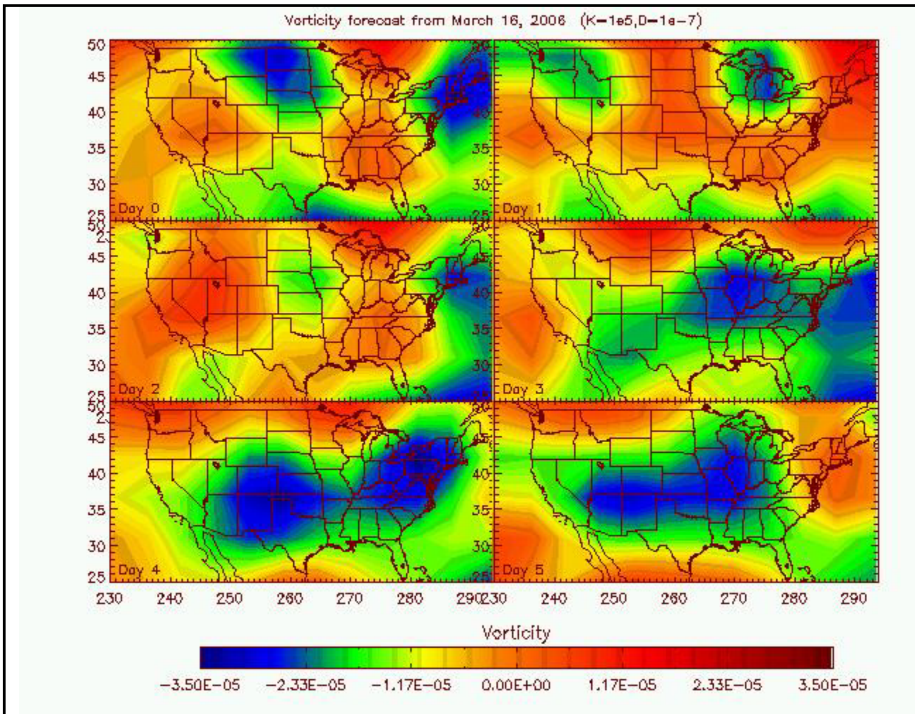
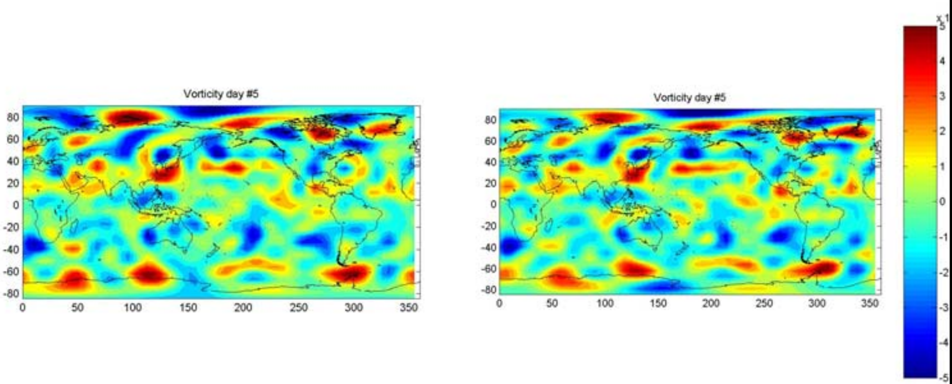
General circulation models (a quasi geostrophic view)

Discussion

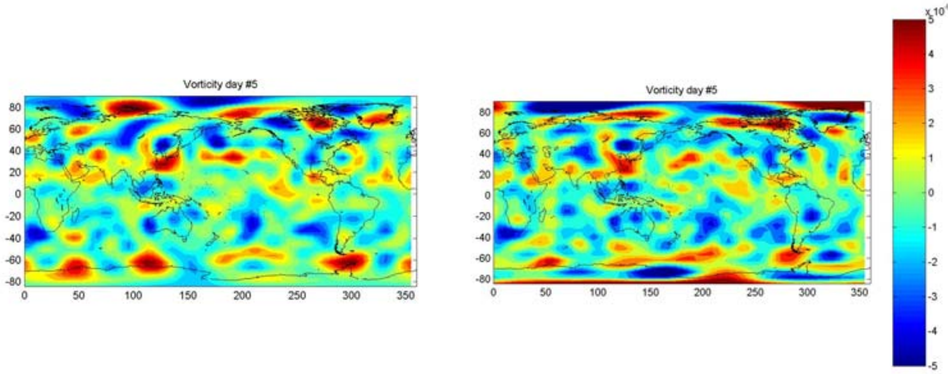
- What range of values for K seem reasonable?
- Does drag help? What values of D seem reasonable?
- How different is your prediction if the initial condition are slightly different?
- Can this initial condition modification help quantify the possible forecast error?
- Does adding mountain topography help?
- In what ways is this model better than the grid point model we built?



Initial conditions?

