Introduction to Atmospheric Physics

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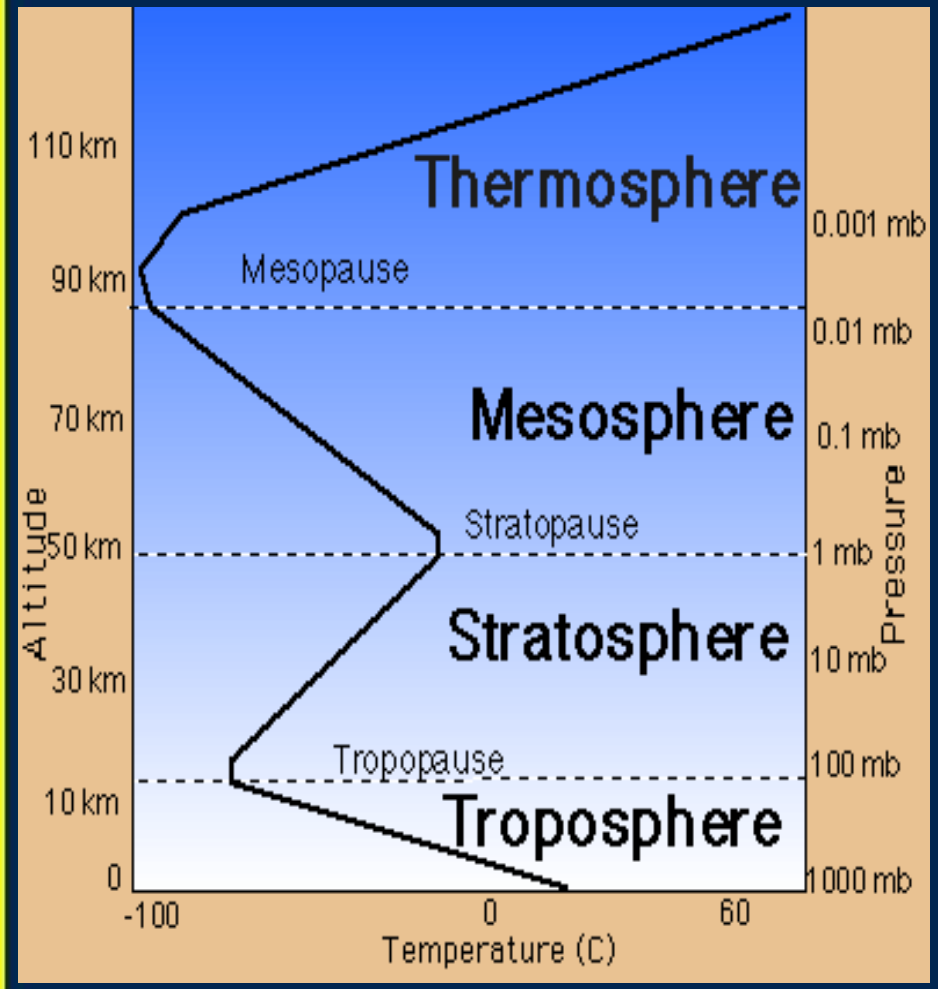
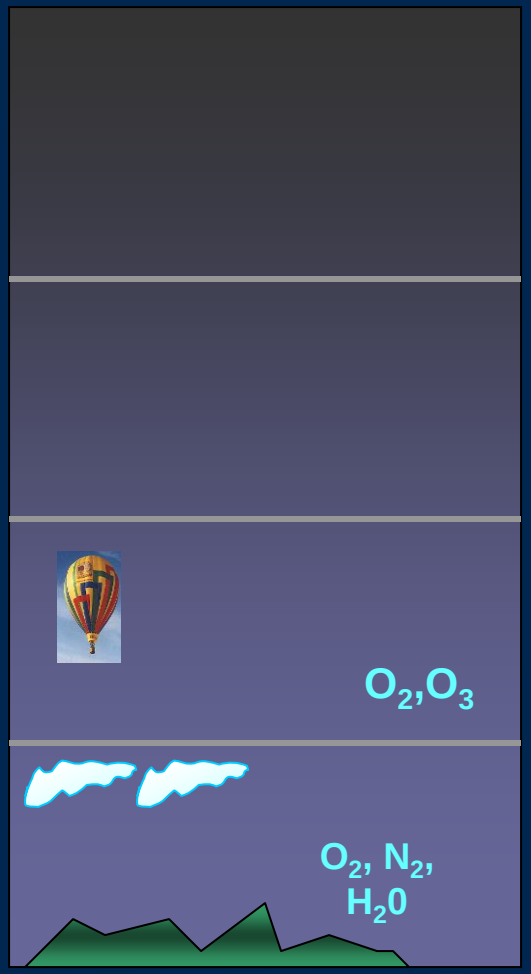
Vertical Structure of Atmosphere



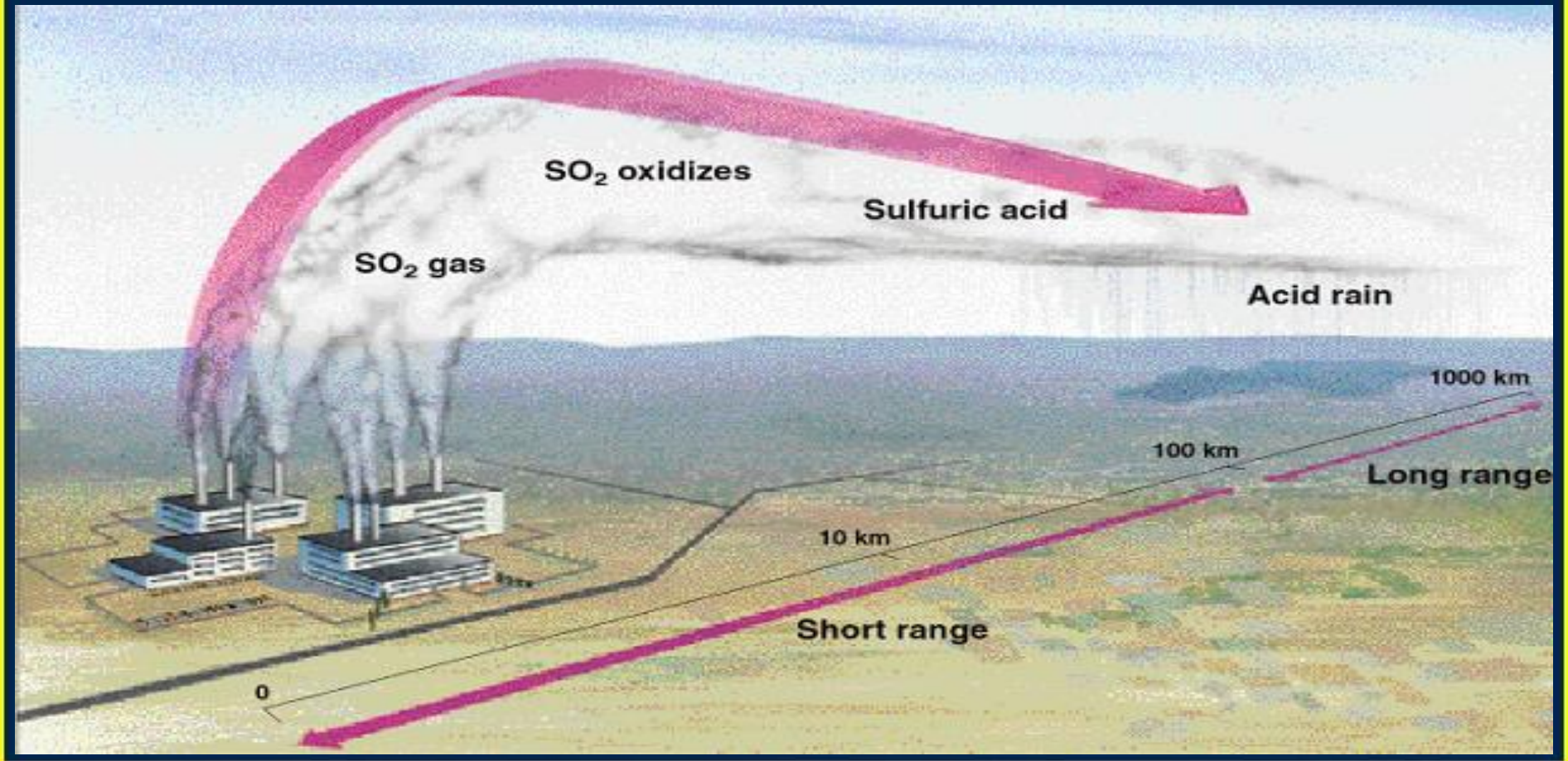


Lapse rate - Temperature with height

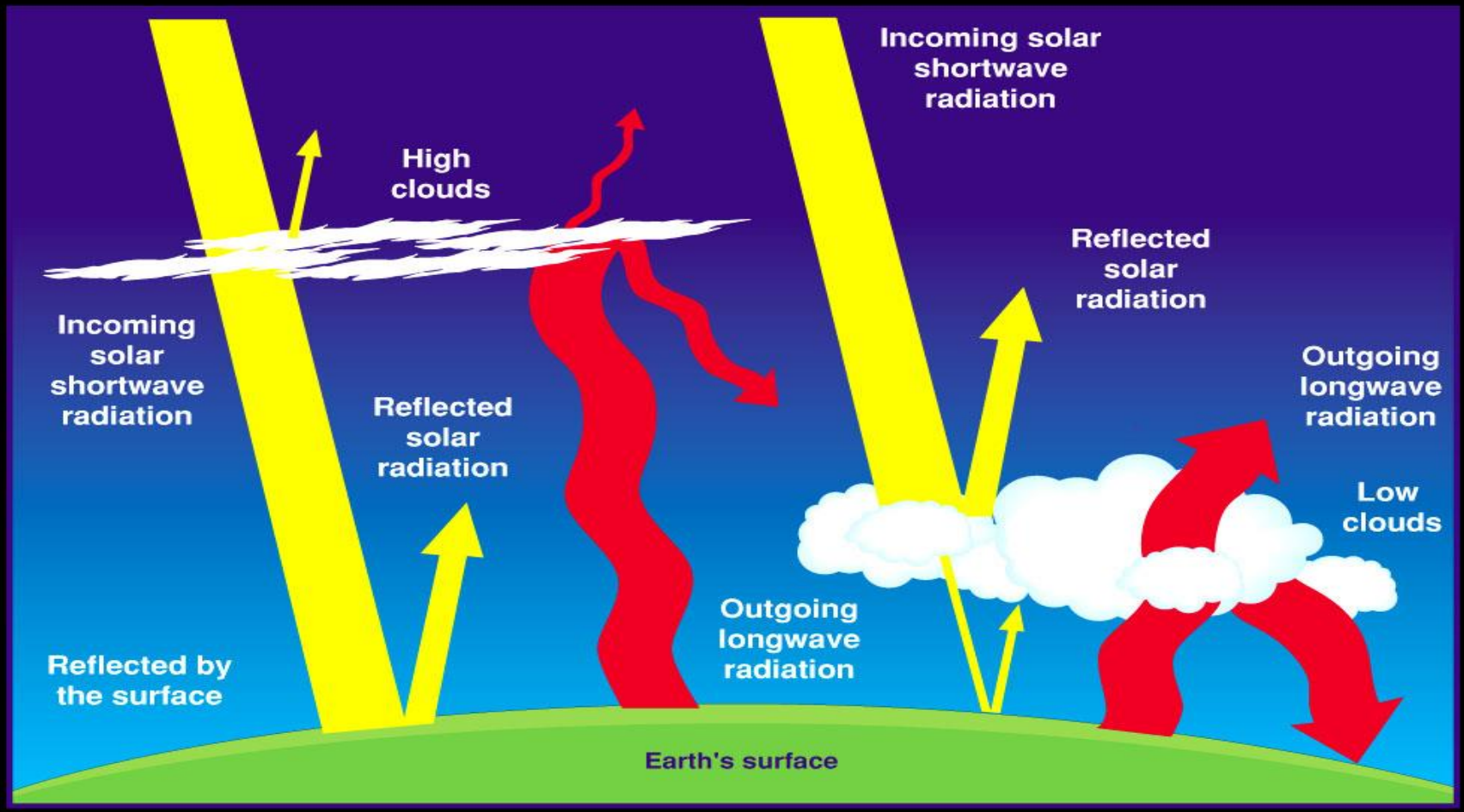
Vertical Structure of Atmosphere

- Lowest layer of the atmosphere where most weather takes place.
- Most thunderstorms don't go much above the top of the troposphere (about 10 km) .
- Pressure and density rapidly decrease with height, and temperature generally decreases with height at a constant rate.
- troposphere is that it is well-mixed.

