Adiabatic temperature changes

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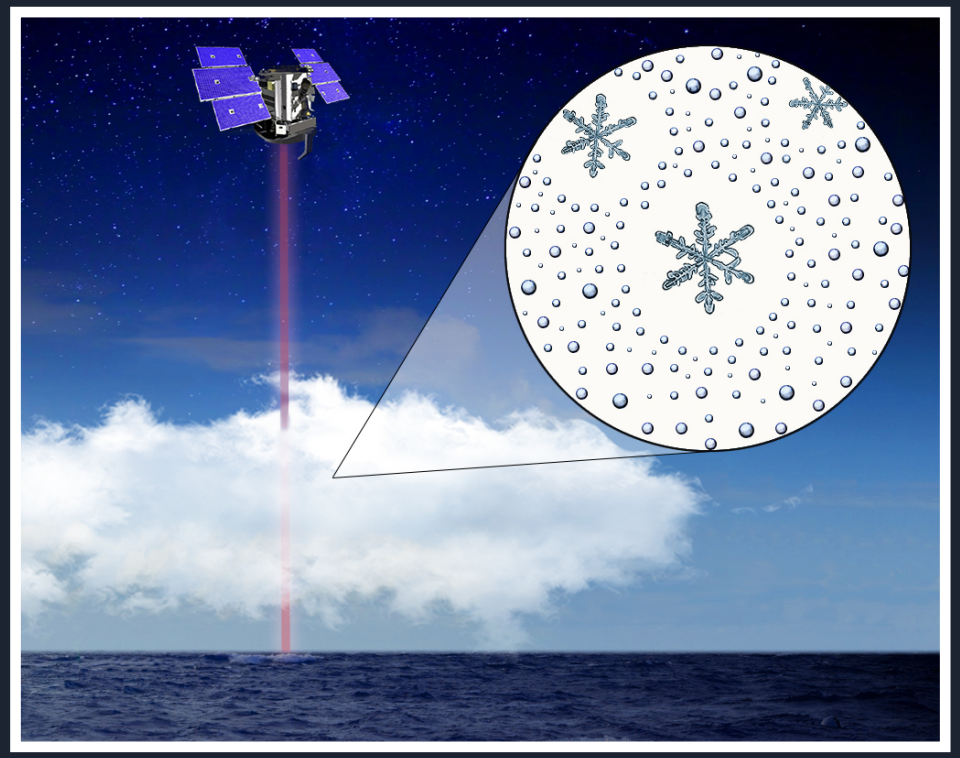

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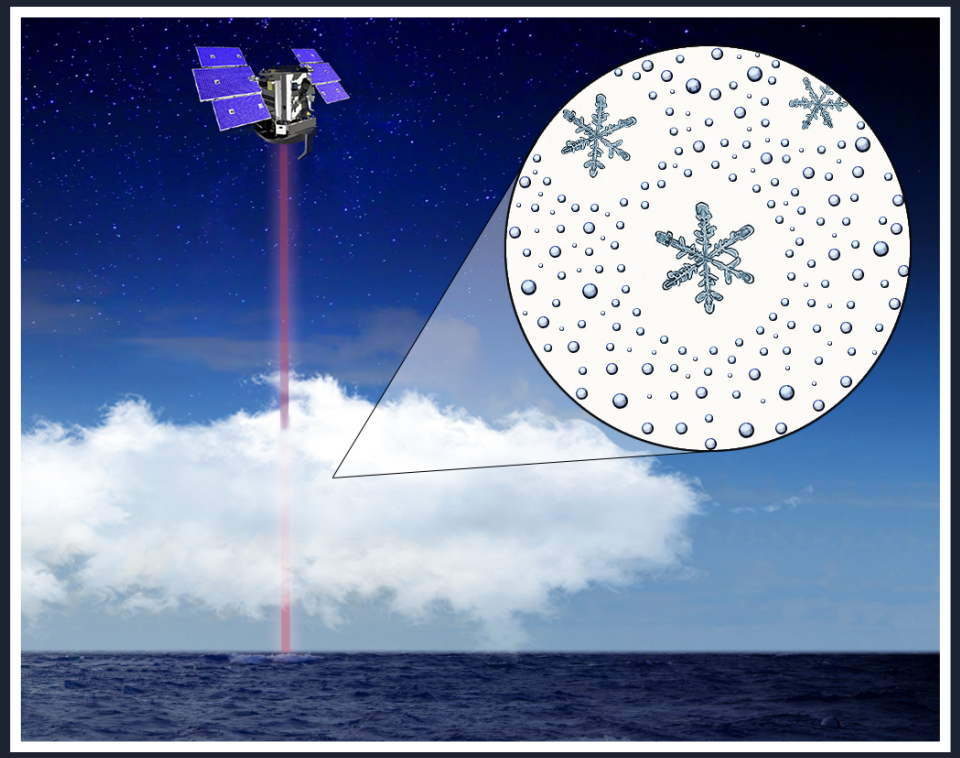

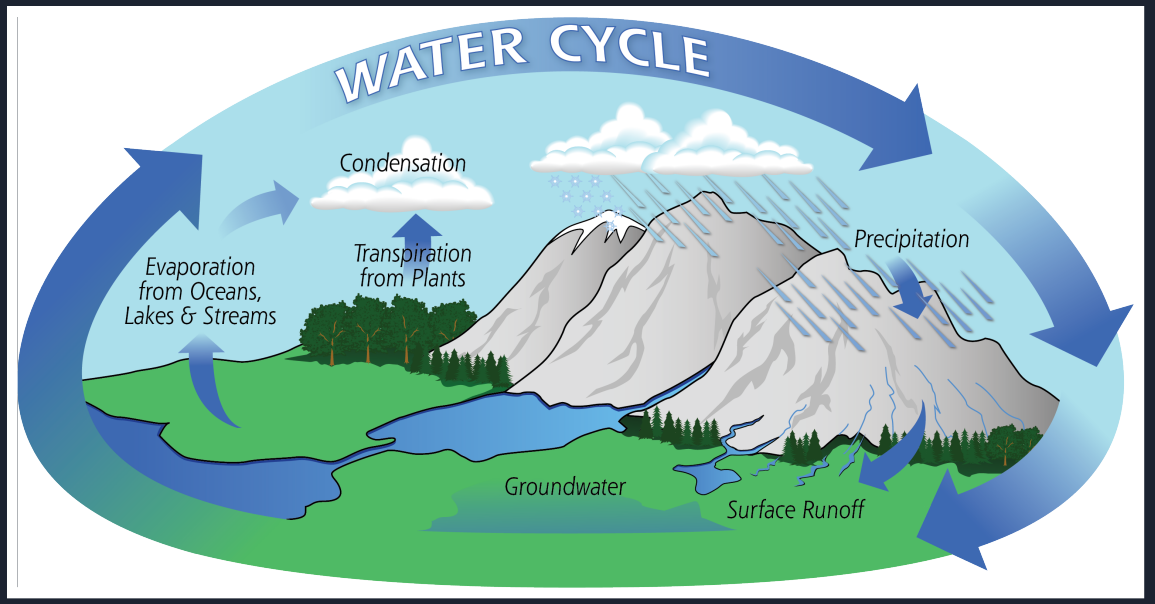

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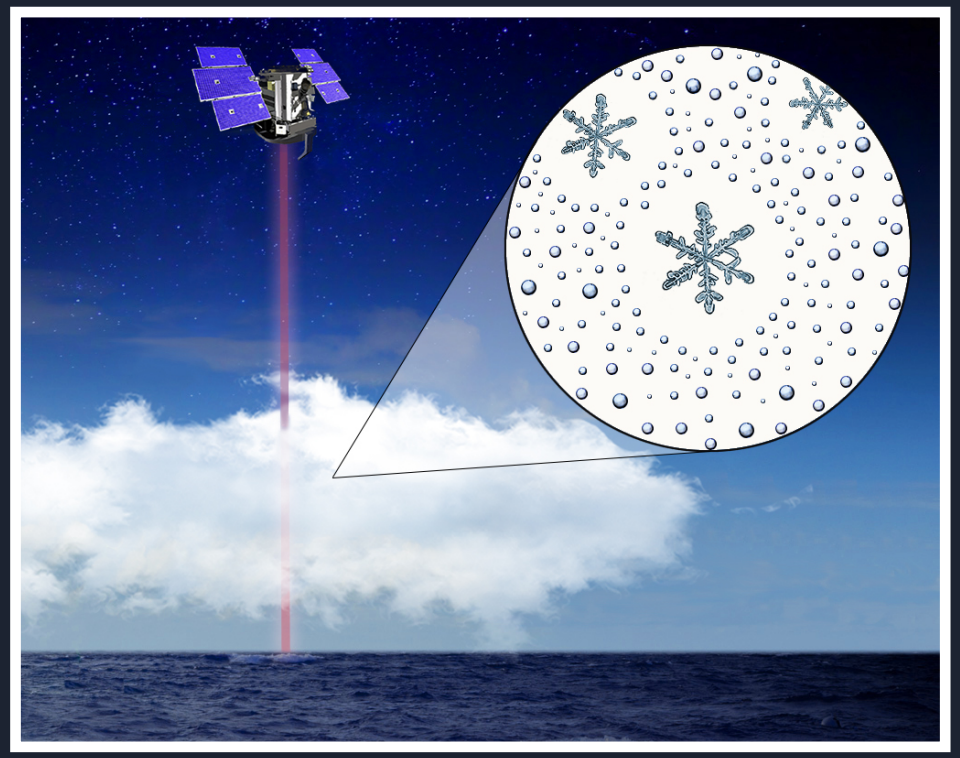
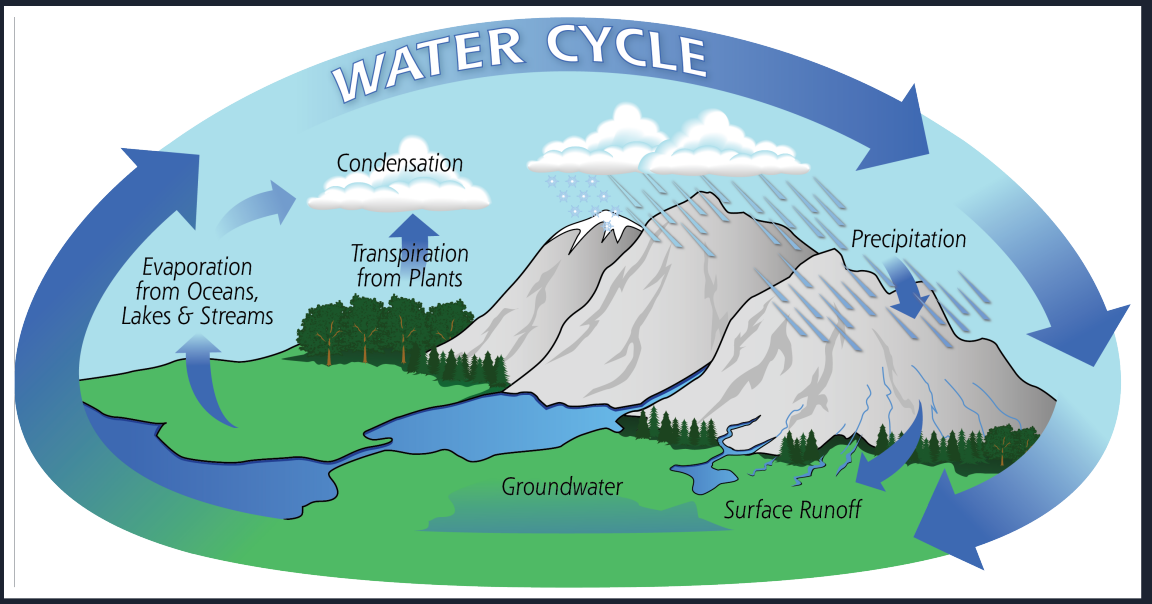
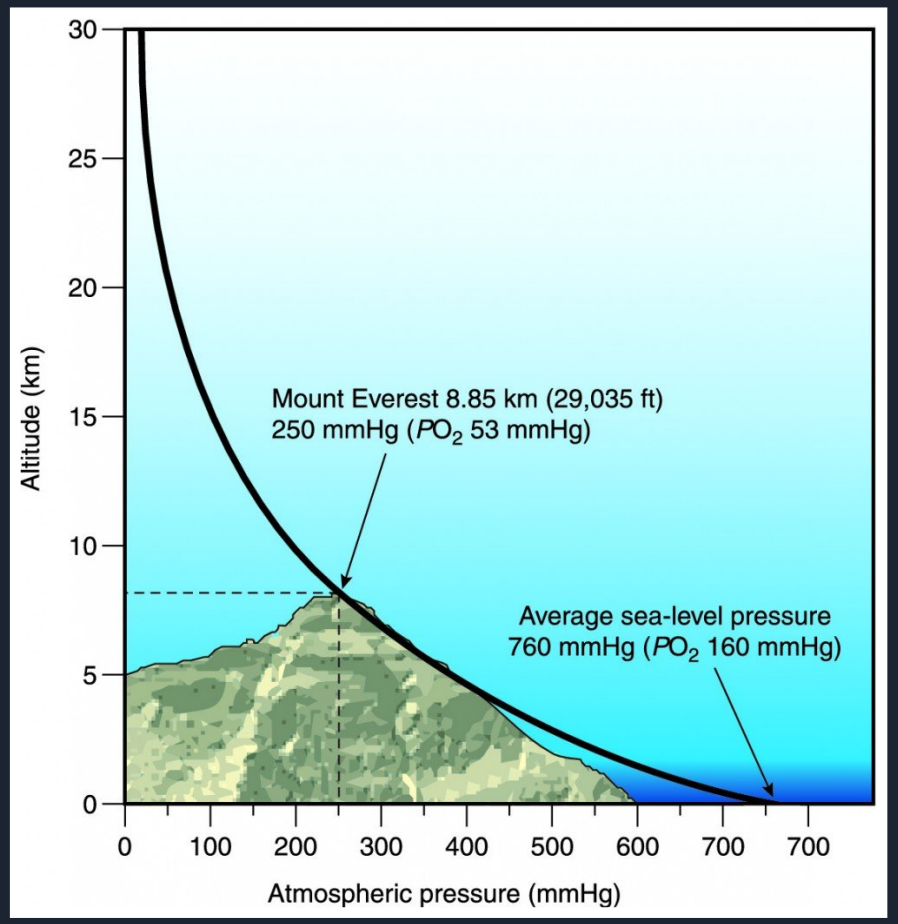




~ *Clouds* are ***formed*** by the ***condensation*** (or ***deposition***) of ***water evaporated*** from the ***surface*** that ***rises*** and ***cools***.

~ The ***key*** to ***understanding temperature changes*** is the ***decrease*** in ***pressure*** with height.



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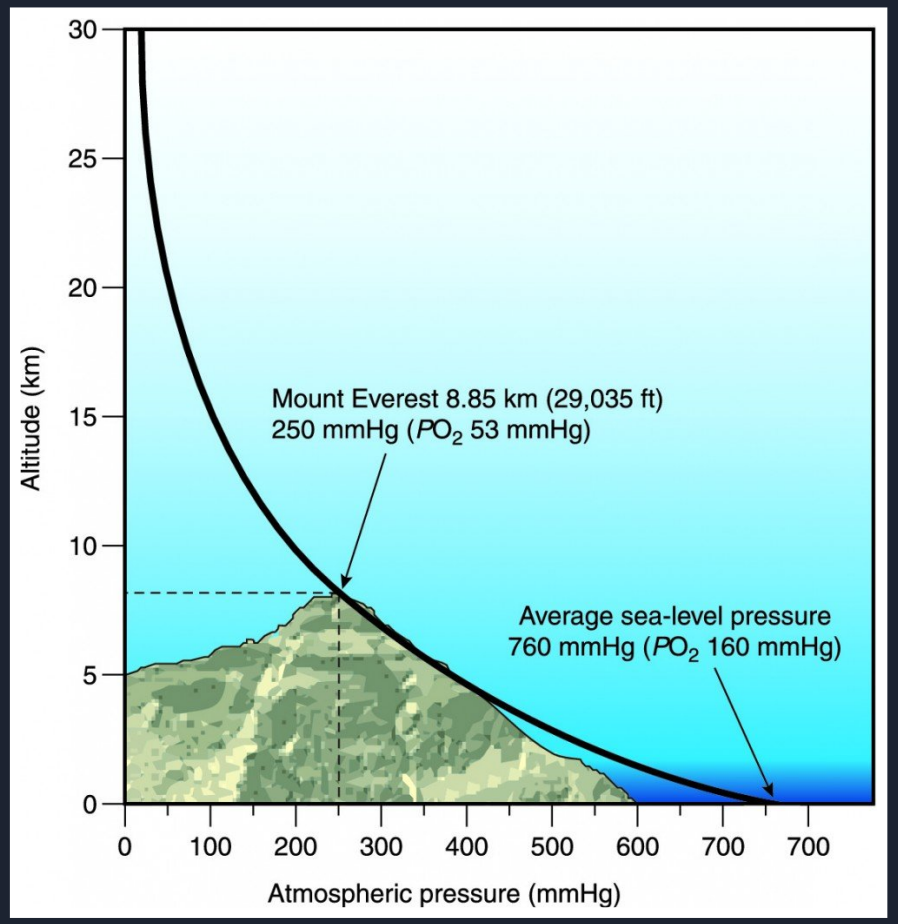

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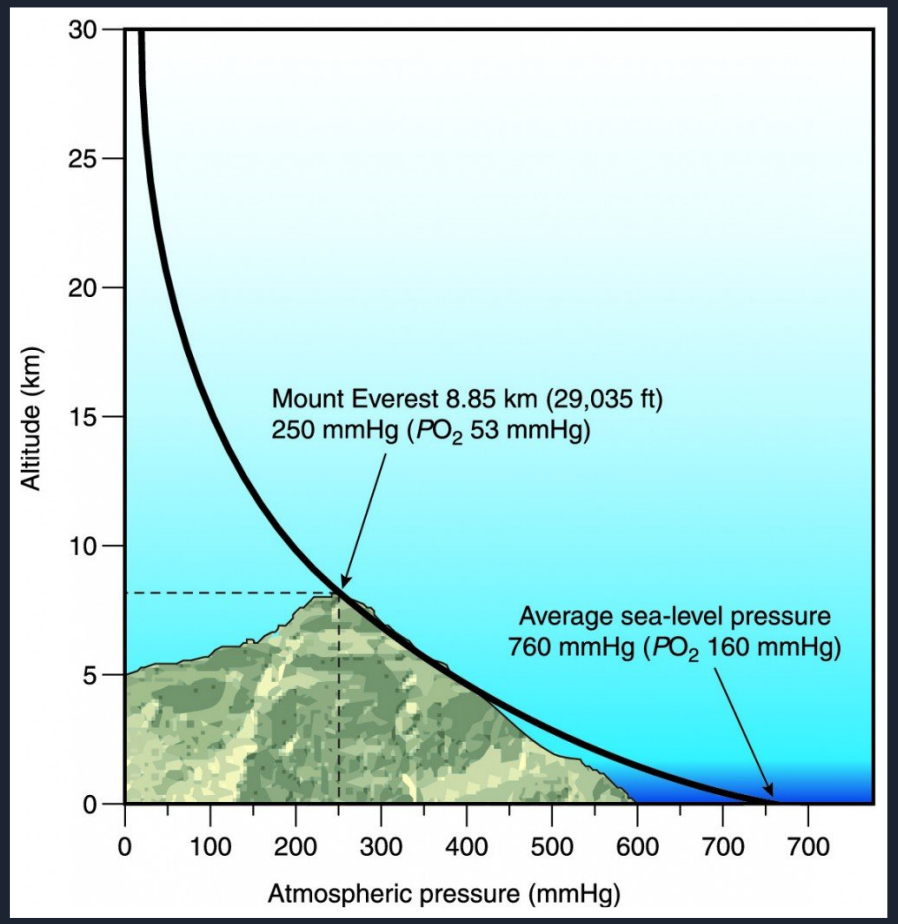

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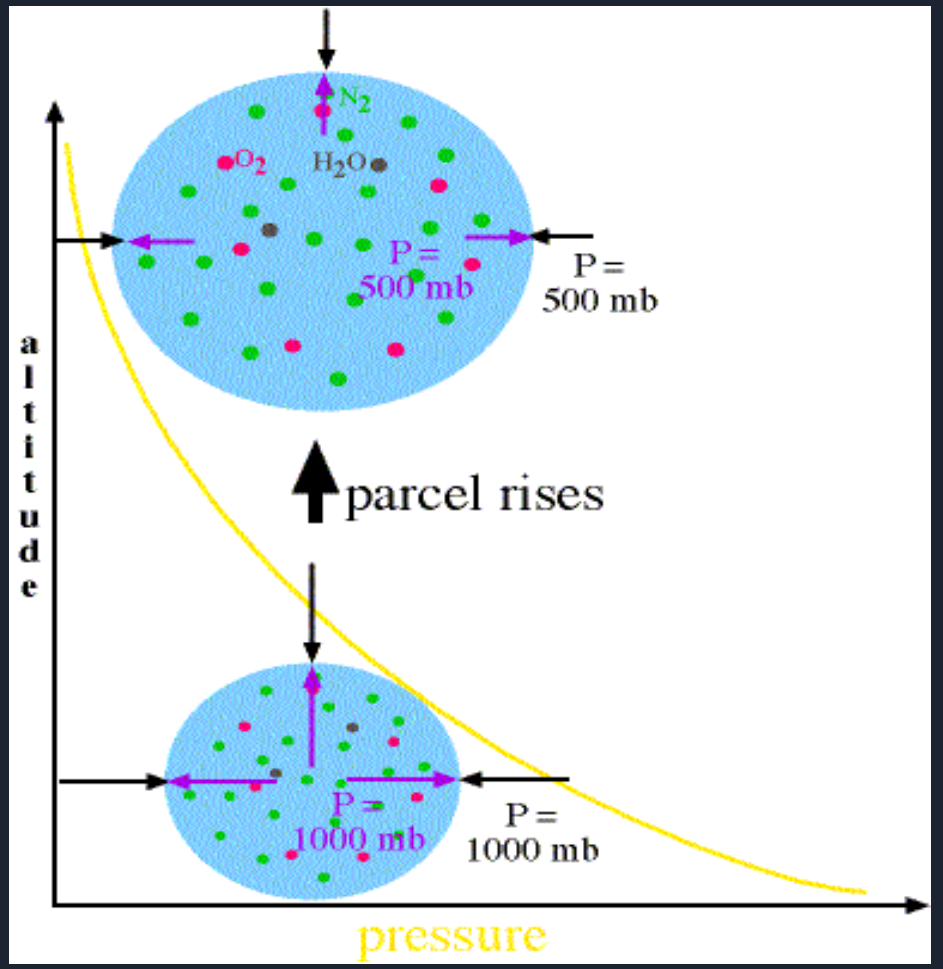

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~ ***Air*** that ***expands cools*** as molecules ***spread out*** to a ***larger volume***, while ***compressed air warms*** as the molecules are confined to a ***smaller volume***.

