PCC 587 Project 2: Write-up due December 3, 2009

Climate Model Simulations of Real and Imaginary Planets

This handout describes the second project, and we hope it explains it well enough to make it work for everyone! If you have questions you think are of general interest, post them to the message board which you can access from the Assignments page on the class web site. If you are having more specific problems, write directly to Dargan. Dargan's going to be on a trip to England from Friday Nov 20 to Monday Nov 30, but will be in e-mail contact this whole time. **There's a glossary of abbreviations and terms at the end of this document.**

We'll be working with climate model simulations with GFDL's AM2.1, the atmospheric component of one of the best climate models in the IPCC AR4. The model contains state of the art parameterizations of clouds, convection, radiative transfer, etc. We'll be considering two different versions of AM2, one with realistic geography and fixed observed sea surface temperatures (SSTs) (set to the average seasonal cycle of ocean temperatures, repeated each year), and an "aquaplanet" simulation with *no topography* and a completely *ocean-covered surface* (a "swamp" lower boundary: a slab ocean which can change temperature in response to energy fluxes, but with no ocean heat transport).

The goal of this project is to develop a better understanding of what determines the major climate features on Earth: the distribution of precipitation, the surface winds, temperatures, etc. One of the big advantages of numerical models is that parameters are easily changed so you can simulate imaginary planets! Checking out a wide range of parameters can really give you a good idea for how complex effects like rotation, latent heating, ocean circulation, etc affect the atmosphere. We'll be making some rather extreme parameter changes within AM2 so you can have a better understanding of these effects.

Here are the simulations we'll be considering:

I. **Full geography AM2** (over fixed, climatological SSTs, including the seasonal cycle):

A. **Control run**
B. **Slow rotation rate** (one-half actual value, i.e., Omega=3.646e-5 s^-1)
C. **Fast rotation rate** (1.5 times actual value, i.e., Omega=1.0938e-4 s^-1)
D. **No topography** (all mountains are bulldozed so the surface is entirely at sea level)

NOTE: To reiterate, all of these simulations are run over the same SSTs (the observed ocean temperatures). That means that the parameter experiments are not entirely clean: in reality, the ocean circulation would adjust and make the SSTs different (running an ocean model to equilibrium requires hundreds of years of simulation, so this wasn't computationally feasible for this project).

II. **Aquaplanet AM2**:

A. **Control run** (uses equinox solar radiation profile, has no seasonal cycle but it has a diurnal cycle)
B. **Non-rotating Earth**, i.e., Omega = 0.
C. **4x preindustrial CO2** levels, i.e., 1320 ppm (the control simulation uses a concentration of 348 ppm). We're not going to hit this any time soon, maybe by 2100.
D. **2% higher solar radiation**, i.e., Q_sol = 1392.3 W/m2 (the control simulation uses Q_sol = 1365 W/m2). Recall that within the solar cycle this value only varies by +/- 1 W/m2, so this 27 W/m2 forcing is a huge change.

NOTE: The aquaplanet simulations are all run over a slab ocean lower boundary, which means the temperature can change but there's no ocean circulation. The slab ocean has a specified heat capacity, which determines how fast the temperature changes in response to surface fluxes. The slab ocean conserves energy in the time mean, i.e., the total surface flux at any point must be zero in the time mean.

We encourage you to work collaboratively on the project assignments, but to turn in individual responses to the questions. We also encourage thoughtful, thorough and succinct answers in your writeups (several sentences or a short paragraph should be adequate for discussing each question). Be brilliant!

Logistics

Where and how to get onto computers

The computer lab is in the Atmospheric Science Geophysics (ATG) Building on the 6th floor (room 623). A class account has been set up with the username *pcc587*. To log in, you will need this username as well as the account password, which has been revealed in class (it's the same password as for Project 1).

To access the PCC 587 account from another computer, run the command "*ssh –Y pcc587@olympus.atmos.washington.edu*" and type the password.

All of the simulations are in the "Project2" directory on this account.