Regional scale pollutant transport occurs in troposphere



Cloud Effects On Earth's Radiation



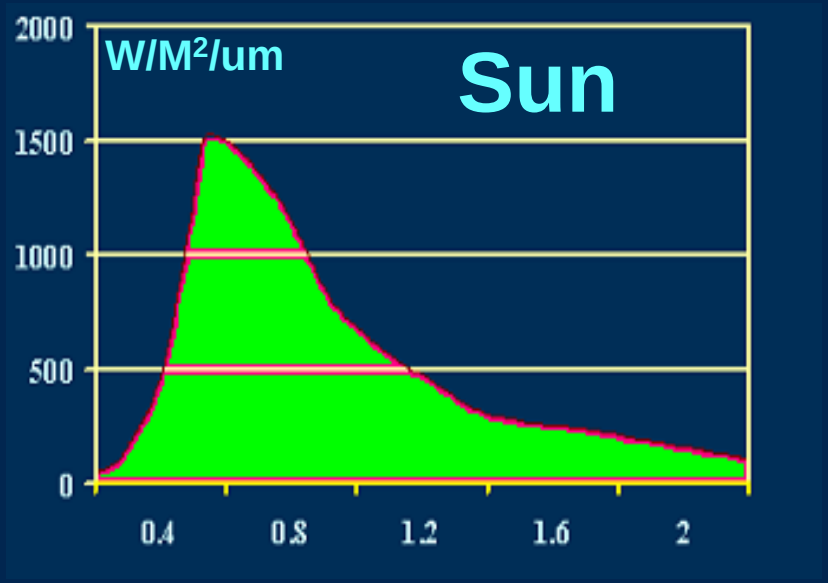
Albedo

- Radiation is not only emitted, absorbed, and transferred, but also reflected.
- The albedo of a surface is its reflectivity, or the ratio of radiation that is reflected to that which hits the surface.
- The sum of the albedos of the many surfaces on the earth are important in determining the earth's energy balance

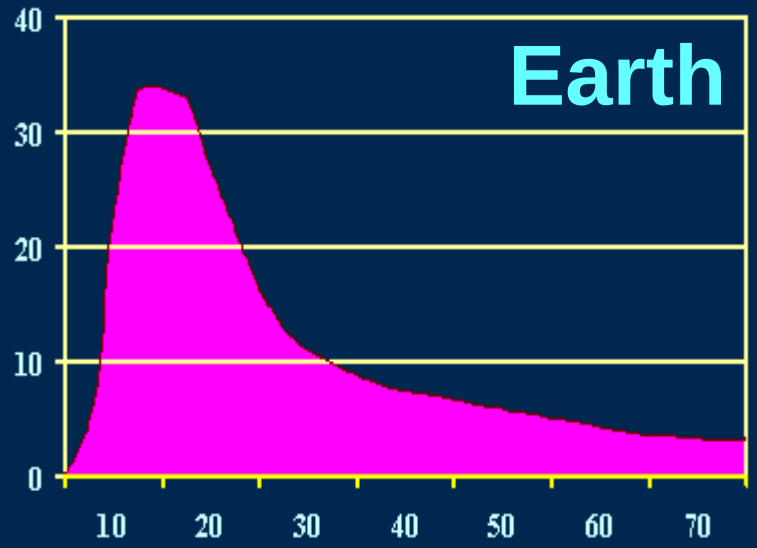
Typical Albedo of Selected Surfaces

Snow	79-95	Dark Soil	5-15
Ice	30-40	Grassy Field	10-30
Thick Clouds	60-90	Forest	5-15
Thin Clouds	30-50	Water	10 (avg.)
Wet Sand	20-30	Venus	78
Dry Sand	35-45	Mars	17
Concrete	17-27	Moon	7
Asphalt	5-10	Earth	34-42

Energy Spectrum



Short wave



Long wave

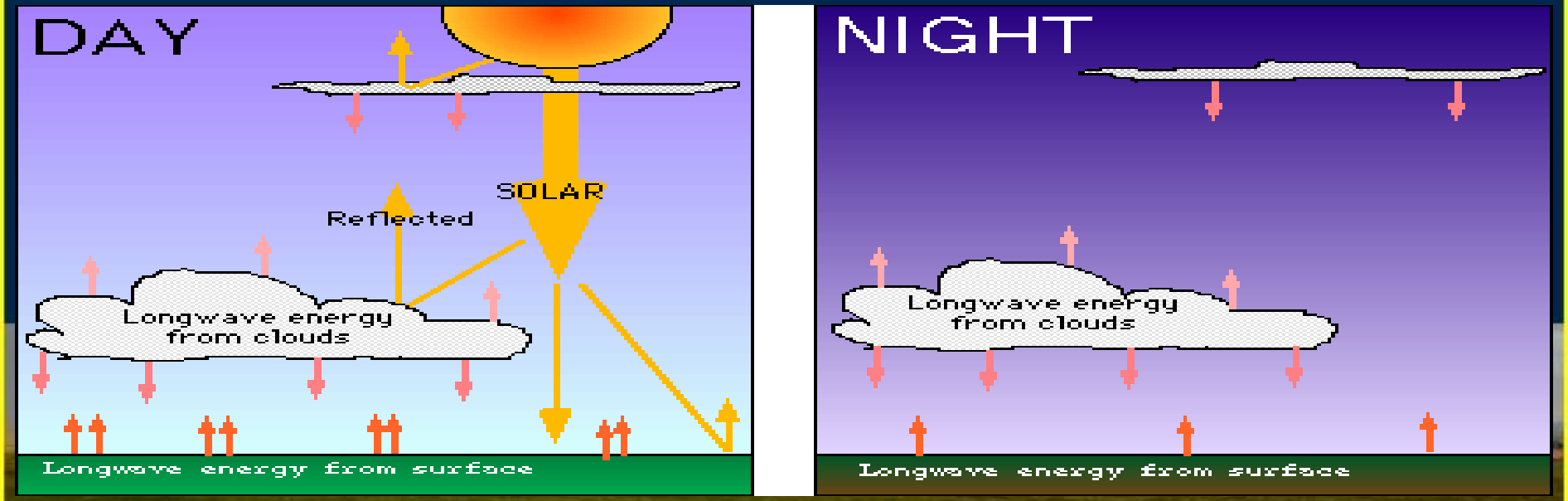
5777 k

$$\lambda_{max} = \frac{2.897\ x\ 10^{6}}{T}$$

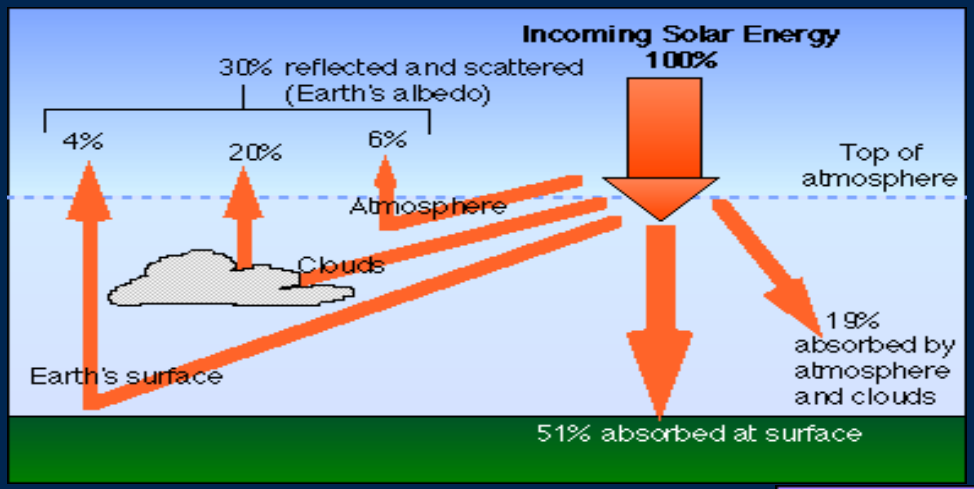
300 K

Clouds

1. Clouds both reflect and release radiation efficiently
2. Shortwave radiation from the sun is efficiently reflected, and longwave radiation from the earth is efficiently absorbed and emitted by the clouds.
3. High, thin clouds radiate heat (longwave radiation) back towards the earth, usually thicker clouds, reflect incoming sunlight, but also absorb and emit heat from the surface.
4. That is why in the summer, very cloudy days seem cooler than clear days, and cloudy nights seem warmer than clear nights.

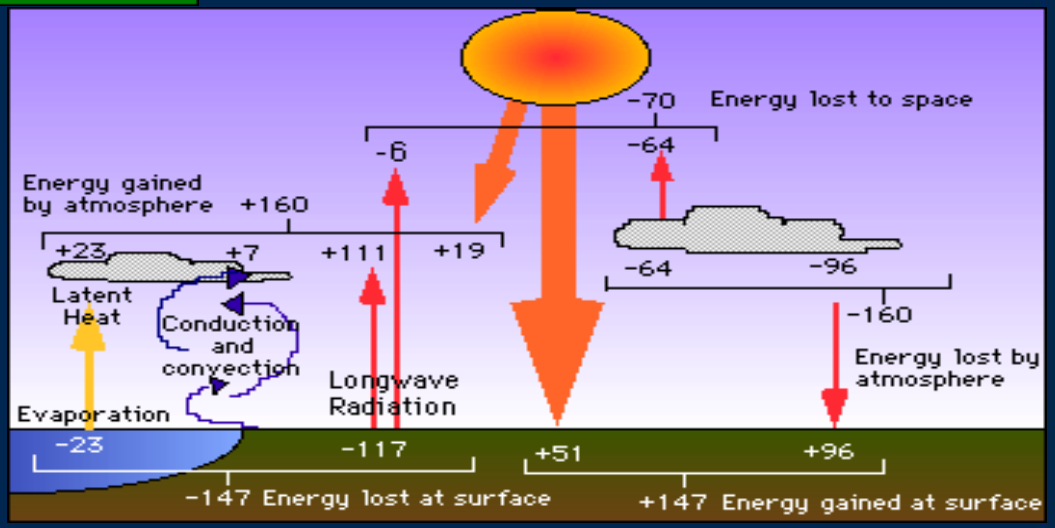


Earth's Energy Balance



average break down of solar radiation as it enters the atmosphere

Combination of incoming radiation with the break down of outgoing radiation

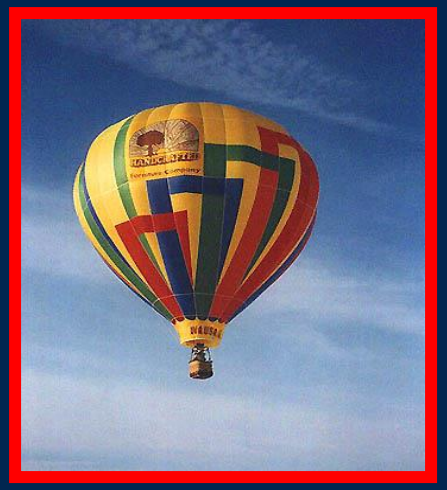


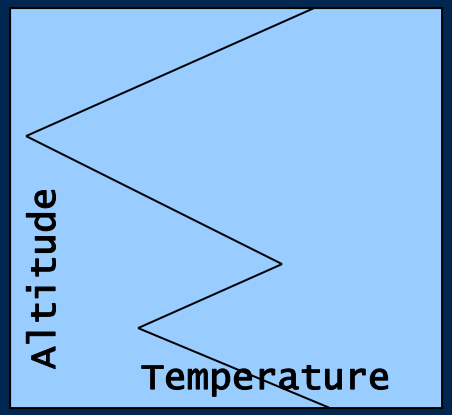
Vertical Temperature

Imagine yourself in a balloon, traveling from the Earth's surface upwards

As you rise, you will notice decrease in air density and air pressure.

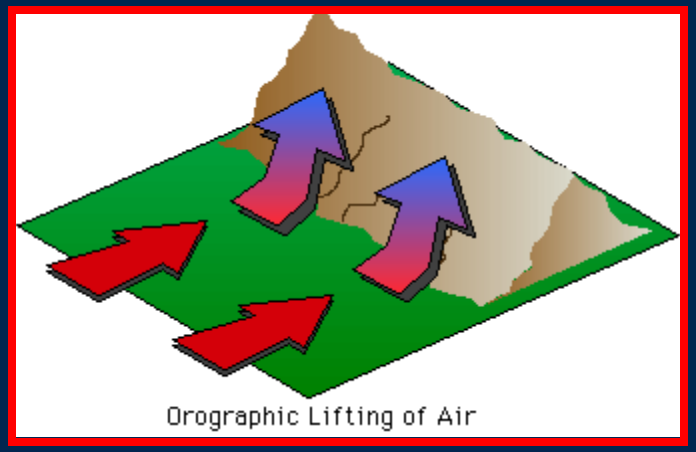
You may be surprised to discover that you may also feel both decrease and increase in air temperature.

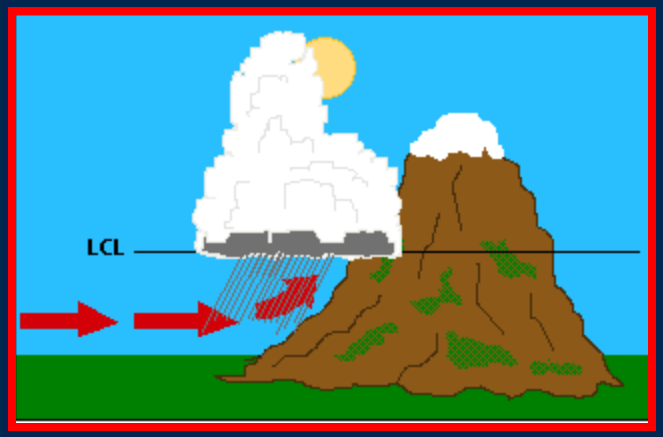




Orographic Lifting

- When air in motion reaches a barrier that it cannot go through or around, it often goes over it.
- This process of a parcel or layer of air rising as a result of the topography is referred to as orographic uplifting.

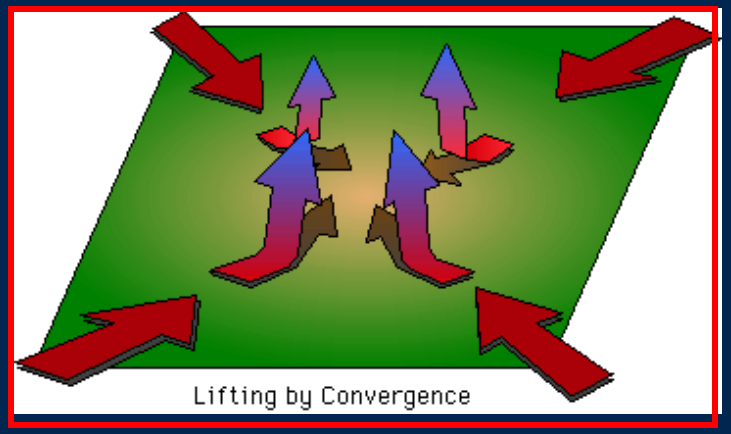




- Moist air moving near the surface encounters a mountain chain. The air is forced to rise.
- As the moist air reaches the LCL (lifted condensation level), water vapor contained in the air parcels begin to condense, forming a cloud.

Convergence Lifting

If winds blowing in different directions meet each other, the different moving air masses become an obstacle to one another.