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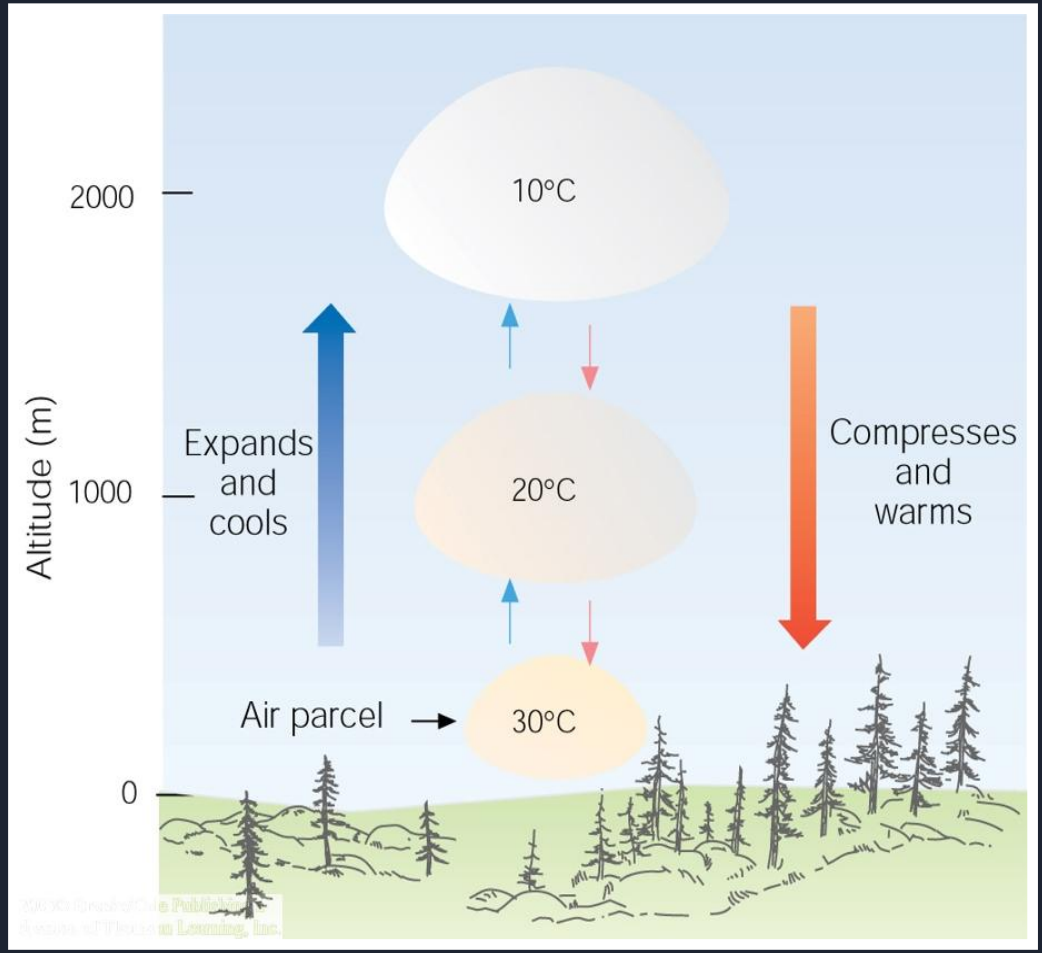
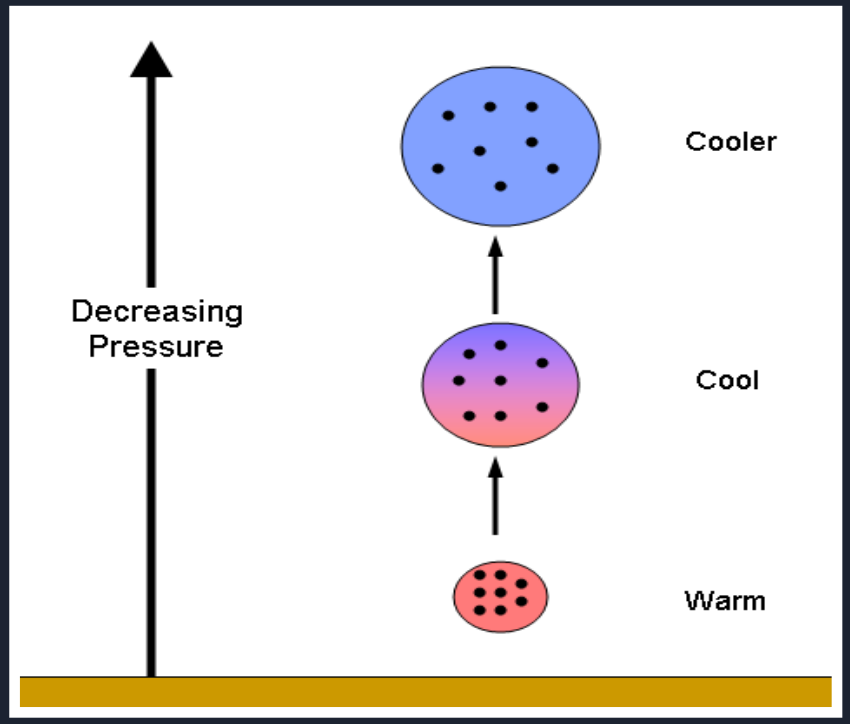


~ Thus, as ***air rises***, it will ***expand*** and ***cool***, and as ***air sinks*** it will ***compress*** and ***warm***.



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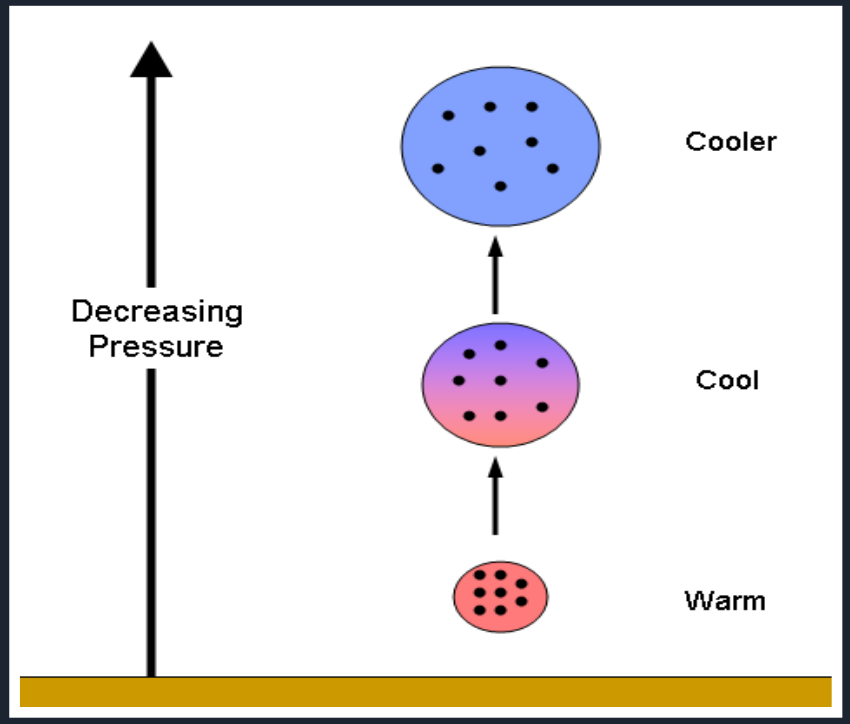

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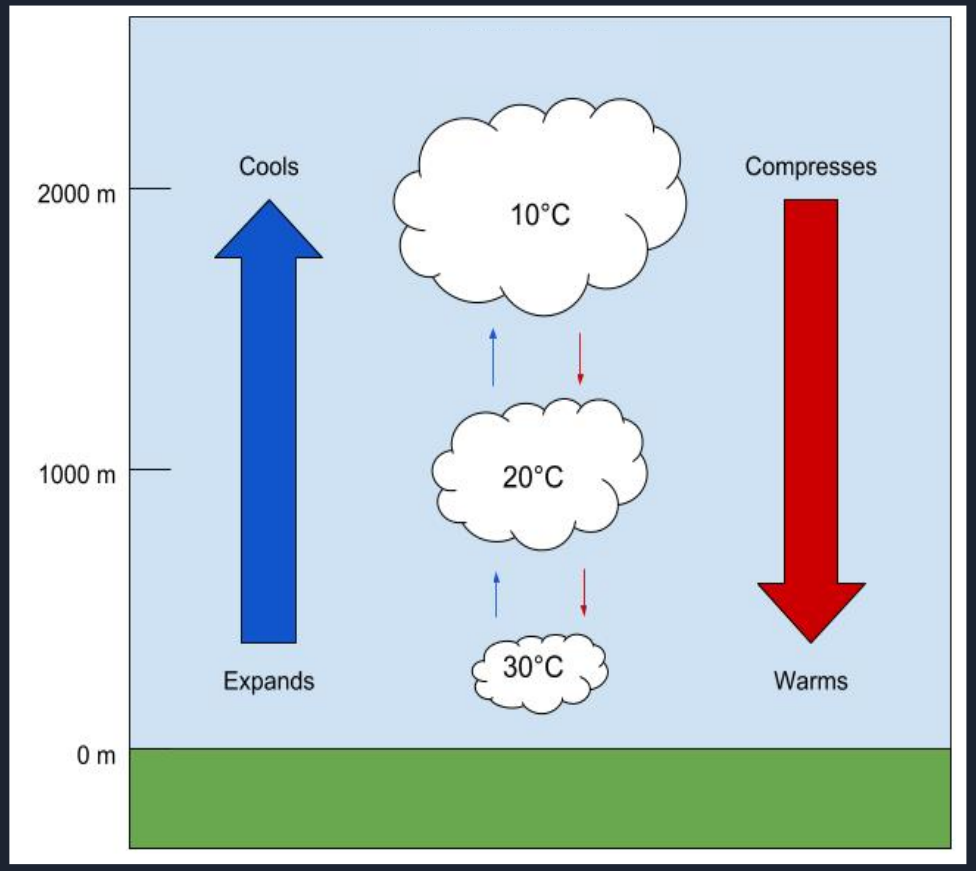

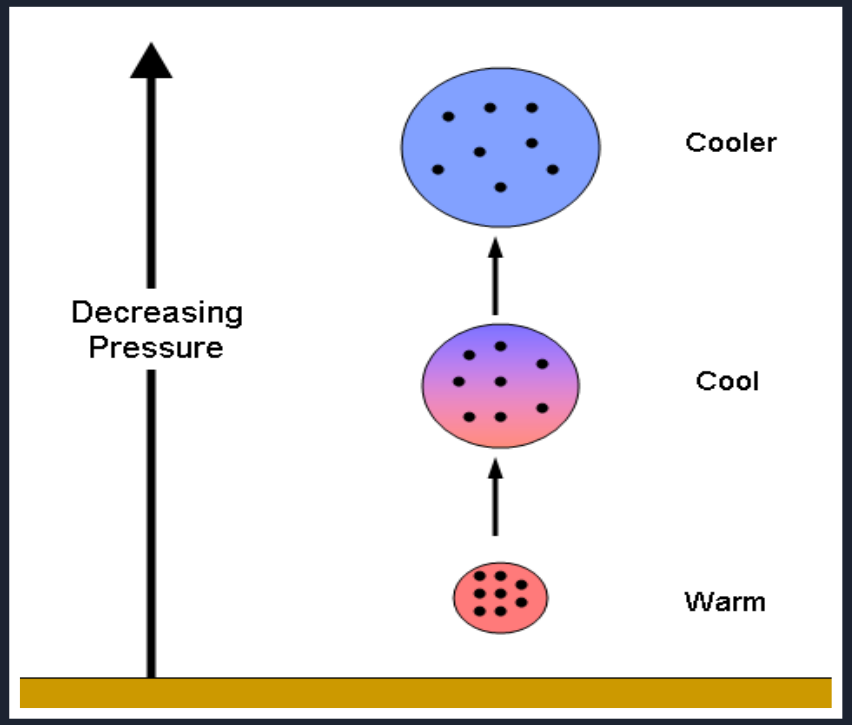

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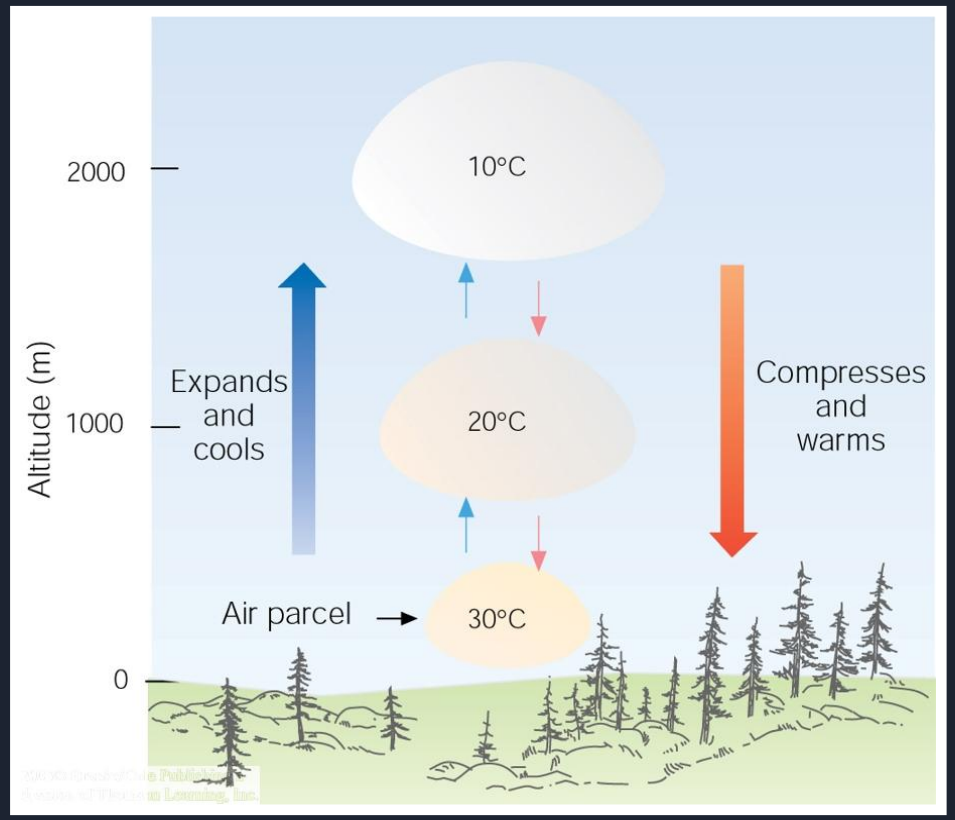
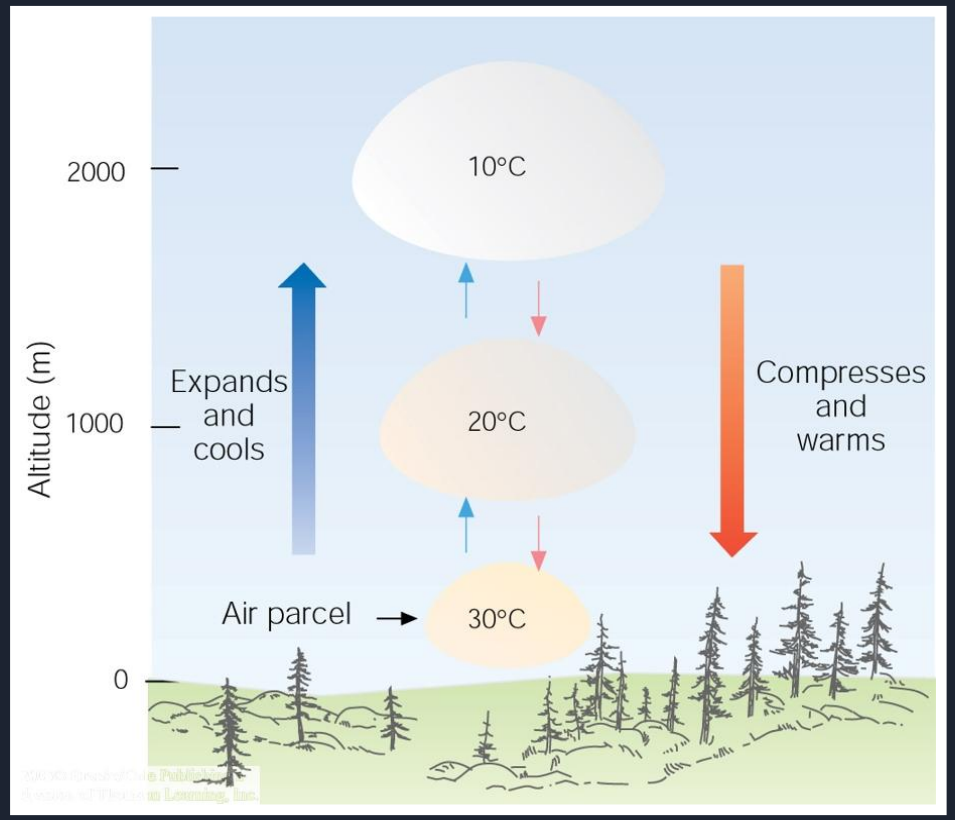


~ As *parcels rise*, they *expand* and *cool* at *-10˚C per kilometer* (km); *sinking air compresses* and *warms* at *+10˚C per km*.



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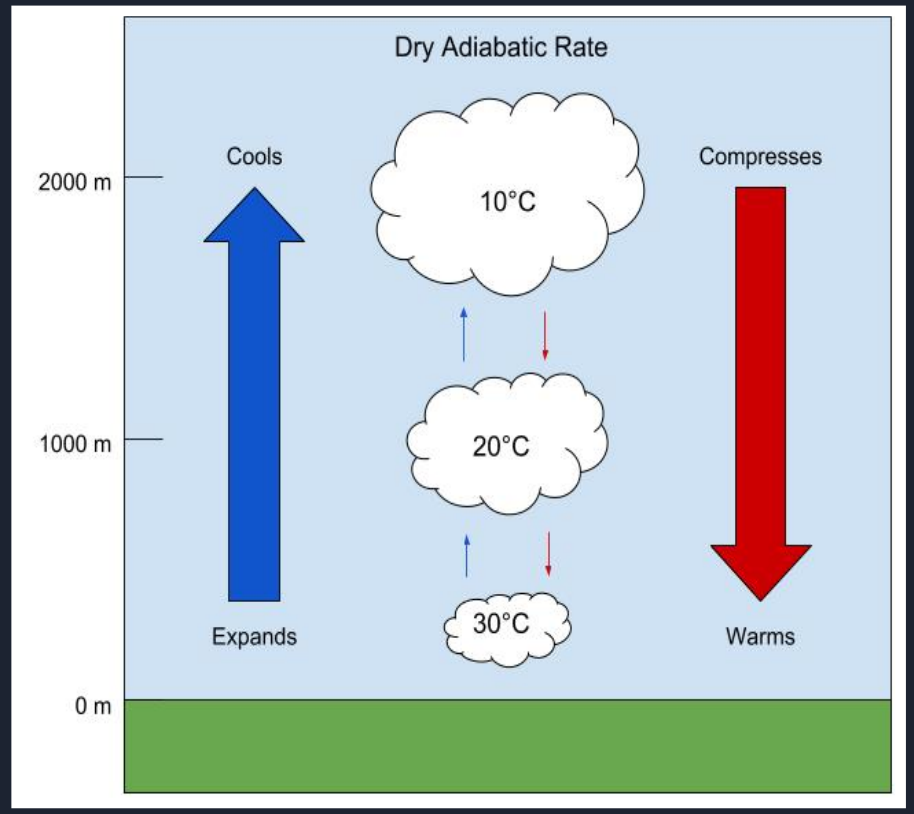

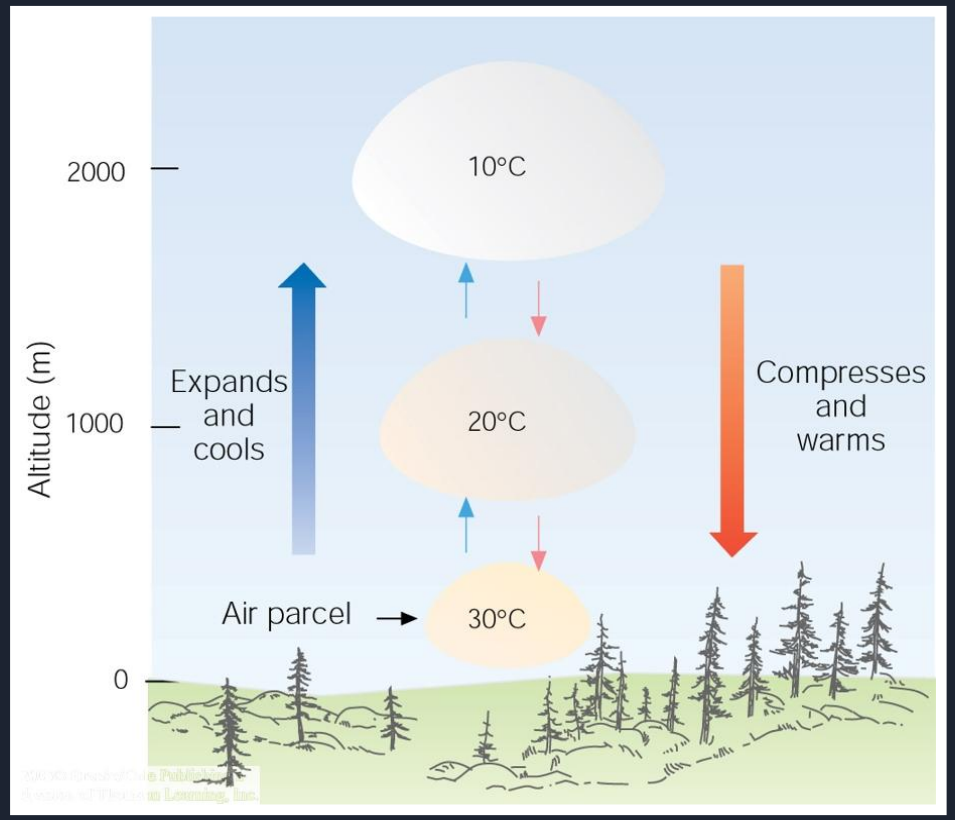

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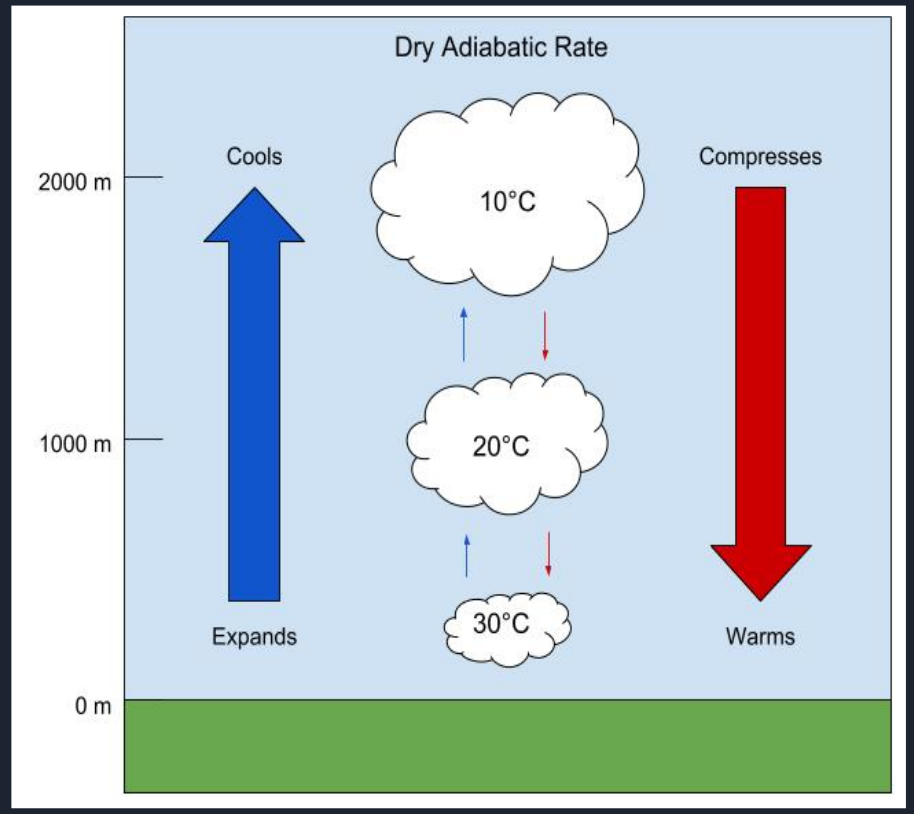

~ This ***rate*** of ***heating*** or ***cooling***, ***only*** applied to ***unsaturated*** air, is the ***dry adiabatic lapse rate***.

