Geophysics Fluid Dynamics (ESS228)

- Course Time

  Lectures: Tu, Th 09:30-10:50

  Discussion: 3315 Croul Hall

- Text Book

  J. R. Holton, **"*An introduction to Dynamic Meteorology*"**, Academic Press (Ch. 1, 2, 3, 4, 6, 8, 11).

  Adrian E. Gill, **"*Atmosphere-Ocean Dynamics*"**, Academic Press (Ch. 5, 6, 7, 8, 9, 10, 11, 12).

- Grade

  Homework (30%), Midterm (35%), Final (35%)

- Homework

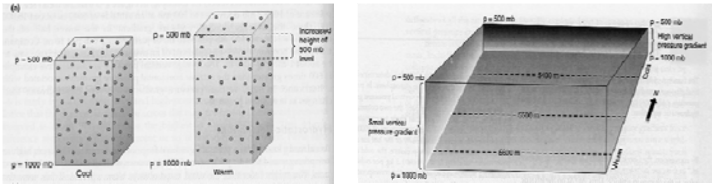
  Issued and due every Thursday

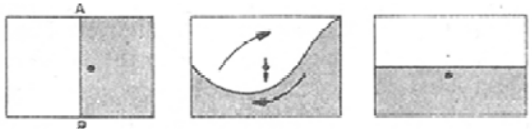
Syllabus

SYLLABUS		
Week 1	1/10 & 1/12	**Introduction and Review of Mathematical Tools** Mathematical tools and estimating with scale Fundamental and apparent forces
Week 2	1/17 & 1/19	**Basic Conservation Laws** Equations of motion, thermodynamic energy equation, Continuity equation
Week 3	1/24 & 1/26	**Applications of the Equations of Motion** Balanced (geostrophic, inertial, cyclostrophic, gradient) flows Thermal wind balance
Week 4	1/31 & 2/2	**Circulation, Vorticity, and Divergence** The Circulation theorem Vorticity and potential vorticity
Week 5	2/7 & 2/9	**Waves in the Atmosphere** Perturbation method Gravity wave, Rossby wave, Kelvin wave
Midterm	**2/14**	
Week 6	2/16	**Adjustment Under Gravity** In a non-rotating system
Week 7	2/21 & 2/23	**Adjustment Under Gravity** In a density-stratified fluid Effect of rotation
Week 8	2/28 & 3/1	**Midlatitude Dynamics: Baroclinic Instabilities** Concept of normal mode Continuously stratified atmosphere Energetics of baroclinic waves
Week 9	3/6 & 3/8	**Ocean Circulation** Wind-driven circulation Western Boundary currents
Week 10	3/13 & 3/15	**Tropical Dynamics** Scale analysis of large-scale tropical motions Equatorial wave theory
Final	**3/22 (8:30am-10am)**	
ESS228: GEOPHYS FLUID DYNAMICS		

What Are the Issues?

- The fundamental aim is to understand the circulations of the atmosphere and ocean and the observed distributions of physical quantities such as temperature.
- The temperature distribution can be viewed as the result of a "competition" between the *sun, which tries to warm the tropics more than the poles* (and so create horizontal contrasts), and ***gravity*** *, which tries to remove horizontal* contrasts and arrange for warmer fluid to overlie colder fluid.
- This "competition“ is complicated by such ***effects as the rotation of the earth***, the variation of the angle between gravity and the rotation axis (the beta effect), and ***contrasts between the properties of air and water***.





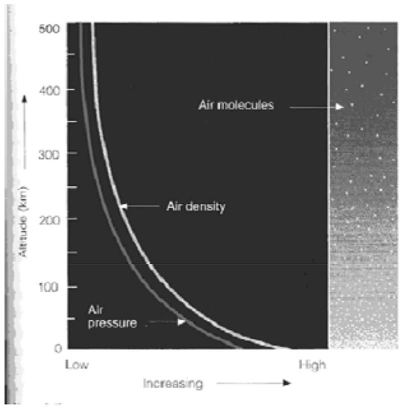
Radiation ➔ Temperature gradient ➔

due to gravity

Density gradient ➔ Pressure gradient force

➔ Motion ➔ Equilibrium

Air Pressure and Air Density



- Weight = mass x gravity
- Density = mass / volume
- Pressure = force / area
  = weight / area

(from *Meteorology Today*)

