SOEE3410 Coupled Ocean and Atmosphere Climate Dynamics
Climate Modelling Exercise

1 Objectives

The aim of this modelling exercise is to reinforce the ideas and concepts associated with coupled processes in global climate change as introduced during the lecture series. By adjusting the initial conditions and forcings of a simple and heavily parameterised climate model, FASTCLIMATE, you will explore the zonal climatic response in surface temperature fields, ice thickness, and ice cover. Parameters that can be adjusted include the levels of atmospheric CO_2, ice and cloud albedo, the atmosphere and cloud short-wave absorption parameter, changes in atmospheric and ocean horizontal advection of heat, and ocean mixed layer depth, among others.

2 The Model

FASTCLIMATE is a very simple global model designed as a teaching tool for exploring climate change processes. The model simulates the major climate related processes on Earth, with special emphasis on polar features such as snow cover and sea ice (it was originally written for a course on polar meteorology. The physical processes are not represented explicitly, but through highly simplified parameterizations tuned to reproduce current climate conditions, and expressed only as zonal averages in 18 latitudinal bands.

The model is written in MATLAB – a high level programming language and data visualization environment – by Dr Peter Guest of the Naval Postgraduate School, Monterey, California. A web based interface allows adjustment of all the parameters in the model; results are returned as a series of graphs via a web page. The entire model, including the generation of all plots should run in 20-30 seconds or so, depending upon the length of simulation and other loads on the computer.

Running the model

Model home page: ***http://kraken/fastclimate***

Note that the model is ONLY accessible from computers on the university network. You can access the model from off-campus only via remote access to a university system, see IT 'Get Connected' support pages: https://it.leeds.ac.uk/it?id=kb_view2

If use are connected to the university VPN, you should be able to access the model at the address above; if accessing the model via a remote desktop client you might need to use the server IP address instead of its name: http://129.11.84.95/fastclimate

You configure the model by setting values for various parameters: e.g. CO_2 concentration, atmosphere and cloud albedo, etc through a form on the model setup page. The default values on the input form are those for the current climate. The acceptable range for these parameters is stated on the form – these indicate values which should not cause the model to crash, but which are not necessarily physically realistic. The input form will not accept values outside of the stated range.

The last two parameters on the form are the length of the model run in years (*tmax*) and the number of years to plot in time series (*plotyears*) – the allows you to run, for example, a 30 year simulation twice, once with *plotyears* = 30 so that the whole 30-year time series is plotted, and once with *plotyears* = 3, to produce a 'close-up' view of the last 3 years of the simulation.

A total of 18 figures are generated, following one of two general types.
1) A pair of figures showing contoured data for the last year of the model run with month along the x-axis, and latitude along the y-axis, with one figure for the current model run, and a 2nd showing the difference between this model run (fig 1a) and a *standard case* – the results obtained with the default (current climate) conditions (fig 1b).

2) Figures showing time-series over the final ‘plotyears’ years of the simulation, usually at a specific latitude. Different coloured lines represent either this model run and the *standard case*, with the difference between them plotted separately (fig2a) or different latitudes (fig2b).

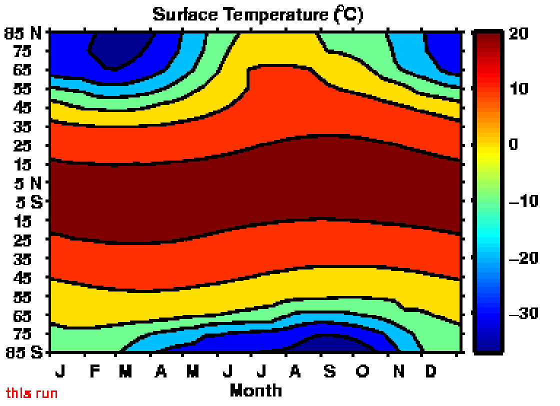

Fig. 1a: surface temperature for this model run.

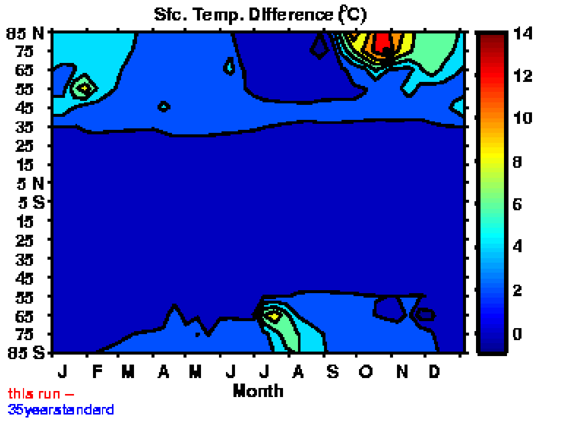

Fig. 1b: difference between surface temperature in this model run and the standard case