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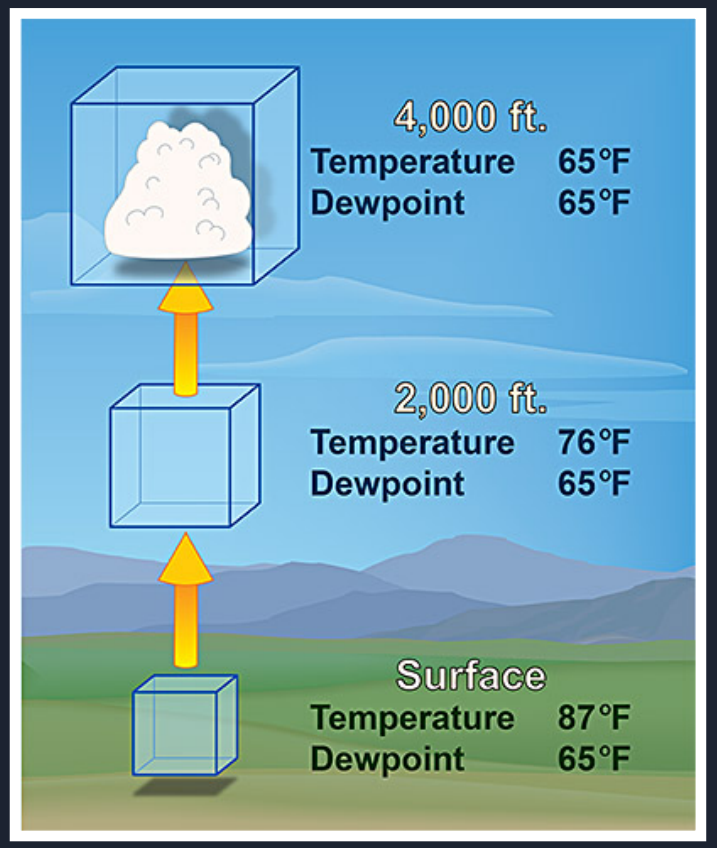

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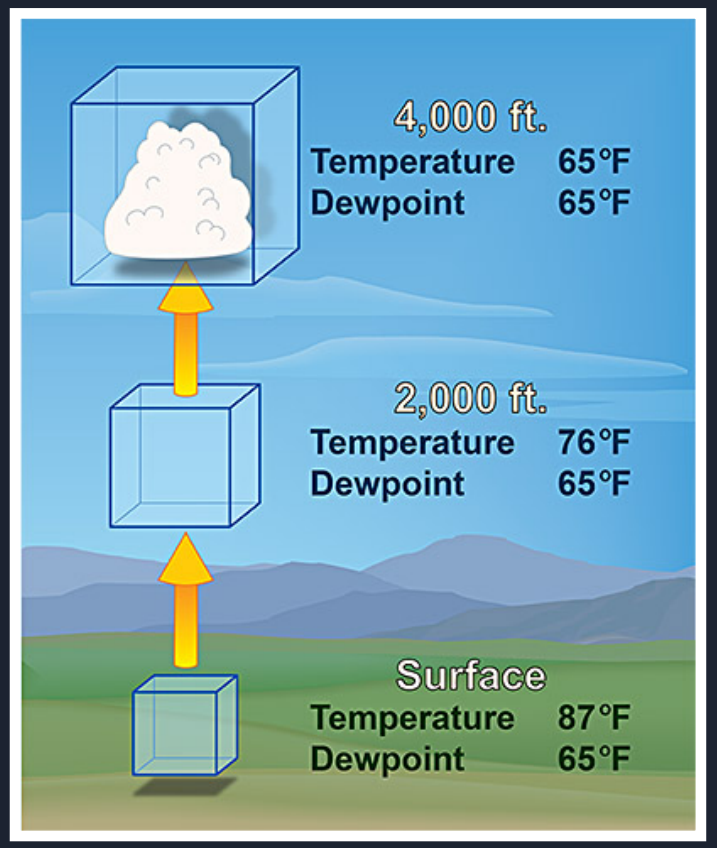

~ The *height* at which *saturation* ***occurs*** is called the *lifting condensation level* (LCL) because *further lifting* will cause the *parcel* to *cool past* the *dew point*, the *air* will *not* be able to *hold* all the *water vapor*, and some *condenses* ***out*** and forms a *cloud*.

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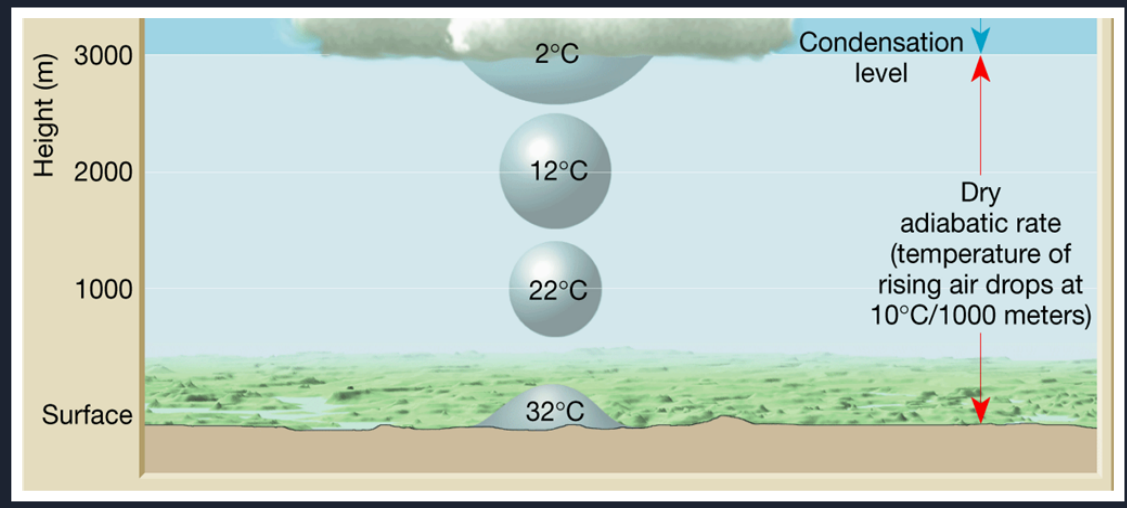

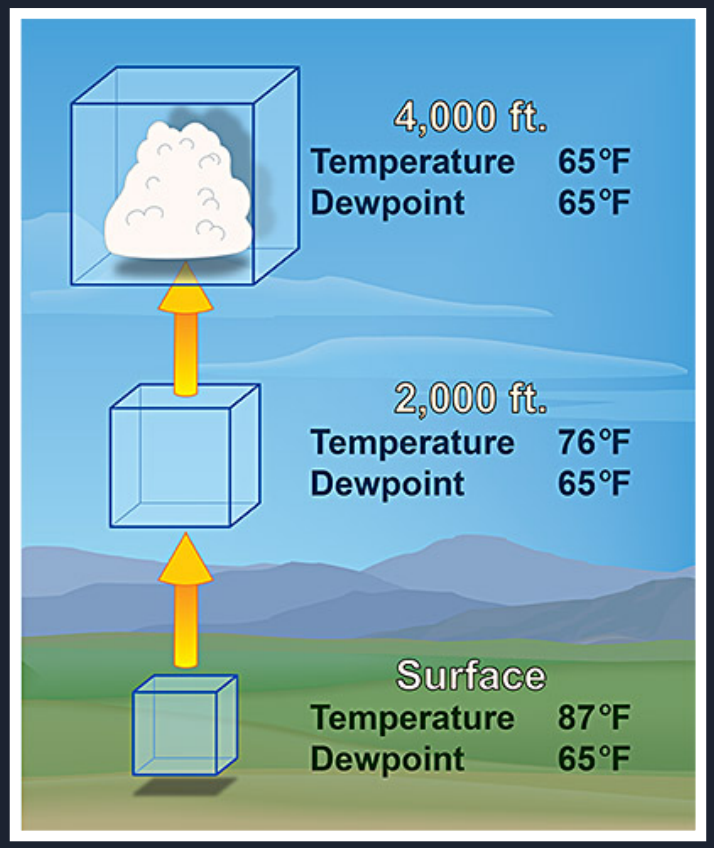

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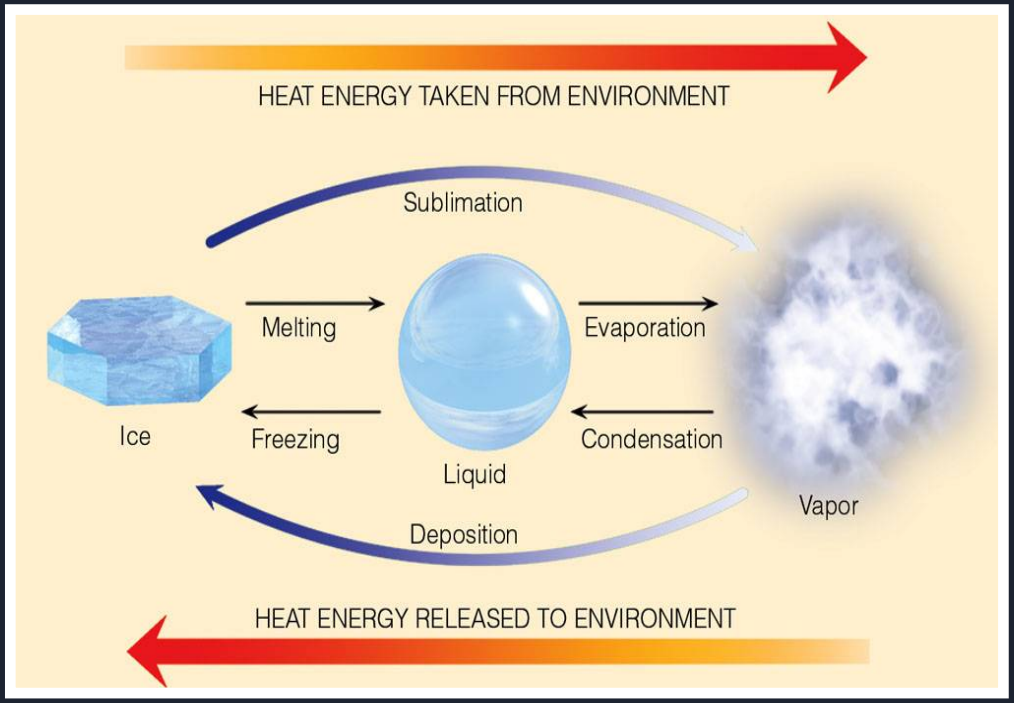

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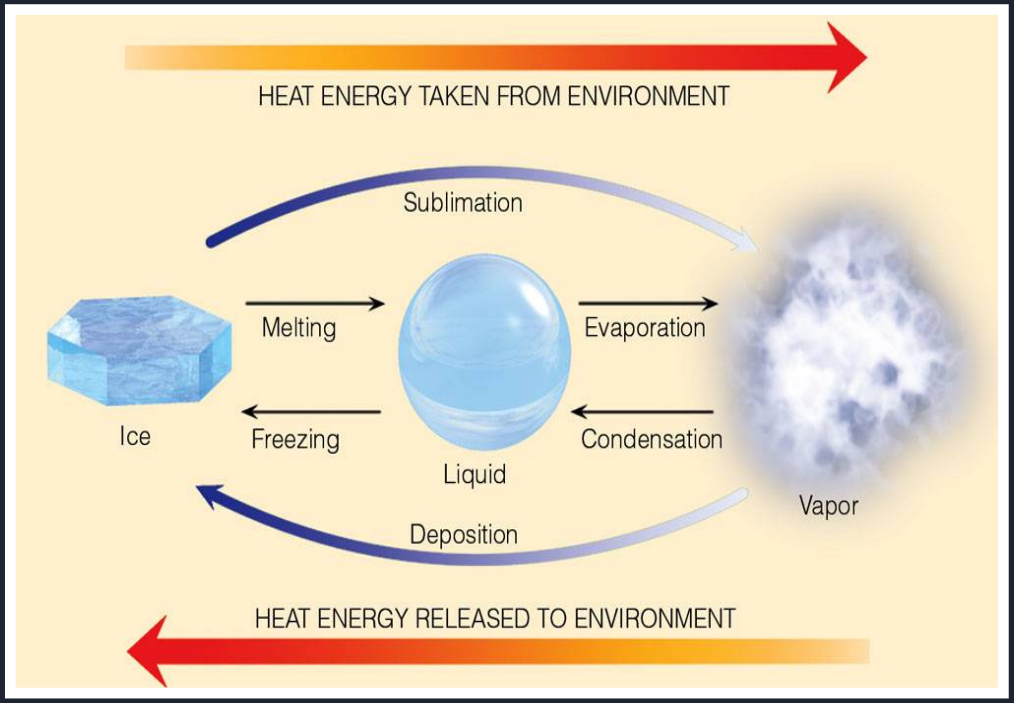

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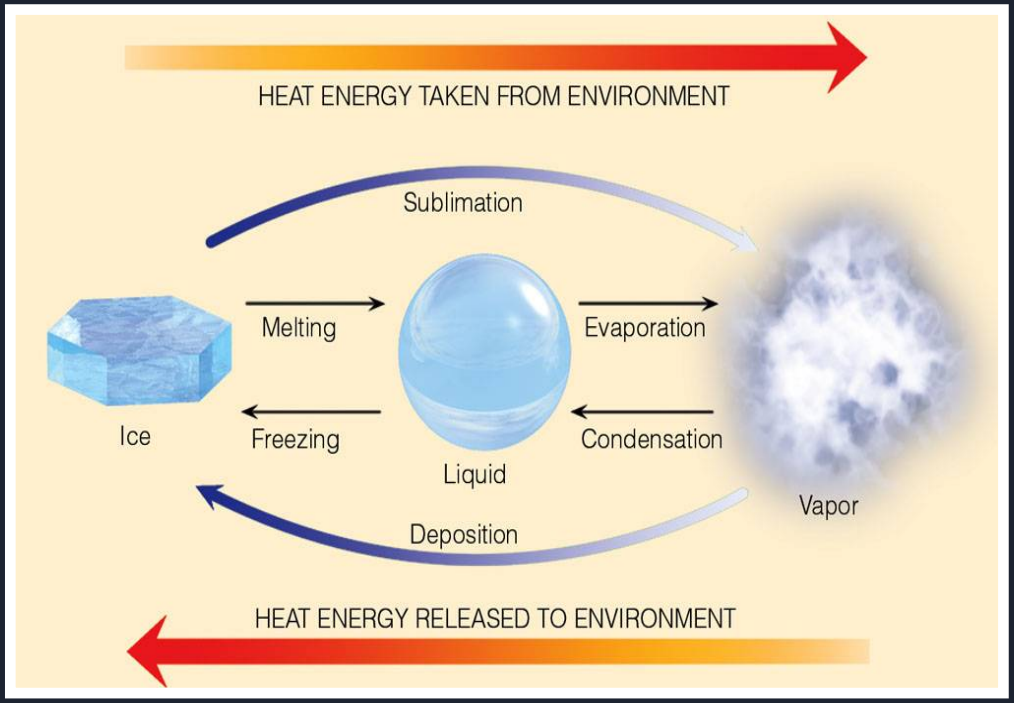

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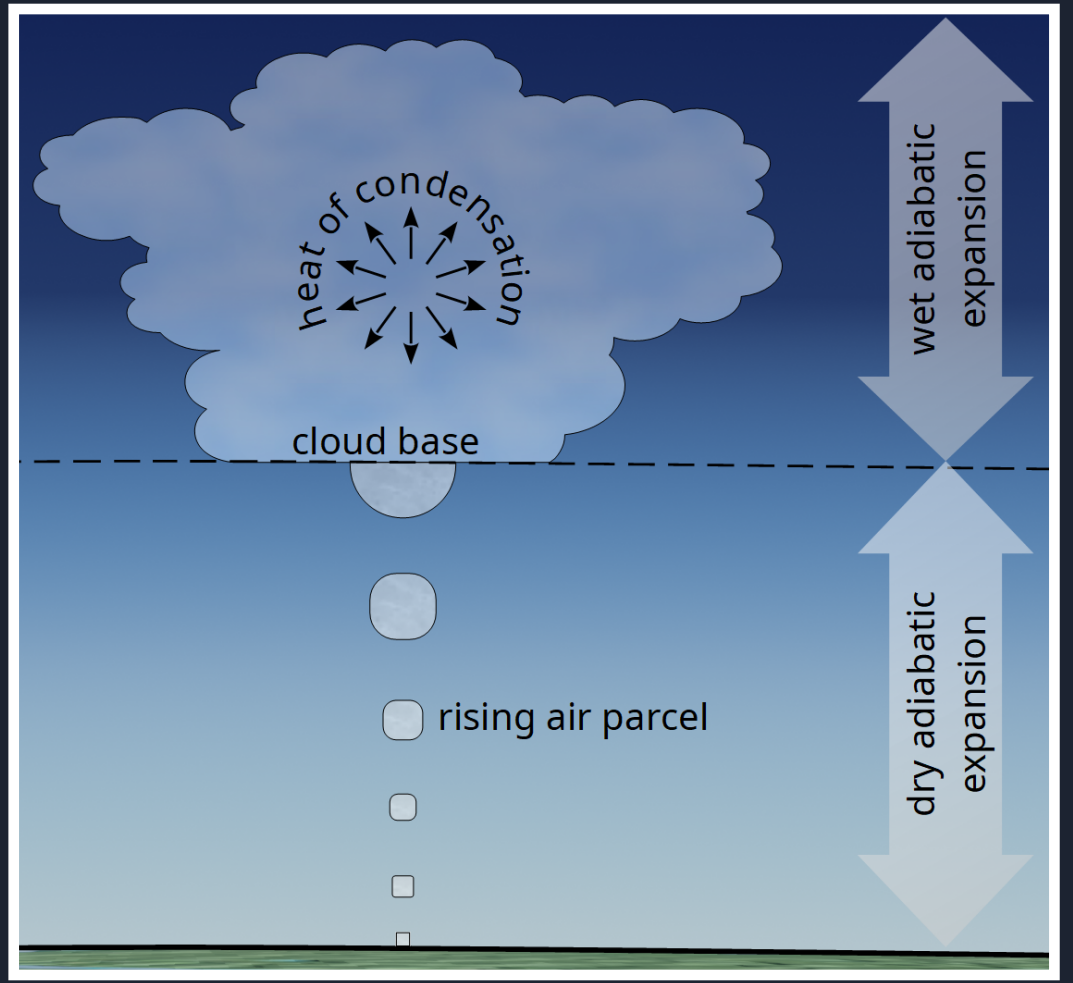

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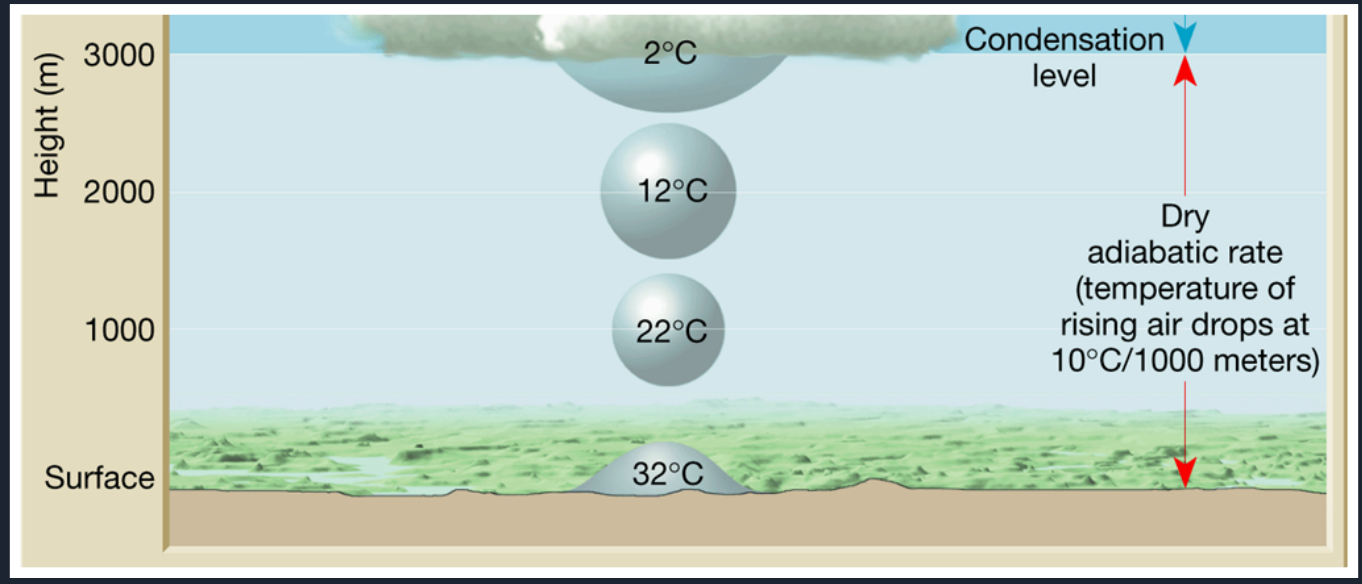
~ This ***reduced rate*** of ***cooling***, which varies between ***5˚*** and ***9˚C per km***, depending on how much vapor is condensing, is called the ***wet*** (or ***saturated***) ***adiabatic lapse rate***.



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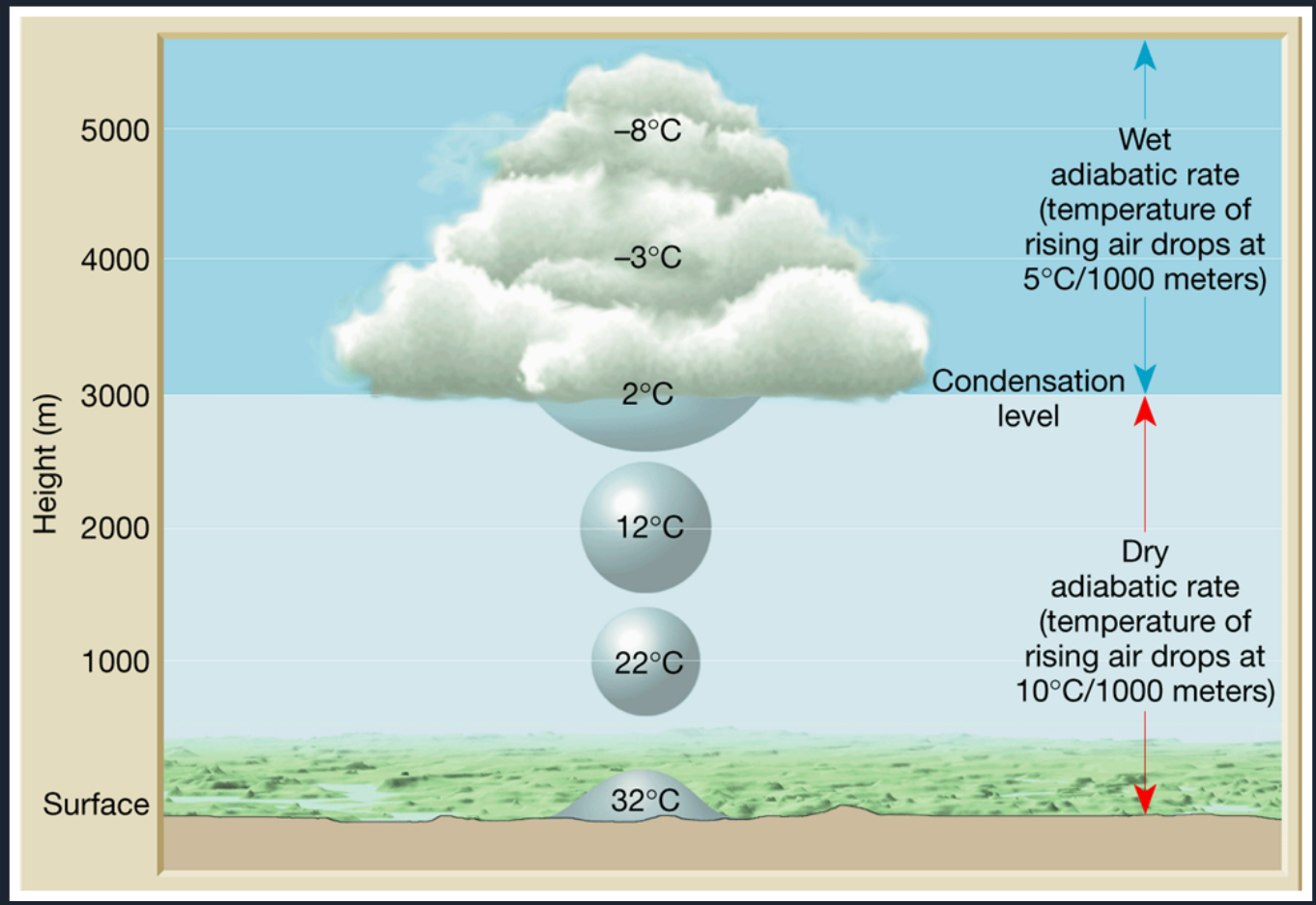
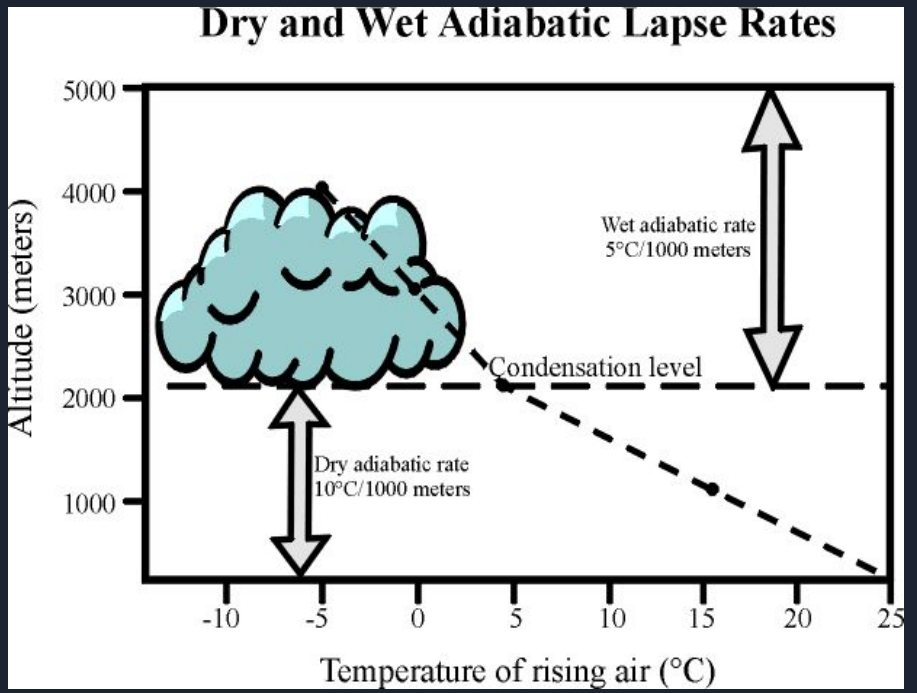
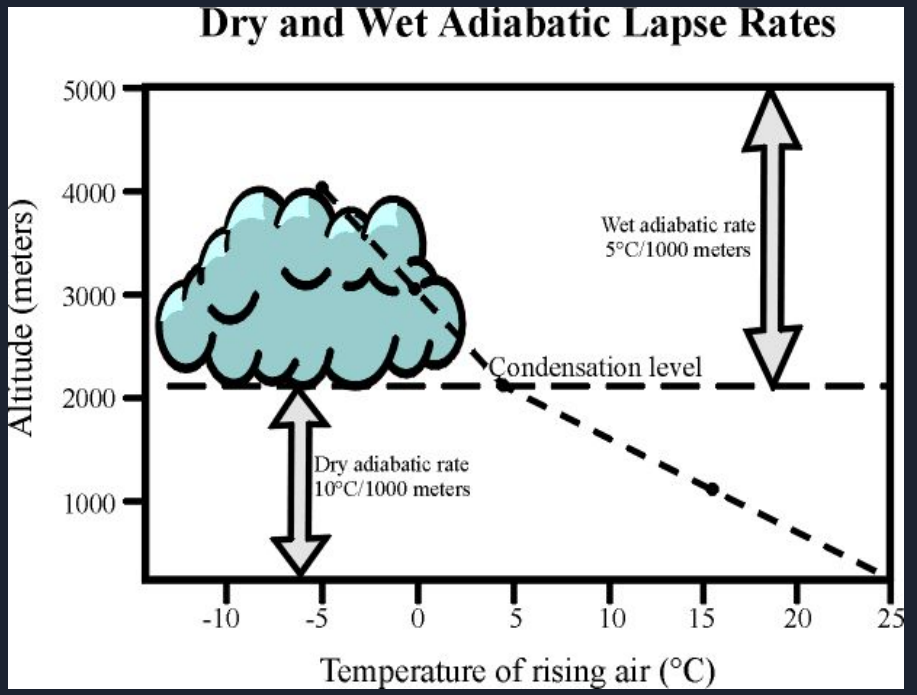



Dry and Wet Adiabatic Lapse Rates
5000
4000
3000
2000
1000
Altitude (meters)
Wet adiabatic rate
5°C/1000 meters
Condensation level
Dry adiabatic rate
10°C/1000 meters
-10
-5
0
5
10
15
20
25
Temperature of rising air (°C)

~ We've learned that when ***air rises***, it ***expands***, ***cools***, and forms ***clouds***, but ***what determines <u>if</u> air rises***?



