EcoGEnIE: A practical course in global ocean ecosystem modelling

`Lesson zero.c:` Ocean circulation and Atlantic overturning stability

Stuff to keep in mind:

- Nothing at all – keep your mind completely empty and let the wonderful truths of GENIE permeate your entire being.

Relevant reading (and references therein):

Atlantic circulation and stability in GENIE:

Hargreaves et al. [2004] (Climate Dynamics, Volume 23, Issue 7 - 8, Dec 2004, Pages 745 – 760)
→ Simple assessment of the likelihood of AMOC collapse.
Marsh et al. [2004] (Climate Dynamics, Volume 23, Issue 7 - 8, Dec 2004, Pages 761 – 777)
→ Characterization of thresholds of AMOC collapse.

0. Readme

0.1 You will need to download a new *restart* file prior to embarking on the experiments with modern ocean circulation.

Change to the `cgenie_output` directory and type (or copy and paste carefully from the PDF …):

```
$ wget http://www.seao2.info/cgenie/labs/Bristol.2016/LAB_2.SPIN.tar.gz
```

This downloads an archived/compressed copy of the 10,000 year spin-up experiment `LAB_2.SPIN`. Extract the contents of this archive by typing:

```
$ tar xfzv LAB_2.SPIN.tar.gz
```

You'll then need to change directory back to `genie-main` to run the model.

1. Geochemical forcing of *c*GENIE ("poking the climate beast" [*Wally Broecker*])

1.1 The ocean biogeochemistry module ('*BIOGEM*') in *c*GENIE provides a framework for applying time- and spatially-variable '*forcings*' of the Earth system – fluxes or restored-to boundary conditions that can be prescribed for any gas, dissolved substance (including temperature and salinity), or particulate matter. Examples include freshwater input (== a negative salinity flux *forcing*) of the North Atlantic to alter ocean circulation, fossil fuel CO_2 emissions to the atmosphere (== a CO_2 gas flux *forcing*), or aeolian iron supply to the surface ocean (a 2-D dust flux *forcing*).

For example: view the *user-config* file: `LAB_2.hosing` – you will see the following lines (under the heading: '`# --- FORCINGS ---`')

```
bg_ctrl_force_GOLDSTEInTS=.true.
bg_par_forcing_name="pyyyyz.Fsal"
bg_par_force_point_i=22
bg_par_force_point_j=33
bg_par_force_point_k=16
bg_par_ocn_force_scale_val_2=-2.0E17
```

The second line points *c*GENIE to a directory located in `cgenie.muffin/genie-forcings` that contains a set of files that define what geochemical property is going to be altered plus information about how the magnitude of the forcing changes with time. (The first line allows the biogeochemistry model to modify the density and hence circulation in the dynamic ocean circulation model.)

There are then three lines (`bg_par_force_point_i=22`, ...) that specify the location in the ocean of the geochemical forcing is going to be applied. The point sources are specified in (`i,j,k`) coordinates, which in this case is (`22,33,16`). For the ocean model resolution we are using, the grid is 36×36×16, longitude (`i`) is counted from left-to-right (1 to 36); latitude (`j`) is counted from bottom-to-top (1 to 36); level depth (`k`) is counted from downwards top-to-bottom (16 down to 1). Thus, (`22,33,16`) is a release of tracer in the North Atlantic, a little south of Greenland, and at the surface (level = 16 out of 16). <u>Refer to the Figure at the end for how the horizontal and vertical grid is specified</u>.

Finally, there is a scaling parameter (`bg_par_ocn_force_scale_val_2`) which modifies the magnitude of the flux to be applied (in units of mol yr^{-1}).

(Section 4 in the *User Manual* describes the original and most flexible provision for applying time-dependent *forcings*.)

1.2 You are going to run an experiment in which you add fresh water to assess the sensitivity of the Atlantic Meridional Overturning Circulation (AMOC) to collapse in a classic 'hosing' experiment.