The air converges and has no place to go but upwards. At the surface air flows inward to the center of low pressure where it converges and then rises

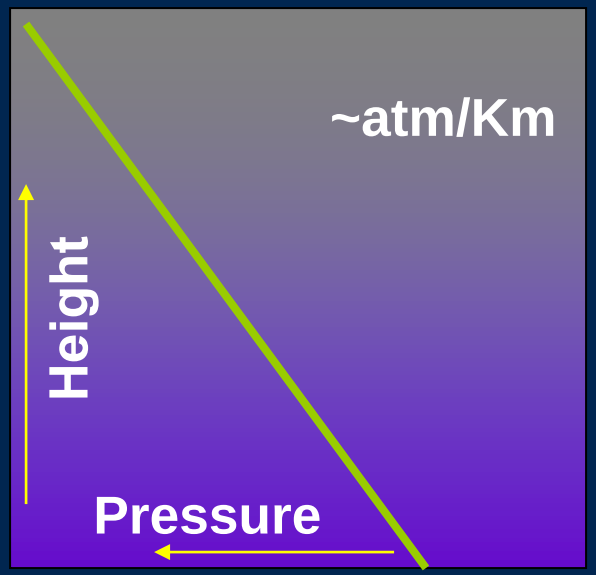
Hydrostatic Equation

Plants atmosphere is plants gravitational field

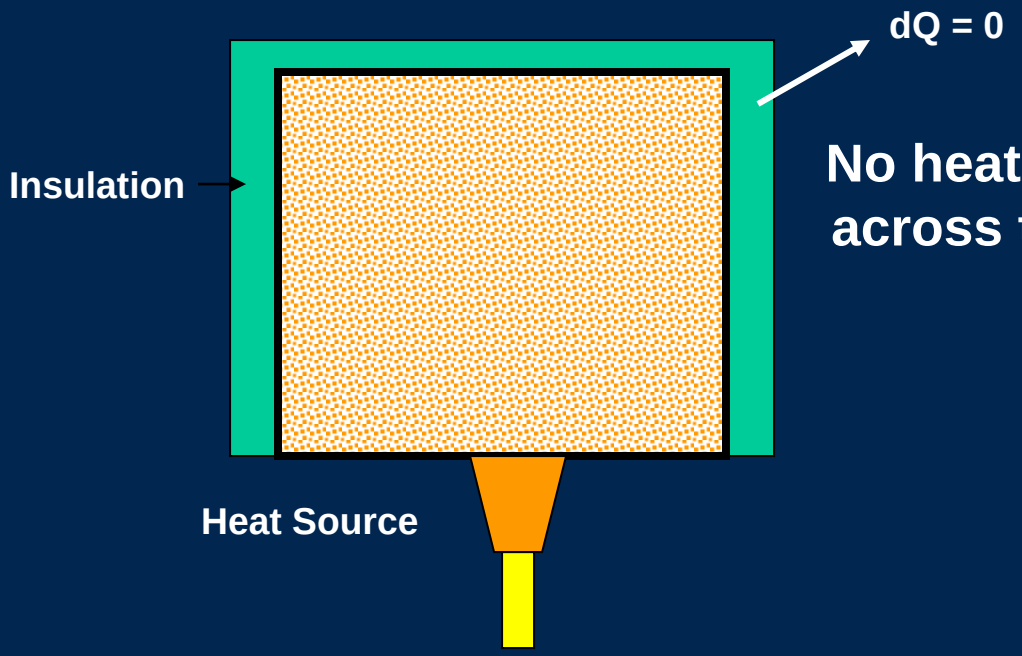
Density falls with altitude

Vertical motion of air is small

$$dp = -g\ \rho\ dz$$



Adiabatic Expansion of Air Parcel



No heat transfer across the walls

$$dQ = dW + dE$$

$$dQ = 0$$

Adiabatic Expansion of Air

- When the warm air rises, it may cool adiabatically, meaning without the exchange of heat between the parcel and the surrounding air.
- The temperature drops in response to the change in pressure.

Expansion - Parcel of Hot Air

Dry Adiabatic Lapse Rate

Balloon expands as it rises and thus does work on its surroundings

Heat Transfer between balloon and surrounding is not zero but is slow enough to ignore

$$\frac{dT}{dZ} = -\frac{gM}{C_p}$$

$$\frac{dT}{dZ} = -\frac{9.81\ m/s2 * 29 g/mol}{3.5 * 8.31 m3\ Pa/mol.K} = -0.00978\ K/m$$

Adiabatic Lapse rate : 9.78 Deg C /1000 M

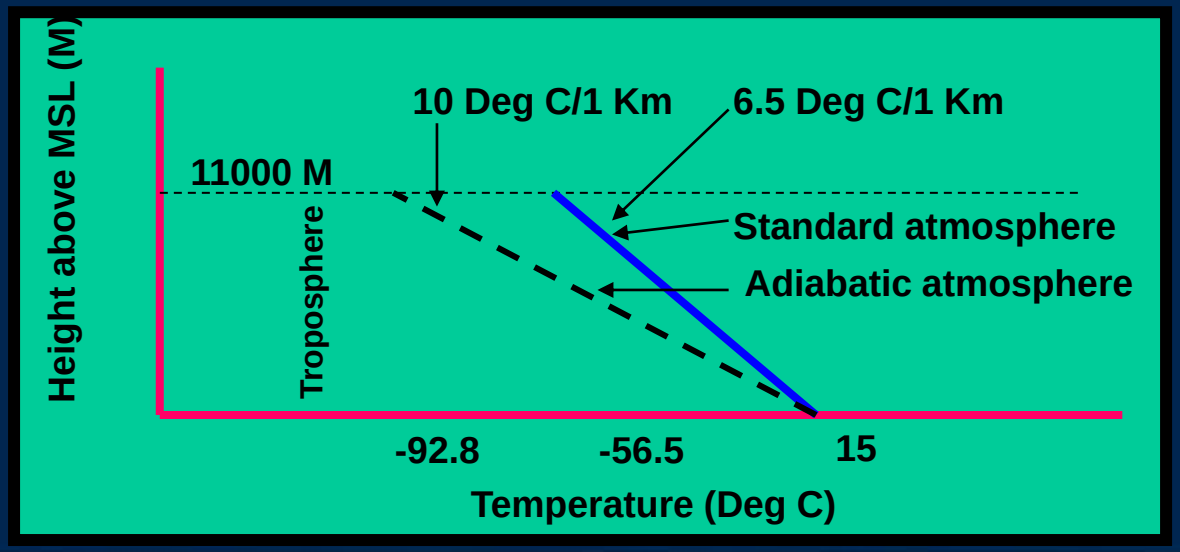
Wet - Adiabatic Lapse Rate

The actual decrease in temperature is less than the estimated value of 10 Deg C per 1Km.

$$\frac{dT}{dZ} = -\frac{gM}{C_p}$$

M : Function of gas composition

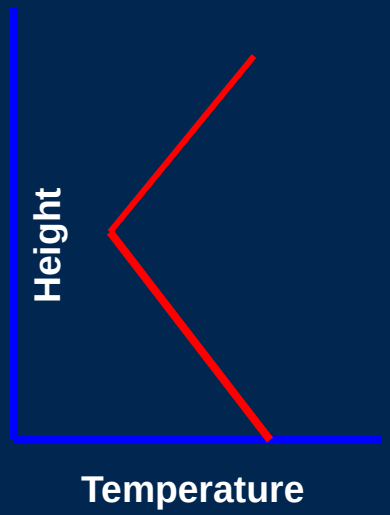
Cp: Function of moisture content



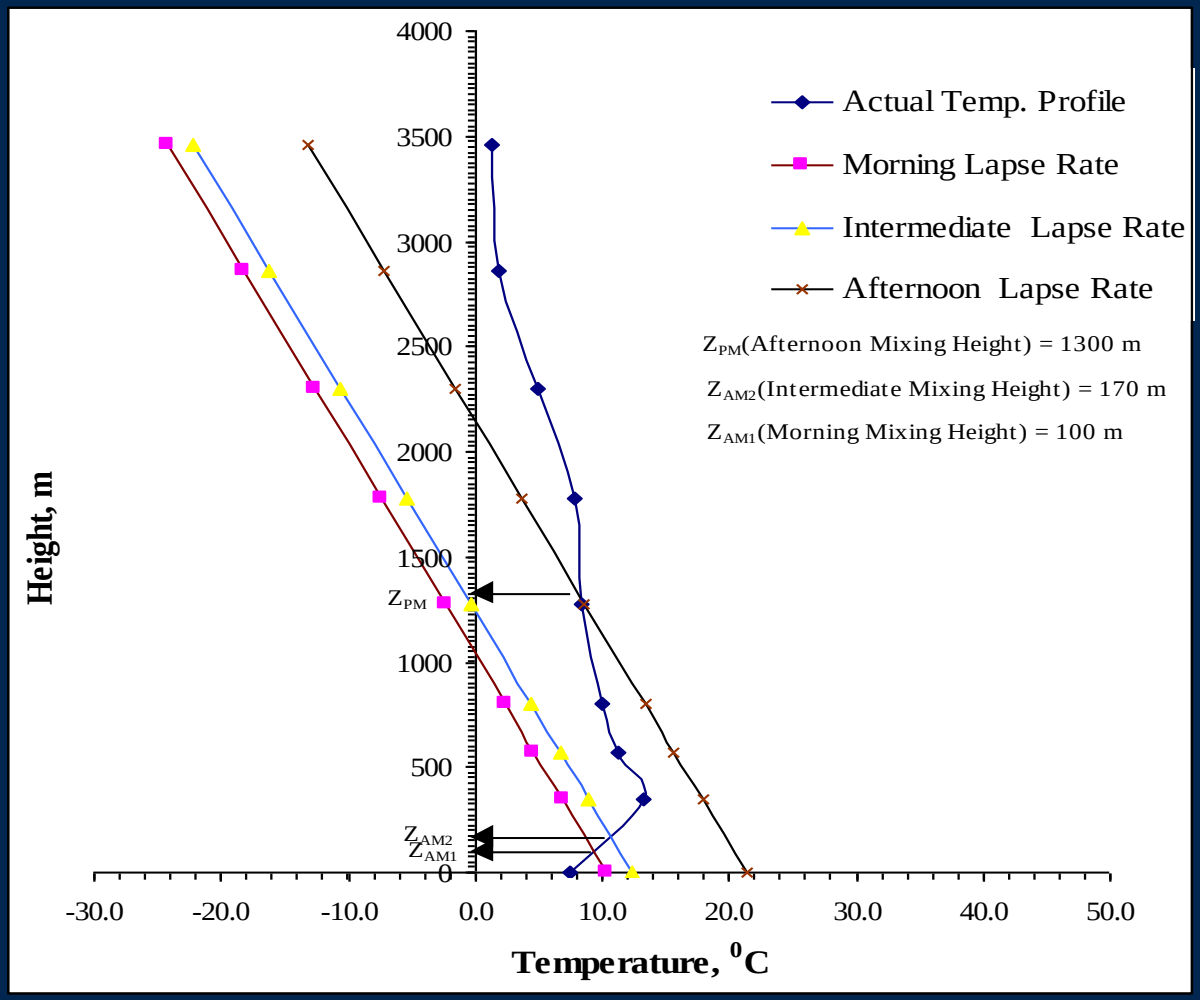
Vertical Temperature Profile

Sodar Technique

Balloon Technique



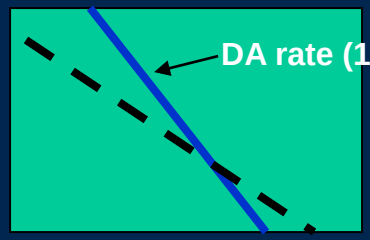
Computation of Vertical Temperature Gradient



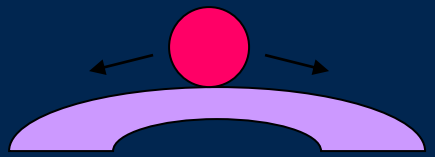
Vertical Temperature Profile Stability Classification

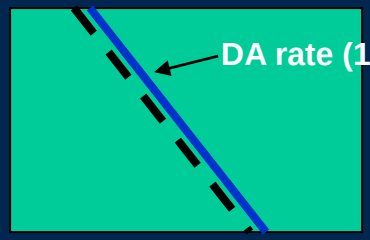
Pasquill Stability class	Temperature Gradient (O^C /100m
A	< -1.9
B	-1.9 to – 1.7
C	-1.7 to -1.5
D	-1.5 to – 0.5
E	-0.5 to 1.5
F	> 1.5