Atmospheric stability

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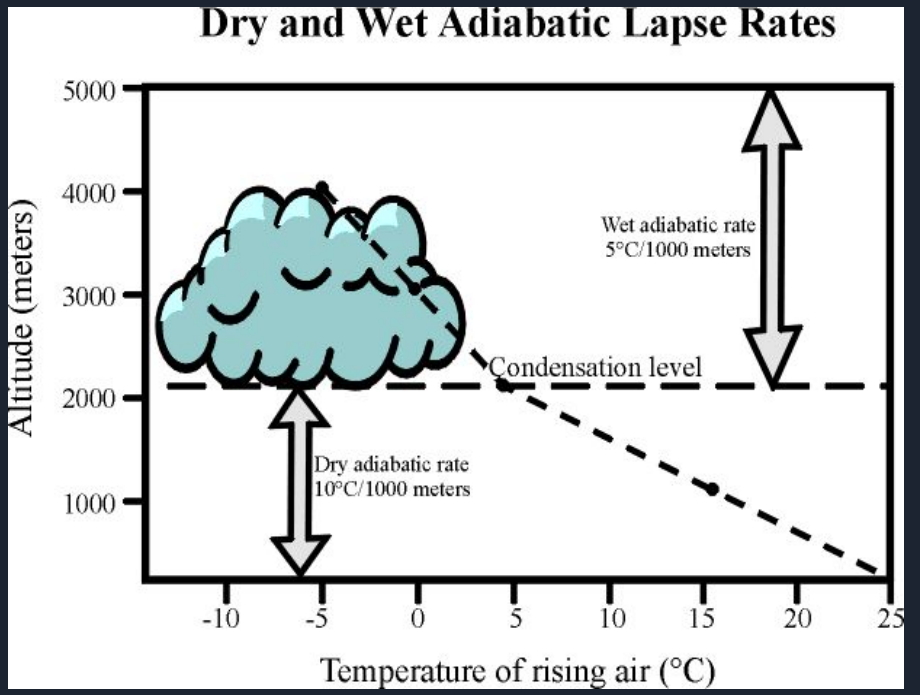

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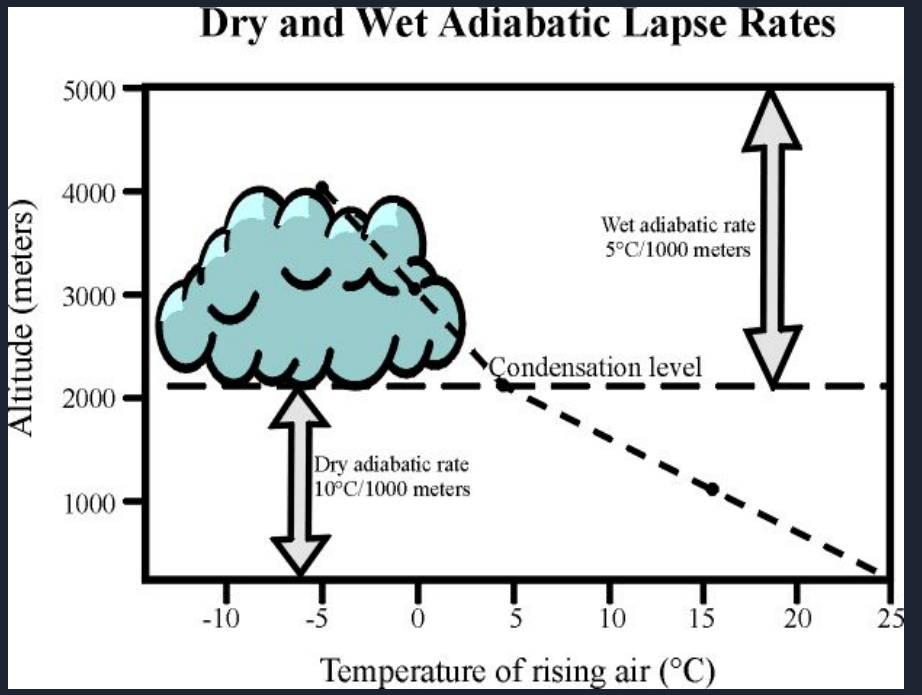

~ The answer relates to ***atmospheric stability*** or determining ***whether parcels*** will ***rise*** on their ***own*** or ***need*** a ***push***.

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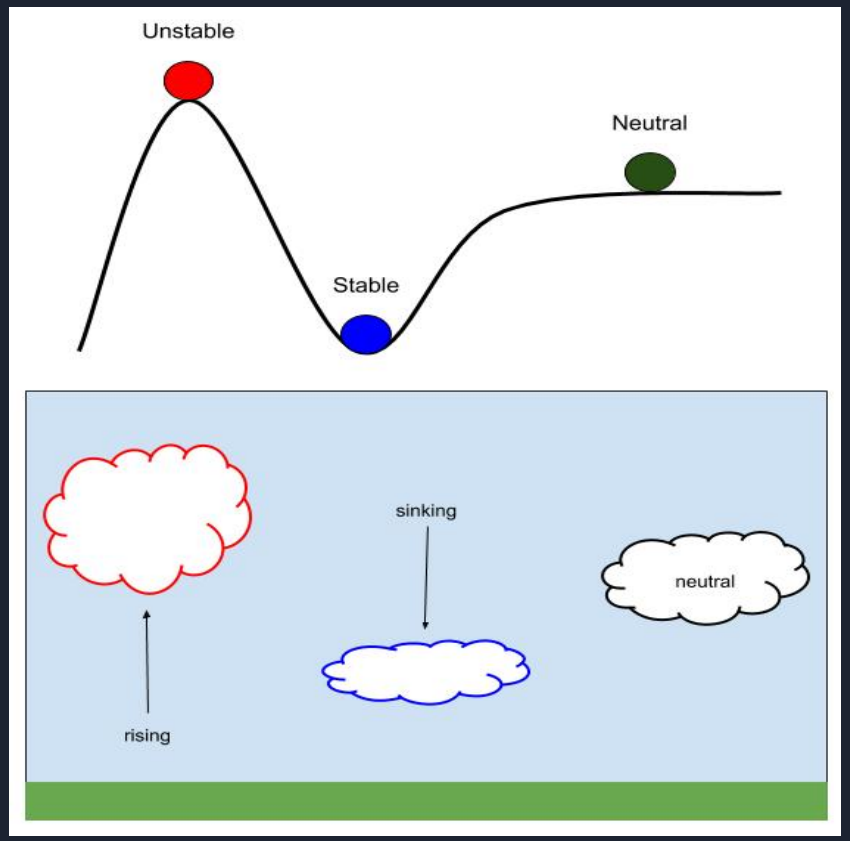

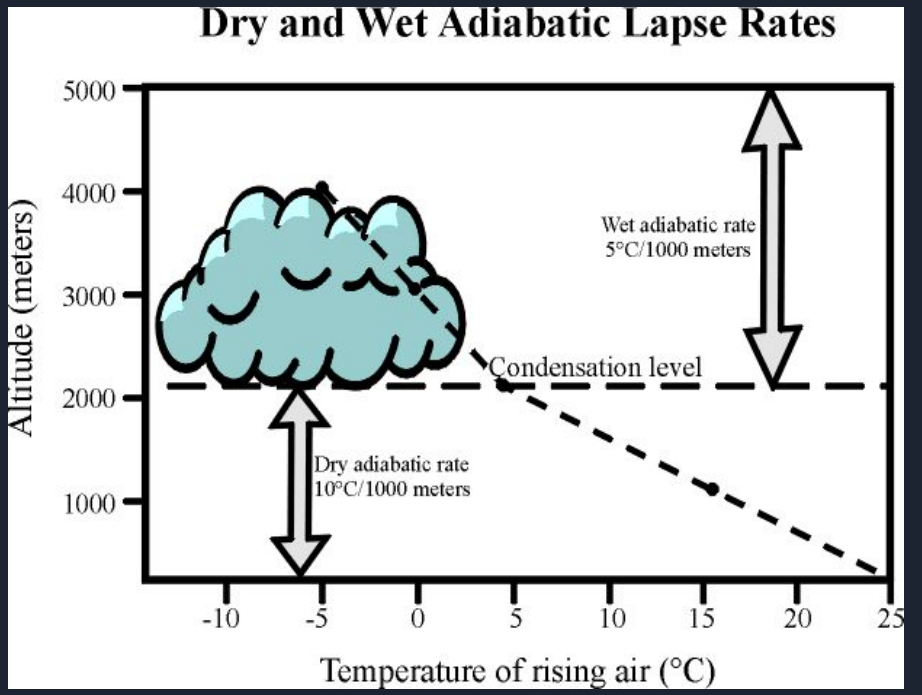

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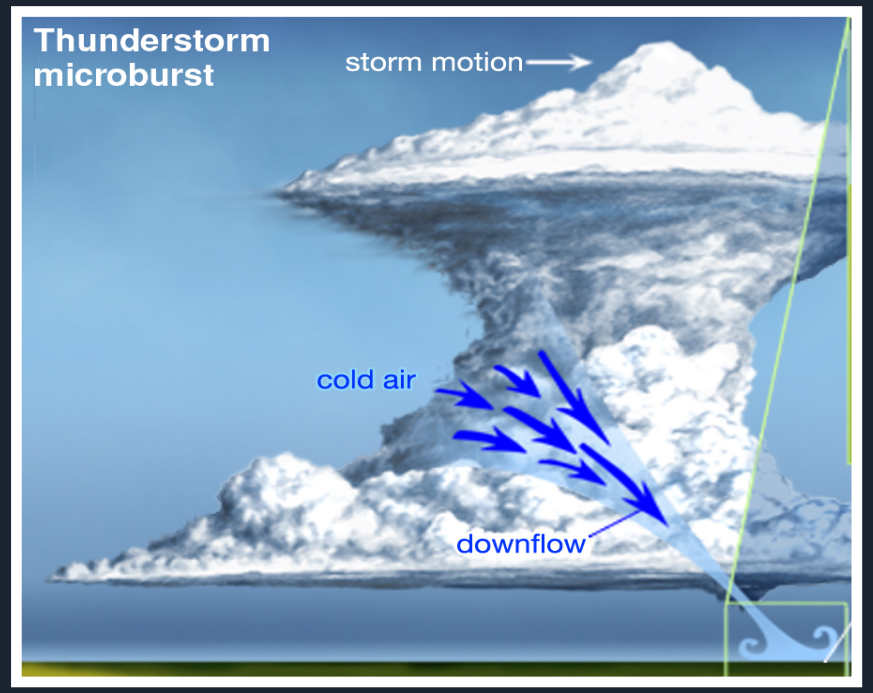

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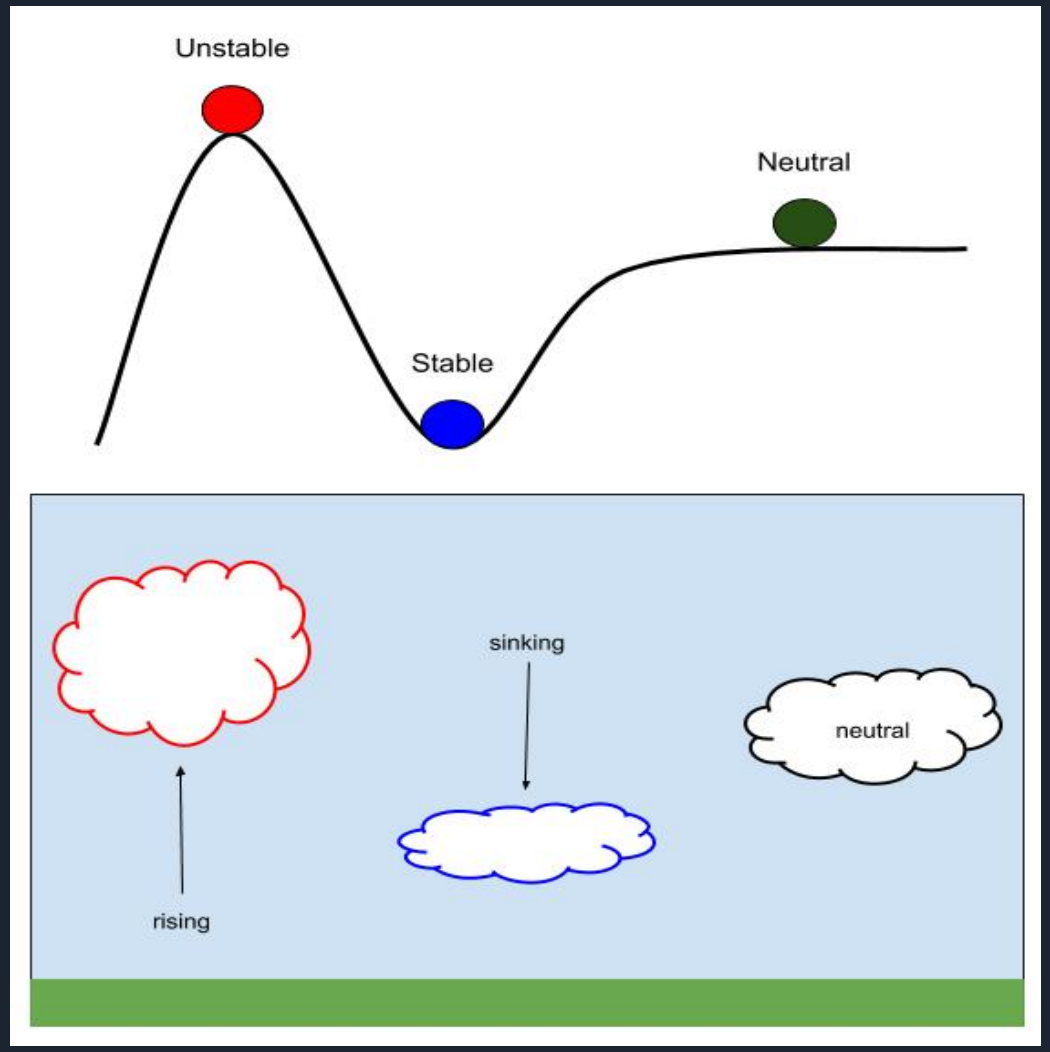

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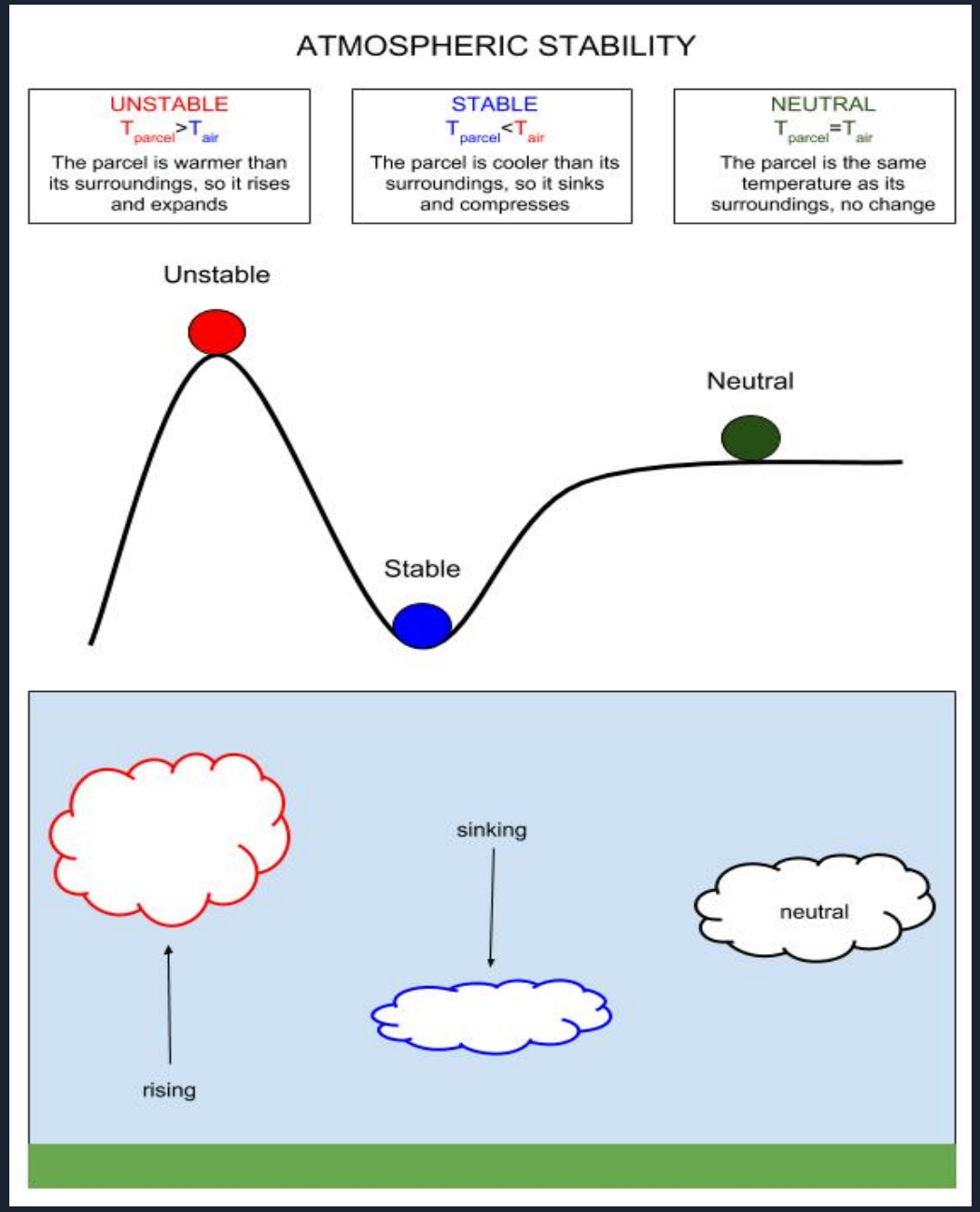

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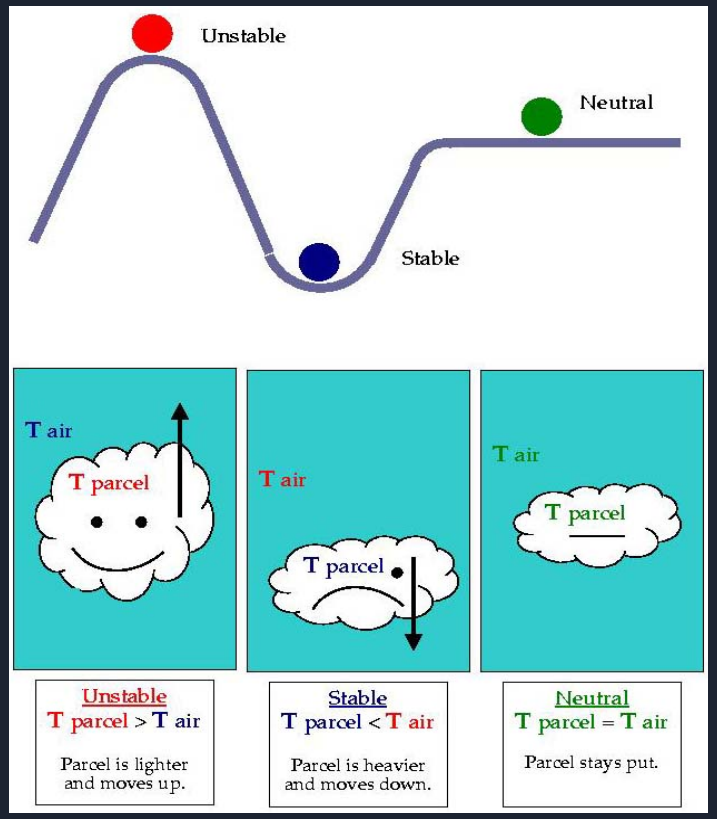
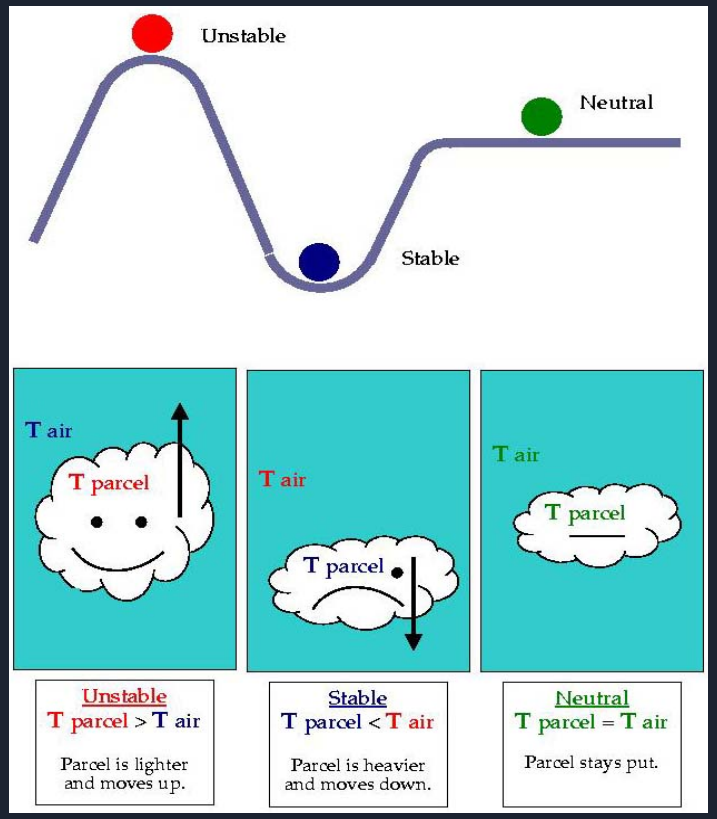

Unstable
Neutral
Stable
T air
T parcel
T air
T parcel
T air
T parcel
Unstable
T parcel > T air
Parcel is lighter and moves up.
Stable
T parcel < T air
Parcel is heavier and moves down.
Neutral
T parcel = T air
Parcel stays put.

