ATMOSPHERIC STABILITY

G.Y. Jayasinghe
EN 11201
BSc inARMT/ GT-2023

LAPSE RATE

- The **lapse rate** is defined as the rate of decrease with height for an atmospheric variable.
- The variable involved is temperature unless specified otherwise

- in general, a lapse rate is the negative of the rate of temperature change with altitude change, thus:
- $\gamma = -dT/dz$
- Where is the lapse rate given in units of temperature divided by units of altitude, *T* = temperature, and *z* = altitude.

Types of lapse-rates

- The **environmental lapse rate** (ELR), is the rate of decrease of temperature with altitude in the stationary atmosphere at a given time and location.
- As an average, the International Civil Aviation Organization (ICAO) defines an international standard atmosphere (ISA) with a temperature lapse rate of 6.49 K(°C)/1,000 m (3.56 °F or 1.98 K(°C)/1,000 Ft) from sea level to 11 km(36,090 ft). From 11 km (36,090 ft or 6.8 mi) up to 20 km (65,620 ft or 12.4 mi), the constant temperature is −56.5 °C (−69.7 °F).

Adiabatic lapse rates

- The adiabatic lapse rates – which refer to the change in temperature of a parcel of air as it moves upwards (or downwards) without exchanging heat with its surroundings. The temperature change that occurs within the air parcel reflects the adjusting balance between potential energy and kinetic energy of the molecules of gas that comprise the moving air mass.
- There are two adiabatic rates:
- Dry adiabatic lapse rate
- Moist (or saturated) adiabatic lapse rate

Dry Adiabatic lapse rate (DALR)

- The **dry adiabatic lapse rate** (DALR) is the rate of temperature decrease with height for a parcel of dry or unsaturated air rising under adiabatic conditions.
- Unsaturated air has less than 100% relative humidity; i.e. its actual temperature is higher than its dew point.
- The term *adiabatic* means that no heat transfer occurs into or out of the parcel. Air has low thermal conductivity, and the bodies of air involved are very large, so transfer of heat by conduction is negligibly small.

DALR (Contd..)

- Under these conditions when the air rises (for instance, by convection) it expands, because the pressure is lower at higher altitudes. As the air parcel expands, it pushes on the air around it, doing work (thermodynamics). Since the parcel does work but gains no heat, it loses internal energy so that its temperature decreases. The rate of temperature decrease is 9.8 °C per 1,000 m (5.38 °F per 1,000 ft) (3.0°C/1,000 ft). The reverse occurs for a sinking parcel of air

SALR

- When the air is saturated with water vapor (at its dew point), the **moist adiabatic lapse rate** (MALR) or **saturated adiabatic lapse rate** (SALR) applies. This lapse rate varies strongly with temperature.
- A typical value is around 5 °C/km (2.7 °F/1,000 ft) (1.5°C/1,000 ft).

- The reason for the difference between the dry and moist adiabatic lapse rate values is that latent heat is released when water condenses, thus decreasing the rate of temperature drop as altitude increases.
-

- This heat release process is an important source of energy in the development of thunderstorms.
- An unsaturated parcel of air of given temperature, altitude and moisture content below that of the corresponding dewpoint cools at the *dry adiabatic lapse rate* as altitude increases until the dewpoint line for the given moisture content is intersected.
- As the water vapor then starts condensing the air parcel subsequently cools at the slower *moist adiabatic lapse rate* if the altitude increases further.

lifting condensation level (LCL)

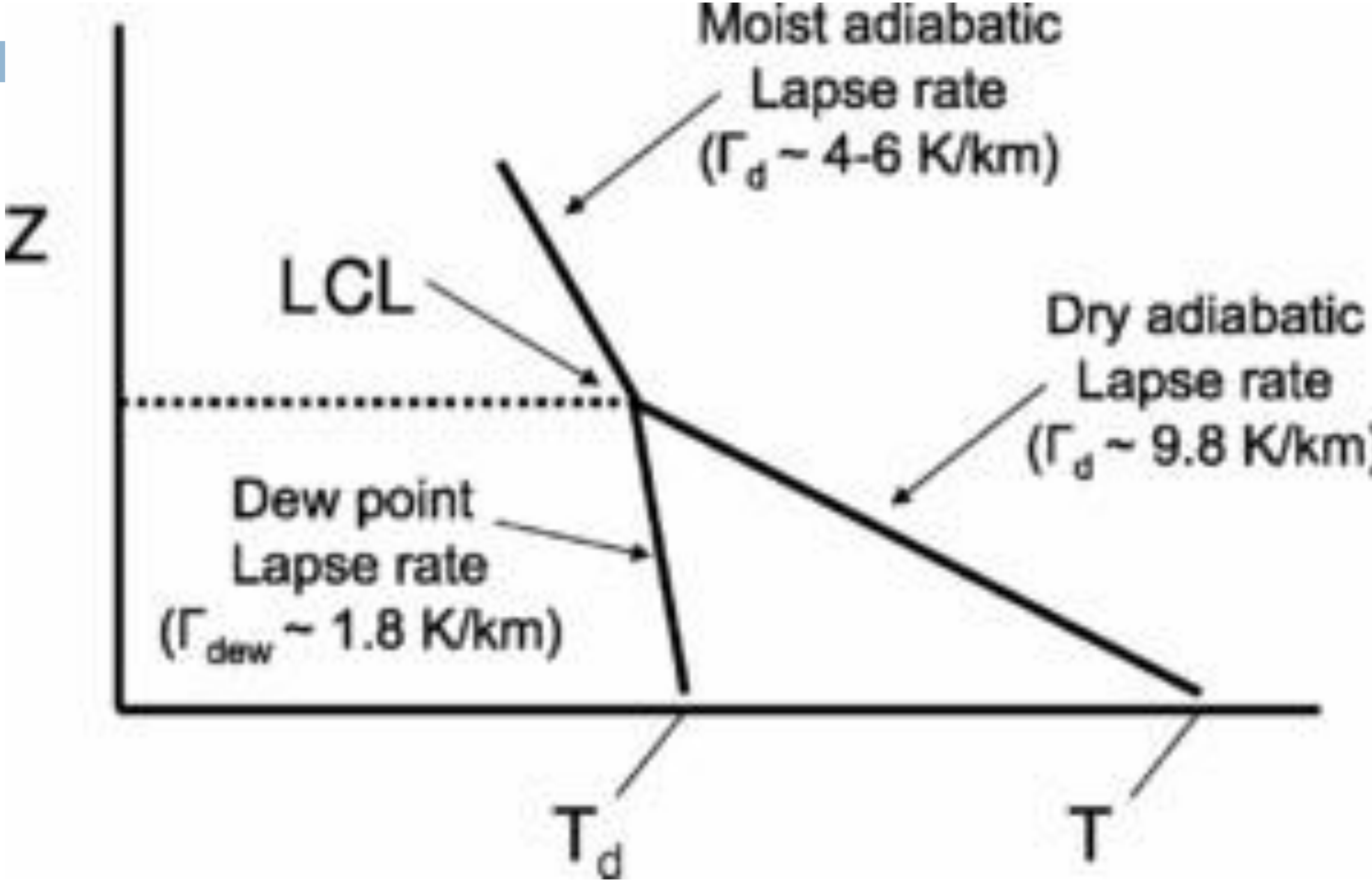
- The lifted condensation level or **lifting condensation level** (LCL) is formally defined as the height at which the relative humidity (RH) of an air parcel will reach 100% when it is cooled by dry adiabatic lifting.
- The RH of air increases when it is cooled, since the amount of water vapor in the air (i.e., its **specific humidity**) remains constant, while the saturation vapor pressure decreases almost exponentially with decreasing temperature. If the air parcel is lifting further beyond the LCL, water vapor in the air parcel will begin condensing, forming cloud droplets.

LCL

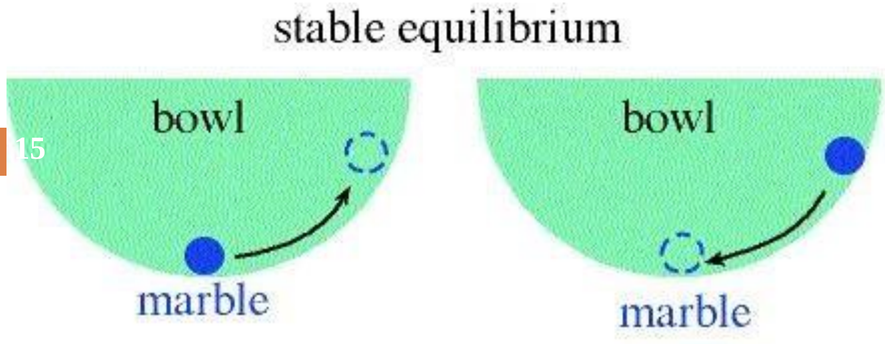
- In the real atmosphere, it is usually necessary for air to be slightly supersaturated, normally by around 0.5%, before condensation occurs; this translates into about 10 meters or so of additional lifting above the LCL. The LCL is a good approximation of the height of the cloud base which will be observed on days when air is lifted mechanically from the surface to the cloud base (e.g., due to convergence of airmasses).

