

# A Hitchhikers Guide to the Black Arts (of Earth system modelling)

## IV: Consequences of fossil fuel CO<sub>2</sub> release and 'ocean acidification'

Relevant reading (and references therein):

Kleypas, J.A., Feely, R.A., Fabry, V.J., Langdon, C., Sabine C.L. and Robbins, L.L. (2006). Impacts of ocean acidification on coral reefs and other marine calcifiers: a guide for future research. Report of a workshop held 18–20 April 2005, St Petersburg, FL, sponsored by NSF, NOAA, and the US Geological Survey, 1-88.

[www.ucar.edu/communications/Final\\_acidification.pdf](http://www.ucar.edu/communications/Final_acidification.pdf)

Orr, J.C., K. Caldeira, V. Fabry, J.-P. Gattuso, P. Haugan, P. Lehodey, S. Pantoja, H.-O. Pörtner, U. Riebesell, T. Trull, M. Hood, E. Urban, and W. Broadgate (2009) Research Priorities for Ocean Acidification, report from the Second Symposium on the Ocean in a High-CO<sub>2</sub> World, Monaco, October 6-9, 2008, convened by SCOR, UNESCO-IOC, IAEA, and IGBP, 25 pp.

<http://ioc3.unesco.org/oanet/index.html>

Royal Society (2005) Ocean acidification due to increasing atmospheric carbon dioxide. Policy document 12/05 Royal Society, London.

<http://royalsociety.org/WorkArea/DownloadAsset.aspx?id=5709>

Turley, C., Findlay, H. S., Mangi, S., Ridgwell, A. and Schimdt, D. N., CO<sub>2</sub> and ocean acidification in Marine Climate Change Ecosystem Linkages Report Card 2009. (Eds. Baxter JM, Buckley PJ and Frost MT), Online science reviews, 25pp (2009).

<http://www.mccip.org.uk/elr/acidification/>



## 10. Exploring the consequences of fossil fuel CO<sub>2</sub> emissions

10.0 For the next experiment(s) you can chuck CO<sub>2</sub> into the atmosphere, just for the hell of it. As much as you want! Apparently, humans are actually doing this now. Imagine that!

The *user-config* for cGENIE, `exp8_co2emissions` is provided and configured with climate being responsive to CO<sub>2</sub> (i.e., it takes account of CO<sub>2</sub>-climate feedbacks):

```
# set CO2-climate feedback  
ea_36=y
```

as well as a rate of calcification in the surface ocean that is responsive to pH (i.e., it takes into account CO<sub>2</sub>-calcification feedbacks, which will additionally interact with climate – see *Ridgwell et al.* [2007b]). Anything could happen!!!

In the *user-config*, a release of CO<sub>2</sub> to the atmosphere is prescribed, which by default is set for 1000 PgC over an interval of a single year. (Releasing CO<sub>2</sub> just over a single year is obviously rather unrealistic, but represents a useful idealized experiment for assessing the time-scale(s) of fossil fuel CO<sub>2</sub> uptake by the ocean.) Additional results output has also been prescribed:

```
bg_ctrl_data_save_slice_ocnatm=.true.  
bg_ctrl_data_save_slice_fairsea=.true.  
bg_ctrl_data_save_slice_carb=.true.  
bg_ctrl_data_save_slice_ocnsed=.true.  
bg_ctrl_data_save_sig_carb_sur=.true.  
bg_ctrl_data_save_slice_misc=.true.  
bg_ctrl_data_save_derived=.true.
```

Because the *base-config* (`cgenie_eb_go_gs_ac_bg.worjh2.BASE`) has changed yet again! (carbon cycle tracers have now been added), you will first need to do a `make cleanall`.

10.1 Run the experiment for e.g., 20 (or more) years, starting from the re-start used previously, i.e.:

```
$ ./runcgenie.sh cgenie_eb_go_gs_ac_bg.worjh2.BASE LABS  
exp8_CO2emissions 20 exp0_modern16_SPINUP
```

and view the run-time output, particularly atmospheric CO<sub>2</sub> (which decays away after the first year as fossil fuel CO<sub>2</sub> is progressively taken up by the ocean), ocean surface temperature (SST), sea-ice extent, and Atlantic Meridional Overturning ('AMO') strength. Viewing the time-series results file `biogem_series_fexport_CaCO3.res` will show how global carbonate production responds to the ensuing ocean acidification, which itself is recorded in the file:

```
biogem_series_misc_surpH.res.
```

In the 3-D netCDF time-slice file, ocean pH is a particularly relevant field to consider together with calcite and aragonite saturation – note that ocean surface waters in which aragonite becomes under-saturated ( $\Omega < 1.0$ ) is regarded as a critical threshold for organisms making aragonite shells and skeletons and spells TROUBLE for some poor calcifying marine organism somewhere.

