Course Outline for ESI-101

- Environmental problems of urban areas
- Air pollution due to vehicles and fire crackers
- Atmospheric Energy Balance
- Global atmospheric circulation
- Stability of Atmosphere

Course Instructor
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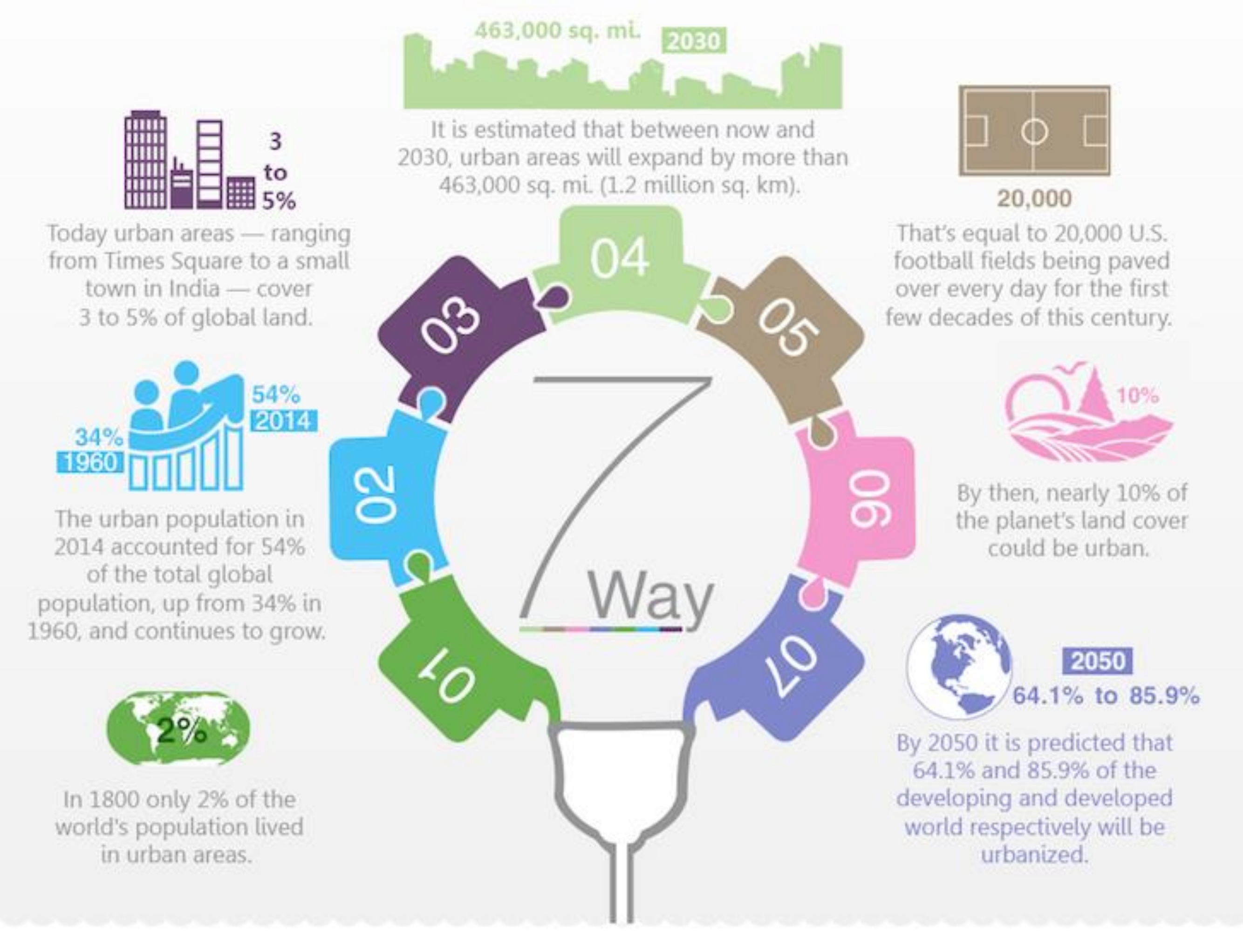
Development of Urban areas

Definition of Urban area

- A city whose population is more than 5000
- 75 % of male working population engaged in non-agricultural pursuits
- population density of more than 400 people per square kilometre



Causes for increasing trend

- Better employment facilities
- Better medical facilities
- Better facilities for trade and commerce
- Better facilities for higher education
- Facilities for entertainment, sports and games
- Proximity to administration and important government offices

