1. Modelling basics &... snowball Earth!

Remember that the various course PDFs on the web http://www.seao2.info/mymuffin.html ... the course guide as well as the **muffin** manual ... may be updated from class-to-class, and you'll need to be always working from the current version. To do this and to force a re-load of the webpage cache in your browser:

- Windows – press the Ctrl-F5 key combination.
- Mac – according to Google (and I am unable to test this) ...
  "In Camino and Firefox, press Shift-Command-R (or hold Shift and click the Reload button). In Safari, hold the Option key and press the Reload button in the toolbar."

1.1 Specific readings

- Snowball Earth review:
  Hoffman and Schrag [2002] (Terra Nova 14, 129-155)
- Model analysis of the inception of a snowball Earth and ice-albedo thresholds:
  Hyde et al. [2000] (Nature 405, 425-429)

1.2 Work plan

The work plan for week #1, is to:

1.2.1 i (Wednesday)

Work through Chapter #1, and specifically:

- Section 1.1 – Basic notes on working methodology and software required.
  For users of WinSCP, there is a convenient way to configure this to enable you to edit files on the remote server directly. By default, if you double-click on a file in the remote server window (the left hand window), then the file is opened. However, by default, a text file

might be opened by Notepad (bad). So in the **WinSCP** Options menu, and the item Preferences, which opens a settings window:

Under Editors – you can add e.g. Notepad++ and associated this with text files. You could also add Panoply and associated with .nc (netCDF) files. Tick the 'Force text transfer ...' check box.

It remains that the easiest way to copy files is to drag them locally, rename them (maybe then edit and save them), and drag them back.

If you set this up correctly, then you can double-click a remote file, edit it, and save it, and the updated file contents will be written back to the remote computer.

- Section 1.2 – Logging in and accessing, configuring, and testing the code.
  In 1.2.2 – Use git clone to get the code.
  Refer to the end of this chapter for notes on configurating the cluster account.
  In 1.2.3 – Your cluster is 'domino' (when it comes to which file is to be edited). Note the footnote explanation on what 'commenting' and 'un-commenting' lines of code involves.
  You can ignore 1.2.5.
- Figure 1.1 – Explore, using a file transfer client (such as **WinSCP**), the model directory structure with the figure as a guide, to help familiarize yourself with where everything is.
- Section 1.3 – Running the model.
  (Also note Figure 1.2.)
- Section 1.4 – Make sure that you are familiar with where the output is, and what the different forms of output are.
  Note that when you run an experiment with a different *base-config*, the model is automatically re-compiled. This is important in the context of submitting jobs to the cluster – see below.
- Section 1.5 – Make sure that you are familiar with how to view all the different sorts of model output.
- Section 1.6 – Submitting jobs to the cluster.
  IMPORTANT: The first time that you want to run an experiment with a NEW *bas-config*, you need to ensure the model re-compiles. Do this by running a brief interactive experiment at the command line. Only then, is it 'safe' to submit to the cluster.
  Note that if you have multiple experiments to submit to the cluster, all using the same *base-config*, you only need to ensure the recompile for the first experiment (and then only if the *base-config* is different from the the last experiment you ran).
- Section 1.7 – *Re-starts*. Be sure to be clear in your mind, that a *re-start* is just a 'normal' experiment that has been previously run. Any new experiment can start from the end of that previously-run experiment.

1.2.2   ii (Friday)

Work through Chapter 2, and specifically:

- Section 2.1. There are 2 sperate exercises to be done here:
  (1) Running multiple model experiments to determine the approximate radiative forcing CO_2 threshold that would induce a snowball climate state.
  (2) Using an experiment in which a snowball state occurs as a *re-start*, determine the radiative forcing threshold required to exit that state.
- Additional/optional – Explore the use and effect of different continental configurations – Section 2.2.2 and/or Section 2.2.3.

- Completely optional – Section 2.2.4 and 2.2.5 (and 2.2.1).

1.3   Cluster account configuration

In order to fully configure your cluster account and enable the **muffin** model to work, you need to edit a special file that is read-in when you log in, and directs **muffin** to some software libraries that it needs.

The file lives in your home directory (the directory you log into), and is called:

```
.bash_profile
```

Now unfortunately ... this file is a 'hidden' file ... to see it at the command line you cannot just type ls to display the directory listing, but rather, you need:

```
$ ls -la
```

In your file transfer client, you need to find somewhere in the settings where it will show 'hidden' files in order to be able to see it.