Atmospheric Stability

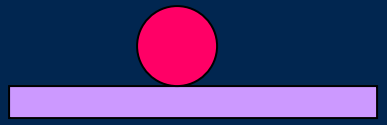


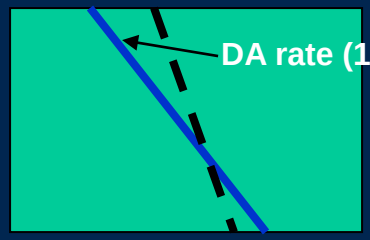
unstable Environment



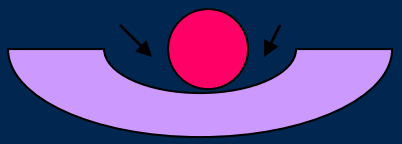


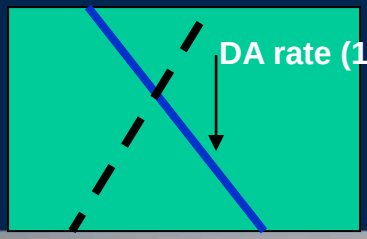
Neutral Environment



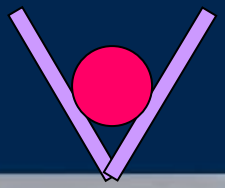


Stable Environment

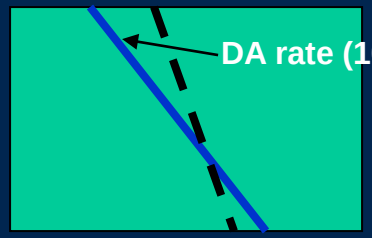


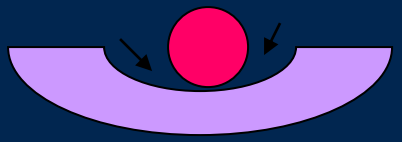


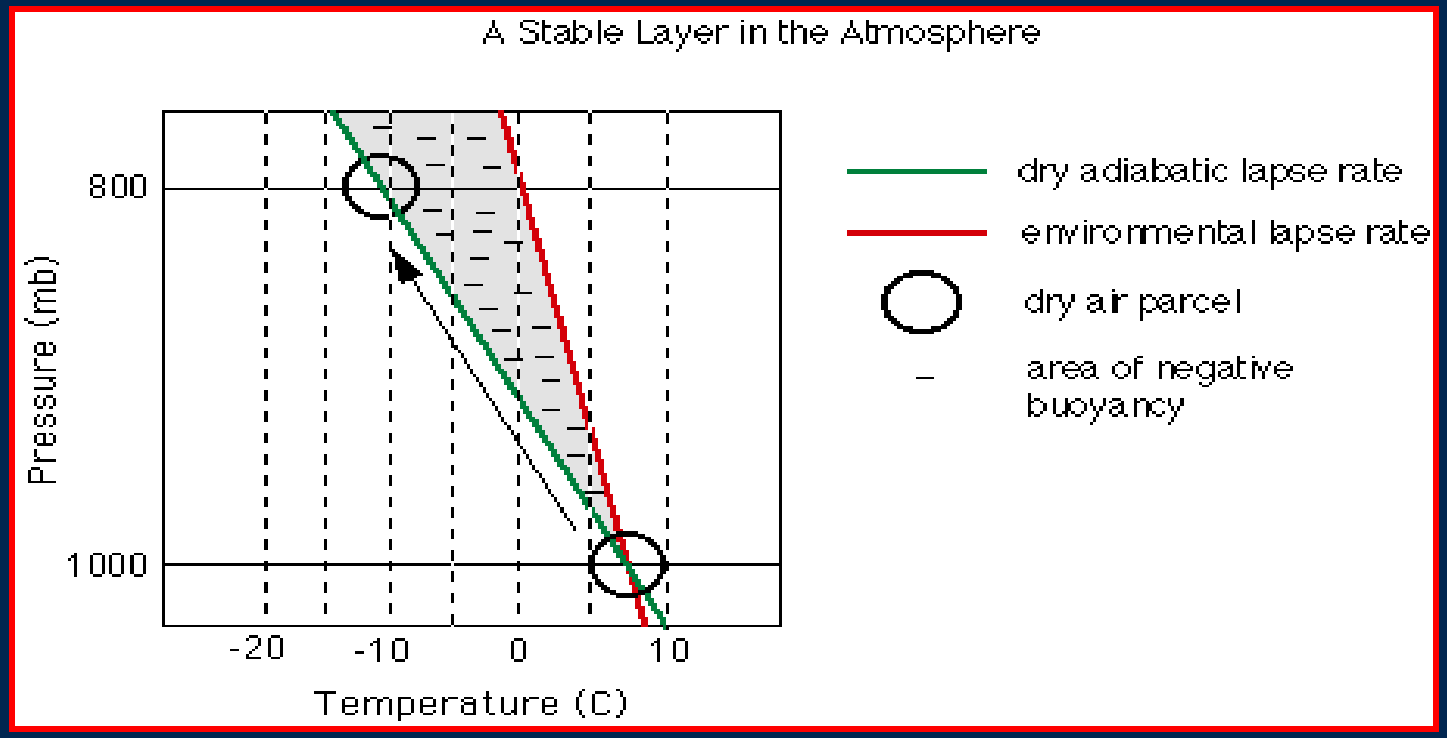
Inversion – Very stable



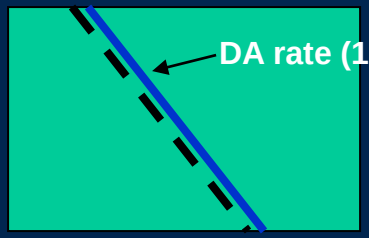
Stable Environment

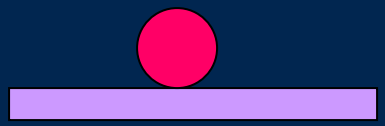


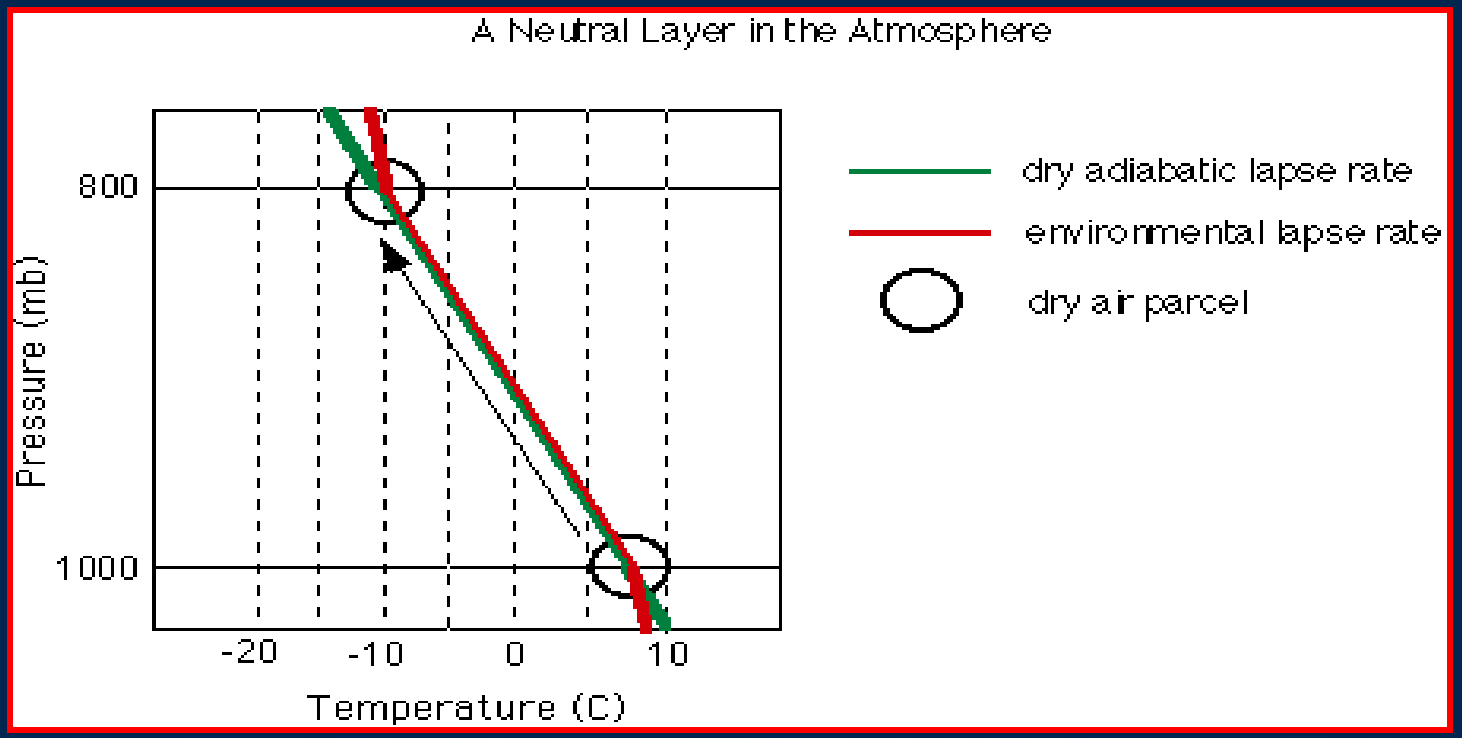




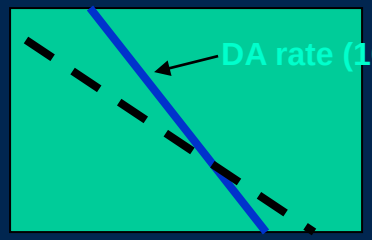
Neutral Environment

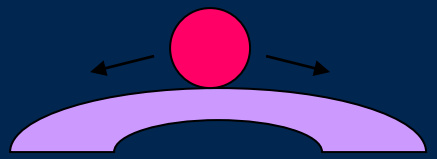


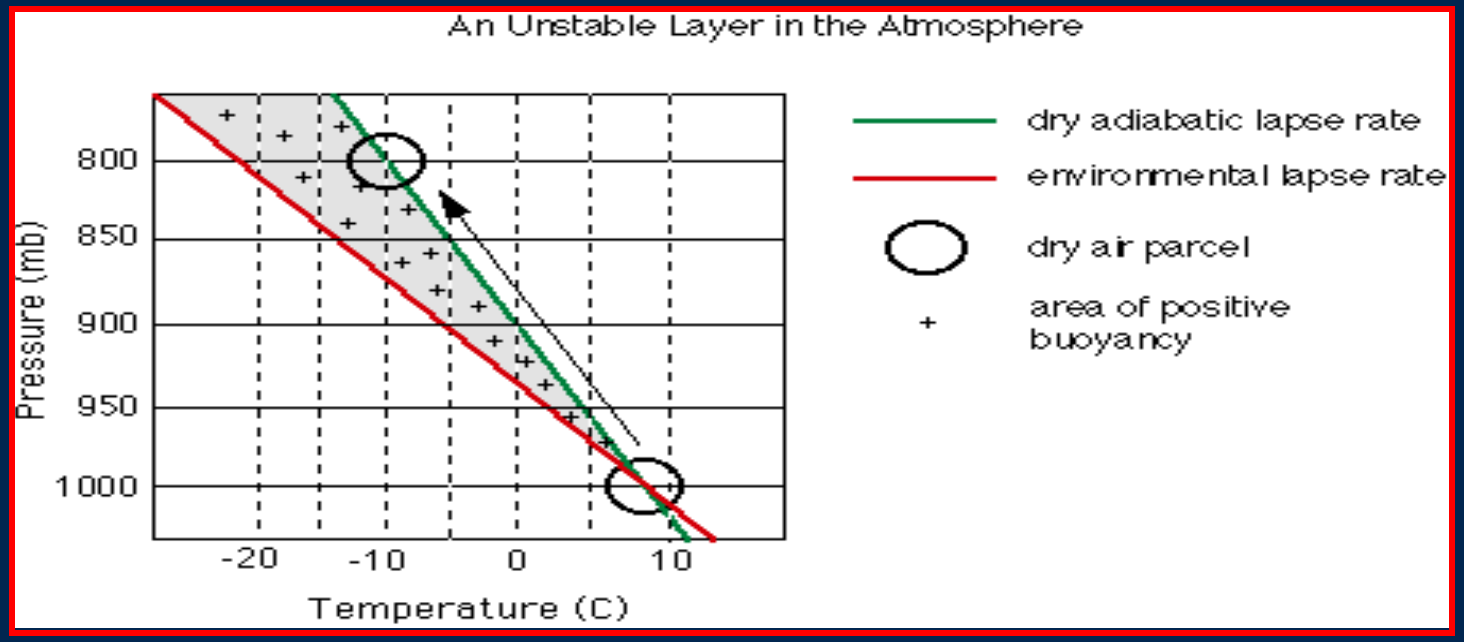




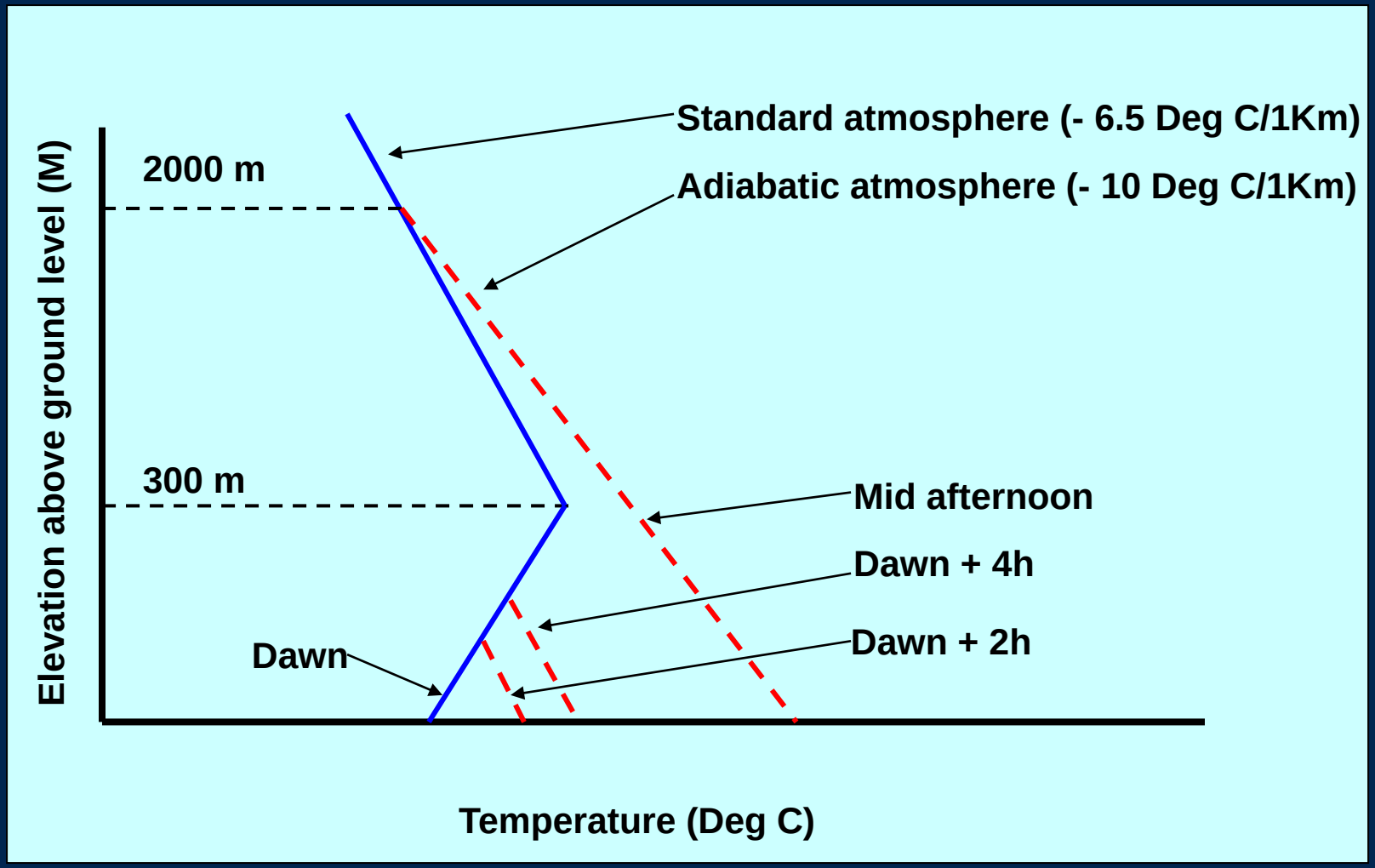
Unstable Environment





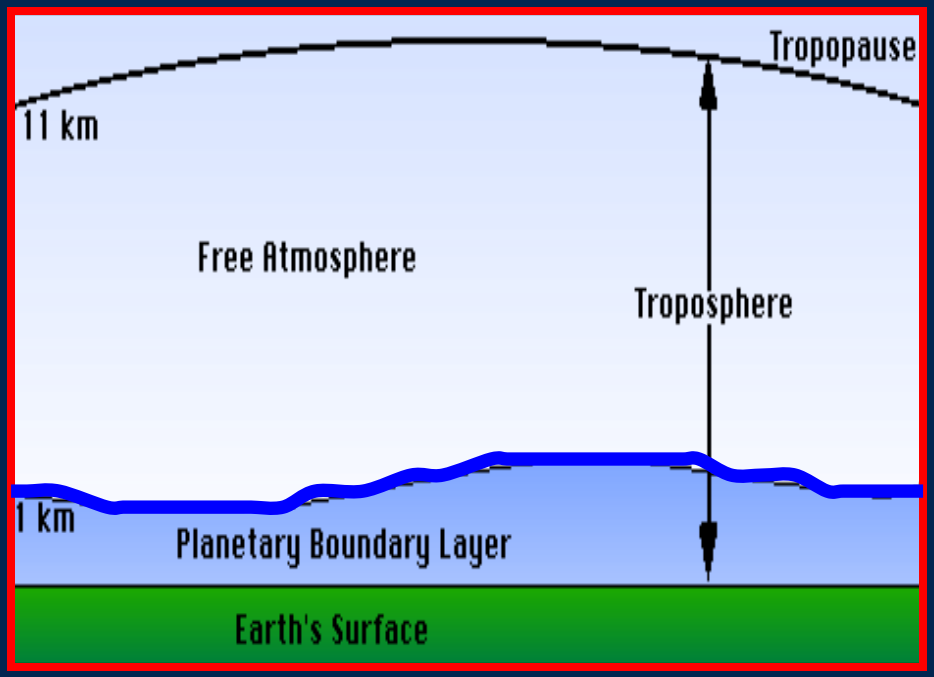


Diurnal variations in stability



What is the Planetary Boundary Layer (PBL)?