The *user-config* file for this is called: `LAB_2.hosing`. The default (`i,j`) location of the flux input is the same (as the dye tracer), but now the injection at the surface (level: `k=16`). Note that the forcing of the salinity tracer is negative (freshwater = negative salinity compared to sea-water)! To orientate you in freshwater forcing space: `bg_par_ocn_force_scale_val_2=-2.0E17` should be sufficient to make 'stuff happen' and quickly. **BUT**, this is a pretty extreme flux (see overleaf for a rough conversion between salinity forcing units (mol yr-1) and fresh water flux (in m^3 s^{-1} or Sv). Much more than this and the model may crash or at the very least, you'll be left with a large freshwater pond in the North Atlantic … (<u>See later for some exciting discussion on units!</u>)

The *base-config* you will be using is different from previously: `cgenie.eb_go_gs_ac_bg.worjh2.rb` – this specifies a 16 vertical levels ocean and also includes seasonality of solar insolation. (But no carbon cycle (yet).)

To run the model for e.g. 20 years using the same *restart*:

```
$ ./runmuffin.sh cgenie.eb_go_gs_ac_bg.worjh2.rb LABS
  LAB_2.hosing 20 LAB_2.SPIN
```

20 years should be long enough to see a collapse start to occur, but you might want to run the model for longer (and it can be submitted as a job, of course). Running for longer will also allow you to have a smaller, less extreme (and maybe more realistic) freshwater input flux.

The most obvious property of the Earth system to follow is the Atlantic overturning strength (`biogem_series_misc_opsi.res`). The AMOC stream-function (in `fields_biogem_2d.nc` 2-D time-slice netCDF results file, field: `phys_opsia`) is also illustrative. You can also try and identify the salinity **anomaly** (see below) due to freshwater input in the 3D salinity tracer field.

There are also important impacts on surface air temperatures and maybe sea-ice extent (in `fields_biogem_2d.nc`). Note the importance (sort of) of the AMOC in transporting heat to the N. Atlantic region (the film the Day After Tomorrow was not entirely inaccurate in this particular respect). Be aware of the possibility of climate impacts far from the location of fresh water forcing. Look out for any significant-looking impacts on sea-ice extent, etc.

Note that as the model is running rather s l o w e r than in the snowball configuration, you might want to think carefully of making use of cluster queuing possibilities (i.e. running multiple experiments at once in the background).

1.3a To more easily assess some of these impacts (and for other sorts of analysis) it is possible to create an **anomaly** (difference) map in Panoply:

1. First open a dataset, e.g., `atm_temp` (`surface air temperature`) in the **2D** netCDF file. You can either double-click the variable name, or, with the variable name highlighted, click the '`Create Plot`' icon.

2. Now, with the `atm_temp` still selected (and the first plot window still open), click on the '`Combine Plot`' icon. A dialogue box will appear and ask you to select a plot to combine the new one with. Make sure the name of your first plot window is selected/highlighted. Click '`Combine`'.

3. You now have a plot window that by default it is showing you the difference between two identical (in time) slices. The two different slices are labeled `Array 1` (LH side) and `Array 2` (RH side).

Keep one array (`Array 1`) fixed to the initial (year 1 (centered on 0.5)) and vary the year in the second array (`Array 2`). Note that you can select in Panoply whether `Array 1 – Array 2` is plotted, or `Array 2 – Array 1`, or various proportional or relative differences.

Note that you can switch off the auto-scaling feature (`Always fit to data`) and center the scale so that no change is white, with positive deviations = red and negative = blue by clicking on `Center on 0` (an often used convention in climate field plotting).

1.3b You can also plot ocean current fields which is sort-of fun and maybe even informative(!):

1. In the **3D** netCDF file, the three components of ocean velocity are represented by the variables: `ocean velocity – u` (Eastwards), `ocean velocity – v` (Northwards), and `ocean velocity – w` (upwards). 2. Open up `velocity – u`. Chose 'lon-lat'.

