EcoGEnIE: A practical course in global ocean ecosystem modelling

`Lesson zero.d:` The oceans ‘biological pump’

0. Readme

0.0 You will need to download a new *restart* file prior to embarking on the experiments. This differs from previous provided *restarts* in that it now includes an iron cycle in the ocean and hence co-limitation of biological productivity by Fe.

To fetch this: change to the `cgenie_output` directory, and type:

```
$ wget http://www.seao2.info/cgenie/labs/Bristol.2016/LAB_4.SPIN.tar.gz
```

Extract the contents of this archive by typing:

```
$ tar xfzv LAB_4.SPIN.tar.gz
```

(then change directory back to `genie-main` to run the model)

1. Exploring the marine carbon cycle

1.0 In the following experiments you can explore some of the ocean biological controls on atmospheric pCO_2 (plus ocean acidification, and the distributions and intensities of oxygen minimum zones, etc etc). A somewhat 'geoengineering' focus is employed … but really this is just an excuse explore how the biological pump in the ocean works, how it regulates atmospheric pCO_2, how sensitive it is to perturbation and what the consequences are of any changes in it are.

You will require a pre-industrial spin-up that is based on a different *base-config* (`cgenie.eb_go_gs_ac_bg.worjh2.BASEFe`) that includes additional tracers for the marine iron cycle. (The location of which was given in Section #0.)

1.1 You will also … require some new files that were not available at the time you installed the model … you need to add these files.

At the command line – change directory to: `cgenie.muffin`, and type:

```
$ svn update
```

1.2 An example *user-config* is provided: `LAB_4a.EXAMPLE`. This includes parameter settings for controlling any one of 3 different possible ocean carbon geoengineering schemes, described below (Section 1.3). By default, these are commented out (== ignored by the model) and only the *forcing* for the A2 emissions scenario (`worjh2.FeMahowald2006`) with no geoengineering is set by default. You might regard this as a control (reference) experiment for all the with-geoengineering experiments you might run. To activate any particular geoengineering *forcing*: simply un-comment (delete the # for) the appropriate pair of lines (the first line being the *forcing* specification, and the second one the total flux *forcing* used in the geoengineering scheme). If you have multiple (un-commented) settings of a parameter (e.g. `bg_par_forcing_name`) the value specified in the last occurrence is the one that is applied. This can get confusing, so if you un-comment out one set of parameter options, comment out (add a # to) the ones you are not using.

The geoengineering (and control) experiments need to be run starting from the end of the provided spin-up:

```
$ ./runmuffin.sh cgenie.eb_go_gs_ac_bg.worjh2.BASEFe LABS
 LAB_4a.EXAMPLE 100 LAB_4.SPIN
```

Because with a modern configuration and additional tracers in the ocean, the model is running rather slower than in some earlier exercises, you may not want to run for more than a century and it may be sufficient to run only for a few decades in order to see something informative happen.

1.3 Each of the example (geoengineering) carbon cycle perturbation scenarios is delineated by its own specific *forcing* – a set of files that live in a uniquely named sub-directory within `genie-forcings`. The two *forcings* are:

- `worjh2.FeMahowald2006.FFe`
- `worjh2.FeMahowald2006.FPO4`

Each *forcing* includes a prescribed dust flux to the ocean surface (the `FeMahowald2006` part of the directory name string). This is necessary because the model configuration you are using includes a co-limitation of biological productivity by iron (Fe) in addition to phosphate (PO_4). (The files associated with the dust forcing are: `biogem_force_flux_sed_det_sig.dat` and `biogem_force_flux_sed_det_SUR.dat` but you do not need to edit these files.) For the role of iron in controlling ocean productivity: possible starting points for background reading are: *Ridgwell and Kohfeld* [2007] (PDF available form my website) or *Jickells et al.* [2005] (*Science*).