Super saturation

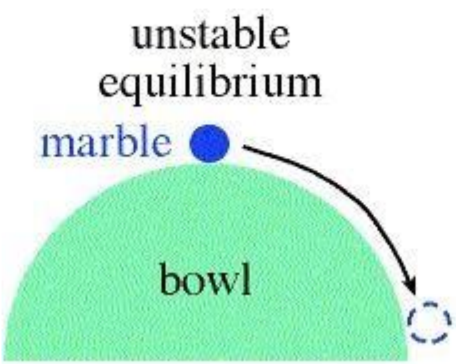
- On Earth, water vapor tends to condense, i.e. turn into a liquid, when the **temperature falls below dew point.** The atmosphere is said to be 'saturated' since it cannot hold any more moisture at that temperature and pressure.
- The excess water vapor then condenses around **suspended particles and dust,** forming precipitation.
- However, condensation may sometimes be much slower, especially when particles and **dust are scarce**. Unable to condense, the excess water vapor therefore remains in the gaseous state: this is known as supersaturation.


Moist adiabatic
Lapse rate
(Γ_d ~ 4-6 K/km)
Z
LCL
Dry adiabatic
Lapse rate
(Γ_d ~ 9.8 K/km)
Dew point
Lapse rate
(Γ_{dew} ~ 1.8 K/km)
T_d
T

Stability



A stable equilibrium: if marble pushed up side of bowl and let go, it will return to original position.



An Unstable equilibrium: if marble on top of bowl receives a push, it will roll off bowl and not return to original position.

How does this relate to the atmosphere? When the atmosphere is stable, a parcel of air will want to return to its original position after being raised or lowered.

When the atmosphere is unstable, a parcel will want to continue on its path away from its original position it pushed upward or downward.

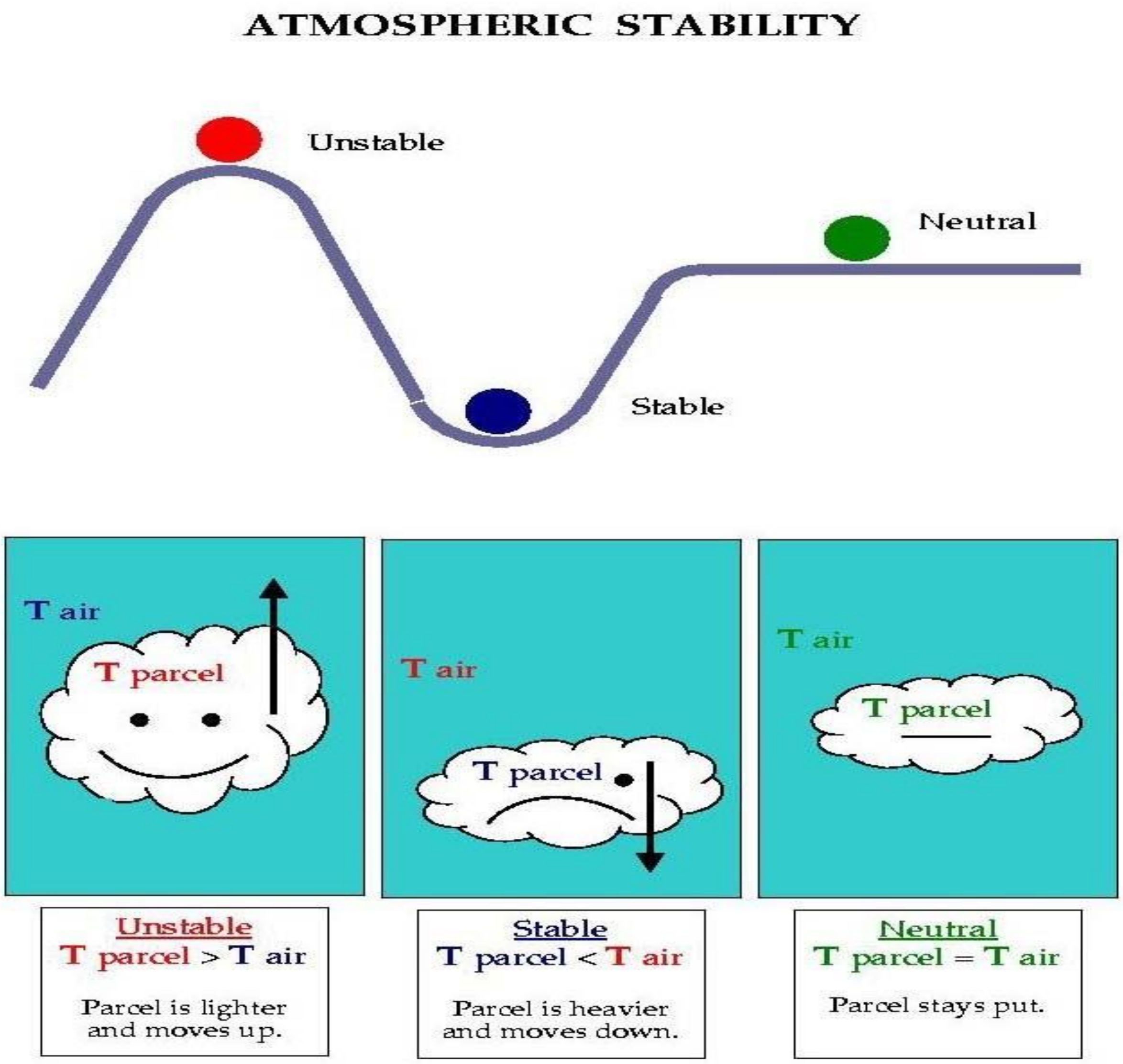
We must compare the parcel's temperature **T_p** with the temperature of the surrounding environment **T_e**.

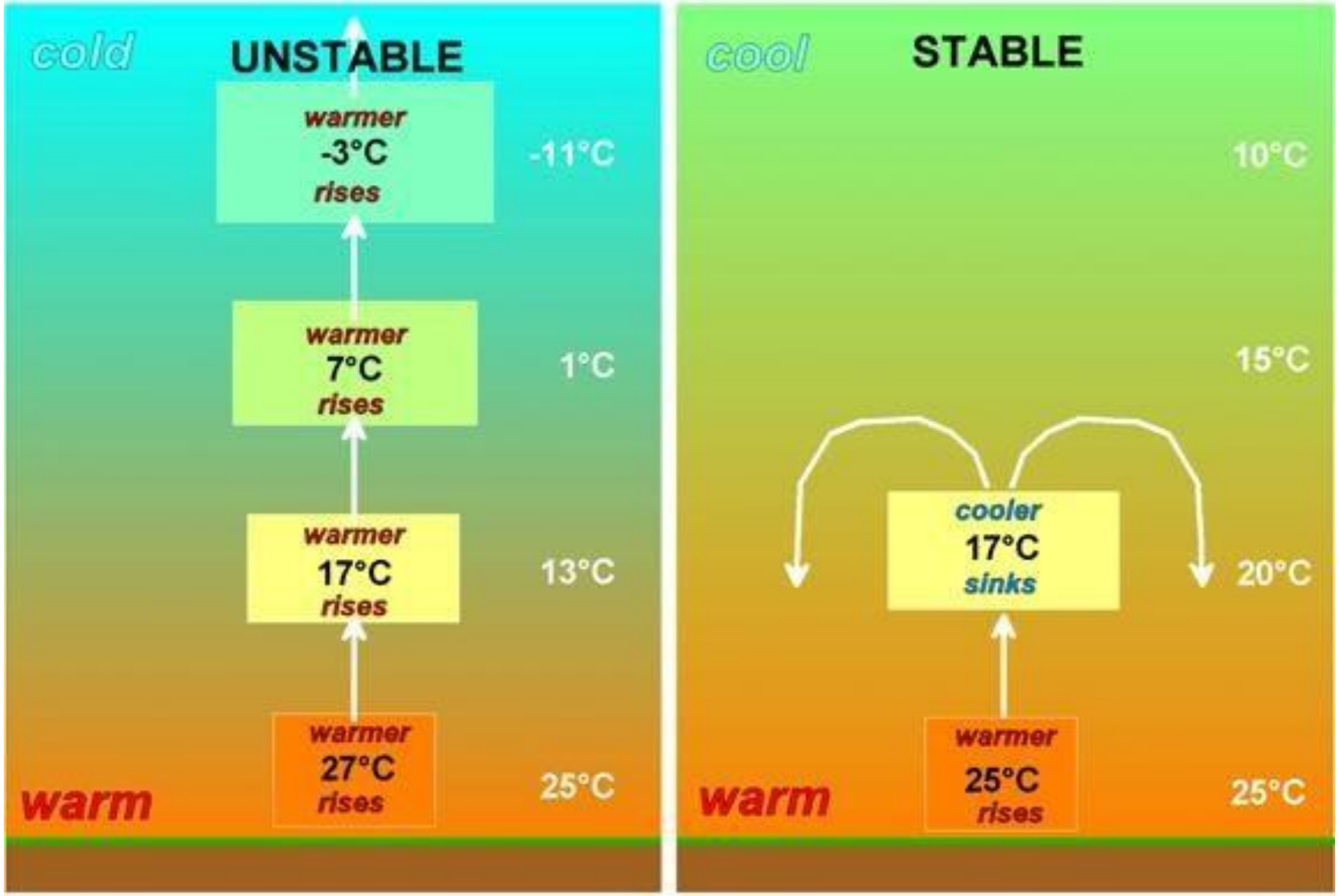
$T_p > T_e$ The parcel is positively buoyant, it is less dense and will rise.

