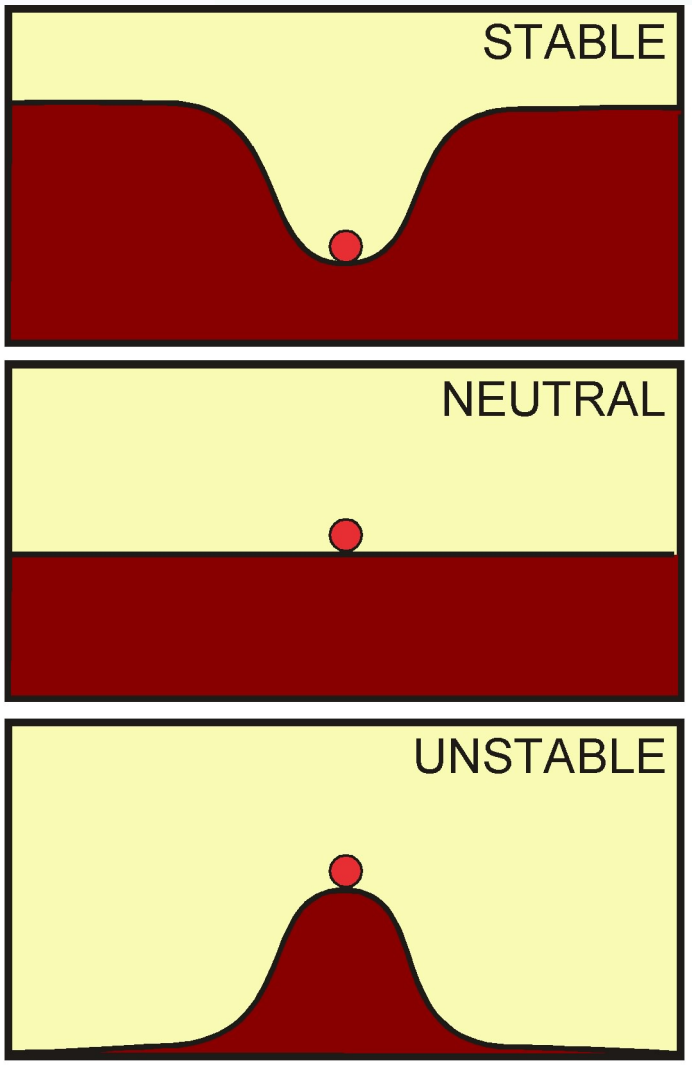
Chapter 6
Atmospheric Stability

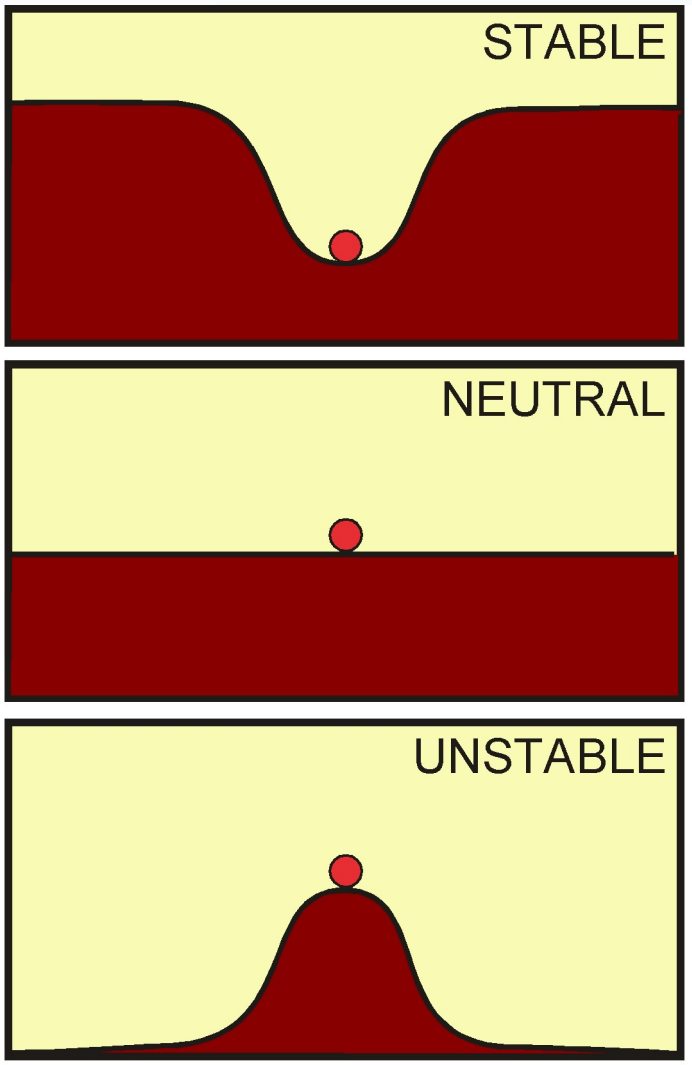
Concept of Stability

- What happens if you push the ball to the left or right in each of these figures?
- How might this apply in the atmosphere?