The specific details of the 2 different example scenarios are:

- **Iron fertilization** (`worjh2.FeMahowald2006.FFe`)

  A constant (with time) flux of dissolved Fe (in addition to whatever Fe dissolves into the surface ocean from the dust flux) is specified in: `biogem_force_flux_ocn_Fe_sig.dat`. The magnitude of the applied flux is then scaled in the *user-config* file by the setting: `bg_par_ocn_force_scale_val_9=1.0e+09`

Note that this is simply an <u>example</u> total global flux. You might consider higher or lower fluxes, as well as potentially how 'practical' the annual production and supply of such quantities might be.

A spatial pattern of the flux is also defined, in the file:
`biogem_force_flux_ocn_Fe_SUR.dat`
An <u>example</u> pattern is set (see Section 1.4 for details on editing this pattern) – here a row of grid cells are marked at the same latitude in the Southern Ocean. You do not need to retain this pattern. In choosing an alternative: think about where in the modern ocean biological productivity is thought to be at least partly limited by the availability of dissolved Fe.

- **Phosphate fertilization** (`worjh2.FeMahowald2006.FPO4`)
  ('macro-nutrient' addition)

  A constant (with time) flux of dissolved PO_4 is specified in:
  `biogem_force_flux_ocn_PO4_sig.dat`. The magnitude of the applied flux is then scaled in the *user-config* by the setting:
  `bg_par_ocn_force_scale_val_8=2.0e+12`
  Again, you should consider this as an <u>example</u> total flux. In choosing a total flux to apply, points of comparison include whatever the total weathering flux (via rivers) of P to the global ocean is. Also: global phosphate (fertilizer) production, which produces an interesting potential conflict between geoengineering and food production, although there are proposals for using fertilized ocean regions for enhanced fish production.

  A spatial pattern of the flux is also defined, in the file:
  `biogem_force_flux_ocn_PO4_SUR.dat`
  Again, an <u>example</u> pattern has been set – here, the Equatorial Atlantic. In choosing your regions(s), think about where in the ocean (again – there may be differences between real ocean and model) productivity is currently limited by PO_4. Also be aware of possible on-set of Fe limitation if you relieve the PO_4 limitation.