~ The ***stability*** of a parcel is ***determined*** by ***comparing*** the ***temperature*** of the ***parcel*** ***to*** that of the ***environment*** at various ***heights***.



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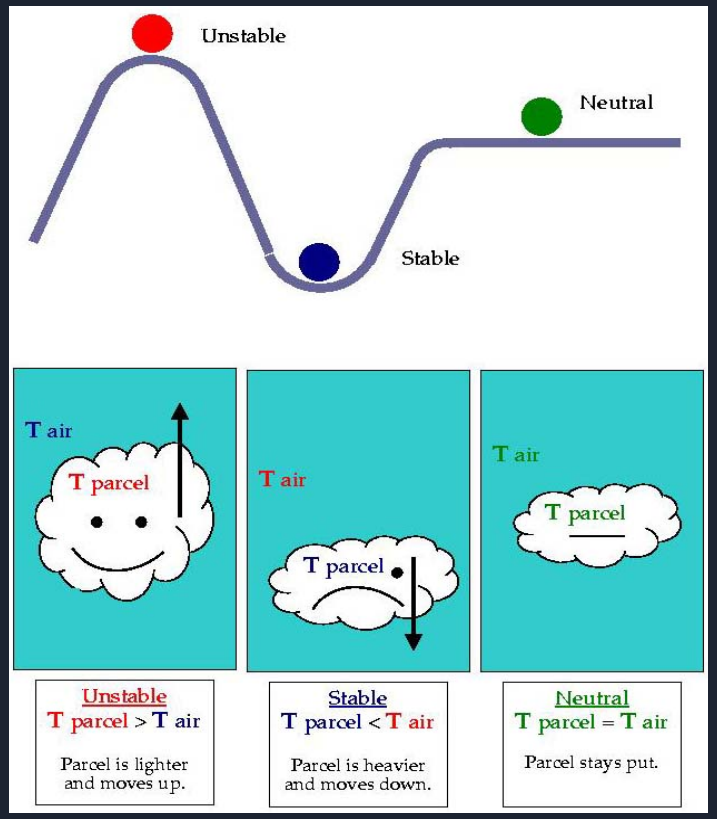
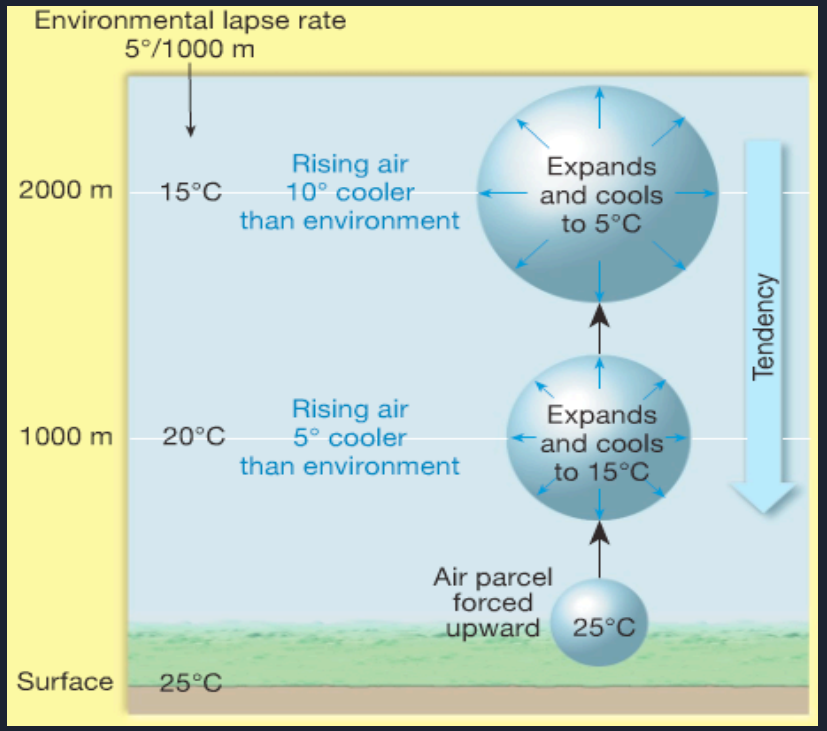
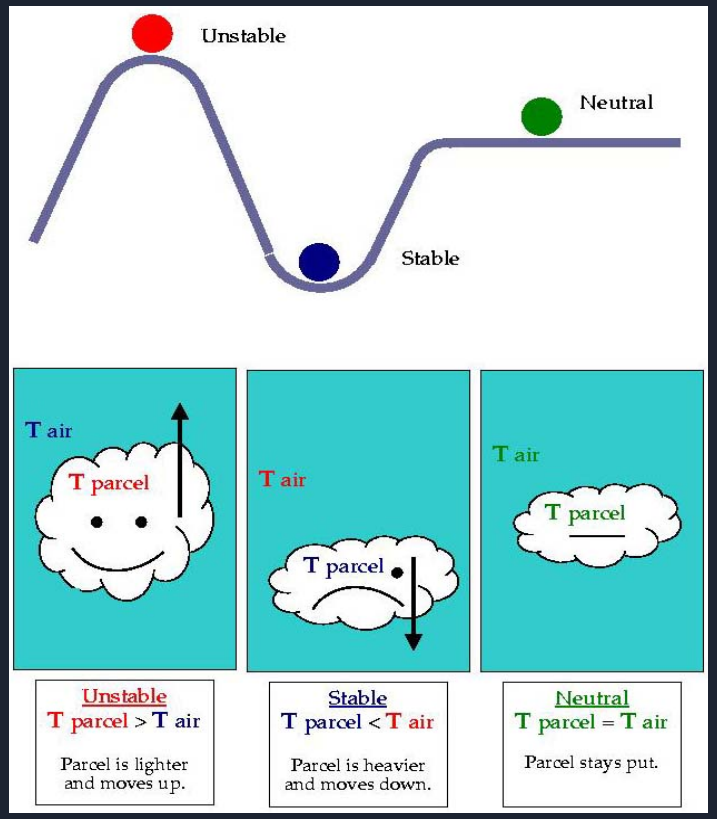


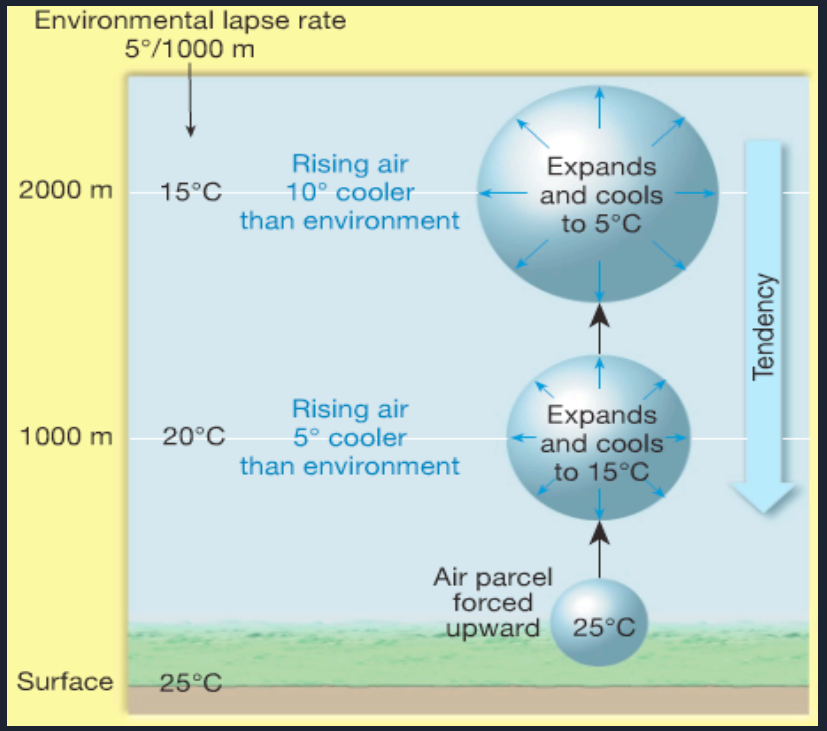
~ Recall that the ***rate*** at which the ***environment changes*** with height is the (environmental) ***lapse rate*** (measured by a ***radiosonde***).

~ The ***stability*** of a parcel is ***determined*** by ***comparing*** the ***temperature*** of the ***parcel*** ***to*** that of the ***environment*** at various ***heights***.

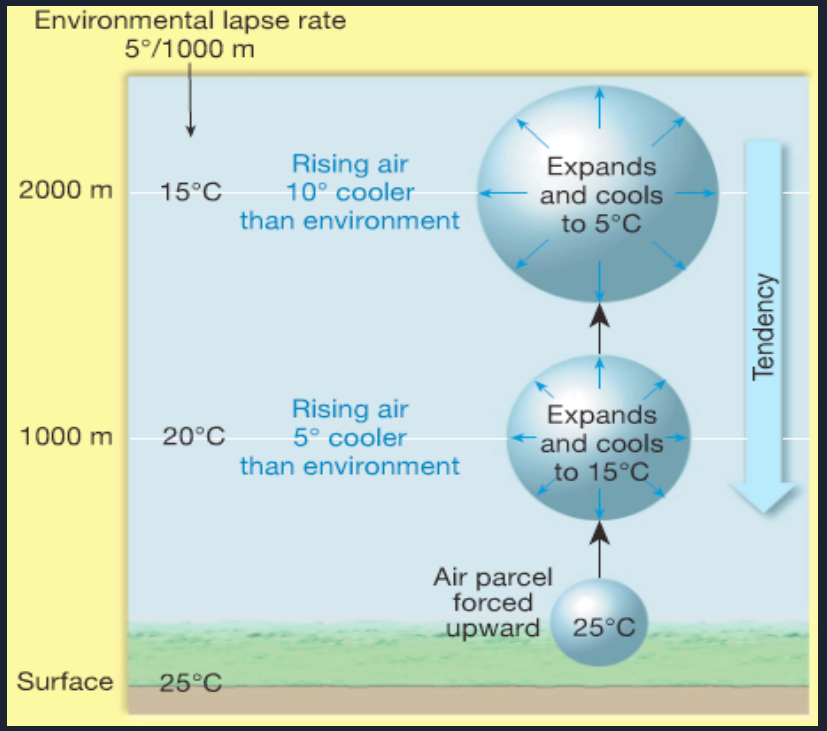




~ Recall that the ***rate*** at which the ***environment changes*** with height is the (environmental) ***lapse rate*** (measured by a ***radiosonde***).

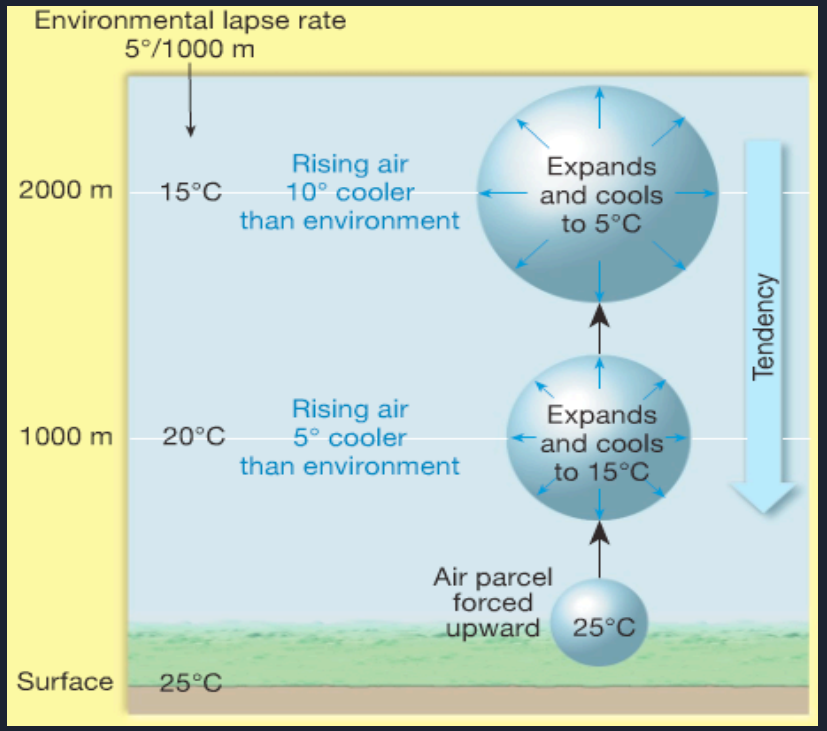

Environmental lapse rate
5°/1000 m
2000 m
15°C
Rising air
10° cooler
than environment
Expands
and cools
to 5°C
Tendency
1000 m
20°C
Rising air
5° cooler
than environment
Expands
and cools
to 15°C
Air parcel
forced
upward
25°C
Surface
25°C

~ In the figure, the ***environmental lapse rate*** is ***5˚C per km***.



~ In the figure, the ***environmental lapse rate*** is ***5˚C per km***.

~ If the ***25˚C***, ***unsaturated parcel*** is ***forced*** to ***rise***, it will ***cool*** at the ***dry adiabatic lapse rate*** of ***10˚C per km***, so at ***1 km*** it is ***15˚C***, ***5˚C cooler*** than the ***environment***.



~ In the figure, the ***environmental lapse rate*** is ***5˚C per km***.

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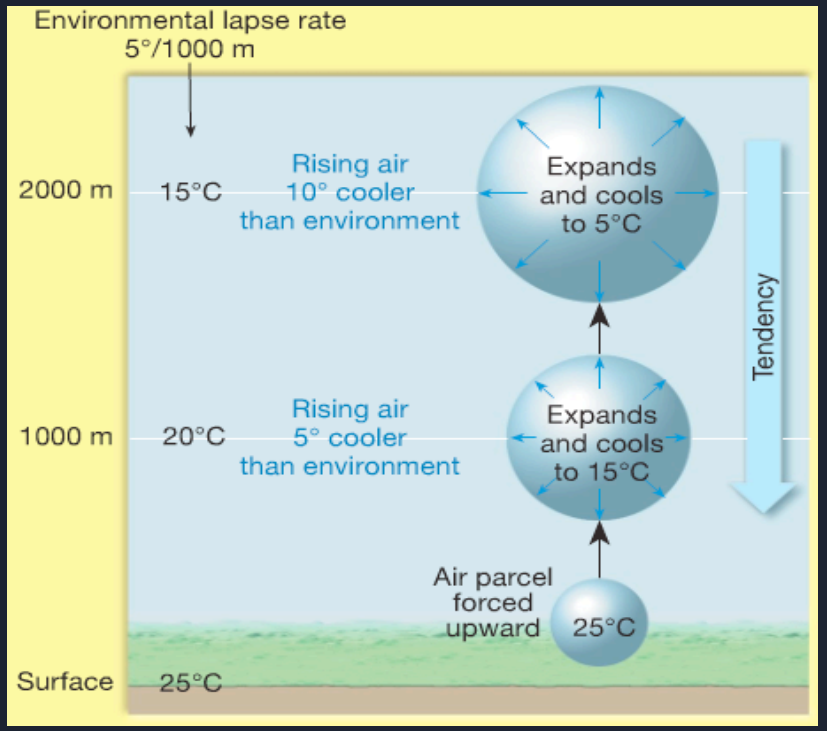
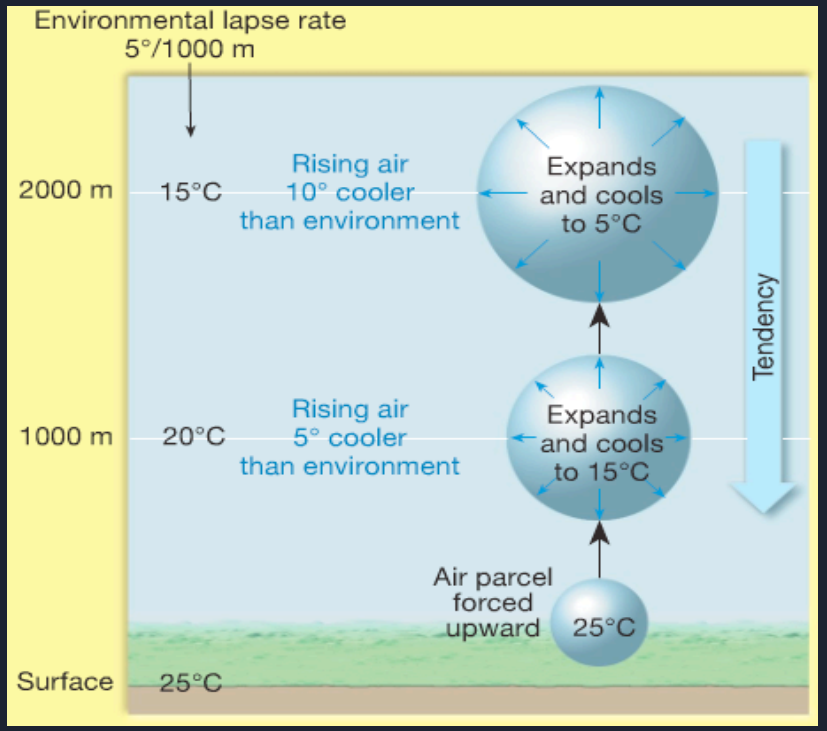


~ If the ***parcel continues*** to be ***forced*** to ***rise*** to ***2 km***, it will cool to ***5˚C***, while the ***environment*** is ***15˚C***.

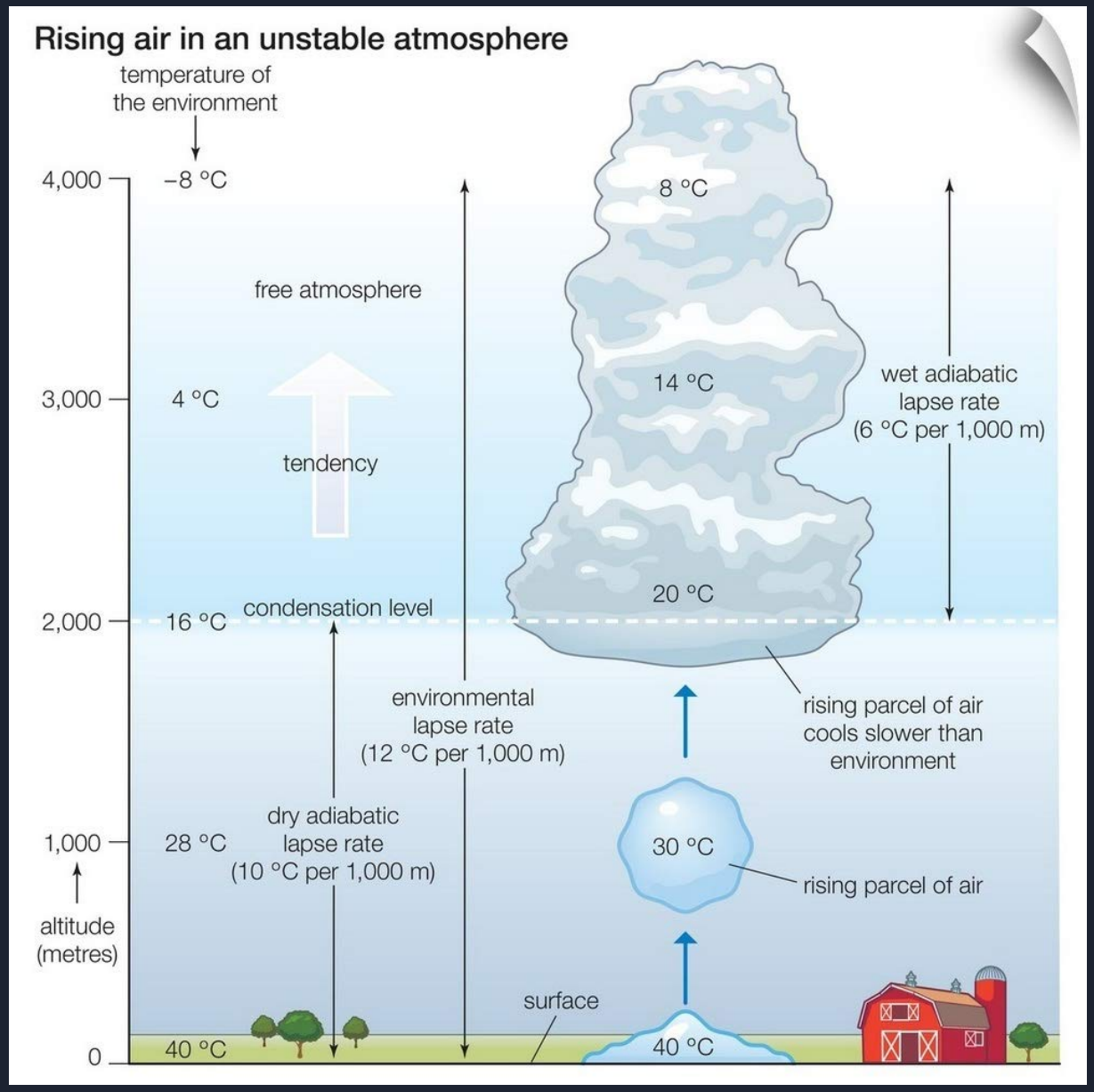
~ In the figure, the ***environmental lapse rate*** is ***5˚C per km***.

~ If the ***25˚C***, ***unsaturated parcel*** is ***forced*** to ***rise***, it will ***cool*** at the ***dry adiabatic lapse rate*** of ***10˚C per km***, so at ***1 km*** it is ***15˚C***, ***5˚C cooler*** than the ***environment***.

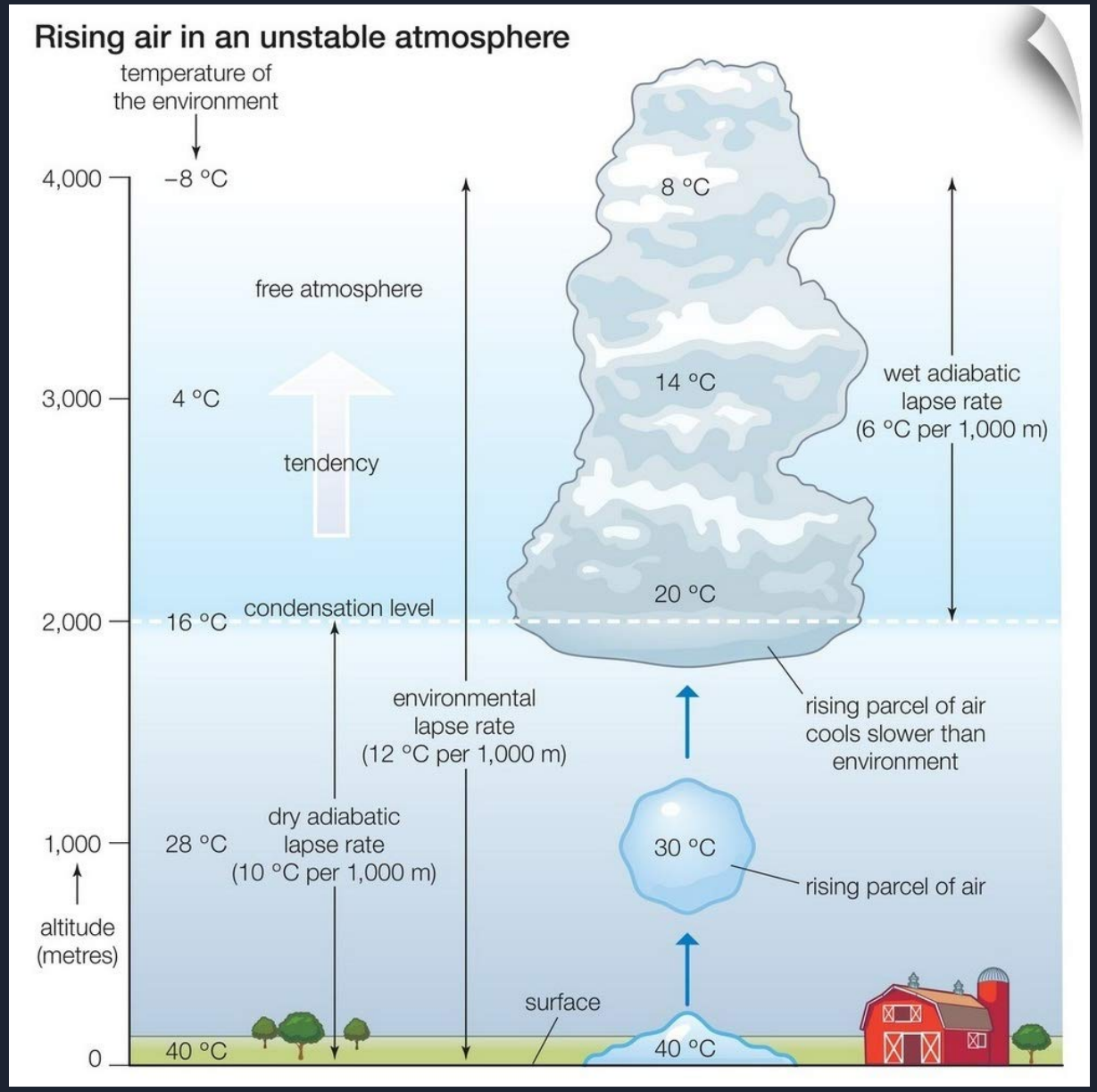


~ If the ***parcel*** ***continues*** to be ***forced*** to ***rise*** to ***2 km***, it will cool to ***5˚C***, while the ***environment*** is ***15˚C***.

