

Atmospheric stability

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Definition caution for meteorology majors!

The atmospheric has two general types of instabilities:

- *Fluid flow instabilities* (not discussed here, but relevant to tropical waves, eyewall mesovortices, baroclinic cyclones, turbulence, wave breaking (ocean or atmosphere), hydraulic jumps, etc.)
- *Parcel instability* (this lecture)

Parcel stability concepts are also known as “static stability”, “gravitational stability”, and “buoyant stability.”

In this lecture, the generic term “stability” is used for parcel stability.

Distinction cited here simply to avoid confusion in future meteorology classes.

General analogy of stability:

A ball is displaced

Stable – returns to its original position

Unstable – accelerates away from its position

Neutral – no acceleration, but will not return to original location. Assuming enough friction, will go to new location and stop; otherwise, it continues at same speed and direction until it encounters a stable or unstable situation.

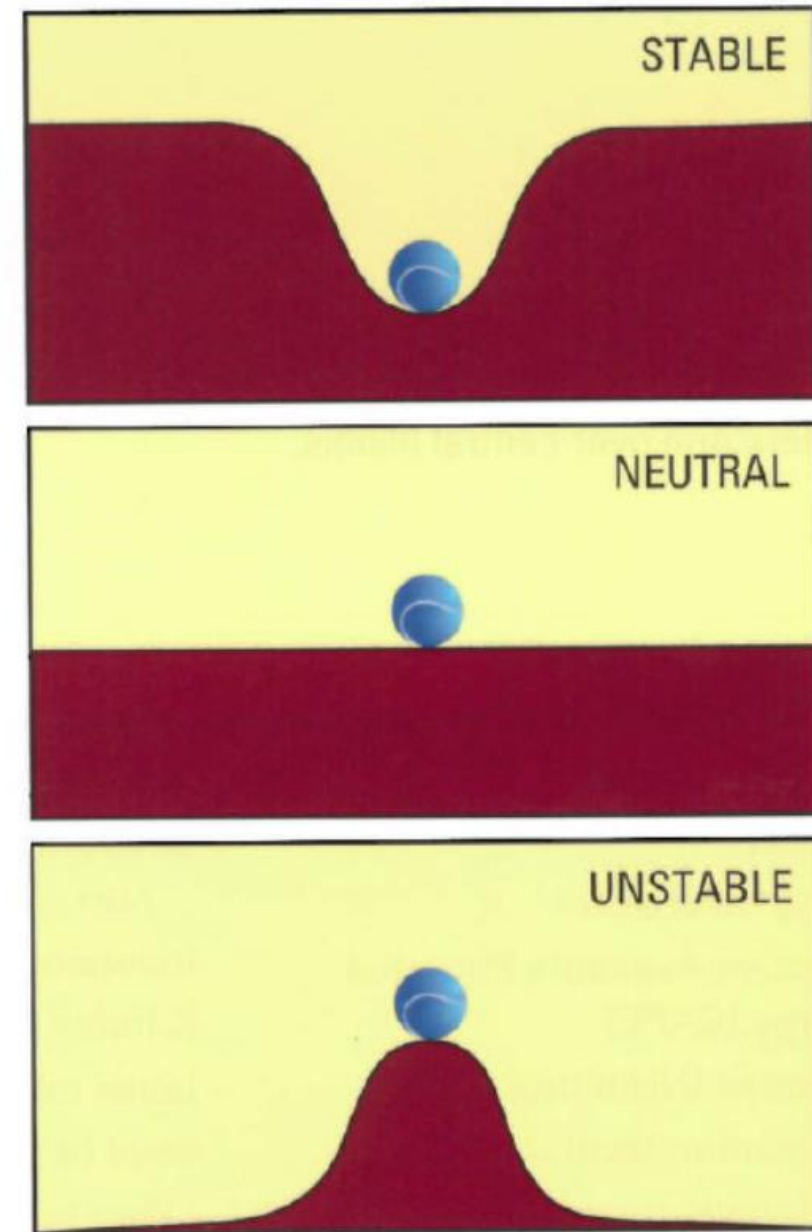


FIGURE 6.1 Stable, neutral, and unstable positions of a ball on a smooth surface.

Essence of chapter:

Instability – when a lifted air parcel accelerates upwards if its **less dense than its environment**. The parcel is buoyant.

A **stable** process is the opposite – a lifted air parcel is **denser than its environment**, resists vertical motion, and will return to its original location if possible.

Second main point: if an otherwise stable lifted parcel changes from a gaseous to liquid state (condensation), under certain environmental conditions, the parcel will become unstable.

In these specific conditions, latent heat release makes the formerly denser parcel warmer than the environment. It is now unstable. This is known as **conditional instability**. It's “conditional” in that **an unsaturated parcel is stable, but a saturated parcel is unstable**.

Building blocks for understanding stability

- The air parcel concept
- Understanding the adiabatic process, and why molecular movement in a parcel changes when lifted.
These changes in molecular motion translate to temperature changes even if unsaturated
- Computing parcel temperature changes when lifted (both unsaturated and saturated)
- The definition of *lapse rate*
- Categories of unstable, conditionally unstable, and stable using lapse rates
- Lifting mechanisms

