Chapter 6

Cloud Development and Forms

Cloud Formation

- Condensation (i.e. clouds,fog) results from:
    - Diabatic cooling (important for fog)
    - Adiabatic cooling (important for clouds)
- Clouds form due to adiabatic cooling in rising air

Γ_d = 9.8ºC/km (unsaturated lapse rate)

Γ_m ~ 5ºC/km (saturated lapse rate)

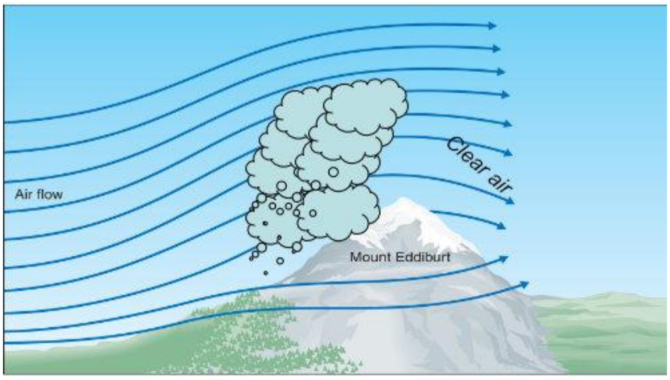
How Does Air Rise?

4 mechanisms cause air to rise:

1) **Orographic lift** – air that rises because it is going over a mountain
2) **Frontal lift** – air that rises at a front
3) **Horizontal convergence** – air that is forced to rise because it is converging
4) **Convection** – air that rises because it is less dense that its surroundings

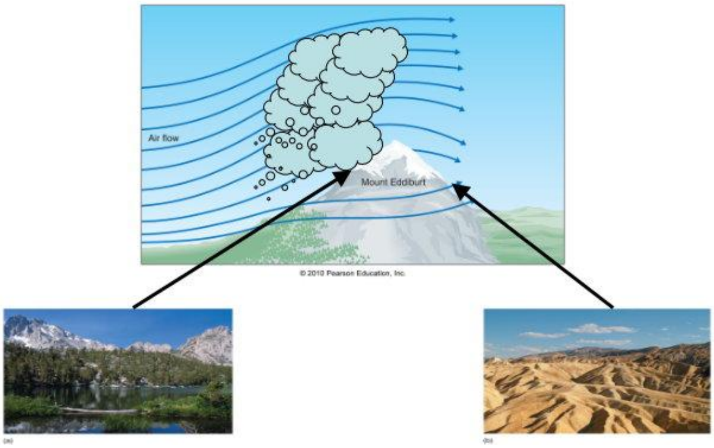
Orographic Lift

Air rises as it approaches a mountain peak



Rain Shadow

- A rain shadow is an area of less precipitation and clouds on the downwind side of a mountain (the anti-cloud!)
    - Air descends downwind of a mountain peak
    - Air warms adiabatically due to compression
    - Precipitation and clouds evaporate to form rain shadow



Frontal Lifting

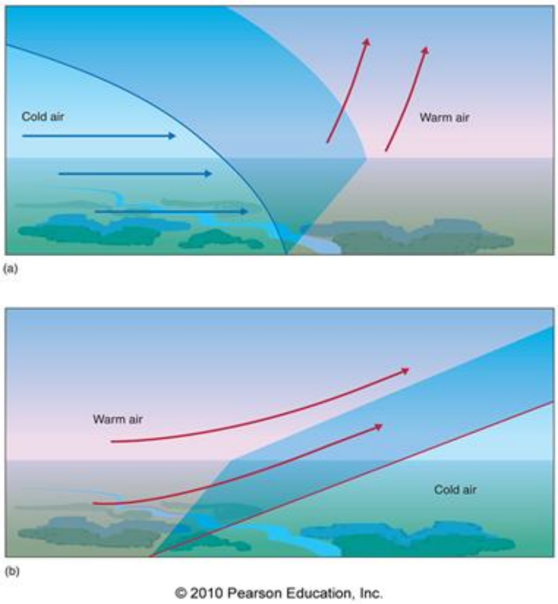
Front – a zone of rapidly changing temperature (strong temperature gradient)

<u>Types of Fronts</u>

1) Cold Front – cold air is advancing
2) Warm Front – warm air is advancing
3) Stationary Front – front isn't moving
4) Occluded Front – you'll find out later

Cold Front
(cold air pushes warm air up)

