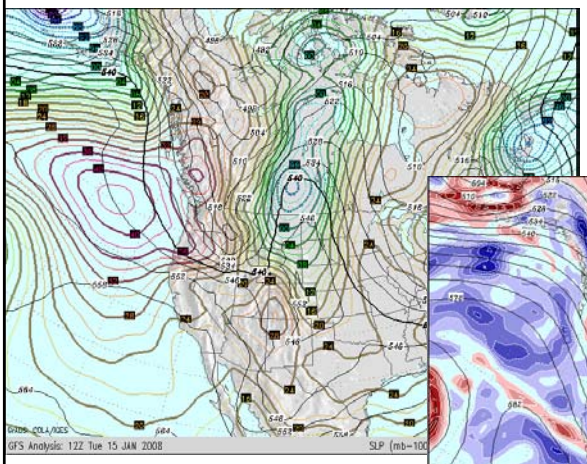
Atmospheric dynamics

(ATOC 5060)

Class aims to…

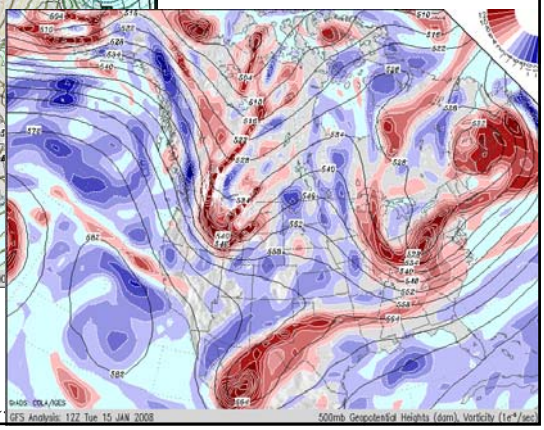
- Develop understanding of what drives atmospheric motions
- Behavior of dynamic structures of the atmosphere on short and long time scales.
- Understand why/how the atmosphere changes
- Be able to predict how/when changes will occur
- Explain changes in terms of transfer of energy from one form to another (kinetic, potential, chemical, …)
- Explain role of time mean flow in contrast to transient flow
- Do this as simply as possible
  (i.e., use some good approximations)

Today's weather



Sea level pressure and

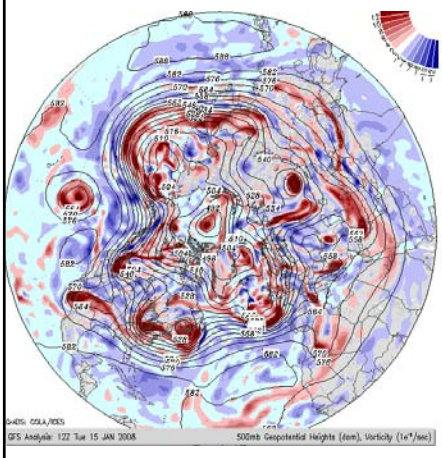
1000-500 hPa "thickness"

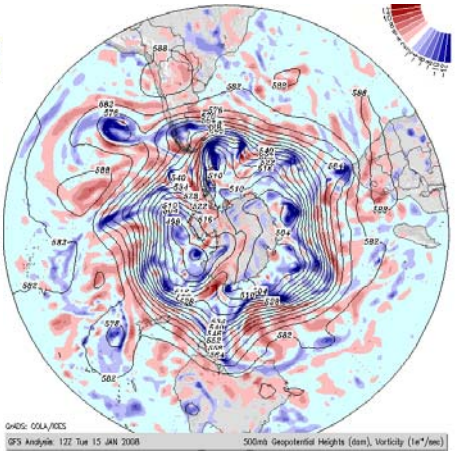


Geopotential height and
relative vorticity at 500 hPa

Global weather (today)

500 hPa geopotential height and vorticity





Northern Hemisphere
(stronger?)

Southern Hemisphere
(less wavy?)

To quantify is to understand

- How do we quantify the atmospheric state?
- ***State variables***
  e.g., temperature, humidity, density, pressure, wind (in 3d), chemical concentration
- Others?
  Vorticity, divergence, potential temperature, potential vorticity, angular momentum, kinetic energy, potential energy, …

Things that are homogenous and do nothing are boring

How do we describe things happening?

- Rules for changes in state variables
- Changes can be in time
- Change can be in space
- Change can be relative to other state variables…example?
- Rules can contains interactions between different state variables.