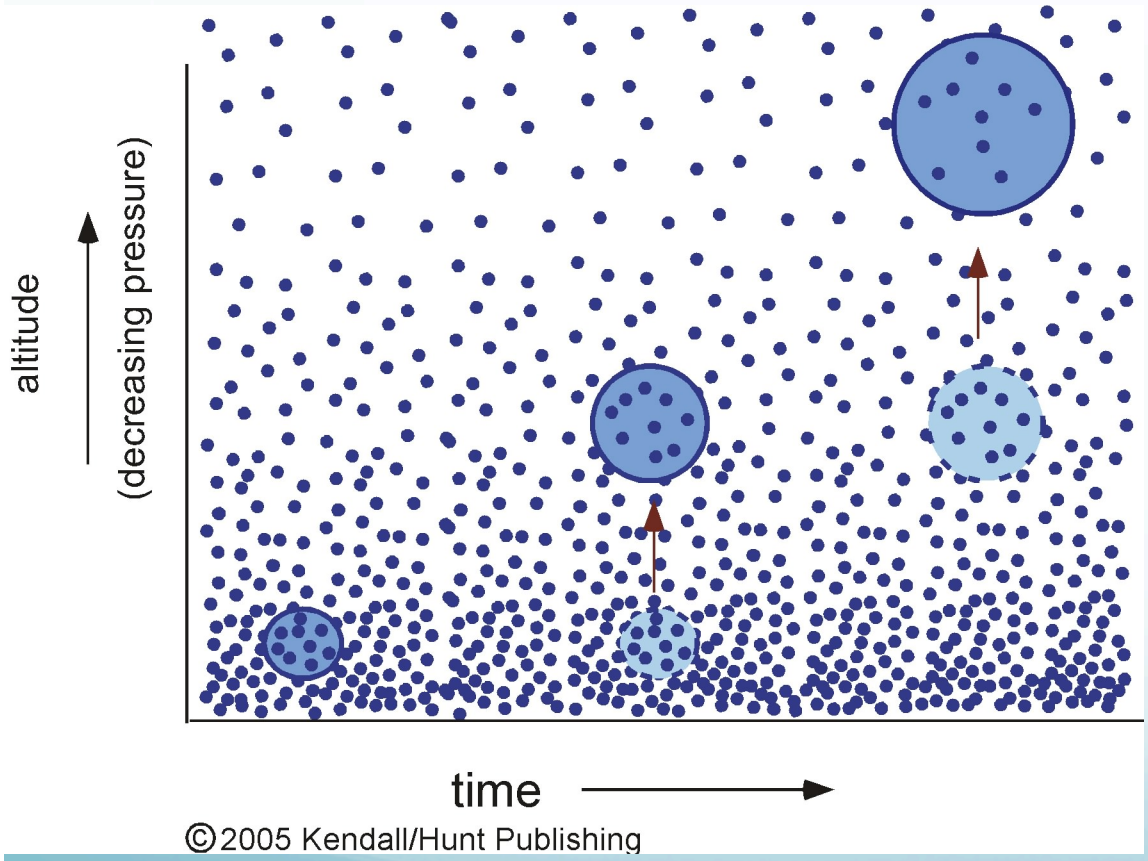


Atmospheric Stability

- **Air parcel:** a distinct blob of air that we will imagine we can identify as it moves through the atmosphere
- Air parcels and stability
  - **Stable**: if the parcel is displaced vertically, it will return to its original position
  - **Neutral**: if the parcel is displaced vertically, it will remain in its new position
  - **Unstable**: if the parcel is displaced vertically, it will accelerate away from its original position in the direction of the initial displacement



Air parcel vertical movement



- How does an air parcel change as it moves in the vertical?
  - Expand as it rises because it encounters lower pressure.
  - Compress as it sinks because it encounters higher pressure.

Adiabatic processes

- **Adiabatic process**: a process in which an air parcel does not mix with its environment or exchange energy with its environment
- What happens to the temperature of an air parcel as it expands (rises) or compresses (sinks)?
  - The air parcel cools as it expands (rises)
  - The air parcel warms as it compresses (sinks)
  - These are examples of adiabatic processes

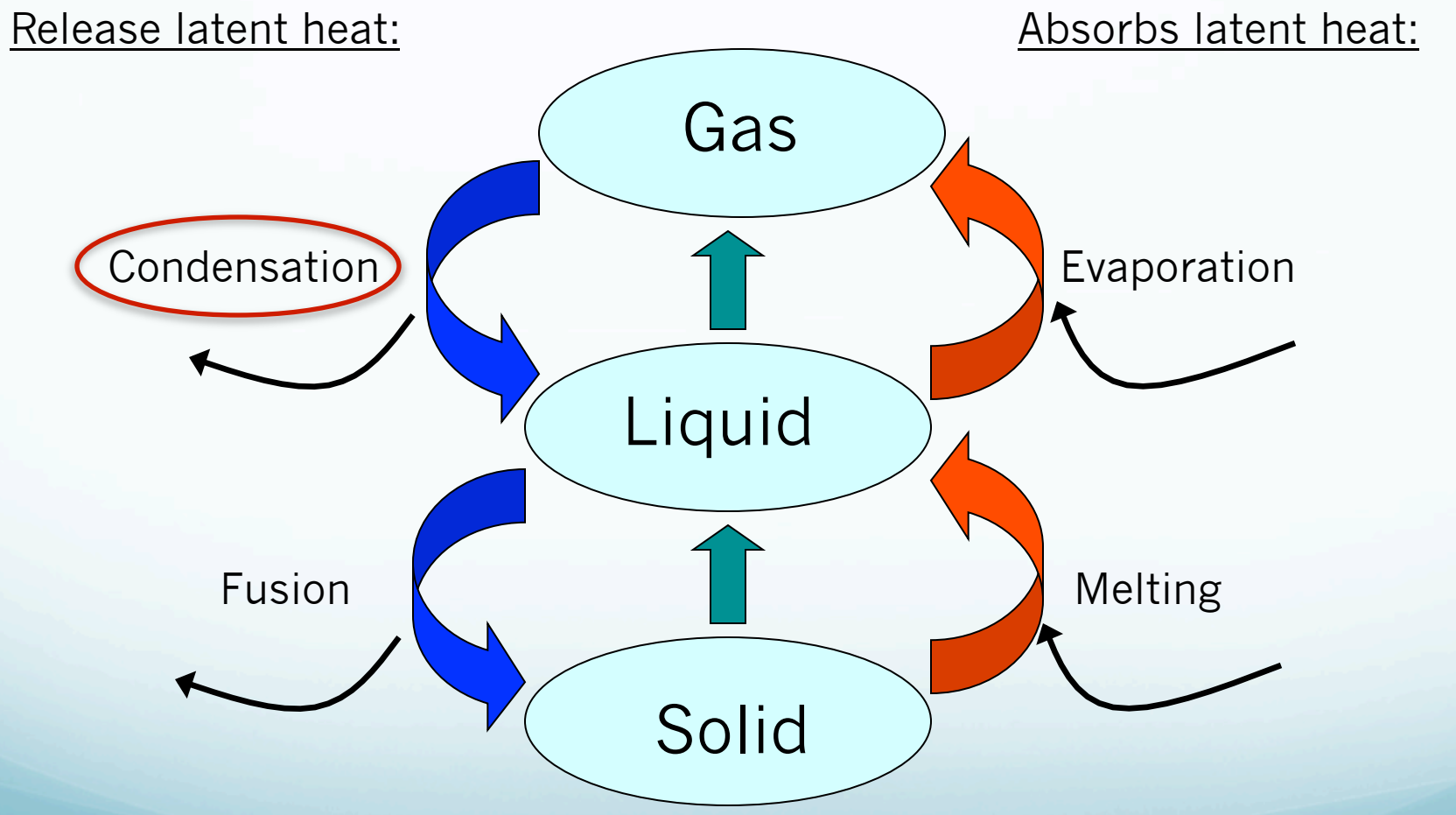
Lapse Rates

- **Lapse rate**: The rate at which temperature changes in the vertical (slope of the temperature vertical profile)
- **Dry adiabatic lapse rate**: the rate at which an unsaturated air parcel will cool if it rises or warm as it sinks (applies to an air parcel with a relative humidity of less than 100%)
  - Dry adiabatic lapse rate = 10°C / km
- **Moist adiabatic lapse rate:** the rate at which a saturated air parcel will cool if it rises or warm if it sinks (applies to an air parcel with a relative humidity of 100%)
  - Moist adiabatic lapse rate = 6°C / km (on average in the troposphere)

What's happening?

