Atmospheric Sciences 321
Science of Climate

Lecture 18:
General Circulation of the Atmosphere: Chapter 6
Community Business

- Homework #6 is posted and due Wednesday. Short.
- Quiz Wednesday on Angular Momentum Conservation
Chapter 6: The Atmosphere

- The atmosphere is the fastest responder and the fastest communicator of information from region to region.

- The Energy Balance

\[
\frac{\partial E_a}{\partial t} = R_a + LE + SH - \Delta F_a
\]

- In the global mean P=E. So, \(-R_a = LP\)
Atmospheric Energy Balance and Precipitation

- In the global mean, P=E, so the atmospheric energy balance can be written,

\[ P = E = -\left( R_a + SH \right) / L \]

- Since SH is generally positive, we need Ra to be negative and to be larger than SH for it to rain. The rate at which P and E can increase in a warmed climate is constrained by the energy balance, which is primarily constrained by the rate at which the atmosphere can cool radiatively.

LP = 80, SH = 20, Ra = −100Wm\(^{-2}\)
Global Mean Precipitation
Climate Model Response to Warming

- Climate models simulate the global climate and its response to greenhouse gas increases and other human influences on climate.
- They warm several degrees by the end of the century.
- The water vapor in the atmosphere increases about 7% per degree of warming, following Clausius-Clapeyron.
- The global mean precipitation goes up only 1-2% per degree of warming.
- This is because of the atmospheric energy constraint on precipitation.
Global Precipitation Sensitivity in Wm$^{-2}$K$^{-1}$

- Models response to warming, we have many modeling groups.

from Pendergrass and Hartmann (2013)
• Models capture Atmospheric Energy Balance
• DP/DT follows
• D(SW+LW)/DT across models, except for two outliers

from Pendergrass and Hartmann (2013)
Hydrologic Cycle Effects

- So latent heat in near-surface air goes up at about 7% per °K global mean, but precipitation rate goes up at only 1-2% per °K.

- This means that when it rains, it can rain harder, but it probably rains a smaller fraction of the time.

- When it is not raining the specific humidity gradient is higher at warmer temperatures, so all being equal it will evaporate more.

- Gives “Wet gets wetter, Dry gets dryer” prediction, which climate models confirm.
What about PDF of Rainfall?

- The probability of higher precipitation rates increases in model simulations, more flooding.

from Pendergrass and Hartmann (2014)
Angular Momentum

- Force times moment arm around the axis of rotation

Two Parts:
- Earth’s angular momentum Due to Rotation
- Relative angular momentum Due to zonal wind

We measure wind relative to the Earth’s spinning surface.
Torque

- Torque is force times moment arm.

- Torque wrench in action.

- Force = kg \( \text{m s}^{-2} \) • Torque = Force times length = kg \( \text{m}^2 \text{s}^{-2} \)
Angular momentum

- Angular Momentum is mass\(\times\)velocity\(\times\)moment arm
- Per unit mass is velocity times moment arm \(m^2s^{-1}\)
Equations!

- Angular momentum has two parts earth and relative

\[ M = (\Omega a \cos \phi + u) a \cos \phi = (u_{\text{earth}} + u) a \cos \phi \]

- The total is conserved, so when we change latitude, we change both.

- The zonal velocity of dirt at the equator is pretty big, nearly the speed of sound.

\[ u_{\text{earth}} = \Omega a \cos \phi = 7.292 \times 10^{-5} \ \text{rad s}^{-1} \cdot 6.37 \times 10^6 \ \text{m} \cdot \cos \phi \]
\[ = 465 \text{ m s}^{-1} \cdot \cos \phi \]
Angular Momentum P.1

- A parcel of air starts at 45°N with a zonal wind of 50 ms$^{-1}$ and conserves angular momentum while it moves to 45°S. What is its zonal velocity when it gets to 45°S??