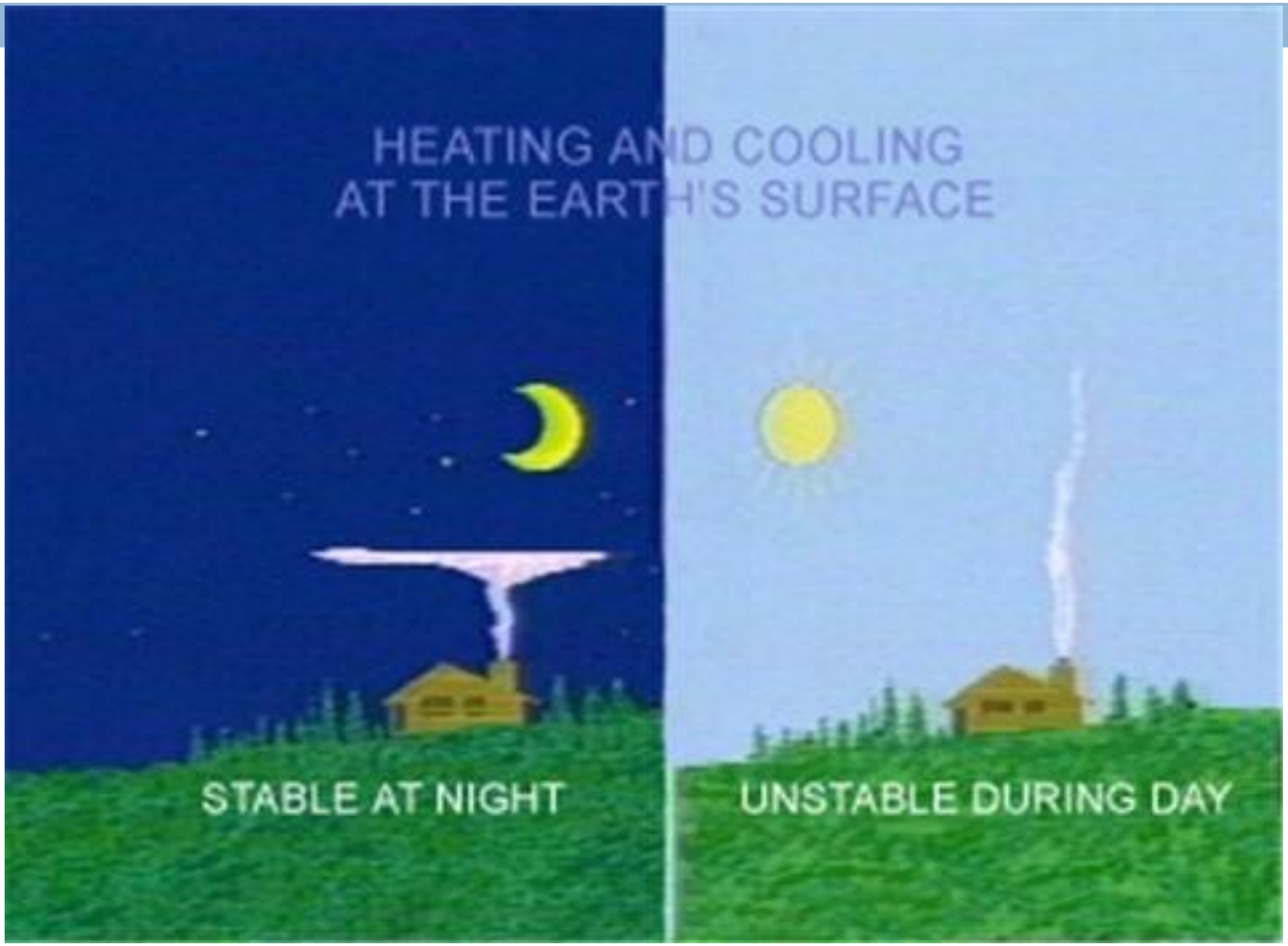
$T_p < T_e$ The parcel is negatively buoyant, it is more dense and will sink.

$T_p = T_e$ The parcel is neutrally buoyant, it will not rise or sink.

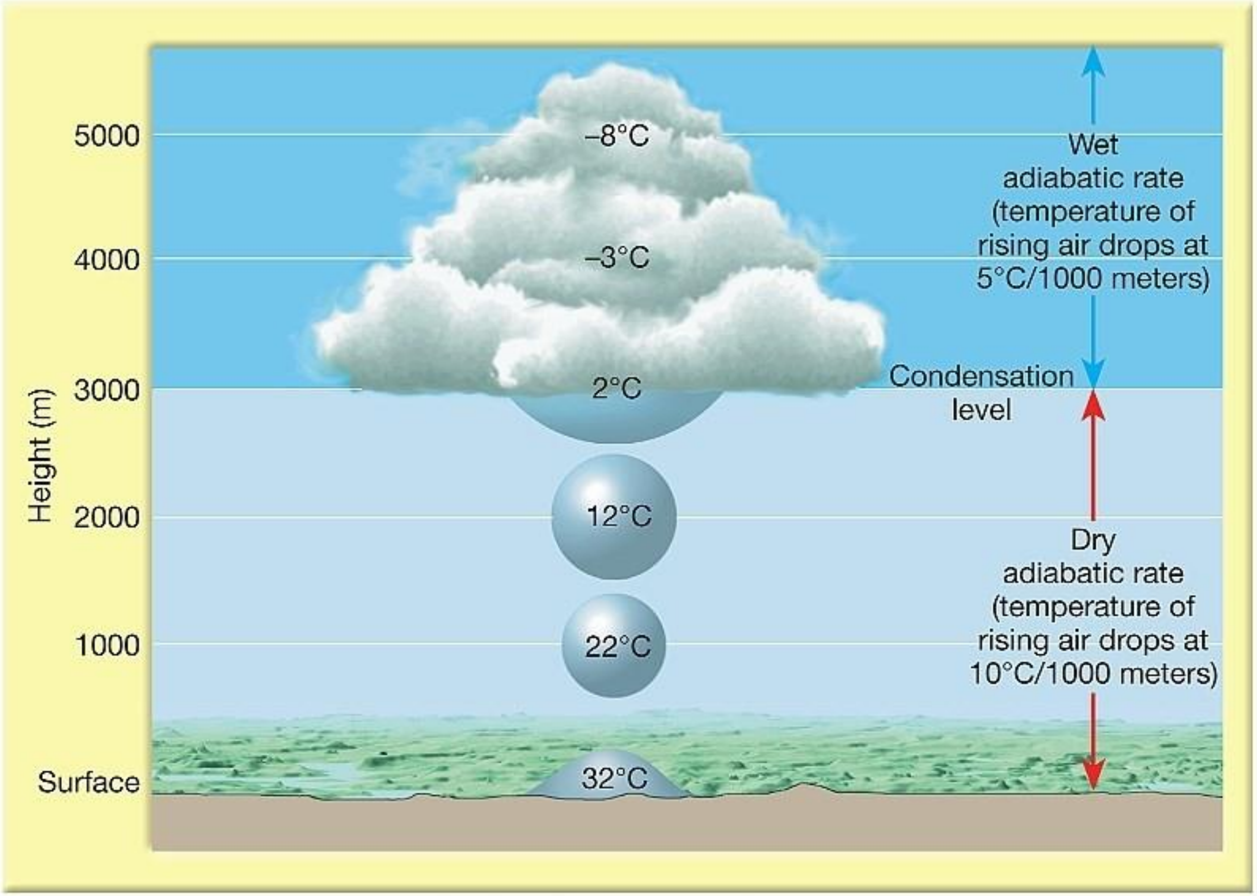
Atmospheric Stability




cold
UNSTABLE
warmer
-3°C
rises
-11°C
warmer
7°C
rises
1°C
warmer
17°C
rises
13°C
warmer
27°C
rises
25°C
warm
cool
STABLE
10°C
15°C
cooler
17°C
sinks
20°C
warmer
25°C
rises
25°C
warm