- Why is the moist adiabatic lapse rate different? Why is it less than the dry adiabatic lapse rate?
- Let's think about what happens to a saturated air parcel as it rises:
  1. The air parcel will cool as it rises (same as unsaturated)
  2. Water vapor will condense as the parcel rises (a cloud forms) when it becomes saturated
  3. As water vapor condenses latent heat is released
  4. The latent heat that is released will offset some of the cooling that occurred as the air parcel rose (the amount of latent heat released will vary, but on average will offset about 4°C / km of cooling)

Recall:
Latent Heat transfer



Clicker Question

- An air parcel is considered _____ if it rises vertically and then returns to its original position (sinks).
  A. Stable
  B. Unstable
  C. Neutral

Clicker Question

- As an air parcel rises it _____ and its temperature _____ adiabatically.
  A. Expands, warms
  B. Expands, cools
  C. Compresses, warms
  D. Compresses, cools

Clicker Question

- True or false: An adiabatic process is one in which an air parcel does not mix with its environment or exchange energy with its environment.
  A. True
  B. False

Clicker Question

- The value of the dry adiabatic lapse rate is _____.

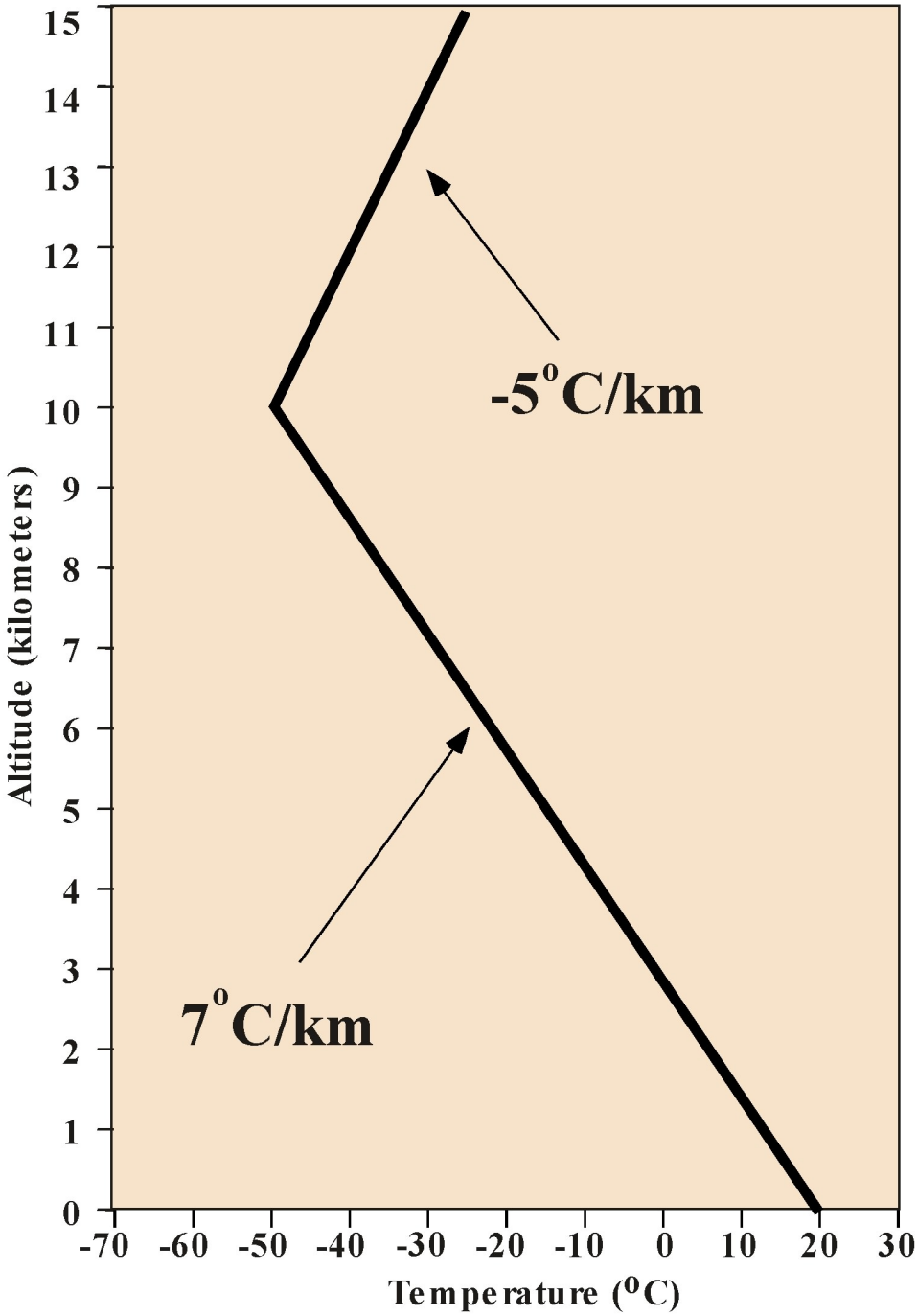
  A. 0 °C / km
  B. 6 °C / km
  C. 10 °C / km
  D. 15 °C / km

Environmental lapse rate

- **Environment**: the atmosphere outside of an air parcel
- **Environmental lapse rate**: the rate at which the environment's temperature decreases with increasing altitude
- Use the environmental lapse rate to determine the temperature of the environment as you move up or down in the atmosphere.
- Use the dry adiabatic lapse rate or moist adiabatic lapse rate to determine the temperature of an air parcel as it rises or sinks in the atmosphere