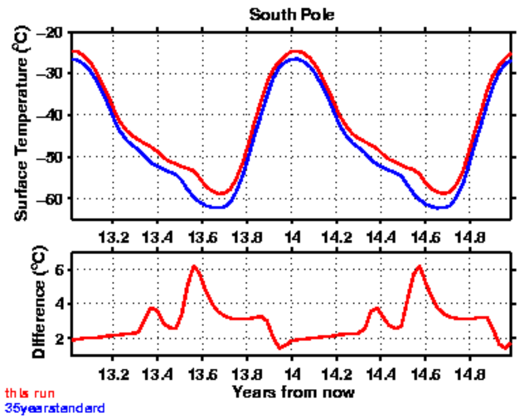

Fig 2a: surface temperature at the south pole for the last 2 years of the (15-year) model run.

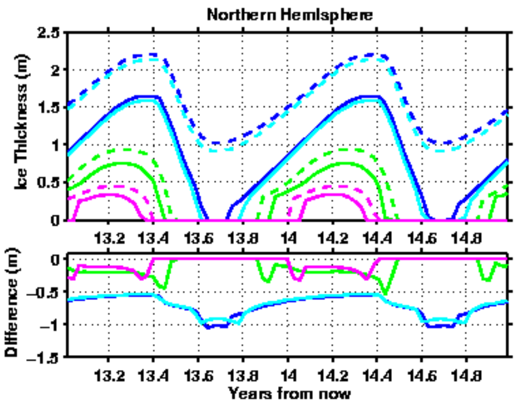

Fig 2b: Blue, cyan, green, and magenta lines represent the latitude bands centered on 85ºN, 75ºN, 65ºN, and 55ºN, respectively; solid lines are this run, dashed lines the standard case.

The output page is created in a randomly named directory on the web server. You can go back to a results page using your browsers ‘history’, but note that all results pages are deleted from the server after 24 hours. You should save the results page to a meaningfully named file in your own workspace on the ISS cluster machines – you will then be able to access it at any time (use the ‘save as complete web page’ option to ensure all figures are saved along with the page)

N.B. After starting the model run, be patient and wait until the results are returned,

- **DO NOT** keep pressing the ‘Run’ button – this will simply start more copies of the model, slowing everything down further.
- **DO NOT** hit the ‘back’ button before the result page is displayed – this will prevent the job on the server from completing, and tie up system memory, also slowing everything down.

A single copy of the model will take about 20 seconds or so to run in the default configuration and with no other load on the server. With many copies running it may take longer.

3 Exercises and Guide to Experiments

The assessment is worth 40% of the total module mark

Your responses should be structured to be **short** and **concise** answers/explanations to the set questions and the experiments you conduct using the model – not essays! Use appropriate figures (copied from model output) to help illustrate all your answers if necessary – annotate them as required. All figures should have captions and be referred to specifically in the text of your answer – do **not** simply include copies of the webpage. Take care when estimating values from figures – if numerical values are very small this may be indicated with a multiplication factor (e.g. x$\mathbf{10^{-3}}$) at one end of the axis, or on the colour scales. It is easy to miss these and wildly overestimate the values shown.

Some tips for good answers:

- When considering the model output, take note of both the relative change from today's climate, *and* the absolute values.
- Try and explain, briefly, the results you observe: why a particular result is obtained (what processes are important) as well as what the result is.
- Always quote numeric values...don't simply state that a region is warmer, state how much warmer. Note whether a change is significant or not (Note that the axis scales change to reflect full range of values. A temperature difference of ~0.01ºC, or change of ice thickness of millimetres is negligible. **Watch out for order of magnitude multipliers on the axis scales – these can be easy to miss**)
- Note any geographic or seasonal differences as well as the mean response.

You may need to run the model more than once with the same input parameters, but with different output periods in order to fully answer a question – e.g. display the full period of a model run to see how conditions change over time, <u>and</u> a short output of just the last year or two in order to see the annual cycle of the final state, or run it again with a short run length to look closely at the first year or two of modelled behaviour. Be prepared to experiment with a few model runs with slightly varying conditions or output times before preparing your answer. In some cases you may need to compare the model output directly with a run with the default settings (current climate).

N.B. Each new question number starts with the default parameters; it does NOT inherit changes made to the model configuration from the previous question. If you use the browser's *back* button to return from the output page to the configuration form, all the changes you made to the form will be retained (this is useful if you want to keep changes to some parameters, but adjust one other parameter over several model runs). To start again with the default parameters, use the link at the bottom of the output page. You can always clear and reset the input form by pressing the reload/refresh button.