Effects- Environmental Problems

- Development of Slum
- Water-logging and drainage
- Management of solid waste
- Non-availability of open space
- Unusual rise in temperature
- Air pollution
- Noise pollution
- Traffic

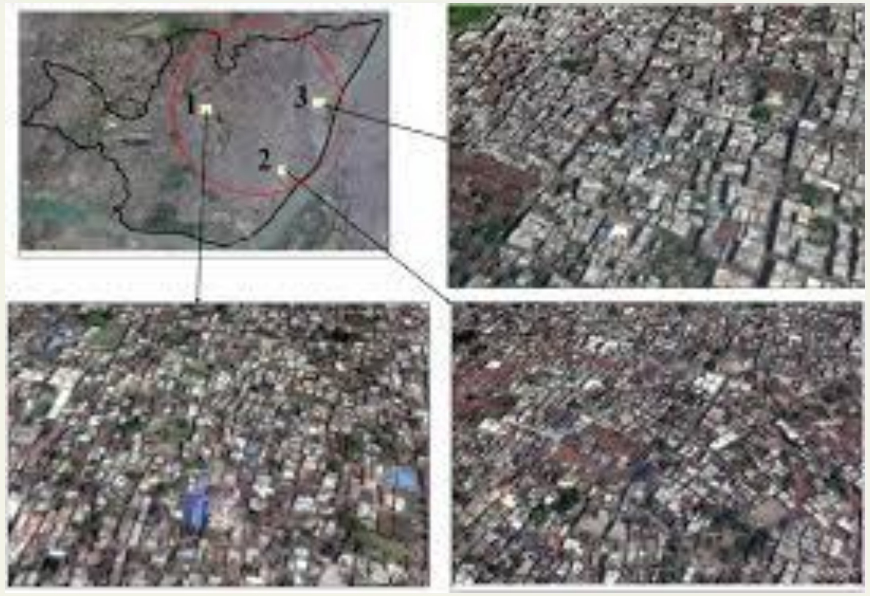
Slum Development

- A slum is a run-down area of a city characterized by substandard housing, poverty, lack of electricity, water shortage, proper sanitation, drainage etc.
- Dispose their waste in an unplanned manner which pollute air and water. The contamination of water causes diseases like typhoid, cholera, and gastroenteritis.

Management of Solid Waste

- Increased population consumes large quantities, releases a lot of solid wastes including municipal wastes, industrial wastes, hazardous wastes etc.
- When these solid wastes are dumped for a longer period of time, these produce foul smell and poisonous gases that add to air pollution, surface run-off from the wastes cause water pollution and become breeding region for diseases.