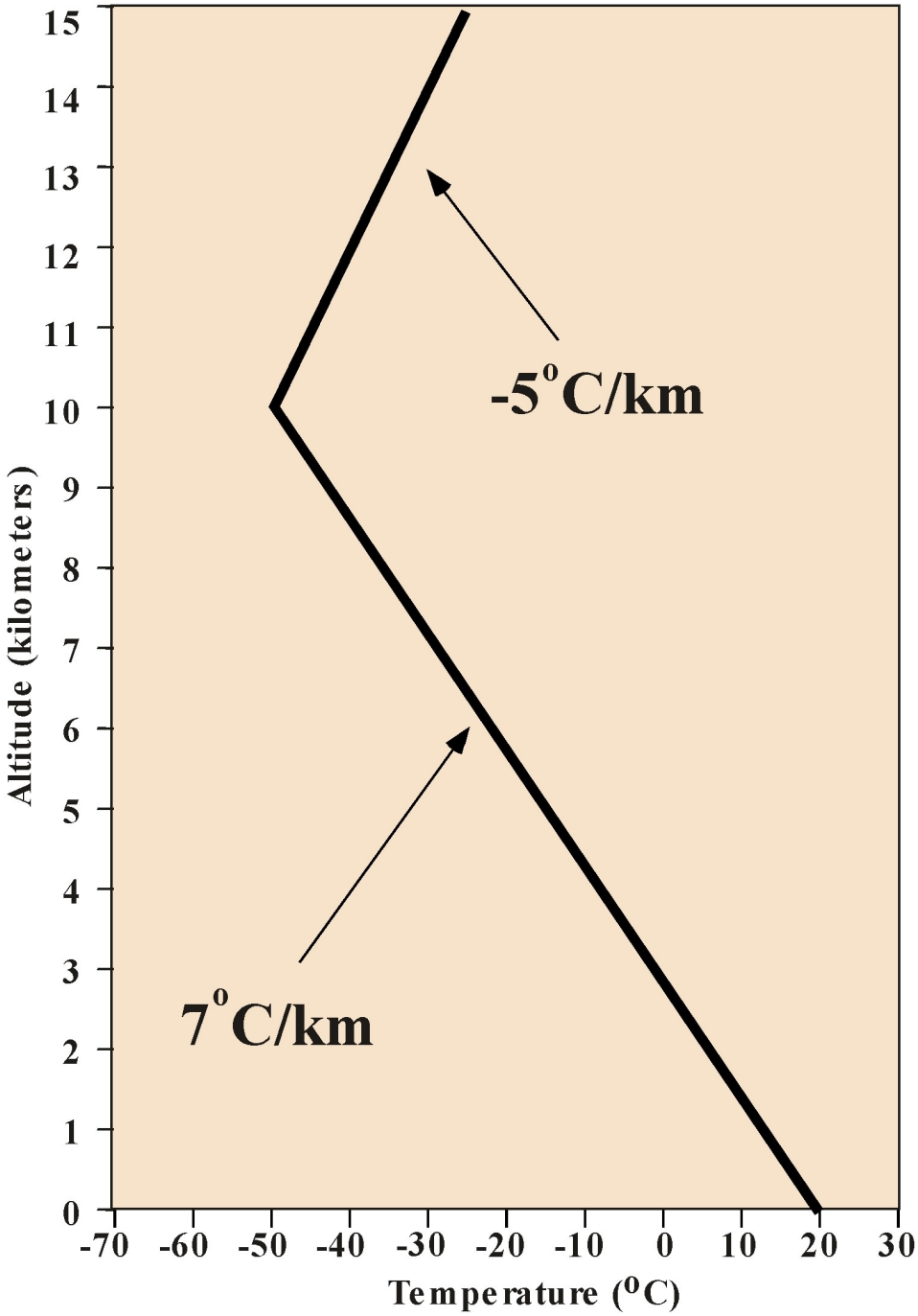
Idealized environmental temperature profile

- What features do you notice?
- How do we measure the environmental temperature profile?
  - Rawinsondes!
- Is the environmental temperature profile always the same?
  - No, it changes from day-to-day and throughout the day.



Inversions

- **Inversion layer:** a layer of the atmosphere where the environmental temperature increases with increasing altitude
- What does a negative environmental lapse rate mean?
  - Recall how environmental lapse rate was defined



Clicker Question

- As a saturated air parcel rises in the atmosphere it will cool at the _____ which has a value of _____.
  A. Environmental lapse rate, 5 °C / km
  B. Moist adiabatic lapse rate, 6 °C / km
  C. Dry adiabatic lapse rate, 10 °C / km
  D. Environmental lapse rate, 15 °C / km

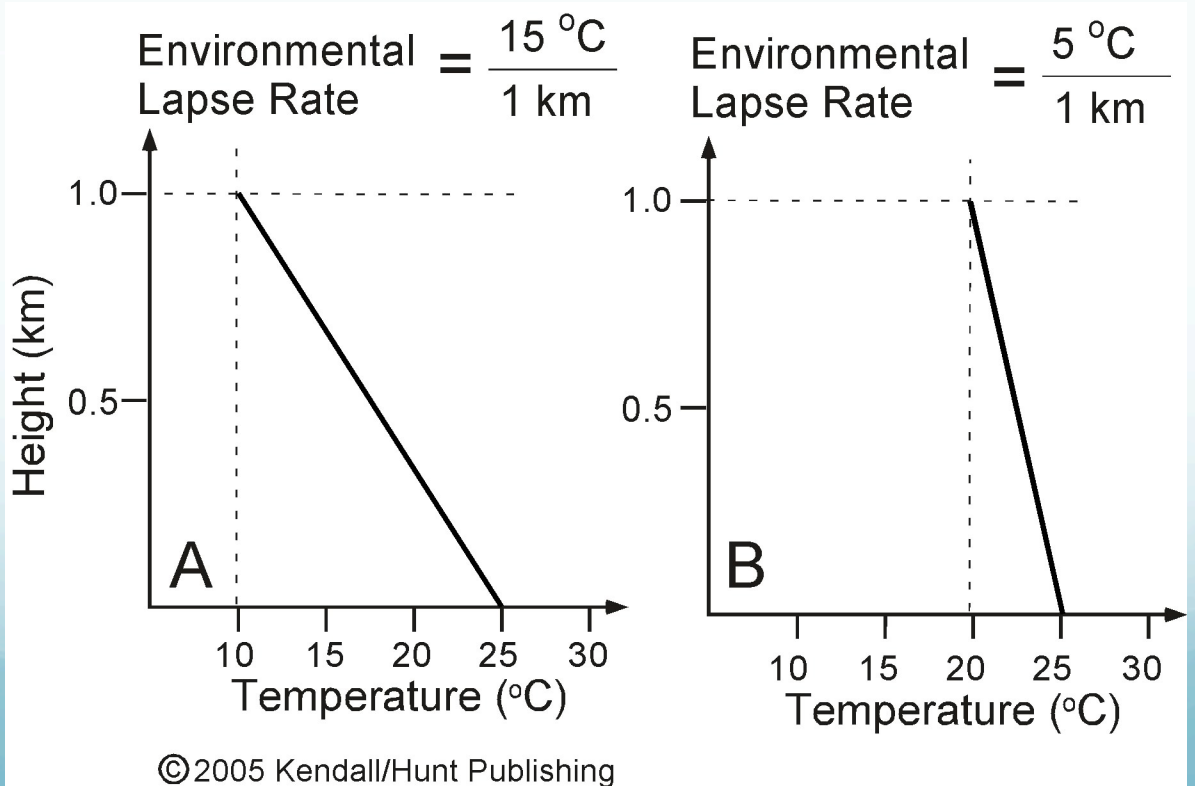
Clicker Discussion Question

- What is the temperature of a saturated air parcel that is lifted 2 km if its initial temperature is 15 °C?