Atmosphere-Ocean Dynamics

Dynamic Meteorology

Atmosphere-Ocean Dynamics

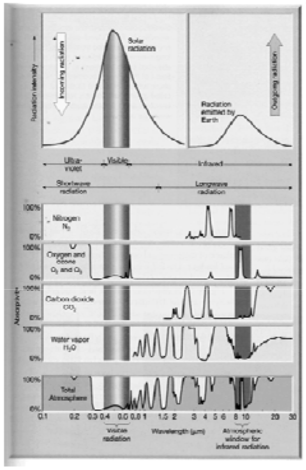
Chapter Three Properties of a Fluid at Rest
Chapter Four Equations Satisfied by a Moving Fluid
Chapter Five Adjustment under Gravity in a Nonrotating System
Chapter Six Adjustment under Gravity of a Density-Stratified Fluid
Chapter Seven Effects of Rotation
Chapter Eight Gravity Waves in a Rotating Fluid
Chapter Nine Forced Motion
Chapter Ten Effects of Side Boundaries
Chapter Eleven The Tropics
Chapter Twelve Mid-latitudes
Chapter Thirteen Instabilities, Fronts, and the General Circulation

Dynamic Meteorology

Chapter 2 Basic Conservation Laws
Chapter 3 Elementary Applications of the Basic Equations
Chapter 4 Circulation and Vorticity
Chapter 6 Synoptic-Scale Motions I: Quasi-geostrophic Analysis
Chapter 8 Synoptic-Scale Motions II: Baroclinic Instability
Chapter 11 Tropical Dynamics

Chapter One **How the Ocean–Atmosphere System Is Driven**

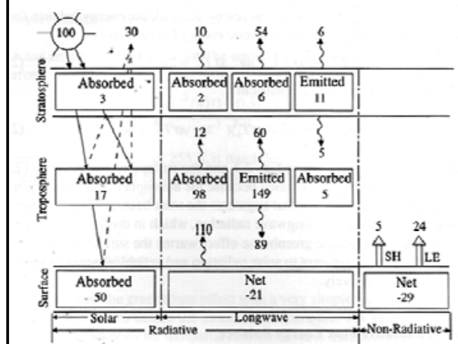
Selective Absorption and Emission



(from *The Atmosphere*)

- ❑ The atmosphere is not a perfect blackbody, it absorbs some wavelength of radiation and is transparent to others (such as solar radiation). ➔ Greenhouse effect.
- ❑ Objective that selectively absorbs radiation usually selectively emit radiation at the same wavelength.
- ❑ For example, water vapor and CO_2 are strong absorbers of infrared radiation and poor absorbers of visible solar radiation.

Vertical Distribution of Energy



(from *Global Physical Climatology*)

Incoming solar radiation

- 70% absorbed by Earth
  - 50% by Earth's surface
  - 20% by atmosphere

Outgoing terrestrial radiation

- 70 (units) back to space
  - 21% by surface
  - 49% by the atmosphere

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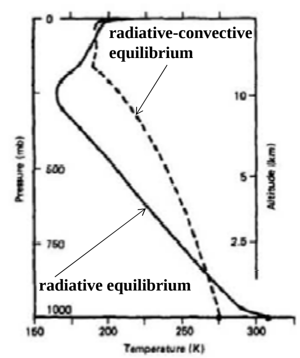
- ❑ This " competition" is complicated by such ***effects as the rotation of the earth***, the variation of the angle between gravity and the rotation axis (the beta effect), and ***contrasts between the properties of air and water***.

Effect of Convection



- ❑ **Radiative Equilibrium**: The temperature distribution that would be obtained based on the radiative energy balance in the absence of fluid motion.
- ❑ **Radiative-Convective Equilibrium:** The temperature distribution that would be obtained based on a balance between radiative and convective effects.
- ❑ Whether or not convection will occur depends on the "lapse" rate, i.e., the rate at which the temperature of the atmosphere decreases with height. Convection will only occur when the lapse rate exceeds a certain value.

Potential Temperature (θ)

❑ The potential temperature of an air parcel is defined as the the temperature the parcel would have if it were moved adiabatically from its existing pressure and temperature to a standard pressure P_0 (generally taken as 1000mb).

$$\theta = T\left(\frac{P_0}{P}\right)^{\frac{R}{C_p}}$$

θ= potential temperature
T = original temperature
P = original pressure
P_0 = standard pressure = 1000 mb
R = gas constant = R_d = 287 J deg^{-1} kg^{-1}
C_p = specific heat = 1004 J deg^{-1} kg^{-1}
R/C_p = 0.286

Dry and Moist Adiabatic Lapse Rates

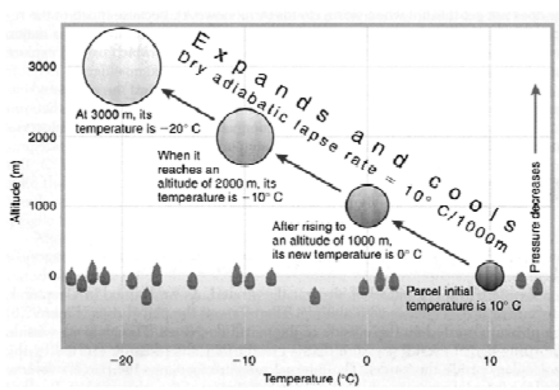
❑ Dry adiabatic lapse rate is constant = 10ºC/km.