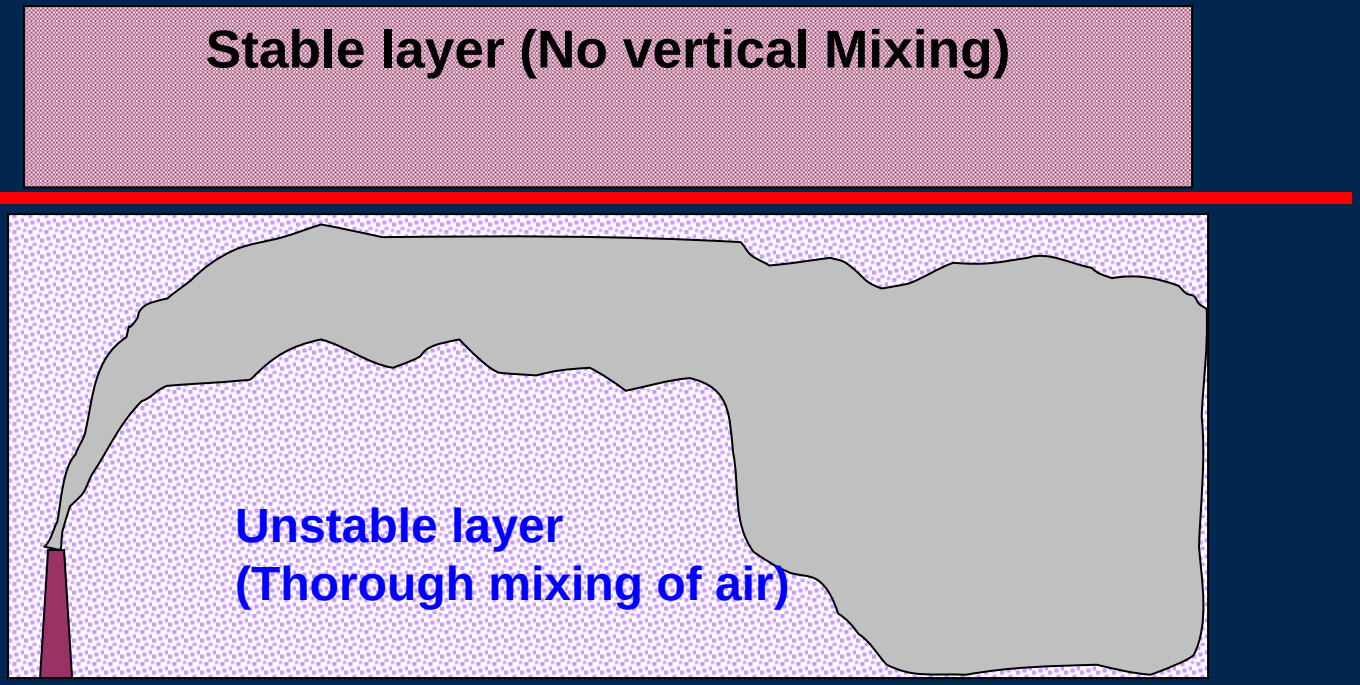
Point at which the influence of surface friction on air motion becomes negligible



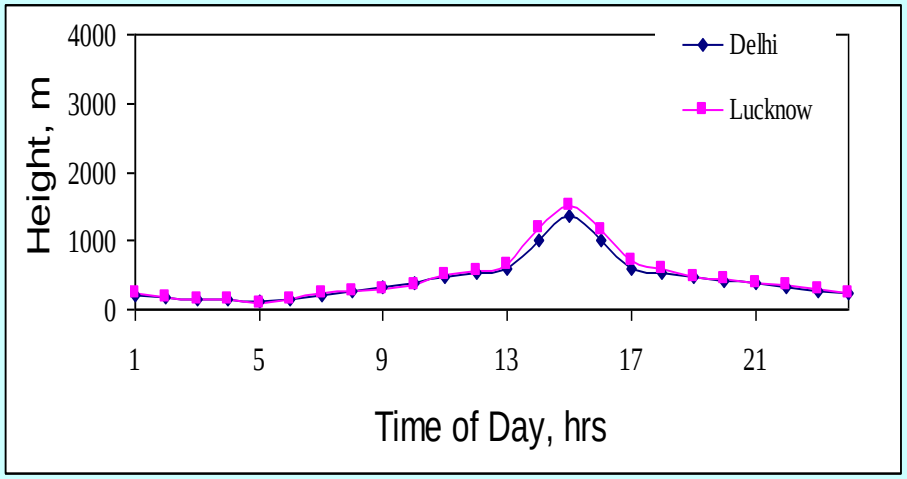
- Significant drag against earth's surface. High energy dissipation (due to friction)
- Continuous turbulence throughout layer.
- Spreads between 100 and 3000 m, diurnal variation over land
- Rapid turbulent mixing in vertical and horizontal direction

Mixing Height

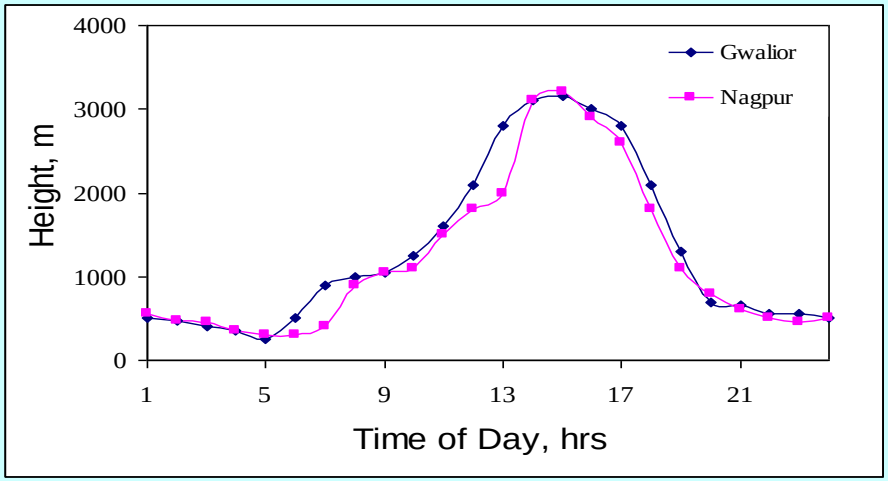
The layer within which the air parcel is thoroughly mixed



Variation in Mixing heights

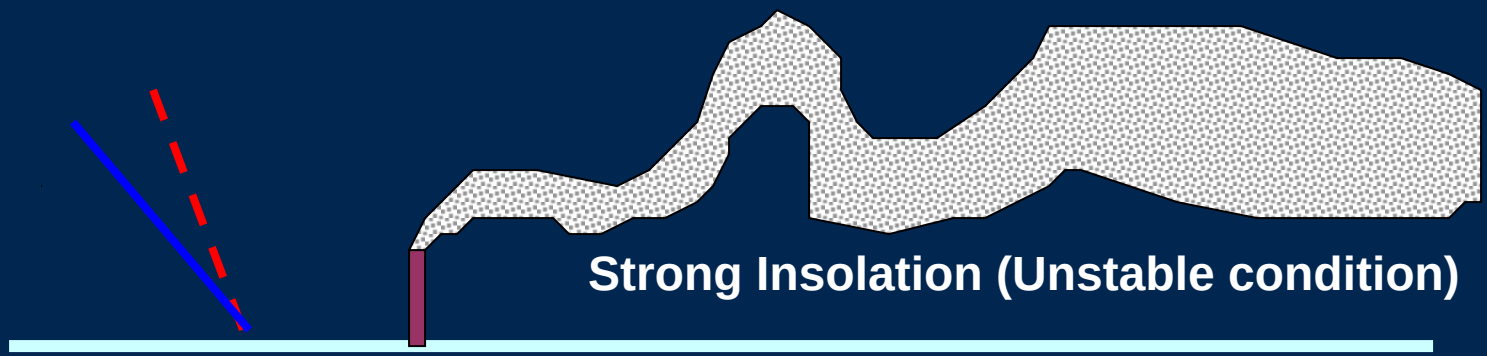


(January)



(May)

Plume Travel

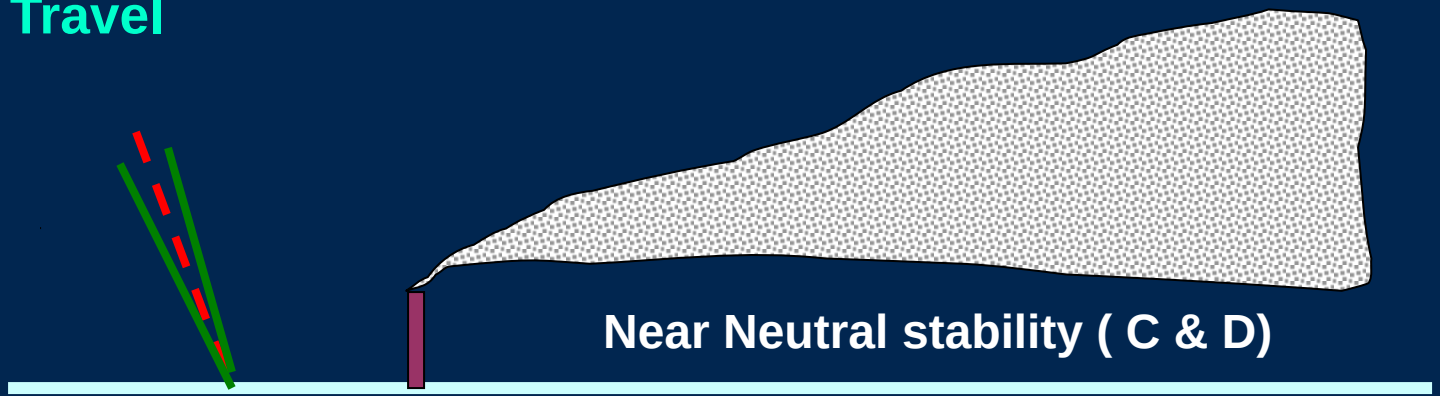


Looping

Low winds

High Winds

Plume Travel



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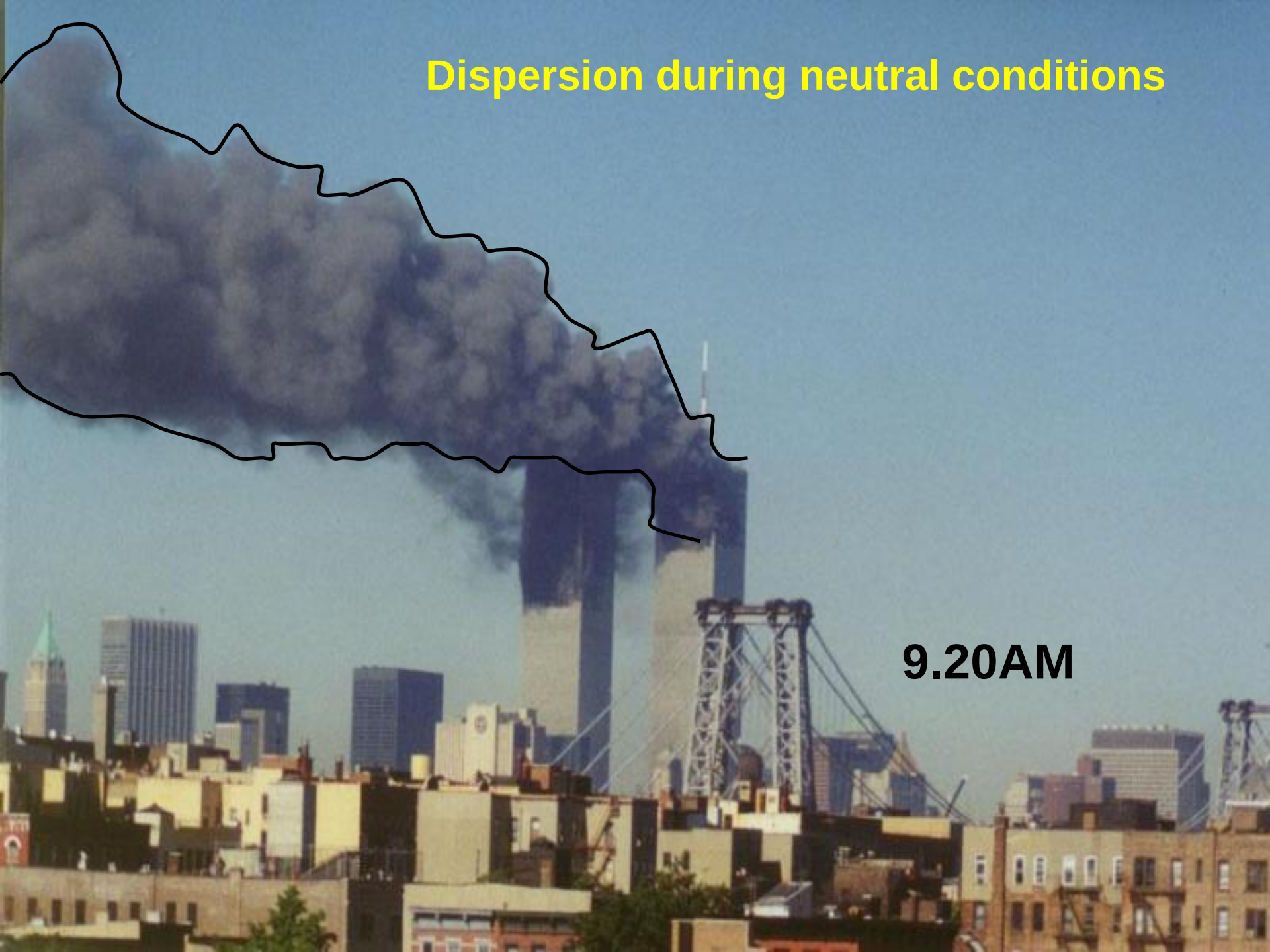