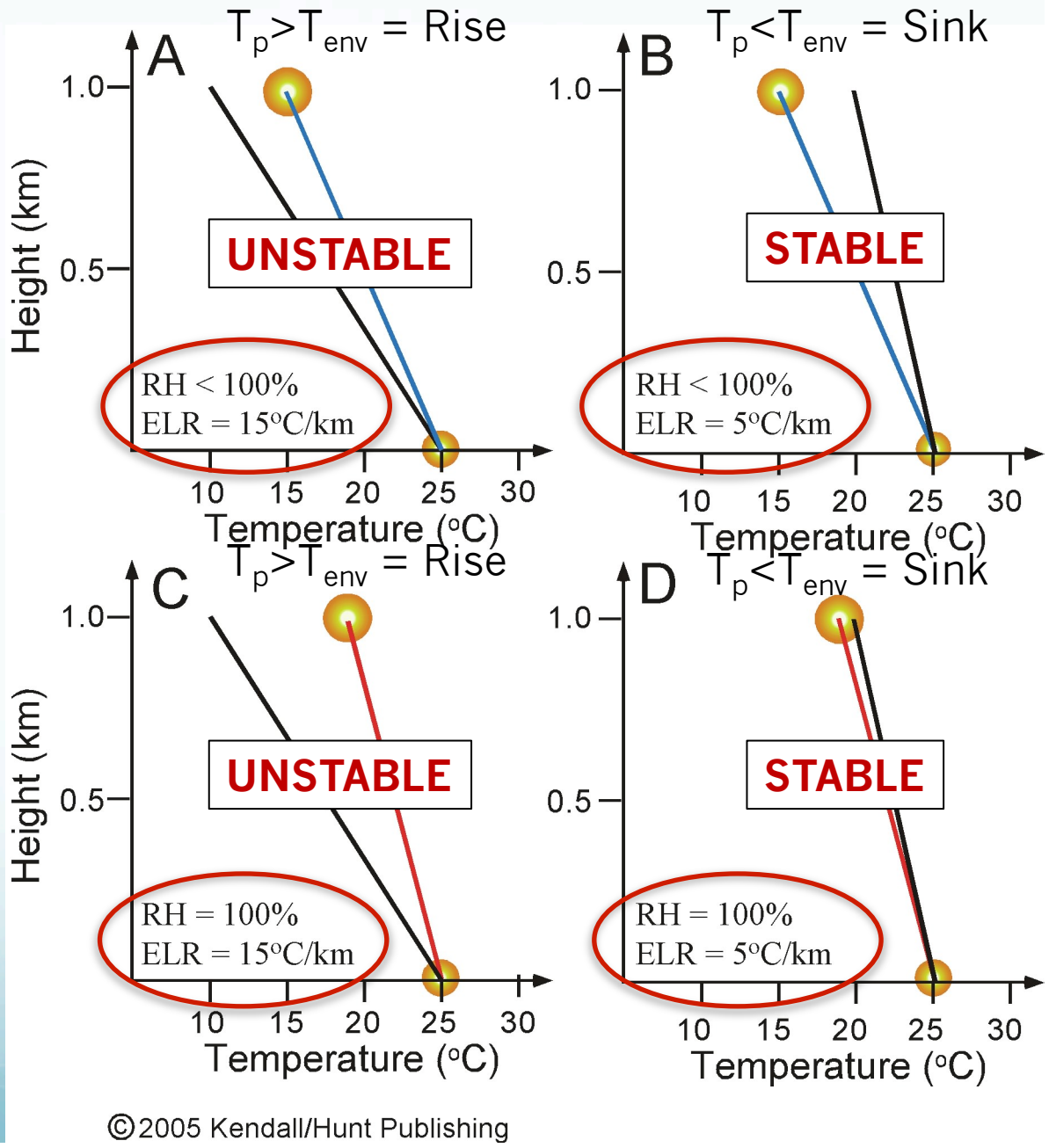
  A. –5 °C
  B. 3 °C
  C. 15 °C
  D. 27 °C
  E. 35 °C

Determining stability

- To determine stability we need to compare the temperature of an air parcel to the temperature of its environment.
  - If an air parcel is warmer than its environment it will rise.
  - If an air parcel is colder than its environment it will sink.

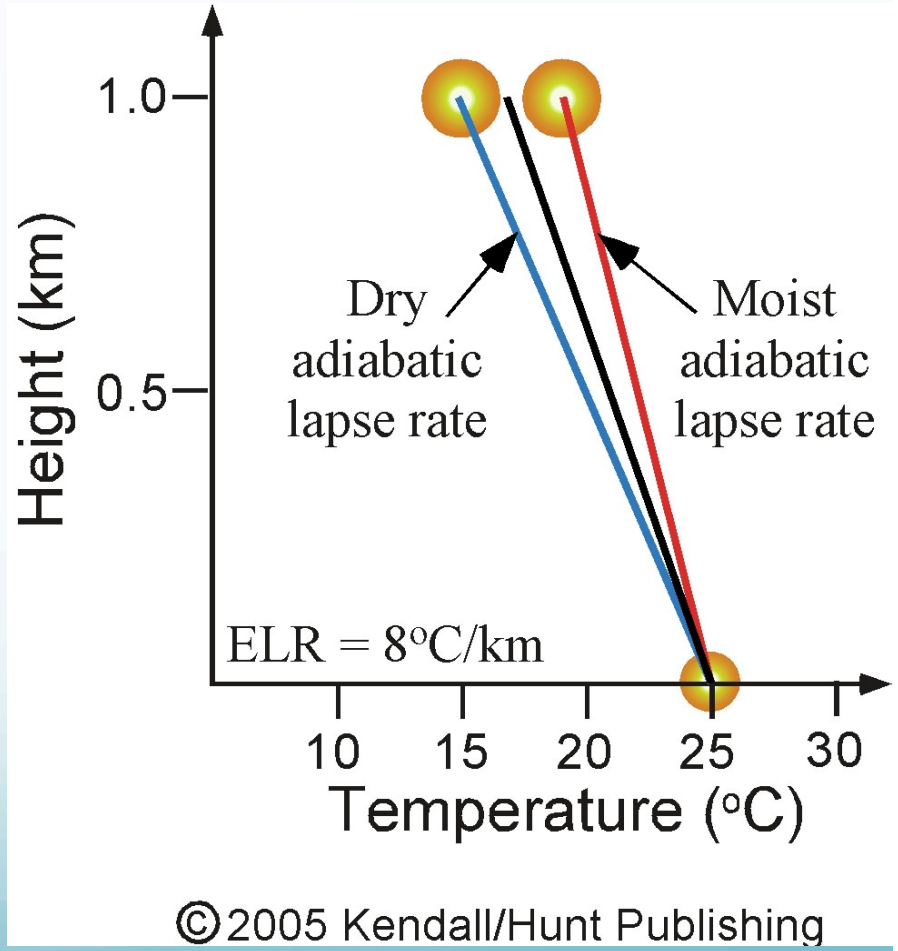


- How does the temperature of the air parcel (T_p) change as it is lifted?
- What is the stability of the air parcel in each panel of this figure?



