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

This exercise will constitute **20% of the total unit marks**.

Presentations will be made on **Friday 2nd November** (Week 4) in the MSci room, starting at **10 am** (i.e., the ‘normal’ EC4 lecture slot).

Devising and running the model experiments, analyzing the experiments, and creating and making the presentation, can be done in groups of ***2, 3, or 4*** (suggested to be as per the existing Lab groups).

The presentation should be **15-25 minutes long**, depending on group size – you will be allocated 5 minutes per group member, plus 5 additional minutes (i.e. 3 people == 20 minutes, 4 people == 25 minutes). You will be informed when you have 5 minutes remaining. (Presentations are significantly over time and/or completely mis-timed may be subject to some sort of penalty.)

Each group (and anyone in the group) may get questions … so everyone needs to understand and to be prepared justify what you have done and found!

The assessment will be marked according to the following scheme: 30% for the quality (particularly visual) of the overall presentation, 40% for the basic science content, e.g. background (context of the problem), model (methodology), results, analysis, conclusions, the remaining 30% (maximum) will be allocated to exceptional and/or enlightening modeling, insights, analysis, and/or implications. All group members will receive equal marks in the assessment.

In summary: the assessment is first and foremost, simply a presentation of the science background to background, methodology, findings & conclusions of Lab session #2 (snowball Earth thresholds and hysteresis). However, additional experiments, analysis, and/or insights, are expected.

I. Climate hysteresis of snowball Earth

I.0 Your task is to: **quantify using *c*GENIE and present the snowball Earth hysteresis loop – both entry and exit from a completely (i.e. >99%) ice-covered ocean state.**

Work in groups, e.g. the same groups as you are already in is just fine.

There will be no change in computer cluster for this exercise, i.e. you current accounts on iwan.ggy.bris.ac.uk will continue to be available until after the presentations.

I.1 it is suggested that you use the *Hyde et al.* [2000] paper (and background to hysteresis loops) as a starting point for the modeling and analysis, plus the other references given in the Lab handout (and here) and any cited (or other) references that seem relevant and likely to help you ...

The goal is to quantify, describe, and explain, the snowball Earth hysteresis loop in *c*GENIE, as per shown in **Figure 2 in *Hyde et al.* [2000]**. This will be done both for:

(i) **entering a snowball state** (as per *Hyde et al.* [2000]),
and
(ii) **exiting a snowball state** (e.g. see: *Caldeira and Kasting* [1992]) which was not done by *Hyde et al.* [2000].

Another example is as per Figure 3,4 in *Stone and Yao* [2004] (although here it is the solar constant rather than long-wave radiation forcing that is being varied).

You will need to extract from the model, 'meaningful' measures of climate (e.g., global surface air temperature, fractional sea-ice coverage) as a function of CO_2 multiples, CO_2 concentration, or (better) radiative forcing. For the latter, in *c*GENIE, the radiative forcing for a doubling of CO_2 is set at: **5.77 W m^{-2}**. See: *Myhre et al.* [1998] (*Geophys. Res. Lett.* **25**, 2715–2718) and/or *IPCC* [2007] for more on what radiative forcing is and how it is related to a relative change in CO_2 concentration.

For making a comparison with *Hyde et al.* [2000] – for going into the snowball, note that they plot the change in radiative with a 'cooling' as positive (a bit daft). Their baseline radiative forcing state (an anomaly of 0 W m^{-2}) I think is equivalent to 278 ppm (maybe check the model references) and hence ~130 ppm is an approximately halving of CO_2 and hence creates ~5 W m^{-2} of cooling. (You might prefer to plot the radiative forcing change as warming being positive, which makes rather more sense ...)

For coming out of a snowball, because the CO_2 and hence radiative forcing threshold is so high compared to going in, you may want to be creative in the plotting (assuming attempting to combine both thresholds into a single plot) and, for instance, one might break the scale between the low radiative forcing interval spanning going in and the high one spanning coming out.

I.2 The minimum requirement for the exercise is to delineate the climate hysteresis loop for a single continental configuration, which to ensure there is a common/equal element to all your presentations, and which will using a very similar configuration to that used in Lab session #2 (although lacking the shallow water 'shelf' surrounding the continent):

```
cgenie_eb_go_gs_ac_bg.woreq1.NONE
```

You presentation *must* include an element of model/experimental description and analysis based on this.