1. Change directory to the "Project2" directory.
   cd Project2
2. List the files in the directory (that first letter is an L):
   ls
3. The file names should be somewhat self-explanatory (there's more detail on the simulations below). There will be one primary program we'll use to diagnose the different simulations: "ncview". To run ncview,
   ncview filename &

I also set up a version of ncview that doesn't show the continent boundaries, for use with the aquaplanet simulations (which don't have continental boundaries). To run this, use the following syntax:

ncviewaqua filename &

Using ncview (by example)

1. Let's check out some data! ncview is a program that allows you to make movies of data quickly and easily. Run ncview on the 8x daily data (output every 3 hours) from the control simulation with the full geography model:

   ncview control.full.8xdaily.nc &

   The ncview interface should pop up.
2. Near the middle of the blue ncview interface, you will see all of the variables listed. In this case, the only useful variable that's outputted is the precipitation, which is called "precip". **Click on precip**. A map and precipitation field will appear.
3. At the **top of the interface window**, there is information about the field that's being plotted ("Total precipitation rate"), the date/time of the frame that's being plotted, and the displayed range of the variable. The line that starts with "Current" changes as you **move the mouse across the map**, and displays the exact value of the field at a particular latitude and longitude.

   The next line of commands allows you to animate the data or click forward in time. **Click the double-right arrow >> to animate.** You can stop the animation at any time by clicking the pause symbol **II**.
4. The next line of commands changes how the data is displayed – the first entry changes the color map, the 4th changes the magnification (left click this button for bigger, right click for smaller), and the 5th allows you to focus on lower or higher values (I sometimes prefer "Low" instead of the default "Linear" when looking at precipitation data). Clicking "Axes" allows you to change the axes (e.g., to display quantities as a function of time and latitude), and "Range" allows you to display a different range (this is useful when comparing two different simulations, to make sure the colors are the same). Another note: if the animation plays too fast (this sometimes happens when you make the window smaller), you can slow it down by using the "Delay" slider.

Exercise 1: Control Simulation Precipitation

1. Examine the 8x daily precipitation data in the control case. There's one year of this data in the file you'll look at with the following command:

   ncview control.full.8xdaily.nc &

   What are the typical length scales and time scales of the precipitation features in the midlatitude Northern Hemisphere and Southern Hemisphere?

2. Next examine the monthly precipitation, zonal (eastward) surface wind ('u_ref'), and meridional (northward) surface wind ('v_ref') data. The file listed below contains the average seasonal cycle of the model, calculated by averaging monthly data over 11 years of simulation (e.g., the first entry in the dataset is the average of all Januarys for 11 yrs, etc). Open this file with the following command:

    ncview control.full.monthlyavg.nc &

   Recall in class we stated that the zone of surface westerlies is located in similar locations as the maximum eddy activity (storminess), which is the location of the largest precipitating features in midlatitudes as well.

   Examine and describe the seasonal cycle of winds and precipitation in the Northern Hemisphere midlatitudes. Why is Seattle dry in the summer?

   Compare/contrast the midlatitude North Pacific seasonal cycle with the seasonal cycle in Europe and in the Southern Hemisphere midlatitudes.

   Describe the seasonal cycle of precipitation/winds in the tropics.

   On all the above questions, make connections to the atmospheric phenomena described in the lectures and Hartmann.

Exercise 2: Perturbing the Full Geography Model

Let's next take a look at the parameter simulations with the full geography model. Remember that the SSTs are identical for all these simulations, so one might not expect much of a change from case to case…

1. **Effect of rotation**: Examine the 8x daily precipitation data for the high rotation case ("highrot.full",1.5x faster planetary rotation rate) and the slow rotation case ("slowrot.full", 0.5x current rotation rate). How do the typical length scales of midlatitude precipitating features change? Speculate on the reason for these changes in scale.

   Examine the average seasonal cycle of winds and temperature of these cases in the "monthlyavg" files (NOTE: these simulations only average over two years of monthly data. There is therefore more random variability in these averages). Do the location of the storms change as well?
2. **Effect of topography**: The "flattopo" simulation bulldozes all topography on Earth, so the surface is at sea level everywhere. This is similar to the experiment that Seager et al ran to check out the influence of the Rockies on UK weather (discussed in Steve's Nov 17 lecture), but this simulation bulldozes globally and keeps SSTs fixed.

   How are the Pacific and Atlantic storm tracks different than in the control case, in terms of intensity and location? The Southern Hemisphere midlatitudes are more ocean-covered. Is there an effect on the circulation anywhere down there?
3. Based on the two simulations above, make an argument for what determines the length scales, intensity, and location of the storm tracks in

the N. Pacific, N. Atlantic, and Southern Hemisphere in the current climate. (This is still very much a research topic, so your answers will be speculative, but make arguments based on what you've seen in these simulations)

Exercise 3: Aquaplanet Simulations & the Effect of Ocean Circulation

Aquaplanet simulations are useful to get an idea of the basic controls on atmospheric circulations. The simulations we'll consider are all forced symmetrically around latitude circles, so the climate can be completely represented with zonal averages. Further, there's no seasonal cycle of the solar heating (we use perpetual equinox conditions), so there's no need to examine the changes with month. This simplifies diagnostics considerably.

