General circulation models
(a quasi geostrophic view)

End of semester project

- Due last week of classes

- Pose a “real” problem
- Build the model to address/solve it.
- Evaluate solution, model, science outcome

BEFORE NEXT CLASS (ideally Monday:

Email me a topic/title/descriptive sentence so we can discuss them in class

- This is non-binding!

- Check web site for PDF file

Project examples

- Option 1) Use this week's model as a starting place for science problem
  - Add a component cloud/ozone/chemistry/water cycle model, what are the radiative balances?
  - Convert and atmosphere-ocean model, do we get ENSO?
  - Add sea-ice, modes of variability
  - Predictability experiments

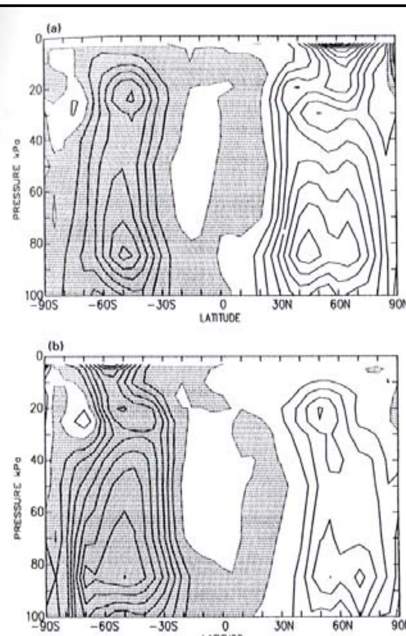
  As a group, turn this into a climate model.

- Option 2) Build more specific model

- (also option 3) use another model, and add to it…

- Feel free to discuss ideas with me

Eddy heat transport ($v'T'$)



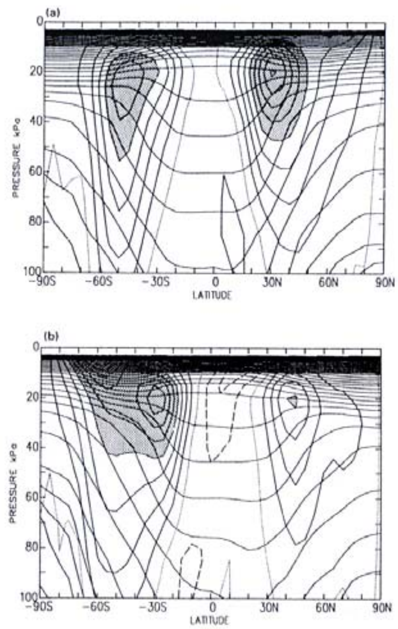
DJF

JJA

Fig. 5.7. Latitude-pressure sections showing the poleward transient eddy temperature flux, $[\overline{v'T'}]$ for (a) DJF and (b) JJA. Contour interval 2 K m s^{-1}, negative values shaded. Based on six years of ECMWF data.

James, 1995

Zonal wind and potential temperature



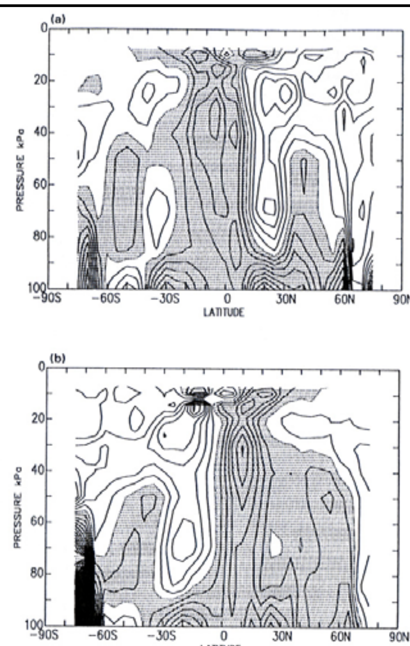
DJF

JJA

Fig. 4.2. Contours of $[\bar{u}]$ and $[\bar{\theta}]$ for (a) DJF; and (b) JJA, based on six years of ECMWF data. Contour interval for $[\bar{u}]$ as in Fig. 4.1. Contour interval for θ is 10 K.

James, 1995

Diabatic heating



DJF

JJA

Fig. 3.7. Latitude–pressure cross sections of the time and zonal mean heating, $[\bar{Q}]$, based on six years of ECMWF data. Contour interval 0.2 K day^{-1}, positive values shaded. (a) DJF. (b) JJA.

James, 1995

Lab assignment

- Create a model of the general circulation of the atmosphere
- What is the spin-up time of the atmosphere?
- How does the circulation change with different heating (shape, and strength)

- Construct a 2-level general circulation model based on QG
- nlon=64 nlat=32 ntrn=21, dtime = ½ hour
- Output once per day, and aim for simulations of 100 days (start will one day!)

Advection with spherical harmonics

$$\frac{\partial q_n^m}{\partial t} = -\left[\nabla \cdot \left(\vec{V}q\right)\right]_n^m + k\nabla^2 q_n^m - D\zeta + FORCING$$

$$\frac{\partial q_n^m}{\partial t} = -\alpha(F,G)_n^m - k\frac{n(n+1)}{a^2}q_n^m$$

$$\alpha(F,G)_n^m = \frac{1}{\cos^2\phi}\left(\frac{\partial F_n^m}{\partial \lambda} + \cos\phi\frac{\partial G_n^m}{\partial \phi}\right) \qquad \nabla^2\psi_n^m = -\frac{n(n+1)}{a^2}\psi_n^m$$

$$F = \frac{\cos\phi}{a}uq \qquad G = \frac{\cos\phi}{a}vq$$

Implementing model code

- What is the state variable?
  (a series of complex coefficients)

- Derive spectral u and v from spectral relative potential vorticity (solve vertically coupled problem)
- Obtain relative potential vorticity field on a grid
- Obtain u and v on a grid
- Calculate non-linear fluxes on a grid
  $u(q+f)$ and $v(q+f)$
- Assign drag ("momentum source")
- Compute flux divergence in spectral form ("alpha")
  (just the advection, as per last week)
- Add in forcing
- Time step the state variable (in spectral form)

Spherical harmonic synthesis

Spherical harmonic analysis

Remember to output state every so often (say, 24 hours?)

This is just the same as last week, but now need to get vorticity from relative potential vorticity before getting u and v

Implementation tips

- Start with model from last week, and make all variables (q, z, u, v, etc) 3d.
  (i.e., add levels)
- Check that this model correctly simulates Rossby waves at each un-coupled level
- Convert prognostic variable from vorticity to relative potential vorticity (this is just a shift in thinking)
- Write a subroutine to obtain vorticity from relative PV
  (this is the key to this problem).
- Add in forcing term

- See code, and particularly a stub in:
  ~dcn/ATOC7500/week10

Wave number trick!

- For spectral variables:
- Complex qg(l,m,k)
- (*l* and *m* are ***array indicies***, not wave numbers)
- "m" = (m-1)

$$n = \text{real}(l+m-2)$$

Discussion questions

- In what way does the simulation look like the real general circulation? In what ways does it not?
- How do you determine if the model is spun up?
- **How does the behaviors change with:**
  - **different Rossby radius of deformation?**
  - **Diabatic heating rates**
  - **Drag coefficient**

- Is the model fundamentally different with topography?
- What are some ways to better choose the forcing?
- How would you expand this model to be a "climate" model?