We'll include in-class exercises and an animation for clarification of concepts

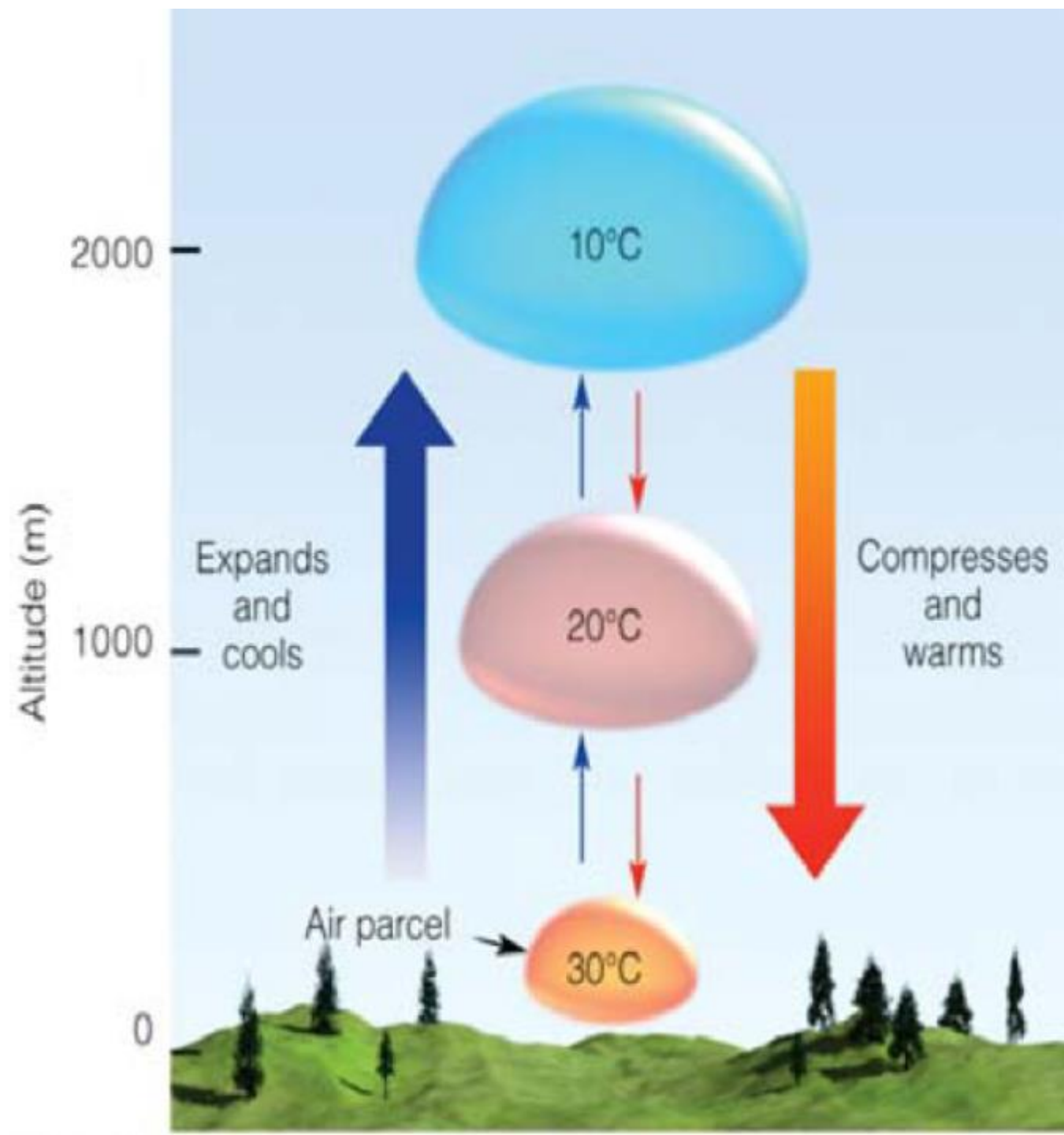
Density is awkward. What else can be used?

Temperature

- For a given pressure, temperature is inversely proportional to density
- Translation – warm air is less dense than cold air
- Unstable – air parcel warmer than environment
- Stable – air parcel colder than environment