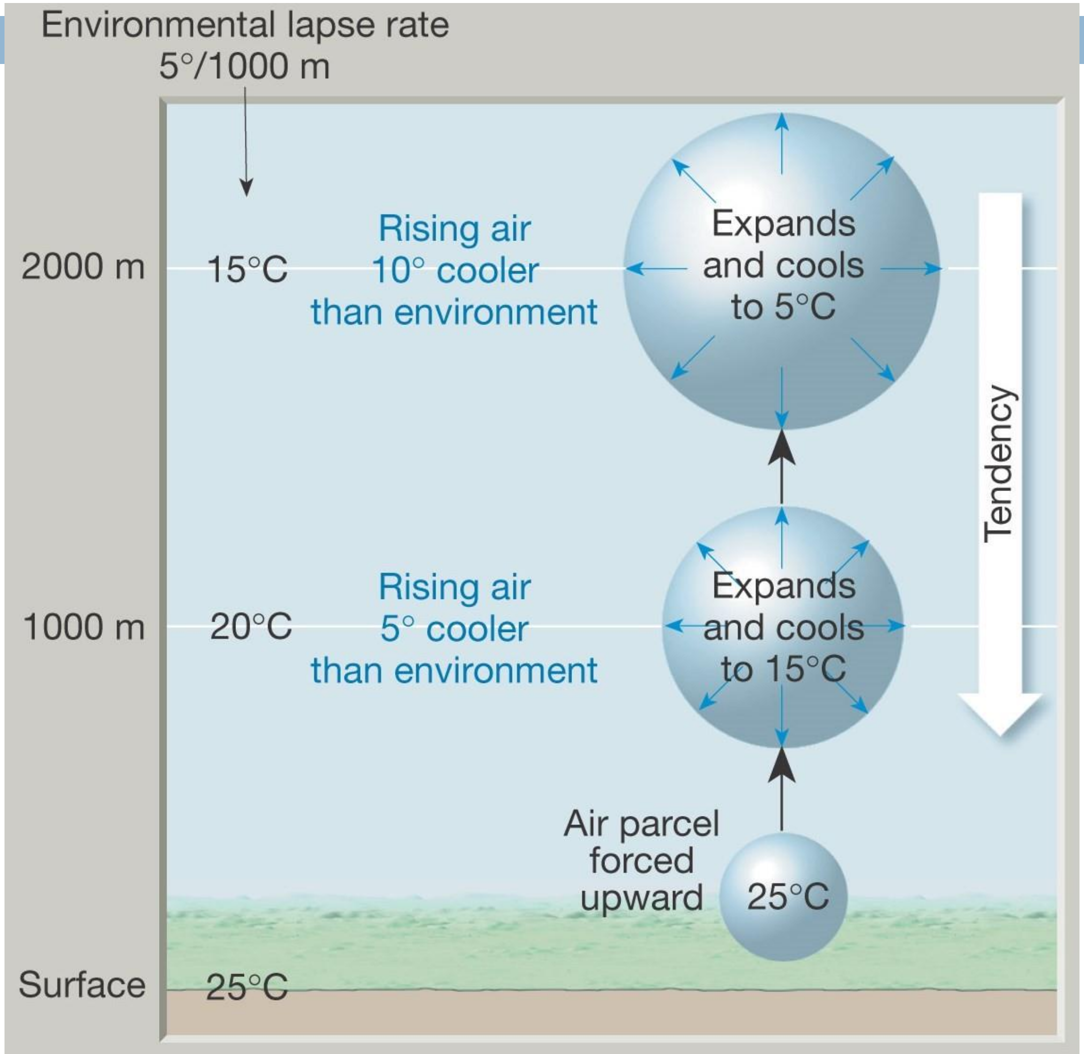

HEATING AND COOLING
AT THE EARTH'S SURFACE
STABLE AT NIGHT
UNSTABLE DURING DAY

Dry vs. Wet Lapse



Static Stability

- Warm air rises
  - How high?
- Cold air sinks
  - How low?
- Environmental vs. adiabatic lapse rates
- Rule:
  - ELR < ALR: stable
  - ELR = ALR: neutral
  - ELR > ALR: unstable

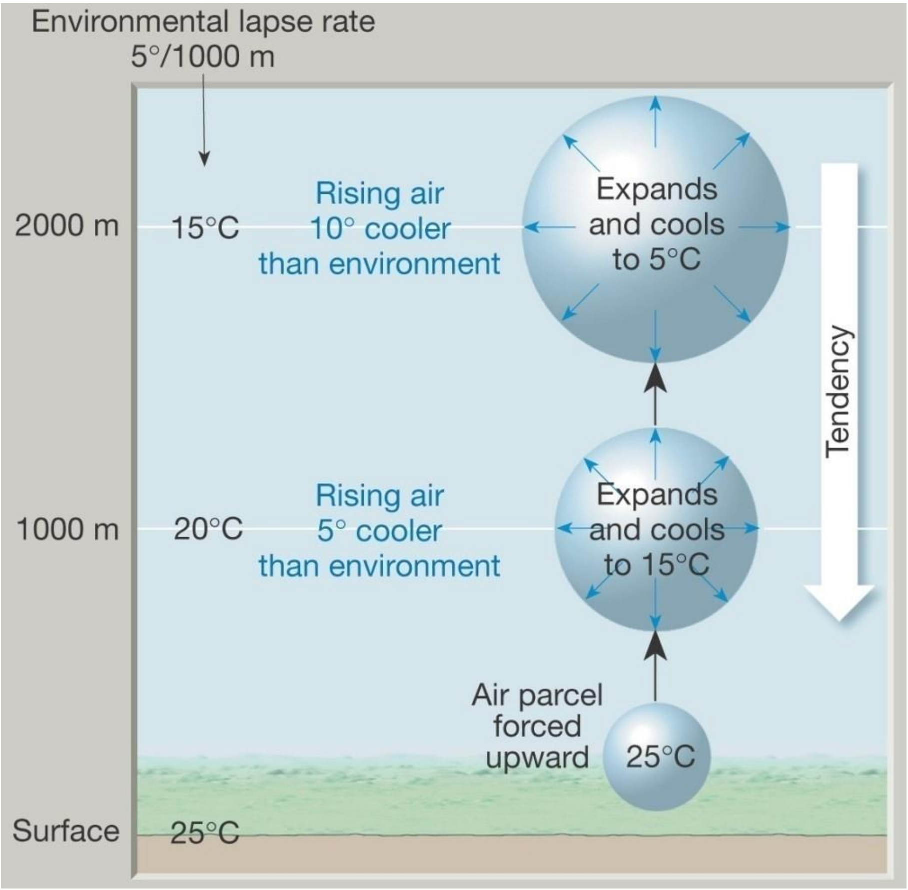


Rule for stability

- ELR < ALR: stable
- ELR > ALR: unstable

Example:

- ALR = 10°C/km
- ELR = 5°C/km
- ELR < ALR: stable

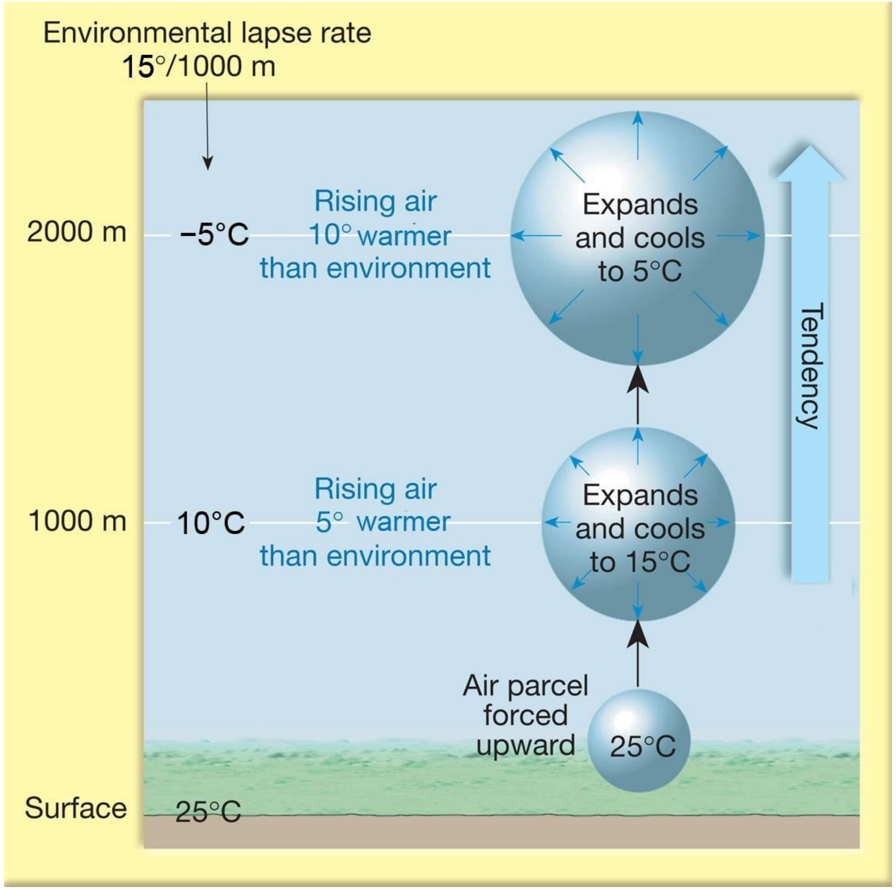


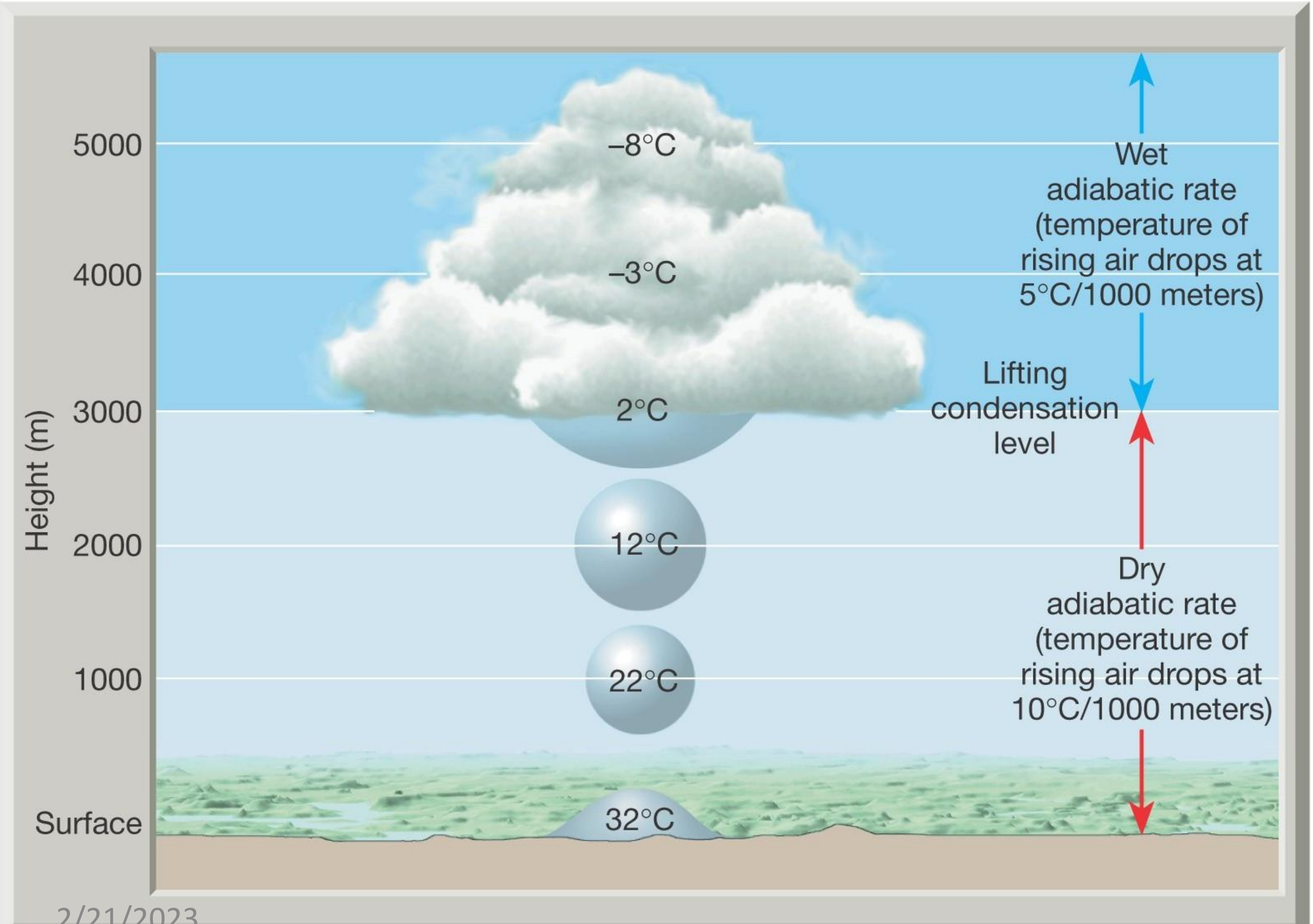
Rule for stability

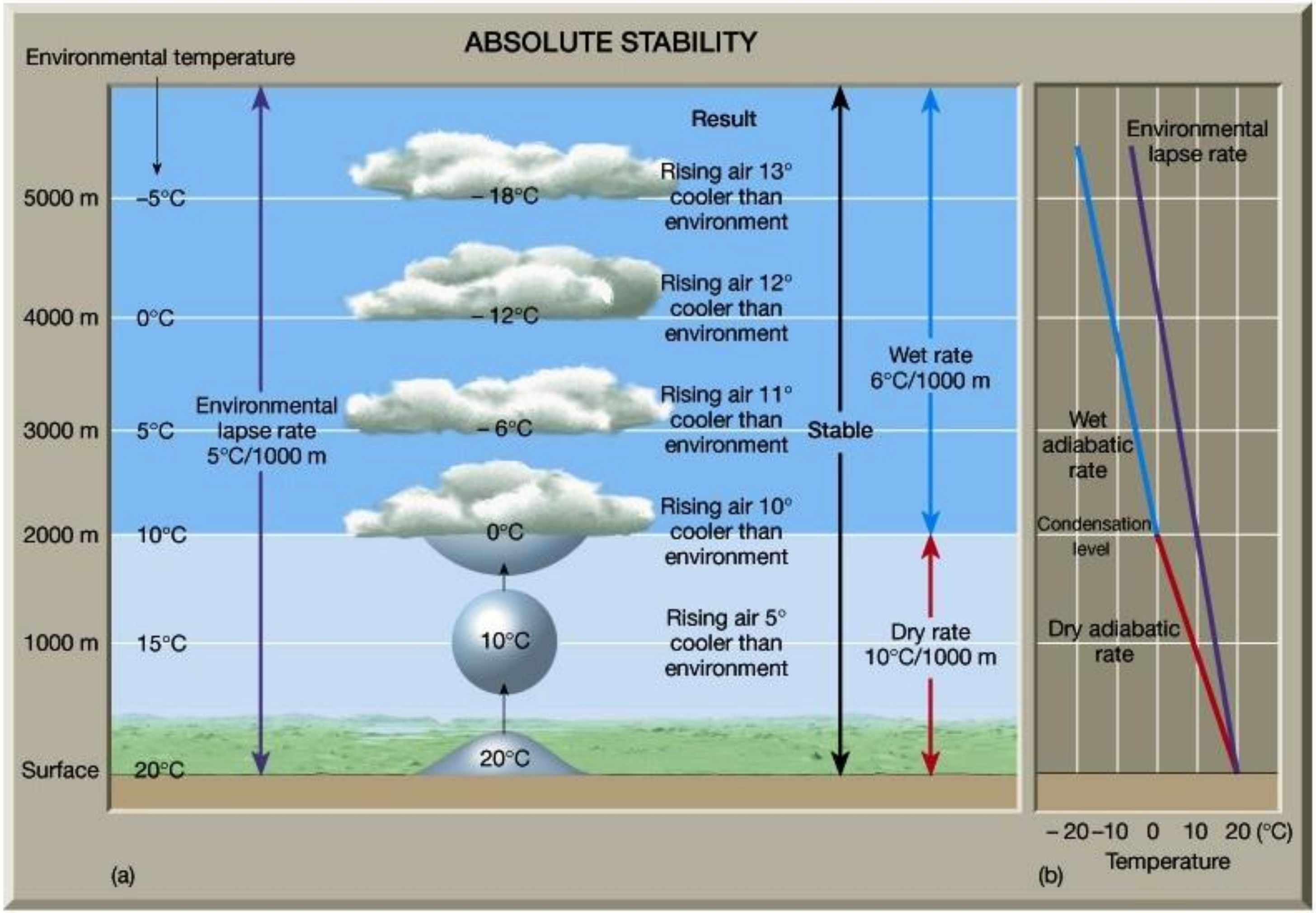
- ELR < ALR: stable
- ELR > ALR: unstable

Example:

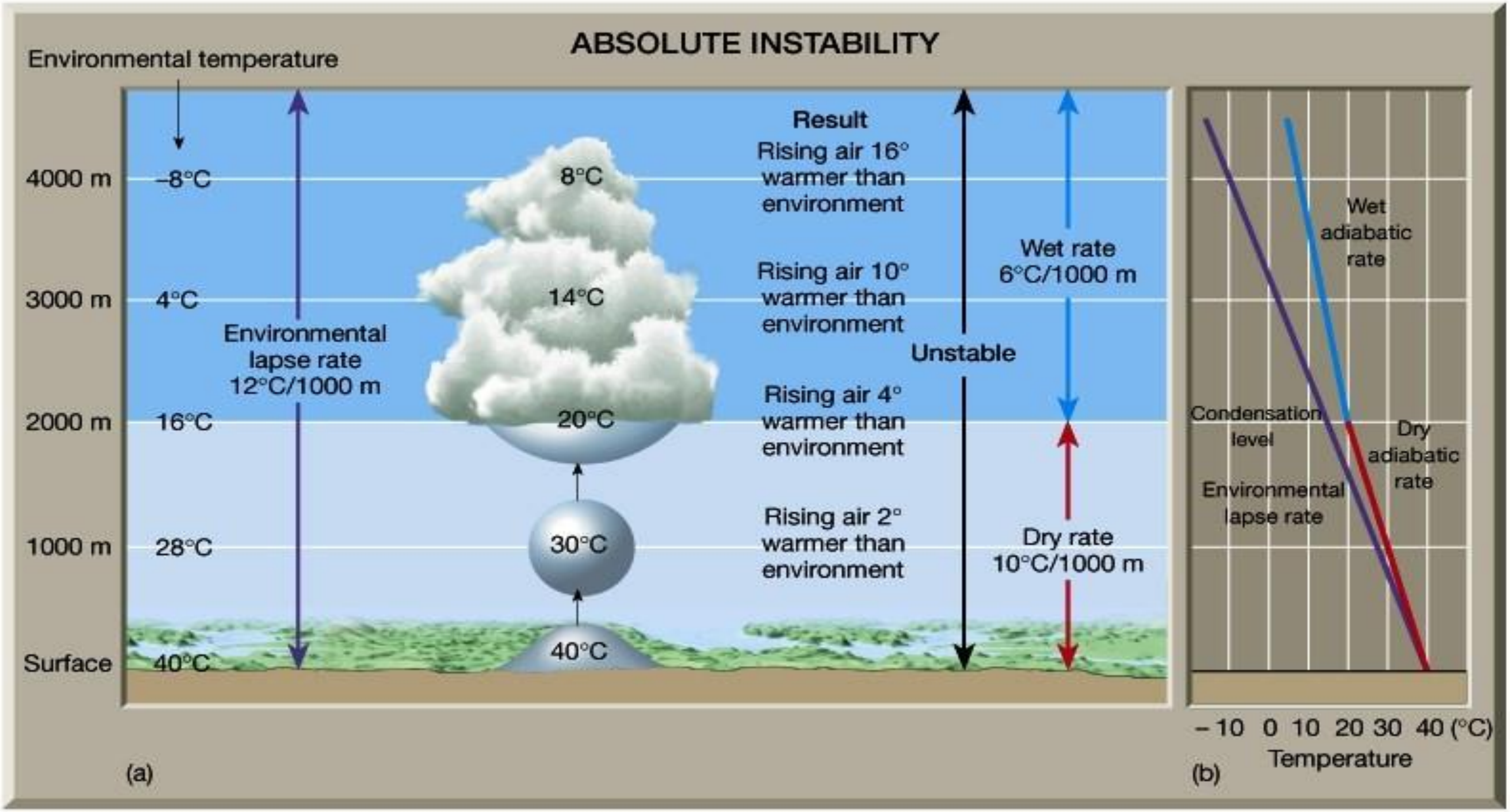
- ALR = 10°C/km
- ELR = 15°C/km
- ELR > ALR: unstable