- 50 ms$^{-1}$, since the moment arm is the same at 45°N and 45°S.
Angular Momentum P.2

A parcel of air starts at 30˚N with a zonal wind of zero ms\(^{-1}\) and conserves angular momentum while it moves to the 10˚N. What is its zonal velocity when it gets to the equator??

\[
M = (\Omega a \cos \phi_{30} + u_{30}) a \cos \phi_{30} = (\Omega a \cos \phi_{10} + u_{10}) a \cos \phi_{10}
\]

\[
u_{10} = (\Omega a \cos \phi_{30} + u_{30}) \frac{a \cos \phi_{30}}{a \cos \phi_{10}} - \Omega a \cos \phi_{10}
\]

\[
u_{10} = \Omega a \left( \frac{\cos 2\phi_{30}}{\cos \phi_{10}} - \cos \phi_{10} \right) = -104 \text{ms}^{-1}
\]
Angular Momentum Balance

- Momentum has to move from easterlies to westerlies
- Mean and Eddy transports both important
Momentum Summary

- Westerly angular momentum moves from the Earth to the air in the tropical easterlies by surface drag.
  - Surface easterlies are generated by the Coriolis acceleration acting on the lower branch of the Hadley Circulation

- Westerly angular momentum is advected poleward in the upper branch of the Hadley Circulation

- Eddies move the momentum across 30N and deliver it to the midlatitude westerlies

- Westerly momentum is moved downward by the eddies and associated Ferrell Cell and return the Earth by surface drag.
mean sea-level pressure and 1000 mb winds

January

July
Asian Monsoon

Offshore winds

Onshore winds
Asian Monsoon Indian Precip.

Wind Vectors and Precipitation

January

Offshore winds

July

Onshore winds
Desert Locations

- explain why all the deserts are located
South American Monsoon?
South and Central American Monsoon

- Precipitation follows the Sun.
Africa and the Sahel Region

- Sahel Region is the boundary between the Sahara desert and wetter regions closer to the equator.

- Above are monthly precipitation bar charts
African Monsoon

- SLP and winds
- In January low pressure and convergence lie along the south coast of West Africa
- During July the low pressure is over the Sahara, a heat low, where it is usually too dry to rain.
Precipitation in Africa

- Examples of seasonal cycle

January

July

March

September
Photos of Desert to Rainforest Transition

- Fig. 6-25 Three photographs showing the variation of surface conditions from the subtropical Sahara Desert to the Intertropical Convergence Zone.

- Top: the Saharan oasis of Ghardaia, Algeria at 32°N. The water table approaches the surface in this depression so that date palms can be grown by irrigation. The annual rainfall is about 75 mm and the surrounding land is barren of vegetation.

- Middle: Sahel region grassland between Agadez and Tanout, Niger at 16°N. The annual rainfall is about 400 mm.

- Bottom: equatorial rain forest on the rim of the Congo Basin near Bondo, Zaire at 4°N. Annual rainfall is about 1800 mm.

(Photos courtesy of S. G. Warren.)
New Topic: The Ocean
Chapter 7

- Thermal and salinity structure
- Density of seawater – both temperature and salinity
- Mixed layer
- Wind driven currents – Ekman Theory
- Thermohaline Circulation
- Ocean Heat Transport
Equation of State of Seawater

- The density of seawater depends on temperature, salinity and pressure. We usually take out the pressure dependence, which is weak, since water is almost incompressible, and talk about potential density and potential temperature.

- We also usually subtract the density of pure water at STP from the actual density, so it varies not from 990 to 1030 Kg m\(^{-3}\), but -10 to 30 parts per thousand ‰. Well, not really, the units are still kg m\(^{-3}\), but with 1000 subtracted.
Equation of State of Seawater

- Potential Density diagram. Formulas are empirical, so we can make a diagram.

Fig. 7-1  Seawater density anomaly ($\rho - 1000 \text{ kg m}^{-3}$) at one atmosphere pressure as a function of temperature (°C) and salinity (%).
Fig. 7-2 Potential temperature (°C), salinity (‰) and potential density (kg m⁻³ – 1000) as functions of pressure (decibar ~ 1 meter of depth) and latitude for the Atlantic (left) and Pacific (right) Oceans. Data are from MIMOC.
Pacific Ocean

Potential Temperature section 160°E in February

Salinity section 160°E in February
Thanks!