1.4 The spatial patterns of an applied flux *forcing* to the ocean can easily be modified. The pattern is specified in a simple ASCII (plain text) file, in the file in the forcing sub-directory ending '`_SUR.dat`'. The file (in this example the default Fe pattern) looks like:

```
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```

Here: '`0`'s represent land and cannot have a forcing associated with them. '`0.0`'s represent a zero flux to the ocean, and '`1.0`'s the default Southern Ocean forcing pattern. Note that a distinction is made between a '`0`' and a '`0.0`' so that you can make out where the continents are and do not necessarily have to count in the 'i' and 'j' grid directions to find a specific location. The grid is the same as you saw previously in the ocean circulation tracing Lab, and which numbered the 'i' and 'j' axes if that helps.

There is no more to changing the pattern of the flux forcing than simply marking with a '`1.0`' where you would like the forcing applied, and a '`0.0`' where it should not be. Note that there should be a single blank line at the bottom of the file. (If you have problems applying a modified spatial pattern – check that this is present.) It is best to keep a copy of the original *forcing* in case you make a mess of the spatial pattern file, but the original can also be recovered from the code server.

1.5 What to look out for in terms of impacts? The concentration of CO_2 in the atmosphere is an obvious and simple metric. Other global properties and inventories (along with this) are summarized together in the files named:
`biogem_year_xxxx_yyy_diag_GLOBAL_AVERAGE.res`
where `xxxx_yyy` represents the time of the mid-point of the saved annual average. In these summary files, changes in the inventory of oxygen in the ocean and the global mean annual POC export flux should be instructive. Similarly, the spatial patterns of dissolved oxygen in the ocean and of surface POC export and dissolved nutrient (phosphate and iron) are important to look out for. There are also time-series files of the evolution with time of a variety of mean surface and mean global properties.

2. Further ideas

2.1 Further modifications of the biological pump in the ocean

Other manipulations of the biological pump and ocean carbon cycle are possible and potentially instructive and the two example below have the potential for profound impacts not only atmospheric pCO_2 but also on dissolved oxygen concentrations in the ocean (and hence implications for the suitability of animal habitat such as for fish).