Warm Front
(Warm air overruns cold air)

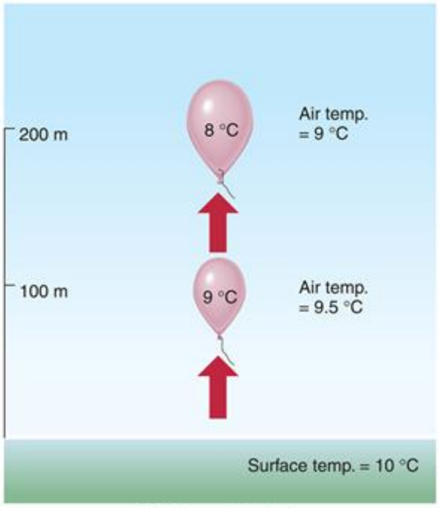


Convergence

- Air must rise when it converges

- Air “bubbles” or “parcels” rise when they are warmed and become less dense than their surroundings (exactly the same way a helium balloon does)

- This is how thunderstorms form!



Atmospheric Stability

Atmospheric stability – a measure of the atmosphere’s susceptibility to vertical motion

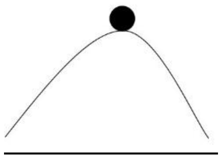
Atmospheric stability depends on the **environmental lapse rate** (Γ_e)

Atmospheric stability comes in 3 flavors:

1) **Absolutely stable**
2) **Absolutely unstable**
3) **Conditionally unstable**

Absolutely Unstable Air

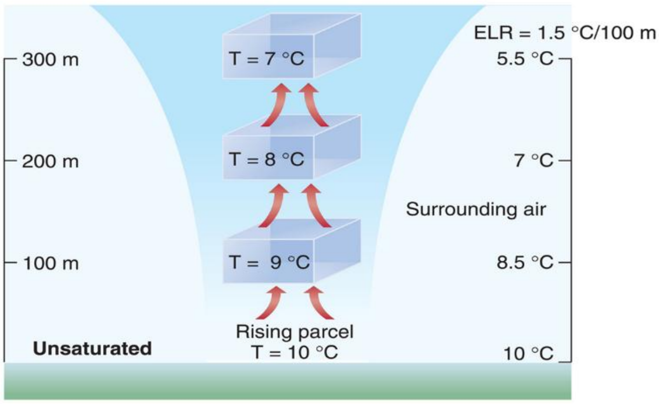
The slightest nudge sends the ball accelerating away…



Absolutely unstable: $\Gamma_e > \Gamma_d$ (unsaturated air)

Γ_e = 1.5°C/100m

Γ_d = 1.0°C/100m

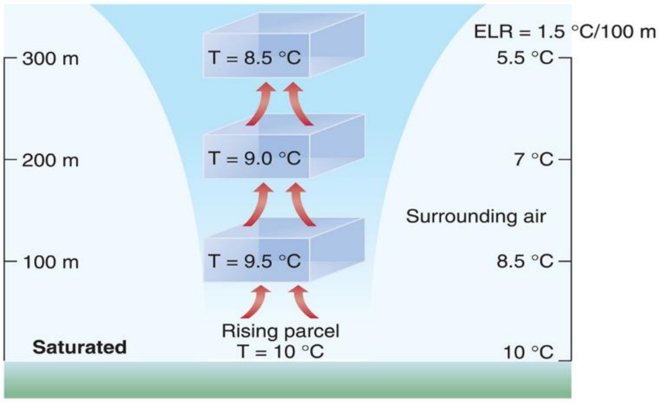


(a)

Absolutely unstable: $\Gamma_e > \Gamma_m$ (saturated air)

$\Gamma_e = 1.5^oC/100m$

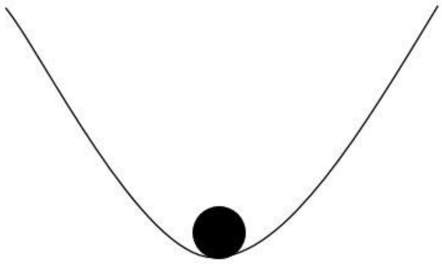
$\Gamma_m = 0.5^oC/100m$



(b)