Conditional instability

- **Conditionally unstable**: the condition required for instability is that the displaced air parcel is saturated
  - Unstable if saturated (follows moist adiabatic lapse rate)
  - Stable if unsaturated (follows dry adiabatic lapse rate)



Summary of stability

Environmental Lapse Rate (ELR)	**Stability**
ELR > 10 deg C / km	Unstable
ELR = 10 deg C / km	Neutral if unsaturated Unstable if saturated
6 deg C / km < ELR < 10 deg C / km	Conditionally unstable (see below)
ELR = 6 deg C / km	Neutral if saturated Stable if unsaturated
ELR < 6 deg C	Stable

Clicker Question

- If an air parcel is _____ than its environment it will _____.
  A. Cooler, rise
  B. Cooler, sink
  C. Warmer, rise
  D. All of the above
  E. Both b and c

Clicker Question

- The vertical temperature profile measured by a rawinsonde gives us the _____.
  A. Dry adiabatic lapse rate
  B. Moist adiabatic lapse rate
  C. Environmental lapse rate

Clicker Discussion Question

- Measurements from a rawinsonde indicate that the environmental lapse rate in a layer of the atmosphere is **15 deg C / km**. Based on this information the stability of this layer of the atmosphere would be _____.
  A. Stable
  B. Unstable
  C. Conditionally unstable
  D. Neutral if saturated, stable if unsaturated
  E. Neutral if unsaturated, unstable if saturated

Clicker Question

- Measurements from a rawinsonde indicate that the environmental lapse rate in a layer of the atmosphere is **4 deg C / km**. Based on this information the stability of this layer of the atmosphere would be _____.
  - A. Stable
  - B. Unstable
  - C. Conditionally unstable
  - D. Neutral if saturated, stable if unsaturated
  - E. Neutral if unsaturated, unstable if saturated

Clicker Question

- Measurements from a rawinsonde indicate that the environmental lapse rate in a layer of the atmosphere is **8 deg C / km**. Based on this information the stability of this layer of the atmosphere would be _____.
  A. Stable
  B. Unstable
  C. Conditionally unstable
  D. Neutral if saturated, stable if unsaturated
  E. Neutral if unsaturated, unstable if saturated

Clicker Question

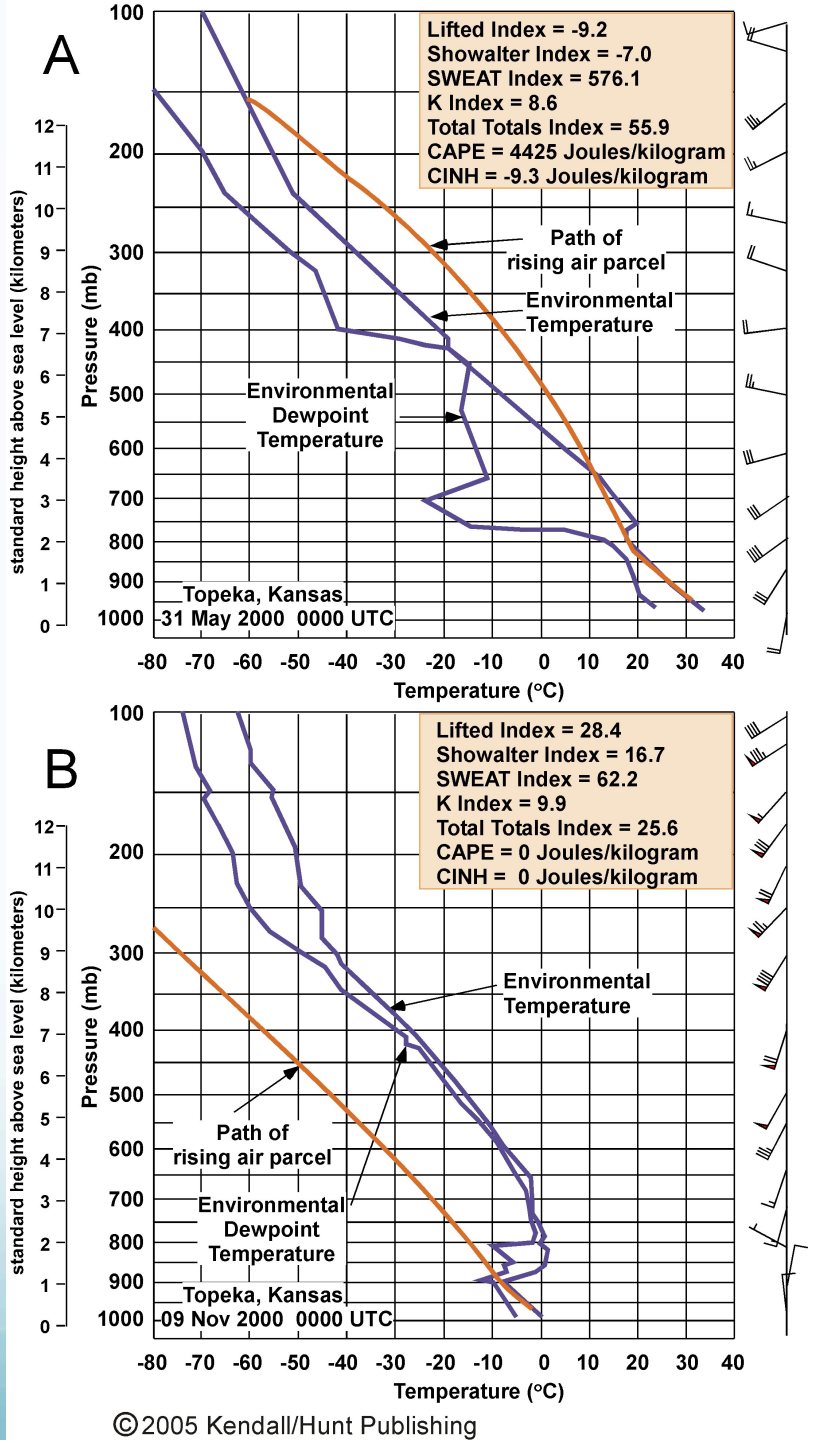
- Measurements from a rawinsonde indicate that the environmental lapse rate in a layer of the atmosphere is **6 deg C / km**. Based on this information the stability of this layer of the atmosphere would be _____.
  A. Stable
  B. Unstable
  C. Conditionally unstable
  D. Neutral if saturated, stable if unsaturated
  E. Neutral if unsaturated, unstable if saturated

Clicker Question

- A **negative** environmental lapse rate indicates that temperature _____ as you go up in height, which we call an _____.
  - A. Increases, inversion
  - B. Increases, adiabatic process
  - C. Decreases, inversion
  - D. Decreases, adiabatic process