- **Remineralization depth**. In the model configuration that you have been using, the degradation of particulate organic matter sinking in the water column proceeds according to a fixed profile of flux with depth (there is no e.g. temperature control on the rate of bacterial degradation of sinking organic matter) with CO_2 and PO_4 released back to the seawater as the particulate flux decreases. The parameter that controls the (e-folding) depth scale of particulate organic matter is:
  `bg_par_bio_remin_POC_eL1=589.9451`

  Either edit this value (found under the heading: `# --- REMINERALIZATION ---`) or add a new line at the end of the *user config* file specifying the value you want. Units are m. Read *Ridgwell et al.* [2007] for additional discussion of this parameter. See Figure 2-4 in *Ridgwell* [2001] (http://www.seao2.org/pubs/ridgwell_thesis.pdf) for an illustration of how the flux of particulate organic matter decreases with depth in the ocean, plus references therein.

  There is also an associated parameter: `bg_par_bio_remin_POC_frac2`, which sets a fraction of organic matter that is assumed to settle through the water column completely un-altered (currently assigned a value of `0.045` == 4.5%), but this is arguably less useful to change than the remineralization length-scale of the more labile fraction (the other 95.5% of particulate organic carbon exported from the ocean surface).

  Note that there may well be no simple parallel that can be found in geoengineering to this process. However, there are hypotheses that during the last glacial and as a result of colder ocean temperatures, the depth scale was longer. Conversely, there are ideas about that the warmer temperatures of the e.g. Eocene ocean and hence faster rates of bacterial metabolism led to a much shallower remineralization depth scale. So a remineralization depth scale that is responsive to temperature may have importance in understanding ocean biogeochemical cycles during both past warm and cold climates as well as obviously, future global change. While you are not implementing a temperature-dependent parameterization explicitly, you can at least test for whether changes in temperature might have important impacts by simply changing the remineralization depth to be shallower (smaller depth-scale under a warming climate) or deeper (greater depth-scale in a colder ocean).

