Chapter 6: Stability

- Concept of Stability
- Lapse Rates
- Determine Stability and Stability Indices
Concept of Stability

STABLE

NEUTRAL

UNSTABLE

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Air Parcel Expands as It Rises
Air Parcel Expands As It Rises...

- Air pressure decreases with elevation.
- If a helium balloon 1 m in diameter is released at sea level, it expands as it floats upward because of the pressure decrease. The balloon would be 6.7 m in diameter as a height of 40 km.

(from The Blue Planet)
What Happens to the Temperature?

- Air molecules in the parcel (or the balloon) have to use their kinetic energy to expand the parcel/balloon.

- Therefore, the molecules lost energy and slow down their motions.
  ➔ The temperature of the air parcel (or balloon) decreases with elevation. The lost energy is used to increase the potential energy of air molecular.

- Similarly when the air parcel descends, the potential energy of air molecular is converted back to kinetic energy.
  ➔ Air temperature rises.
Adiabatic Process

• If a material changes its state (pressure, volume, or temperature) without any heat being added to it or withdrawn from it, the change is said to be adiabatic.

• The adiabatic process often occurs when air rises or descends and is an important process in the atmosphere.
Diabatic Process

- Involve the direct addition or removal of heat energy.
- Example: Air passing over a cool surface loses energy through conduction.
• Air parcels that do not contain cloud (are not saturated) cool at the dry adiabatic lapse rate as they rise through the atmosphere.
• Dry adiabatic lapse rate = 10°C/1km
Lapse Rates

• A lapse rate is the rate at which temperature decreases (lapses) with increasing altitude.

• 3 different lapse rates we need to consider:
  (1) dry adiabatic lapse rate
  (2) moist adiabatic lapse rate
  (3) environmental lapse rate
Dry Adiabatic Lapse Rate

(a) 100 m  
Surface  
T = 9 °C  

(b)  
200 m  
100 m  
T = 8 °C  

(c)  
300 m  
200 m  
100 m  
T = 7 °C  

Surface  
T = 10 °C
Moist Adiabatic Lapse Rate

- Air parcels that get saturated as they rise will cool at a rate smaller than the dry adiabatic lapse rate due to the heating produced by the condensation of water vapor.
- This moist adiabatic lapse rate is not a constant but determined by considering the combined effects of expansion cooling and latent heating.

- In the lower troposphere, the rate is $10^\circ$C/km $- 4^\circ$C/km = $6^\circ$C/km.
- In the middle troposphere, the rate is $10^\circ$C/km $- 2^\circ$C/km = $8^\circ$C/km.
- Near tropopause, the rate is $10^\circ$C/km $- 0^\circ$C/km = $10^\circ$C/km.
Latent heat is the heat released or absorbed per unit mass when water changes phase.

Latent heating is an efficient way of transferring energy globally and is an important energy source for Earth’s weather and climate.
Environmental Lapse Rate

• The environmental lapse rate is referred to as the rate at which the air temperature surrounding us (or the air parcels) would be changed if we were to climb upward into the atmosphere.

• This rate varies from time to time and from place to place.

• A rawinsonde’s thermometer measures the environmental lapse rate.
Environmental Lapse Rate

- The environmental (or ambient) lapse rate is referred to the vertical change in temperature through still air.

- The environmental lapse rate is not fixed. It changes from day to day and from place to place.

\[ \text{environmental lapse rate} = 0.5^\circ \text{C}/100\text{m} \]

(from *Understanding Weather & Climate*)
An Example of Environmental Lapse rate

Negative lapse rate is an inversion

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How to Determine Stability

• How do we determine where the atmosphere is unstable – under which convective clouds and storms may form?

→ Answer: Compare the environmental lapse rate with the dry/moist lapse rate
Static Stability of the Atmosphere

$\Gamma_e =$ environmental lapse rate
$\Gamma_d =$ dry adiabatic lapse rate
$\Gamma_m =$ moist adiabatic lapse rate

- Absolutely Stable
  $\Gamma_e < \Gamma_m$

- Absolutely Unstable
  $\Gamma_e > \Gamma_d$

- Conditionally Unstable
  $\Gamma_m < \Gamma_e < \Gamma_d$

(from Meteorology Today)
Absolutely Stable Atmosphere

(a) Lifted, unsaturated air at each level is colder and heavier than the air around it. If given the chance, the parcel would return to its original position.