- ***Sound like differential equations ?***

Atmosphere conserves

- Energy (mechanical, heat, chemical…)
- Mass (of air, and other gases)
- Momentum (and angular momentum)

To describe motion, we can make use of:

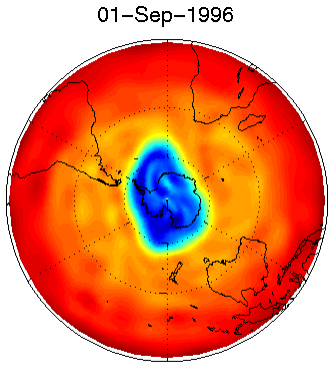
- Newton's 2nd law ($\sum F = ma$)
- First Law of Thermodynamics
- We need to account for fact that earth is rotating, spherical and there is gravity

Syllabus

- Dynamics of the middle atmosphere (20-100 km)
- Tropical dynamics
- The General Circulation of the Atmosphere (on Earth… mostly)
- Instability of large scale waves
- Waves in the atmosphere
- Ways to simplify the full equations to be more useful
- Governing laws of atmospheric motion

Polar stratospheric vortex

Low pressure center over very cold winter pole

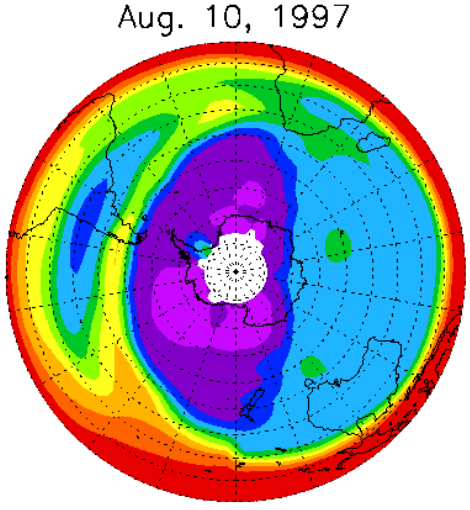


Colors show potential vorticity at 10 hPa (~ 30 km)

Energy lost by winter (night) cooling, but balanced by deposition of kinetic energy by atmospheric waves

Also exists on Mars… and Jupiter…

"See" dynamics from chemicals

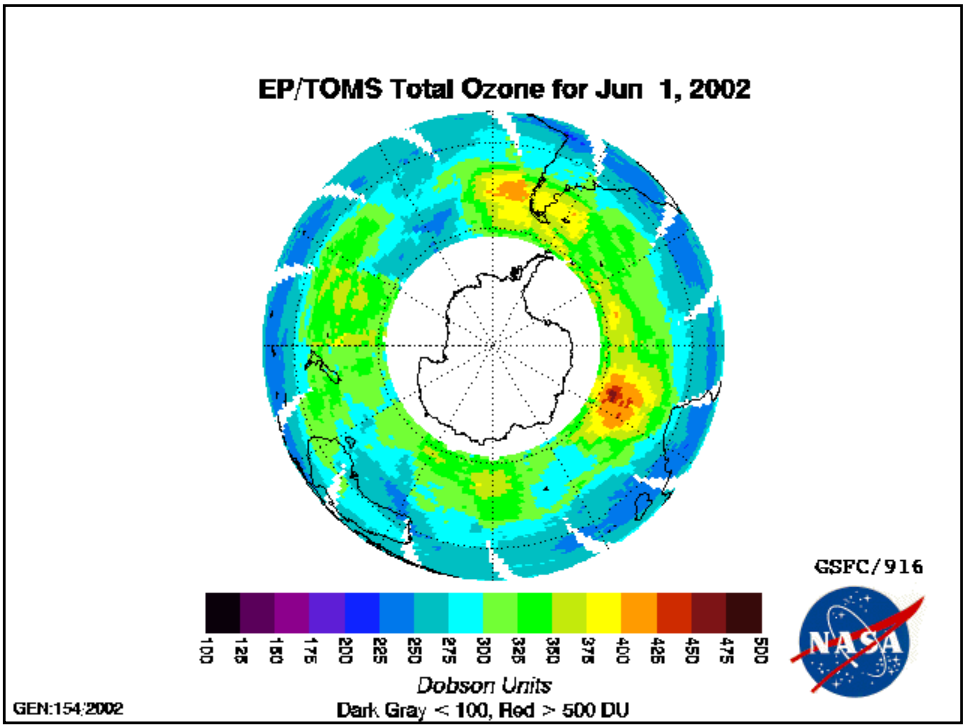


Satellite measurements of nitrous oxide (N_2O).