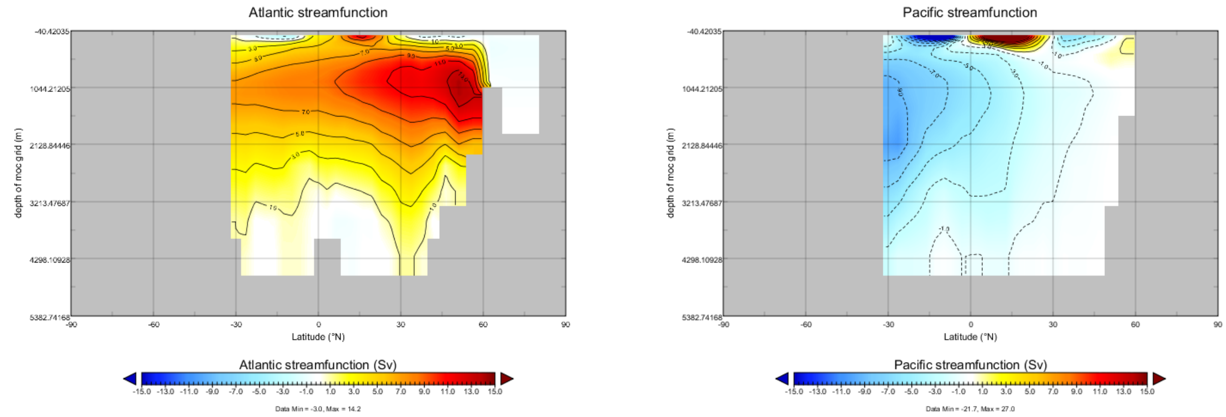
2. Select/highlight `velocity – v`. and click on the '`Combine Plot`' icon (as per before).

3. Rather than a difference map, which is what you get by default, i.e. 'Array 1 – Array 2' – from the drop-down menu (next to the 'Interpolate' button) select 'Vector Magnitude'.

4. You should have a color contoured (or not if you prefer plotting without contouring on) map of ocean current speed, with velocity vectors (direction and magnitude) overlain. You'll need to re-scale the velocity vectors to properly see them – from the 'Contours and Vectors' tab – change the 'Scale Length' to e.g. 0.1. When fresh-water hosing – look out for impacts on the N. Atlantic current system associated with the AMOC.

5. You can repeat this for deeper depth levels in the ocean – e.g. between about 1500 and 2000 m is a good place to go looking for the Western boundary current (and AMOC return) in the model (such as it exists at this low resolution) but you'll need to re-scale the velocity vectors again (e.g. to 0.01 to less).

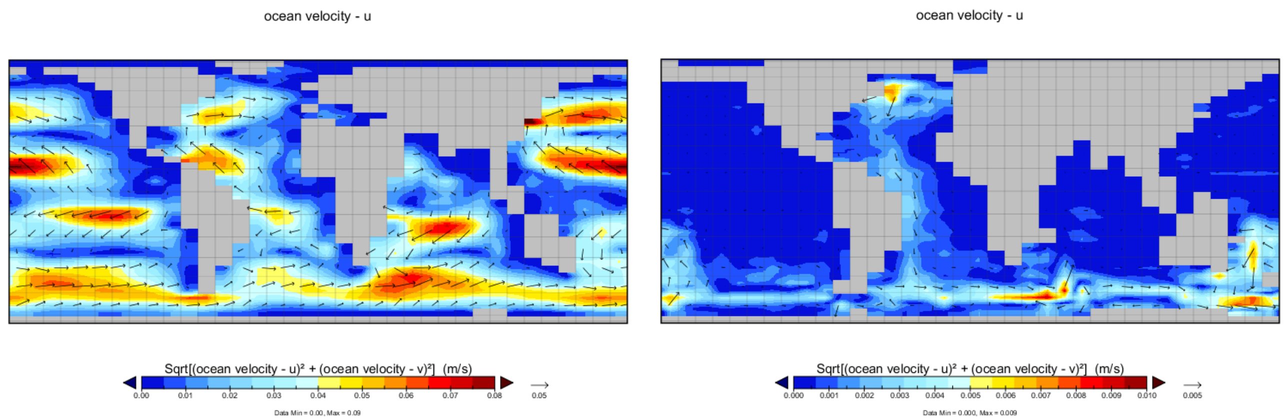
1.3c Example plots of the overturning streamfunction (2D netCDF file). (e.g. for Atlantic: netCDF parameter name: `phys_opsia`, long-name: `Atlantic streamfunction`).