You will need to open, edit, and save this file, which can be done:

1. Directly in a command-line editor such as vi.

2. Indirectly, by dragging the file locally, editing, saving, and dragging back (but remember that your file transfer client needs to be able to 'see' the hidden file in the first place).

3. By – if you have set up your file transfer client in this way – double-clicking the file, editing and saving. (But you still need to be able to 'see' it!)

At the end of .bash_profile, add the following lines:

```
# User specific environment and startup programs
PATH=$PATH:$HOME/bin
export PATH
PATH=$PATH:/state/partition1/apps/netcdf-c-4.4.1.1-fortran-4.4.4/lib
export PATH
PATH=$PATH:/state/partition1/apps/netcdf-c-4.4.1.1-fortran-4.4.4/include
export PATH
LD_LIBRARY_PATH=$LD_LIBRARY_PATH:/state/partition1/apps/netcdf-c-4.4.1.1-fortran-4.4.4/lib
export LD_LIBRARY_PATH
export CGENIE_PYTHON=/state/partition1/apps/Python-2.7.13/bin/python2.7
```

You can copy-paste from this document ... with care. Or find the information from the following link.

2. Ocean circulation
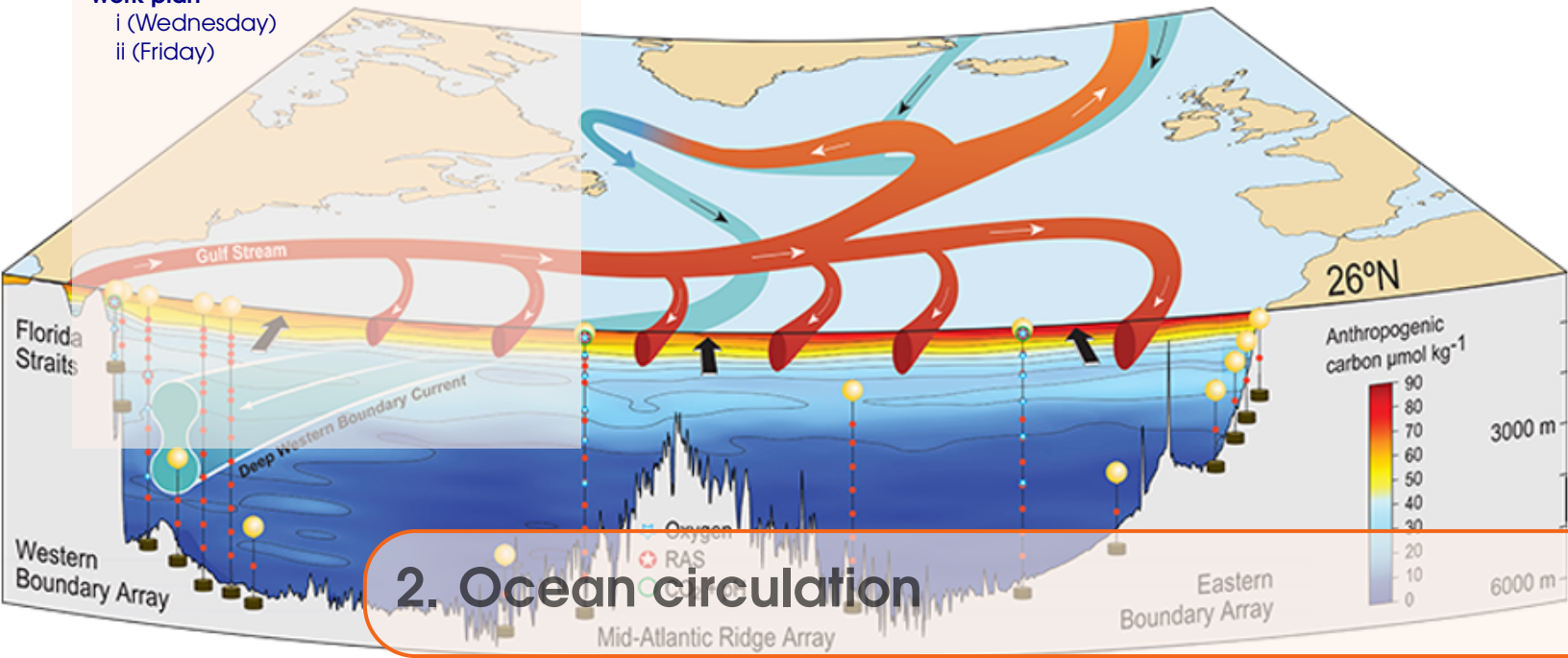
From last week – updates and points to note, are:

1. When ... and only when changing a *base-config* for your next experiment, will you need to re-compile the model before submitting a job to the cluster.
   e.g. if you had just been running experiments with a *base-config* file `base1`, and then you want to change continental configuration defined by *base-config* file `base2`, you cannot directly go and submit a job to the cluster queue using `base2`. Instead, you need to start running the new experiment interactively (at the command line). `runmuffin` will recognise that a different *base-config* file is being used, and automatically `make cleanall` and then re-compiled the model. You can either run the experiment for just one year, or kill (CTRL-C) the experiment once it has started running (after completing compiling). Then, you can submit the experiment as a job to the cluster queue.
   You do not need to re-compile **muffin** again until you want to switch to yet another new (or the previous) *base-config*. i.e. it is not necessary to re-compile before each and every experiment, only if the *base-config* has changed.

2. For Section 2.2.3, the key *user-config* file was not provided for you at the time ... The instructions have now been updated and the necessary file has now been added to the **muffin** code base.
   To update your **muffin** code-base – from the directory `cgenie.muffin`, type:

   ```
   $ git pull
   ```

   Do this if you wish to re-visit and complete Section 2.2.3.
   NOTE that you may be required, from time-to-time during the course, to update your installed **muffin** code base in exactly this way. (You will be notified each time when this is necessary.)

2.1   Specific readings

1. Atlantic circulation and stability in GENIE