Source in low latitudes can not penetrate vortex "wall" (for dynamic reasons).

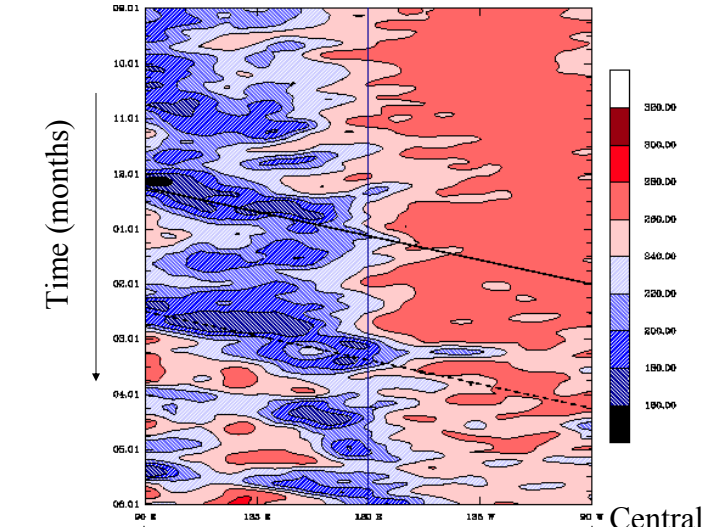
N_2O destroyed inside vortex by chemical reactions.

Similar to ozone



Tropical variability (e.g, MJO)

Outgoing longwave radiation (OLR)

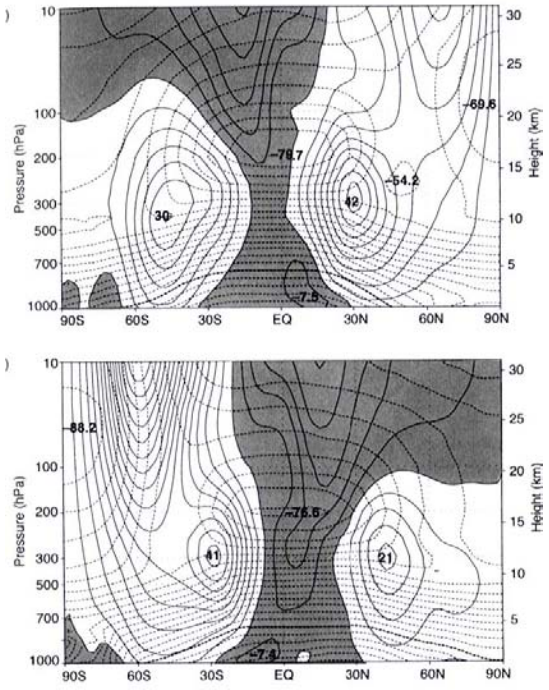


Indonesia

Longitude

(Tropical Pacific Ocean)

Central America



Westerly wind and temperature

Temperature and wind field related
(thermal wind balance)

i.e., $\partial u/\partial z \sim \partial T/\partial y$

- Knowing temperature gradient, estimate jet.
- Knowing jet, estimate gradient.

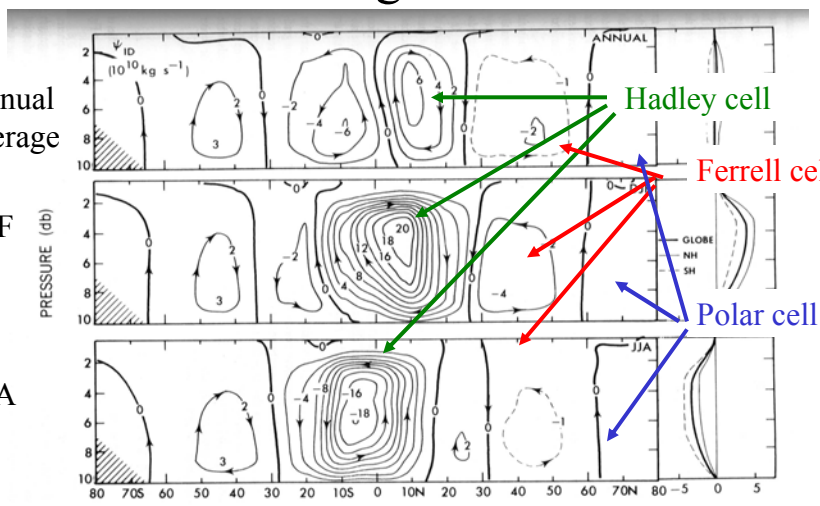
We want to understand what balances give rise to this robust structure.