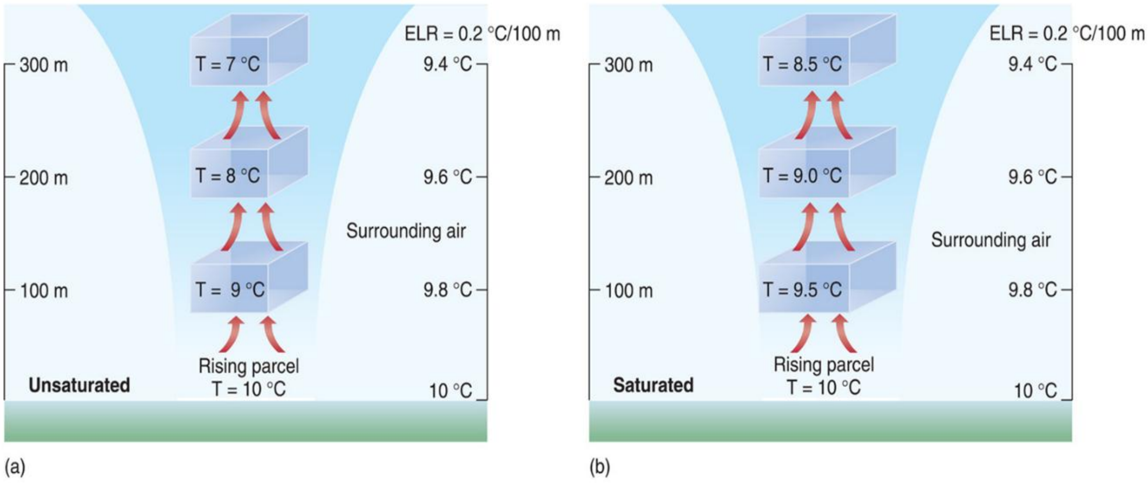
Absolutely Stable Air

Any push and the ball will go back to the valley and come to rest again…



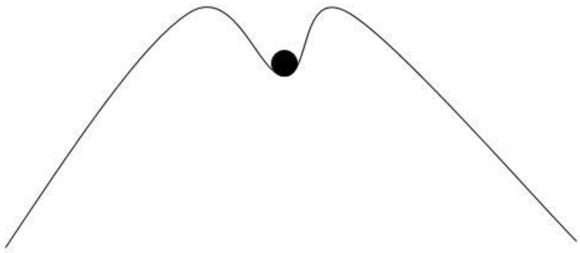
$\Gamma_d = 1.0^oC/100m$
$\Gamma_e = 0.2^oC/100m$

$\Gamma_m = 0.5^oC/100m$
$\Gamma_e = 0.2^oC/100m$



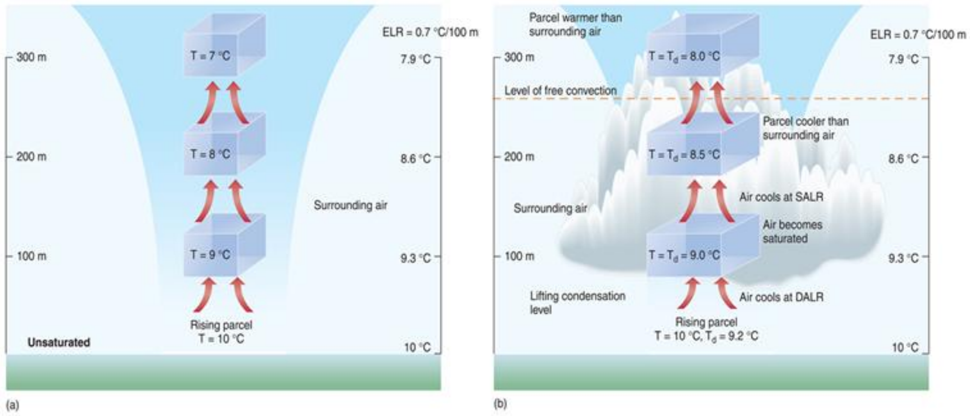
Conditionally Unstable Air

If the ball is pushed high enough, it will go over the hump and accelerate away… (otherwise it comes back to rest)



Γ_d = 1.0°C/100m Γ_m = 0.5°C/100m

Γ_e = 0.7°C/100m Γ_e = 0.7°C/100m



<u>Stability Summary</u>

Absolutely unstable:

$$\Gamma_e > \text{ both } \Gamma_d \text{ and } \Gamma_m$$

Absolutely stable:

$$\Gamma_e < \text{ both } \Gamma_d \text{ and } \Gamma_m$$

Conditionally unstable

$$\Gamma_d > \Gamma_e > \Gamma_m$$

Limitations on Convection

- What stops vertical motion?
    - The only "stopper" is if air becomes more dense (colder) than its surroundings!!
- This happens in 2 ways:

1) Stable air aloft
2) Entrainment – intake of drier air from surroundings

- **Lifting condensation level (LCL)** – The level at which a cloud forms (altitude of cloud base)

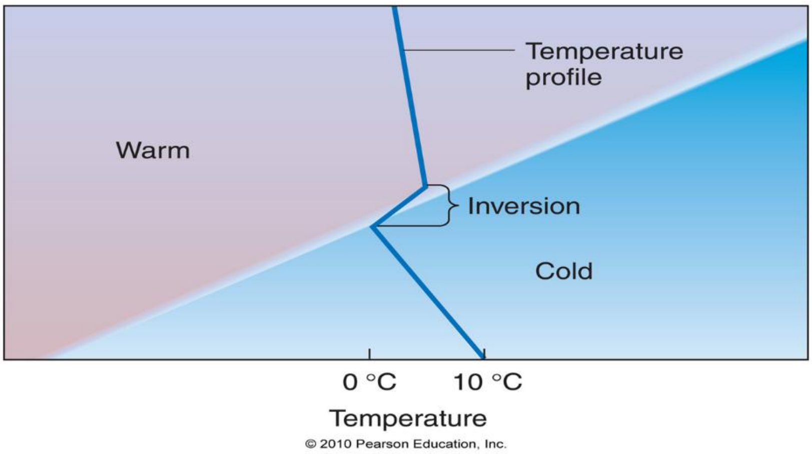
- **Level of Free Convection (LFC)** – the level at which air becomes less dense (warmer) than its surroundings

Inversions – Extremely Stable Air

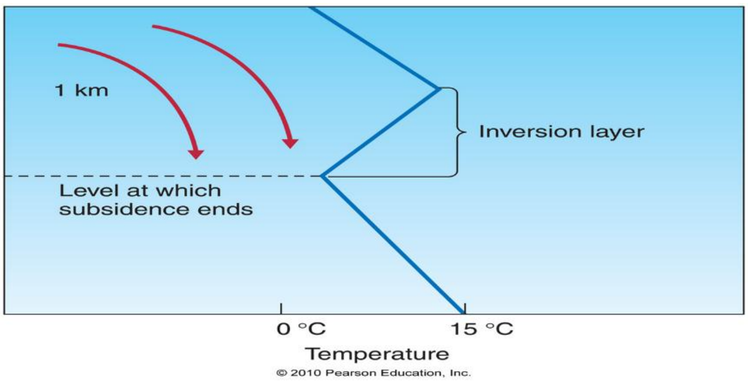
Inversion – when temperature increases with height

Types of Inversions

1) Radiation inversion – caused by nighttime cooling of surface air
2) Frontal inversion – occurs at fronts



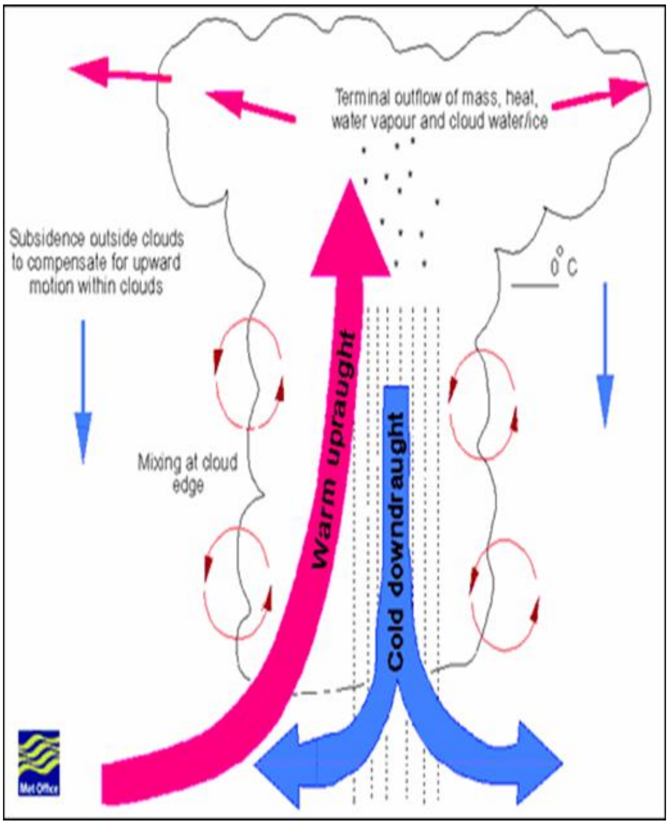
3) Subsidence inversion – caused by sinking air above a static layer