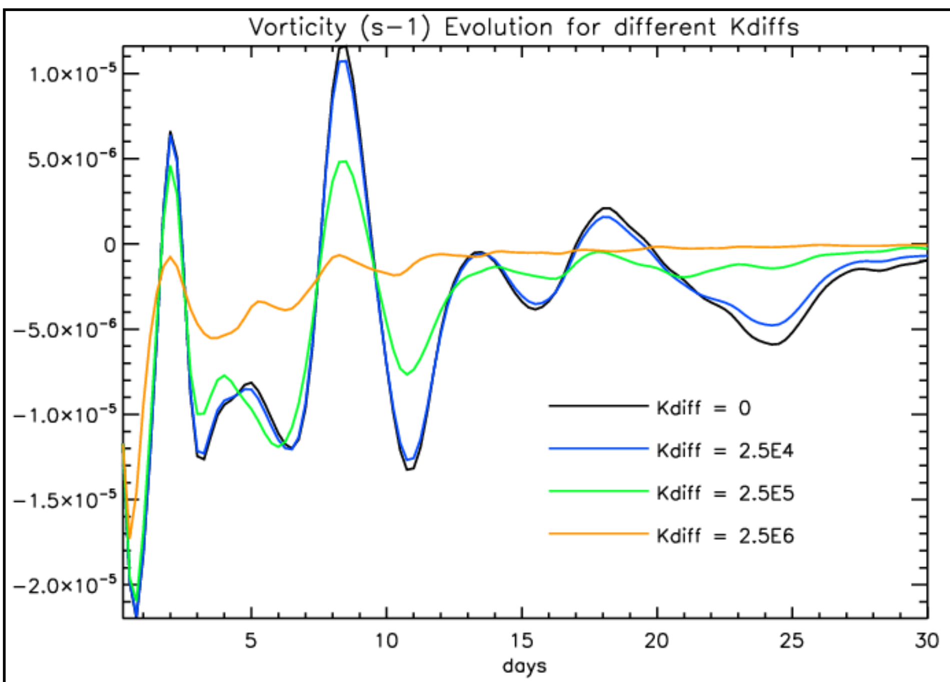


Topography



No mountains

Mountains



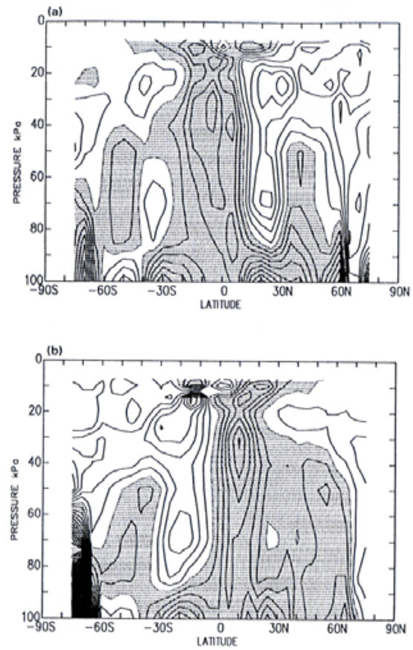
NDBVM review

- Generally successful
- Using spectral method, did not encounter non-linear instabilities.
- Mountains and drag seemed to help in some respects (difficult to access for a single forecast)
- However, ultimately dissipative (diffusion, drag, time filter…)
- So, ultimately all signal will be lost… just a matter of time.
- ***Can this model be used to simulate climate?***

General circulation

- Heat at tropics, cooling in poles
- Conservation of angular momentum gives jets
- Strong gets lead to baroclinic waves (cyclogenesis)
- Waves/eddies transport energy poleward
- Waves/eddies dissipate through drag
- ***Require conservation of every, momentum (and mass), plus thermal forcing and dissipation?***

Diabatic heating



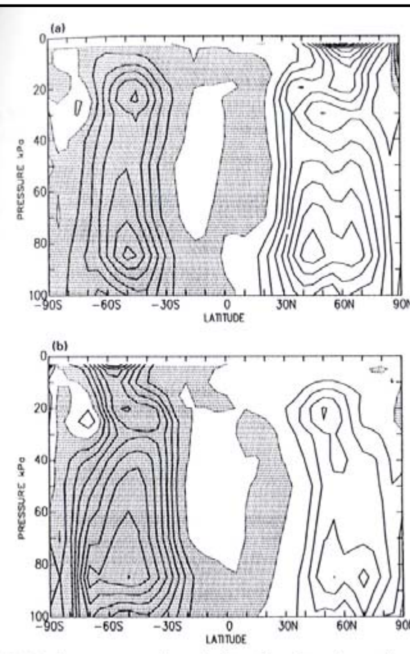
DJF

JJA

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

James, 1995

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

Quasi-geostrophic systems

- Only one variable needed:
  quasi geostrophic potential vorticity
- Thus greatly simplifies mathematics, but retains much of the dynamics
  (for all, but the tropics)

$$\frac{dQ}{dt} = 0 \qquad \text{or} \qquad \frac{dQ}{dt} = +forcing - dissipation$$

Advection with spherical harmonics

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

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

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

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

Lab assignment

- Create a model of the general circulation of the atmosphere
- What is the spin-up time of the atmosphere?

- 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!)

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 $v(q+f)$

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 (David will provide a subroutine)

Discussion question

- 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
- 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?