~ At these heights, the ***parcel*** is ***colder*** than the environment, or ***stable***, and would ***sink*** ***back down*** (if it's able).


Rising air in an unstable atmosphere
temperature of the environment
4,000
−8 °C
3,000
4 °C
2,000
16 °C
1,000
28 °C
0
altitude (metres)
free atmosphere
tendency
condensation level
dry adiabatic lapse rate (10 °C per 1,000 m)
environmental lapse rate (12 °C per 1,000 m)
wet adiabatic lapse rate (6 °C per 1,000 m)
8 °C
14 °C
20 °C
rising parcel of air cools slower than environment
30 °C
rising parcel of air
surface
40 °C
40 °C

~ The ***environmental lapse rate*** ***changes*** with time, height, and location, while the ***parcels' adiabatic lapse rates*** are ***constants***.



~ We *define three stability conditions*: *absolute stability*, *absolute instability*, and *conditional instability*.

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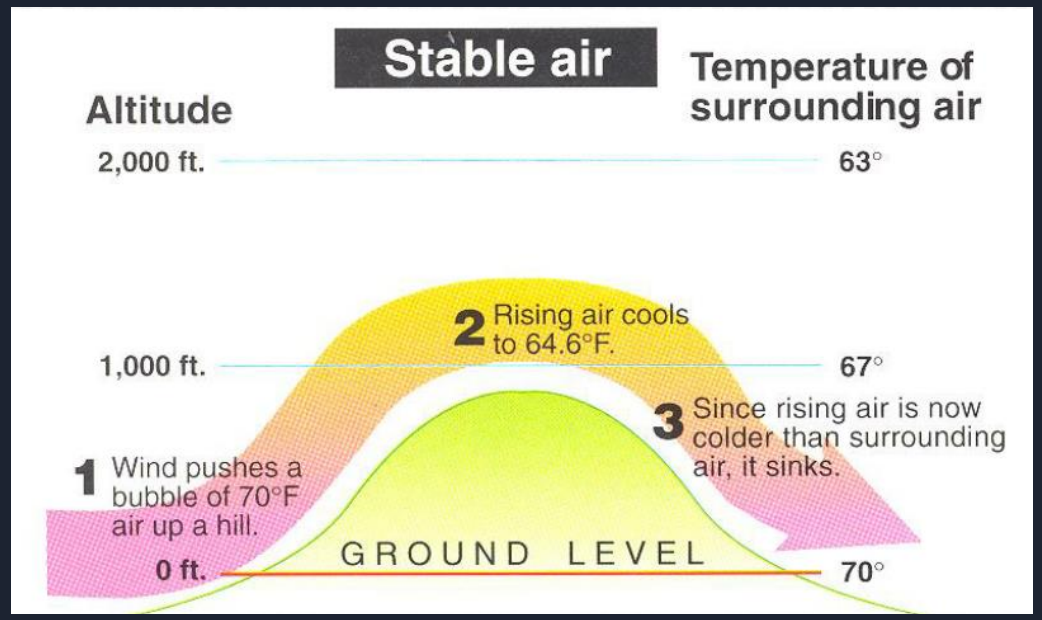
~ *Absolute stability* occurs when the *environmental lapse rate* is *less* than the *wet adiabatic lapse rate*, or the *environment* is *cooling less than* the *parcel with height*.



~ We ***define three stability conditions***: ***absolute stability***, ***absolute instability***, and ***conditional instability***.

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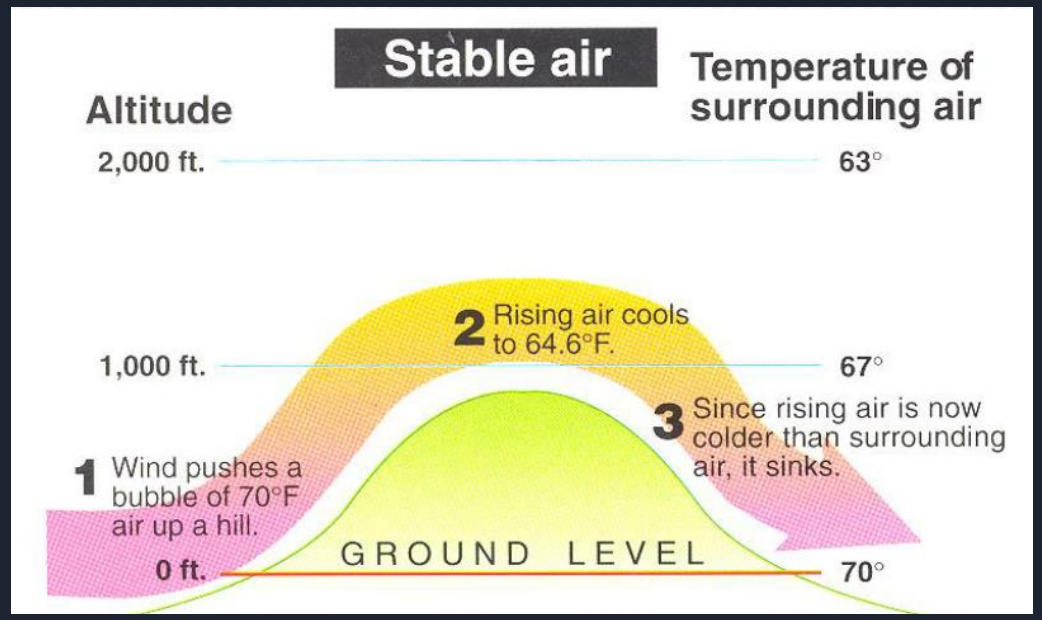

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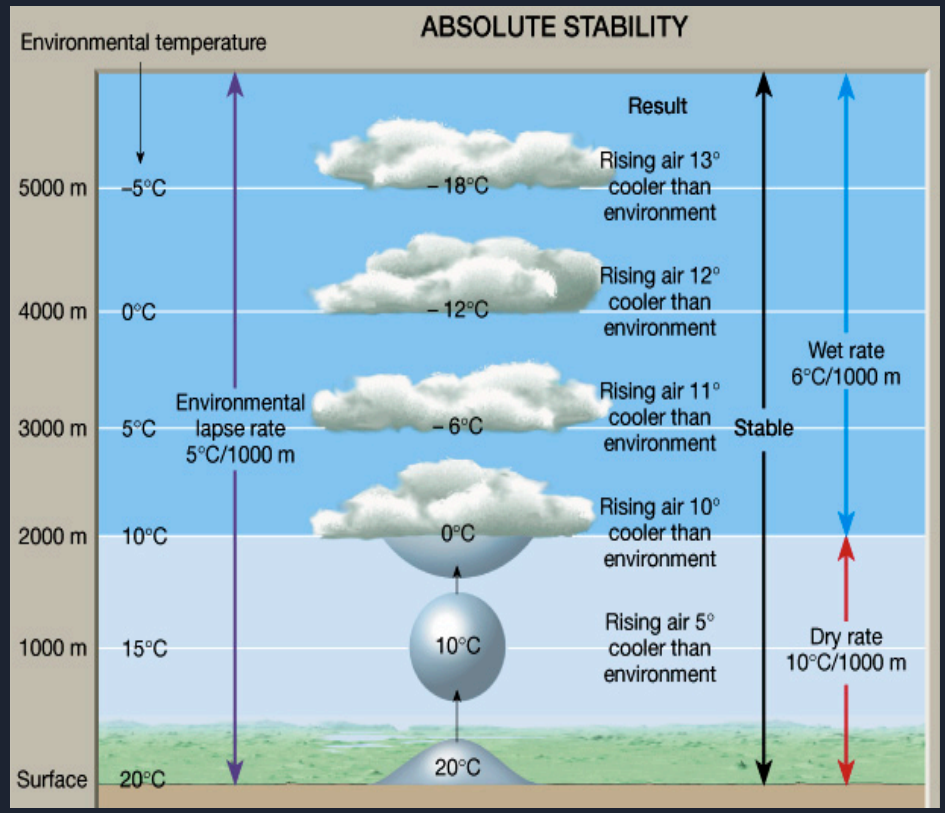
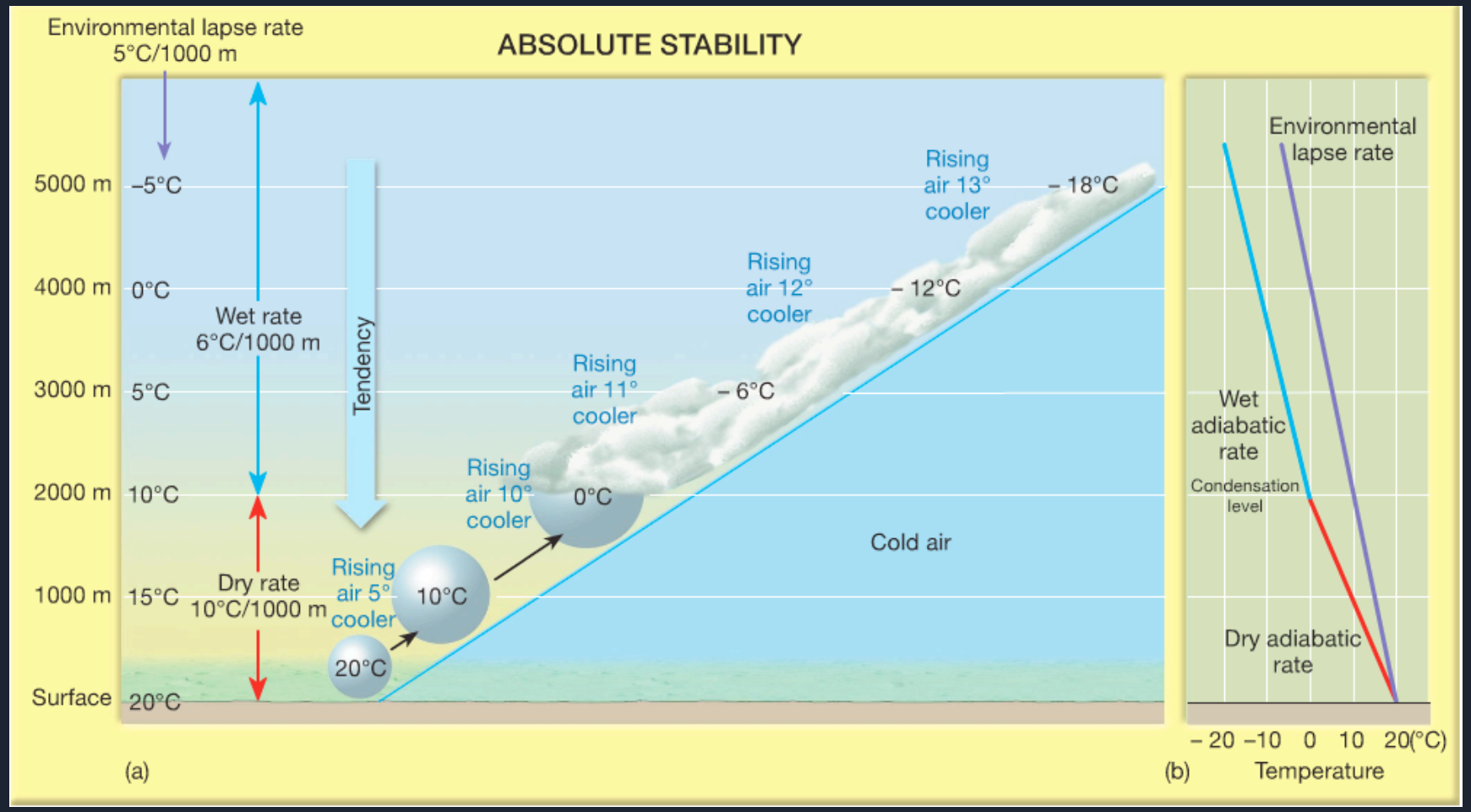
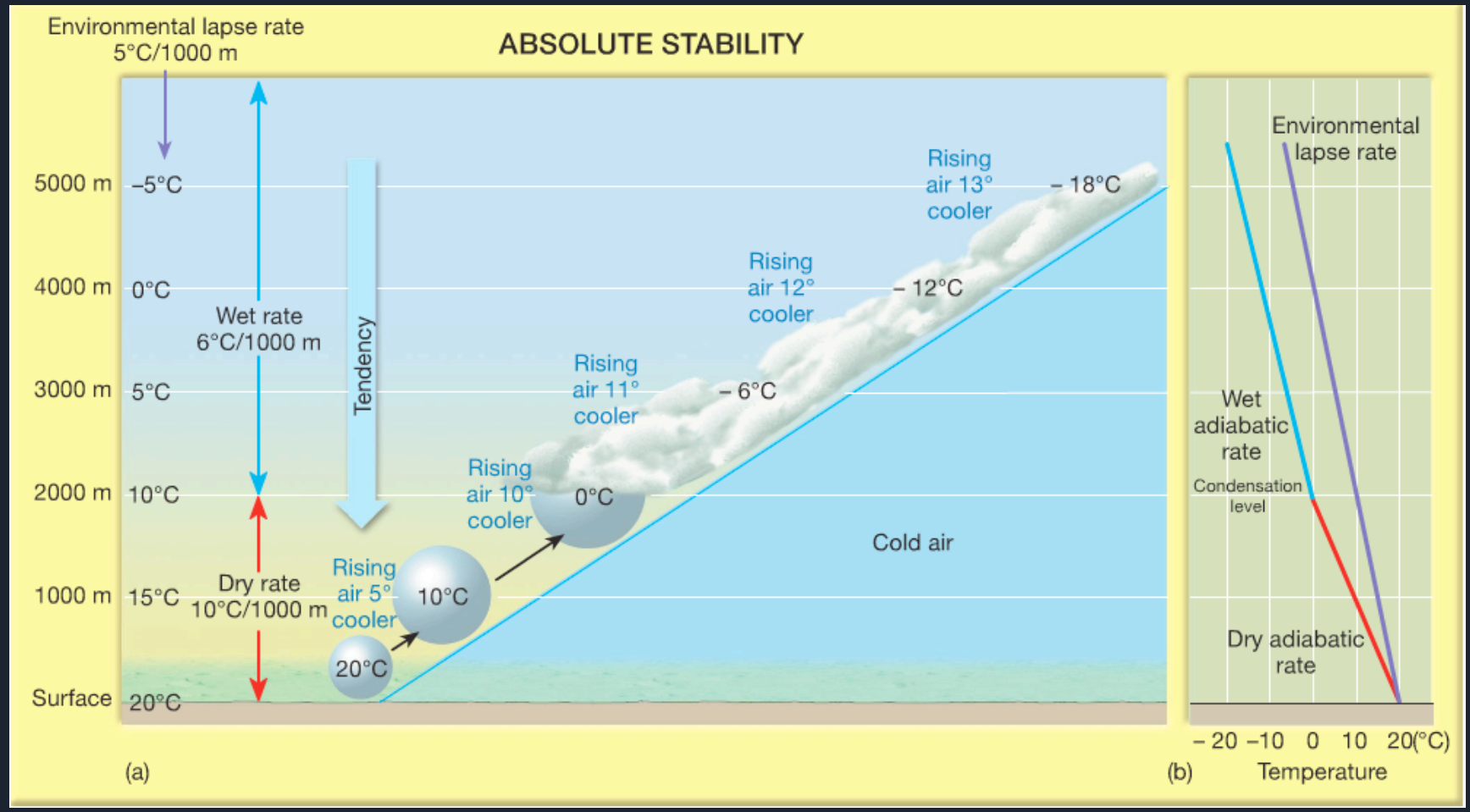



ABSOLUTE STABILITY
Environmental lapse rate
5°C/1000 m
5000 m
4000 m
3000 m
2000 m
1000 m
Surface
–5°C
0°C
5°C
10°C
15°C
20°C
Wet rate
6°C/1000 m
Dry rate
10°C/1000 m
Tendency
Rising air 5° cooler
10°C
20°C
Rising air 10° cooler
0°C
Rising air 11° cooler
– 6°C
Rising air 12° cooler
– 12°C
Rising air 13° cooler
– 18°C
Cold air
(a)
Environmental lapse rate
Wet adiabatic rate
Condensation level
Dry adiabatic rate
– 20 –10 0 10 20(°C)
Temperature
(b)

~ The figure shows a ***wet adiabatic lapse rate*** of ***6˚C per km*** and an ***environmental lapse rate*** of ***5˚C per km***; the ***parcel*** is ***stable***, but is being ***forced*** to ***rise*** due to ***frontal wedging***.



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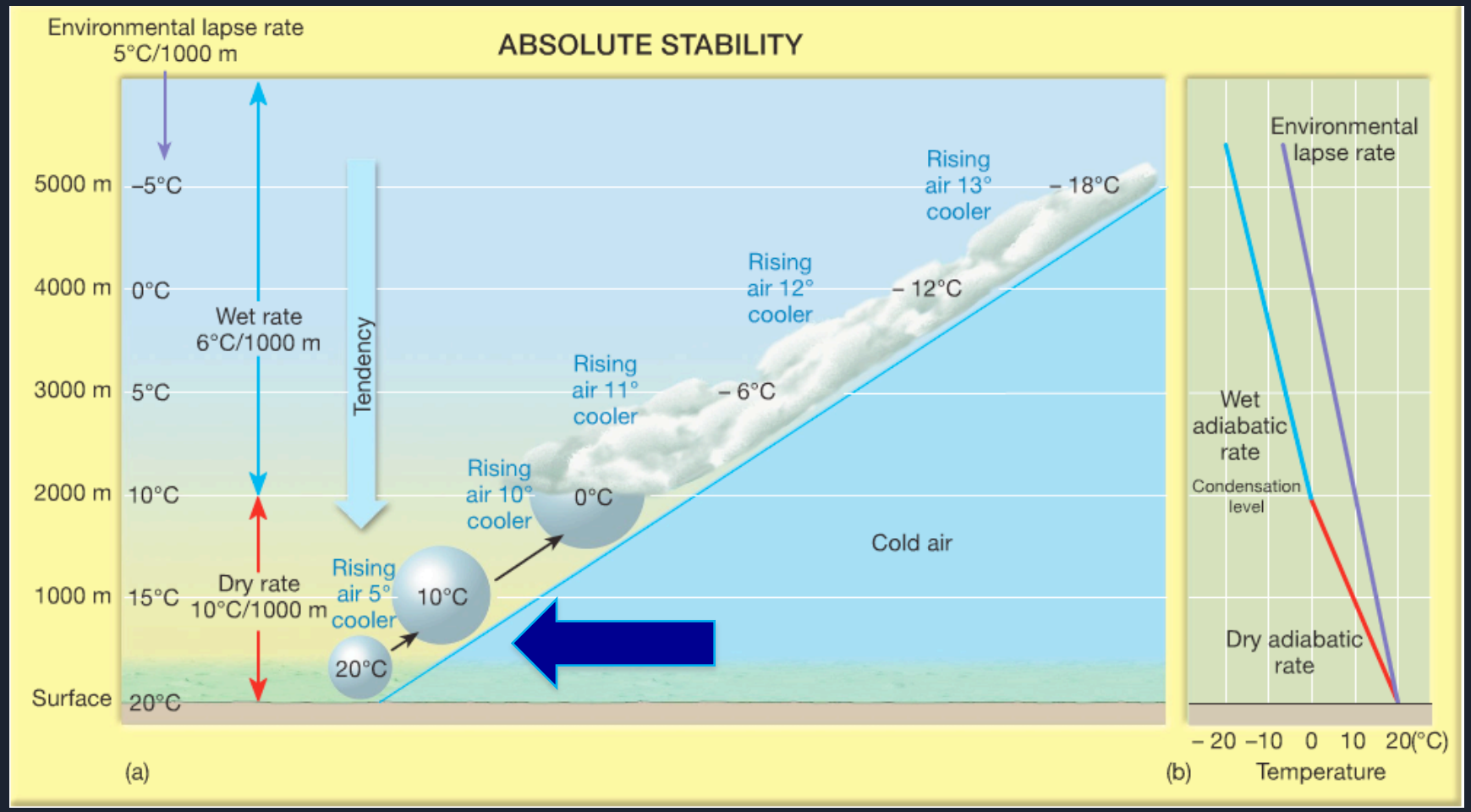
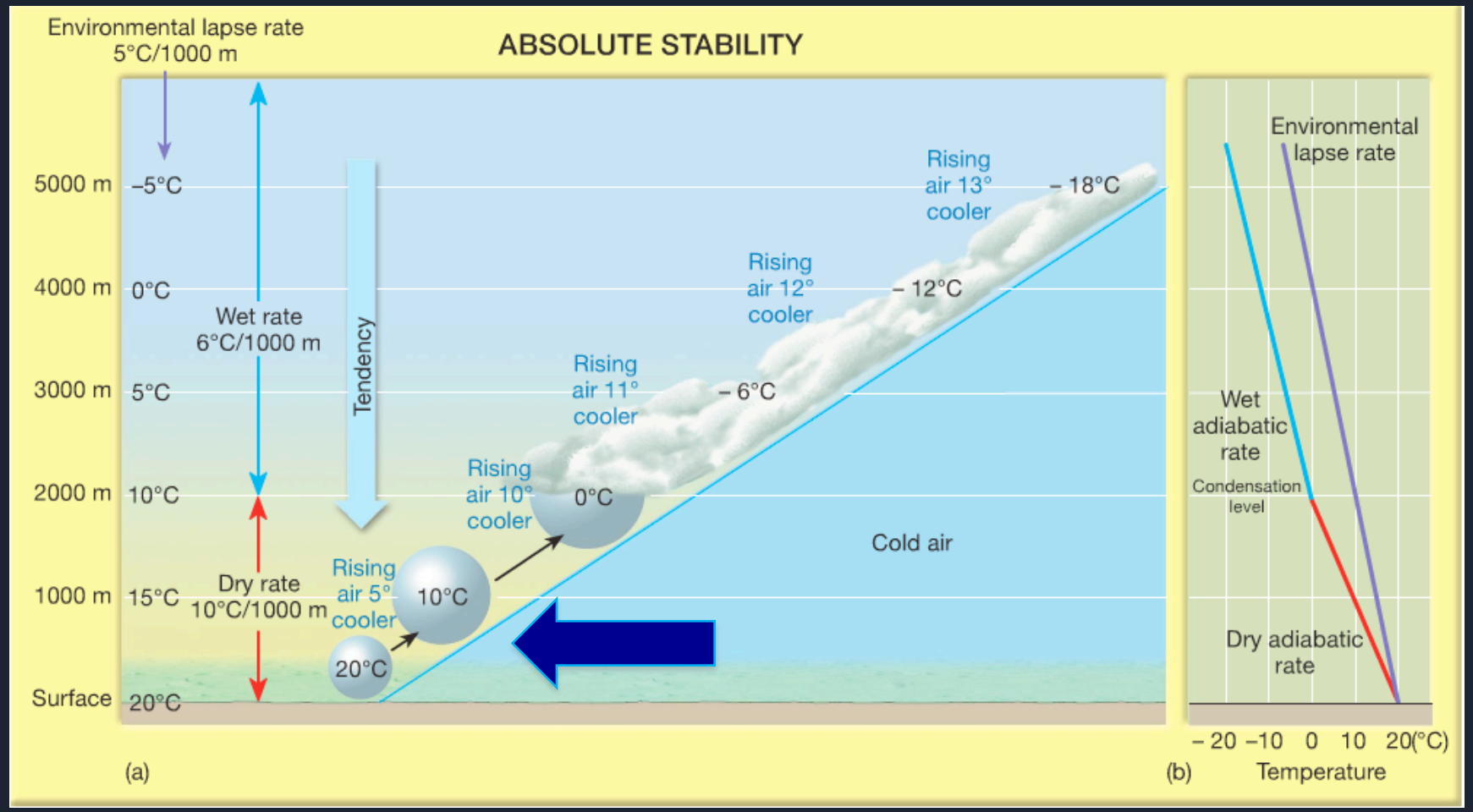


~ If *stable air* is ***forced*** to ***rise***, the *clouds* that form are *widespread* and have *little vertical depth* with dark and dreary weather.