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

- Characterization of thresholds of AMOC collapse.:
  Marsh et al. [2004] (Climate Dynamics, Volume 23, Issue 7 - 8, Dec 2004, Pages 761 – 777)

- Role of changing ocean circulation in atmospheric radiocarbon variability during the Younger Dryas.
  Singaraye et al. [2008] (GRL 35, doi:10.1029/2008GL034074)

- Deep-sea CaCO3 sediment and atmospheric CO2 response to AMOC shutdown:
  Chikamoto et al. [2008] (JGR 113, doi:10.1029/2007JG00066)

2. Miscellaneous (model) Atlantic circulation and stability

- Background to the Atlantic Meridional Overturning Circulation and hypothesized hysteresis:
  Rahmstorf et al. [2006] (In: Encyclopedia of Quaternary Sciences, Edited by S. A. Elias. Elsevier, Amsterdam)

- Future predictions of AMOC strength:
  IPCC [2007] (e.g., Section 10.3.4)

- Impacts on marine ecosystems and carbon cycling:
  Schmittner [2005] (Nature 434, 628– 633)

- Climate-carbon cycle model response to freshwater discharge:
  Obata [2007] (J. Clim. 20, 5962–5976)

2.2   Work plan

2.2.1   i (Wednesday)

Work through Chapter #3, and specifically:

- Section 3.1 – Introducing forcings of the model and developing ways of visualizing and tracing ocean circulation in the model.

- Section 3.2 – How to force/induce changes in ocean circulation in the model. Further visualization of ocean circulation.

- (optional) – Section 3.3.1 – Exploring the sensitivity of ocean circulation to the spatial pattern/location of the (freshwater) perturbation.

- (optional) – Section 3.3.4 – Diagnosing the 'age' of a water mass.

2.2.2   ii (Friday)

1. First, read through the rather incomplete Chapter 5, which should at the very least, give you some ides and further information on understanding/diagnosing ocean circulation in the model.

2. Next ... transfer to the cluster .... by `wget`, the following *re-start* experiment archives:

- muffin.CB.eg_ww_lo.BASES.SPIN.tar.gz
- muffin.CB.eg_rw_lo.BASES.SPIN.tar.gz
- muffin.CB.eg_ep_lo.BASES.SPIN.tar.gz
- muffin.CB.eg_ee_lo.BASES.SPIN.tar.gz

and then unpack (to `genie_output`).

Create a series of 4 new *user-config* files, each with the following contents:

```
#
# --- CLIMATE ---------------------------------------------------------
#
# scaling for atmospheric CO2 radiative forcing, relative to 278 ppm
ea_radfor_scl_co2=1.0
#
# --- BIOLOGICAL NEW PRODUCTION ---------------------------------------
#
# Set no biological production
bg_par_bio_prodopt='NONE'
#
# --- DATA SAVING -----------------------------------------------------
#
# Set BASIC + full physics save level (9)
# (assume default time-series and time-slice save intervals)
bg_par_data_save_level=9
bg_ctrl_debug_lvl0=.true.
ma_debug_loop=1
#
# --- END -------------------------------------------------------------
#
```

Then you are going to need some *base-config* files. You should copy and rename the following files in `cgenie.muffin/genie-main/configs`:

- muffin.CB.eg_ww_lo.BASES.config
- muffin.CB.eg_rw_lo.BASES.config
- muffin.CB.eg_ep_lo.BASES.config
- muffin.CB.eg_ee_lo.BASES.config

and edit them (delete lines) such that the 'TRACER CONFIGURATION' section ends up looking like:

```
# **********************************************************************
# TRACER CONFIGURATION
# **********************************************************************
# the total number of tracers includes T and S
# T and S do not need to be explicited selected and initialzied
# **********************************************************************
# Set number of tracers
GOLDSTEINNTRACSOPTS='$(DEFINE)GOLDSTEINNTRACS=2'
# **********************************************************************
```

Basically, you are just removing all the carbon/biogeochemical cycle tracers (and leaving just temperature and salinity).

Finally, run the 4 experiments using the *re-starts* you downloaded, the new *user-config* files

you created, and the copy/edited *base-configs*. Running for e.g. 10 years is sufficient.

Assess the nature of ocean circulation in the 4 different abstract continental configurations and try and deduce *why* the circulation patters are what they are. Refer to the references given in Chapter 5.

3. The last thing to do ... is to make some 'worlds' and then run them(!) (and deduce how the ocean circulates). See Chapter 16.

Prior to the end of the class, submit your various worlds as jobs to the cluster, running for 5,000 or 10,000 years to steady state (hopefully!).

3. Alternative Worlds and data visualization

3.1 Work plan

3.1.1 i (Wednesday)

Fake (alternative) Worlds are a useful tool for developing a general understanding of how climate (and ocean circulation) and global biogeochemical cycles operate. Different model resolutions and continental configurations can be generate and run to test specific hypotheses about the role and sensitivity of different elements in Earth system to emergent patterns of climate (and biogeochemical cycling). Ensembles of differing Worlds can also be utilized to more generalize understanding as well as in a fishing expedition of new or unexpected phenomena and system behaviours.

Generate and explore (analyse) some fake (alternative) Worlds, using the tools ot diagnose and understand ocean circulation and clmiate that you have already learnt.

3.1.2 ii (Friday)

First, read/work through Chapter 13 in the muffin manual.

You may need to refresh or learn a few basic MATLAB skills such as plotting of simple text (ASCII) files (but read through Chapter 13 first to see what is needed). For instance from the 'matlabananas' text book, you might familiarize yourself with Sections:

- Section 1.6 – *Loading and saving data*, and specifically, sub-sections: 1.6.1 – Where am I? and 1.6.2 – Loading and importing data.
- Section 1.4 – *Basic graphing (aka. 'data visualization')*, and specifically, sub-sections: 1.4.1 – Plotting, 1.4.2 – Graph labelling, 1.4.4 – Saving graphics and figures.

and if you need more info on concepts such as *variables* and *arrays* in **MATLAB**, first:

- Section 1.2 – *Basic concepts*, and specifically, sub-sections: 1.2.1 – Variables.

- Section 1.3 – *Vectors and arrays #1*, and specifically, sub-sections: 1.3.2 – Basic vector manipulation, 1.3.4 – Addressing elements in vectors.
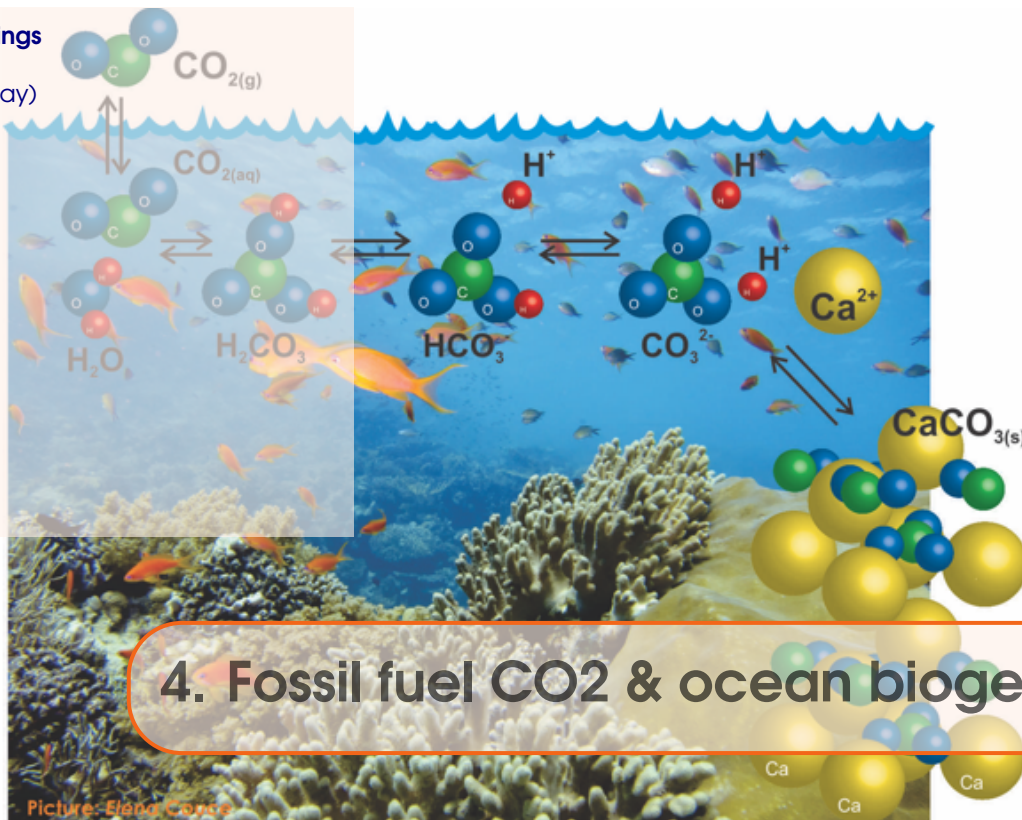
Armed with this knowledge, try plotting some time-series data from your model experiments.