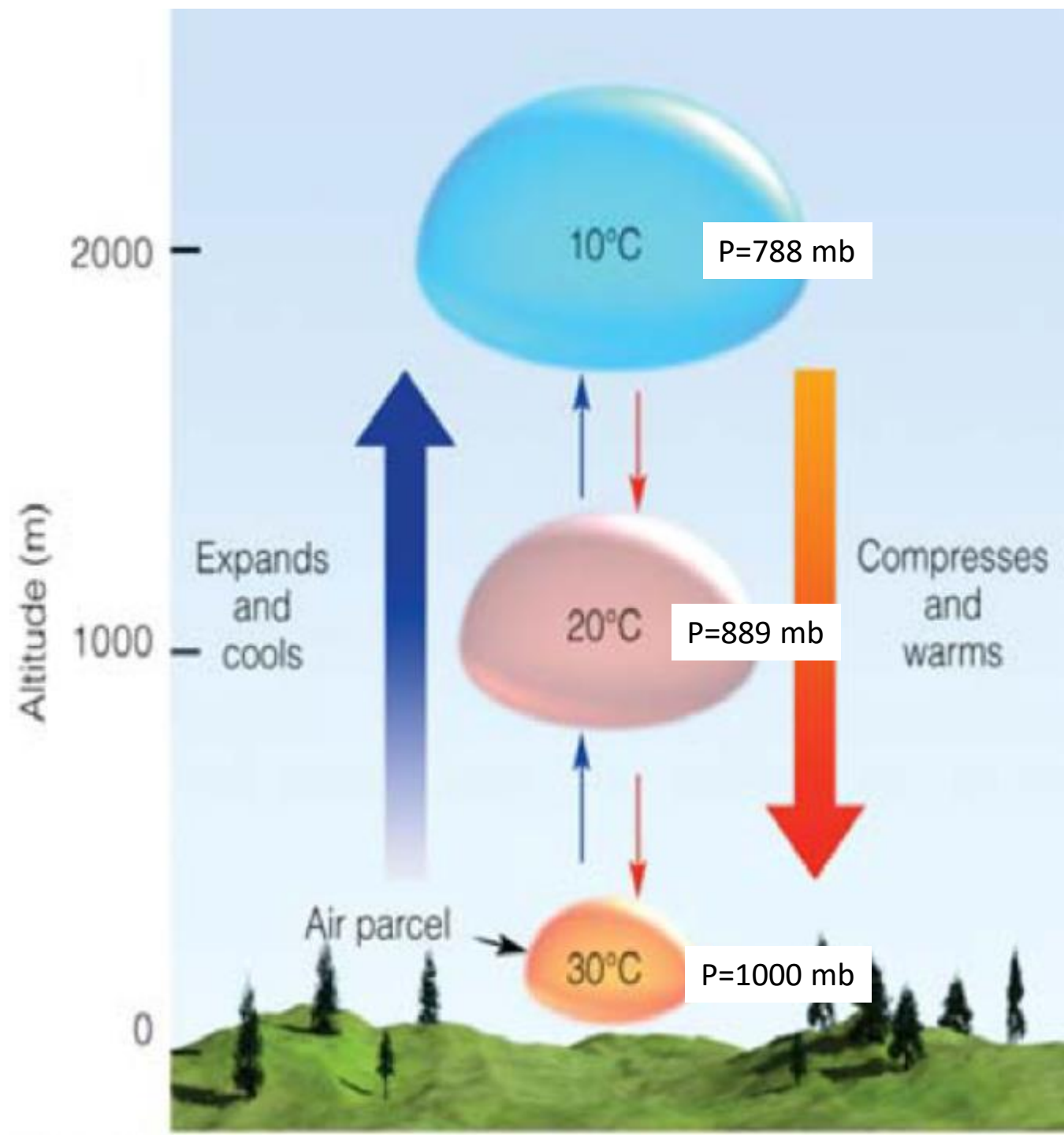
Air parcel concept

- Imagine a bubble of rising air insulated from its environment
- No heat is added or removed from the parcel. This is called an **adiabatic process**.
- Yet, the parcel's temperature decreases as it rises. Why?



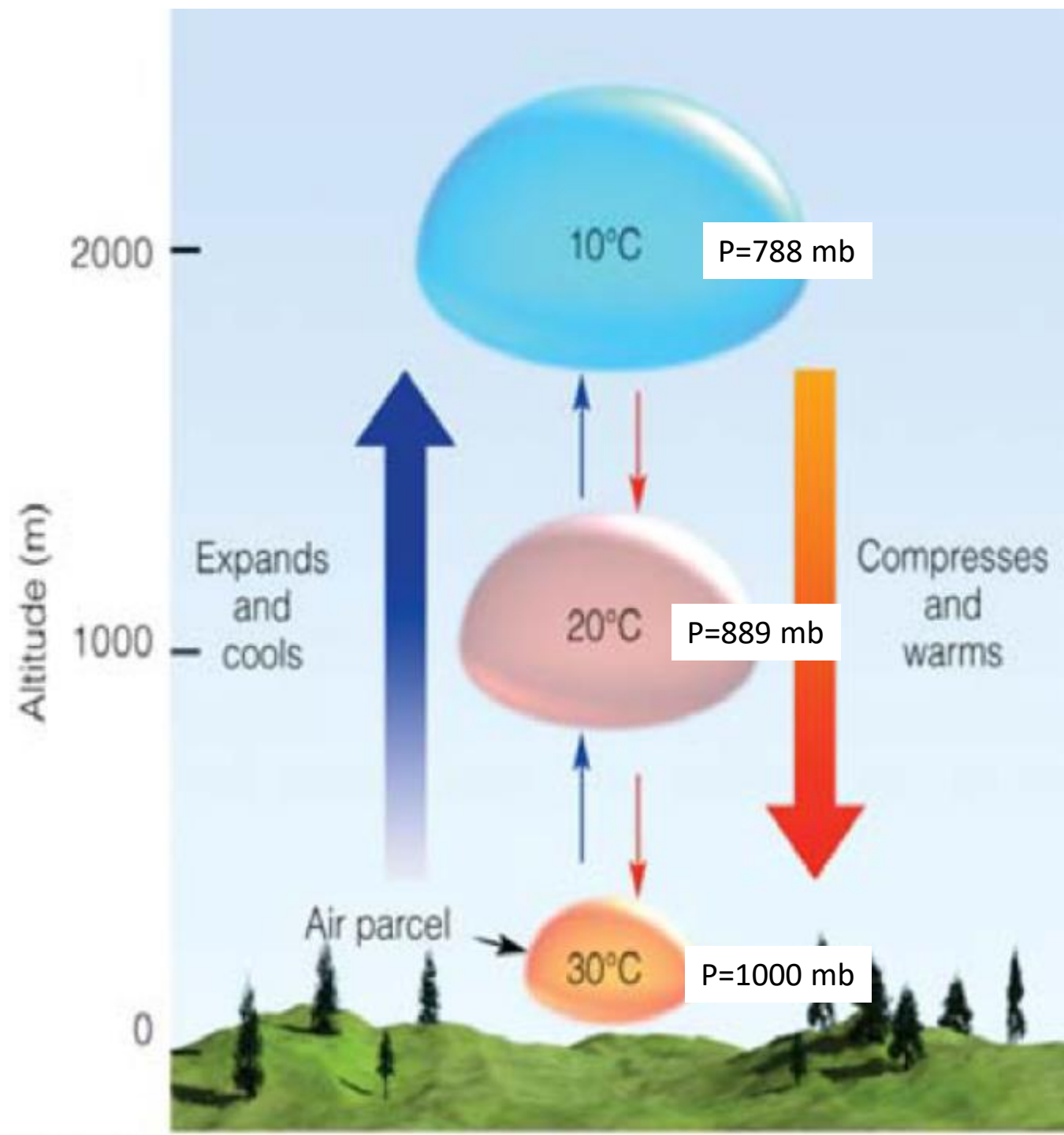
Parcel temperature changes as outside pressure changes