Examples of real environmental profiles

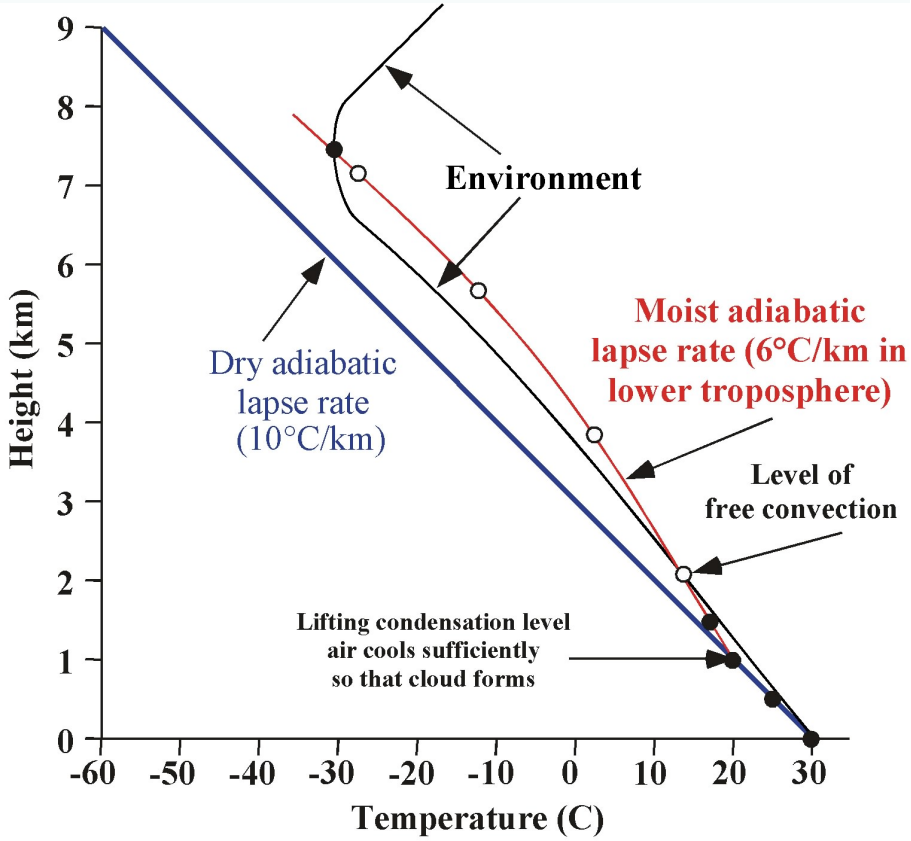
- What is the stability of the air parcel as it rises through the environmental temperature profile?
- Does the stability change if we look at different levels of the atmosphere?
- How can the stability of an atmospheric layer be changed?
- What happens to the stability of the lower part of the atmosphere over the course of a day?



Stability and thunderstorms

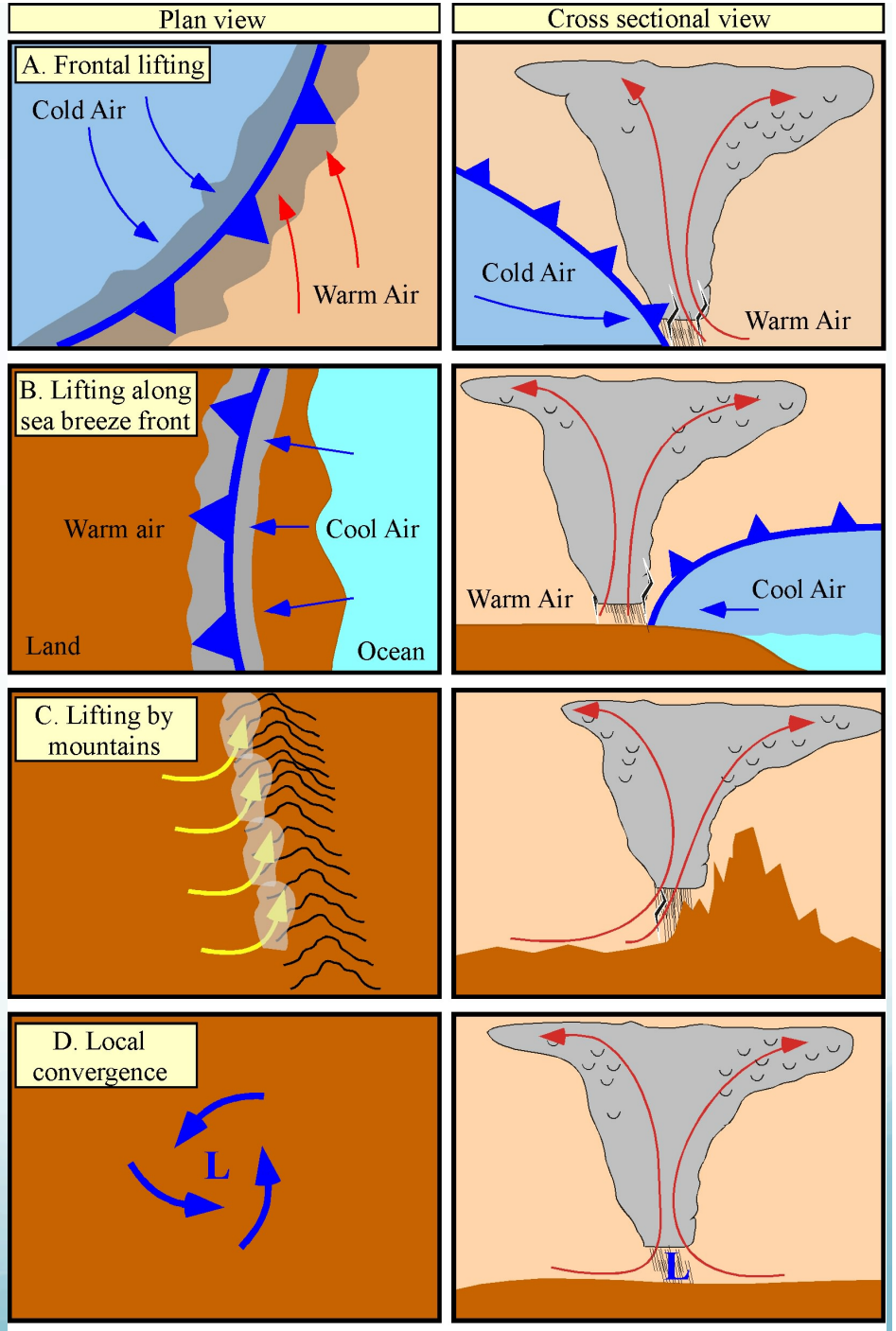
Convection: an air parcel rising buoyantly because it is warmer than its environment