~ The ***most stable*** atmosphere is when the environmental ***temperature increases*** with height, called an ***inversion***.

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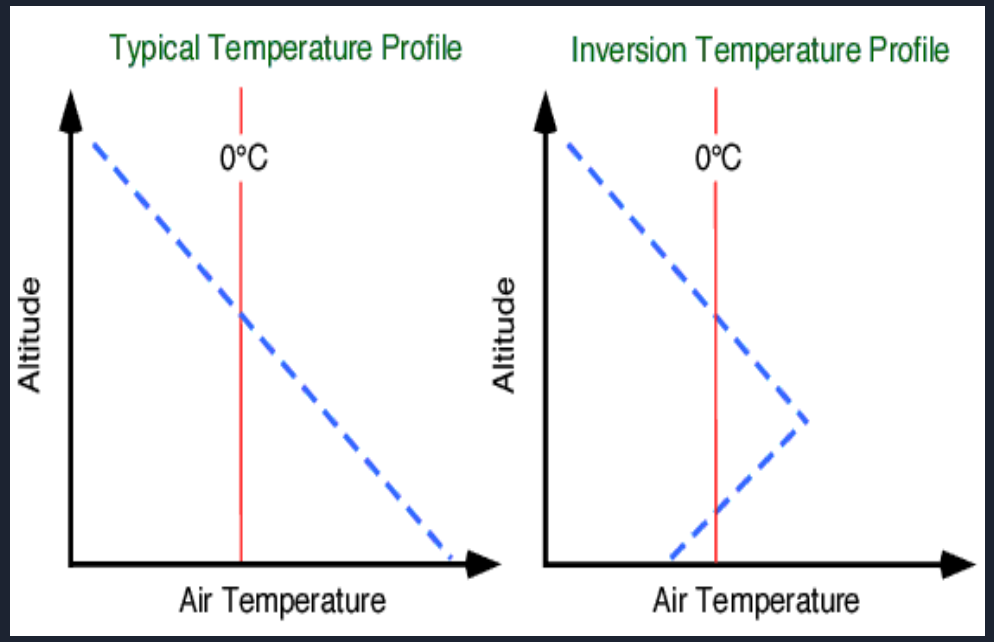

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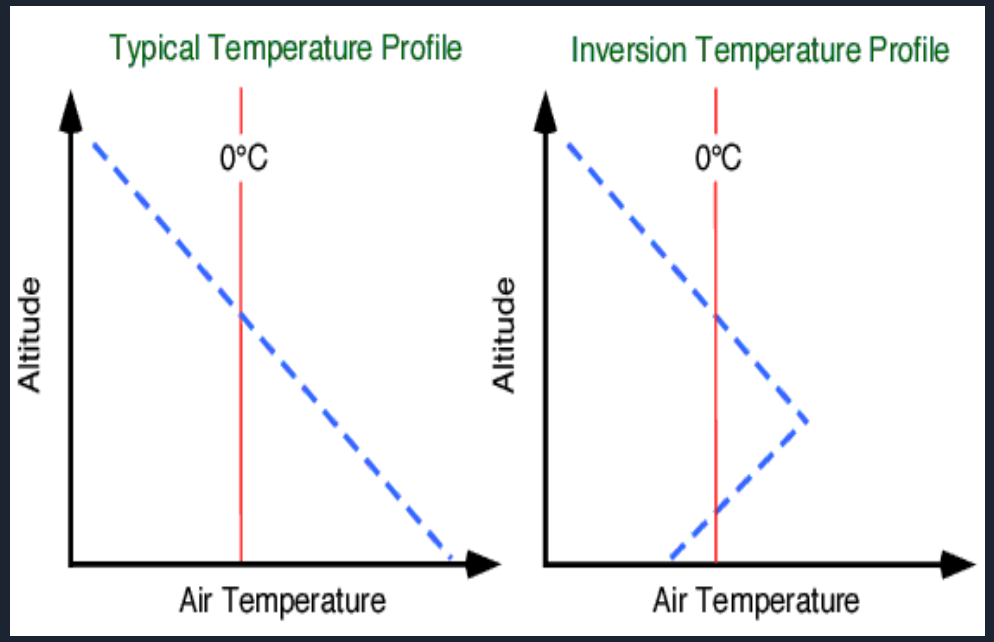

~ ***Inversions*** happen when the ***ground cools*** more ***rapidly*** than the air just above, or when there is ***sinking air aloft*** that ***warms*** as it ***descends***.

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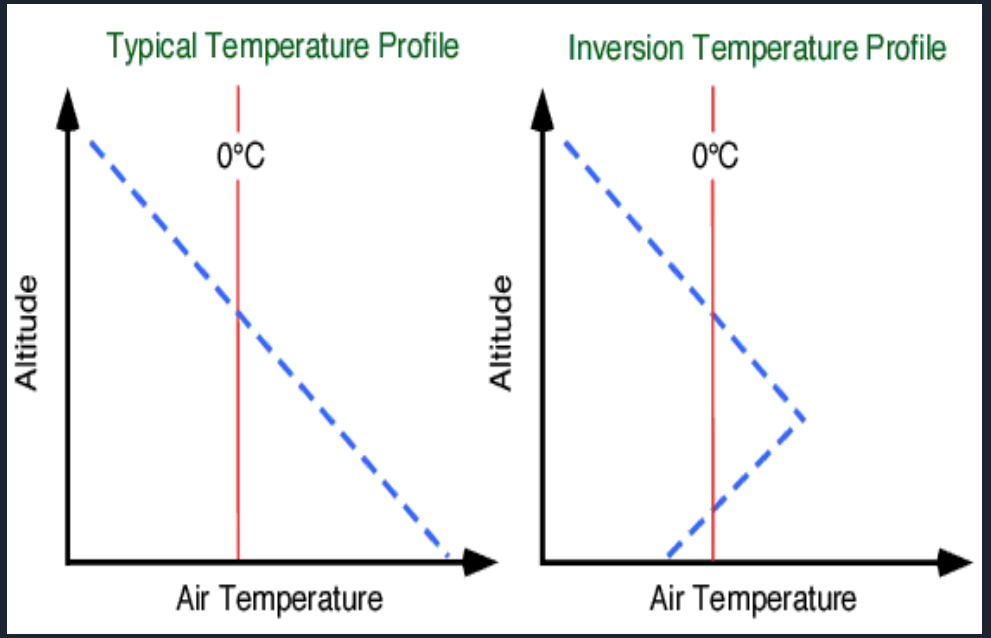

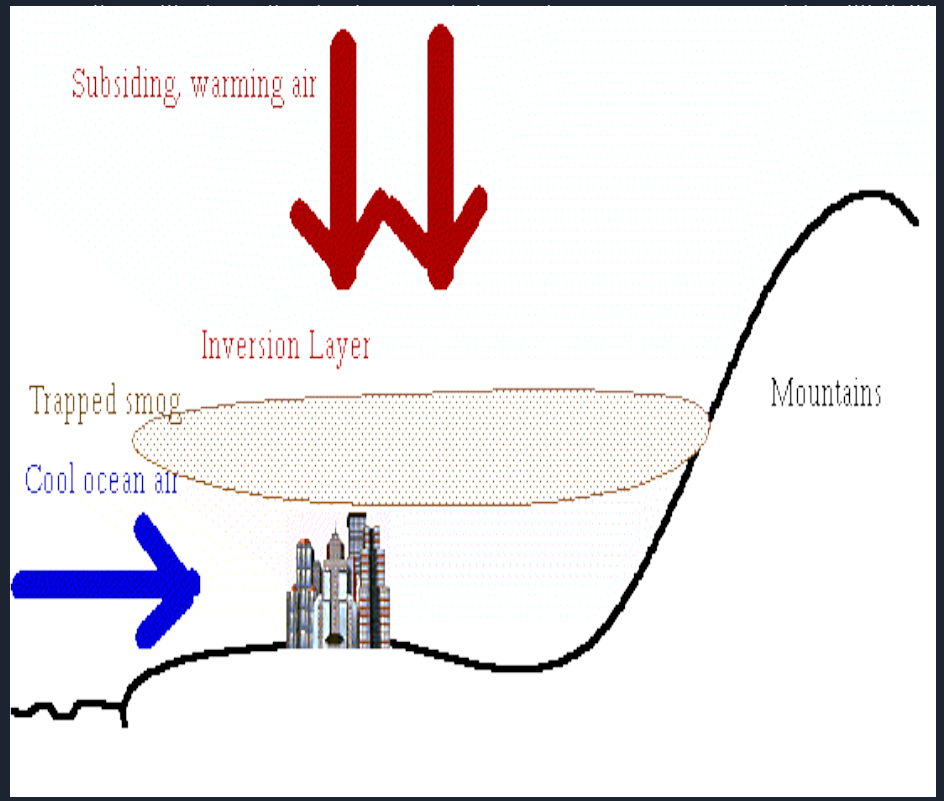

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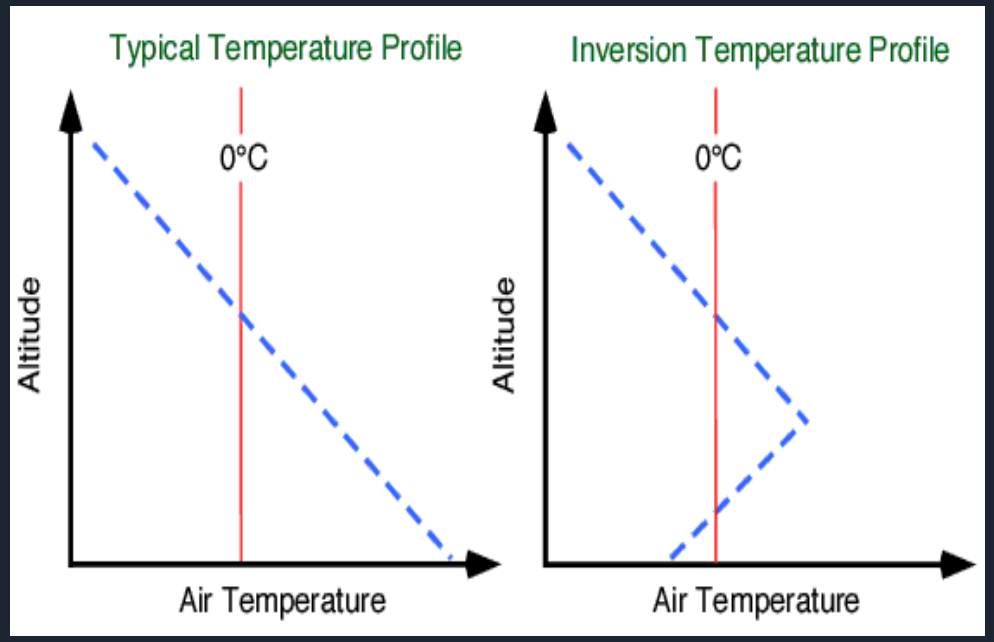
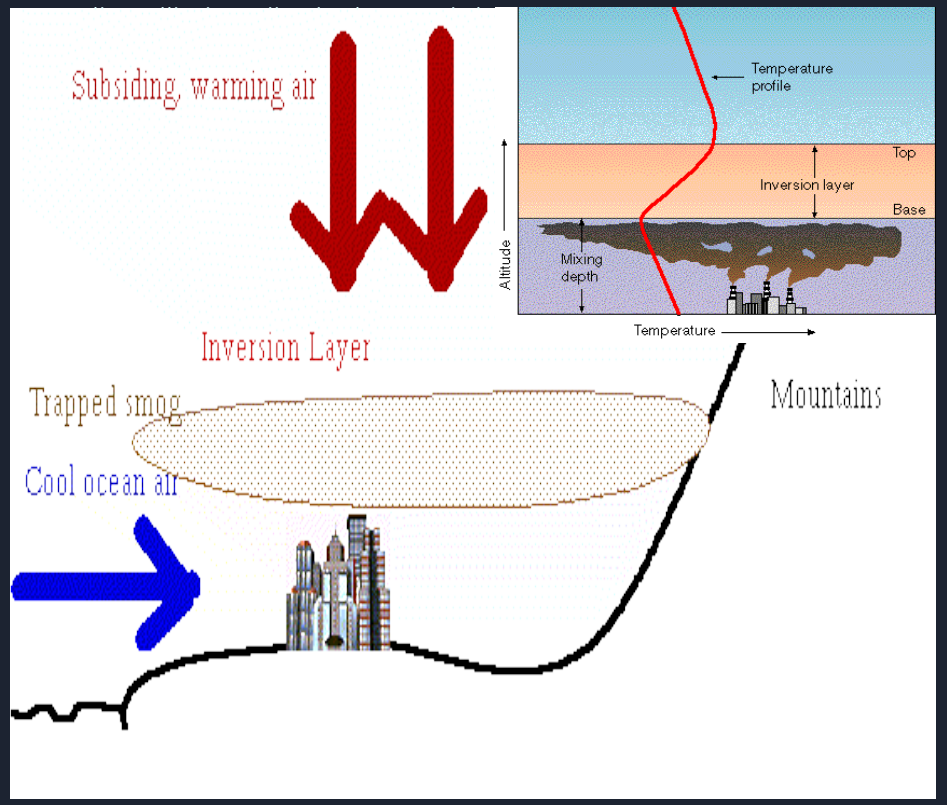
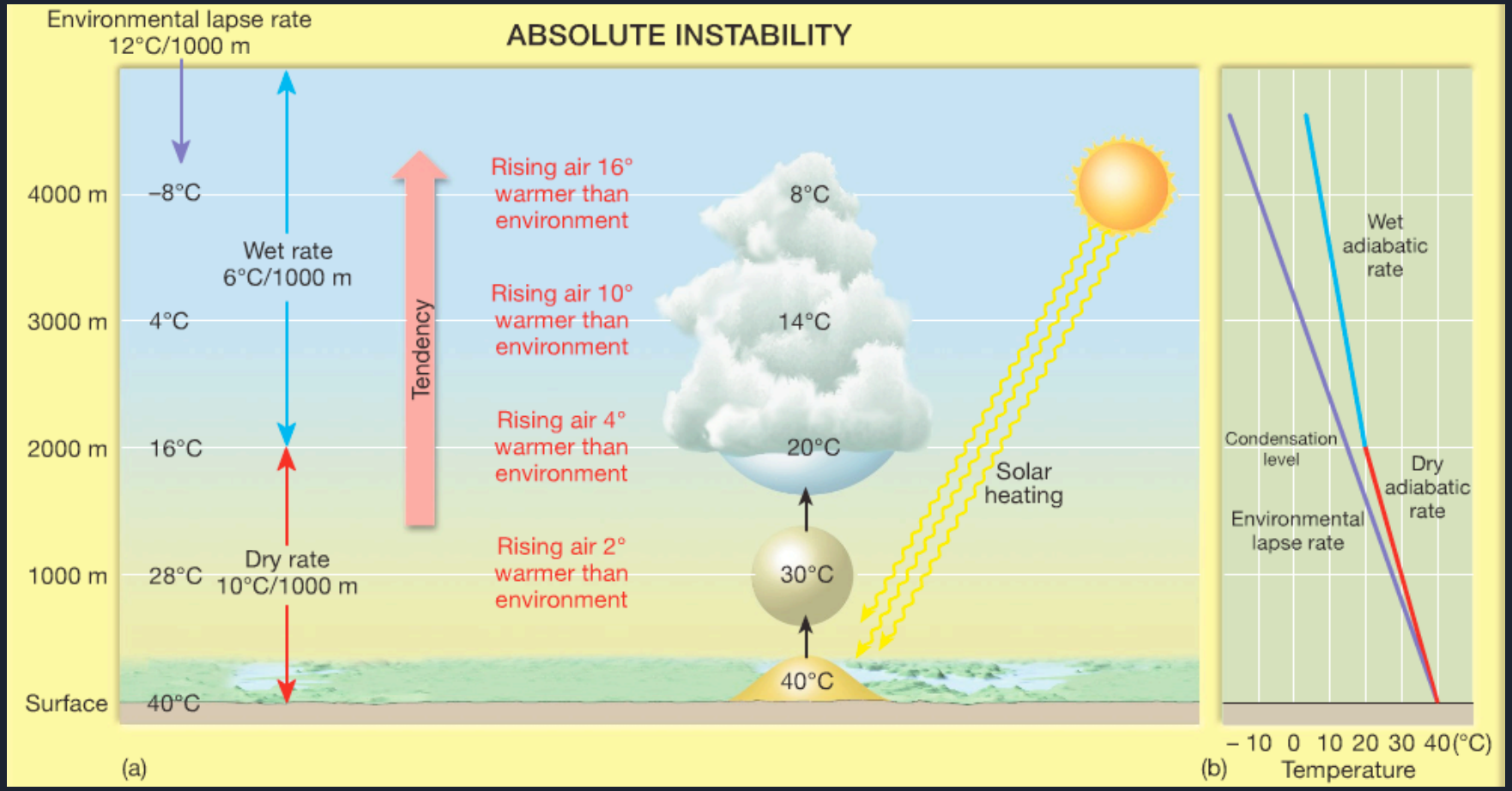
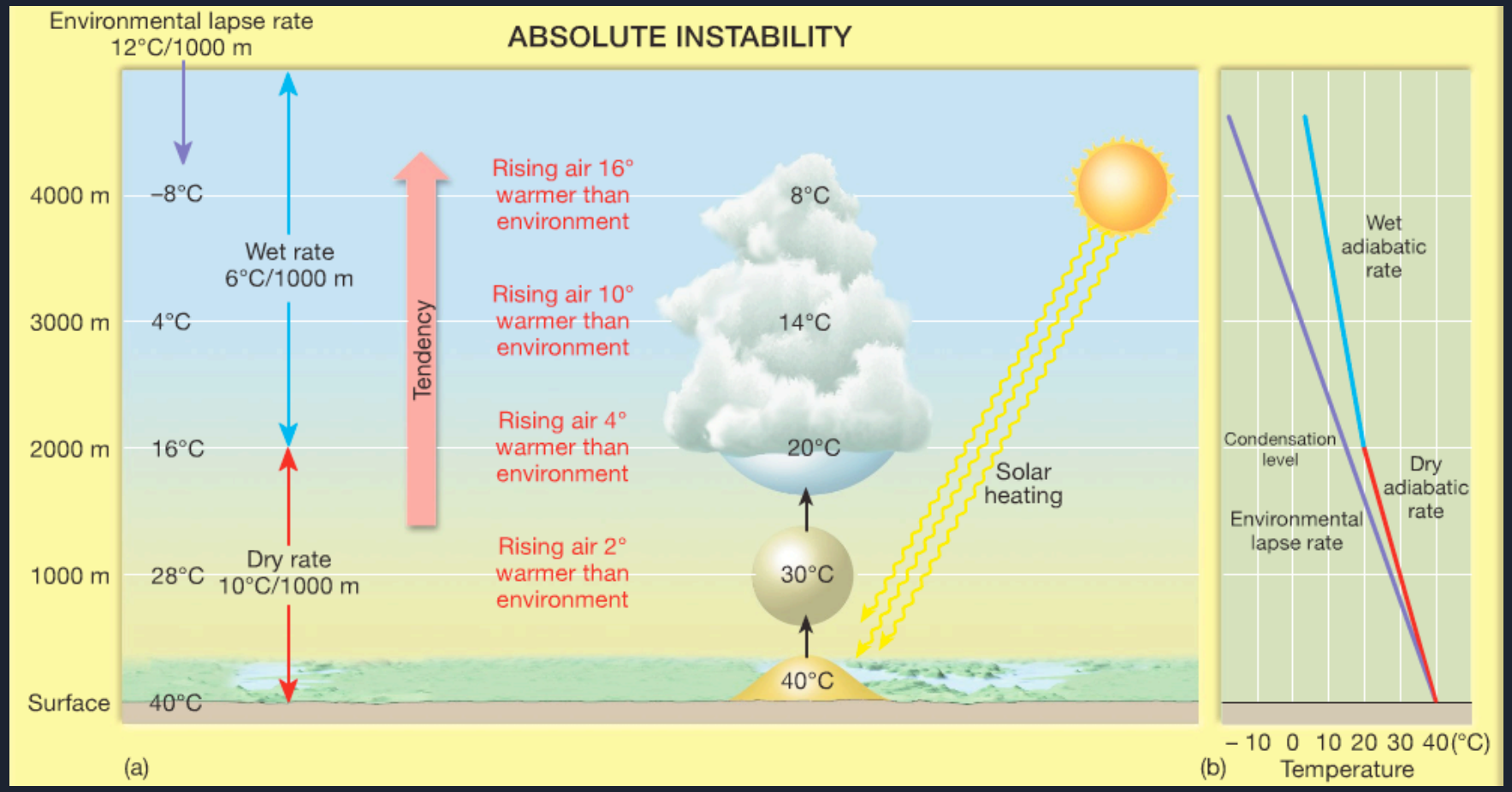




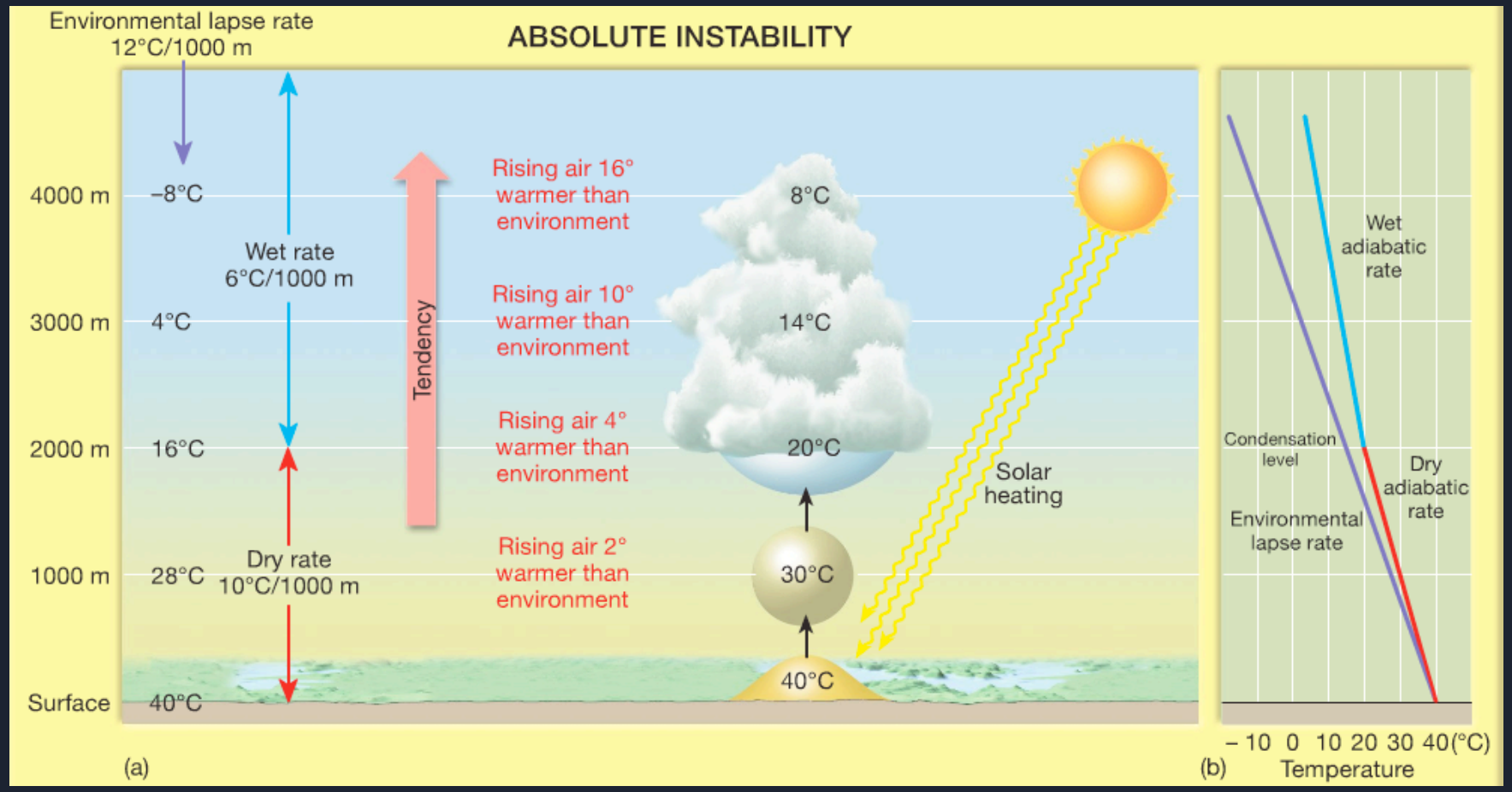
~ ***Inversions*** happen when the ***ground cools*** more ***rapidly*** than the air just above, or when there is ***sinking air aloft*** that ***warms*** as it ***descends***.