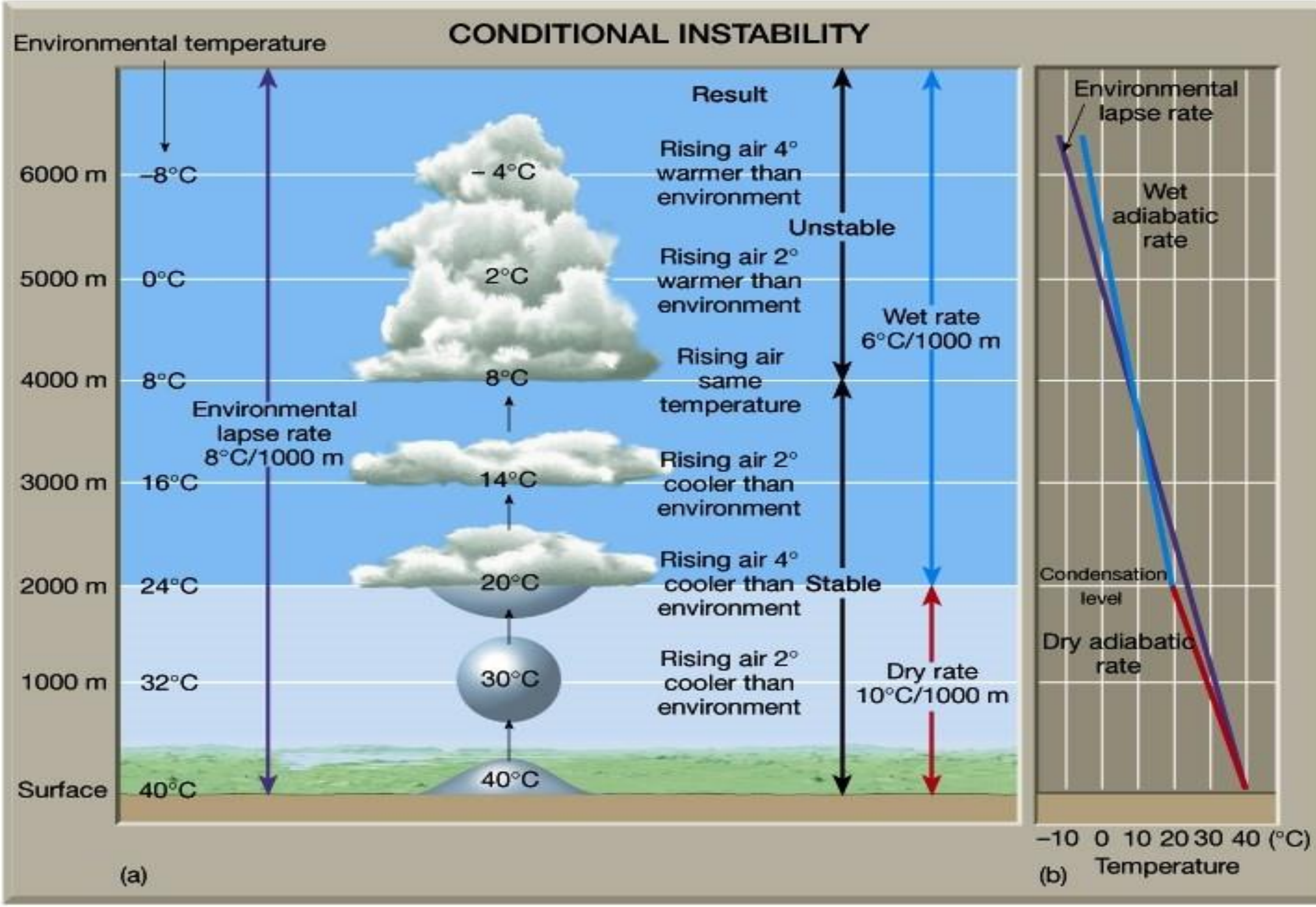

5000
4000
3000
2000
1000
Surface
Height (m)
–8°C
–3°C
2°C
12°C
22°C
32°C
Wet
adiabatic rate
(temperature of
rising air drops at
5°C/1000 meters)
Lifting
condensation
level
Dry
adiabatic rate
(temperature of
rising air drops at
10°C/1000 meters)



If we (somehow) lift the parcel: It will cool at the dry adiabatic lapse rate. The parcel will find itself cooler than the environmental (sounding) temperature. At the same pressure, a cooler parcel will be more dense than the environment. Being denser, the parcel will descend back to where it came from. STABLE!



If we (somehow) lift the parcel: It will cool at the dry adiabatic lapse rate. The parcel will find itself warmer than the environmental (sounding) temperature. At the same pressure, a warmer parcel will be less dense than the environment. Being less dense, the parcel will ascend and move farther from where it came from. UNSTABLE!



If we (somehow) lift the parcel: It will cool at the dry adiabatic lapse rate. The parcel will find itself at the same temperature than the environmental (sounding) temperature. Being the same density, the parcel will not be accelerated in any direction and will remain where it is. NEUTRAL STABILITY! -- Dry Neutral, or Conditional Instability

Things to realize from these diagrams:
the dry adiabat is always below the moist adiabat
if the environmental laps rate is:

- between the moist and dry --> conditionally stable
- above the moist and dry --> stable
- below the moist and dry --> unstable

✓Effects of atmospheric **instability** in **moist atmospheres** include thunderstorm development, which over warm oceans can lead to tropical **cyclogenesis**, and ***turbulence***.

✓In **dry atmospheres**, inferior **mirages**, dust devils, steam devils, and fire whirls can form.

✓**Stable** atmospheres can be associated with **drizzle, fog**, **increased air pollution**, a lack of turbulence, and undular bore formation.

Stable atmosphere

Stable conditions, such as during a clear and calm night, will cause pollutants to become trapped near ground level. Drizzle occurs within a moist air mass when it is stable. Air within a stable layer is not turbulent.

Unstable Atmosphere

✓Within an unstable layer in the troposphere, the lifting of air parcels will occur, and continue for as long as the nearby atmosphere remains unstable.

✓Once overturning through the depth of the troposphere occurs (with convection being capped by the relatively warmer, more stable layer of the stratosphere), deep convective currents lead to thunderstorm development when enough moisture is present.

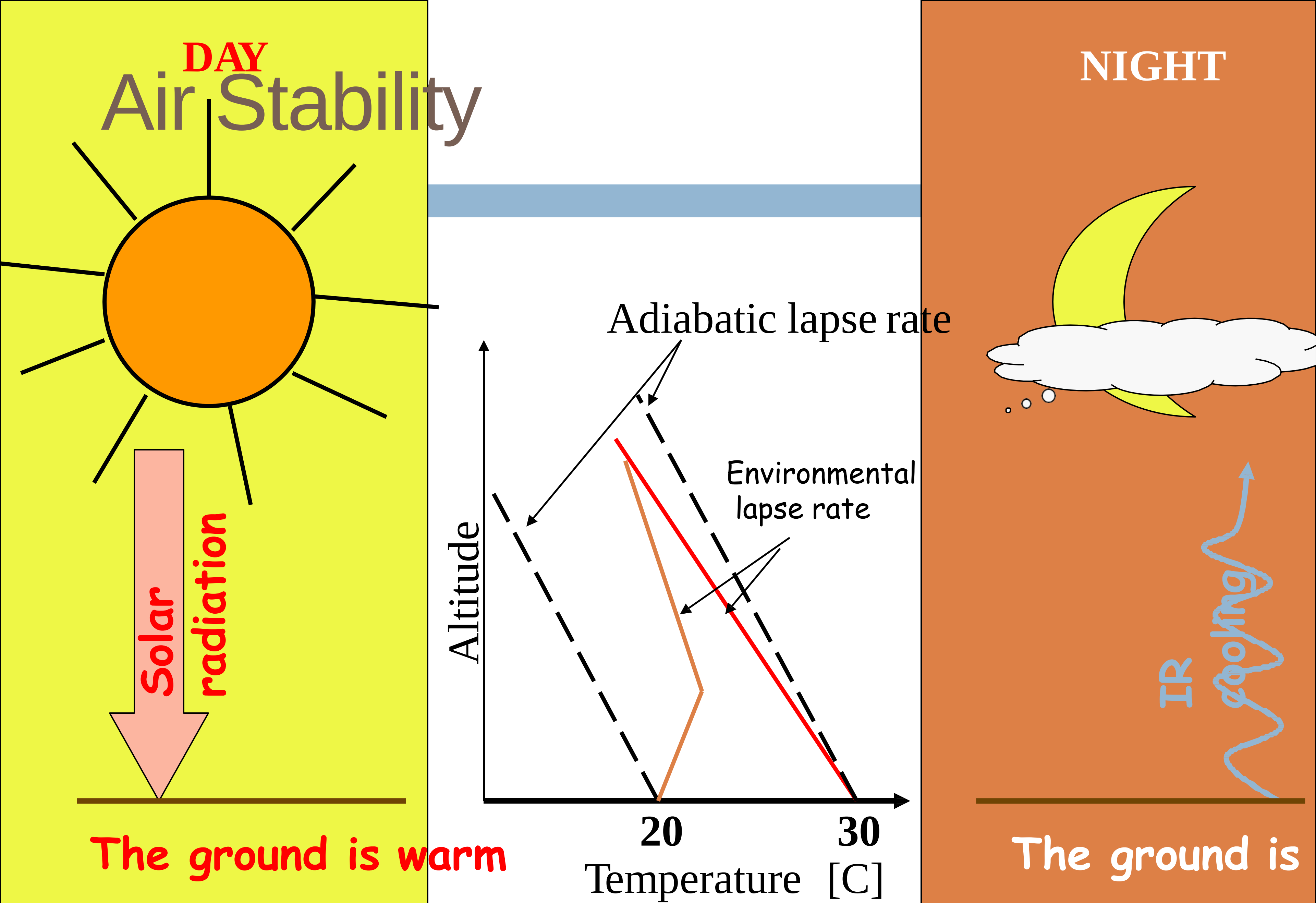
✓Over warm ocean waters and within a region of the troposphere with light vertical wind shear and significant low level spin (or vorticity), such thunderstorm activity can grow in coverage and develop into a tropical cyclone

✓Over hot surfaces during warm days, unstable dry air can lead to significant refraction of the light within the air layer, which causes inferior mirages.