Secondly, read/work through Chapter 13 in the muffin manual.

4. Fossil fuel CO2 & ocean biogeochemistry

Picture: Elena Cama

4.1 Specific readings

- 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

- 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-CO2 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., CO2 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/

4.2 Work plan

4.2.1 i (Wednesday)

Chapter 6, and in particular Section 6.1 (all of), plus Section 6.2.1.

4.2.2 ii (Friday)

Using the 'excuse' of geoengineering ... perturb and elucidate the response of the global carbon cycle and climate system (and thereby hence learn something new/different about Earth system dynamics compared to e.g. its response only under standard future carbon emissions scenarios).

Sections 8.1 (al of), plus note contents of Section 8.2.1.

5. Marine ecosystems and dynamics

You will be working with highly idealised marine ecosystems representations ... The aim is to explore why the model behaves as it does. The assumption is that this will give us some insight into why the real world behaves as it does. Perhaps. (It is up to you to question the validity of this assumption.)

5.1 Specific readings

First read:

- Ward et al. [2017] – Ward, B. A., Wilson, J. D., Death, R. M., Monteiro, F. M., Yool, A., and Ridgwell, A.: EcoGEnIE 1.0: plankton ecology in the cGEnIE Earth system model, Geosci. Model Dev. DOI: 10.5194/gmd-11-4241-2018 (2018).
  https://www.geosci-model-dev.net/11/4241/2018/gmd-11-4241-2018.pdf

5.2 Work plan

5.2.1 i (Wednesday)

Work through:

  10.1 – *Getting going with **ECOGEM***
  10.2 – *Ecosystem configuration*
  10.3 – *Increasing ecological complexity*

5.2.2 ii (Friday)

Chapter 10 (continued).
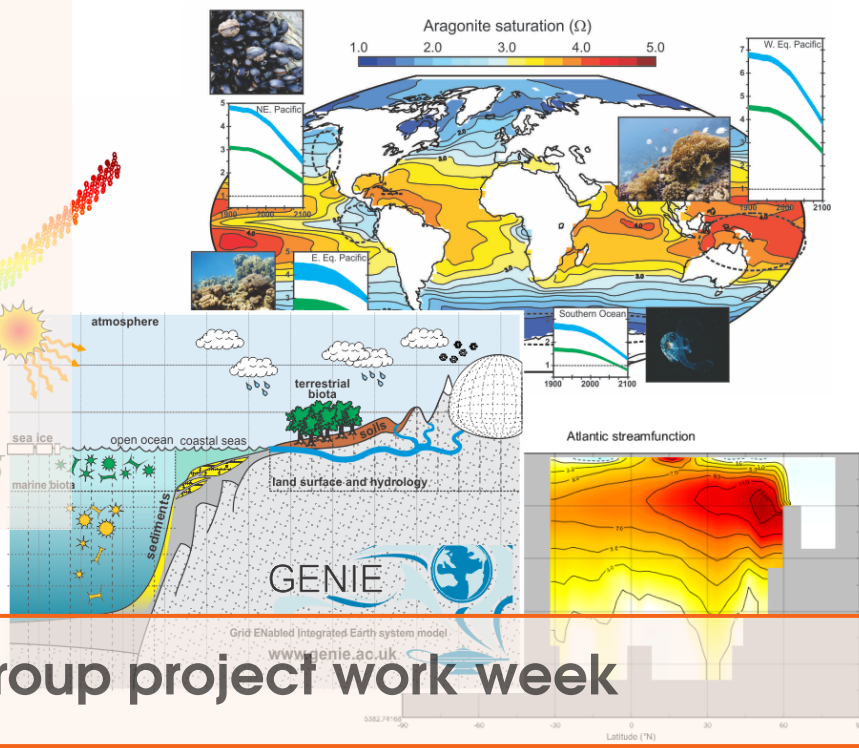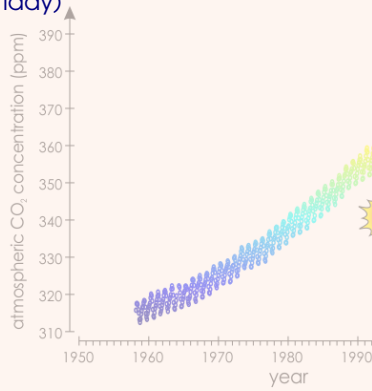
6. Group project work week

