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
<table>
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<tr>
<th>Week</th>
<th>Dates</th>
<th>Topic</th>
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<tr>
<td>1</td>
<td>1/10 &amp; 1/12</td>
<td>Introduction and Review of Mathematical Tools</td>
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<td>Mathematical tools and estimating with scale</td>
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<td>Fundamental and apparent forces</td>
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<td>2</td>
<td>1/17 &amp; 1/19</td>
<td>Basic Conservation Laws</td>
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<td>Equations of motion, thermodynamic energy equation,</td>
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<td>Continuity equation</td>
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<td>3</td>
<td>1/24 &amp; 1/26</td>
<td>Applications of the Equations of Motion</td>
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<td>Balanced (geostrophic, inertial, cyclostrophic, gradient) flows</td>
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<td>Thermal wind balance</td>
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<td>4</td>
<td>1/31 &amp; 2/2</td>
<td>Circulation, Vorticity, and Divergence</td>
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<td>The Circulation theorem</td>
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<td>Vorticity and potential vorticity</td>
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<td>5</td>
<td>2/7 &amp; 2/9</td>
<td>Waves in the Atmosphere</td>
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<td>Perturbation method</td>
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<td>Gravity wave, Rossby wave, Kelvin wave</td>
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<td>Midterm</td>
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<td>Adjustment Under Gravity</td>
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<td>In a non-rotating system</td>
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<td>7</td>
<td>2/21 &amp; 2/23</td>
<td>Adjustment Under Gravity</td>
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<td>In a density-stratified fluid</td>
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<td>Effect of rotation</td>
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<td>8</td>
<td>2/28 &amp; 3/1</td>
<td>Midlatitude Dynamics: Baroclinic Instabilities</td>
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<td>Concept of normal mode</td>
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<td>Continuously stratified atmosphere</td>
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<td>Energetics of baroclinic waves</td>
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<td>9</td>
<td>3/6 &amp; 3/8</td>
<td>Ocean Circulation</td>
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<td>Wind-driven circulation</td>
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<td>Western Boundary currents</td>
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<td>10</td>
<td>3/13 &amp; 3/15</td>
<td>Tropical Dynamics</td>
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<td>Scale analysis of large-scale tropical motions</td>
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<td>Equatorial wave theory</td>
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<td>Final</td>
<td>3/22</td>
<td>(8:30am-10am)</td>
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**ESS227: 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 $\Rightarrow$ Temperature gradient $\Rightarrow$

$du$e to gravity

Density gradient $\Rightarrow$ Pressure gradient force

$\Rightarrow$ Motion $\Rightarrow$ Equilibrium
Air Pressure and Air Density

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

(from Meteorology Today)
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

ESS227
Prof. Jin-Yi Yu
Atmosphere-Ocean Dynamics

Chapter Three  Properties of a Fluid at Rest
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Prof. Jin-Yi Yu
Chapter One  How the Ocean–Atmosphere System Is Driven

1.1 Introduction
1.2 The Amount of Energy Received by the Earth
1.3 Radiative Equilibrium Models
1.4 The Greenhouse Effect
1.5 Effects of Convection
1.6 Effects of Horizontal Gradients
1.7 Variability in Radiative Driving of the Earth
Selecting Absorption and Emission

- 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 CO2 are strong absorbers of infrared radiation and poor absorbers of visible solar radiation.

(from The Atmosphere)
Vertical Distribution of Energy

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

(from Global Physical Climatology)
What Are the Issues?

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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.
The potential temperature of an air parcel is defined as 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).

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

- $\theta$ = potential temperature
- $T$ = original temperature
- $P$ = original pressure
- $P_0$ = standard pressure = 1000 mb
- $R$ = gas constant = $R_d = 287 \text{ J deg}^{-1} \text{ kg}^{-1}$
- $C_p$ = 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 = 10°C/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

At 3000 m, its temperature is $-20^\circ$ C

When it reaches an altitude of 2000 m, its temperature is $-10^\circ$ C

After rising to an altitude of 1000 m, its new temperature is $0^\circ$ C

Parcel initial temperature is $10^\circ$ C

Expands and cools

Dry adiabatic lapse rate = $10^\circ$ C/1000 m

Pressure decreases

(from Meteorology: Understanding the Atmosphere)
Moist Adiabatic Lapse Rate

The parcel's temperature is 
\(-12^\circ C\) when it reaches 3000 m

At 2000 m the parcel's temperature is \(-6^\circ C\)

At 1000 m the parcel's temperature is \(0^\circ C\)

Dry ascent \(10^\circ C/1000 \text{ m}\)

Pressure decreases

Parcel initial temperature is \(10^\circ C\)

(from Meteorology: Understanding the Atmosphere)
Zenith Angle and Insolation

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

(from Meteorology: Understanding the Atmosphere)
Latitudinal Variations of Net Energy

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

(from Meteorology: Understanding the Atmosphere)
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)
Radiation $\Rightarrow$ Temperature gradient $\Rightarrow$

due to gravity

Density gradient $\Rightarrow$ Pressure gradient force

$\Rightarrow$ Motion $\Rightarrow$ Equilibrium
How Do Atmosphere and Ocean Transport Heat?

Atmospheric Circulation

Ocean Circulation

(from USA Today)

(from The Earth System)
Geophys. 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*. 