How does the Stability of the Atmosphere Change During the Day?

- Daytime:
  - The sun heats the ground.
  - The boundary layer is heated from below.
  - The environmental lapse rate is steep.
  - The atmosphere can become unstable.
- Morning and evening hours:
  - Radiation cooling results in temperature inversion.
  - The boundary layer is cooler than the air above.
  - The environmental lapse rate becomes less steep.
  - The atmosphere is stable.

Air Stability



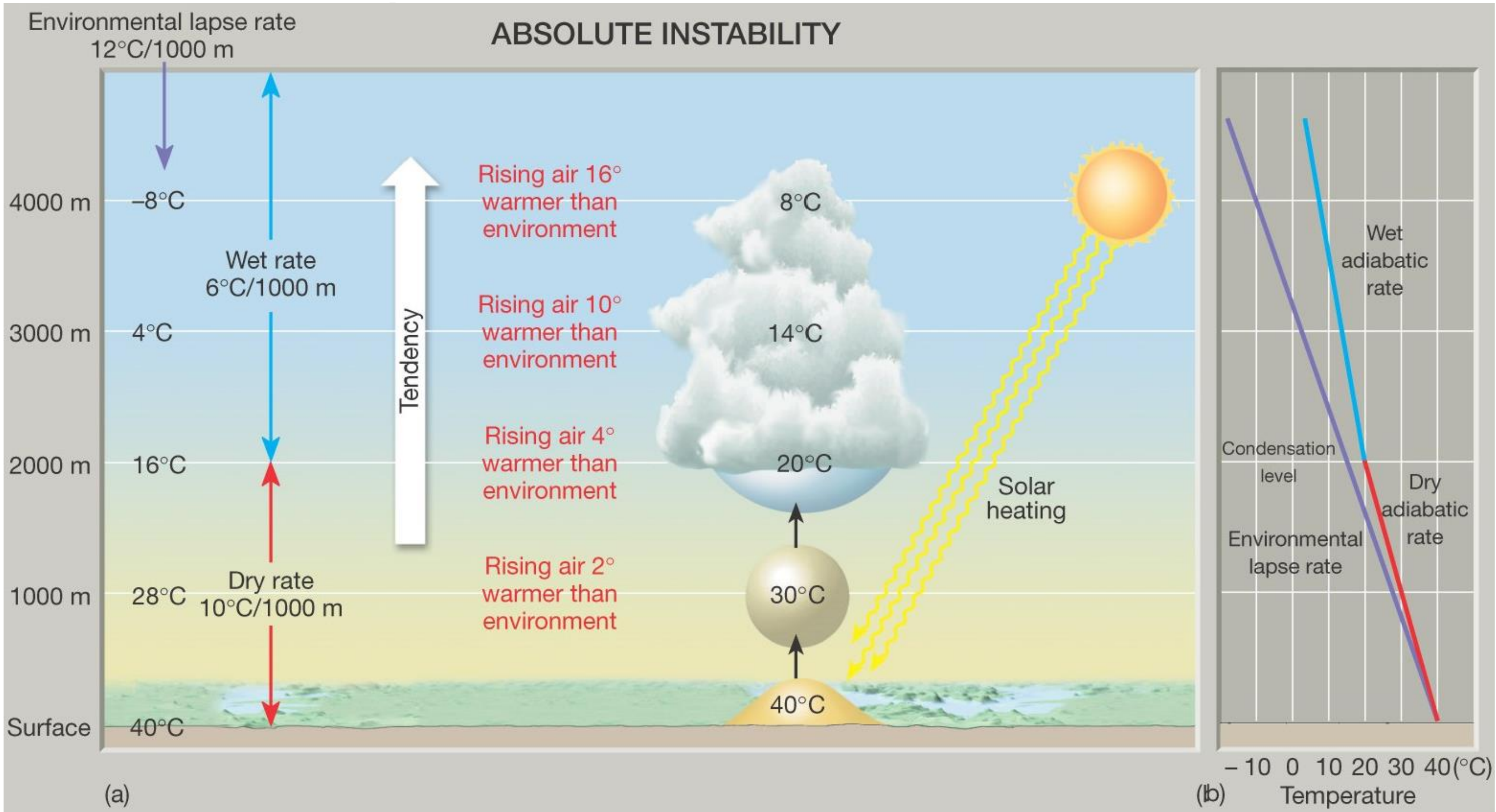
K-Index

- The K index is derived arithmetically: K-index = (850 hPa temperature - 500 hPa temperature) + 850 hPa dew point - 700 hPa dew point depression
- The temperature difference between 850 hPa (5,000 feet (1,500 m) above sea level) and 500 hPa (18,000 feet (5,500 m) above sea level) is used to parameterize the vertical temperature lapse rate.
- The 850 hPa dew point provides information on the moisture content of the lower atmosphere.
- The vertical extent of the moist layer is represented by the difference of the 700 hPa temperature (10,000 feet (3,000 m) above sea level) and 700 hPa dew point

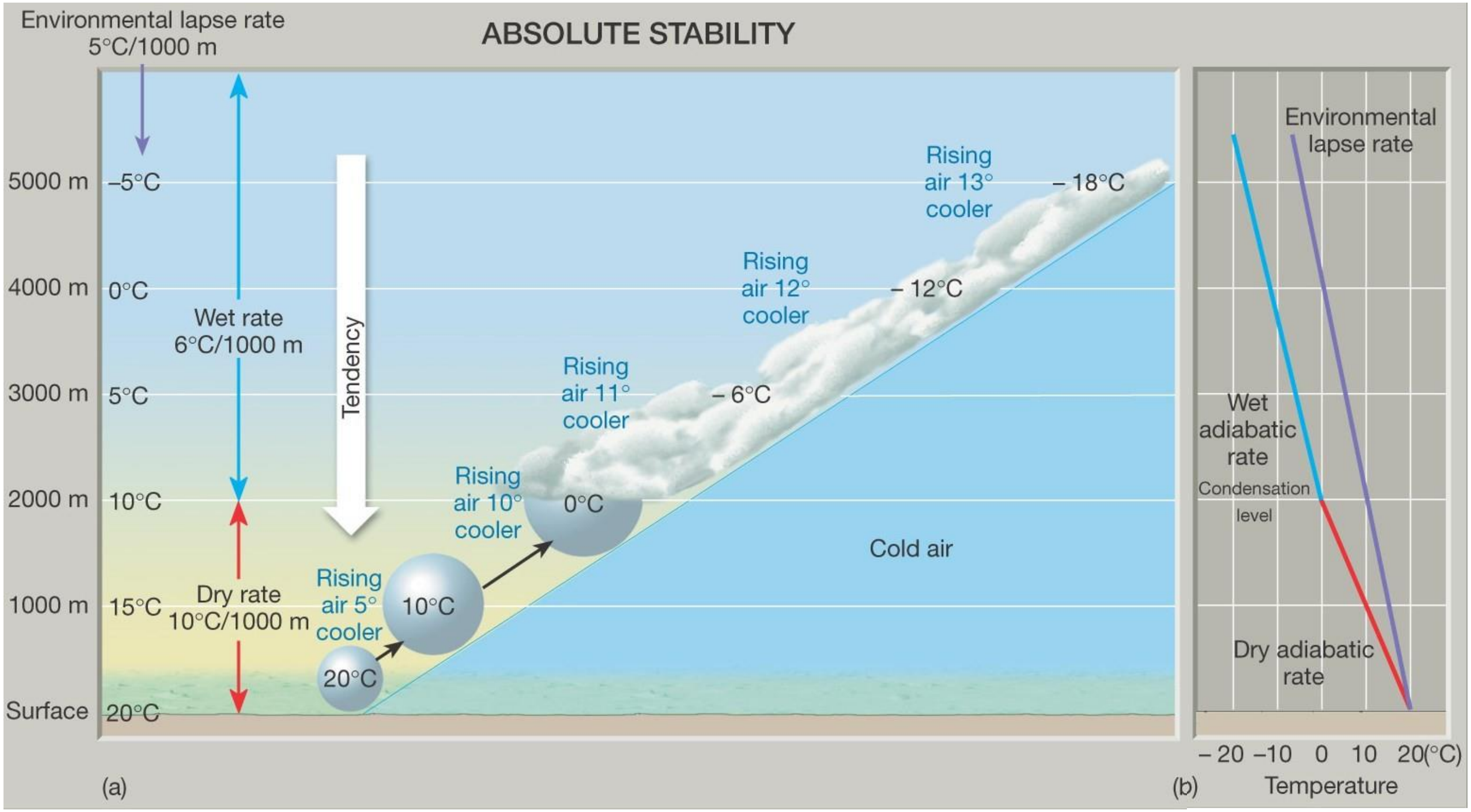
K-Index

K-index value	Thunderstorm Probability
Less than 20	None
20 to 25	Isolated thunderstorms
26 to 30	Widely scattered thunderstorms
31 to 35	Scattered thunderstorms
Above 35	Numerous thunderstorms