ABSOLUTE INSTABILITY
Environmental lapse rate
12°C/1000 m
4000 m
3000 m
2000 m
1000 m
Surface
–8°C
4°C
16°C
28°C
40°C
Wet rate
6°C/1000 m
Dry rate
10°C/1000 m
Tendency
Rising air 16° warmer than environment
Rising air 10° warmer than environment
Rising air 4° warmer than environment
Rising air 2° warmer than environment
8°C
14°C
20°C
30°C
40°C
Solar heating
(a)
Wet adiabatic rate
Dry adiabatic rate
Condensation level
Environmental lapse rate
– 10 0 10 20 30 40(°C)
Temperature
(b)

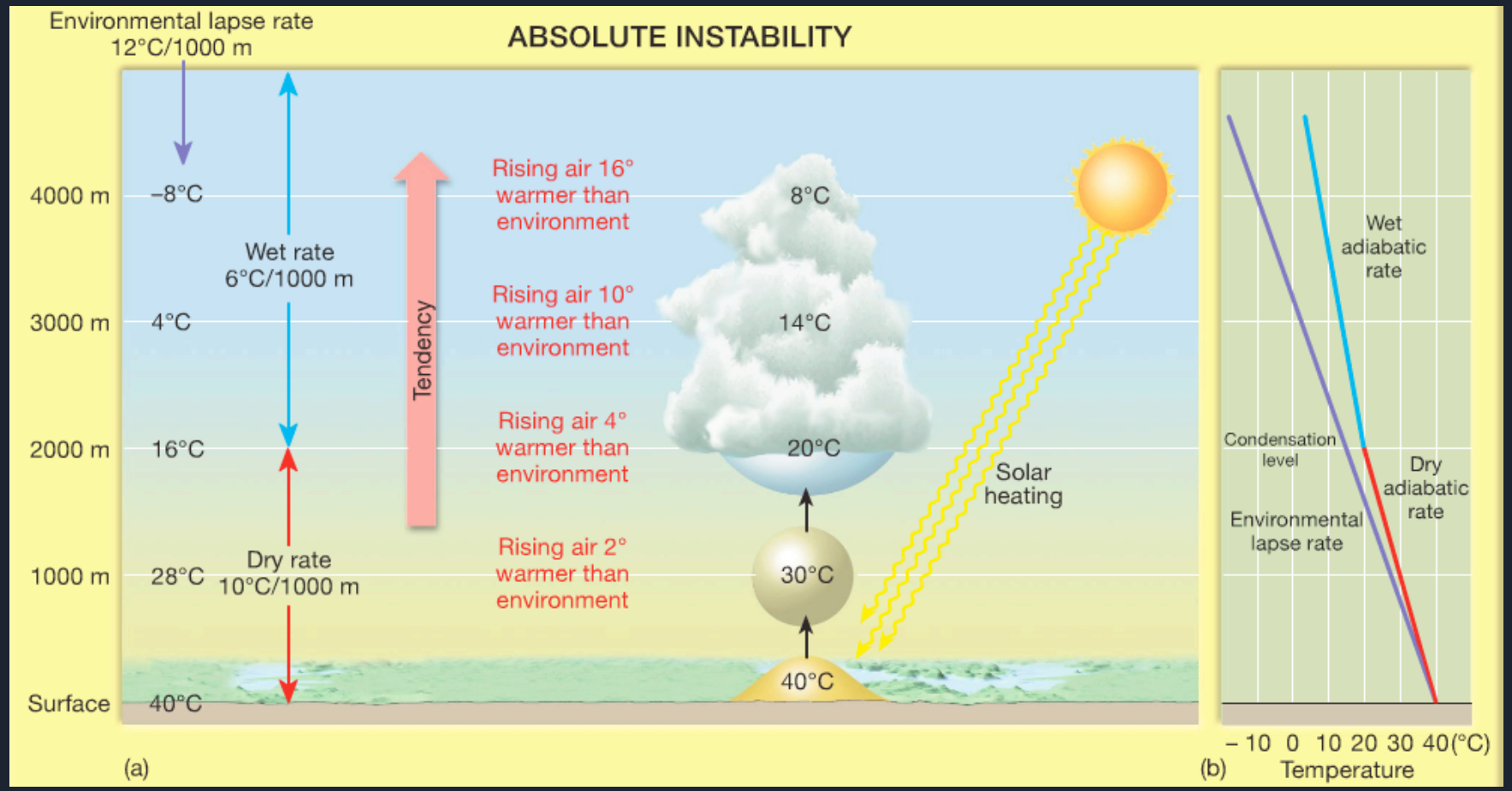
~ On the other end of the spectrum, we have ***absolute instability***: the ***environmental lapse rate*** is ***greater*** ***than*** the ***dry adiabatic lapse rate***.



~ Under these circumstances, the ***parcel*** is ***always warmer*** than the ***environment*** and will ***rise*** due to its ***own*** ***buoyancy*** (i.e., it needs ***no forcing***).



~ ***Unstable air*** that is lifted will produce ***towering***, ***cumulus*** clouds with ***heavy precipitation***, like ***thunderstorms*** and ***lake effect snow***.



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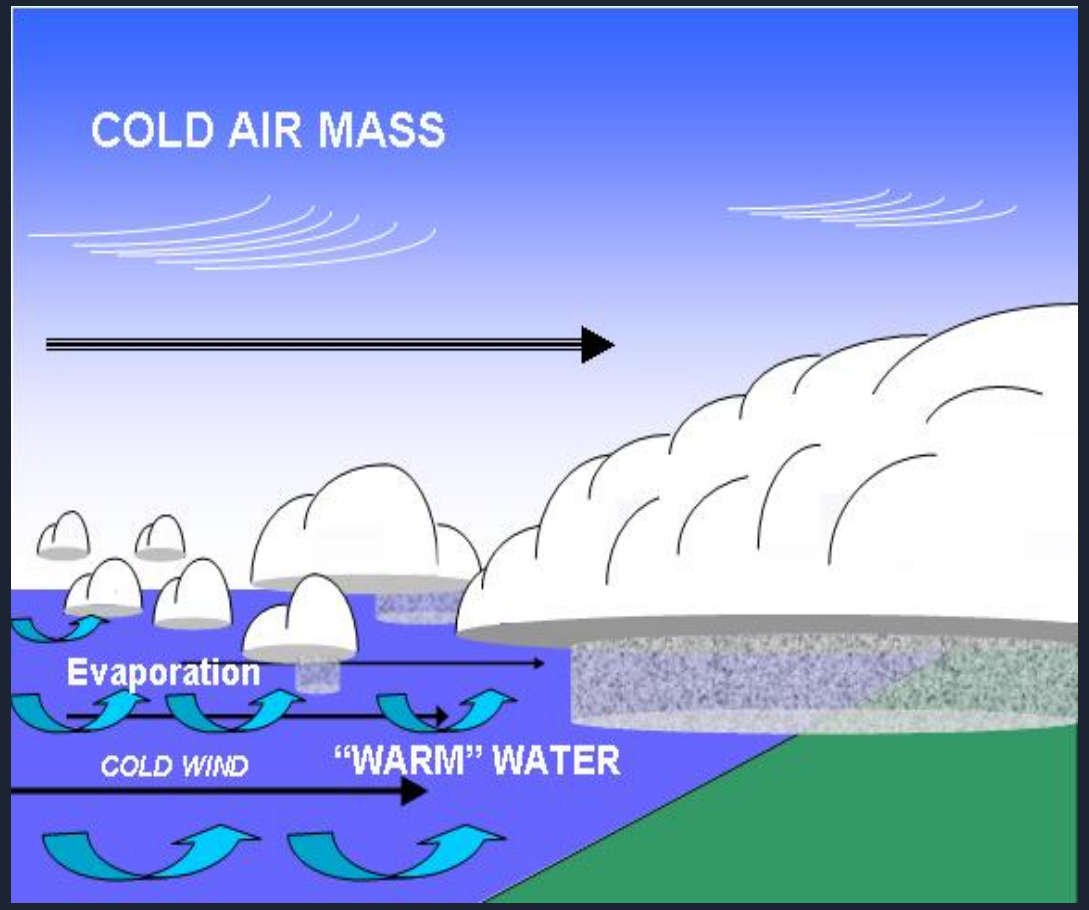

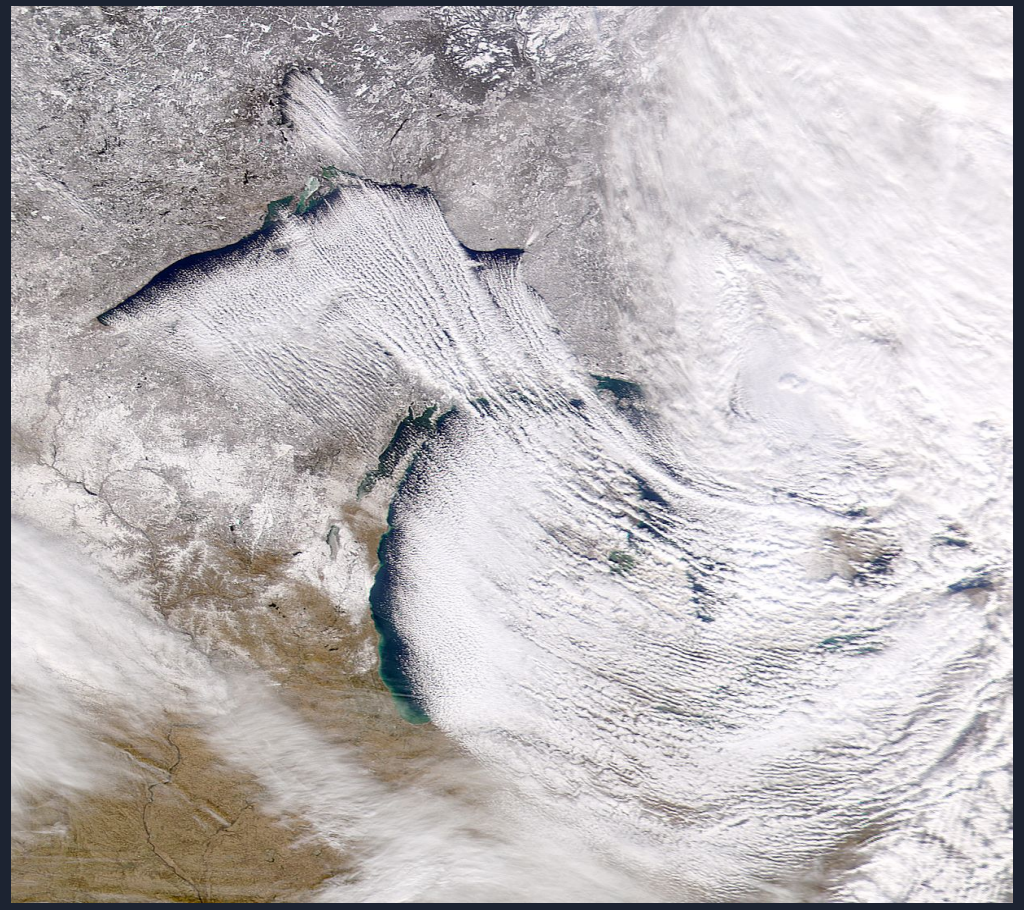

~ In the ***middle*** of these two ***extremes*** is ***conditional instability*** where the ***environmental lapse rate*** is ***between*** the ***wet*** and ***dry adiabatic lapse rates*** (i.e., between 5˚C / km and 10˚C / km).

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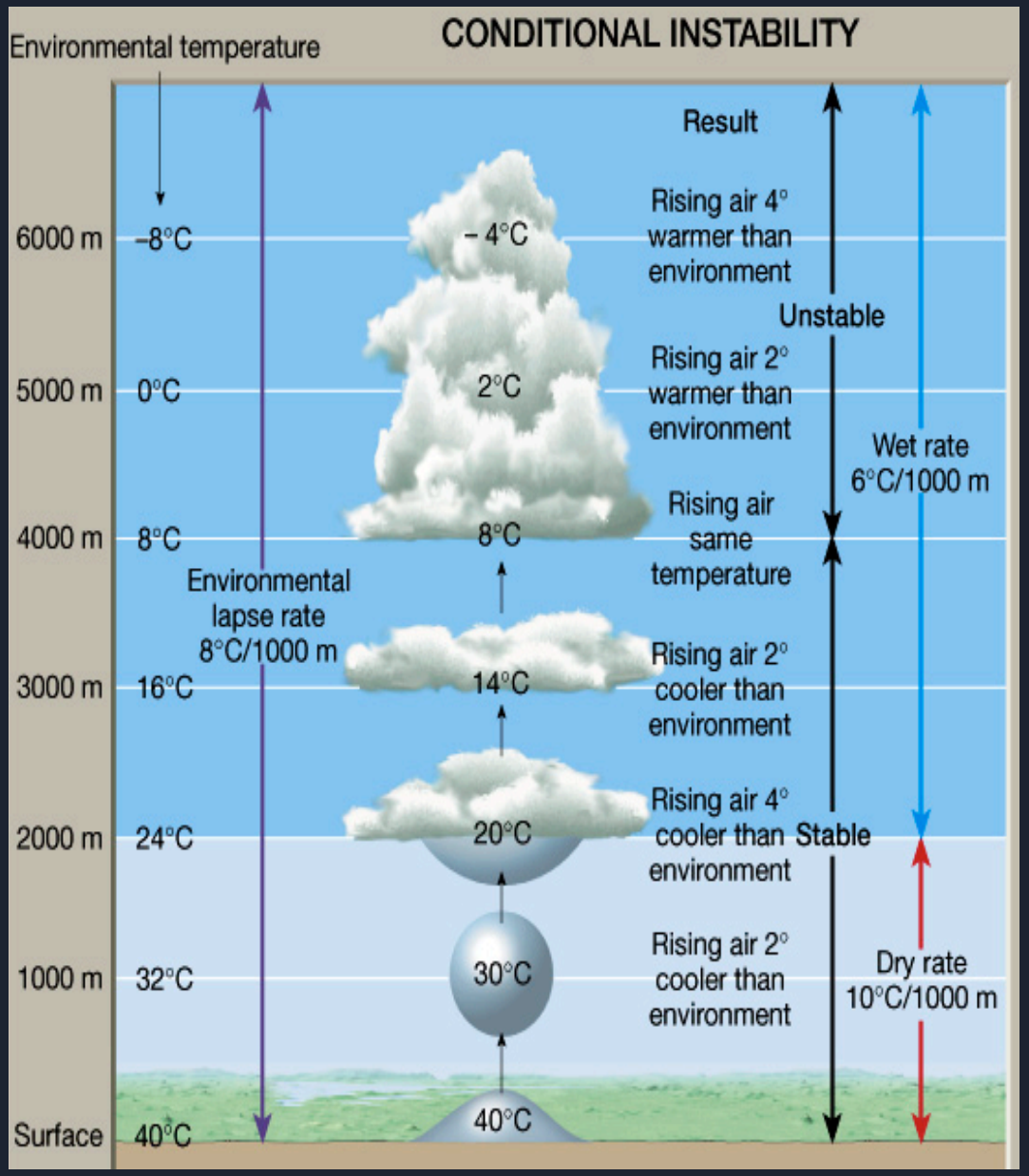
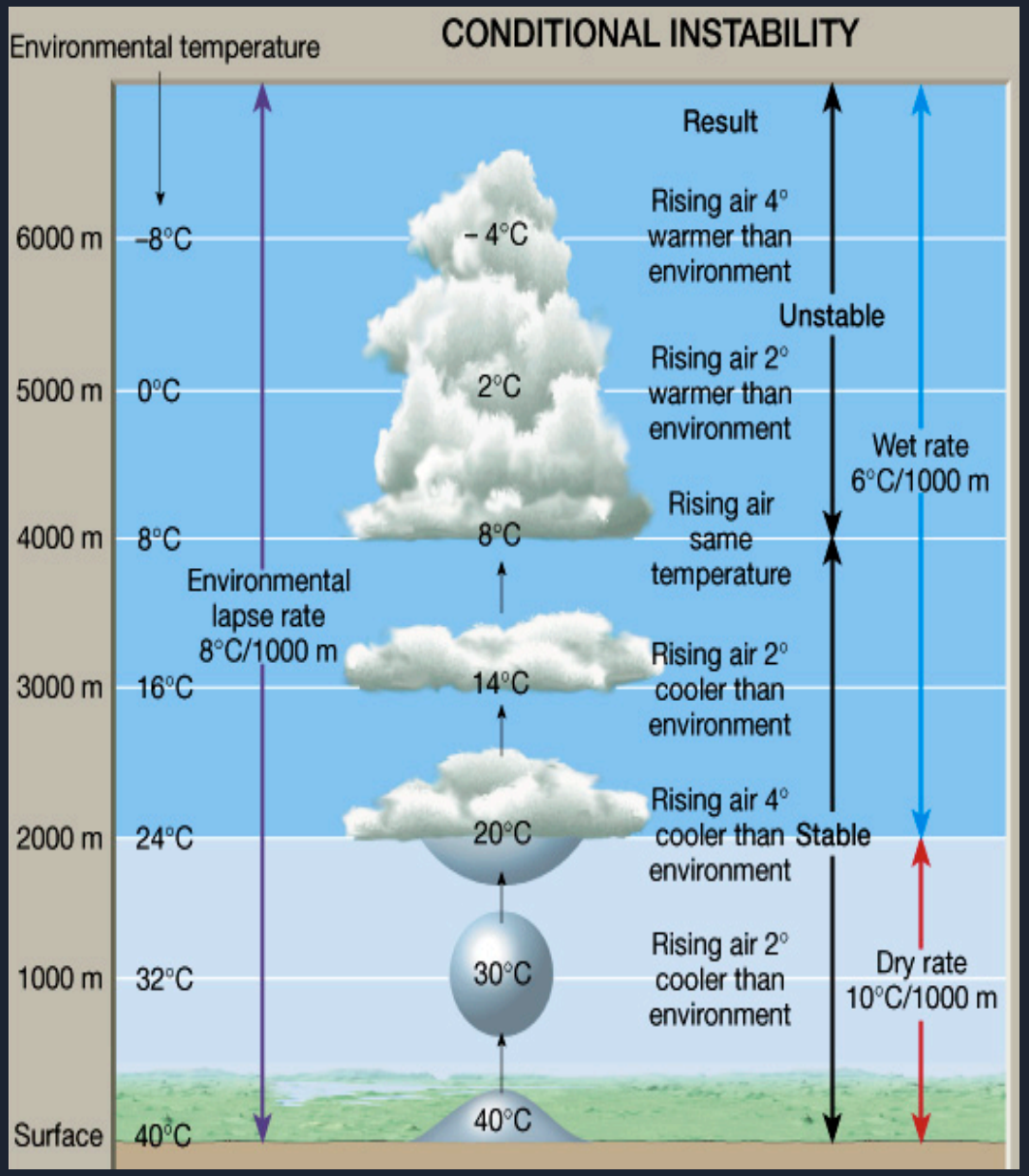
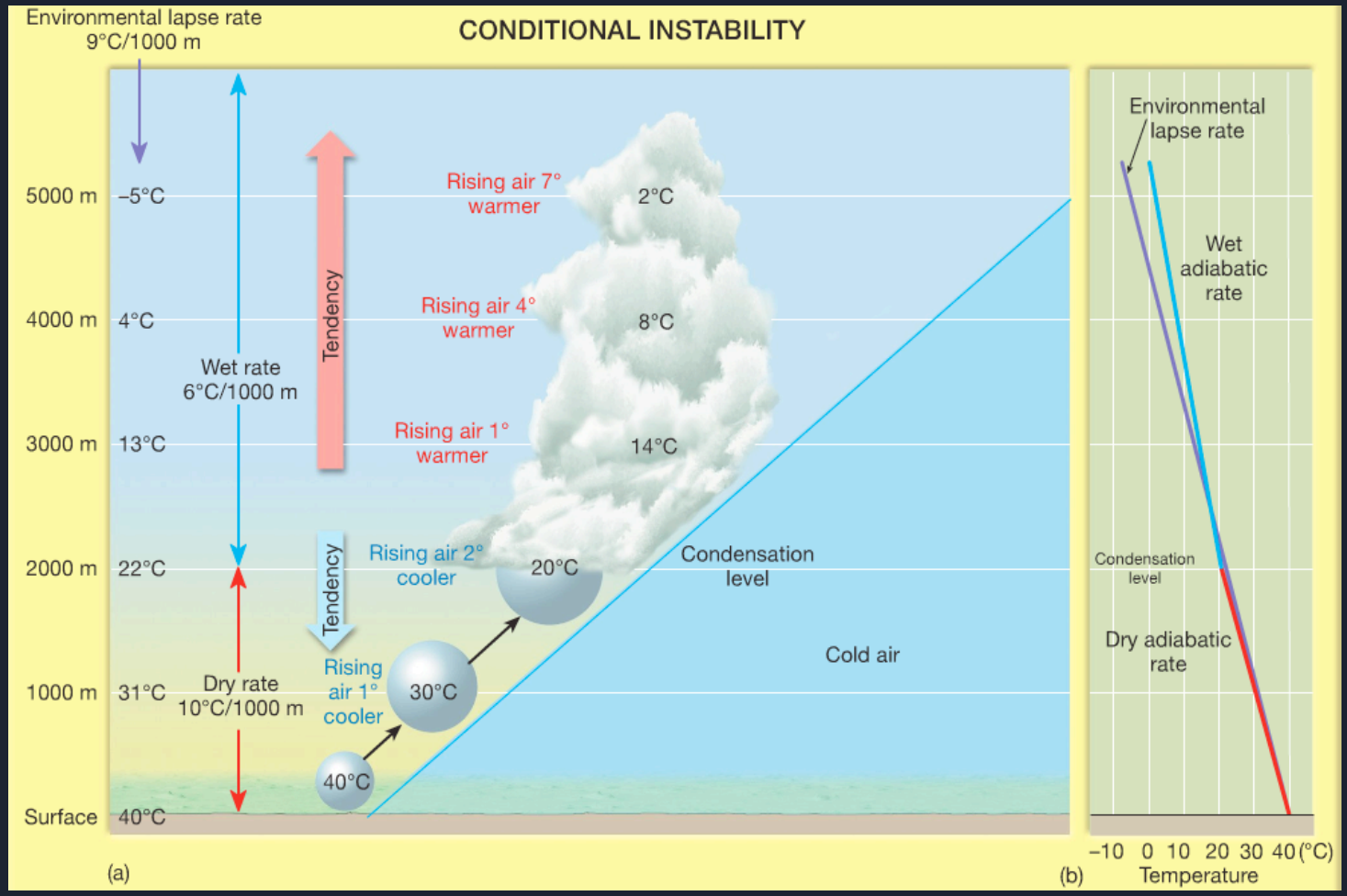


~ Stated another way, the atmosphere is ***conditionally unstable*** when it is ***stable*** with respect ***to unsaturated*** (***dry***) rising ***parcels***, but ***unstable*** with respect to ***saturated parcels***.




CONDITIONAL INSTABILITY
Environmental lapse rate
9°C/1000 m
5000 m
4000 m
3000 m
2000 m
1000 m
Surface
–5°C
4°C
13°C
22°C
31°C
40°C
Wet rate
6°C/1000 m
Dry rate
10°C/1000 m
Tendency
Tendency
Rising air 7°
warmer
Rising air 4°
warmer
Rising air 1°
warmer
Rising air 2°
cooler
Rising
air 1°
cooler
2°C
8°C
14°C
20°C
30°C
40°C
Condensation
level
Cold air
(a)
Environmental
lapse rate
Wet
adiabatic
rate
Condensation
level
Dry adiabatic
rate
–10 0 10 20 30 40 (°C)
Temperature
(b)

~ The ***unsaturated parcel*** ***cools faster*** than the ***environment*** and is ***stable***; once the parcel is ***saturated***, however, it ***cools*** at a ***slower rate***, is ***warmer***, is ***unstable***, and will rise.