❑ Moist adiabatic lapse rate is NOT a constant. It depends on the temperature of saturated air parcel.

❑ The higher the air temperature, the smaller the moist adiabatic lapse rate.

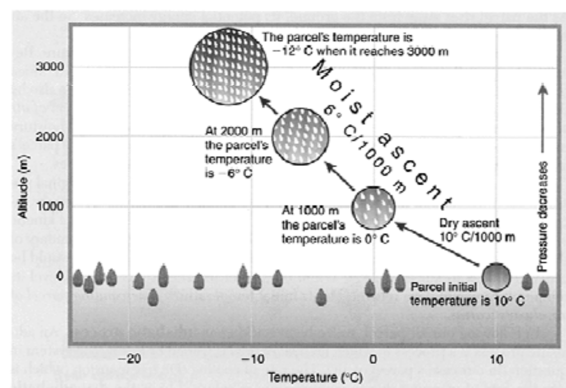
➔When warm, saturated air cools, it causes more condensation (and more latent heat release) than for cold, saturated air.

Dry Adiabatic Lapse Rate



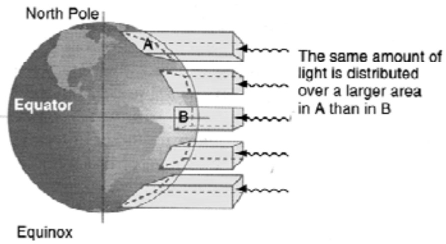
(from *Meteorology: Understanding the Atmosphere*)

Moist Adiabatic Lapse Rate



(from *Meteorology: Understanding the Atmosphere*)

Zenith Angle and Insolation



(from *Meteorology: Understanding the Atmosphere*)

- The larger the solar zenith angle, the weaker the insolation, because the same amount of sunlight has to be spread over a larger area.

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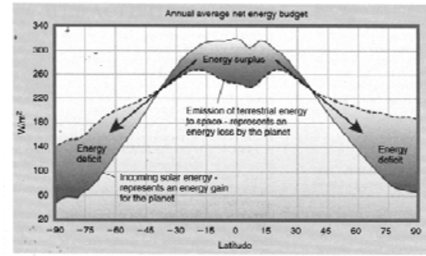
Latitudinal Variations of Net Energy



(from *Meteorology: Understanding the Atmosphere*)

- Polarward heat flux is needed to transport radiation energy from the tropics to higher latitudes.

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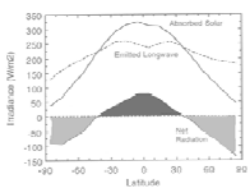
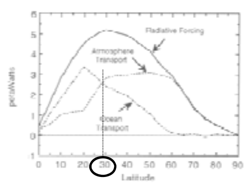
Polarward Energy Transport

Annual-Mean Radiative Energy



Polarward heat flux is needed to transport radiative energy from the tropics to higher latitudes

Polarward Heat Flux



The atmosphere dominates the polarward heat transport at middle and high latitudes. The ocean dominates the transport at lower latitudes.

(1 petaWatts = 10^{15} W)

(figures from *Global Physical Climatology*)

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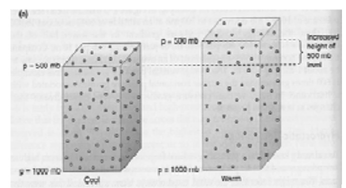

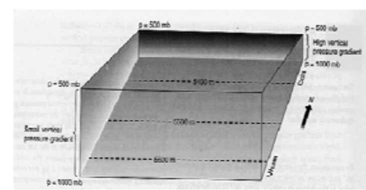

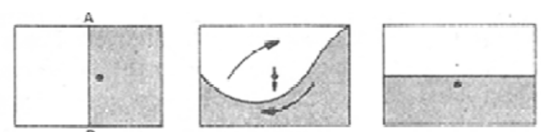

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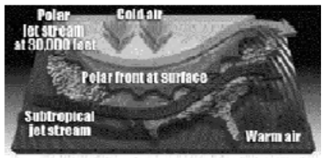
How Do Atmosphere and Ocean Transport Heat?

Atmospheric Circulation



(from USA Today)

Ocean Circulation

(from *The Earth System*)

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Geophs. Fluid Motion and Global Energy Balance

❑ Vertical temperature gradients

➔ Convection occurs that tries to reduce the vertical gradients

➔ Vertical variation of air density (i.e., ***stratification***)

❑ Horizontal temperature gradients

➔Fluid motion takes place to reduce the gradients

➔The motion (i.e., the ***adjustment***) ***takes place in a rotating and stratified system***.

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