- What happens to the relative humidity of an unsaturated air parcel as it is lifted?
- **Lifting condensation level**: the level where condensation first occurs as an air parcel is lifted (where the relative humidity of the air parcel becomes 100%)
- **Level of free convection**: the level where an air parcel first becomes buoyant (warmer than its environment)



Lifting mechanisms

- How are air parcels lifted?
  - Along fronts
    - Due to temperature difference which creates air density difference
  - By mountains
    - Physical barrier pushes air up
  - By convergence of air
    - At the surface, the air cannot go down, so must go up



Ingredients for a cloud

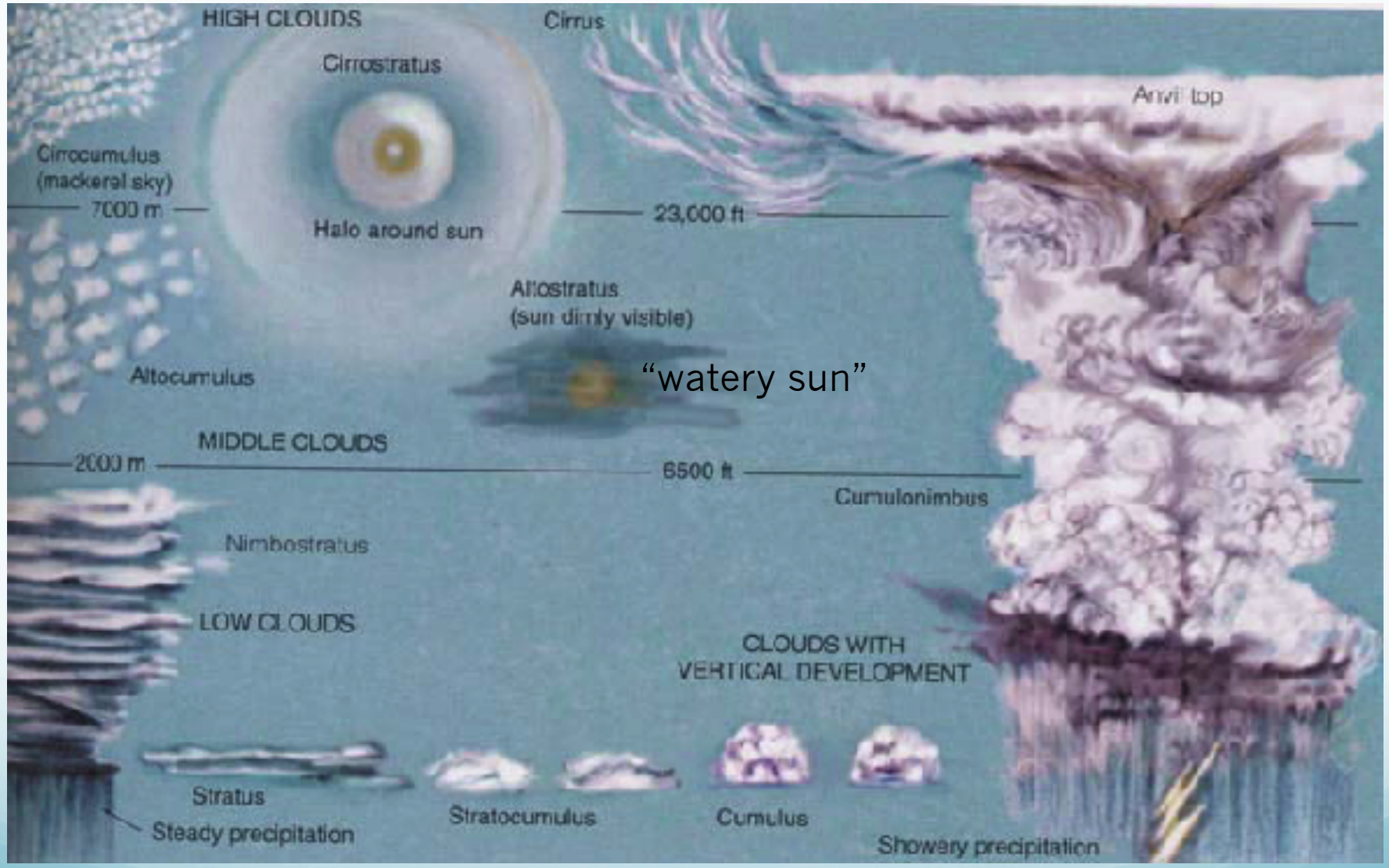
- **Water vapor**
- **Saturation**
  - How do we achieve saturation in the atmosphere with respect to making clouds?
    - Cooling to the dew point
  - How do we cool an air parcel to the dew point?
    - By lifting an air parcel! As the parcel rises, it cools adiabatically
    - Overnight cooling at the surface can lead to fog
- 3rd ingredient needed?
  - **Cloud Condensation Nuclei!**
  - Aerosols, small particles in the atmosphere
    - From pollution, dust, sea salts from oceans, etc.

Clouds

- Clouds form when an air parcel is lifted to the lifting condensation level and condensation occurs
- There are four basic types of clouds based on Latin words:
  - Stratus: layered cloud
    - “spread out”
  - Cumulus: puffy (cotton ball) cloud
    - “heap”
  - Cirrus: wispy cloud
    - “curl of hair”
  - Nimbus: raining cloud
    - “rain cloud” or “rain storm”

Cloud categories

- There are also four categories based on height, vertical development, and appearance
  - **Low** (0-2 km): stratus, stratocumulus, nimbostratus
  - **Middle** (2-6 km): altostratus, altocumulus
  - **High** (>6 km): cirrus, cirrostratus, cirrocumulus
  - **Vertically developed**: cumulus, cumulonimbus
- Cumuliform clouds occur more in unstable environments when the air parcels undergo a lot of vertical motion
- Stratiform clouds occur in more stable environments



A cumulonimbus cloud is a thunderstorm!

Clicker Question

- Air parcels can be lifted by:
  A. Cold air displacing warmer air along a front
  B. As air blows up against mountains
  C. As air diverges at the surface
  D. All of the above
  E. Only a and b

Clicker Question

- A cumulonimbus cloud would form in a(n) _____ environment and by definition _____.
  A. Stable, is precipitating
  B. Stable, is NOT precipitating
  C. Unstable, is precipitating
  D. Unstable, is NOT precipitating

Clicker Question

- The appearance of a “watery sun” through a cloud is an indication that the cloud type is:
  A. Cumulus
  B. Stratus
  C. Cirrostratus
  D. Altostratus
  E. Nimbostratus

Clicker Question

- Thin, high, wispy clouds are called:
  A. Cumulus
  B. Stratus
  C. Cirrus
  D. Nimbus