- Parcel expands since pressure decreases with height
- Air molecules “push” out the parcel’s walls
- Some of the kinetic energy of the parcel’s molecules is used in this process
- The average kinetic energy decreases
- Temperature is related to average kinetic energy
- Hence, the parcel’s temperature decreases as a parcel ascends, even though no heat is added or removed from it. Often called expansion cooling
- See discussion on pg 107 on letting air out of tire



Parcel temperature changes as outside pressure changes

- Note sinking air warms
- Environment “pushes” on parcel’s walls
- Parcel’s average kinetic energy increases
- Subsidence warms an air parcel. Also called compression warming



Definition of lapse rate

- Lapse rate – the rate temperature changes with height
- Has units °C/km
- Environmental Lapse Rate (ELR) – how temperature changes with height outside parcels
 - Varies spatially and hourly
 - Generally environmental temperature decreases between 4°C/km and 9°C/km
 - If *environmental temperature increases with height*, that's known as an *inversion*
 - Measured by balloons from NWS offices, supplemented by satellite estimates
- Dry Adiabatic Lapse Rate (DLR) – the rate unsaturated parcels cool with height
 - This is a constant
 - Lifted parcels cool at 10°C/km
 - Sinking parcels warm at 10°C/km
 - Not really “dry”, but unsaturated
- Moist Adiabatic Lapse Rate (MLR) – the rate saturated parcels cool with height
 - This is NOT a constant.
 - For simplicity, in this lecture only, assume lifted saturated parcel cools at 6°C/km
 - Latent heat release is 4°C/km. Hence, $MLR = DLR - \text{latent heat release} = 10 - 4 = 6^\circ\text{C/km}$
 - The latent heat release partially offsets the parcel's adiabatic expansion cooling.
 - Assumes all condensate falls out of lifted parcel
 - This means sinking parcels always warm at dry adiabatic rate!

Parcel exercises

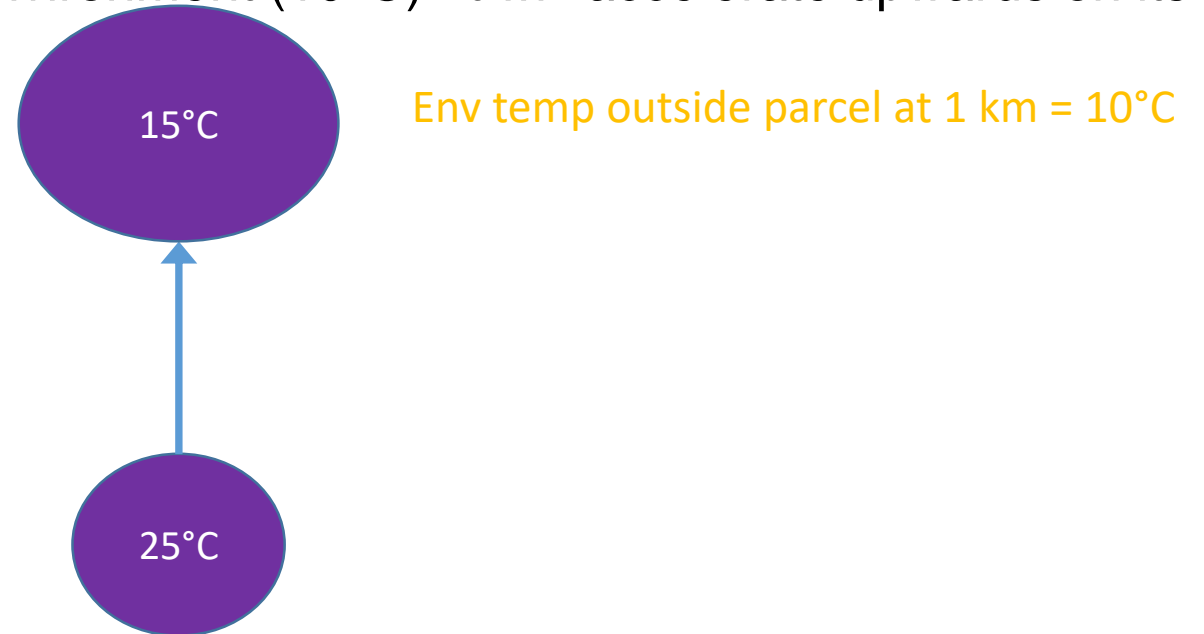
- A parcel with surface temperature of 25°C is lifted 1 km. It remains unsaturated while lifted.
- What is the temperature at 1km?

Parcel exercises

- A parcel with surface temperature of 25°C is lifted 1 km. It remains unsaturated while lifted.
- What is the temperature at 1km?
- 15°C (from 25°C - 10°C)
- The temperature outside the parcel at 1 km is 10°C. Is the parcel stable or unstable?

Parcel exercises

- A parcel with surface temperature of 25°C is lifted 1 km. It remains unsaturated while lifted.
- What is the temperature at 1km?
- 15°C (from 25°C - 10°C)
- The temperature outside the parcel at 1 km is 10°C. Is the parcel stable or unstable?
- Unstable. The parcel is warmer (15°C) than the environment (10°C). It will accelerate upwards on its own buoyancy without the need for further lift.



Likewise, if the temperature outside the parcel at 1 km is 20°C, the parcel is stable. The parcel resists lifting and will return to its original position....unless forced by an external lifting mechanism.

Parcel exercises

- A parcel has a surface temperature of 25°C and is saturated. It is lifted 1 km.
- What is the temperature at 1km?

Parcel exercises

- A parcel has a surface temperature of 25°C and is saturated. It is lifted 1 km.
- What is the temperature at 1km?
- 19°C (from $25^{\circ}\text{C} - 6^{\circ}\text{C}$)
- The temperature outside the parcel at 1 km is 20°C . Is the parcel stable or unstable?