6.1 Specific readings

n/a

6.2 Work plan
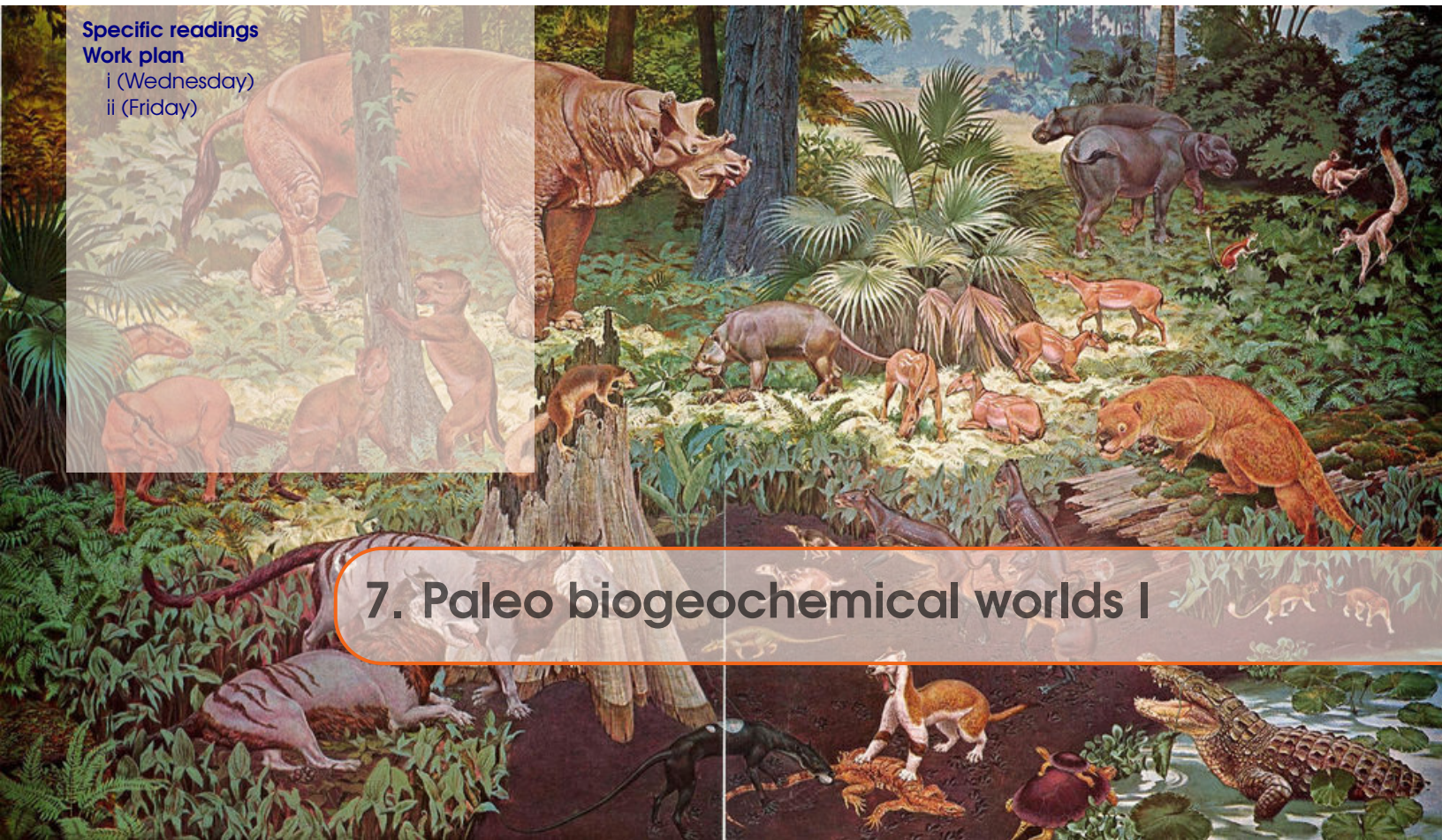
6.2.1 i (Wednesday)

(work on group research project)