Dispersion during neutral conditions
9.20AM

inversions

60° F

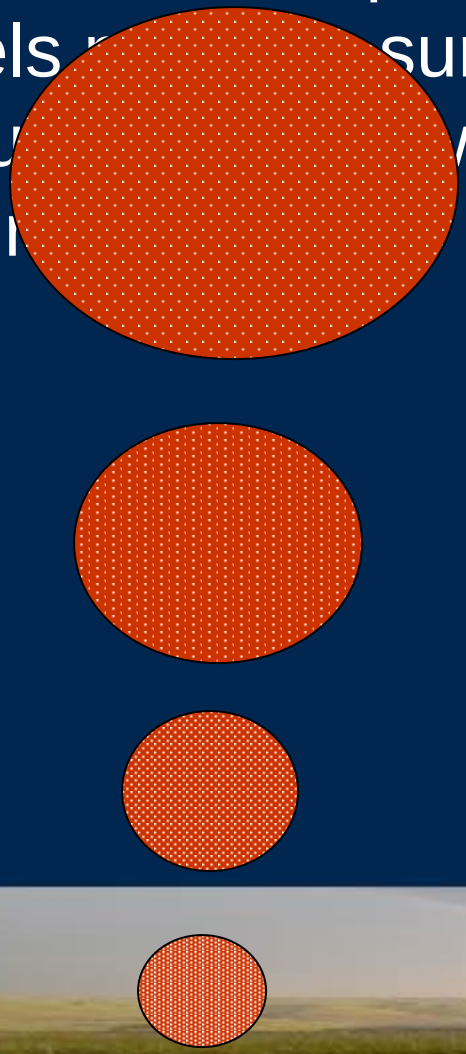
65° F

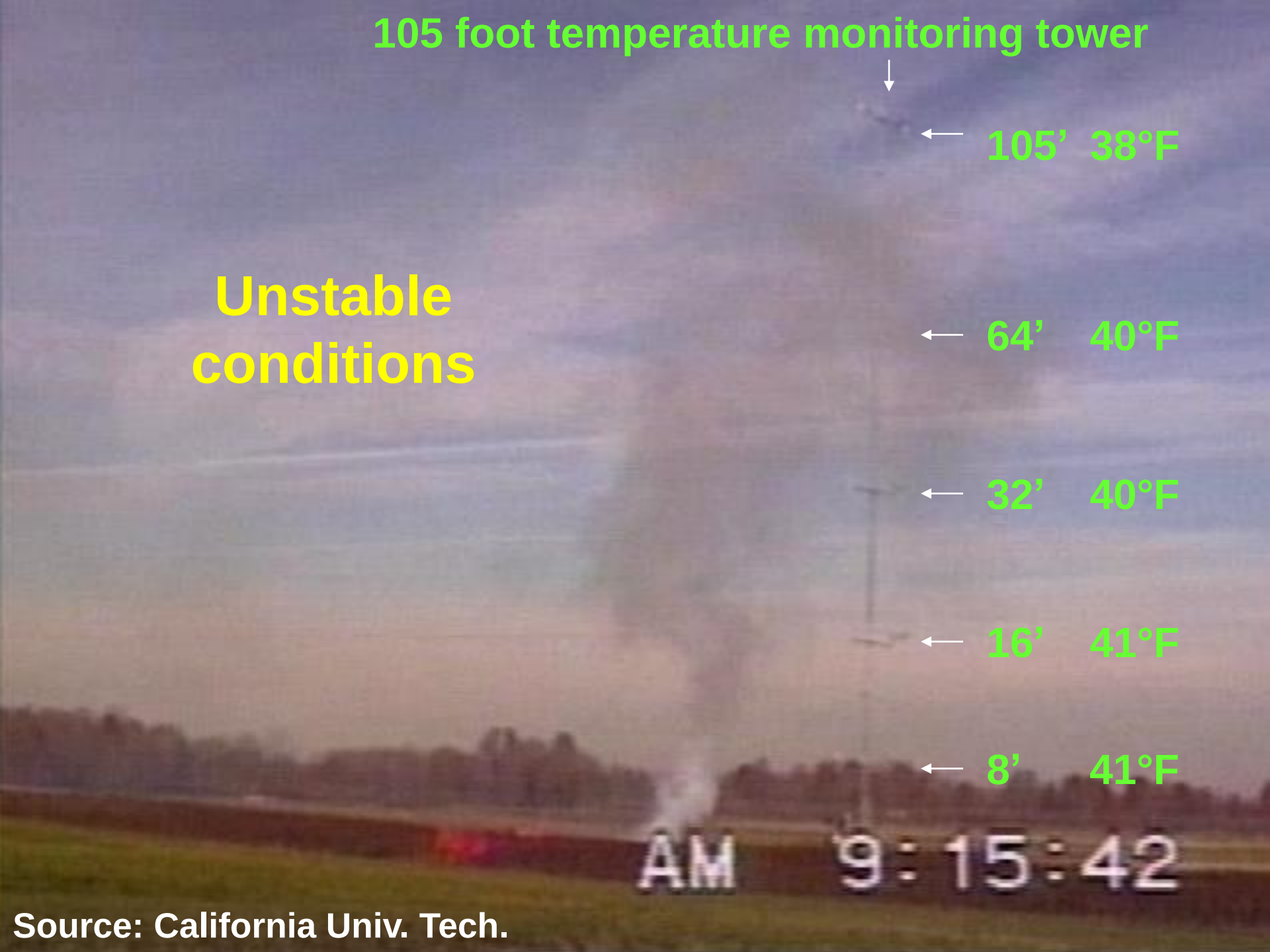
70° F

75 ° F

80 ° F

When the atmosphere is UNSTABLE air parcels [illegible] surface will rise and expand becau[illegible]warmer & less dense than the air





Source: California Univ. Tech.

65 °F

60 °F

55 °F

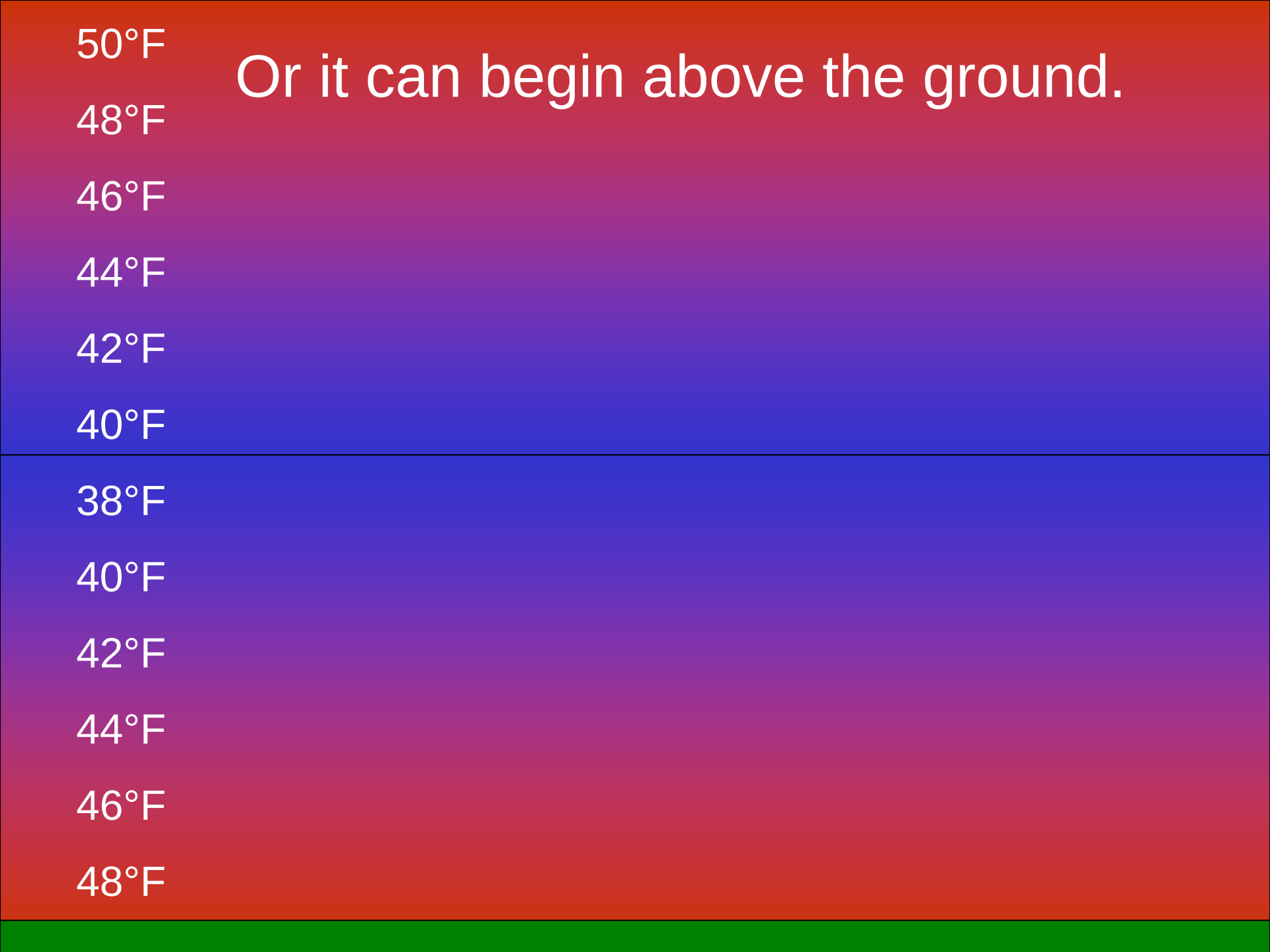
50 °F

45 °F

40 °F

A temperature inversion is an area where temperature increases with height.

It can begin at the ground.


50°F
48°F
46°F
44°F
42°F
40°F
38°F
40°F
42°F
44°F
46°F
48°F
Or it can begin above the ground.

65° F

60° F

55° F

50° F

45° F

40° F

When temperature increases with height the atmosphere is STABLE.

Vertical mixing of the air and dispersion of gas is suppressed.

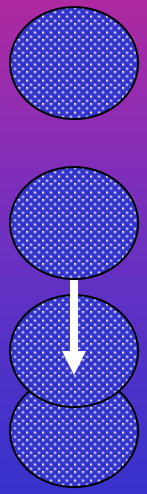
65° F

A parcel of air near the surface is always cooler & more dense than the air above, so it can't rise and disperse.

60° F

If forced down by a current of air, it will immediately rise back.

55° F



50° F

45° F

40° F

65° F

60° F

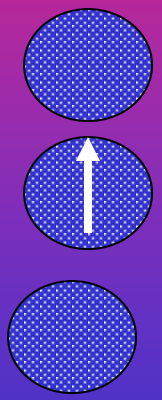
55° F

50° F

45° F

40° F

It will immediately sink back due to stable conditions



65° F

60° F

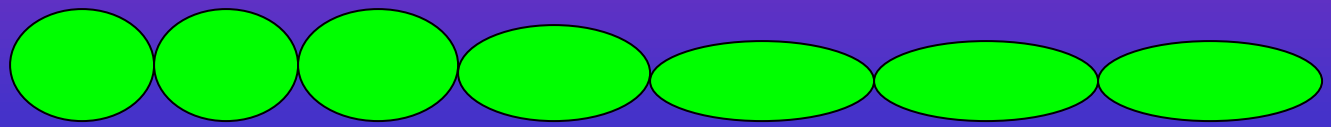
55° F

50° F

45° F

40° F

The parcel of air can't rise and disperse, but it can be move laterally in the light variable winds typical of a surface inversion