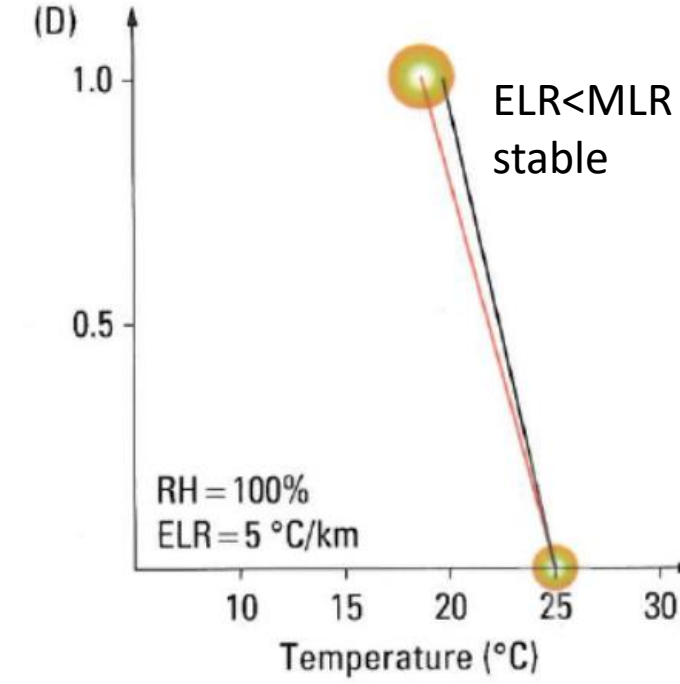
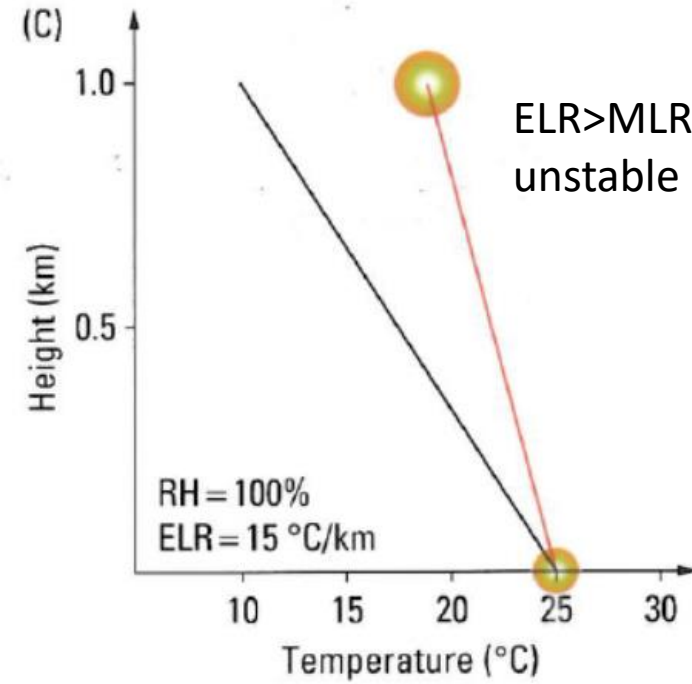
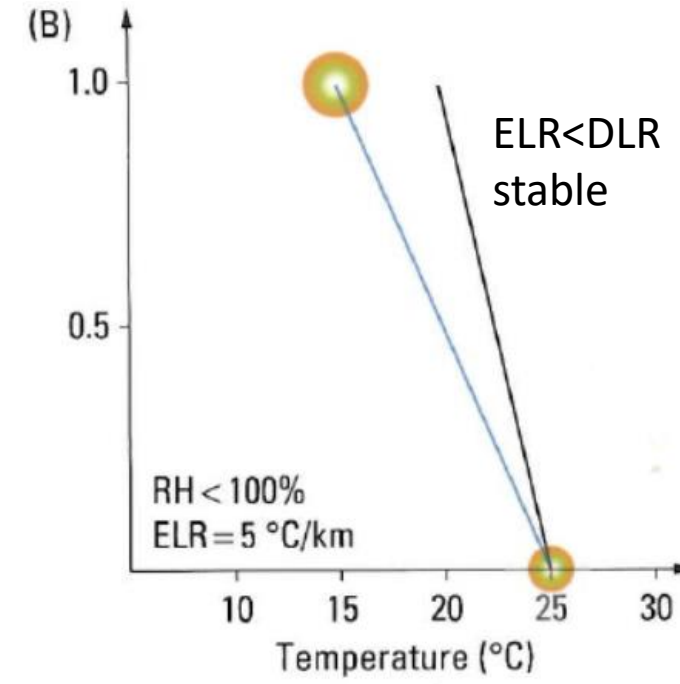
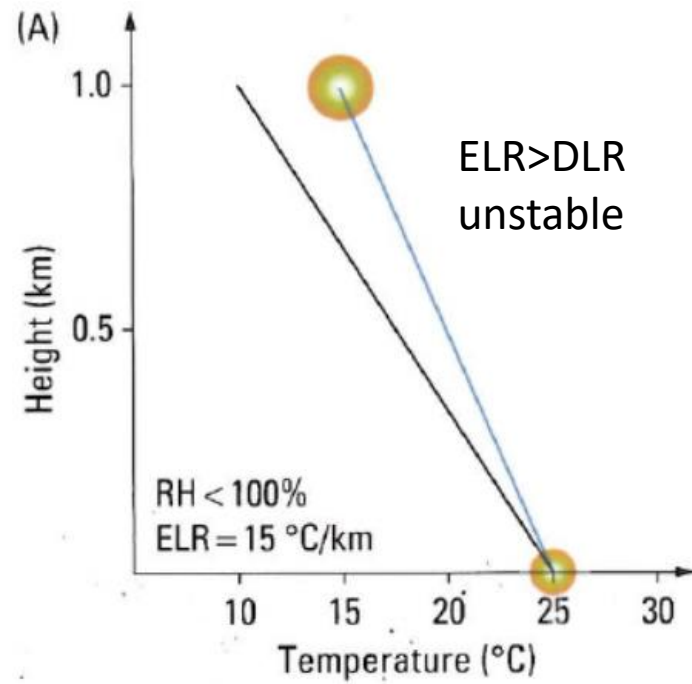
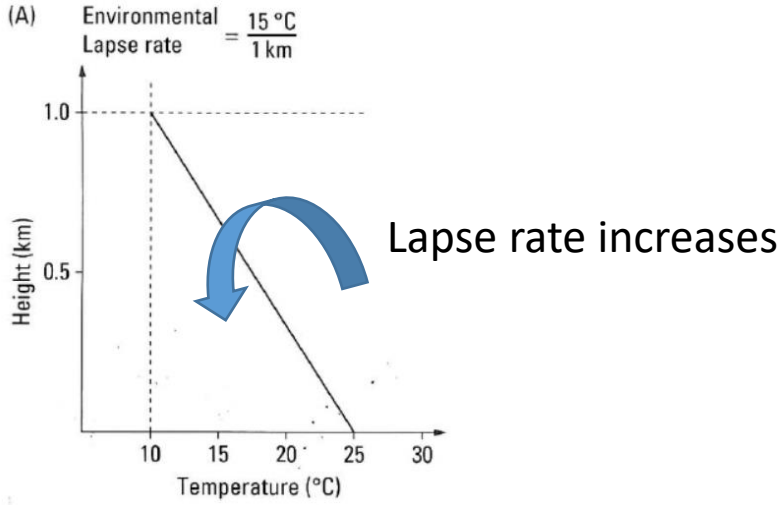
Parcel exercises