Note that autoscaling has been turned off and the min and max plotting limits set manually. By convention, streamfunctions are plotted with their scale symmetrical around zero, giving red and 'warm' colors for positive value and clockwise overturning, and blues and 'cold' colors for negative values and anti-clockwise overturning. Also shown is the same for the Pacific.

1.3d Example plots of ocean current fields (3D netCDF file). Again scaling has been set manually to create an easy-to-interpret axis scale. On the left is the surface field, and on the right an intermediate depth (illustrating what approximates the Deep Western Boundary current in the model in the Atlantic).

1.6e Finally, a brief note on units ... the freshwater forcing is implemented as negative salinity, just to really



screw with your mind. The generic internal *c*GENIE model units for the forcing end up as PSU kg^{-1} yr^{-1}. Which sort of does not make much sense ...

Start, by thinking of a value of `bg_par_ocn_force_scale_val_2` of `-34.9` as equivalent to taking all the salt out of 1 kg of freshwater (since the mean global salinity is 34.9 PSU). Or equivalently, since the ocean volume is fixed, an applied forcing value of -34.9 is equivalent to adding 1 kg of freshwater to a (surface) box. So, a value of `bg_par_ocn_force_scale_val_2` of -3.49×10^4 (-3.49E04) would be a flux of 1 m^3 yr^{-1} (1000 kg m^{-3}) of freshwater.

So, in the example earlier (`bg_par_ocn_force_scale_val_2=-1.0E18`), the freshwater flux is $1.0\times10^{18}/3.49\times10^4 = 2.8653\times10^{13}$ m^3 yr^{-1}.

The literature invariably gives freshwater fluxes in units of Sv (10^6 m^3 s^{-1}). So in the example, the freshwater flux is: 9.0797×10^5 m^3 s^{-1} ($365.25\times24\times3600 = 31557600$ s yr^{-1}). Or 0.9 Sv. Read the literature … but generally, fluxes of ca. 0.05 Sv and larger (and to quite specific places) are applied in models in order to induce a collapse of the AMOC.

36	10	09	08	09	10	11	11	10	08	07	07	07	07	07	11	13	14	14	12	12	93	93	91	91	09	05	05	08	10	11	11	11	12	12	11	11
35	94	94	94	94	94	94	94	94	94	16	94	94	94	94	94	94	94	91	91	14	12	93	91	12	09	06	07	12	94	94	94	94	94	94	94	94
34	94	94	94	94	92	92	08	07	10	15	12	09	93	93	94	94	94	91	91	91	06	05	05	06	09	12	93	93	94	94	94	94	94	94	94	94
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	01	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**

***c*GENIE grid** (36×36 'worjh2' configuration)**.**

Light blue numbers are the 'i' co-ordinates. Green numbers are the 'j' co-ordinates. The depth of the ocean at any location is indicated by its 'k' value – a number between 1 and 16, with 16 being the surface layer of the ocean, and 1 the maximum possible depth anywhere. Numbers > 90 (91, 92, 93, 94) and shaded grey are land (and specify the direction of run-off). Location (22,33,08) is highlighted in yellow. The longitude of the western edge of the grid is at 260˚W, and the increments are 10˚.

k	**mid depth** (m)	**base of layer** (m)
16.00	38.91	80.84
15.00	126.04	174.75
14.00	227.26	283.85
13.00	344.84	410.58
12.00	481.44	557.80
11.00	640.12	728.83
10.00	824.45	927.51
9.00	1038.59	1158.31
8.00	1287.35	1426.43
7.00	1576.33	1737.90
6.00	1912.04	2099.73
5.00	2302.02	2520.05
4.00	2755.05	3008.34
3.00	3281.33	3575.57
2.00	3892.71	4234.52
1.00	4602.92	5000.00

***c*GENIE ocean vertical level definitions.**