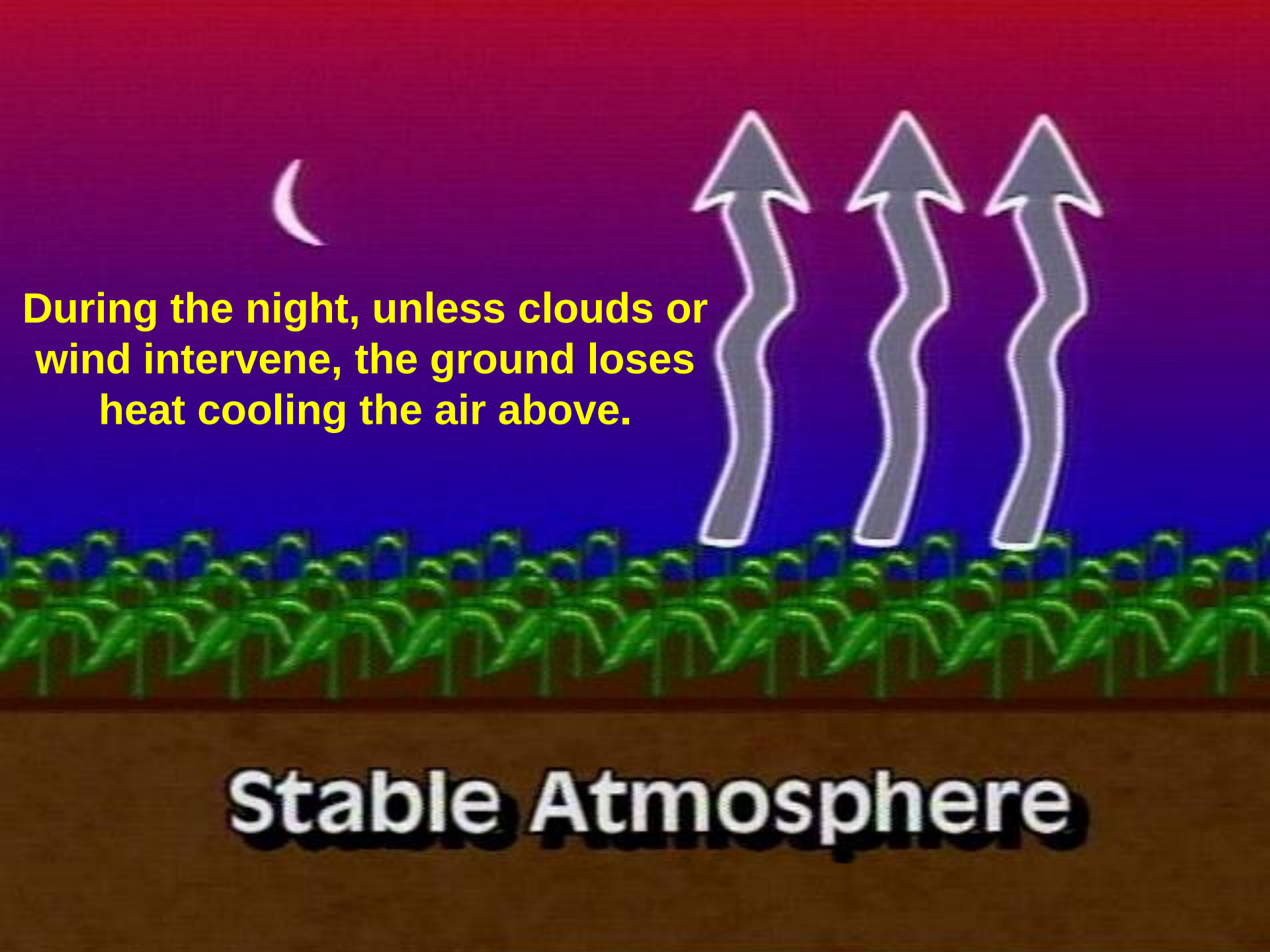



AM 6:57:36

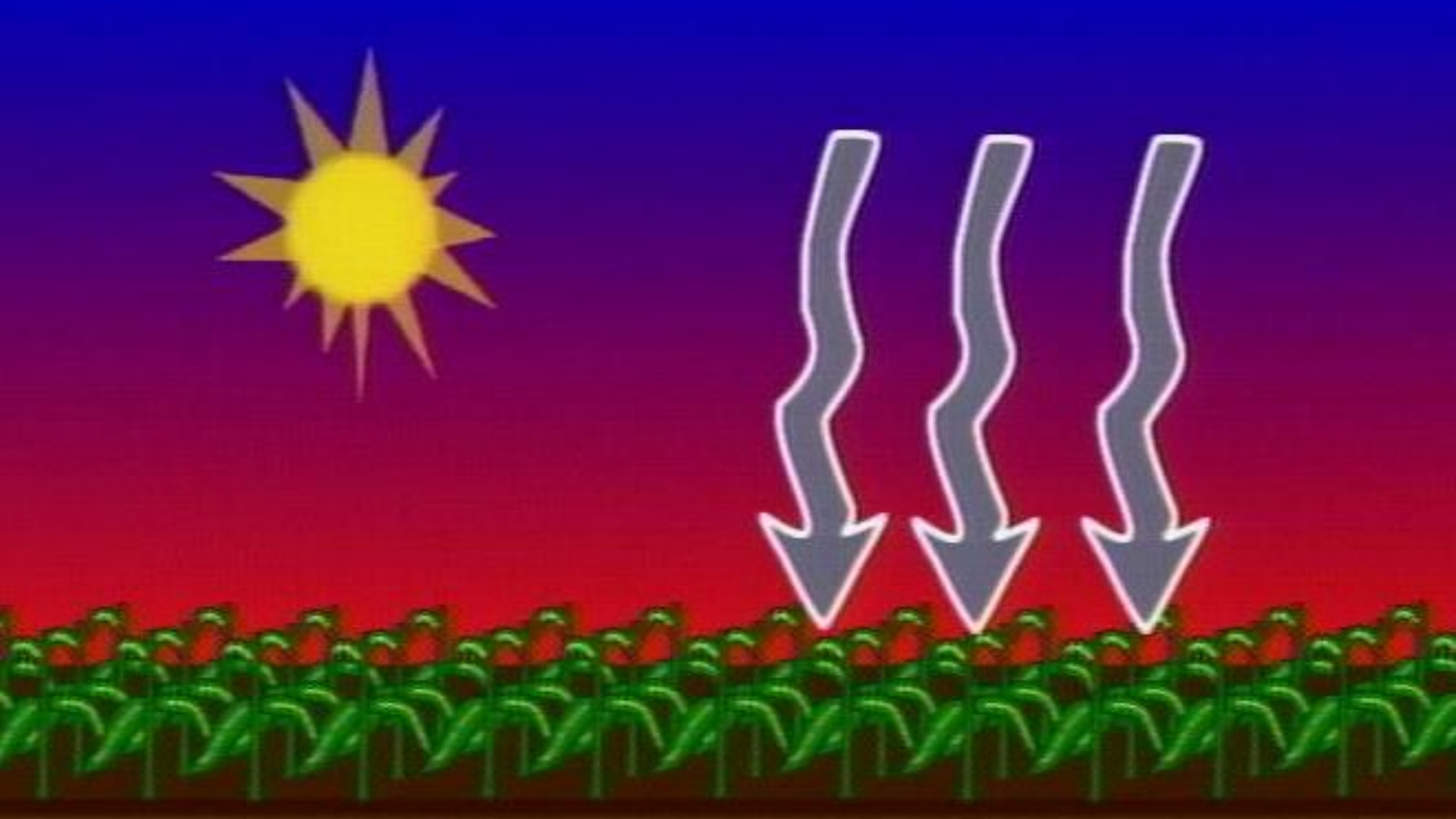

AM 6:57:44


AM 7:00:46

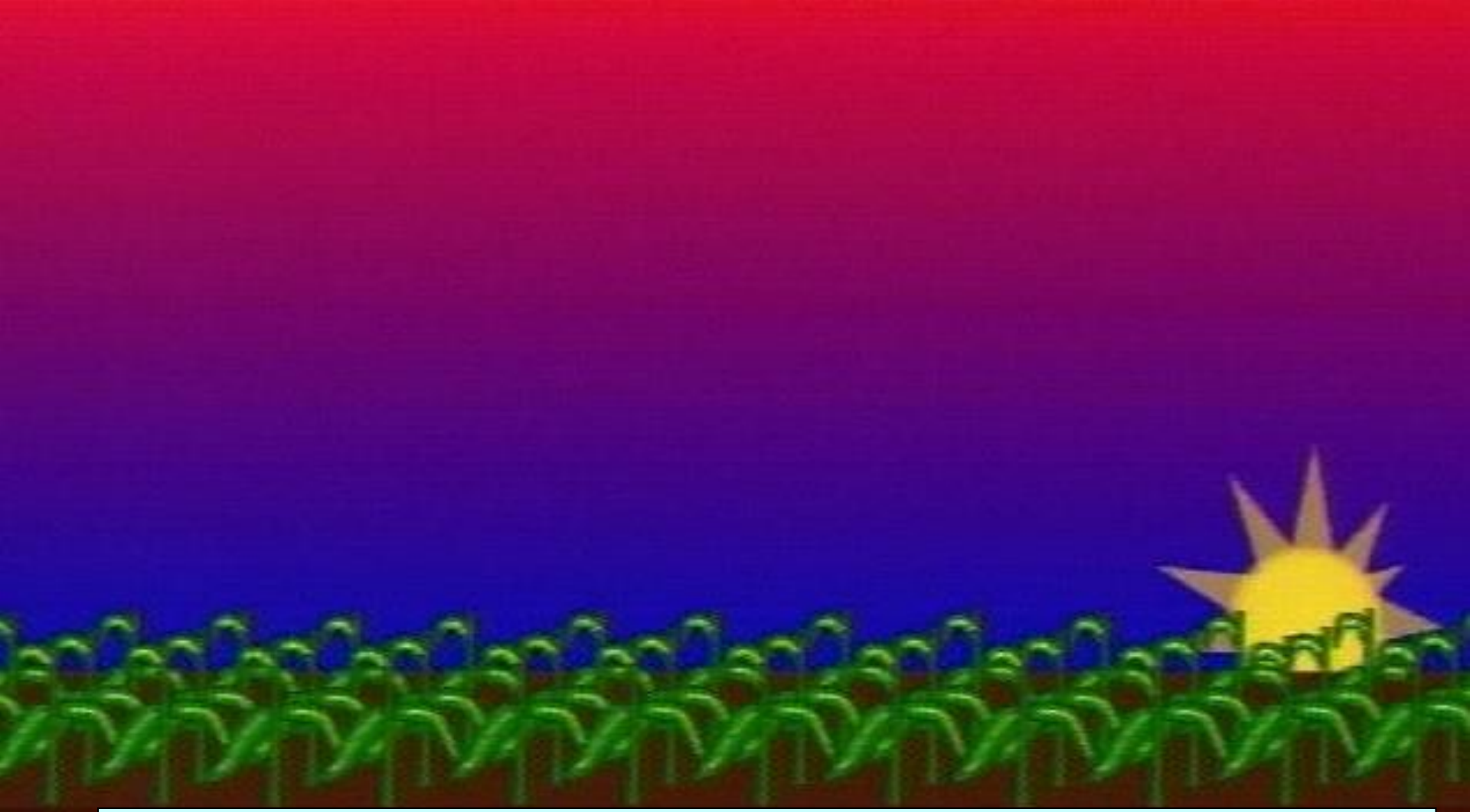
Layering observed when $PM_{2.5}$ released at ground level or top of tower. Clouds moving in different directions.


During the night, unless clouds or wind intervene, the ground loses heat cooling the air above.
Stable Atmosphere


Unless wind intervenes the surface inversion will continue until the sun begins to heats the ground
Stable Atmosphere



During the day when cloud cover is light, the sun heats the ground warming the air above. This causes in unstable conditions unless wind intervenes.



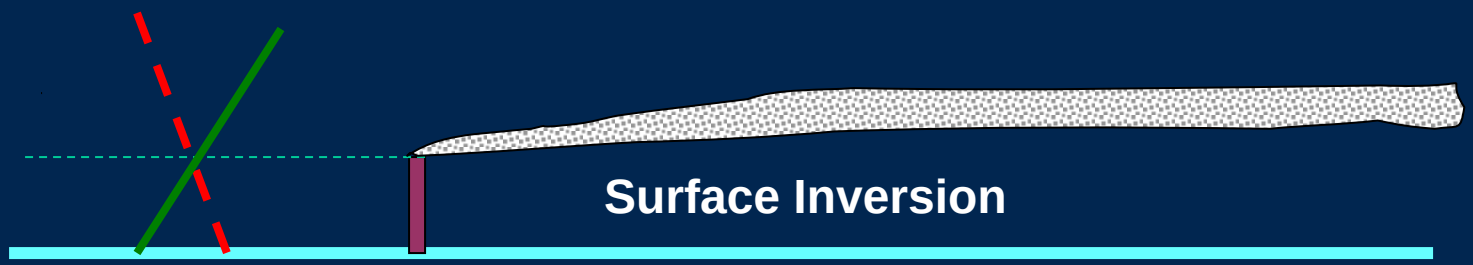
As the sun sets the ground begins to lose more heat than it gains, cooling the air above. In the absence of heavy cloud cover and/or wind a surface inversion will begin to form.

How to recognize a surface inversion

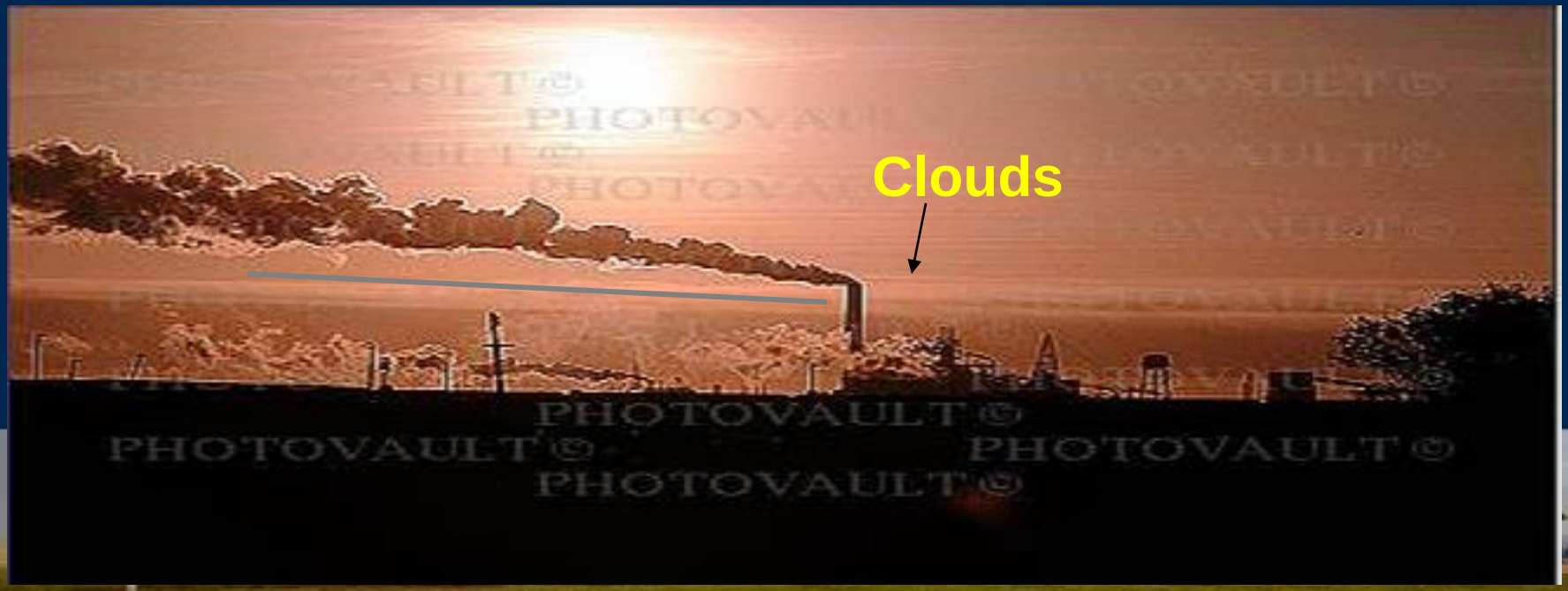
- Sunset to just after sunrise
- Windless to low wind conditions (<2-3 mph)
- Clear to partly cloudy skies
- Ground fog (if sufficient humidity exists)
- Dust hanging over a roadway
- Smoke from a chimney forming a layer
- Dew or frost (if sufficient humidity exists)


Signs of a surface inversion in the early morning
Lack of heavy cloud cover
Windless or light variable wind
Ground Fog