In the 2-D netCDF time-slice file you are given water column integrals of dissolved things (e.g., DIC - `ocn_DIC_int`) (see: *Sabine et al.* [2004]; *Science* **305**). Also saved is the benthic (bottom water) conditions of ocean properties and carbonate chemistry – relevant for assessing the changes in environmental conditions affecting e.g. cold-water (deep-dwelling) corals.

Also try creating difference maps in Panoply to assess the geographical characteristics of ocean acidification impacts. Ideally, one would run a parallel experiment, identical except for zero CO<sub>2</sub> release being specified, to act as a 'control' for the calculation of the differences. A difference map for the water-column integral of DIC (2D netCDF file), for instance, reveals where fossil fuel CO<sub>2</sub> is preferentially taken up by the ocean.

10.2 You can easily modify the experimental design to release more/less CO<sub>2</sub> as you did for the red dye tracer. In the *user-config* file, the lines:

```
bg_par_atm_force_scale_val_3=1000.0  
bg_par_atm_force_scale_val_4=-27.0
```

scale the CO<sub>2</sub> flux and its  $\delta^{13}\text{C}$  isotopic signature, respectively. The scaling values are given to you for a CO<sub>2</sub> release of 1000 PgC yr<sup>-1</sup> (current emissions are about 8 PgC yr<sup>-1</sup>) at -27‰ (typical of

fossil fuel carbon). Altering the value assigned to `bg_par_atm_force_scale_val_3` in the *user-config* file gives immediate control over emissions rate.

You can also adjust the emissions to have a time-varying rate by editing the file:

```
biogem_force_flux_atm_pCO2_sig.dat
```

which can be found in the directory:

```
cgenie/genie_forcings/pyyyyyz_FpCO2_Fp13CO2
```

The format of this file is:

```
-START-OF-DATA-
    0.0  8.3333e+013
    1.0  8.3333e+013
    1.0  0.0
999999.9  0.0
-END-OF-DATA-
```

and defines a total emission of 1000 PgC ( $8.333 \times 10^{16}$  mol CO<sub>2</sub>) over the first 1 year of the model experiment. (Year 999999.9 has no special meaning and is simply just way in the future ...)

Pause ... and note briefly how the final CO<sub>2</sub> flux is arrived at. GENIE calculates it by multiplying the value in the *forcing* file ( $8.3333e+013$ ) by a modifying parameter in the *user config* file (1000.0). The total flux is hence:  $8.333 \times 10^{13} \times 1000 = 8.333 \times 10^{16}$  mol CO<sub>2</sub>.

Equally, we could have had 1.0 in the *forcing* file and  $8.3333e+016$  as the value of `bg_par_atm_force_scale_val_3`. OR, the other way around.

The way you have been given is simply for my own convenience in 'hiding' the units conversion in the *forcing* file and allowing me to simply enter a value in PgC yr<sup>-1</sup> in the *user config* file. It is entirely up to you if you prefer to do things differently.

- 10.3 Between the start and end 'tags', the data is in 2 columns: the first contains a series of tie-points for defining the timing of changes in emissions, and the 2nd contains the flux information (units of mol yr<sup>-1</sup>). At each time-step of the model the CO<sub>2</sub> flux is interpolated between these time points.

The purpose of:

```
0.0  8.3333e+013
1.0  8.3333e+013
1.0  0.0
```

is thus to effect a sharp turn-off of the flux at the end of first year. To extend the period of emissions – for example:

```
0.0  8.3333e+013
10.0 8.3333e+013
10.0  0.0
```

would give you 1000 PgC yr<sup>-1</sup> over 10 years. In contrast;

```
0.0  0.0
10.0 8.3333e+013
```

would result in a linear ramp, zero at the start of year 0.0 to  $8.3333e+016$  mol yr<sup>-1</sup> at year 10.0 (a total CO<sub>2</sub> emission of  $1000 \times 10 \times 0.5 = 5000$  PgC over 10 years).

It is also possible to provide a simple scaling of the duration of the pulse by adding the lines:

```
bg_par_atm_force_scale_time_3=10.0
bg_par_atm_force_scale_time_4=10.0
```

which would scale the duration of the pulse (of CO<sub>2</sub> and its isotopic signature) by a factor to 10, i.e., to 10 years. (Remember, that without changing the default emissions rate, you will end up with 10,000 PgC total CO<sub>2</sub> emitted ... !)

- 10.4 By editing (and saving) the flux (and/or timing information) you can exert fine control on the CO<sub>2</sub> emissions trajectory and total fossil fuel burn. For instance, the IPCC 'SRES' scenarios of possible future CO<sub>2</sub> emissions can be reconstructed and their implications tested in GENIE. Play with different CO<sub>2</sub> releases and note their impact on climate and ocean biogeochemistry. Much more realistic and appropriate to our current global experimenting is a lower rate (order of 10 or 20 PgC yr<sup>-1</sup>) released over a longer interval.