Your answers should be submitted for marking as a single document (word or PDF) via the Turnitin submission form on the module pages on Minerva.

There is a strict length limit of **1000 words** and **6 pages** (including all figures) for the main exercise.

1. Run FASTCLIMATE with an initial temperature offset of +10 ºC:

a. What is the final mean global temperature difference from today's climate after 15 years, is it a significant difference?
b. How do the surface temperature and its difference from today, change over the full 15 years of the model run? Why does this behaviour occur?
c. How does the maximum warming early in first year of model run differ between 65°N and 65°S?

[5 marks]

2. Double the present level of CO_2 in the model (co2 = 2), run the model for 5 years. In the final year of the model run:

a. At what latitude and time of year is the maximum temperature difference from current climate found?
b. Where and when is the absolute minimum warming relative to current climate found? Why is this?
c. What is the major difference in response of the northern and southern hemispheres, and what is the primary cause of these differences?
d. How does the Arctic sea ice change relative to current climate during the summer months?
e. Has the southernmost extent of Arctic sea ice changed significantly at the end of winter (March/April)?
f. What has happened to the thickness of Arctic sea ice at the end of winter (March/April)?

[10 marks]

3. Examine the sensitivity of sea ice cover to summer thick ice albedo (*alboicesum*) (default = 0.65).
(For reference: The summer thick ice albedo, alboicesum, applies to melting ice which is thicker than zicethick, which by default is 0.5 meters. Melting ice that is thinner than zicethick has an albedo scaled linearly between alboicesum and albonoice.)

a. What physical processes might affect the albedo of thick summer ice?
b. Reduce *alboicesum* to 0.6, how does the sea ice thickness respond over a 10-year model run in Northern and Southern hemispheres?
c. Why do the northern and southern hemispheres differ?

[5 marks]

4. If you switch off ocean horizontal advection (Kho1 = 0):

a. What oceanic process could we be stopping?
b. What is the response of the surface temperature distribution?
c. What is the response of sea ice, and how does it differ between hemispheres?
d. Does this seem like a realistic scenario, and why?

[8 marks]

5. Global dimming results from reflection of sunlight by man-made aerosol particles in the air, which modify the atmosphere/cloud albedo (*albatm*). Experiment with adjusting this model parameter – for a climate with double the current CO_2 concentration:

a. What value reduces the warming in the tropics to zero?

b. What value is required to offset the *mean* global warming caused by a doubling of CO_2 concentration. (N.B. There is no plot of global mean temperature – estimate it from the plots available.)
c. How does the temperature difference from current climate vary with latitude? Why do these differences remain?

[5 marks]

4 FASTCLIMATE Model Caveats

1. FASTCLIMATE is a highly simplified climate model designed for interactive educational use on the web. It is not intended for research purposes!
2. The FASTCLIMATE parameters are tuned to simulate today's climate; these tuned values may not be valid for other climate scenarios.
3. The effect of different CO_2 concentrations is simulated in FASTCLIMATE by adjusting the long-wave emissivities in such a way as to match the average global temperature response predicted by an ensemble of sophisticated global climate models called General Circulation Models (GCMs).
4. Anthropogenic sulphate particles block solar radiation and may counteract CO_2 warming. Anthropogenic or natural aerosols (suspended particles) are **not** explicitly included in FASTCLIMATE, although they are included in the GCM results used to tune FASTCLIMATE.
5. Water vapour and clouds are crucial factors which affect the surface temperature. For example, virtually all GCMs predict that the direct effect of increased CO_2 on global warming is less than the indirect effect of increased water vapour which occurs due to a strong positive feedback response to the direct CO_2-induced warming. FASTCLIMATE does not explicitly model water vapour or clouds.
6. Most of the non-radiative heat energy that is transported vertically and horizontally on Earth is in the form of latent heat, i.e. water vapour. FASTCLIMATE does not explicitly include water vapour. However, the transfer coefficients that are used to specify non-radiative heat transport have been adjusted to account for latent heat transfer.
7. Glaciers are not included in the model. Snow thickness is not modelled, although snow coverage is. Latent heat effects associated with snow or glaciers are not in FASTCLIMATE. Latent heat associated with freezing/melting of sea ice is explicitly modelled.
8. Deep ocean currents and deep ocean convection are not in FASTCLIMATE.
9. Sea ice dynamics (except for divergence) are not in FASTCLIMATE.
10. FASTCLIMATE was developed entirely by Peter Guest and has not been subject to any official peer review.

5 Acknowledgements

The FASCLIMATE model code was developed by Dr Peter Guest of the Naval Postgraduate School, Monterey, CA, for use in his own teaching and is used here with his permission.