

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

V: The late Cretaceous Equator-to-pole paradox



Cretaceous forest 120 Million years ago on the Antarctic Peninsula.
Reconstruction based on PhD work of Jodie Howe, University of Leeds/BAS,
painted by Robert Nichols.

Relevant reading:

- Barron, E.: A warm equable Cretaceous: the nature of the problem, *Earth-Science Reviews* **19**, 305–338, 1983.
- Bice, K. L., and R. D. Norris, Possible Atmospheric CO₂ extremes of the middle Cretaceous (late Albian-Turonian), *Paleoceanography* **17**, doi: 10.1029/2002PA000778, 2002.
- Bice, K. L., B. T. Huber, and R. D. Norris, Extreme polar warmth during the Cretaceous greenhouse?: Paradox of the Late Turonian $\delta^{18}\text{O}$ record at DSDP Site 511, *Paleoceanography* **18**, doi: 10.1029/2002PA000848, 2003.
- Bice, K. L., D. Birgel, P. A. Meyers, K. A. Dahl, K. Hinrichs, and R. D. Norris, A multiple proxy and model study of Cretaceous upper ocean temperatures and atmospheric CO₂ concentrations, *Paleoceanography* **21**, PA2002, doi:10.1029/2005PA001203, 2006.
- Donnadieu, Y., et al., Modelling the primary control of paleogeography on Cretaceous climate, *Earth and Planetary Science Letters* **248**, 426–437, 2006.
- Huber, B. T., Norris, R. D., and MacLeod, K. G.: Deep-sea paleotemperature record of extreme warmth during the Cretaceous, *Geology* **30**, 123–126, 2002.
- Hunter, S. J., et al., Modelling Maastrichtian climate: investigating the role of geography, atmospheric CO₂ and vegetation, *Clim. Past Discuss.* **4**, 981–1019, 2008.
- Jenkyns, H. C., Forster, A., Schouten, S., and Sinninghe Damste, J. S.: High temperatures in the Late Cretaceous Arctic Ocean, *Nature* **432**, 888–892, 2004.

11. Understanding the climate of the Cretaceous (and Palaeogene)

11.0 Possible reading: *Jenkyns et al.* [2004], *Huber et al.* [2002] + a skim through *Bice and Norris* [2002] (asp. Figures 3+4 (plus discussion)).

11.1 Before you can run the GENIE Maastrichtian (70.6-66.5 Ma) configuration, you first need to get rid of the previous configuration (assuming it was different) of cGENIE (i.e, make cleanall).

To check that everything looks OK, run experiment `exp11_Cretaceous` briefly (e.g. 10 years):

```
$ ./runcgenie.sh cgenie_eb_go_gs_ac_bg.p0067f.NONE LABS  
exp11_Cretaceous 10
```

Because the climate system is being started from 'cold' (no *restart*), the system rapidly drifts away from its default starting conditions.

Note that no carbon cycle is selected (for speed).

11.2 A previously spun-up state of Maastrichtian climate (`exp0_Cretaceous_SPINUP`) is provided as a starting point. This *restart* can be used as follows (and as per previous experiments):

```
$ ./runcgenie.sh cgenie_eb_go_gs_ac_bg.p0067f.NONE LABS  
exp11_Cretaceous 10 exp0_Cretaceous_SPINUP
```

Note that climate (as indicated by e.g. SST) is now effectively stable (a small drift still exists).

Explore the patterns of temperature and salinity in the ocean. Can you tell where deep water is being formed? Ocean velocity fields can help here and can be plotted as per described in **Lab III**. Would biogeochemistry fields (if there carbon tracers had been included) 'help' in tracing the large-scale circulation of the ocean? View a selection of horizontal and vertical slices of PO₄ and dissolved O₂ in the ocean from your **Lab IV** experiments and judge to what extent they help illustrate the volume of the ocean occupied e.g. North Atlantic Deep Water.

11.3 Your task here is ... 'simple' (lol) – Account for the Cretaceous reduced Equator-to-pole surface temperature gradient (compared to modern), particularly the apparently much warmer poles. Different data-based time-slices (including the Maastrichtian) are provided in *Huber et al.* [2002]. BUT ... the low latitude $\delta^{18}\text{O}$ based temperatures are now not considered reliable. *Jenkyns et al.* [2004] contains high latitude (Arctic) data for the Maastrichtian. There are proxy-derived latitudinal temperature gradients and model-data studies (e.g., by Karen Bice) for earlier in the Cretaceous – the problem is essentially the same.

The 2-D NetCDF results file contains the surface air temperature field (and sea-ice cover, if any). The 3-D NetCDF results file contains fields for ocean temperatures (and salinity). Both contain continental configuration and ocean bathymetry. Remember to switch off the modern continental outline in Panoply to prevent extreme annoyance.

Panoply will plot the zonal average for you (as used in model-data comparisons – e.g., see *Bice and Norris* [2002]) – in the Array(s) tab, the Plot can be set to Zonal Averages rather than Map. You can get a smooth curve by selecting Interpolate. Remember you can set (and fix) scales rather than let Panoply auto-scale continually.