6.2.2 ii (Friday)

(work on group research project)

7. Paleo biogeochemical worlds I

7.1 Specific readings

- Meyer, K.M., A. Ridgwell, and J.L. Payne, The influence of the biological pump on ocean chemistry: implications for long-term trends in marine redox chemistry, the global carbon cycle, and the evolution of marine animal ecosystems, Geobiology, DOI: 10.1111/gbi.12176 (2016).

- Monteiro, F.M., R.D. Pancost, A. Ridgwell, and Y. Donnadieu, Nutrients as the dominant control on the extent of anoxia and euxinia across the Cenomanian-Turonian oceanic anoxic event (OAE2): Model-data comparison, Paleoceanography, DOI: 10.1029/2012PA002351 (2012).

- Ridgwell, A., J. Hargreaves, N. Edwards, J. Annan, T. Lenton, R. Marsh, A. Yool, and A. Watson, Marine geochemical data assimilation in an efficient Earth System Model of global biogeochemical cycling, Biogeosciences 4, 87-104 (2007).

- Tagliabue, A., O. Aumont, R. DeAth, J.P. Dunne, S. Dutkiewicz, E. Galbraith, K. Misumi, J.K. Moore, A. Ridgwell, E. Sherman, C. Stock, M. Vichi, C. Völker, and A. Yool, How well do global ocean biogeochemistry models simulate dissolved iron distributions?, GBC, DOI: 10.1002/2015GB005289 (2016).
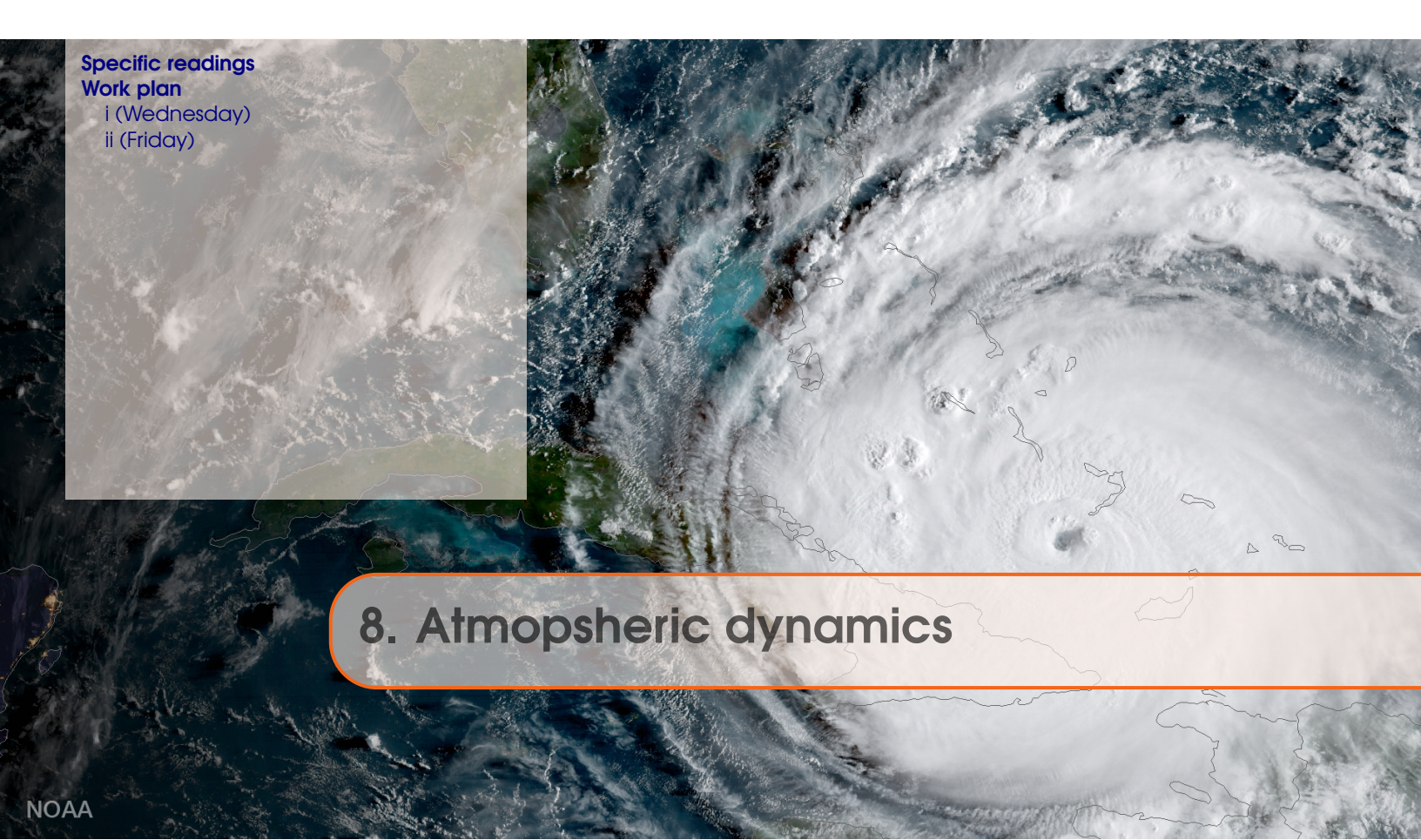
7.2 Work plan