Entrainment

- Mixing with surrounding drier, cooler air cools rising parcels through:

1) Mixing
2) Evaporation



Cloud Types

Old classification of clouds

1) Cirrus (high, thin, wispy)
2) Stratus (layered)
3) Cumulus (puffy, vertically-developed)
4) Nimbus (rain-producing)

New classification of clouds

1) High clouds (higher than 6 km)
2) Middle clouds (b/w 2 and 6 km)
3) Low clouds (below 2 km)
4) Clouds with vertical development

High Clouds (> 6 km)

- Composed of ice crystals
- Principal types:
    1) Cirrus
    2) Cirrostratus
    3) Cirrocumulus

Cirrus

Cirrostratus

Cirrocumulus

Other High Clouds - Contrails

Middle Clouds (between 2 and 6 km)

- Composed mostly of supercooled water
- Principal types:
    - Altostratus
    - Altocumulus

Altostratus

Altocumulus

Low Clouds (< 2 km)

- Composed of liquid water
- Principal types:
  1) Stratus
  2) Nimbostratus
  3) Stratocumulus

Stratus

Nimbostratus

Stratocumulus

Cumulus Clouds

Cumulus clouds can extend the entire depth of the atmosphere

Principal types:

1) Cumulus

   - cumulus humilis (fair-weather cumulus)

   - cumulus congestus (fortress-like)

2) Cumulonimbus

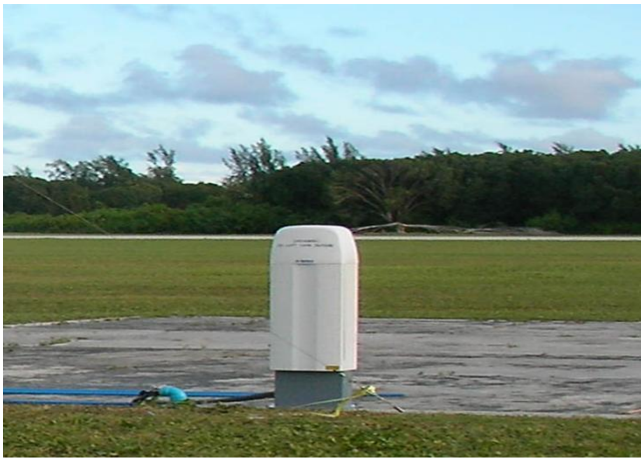
Cumulus Humilis

Cumulus Congestus

Cumulonimbus

Observing Clouds

- **Ceilometers** – automated instrument that measures the height of the cloud base, or ceiling, as well as coverage



Cloud Coverage

TABLE 6-3 Cloud Coverage

Amount of Cloud Coverage	Condition
0	Clear
1/8 to 2/8	Few*
3/8 to 4/8	Scattered
5/8 to 7/8	Broken
8/8	Overcast

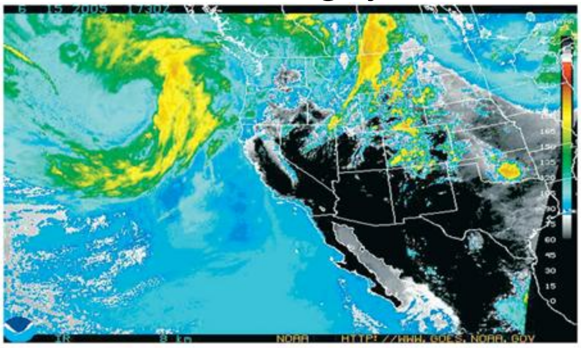
** Any cloud coverage at all up to 2/8 is classified as "few."*

- Satellite imagery is also a primary tool for observing clouds and cloud motions
    - ➢ Visible satellite imagery
    - ➢ Infrared satellite imagery
    - ➢ Water vapor satellite imagery

Visible Satellite Imagery

(a)

Infrared Satellite Imagery



(c)

Water Vapor Satellite Imagery