(b) Lifted, saturated air at each position is colder and heavier than the air surrounding it. If released, the parcel would return to its original position.

(from Meteorology Today)
Absolutely Unstable Atmosphere

(a) The rising, unsaturated air parcel at each level is warmer and lighter than the air around it. If given the chance, the air parcel would accelerate away from its original position.

(b) The rising, saturated air parcel is warmer than its surroundings. If given the chance, it also would move away from its original position.

(from Meteorology Today)
Real-Life Examples in Topeka, Kansas

Unstable Atmosphere (May)

Stable Atmosphere (November)
An Example
How Thunderstorm Forms?

- **Condensation Level**
  where saturation first occurs and where cloud base is formed.

- **Lifting Condensation Level**
  if the air is lifted to reach the condensation.

- **Level of Free Convection**
  where the air first becomes buoyant (its temperature first exceeds the surrounding environment’s temperature)

- Airs pass the level of free convection can form thunderstorms.
How to Change Environmental Lapse Rate?

Daytime

Nighttime

- During the day, surface insolation gains result in greater heating near the surface than aloft.
- At night, the situation reverses as terrestrial radiation loss causes near surface chilling → a *temperature inversion.*
Four Ways to Lift Air Upward

1. Localized Convection
   - Cold air descends
   - Rising air
   - Condensation level
   - Warm, low density air rises
   - Air heated by the ground

2. Convergence Lifting
   - Sea
   - Cold air
   - Warm air
   - Cold front
   - Warm front

3. Orographic Lifting
   - Topography forces wind to flow upward
   - Dry air descends
   - Moist air rises

4. Frontal Lifting
   - Frontal lifting—Cold air beneath warm
   - Frontal lifting—Warm air over cold
   - Rain
   - Cold air
   - Warm front

(from “The Blue Planet”)

Prof. Jin-Yi Yu
# Stability Indices

1. Environmental Lapse rate
2. Lifted Index = T (environment at 500mb) – T (parcel lifted to 500mb)
3. Showalter Index: similar to lifted index but was lifted to 850mb
4. CAPE (Convective Available Potential Energy): derived from soundings
5. Convective INHibition (CINH) Index
6. K Index
7. Total Totals Index
8. SWEAT (Severe Weather Threat) Index

## TABLE 6.2

<table>
<thead>
<tr>
<th>Stability</th>
<th>LI</th>
<th>SI</th>
<th>CAPE</th>
<th>TT</th>
<th>SW</th>
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<tbody>
<tr>
<td>Very stable (no significant activity)</td>
<td>&gt; +3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stable (Showers possible; T’showers unlikely)</td>
<td>0 to +3</td>
<td>&gt; +2</td>
<td>&lt;0</td>
<td></td>
<td></td>
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<tr>
<td>Marginally unstable (T’showers possible)</td>
<td>-2 to 0</td>
<td>0 to 2</td>
<td>0 to 1000</td>
<td>45 to 50</td>
<td></td>
</tr>
<tr>
<td>Moderately unstable (Thunderstorms possible)</td>
<td>4 to 2</td>
<td>-3 to 0</td>
<td>1000 to 2500</td>
<td>50 to 55</td>
<td>250 to 300</td>
</tr>
<tr>
<td>Very unstable (Severe T’storms possible)</td>
<td>-6 to -4</td>
<td>-6 to -3</td>
<td>2500 to 3500</td>
<td>55 to 60</td>
<td>300 to 400</td>
</tr>
<tr>
<td>Extremely unstable (Severe T’storms probable; tornadoes possible)</td>
<td>&lt; -6</td>
<td>&lt; -6</td>
<td>&gt; 3500</td>
<td>60</td>
<td>&gt; 400</td>
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