- A parcel has a surface temperature of 25°C and is saturated. It is lifted 1 km.
- What is the temperature at 1km?
- 19°C (from 25°C - 6°C)
- The temperature outside the parcel at 1 km is 20°C. Is the parcel stable or unstable?
- Stable. The parcel is cooler (19°C) than the environment (20°C).



These are the same exercises as Fig. 6.5, without the lapse rate graphics

Stability examination using lapse rates



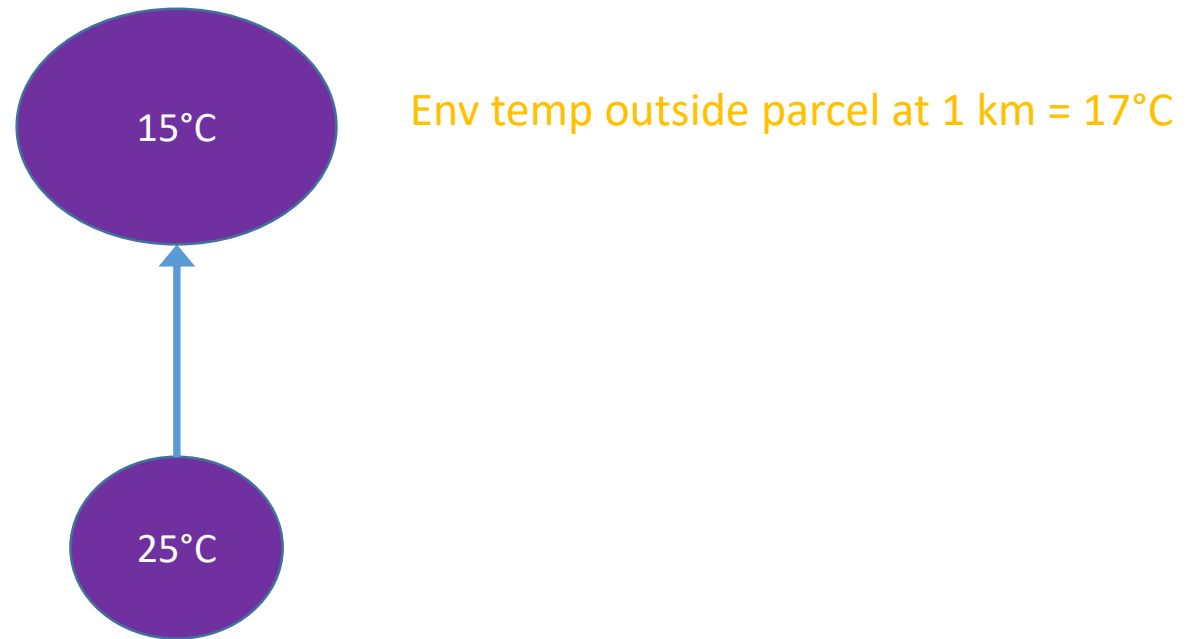
If unsaturated, compare slopes of ELR and DLR