(Because the configuration is slightly different to that used in Lab session #2, you cannot simply get away with writing up your previous results.)

I.3 Some *suggestions* for further analysis …

- Are the thresholds dependent on seasonality? In the basic *c*GENIE snowball *user-config* seasonality has been disabled. Does this matter? As per the snowball Lab session – to include seasonal insolation forcing of climate, change the following lines in the *user-config*:

```
ea_dosc=.true.
go_dosc=.true.
gs_dosc=.true.
```

- How important is the continental configuration to where the runaway feedback ice-albedo transition occurs? You have been provided with a number of (idealized) continental positions and degrees of fragmentation (`wopol1`, `wopol2`, `woreq1`, `woreq2`).

There are 4 alternative *base-configs*, with which to define different continental configurations:

1. `cgenie_eb_go_gs_ac_bg.wopol1.NONE` – **a single polar super-continent**, with an ocean resolution of 36×36 with 8 vertical levels. (Note potential 'l' and 1'1 confusion in 'wopol1'.)
2. `cgenie_eb_go_gs_ac_bg.wopol2.NONE` – **one continent at each pole**, with an ocean resolution of 36×36 with 8 vertical levels.
3. `cgenie_eb_go_gs_ac_bg.woreq1.NONE` – **a single Equatorially-centred super-continent**, with an ocean resolution of 36×36 with 8 vertical levels.
4. `cgenie_eb_go_gs_ac_bg.woreq2.NONE` – **two continents straddling the Equator**, with an ocean resolution of 36×36 with 8 vertical levels.

I.4 The alternative configurations are run similarly to as per before (with 100 years run-time specified here solely as an example), i.e.:

```
$ ./runcgenie.sh cgenie_eb_go_gs_ac_bg.xxxxx.NONE LABS expxxx_snowball 100
```

You are using a different *base-config* file name: `cgenie_eb_go_gs_ac_bg.xxxxx.NONE` here, where `xxxxx` is one of: `wopol1`, `wopol2`, `woreq1`, or `woreq2`.
Also note that the '`.t100`' has been omitted in the naming convention for these 4 alternative configurations as well as being omitted from the naming of the `./runcgenie.sh` command.

Although the *base-config* is being changed between different configurations, in this particular exercise you can get away with not doing a '`make cleanall`' in between different configurations.

You have been provided with a generic *user-config* file: `expxxx_snowball` for basing your experiment definitions on, but in truth, it is really just the same file as before ;)
(maybe I changed the default setting of `ea_radfor_scl_co2` by accident, otherwise the same)

Note that I have not provided any *re-starts* for these configurations. You may (or may not) want to create some (you will need to judge for yourselves how long to run the re-start experiments for to achieve as close to steady-state as you think is 'sufficient'). Remember that *re-starts* are just 'normal' experiments (but started from 'cold').

I.5 <u>Other thoughts, ideas, hypotheses, tests, and assumptions, may of course be equally employed in addition to, or instead of some or all of the above, and could turn out to be more valid and/or interesting.</u>

Note that you <u>do not necessarily have to test ALL these different configurations</u>! I do not want to see bloated and incoherent talks that solely consist of 1000s of model runs with no real conclusion or insight …

Contact me if you have questions about the feasibility of doing experiments and/or analysis outside of what you have been taught and provided with to date and basic help in achieving this (if feasible).

Overall: think critically about the model configuration, the experimental design, and the nature of the scientific question (based on your background reading of snowball Earth). Some of the exploration/testing suggestions (above) may not necessarily give substantially different results from the default (lab session) configuration. Such a finding would be as valid and interesting as determining an important dependence of a certain assumption, and would for instance indicate that the associated paleo uncertainties are not critical to model assessment of the question.

Be prepared to justify (maybe only briefly will be necessary) all your choices for experimental design and model settings, e.g., range of radiative forcing assessed, continental configuration(s), model resolution and solar forcing, use of *re-starts* (if any), run duration, etc. etc. etc. etc.