Wind and temperatures related to overturning circulation

Annual average

DJF

JJA



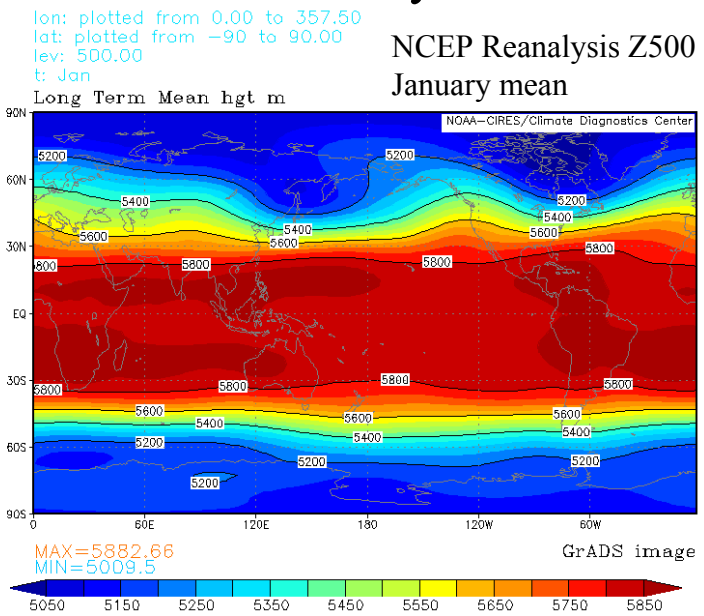
Hadley cell

Ferrell cell

Polar cell

FIGURE 7.19. Zonal-mean cross sections of the mass stream function in 10^{10} kg s^{-1} for annual, DJF, and JJA mean conditions. Vertical profiles of the hemispheric and global mean values are shown on the right.

Stationary flow



NCEP Reanalysis Z500
January mean

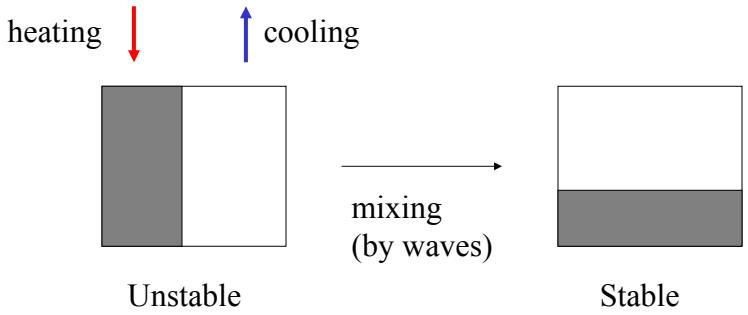
- Growth of waves in the atmosphere?
- (baroclinic spinup)

How do waves grow

Temperature increases in tropics, increasing potential energy

Temperature decreases at poles, decreasing potential energy

Eventually this becomes unstable, and waves grow.



Common themes in topics

- Conservation laws hold
- Atmosphere can sustain wave motions on many scale
- There are mechanism that lead to instability, and wave growth
- Waves transport momentum and energy, which can alter behavior of the mean state
- The atmosphere is always moving
- “Stable” states represent a balance between two (or more) opposing influences

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ATOC 5060

Focus on being able to use theory for atmospheric problems

- Tuesdays: lectures covering foundation material
  (review last homework exercises)
- Thursdays: application of theory to problems
  (set up new problems/exercises)

- Weekly homework exercises (many from the text) to be reviewed in the following class by a random person
- Projects or a research nature
- ***Strongly*** encouraged to read ahead, and read from other sources. Many of the details needed for homework assignments will require you to study the text.
- I expect you to spend at least as much time in class as out of class. Doing so will get you an average passing grade.

Homework

Three questions

1. Approximating the role of earth's rotation
   (To go over in class)
2. Review of partial derivatives, potential temperature and coordinates
   Especially, review "advection"
3. Review of scale analysis
   (a theme in the first few weeks)

(i.e., read chapter 1, 2 and 3 of the text book)