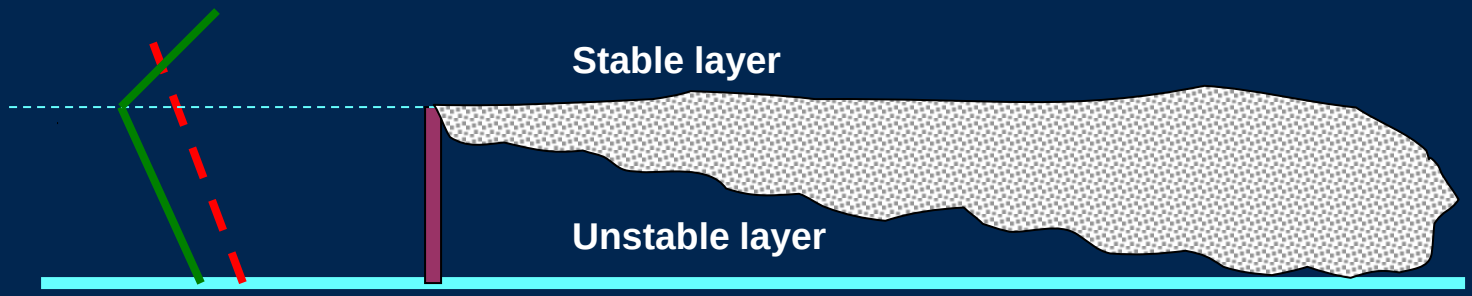
Inversion Below Plume



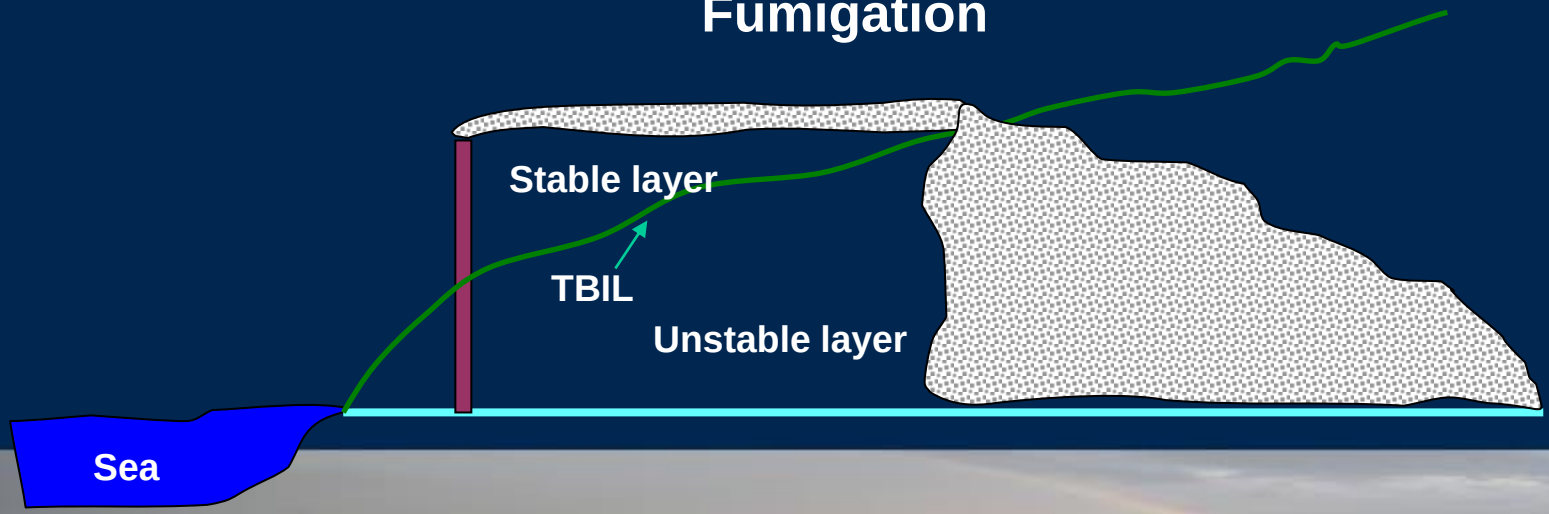
Fanning



Plume Travel

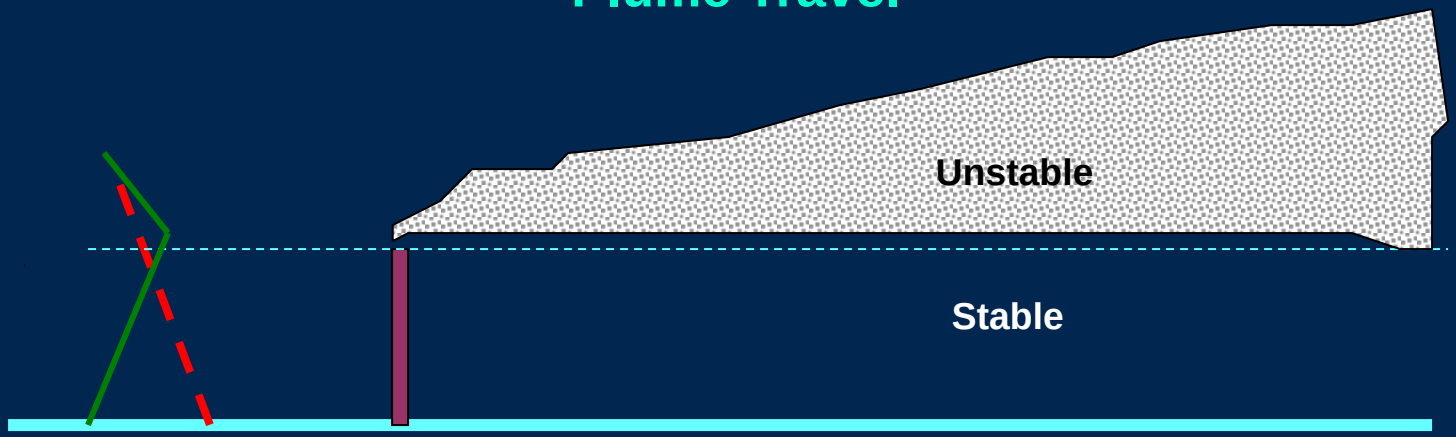


Fumigation

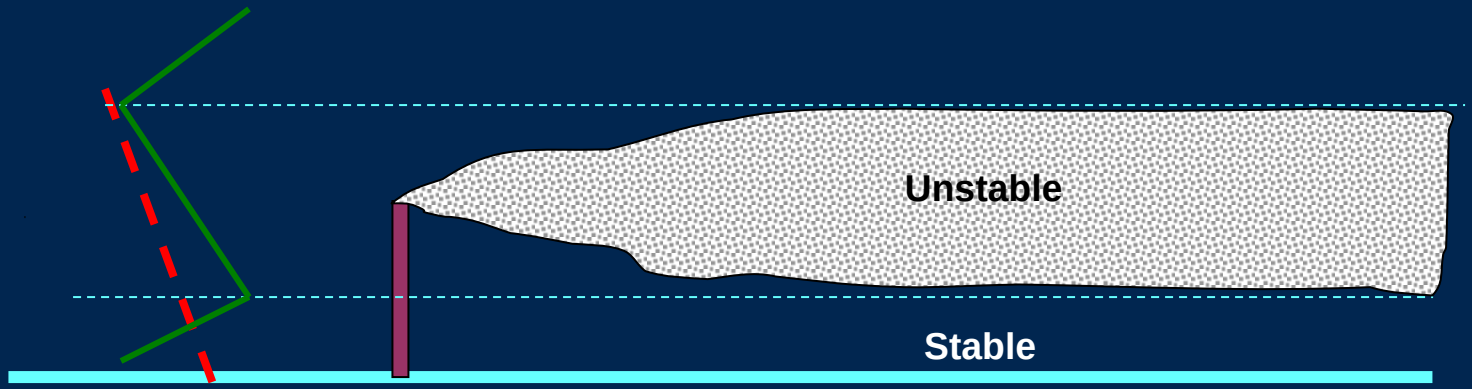



Fumigation

Plume Travel



Lofting – Inversion below stack



Trapping


Inversion below stack
Stability-A (top)
Stability-F (Down)


Modeling is a
difficult task due
to complexities

Quiz

Guess the Environmental Conditions

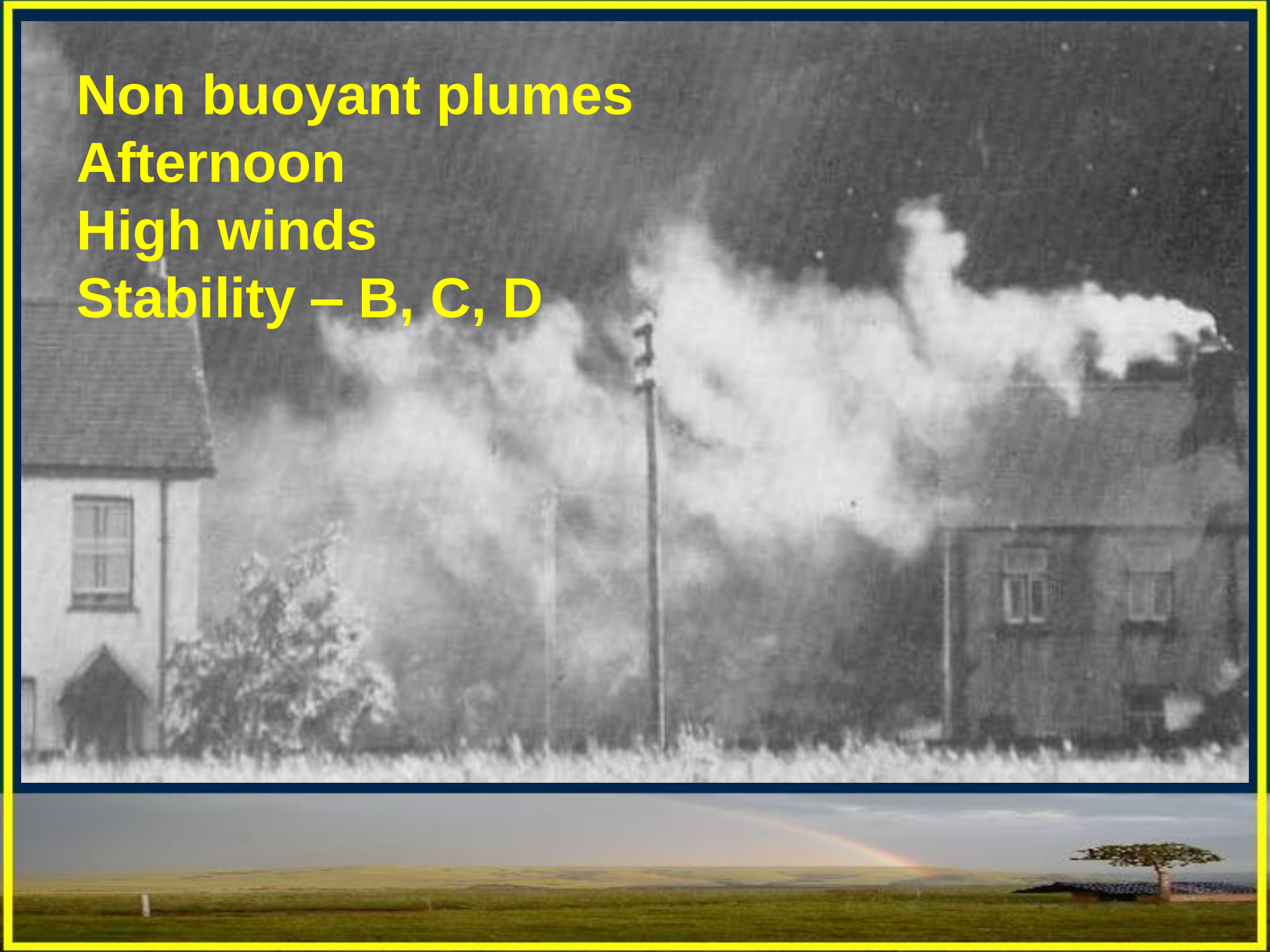
Calm

Unstable

Afternoon


Summer afternoon
Stability-A
Moderate winds


Summer afternoon
Stability-A
High winds
Wind speed > 1.5 times Stack “V”

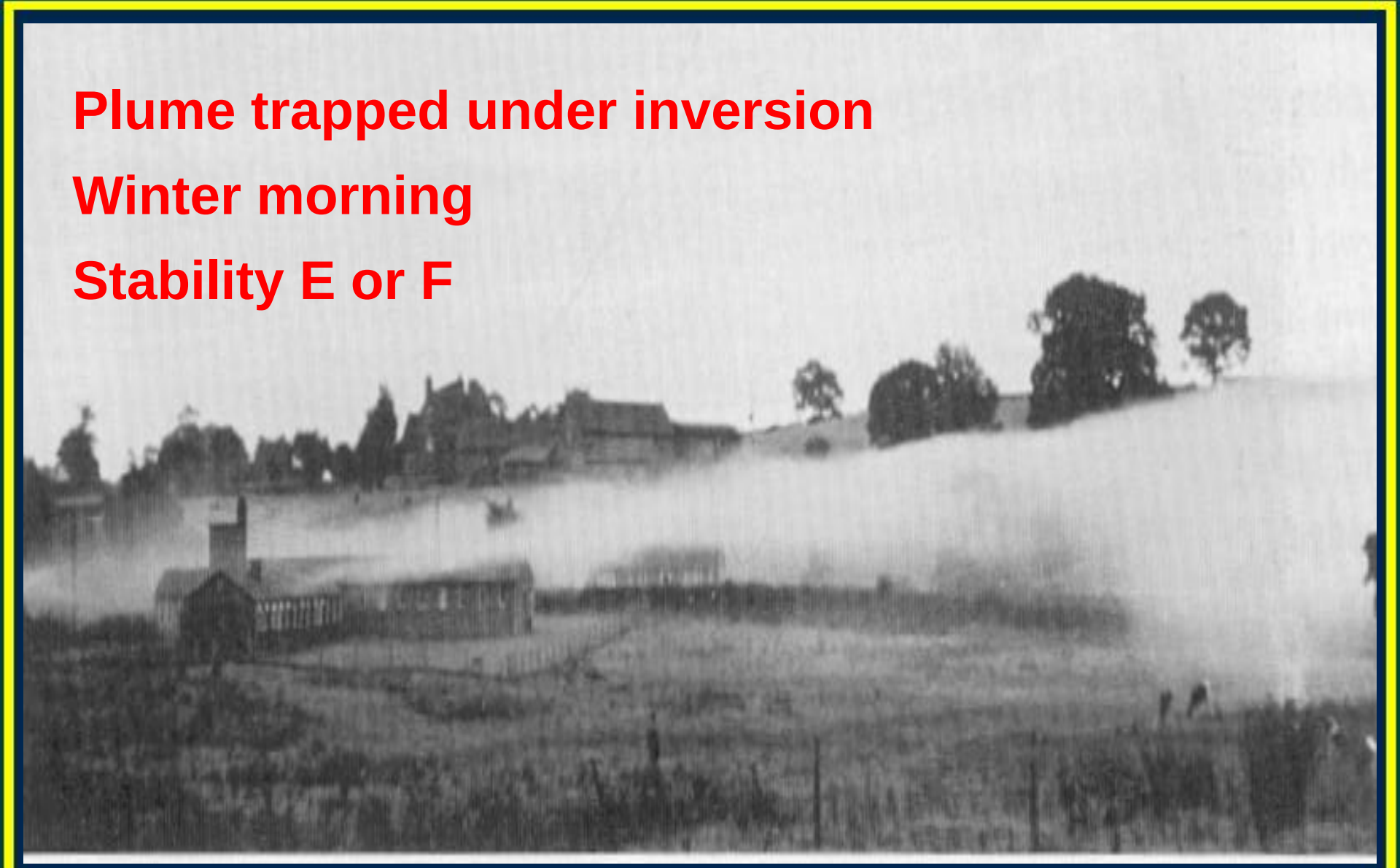

Non buoyant plumes
Afternoon
High winds
Stability – B, C, D


Afternoon
Moderate winds
Stability – D

Plume trapped under inversion

Winter morning

Stability E or F




Strong lapse conditions
Summer noon
Stability A


Surface inversion
Evening
Strong winds
Stability D

Thanks