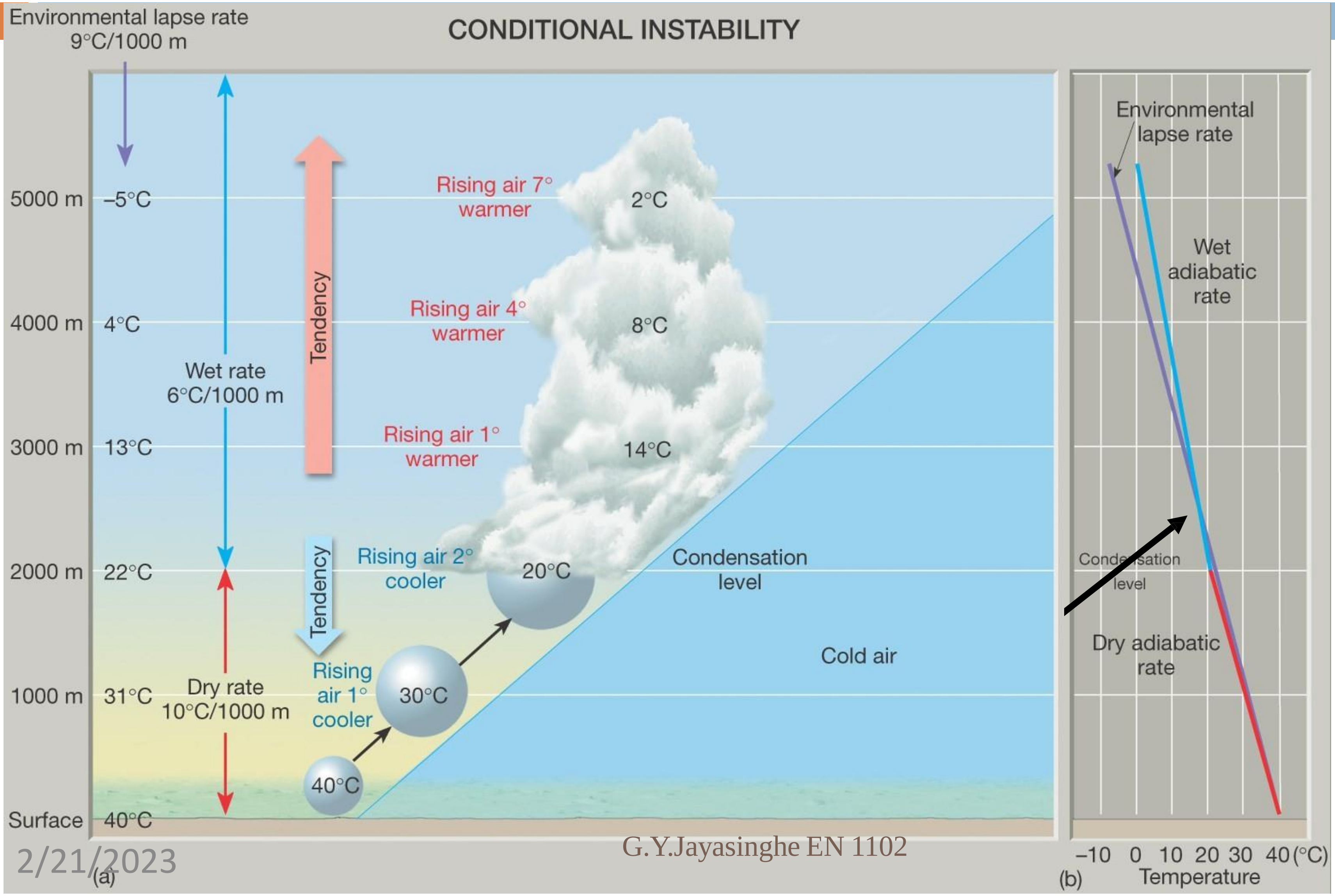
Is air stable or unstable?



Stable or unstable?



Stable or unstable?



Indices used for its determination

- **Lifted Index:** a dimensionless number which described the temperature difference between an air parcel lifted adiabatically Tp(p) and the temperature of the environment Te(p) at a given pressure height in the troposphere, usually 500 hPa (mb).
- When the value is positive, the atmosphere (at the respective height) is stable and when the value is negative, the atmosphere is unstable. Thunderstorms are expected with values below -2, and **severe weather** is anticipated with values below -6.

Assignment

1. (a).An air parcel at the surface is non-saturated and has a temperature of 30 deg C and a Tdew of 25 deg C. Assuming it moves adiabatically (DALR 10deg C/1km) and the SALR = -8.5 deg C/1 km what will be the air temperature at 3000 m?

   (b). What would be the temperature at 3000 m if the SALR was -6.5 deg C/1000 m? (i.e. assuming the only thing that changed from the above problem is the SALR)

Answer

- Air is initially dry so we need to find when the air has cooled down to Tdew (i.e. Tair=Tdew). DALR=-10 deg C/1 km
- T0=30 deg C z0= 0 m T1= 25 deg C z1=? m
- $DALR = \dfrac{T1 - T0}{z1 - z0}$
- $\dfrac{-10}{1000} = \dfrac{25 - 30}{z1 - 0}$
- $\dfrac{-10}{1000} = \dfrac{-5}{z1}$

- $\frac{1000}{-10} = \frac{z1}{-5}$
- $\frac{1000}{-10} * -5 = z1$
- 500 m= z1 (**25 Marks**)
- So at this height the air is saturated - now can calculate what the temperature will be at 3000 m.SALR=-8.5deg C/1 km
- T1=25 deg Cz1= 0 mT2= ?deg Cz2=3000 m
- $SALR = \frac{T2-T1}{z2-z1}$

$$\frac{-8.5}{1000} = \frac{T2 - 25}{3000 - 500}$$

$$\frac{-8.5}{1000} = \frac{T2 - 25}{2500}$$

$$\frac{-8.5 \times 2500}{1000} = T2 - 25$$

$$-21.25 = T2 - 25$$

$$-21.25 + 25 = T2$$

3.75 deg C = T2

Temperature at 3000 m is **3.75** deg C

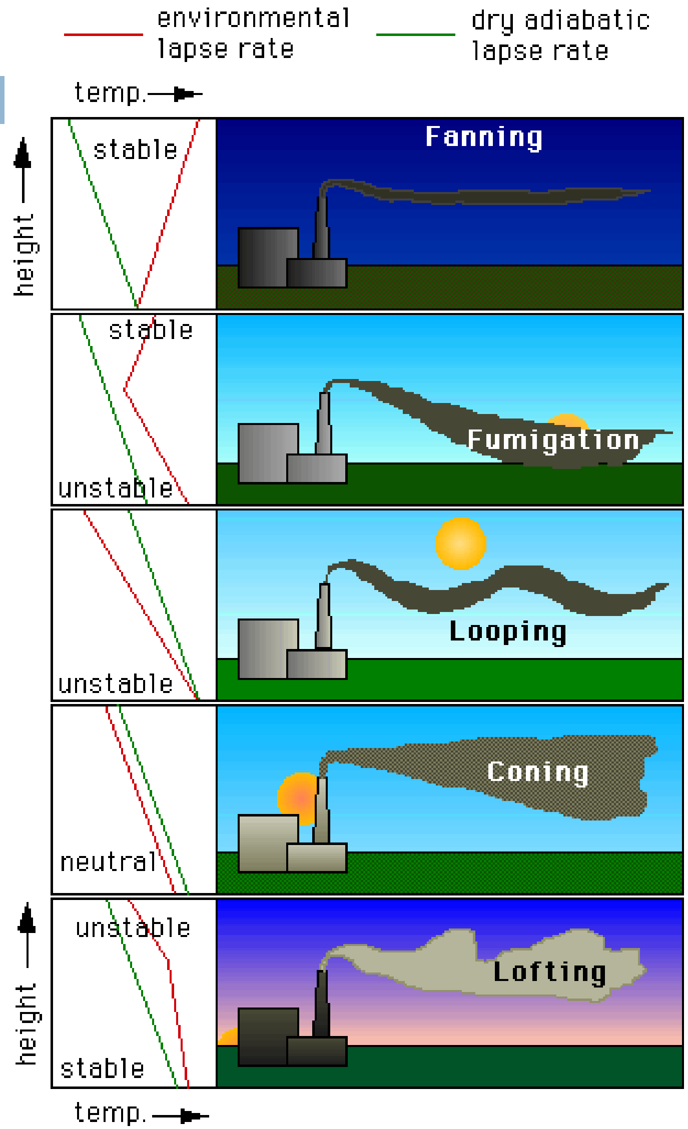
(25 marks)

- What would be the temperature at 3000 m if the SALR was -6.5 deg C/1000 m? (i.e. assuming the only thing that changed from the above problem is the SALR).

- SALR=-6.5deg C/1 km
- T1=25 deg C z1= 500 m T2= ? deg C z2=3000 m
- SALR= $\frac{T2- T1}{z2-z1}$

- $\frac{-6.5}{1000} = \frac{T2- 25}{3000 - 500}$ (25 Marks)
- $\frac{- 6.5}{1000}= \frac{T2- 25}{2500}$
- $\frac{- 6.5 *2500}{1000}= T2- 25$
- -16.25 = T2-25
- -16.25 +25= T2
- 8.75 deg C= T2 (25 Marks)
- Temperature at 3000 m is 8.75 deg C

Stability and Pollution



Stable atmosphere

Stable aloft: unstable below

unstable atmosphere

Neutral atmosphere

Unstable aloft: Stable below