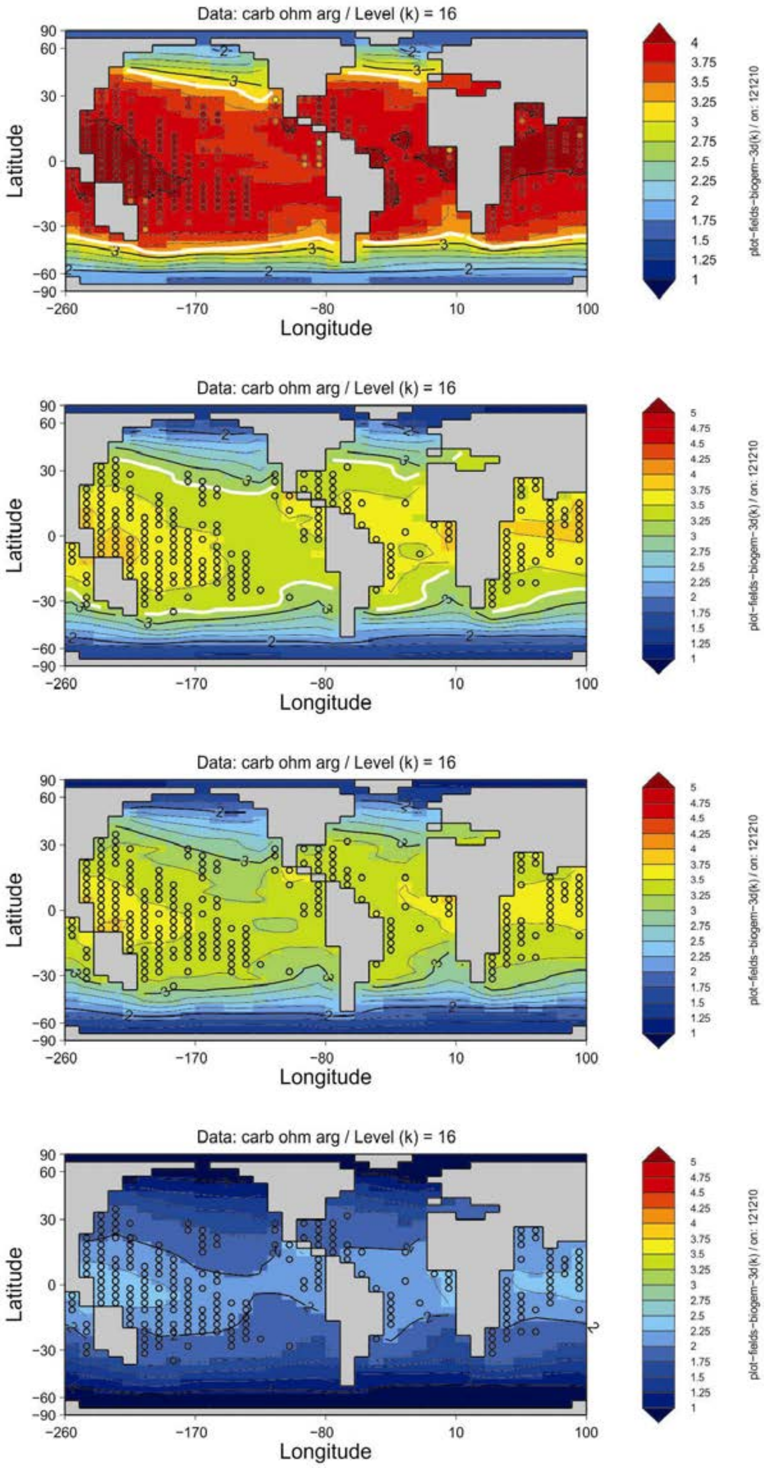
- **Macro nutrient inventory and uptake**. Suggestions have been made that nutrients were used more efficiently during the last glacial and now for instance and hence important in explaining low glacial atmospheric CO_2. The nutrient-to-carbon ratio in organic matter is controlled by: `bg_par_bio_red_POP_POC=106.0`.

  To change the default value (`106.0`), add a new line at the end of the *user-config* file specifying the value you want. A larger number means that PO_4 is being utilized more efficiently and more organic matter is being produced for the same nutrient consumption.

  You can also test the effect of there being more PO_4 in the ocean overall – to increase the inventory of the ocean as a whole in one go, e.g. add the line:

  `bg_ocn_dinit_8=1.0E-6`

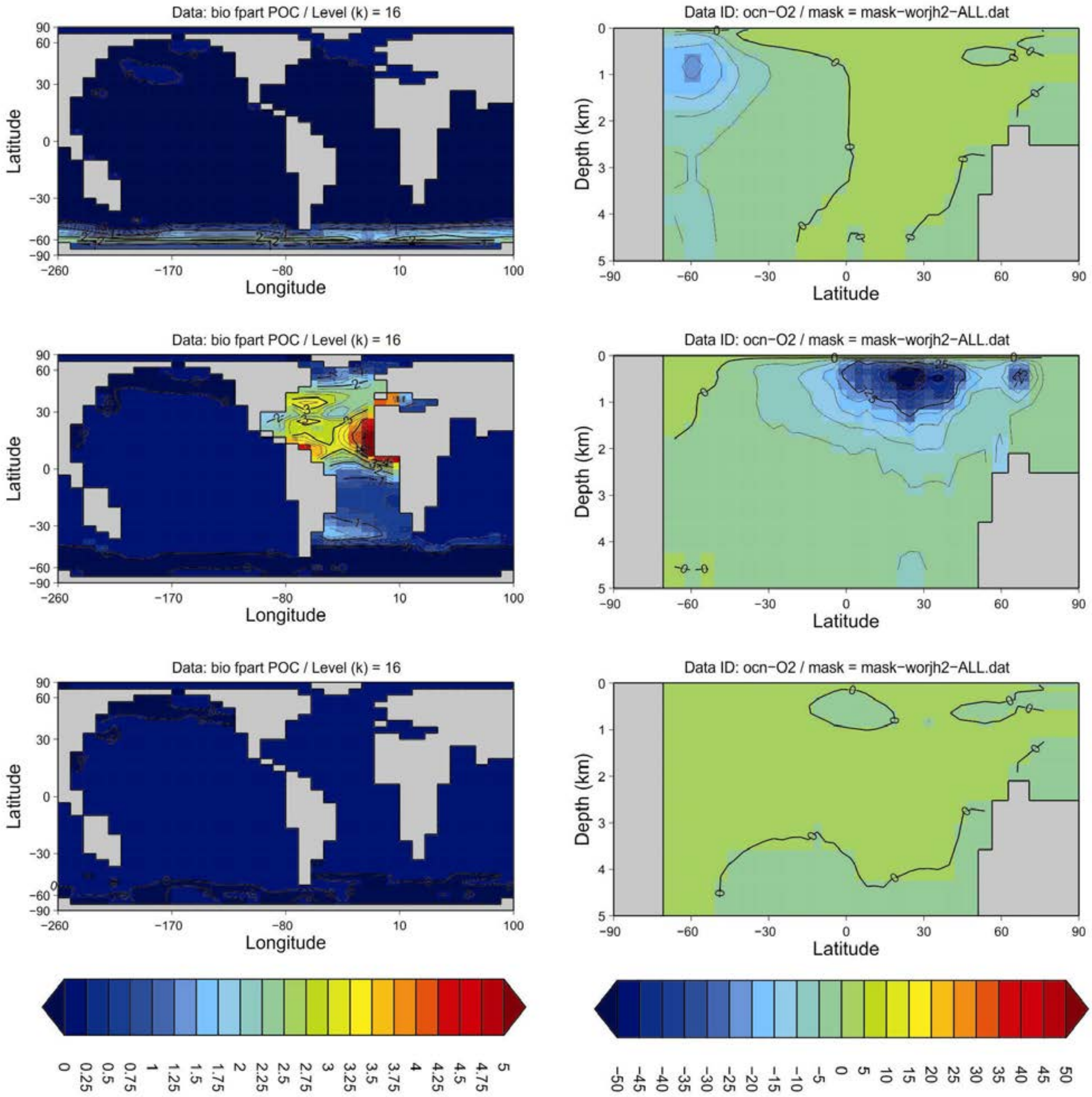
  which will add 1 μmol kg^{-1} of PO_4 uniformly to the ocean. (A larger/smaller number will obviously increase the glacial nutrient inventory by more/less.)



Mean annual ocean surface saturation (aragonite) changes.

Top: pre-industrial model ocean surface saturation (aragonite) with ReefBase tropical coral reef locations re-gridded to the GENIE grid and color-coded with modern observationally-based saturation values.
2nd and 3rd down: Year 1994 and 2010 ocean surface saturation (aragonite) with ReefBase reef locations.
Bottom: Year 2010 ocean surface saturation (aragonite) under the A2 CO_2 emissions scenario.
The thick white line delineates the 3.25 saturation contour (inferred to reflect a limitation on corals).

Examples here produced using MATLAB (plotting scripts are located in genie-matlab) but equally do-able in Panoply with the exception of achieving a data overlay. These are provided simply to illustrate some of the impacts you might consider and possible ways of visualizing them.



Ocean surface export (particulate organic carbon) and zonal [O_2] anomalies.

Left: anomalies of global mean annual export production, for Fe fertilization (top), PO_4 addition (middle), and ocean liming (bottom).

Right: Zonal mean anomalies of dissolved O_2 concentrations.

Examples here produced using MATLAB (plotting scripts are located in genie-matlab) but equally do-able in Panoply with the exception of achieving a data overlay. These are provided simply to illustrate some of the impacts you might consider and possible ways of visualizing them.