Projects for ICTP Summer School

We will be running the flexible GCM 'Isca' at the summer school: http://tiny.cc/Isca

Quick summary: Atmospheric Primitive Equation model, open source, flexible configuration, choice of parameterizations (simple or complex), Python front end. Main features are:

Dynamical Core

- Spectral, typically use triangular truncation (e.g. T42)
- Zonally symmetric option
- (Also options for zonal wavenumbers 0,1,2 only, with high meridional resolution, etc.)

Forcing options

- Thermal relaxation, (eg. Held-Suarez) or a generalization to include obliquity/seasons and configurable mixed layer.

- Radiation, with following possibilities:

  1. Grey scheme with fixed optical depth.
  2. Grey scheme (and two-band scheme) with water vapour feedback.
  3. RRTM (comprehensive, multi-band, widely used).
  4. SOCRATES (comprehensive, multi-band, Met Office).

- Incoming radiation determined from orbital parameters. Eccentricity and obliquity can be fully varied, with Kepler's laws satisfied. Tidally-locked configuration available.

Geometry

- Aquaplanet (uniform surface).
- Realistic or idealized continents (configurable).
- Mixed-layer ocean.
- Q fluxes (i.e. specified ocean heat transport)
- Topography, idealized or realistic, configurable.

Land

- Specified evaporative resistance.

- Configurable bucket model.
- Configurable heat capacity (like a slab).

Convection schemes

- Simple or complex Betts-Miller.
- Relaxed Arakawa Schubert (a mass flux scheme).
- Convective adjustment.
- Limitation: no interactive clouds.

Possible Experiments

Below is a list of possible experiments you could perform at the Summer School. The experiments are meant to be real research problems, so by definition it is not quite clear how they will proceed. (The 'analysis' sections below,in particular, are suggestions only.) Please discuss in your group and with members of the faculty here. Here are a few points to note:

- Each group will work on one (or possibly more) research problem. Some of the problems below could involve two or more groups, in which case the groups should co-ordinate to avoid too much duplication.
- For many of the experiments some Python scripts have been set up to get you going. One you get the hang of things you can change them, perform some experiments you design yourselves, etc. You don't have to use the Python scripts to run the model, but it makes things easier.
- Typically, an experiment will complete in a few hours at T42 resolution. The first day, you might wish to run at T21.
- Although we use generally Python to perform analysis on the model, that is not necessary. Some people may be more comfortable with Matlab for example.
- Some of the projects may require continuation after the Summer School!

1. Climate Sensitivity and climate variability

Goal: Look at if and how climate sensitivity and variability (both seasonal variability and natural variability) are related,and whether results are robust to different model formulations. Also look at some properties of global warming itself.

Experiments:

1. Run two (or more) versions of the model, with different radiation schemes or possibly different convection schemes, to equilibrium, with seasonal cycles and continents and a mixed-layer ocean.

2. Double or quadruple CO2 in each configuration, and run to equilibrium.

Analysis:

1. Look at climate sensitivity in each, and the seasonal and natural climate variability, and see if and how they are related.
2. Jet latitudes, tropopause height, Hadley Cell width etc.
3. Many other possibilities for looking at other aspects of climate variability, or even 'emergent constraint' type analyses. Simple analyses also suffice.

.

2. Hadley Cell, Moisture and Eddies

Goal: Understand how the Hadley Cell is affected by both moisture and eddies in a simple configuration. The dry case is commonly done, but has not been properly done with moisture.

**Experiments: **

1. Take a simple moist model (e.g. grey radiation, aquaplanet). Run to equilibrium in fully 3-D case and in zonally-symmetric case.
2. Repeat experiments with a dry model.
3. Possibly repeat both of the above with a seasonal cycle (non-zero obliquity).
4. Possibly repeat with a model with water vapour feedback in the radiation.

Analysis:

1. Examine how strength and extent of Hadley Cell differs with and without moisture in zonally-symmetric and eddying cases.
2. Look at angular momentum conservation, termination due to baroclinic instability etc.

3. Storm tracks, continents and reversed rotation

Goal: Understand how location of the storm tracks depends on continental locations, and how they would change if rotation were reversed.

Experiments:

1. Take a moist model with full radiation scheme and realistic continents. Run to equilibrium.
2. Reverse the rotation. Run to equilibrium.

Analysis:

1. Location of storm tracks (e.g. KE) and jet position.
2. Eady growth rate, other diagnostics.
3. This project could connect to the doubled rotation rate (planetary project 1.)