The following 'controls' over the climate system are provided to you in the form of a list of parameter that you can edit the value of. In the `exp11_Cretaceous user-config`, listed under # --- ADDITIONAL --- (at the very bottom of the file):

```
# --- ADDITIONAL -----  
#  
# === ATMOSPHERE ===  
# CO2 radiative forcing scaling factor [DEFAULT = 4.0]  
ea_radfor_scl_co2=4.0  
# CH4 radiative forcing scaling factor [DEFAULT = 1.0]  
ea_radfor_scl_ch4=1.0  
# Equator-to-pole different in planetary albedo [DEFAULT = 0.260]  
ea_albedop_amp=0.260  
# Baseline planetary albedo [DEFAULT = 0.200]  
ea_albedop_offs=0.200
```

```
# atmospheric diffusivity of temperature (horizontal) [DEFAULT = 5.0e6]
ea_12=5.0e6
# === OCEAN ===
# ocean diffusivity of temperature + salinity (horizontal) [DEFAULT = 1494.4]
go_14=1494.4
# scaling for wind stress (set values of both identical) [DEFAULT = 1.531]
go_13=1.531
ea_11=1.531
```

Most of these parameters are associated with the radiative forcing of climate or atmospheric transports:

(i) The line:

```
ea_radfor_scl_co2=4.0
```

specifies a radiative forcing of climate by CO₂ equivalent to 4 times modern CO₂ (i.e., 4×278 ppm = 1112 ppm). The line:

```
ea_radfor_scl_ch4=1.0
```

specifies a radiative forcing of climate by CH₄ equivalent to 1 times modern CH₄ (i.e., 1×700 ppb).

(ii) cGENIE, as configured here, does not have a land surface scheme (no snow cover) nor clouds, so a planetary albedo is prescribed (see Figure). This varies with latitude and is parameterized after a fully coupled GCM simulation. There is a parameter which controls how the albedo varies as a function of latitude, which can be adjusted:

```
ea_albedop_amp=0.260
```

However, if you vary this, why are you doing it? (What is the physical justification for giving the poles a higher or lower albedo relative to the Equator?)

There is also a parameter that sets the baseline (minimum) albedo:

```
ea_albedop_offs=0.200
```

i.e., albedo is primarily a sum of the baseline value plus the Equator-to-pole slope (times the latitude).

(iii) The diffusivity of heat in the atmosphere (since it is a simple 2-D atmospheric model, with no atmospheric circulation, the atmosphere is made 'diffusive' to help capture heat and moisture transport) is:

```
ea_12=5.0e6
```

Note that the maximum value the model can cope with is ca. 1.0e7. (Why might the model be unable to successfully calculate the effects of excessively high rates of diffusivity?)

(iv) There are also a couple of ocean parameters that control ocean (heat) transport. In particular:

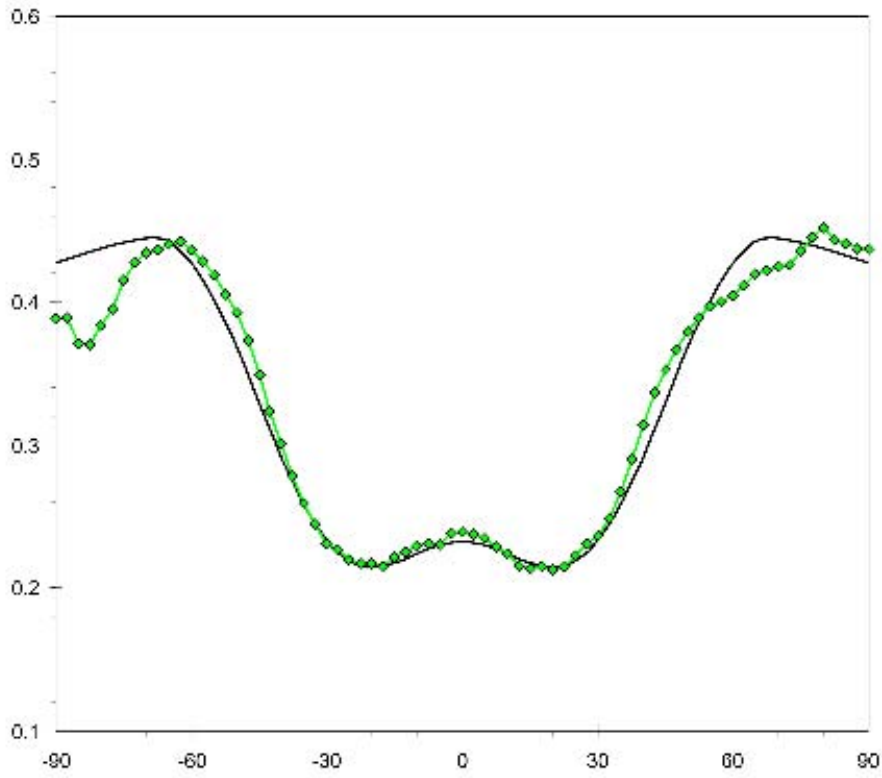
```
go_13=1.531
```

```
ea_11=1.531
```

which scale the wind stress on the ocean. A higher value will produce a more vigorous wind-driven circulation (e.g., gyres) and hence the potential for more rapid polewards heat transport. Note that both values must be set identical.

Note that the effects of these can be viewed by plotting the surface current velocity field as per described in **Lab III**.

- 11.4 Run the model for however long you think is necessary (/justified). The surface climate will approach equilibrium 'relatively' quickly. Deep ocean temperatures will typically take thousands of years to fully adjust ... You can assess how the model approaches equilibrium most easily from the atmospheric temperature time-series results file, and from the ocean temperature time-series results file (allowing to you to contrast surface and whole ocean temperature changes).



Prescribed planetary albedo.

The latitudinal (from 90°S (-90°N) on the left, to 90°N on the right) profile of planetary albedo as calculated in a fully coupled GCM is given in green, and the cGENIE 'fit' in black.