If saturated, compare slopes of ELR and MLR

Saturated is when $\text{RH} = 100\%$

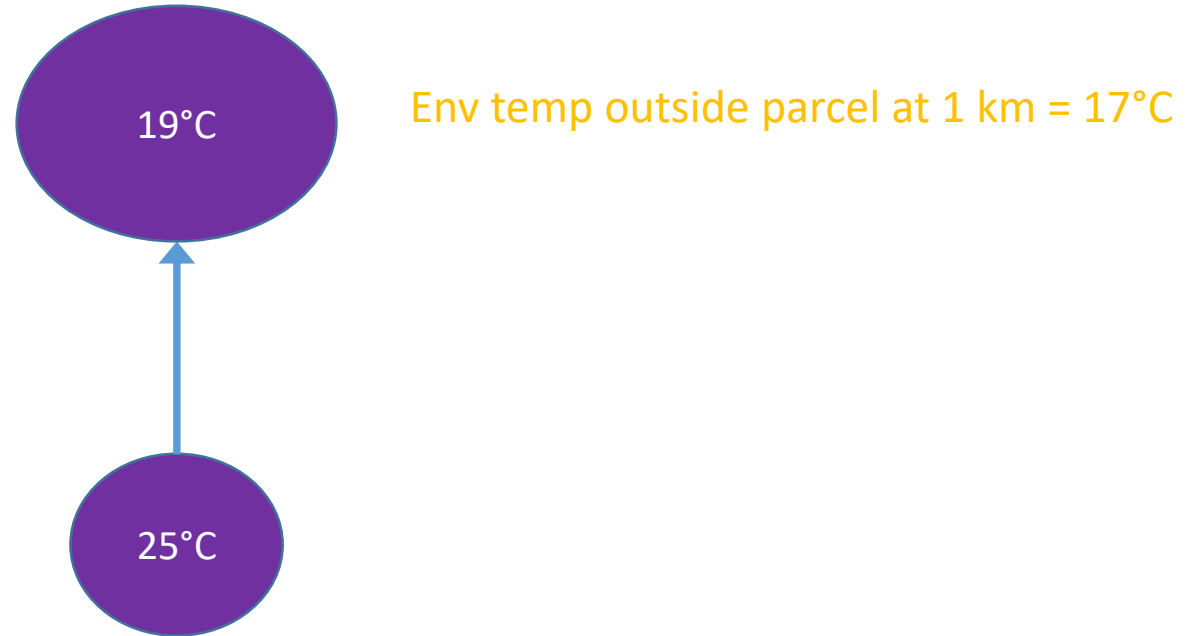
Parcel exercises

- Surface parcel of 25°C is lifted 1 km and remains unsaturated. At 1 km its temperature is 15°C.
- The temperature outside the parcel at 1 km is 17°C. The parcel is **stable**.
- The parcel is cooler (15°C) than the environment (17°C).



Parcel exercises

- Surface parcel of 25°C is lifted 1 km and is saturated. At 1 km its temperature is 19°C.
- The temperature outside the parcel at 1 km is 17°C. The parcel is **unstable**.
- The parcel is warmer (19°C) than the environment (17°C).



Conditional instability

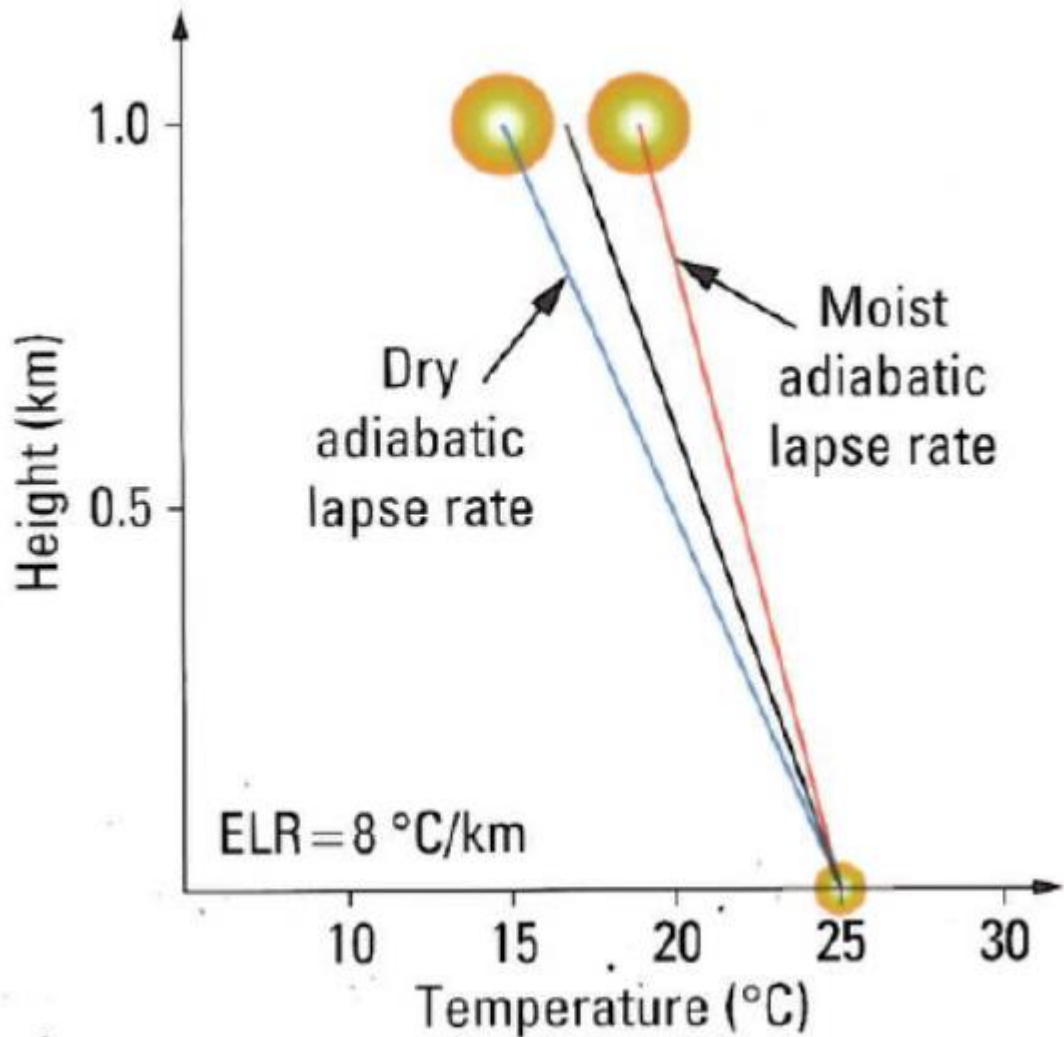
- A lifted unsaturated parcel is stable.
- A lifted saturated parcel is unstable.