4. Seasonal cycle, hysteresis and mixed-layer depth

Goal: Understand how seasonal lags are affected by continents, mixed-layer depth, length of season.

Experiments

1. Configure the moist model with two different arrangements of idealized continents and mixed layer depths (maybe a realistic one, too).
2. Run to equilibrium, and then for many more years, with varying year lengths (e.g. a 5 year orbit around the sun).

Analysis

1. Look at seasonal amplitude in each case, and lag with respect to season, geographical variability.
2. Look for hysteresis, tropical vs midlatitude differences etc.

5. Oceanic heat transport effects on atmospheric circulation (2+ projects)

Goal: Understand if and how the atmospheric circulation is affected by ocean heat transport (Q-fluxes), with and without continents, with and without seasons.

Experiments

1. Run a moist atmospheric experiment, with realistic continents, with a mixed-layer ocean with no Q fluxes. ('Q flux' is the name give to a heat transport by the ocean that is imposed, rather than calculated dynamically. Historically Q fluxes were used to compensate for an imperfect ocean, but here we are using them for controlled experiments.)
2. Repeat with an analytic Q flux meant to mimic ocean heat transport.
3. Repeat with various different forms of Q flux read in from files. Look at cross-equatorial q-fluxes and their effects on ITCZ, Hadley Cell, etc.
4. Repeat the entire experiment with no continents, as time permits.
5. Repeat with a seasonal cycle (with or without continents).

Analysis

The above could be divided into two experiments, for example with one group looking at seasons, another at continents, etc

1. Look at heat transport by atmosphere as a function of latitude.
2. Look at strength of Hadley Cell, ITCZ position, storm tracks etc.

6. Obliquity changes

Goal: Understand how the climate would change at higher or lower obliquity, varying from small (realistic) changes to large idealized changes.

Experiments

1. Run control experiment with continents, mixed-layer ocean, no Q-fluxes, radiation and moisture.
2. Repeat with varying values of obliquity. Run each experiment for a few years until equilibrium is reached.
3. Repeat with an aquaplanet, or Q fluxes, or different physics, or whatever seems interesting.

Analysis

1. Look at temperature distribution, heat transport, Hadley Cell strength etc etc.

7. Ice albedo feedback and snowball Earth

Goal: Explore the effects of ice-albedo feedback on the climate of the model, with and without continents and seasons. *Note,* this experiment may require the user to make changes in the Fortran code.

Experiments

1. First, implement some form of temperature dependent surface albedo in the model.
2. Obtain stable climate with that albedo, either seasonally-varying or with annual average forcing (may require some experimentation).
3. Reduce or increase the solar constant and/or the CO2 levels. See what requirements are needed for a snowball Earth, and then, given and snowball Earth, what is needed to get out of it.

Analysis

1. Dependent on what results are obtained. The usual diagnostics, and also explore whether it is possible to get multiple equilibrium.
2. Could combine this experiment with obliquity ones if all goes well.

8. Other climate possibilities?

Roll your own here.

Towards Other Planets

1. Effects of rotation rate and size of planet

Goal: Understand the basic effects of changing planetary parameters and the power of nondimensionalization.

Experiments:

1. Change one or more of rotation rate, planetary radius, and possibly (harder) surface pressure, perhaps using a thermal-damping forcing.
2. Run to equilibrium.
3. Repeat with a more realistic moist model with continents.

Analysis

1. Plot such things as number of jets, superrotation, KE, etc etc as parameters change.
2. Explore how the fields change with nondimensional parameters, such as the external Rossby number and Ekman number. Do an experiment in which radius and rotation are both changed, but in such a way as to keep the external Rossby number constant.

2. Effects of gravity in dry and moist atmospheres.

The effects of gravity can be *completely scaled out* in a dry primitive equation model with simple forcing. (This is true, but not widely known.) That is, doubling gravity has *no effect* in a dry model. Is this true in a moist model?

Experiments:

1. Run a dry model with 1g and 2g to equilibrium. (g = gravity).
2. Repeat with a moist model, e.g. with RRTM radiation scheme.

Analysis:

1. Demonstrate the truth of the premise that g does not affect a dry model, after appropriate scaling.
2. Examine whether this holds for a moist model.

3. Other planetary options?

For example, look at the effects of moisture on a tidally-locked exoplanet. Configure dry and moist versions of a tidally-locked planet and look at their differences.