7.2.1 i (Wednesday)

(Group presentations.)

7.2.2   ii (Friday)

Marine ecology and biogeochemical cycles in past worlds.

NOAA

8. Atmopsheric dynamics

9. Paleo biogeochemical worlds II

(UCR holiday)
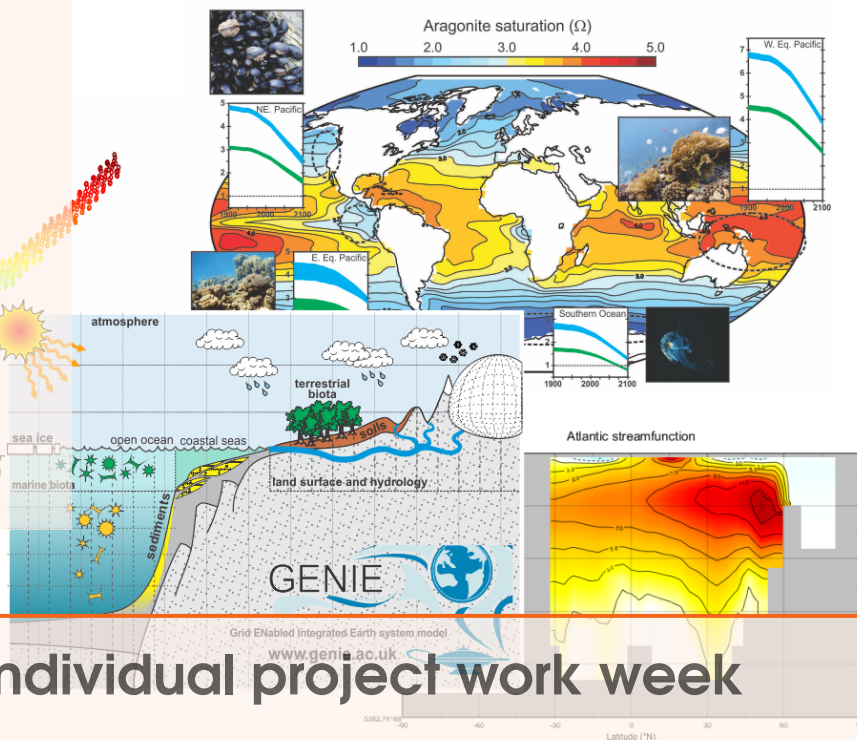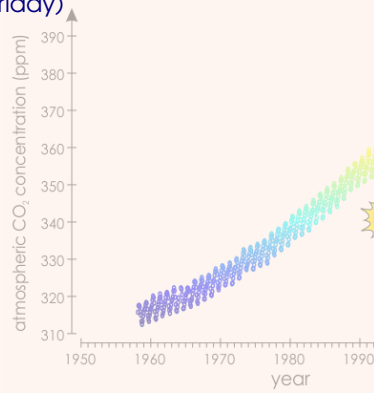
10. Individual project work week

10.1 Specific readings

n/a

10.2 Work plan

10.2.1 i (Wednesday)

(work on individual research project)

10.2.2 ii (Friday)

(work on individual research project)