorial/scripts
```

```
> ./create_newcase -case ~/cases/i.day5.1 -mach yellowstone -res f19_g16 -
compset IGCLM45
```

IGCLM45 is the short name for I_2000_GLC_CLM45_CISM1: create_newcase tells us that this is:

DATM: CLM: RTM: SICE: SOCN: CISM: SWAV: present day: clm4.5 physics: clm4.5 Satellite phenology: cism1: QIAN atm input data for 1972-2004:

In general, compsets with a second letter of G (e.g., BG, FG, IG) have an active glacier model.

Configure and build the model

```
> cd ~/cases/i.day5.1
```

For ice-sheet modeling, a setting of interest is GLC_GRID. The default value is gland5UM, which refers to the 5-km Greenland grid. You can confirm this setting as follows:

```
> grep CISM_GRID *.xml
```

Now setup and build the case. You will be making source code modifications, so will have to rebuild the code later. But let's start a build using the unmodified code, so that this can proceed while you work on the modifications. The rebuild with the modified code will then proceed much faster.

```
> ./cesm_setup
```

```
> ./i.day5.1.build
```

Modify source code to perform a global warming / cooling experiment

Your IG case is configured to run with atmospheric data for the years 1972 – 2004 from an NCEP reanalysis. What if the surface air temperature were higher or lower than the values in the reanalysis?

To find out, you can change a single line of code in CLM. The safest way to change a file is to make a copy of the file in one of your SourceMods directories and change it there, leaving the original version unchanged. In this way you can easily keep track of your code changes.

Since the initial build is taking up your terminal window, you will need to open a new terminal window to do the following.

The file you will modify is called DriverInitMod.F90, and it is part of the CLM source code. Type the following to copy it to the CLM SourceMods directory:

```
> cd ~/cases/i.day5.1
> cp
/glade/p/cesm/tutorial/cesm1_2_2.tutorial/models/lnd/clm/src/clm4_5/biogeophy
s/clm_driverInitMod.F90 SourceMods/src.clm/
```

Now go to the CLM SourceMods directory:

```
> cd SourceMods/src.clm
> ls
```

There will be a single file, "clm_driverInitMod.F90". When the code is built, any files that are in this directory will automatically replace files of the same name in the CLM source code directory.

You will edit the version of "clm_driverInitMod.F90" in the CLM SourceMods directory. Find this line of code:

```
tbot_c = tbot_g-lapse_glcmec*(hsurf_c-hsurf_g)   ! sfc temp for column
```

This part of the code sets the surface air temperature, "tbot_c", for glacier columns. Recall that in each grid cell containing glacial ice, the glaciated area is divided into several columns, each with a different elevation. The surface air temperature at the mean gridcell elevation is "tbot_g". For each column, "tbot_g" is adjusted by adding a term proportional to the elevation difference between the mean gridcell elevation "hsurf_g" and the local column elevation "hsurf_c".

You will change this line to something like this:

```
tbot_c = tbot_g-lapse_glcmec*(hsurf_c-hsurf_g) + 5.0  ! sfc temp for column,
plus five degrees
```

In this way you will have a crude version of a global warming (or cooling) simulation. Later we will see how this temperature change affects the surface mass balance of the Greenland ice sheet.

Once you've made your code changes in SourceMods/src.clm, go back to the case directory and rebuild the model. **You will need to wait for the initial build to complete before doing this step; if the initial build is still underway, you could take a few minutes to explore the ice sheet code directory structure, as discussed below in the appendix.**

```
> cd ../..
> ls
> ./i.day5.1.build
```

This build should go much faster than the initial build, because only the file you changed and a few other files that depend on it need to be rebuilt.

If the build fails, you will get an error message pointing you to a log file in another directory. If you look at the bottom of that log file, you will usually see what went wrong.

If the code builds successfully, you will see on your screen a message like this:

```
 CCSM BUILDEXE SCRIPT HAS FINISHED SUCCESSFULLY
```

Submit the run

It's often a good idea to first do a short test run, to make sure you haven't introduced any errors that prevent the model from running. So, we'll first do the default 5-day run.

Edit i.day5.1.run: Shorten the wall-clock limit so that the run can get through the queue more quickly. Change this line:

```
#BSUB -W 2:00
```

to:

```
#BSUB -W 0:10
```

Then submit the run:

```
> ./i.day5.1.submit

> bjobs
```

When the run completes, confirm that it was successful:

```
> tail CaseStatus
```

You should see a line beginning with "run SUCCESSFUL" at the bottom of this file. If you instead see "run FAILED", you will have to look through your log files to determine the cause of the failure, fix it, then resubmit this short test run.

You can now do a longer, 4-year run:

```
> ./xmlchange STOP_OPTION=nyears,STOP_N=4
```

Also, edit i.day5.1.run: Lengthen the wall-clock limit to allow enough time for this longer run. Change this line:

```
#BSUB -W 0:10
```

to:

```
#BSUB -W 0:50
```

Then submit the run:

```
> ./i.day5.1.submit
```

```
> bjobs
```

Wait for the run to finish

The run will take 20-30 min. to complete. While you're waiting, you can take some time to look through these three things:

(1) The various namelist settings that can be used to control CISM's evolution:

http://www.cesm.ucar.edu/models/cesm1.2/cesm/doc/modelnl/nl_cism.html

The settings under the headings "cism.config Options" and "cism.config Parameters" are particularly useful.

Note that the options under headings beginning with "cism.config" will appear in the cism.config file in your run directory; options in the first few sections (which do not mention "cism.config") will appear in cism_in. However, both sets of options are modified in the same way: via the *user_nl_cism* file in your case directory.

(2) The glc log file from your initial 5-day run. From your case directory, do the following:

```
> cd logs
```

```
> ls

> gunzip glc.log.*
> less glc.log.*
```

Scroll through the log file. You will see information about the Glimmer-CISM input parameters, followed by some model diagnostics that are written out during the run. If the run finished successfully, you will see this near the end:

> Successful completion of glc model

There are similar log files for other components (e.g., *lnd* and *atm*). The logfile with the *cesm* prefix combines diagnostics from each component.

(3) The CISM source code, as described in the Appendix.

<u>View the results</u>

Now we will look at some output from your IG run. When a run completes successfully, output is written to several archive directories. Let's first look at some CLM output:

```
> cd /glade/scratch/$USER/archive/i.day5.1/lnd/hist
> ls
```

You should see one file for each month of the run. Each of the monthly files contains a number of monthly average fields. This command will tell you about the contents of the first monthly file:

```
> module load netcdf
> ncdump -h i.day5.1.clm2.h0.0001-01.nc  | less
```

In addition, for an IG compset, the CLM namelist is automatically set up to also output supplementary history files with annual-average values of QICE. This is the surface mass balance of glaciated grid cells in units of mm/s. (To convert to the more useful units of m/yr, you would multiply by 3.16e4.) Values are positive where the ice is growing and negative where ice is melting.

Look at the annual average file for year 4:

```
> module load ncview
> ncview i.day5.1.clm2.h1.0005-01-01-00000.nc
```

Click on the box labeled 'QICE'. You should see a global plot of QICE on the global land grid. We recommend changing the color scheme: First, click on the button labeled "3gauss";

continue to click until it reads "default". Then click on the button labeled "range"; change the range to -2e-5 to 2e-5, then click "OK".

Depending on the temperature change you chose, you may be able to see QICE not only in Greenland and Antarctica, but also in the Alaskan coastal range, Patagonia, New Zealand, the Himalayas and the Canadian Archipelago. Note that the annual surface mass balance is positive for almost all of Antarctica. The mass balance is positive for most of Greenland, except for a patch in the southwest part of the ice sheet.

Recall that the surface mass balance is computed in CLM for multiple elevation classes and then downscaled to the ice sheet grid in CISM. Let's see what the mass balance looks like after downscaling. First go to the directory with GLC history files:

```
> cd /glade/scratch/$USER/archive/i.day5.1/glc/hist
> ls
```

First, combine the available years, so that you can easily scroll through these years in ncview:

```
> module load nco
> ncrcat i.day5.1.cism.h.0002-01-01-00000.nc i.day5.1.cism.h.0003-01-01-
00000.nc i.day5.1.cism.h.0004-01-01-00000.nc i.day5.1.cism.h.0005-01-01-
00000.nc i.day5.1.cism.h.allyears.nc
```

(You can ignore the warning about *scale_factor.*)

View the resulting file:

```
 > ncview i.day5.1.cism.h.allyears.nc
```

You will see several 2D fields. First, view the ice thickness, ''thk''. The thickness of the ice sheet does not change much during this short run.

Next, look at the surface mass balance, which in CISM is called ''acab'' (for accumulation/ablation). The units are m/yr. Change the color scheme: First, click on the button labeled "3gauss"; continue to click until it reads "default". Then click on the button labeled "range"; change the range to -2 to 2, then click "OK". Near the bottom of the panel, click on the current time box to advance by one year at a time. Watch how the surface mass balance changes.

Given constant atmospheric forcing from year to year, the model must run for several decades before the mass balance approaches a steady state. But the general pattern is apparent after a few simulation years. For unaltered NCEP forcing, the pattern is as follows:

- In most of the ice sheet, the mass balance is small and positive (green shading).
- In the southeast, the mass balance is large and positive (red shading).

• In the southwest and in some coastal regions, the mass balance is negative (blue and purple shading).

These features are fairly realistic. The pattern would be improved if the surface mass balance were computed in CLM at higher (e.g., 1 degree) resolution.

Remember that you were running a climate change experiment. Depending on the size of the temperature change, you may or may not see similar features in your CISM history file.

Finally, create a difference map showing the changes in your run relative to a control run that was done without any changes to the source code:

```
> ncdiff i.day5.1.cism.h.allyears.nc
/glade/scratch/sacks/archive/i.day5.1.CONTROL/glc/hist/i.day5.1.cism.h.allyea
rs.nc diffs.nc
```

```
> ncview diffs.nc
```

Click on acab, change the color scheme as desired (for a 5-degree warming experiment, the "default" scheme with range -2 to 2 works well), and scroll through to year 4.

Positive values indicate more accumulation (or less ablation) in your experiment; negative values indicate less accumulation. If you performed a warming experiment, you should see mostly negative values around the margins of Greenland.

Appendix: Ice sheet model directory structure

Go back to the CESM code:

```
> cd /glade/p/cesm/tutorial/cesm1_2_2.tutorial/models
> ls
```

The models directory contains several subdirectories:

atm = atmosphere
csm_share = shared code
dead_share = shared code for "dead" models
drv = driver (includes coupler modules)
glc = ice sheet (CISM)
ice = sea ice
lnd = land
ocn = ocean
rof = runoff
utils = utilities
wav = wave model

NOTE: In CESM, ''ice'' refers to the sea ice model. The ice-sheet model is not in the ''ice'' directory, but in the ''glc'' directory. Let's take a quick tour of ''glc'':

```
> cd glc
> ls
```

The active ice sheet model is in the ''cism'' (Community Ice Sheet Model) directory. The directories ''sglc'' and ''xglc'' contain the stub and dead components.

Go to the CISM directory:

```
> cd cism
> ls
```

The source code resides in several subdirectories:

- glimmer-cism = Glimmer-CISM code; especially see the following subdirectories:
  - libglide
  - libglimmer
  - libglint
- source_glc = code needed to link Glimmer-CISM to the CESM coupler
- drivers = more code associated with the coupler

Feel free to explore these directories while waiting for the model to build or run.