Clearly, this model will not simulate climate with nearly as much realism though: there are no continents, and also no ocean circulation. Let's examine the difference between the precipitation & wind distributions in the control full geography case versus the control aquaplanet case, and try to isolate the effect of ocean circulation.

1. First, look at the 4xdaily precipitation data (this model outputs every 6 hours):

   ncviewaqua control.aqua.4xdaily.nc &

   (The "ncviewaqua" command just shows without continental boundaries).

   How are the length scales and time scales of midlatitude precipitating features different than in the full geography model? How are tropical features different?
2. Next let's study the time mean fields (NOTE: I saved more variables in this file, so you can study the energy budget in more detail if you want to in Exercise 5). Run this command:

   ncviewaqua control.aqua.avg.nc &

   I find it useful to click on the plot windows, which results in a line plot being shown. If you change the "X Axis" at the bottom to "Lat", you can generate line plots of the data as a function of latitude.

   Examine the surface zonal winds. What would the surface friction tendency be? How is momentum thus being transported within the atmospheric circulation?

   Examine precip and evap. Where is moisture being transported by the atmospheric circulation?

   Compare with the zonally averaged surface winds and precipitation fields in the full geography model. What aspects of the circulation are simulated well, and where are the biggest biases?

   Let's explore the tropics in more detail, starting with the averaged SSTs ("t_surf"). Based on the material given in class (in my lectures and in Steve's), why do you think the SSTs are so different in the tropics in the two cases? Any connection to other tropical biases?

Exercise 4: Parameter experiments with the aquaplanet model

1. First let's check out the effect of increases in temperature, both by increasing CO2 content, or by increasing the solar constant. Check out the mean fields in these two simulations:
   ncviewaqua 4xco2.aqua.avg.nc &
   ncviewaqua highsol.aqua.avg.nc &
   What are the temperature changes associated with these two forcings (e.g., at the equator, at the pole, and a rough global average)? What are the primary changes in the precipitation and surface winds? Do these agree with the ideas presented in class about possible changes with global warming?
2. The non-rotating simulation is pretty cool – check out the daily data for some crazy precipitation patterns of variability. Study the mean temperature distribution and mean winds in this case, and explain.

Exercise 5: Freestyle

There's a wealth of information in the simulations you've been provided. Choose a topic that you're interested in studying in more detail with these simulations, and write approximately a page on this. Extra credit for especially brilliant investigations.

Some possible topics:

1. Calculate the zonal mean moisture fluxes in the aquaplanet simulations. How do these change and why? Moisture contents clearly increase as temperatures rise. What is the effect on precipitation distributions? What are the small differences in the moisture transport and precipitation distributions between the 4xCO2 case and high solar cases? Other energy fluxes can be calculated as well (remember the total energy flux divergence must balance shortwave in minus longwave out). How does this change with the different aquaplanet simulations?
2. What are the climate impacts of the parameter changes in Exercise 2? How would you expect forests, biology, etc to be different under these different climates if this state were to persist for a long time? **Be specific** and give thorough scientific arguments. Answers to this question should be especially brilliant. Share expertise among your fellow students (and teach your instructor something!).
3. Prevalence of westerly wind bursts in different simulations. As Steve mentioned in lecture on 11-19, westerly wind bursts are important for the dynamics of ENSO. Is there a tendency towards stronger westerly wind anomalies than easterly wind anomalies at the equator in any of the simulations? Explore the variance and skewness of tropical surface winds. What's the character of this variability: is it associated with precipitation features, etc. Do the anomalies propagate at all?

To facilitate the more quantitative investigations, I've put matlab routines in the Project 2 directory that can be used to take zonal means ("zmfull.m" and "zmaqua.m"). These have all the syntax you need to load in data from matlab files, etc., so you should be able to write your own routines based on these.

Glossary:

SST: Sea surface temperature
Zonal: in the longitudinal direction. Zonal wind = east/west wind. Zonal average: an average around latitude circles. u = zonal wind.
Meridional: in the latitudinal direction. Meridional wind = north/south wind. v = meridional wind.
GCM: General circulation model or global climate model.
Aquaplanet: The ocean-covered simulations that we're considering.
Slab ocean: An ocean that can adjust its temperature to conserve energy, but has no circulation. The slab ocean has a heat capacity that determines how quickly it responds to perturbations. In the time mean, the sum of all surface fluxes must be zero at every location in a slab ocean simulation.