Quick thought questions

- What physical process is making the distinction in conditional instability?
- Why does temperature decrease in parcels without heated added or removed from system?
- Is an inversion a stable or unstable situation?

Counterintuitive discussion – how can an inversion contribute to severe thunderstorms? (“Loaded gun” concept; also called a “goal post” signature). See pg 118.

Conditional instability examination using lapse rates



$DLR > ELR > MLR$

Conditionally unstable

Terms for levels of cloud formation and buoyancy

Lifting Condensation Level (LCL) – Level where a lifted air parcel first saturates. “Base of a cloud.”

Level of Free Convection (LFC) – Level where a lifted air parcel is first warmer than its environment. This is where a parcel first becomes buoyant (unstable).

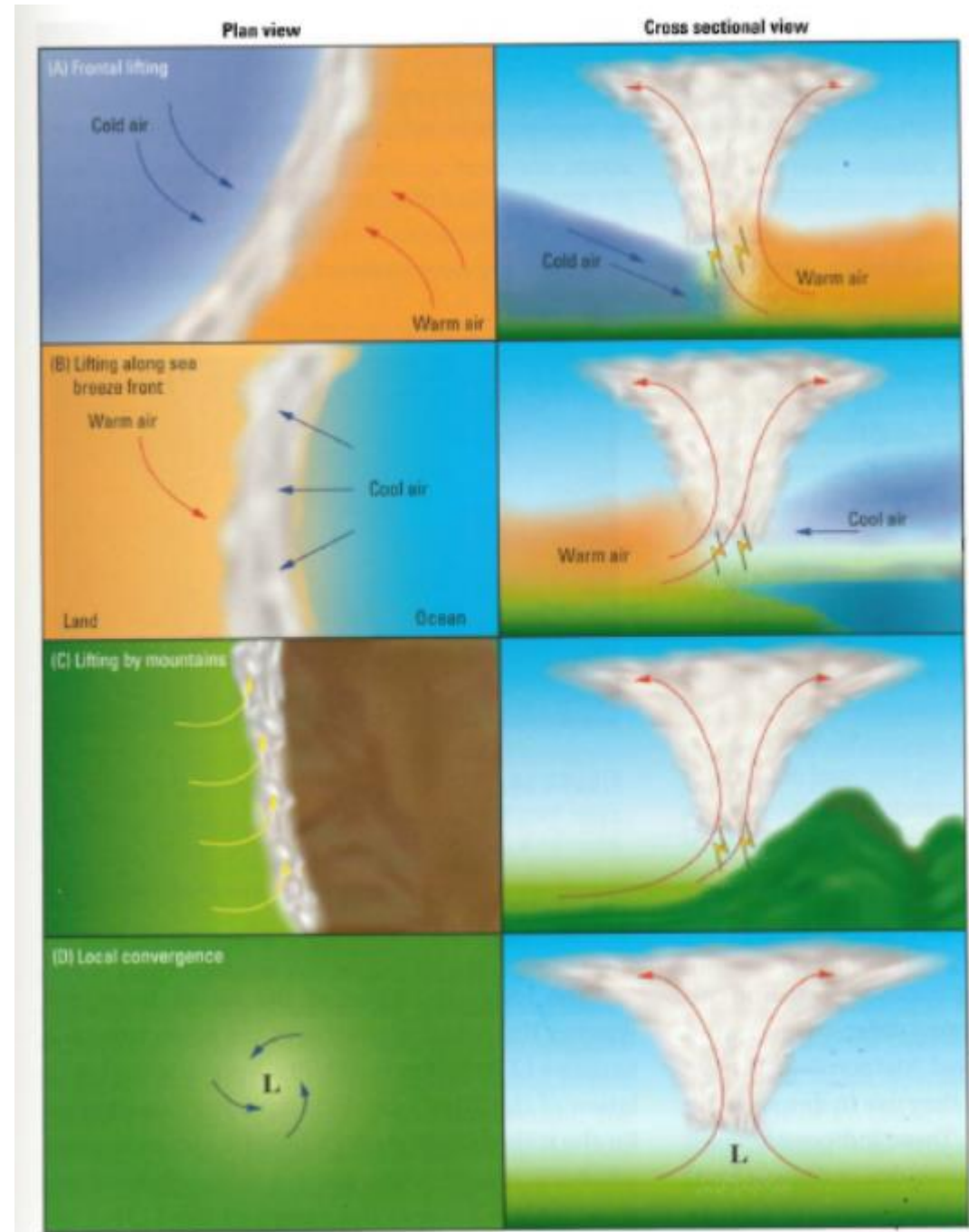
The LCL is NOT necessarily where a parcel first becomes unstable. It often is still cooler than its environment. Usually the LFC is above the LCL. But they can sometimes coincide.

Some kind of external lifting is required for a parcel to reach the LFC. Then, the parcel can accelerate upwards on its own buoyancy. This results in **cumulus clouds**.

If an air parcel has been mechanically lifted to its LCL, but cannot reach its LFC, the result is **stratus clouds** (assuming the lifting continues).

Lifting mechanisms

- Front
 - Sea breeze
 - Mountains
 - Surface convergence
- (not shown)
- Divergence aloft, often from cyclonic vorticity advection aloft (i.e., an “upper-level disturbance”). This is often....but not always, an upper-level trough. We will discuss later this semester.
 - Surface heating



Advanced material

- Meteorologists use thermodynamic charts to determine stability. This will be discussed Wednesday.
- Empirical equations in computer models are often used for terms such as LCL. Other stability equations require iterations. This will be taught in the technically advanced lecture.

Additional material

See <http://weathercsi.net/jsu-class-material.html>