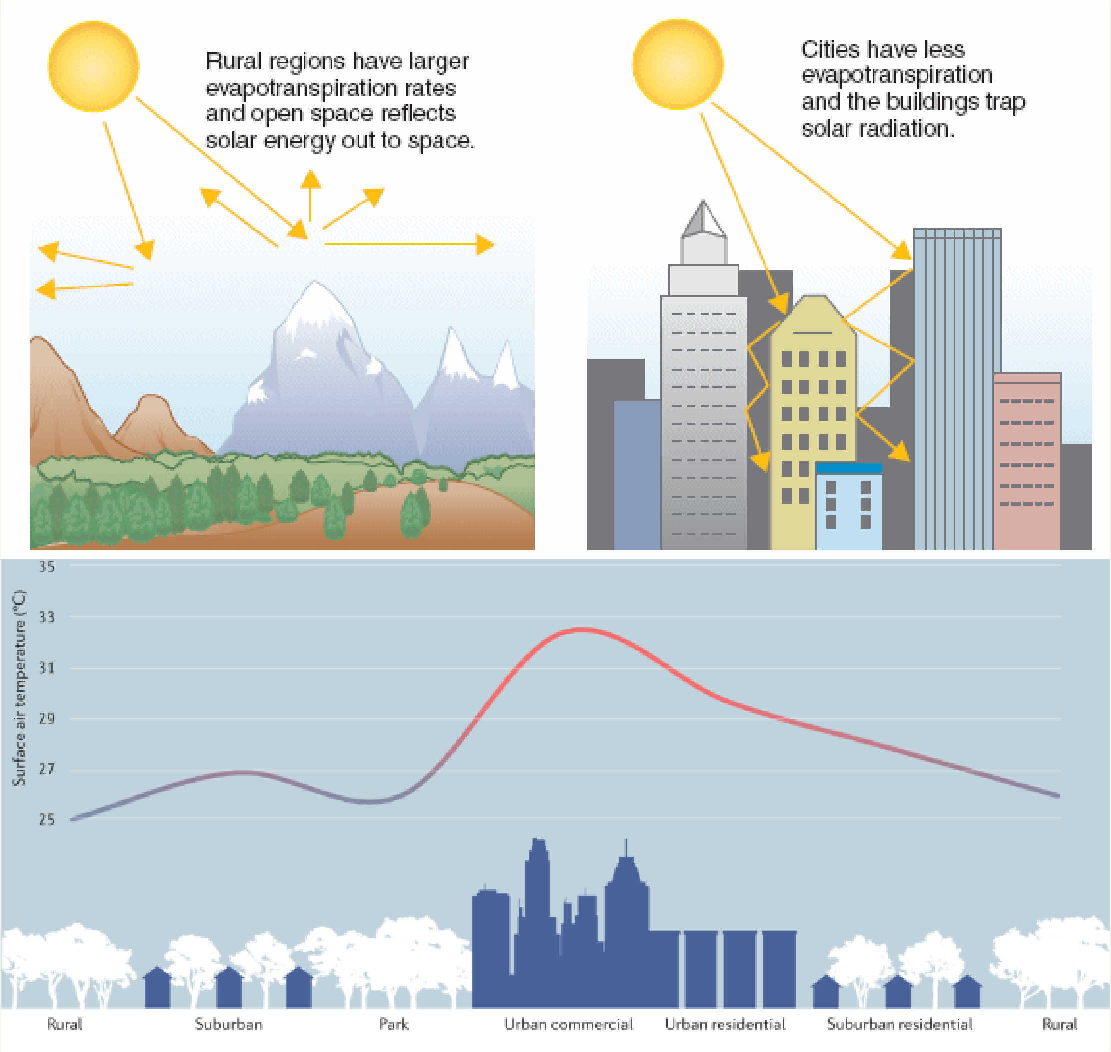
Non-availability of open space



Due to unplanned urbanization and thick population density, urban areas are highly congested without open spaces for parks, play grounds and recreation centres. This results in non availability of free and clean air and space of playing and recreation.

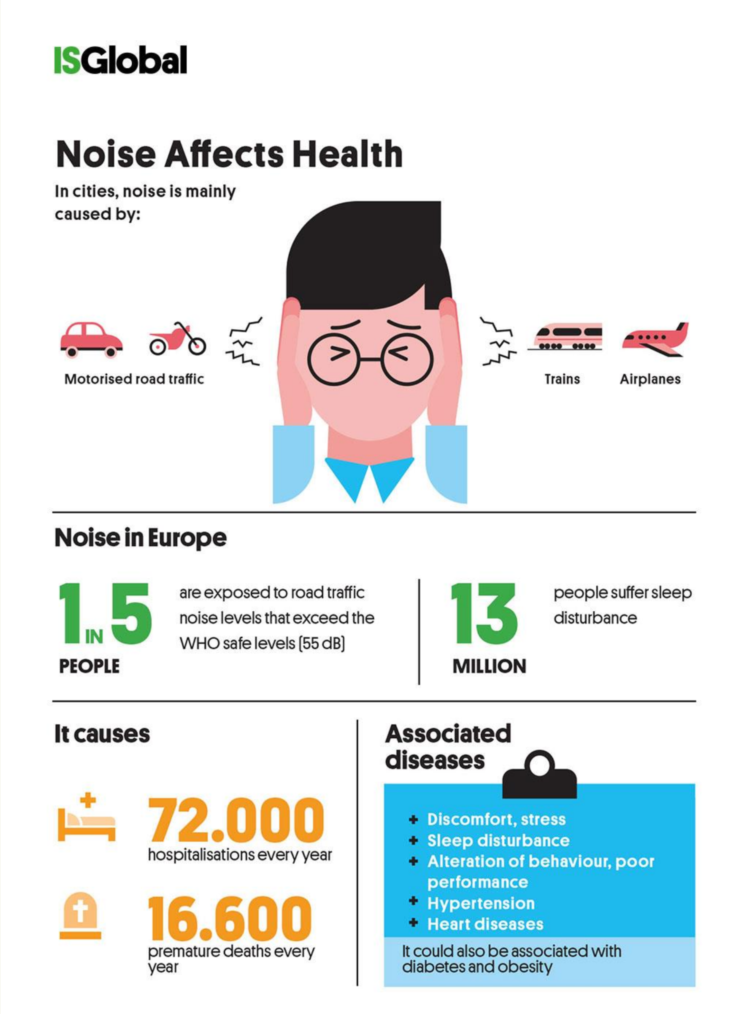
Unusual rise in temperature

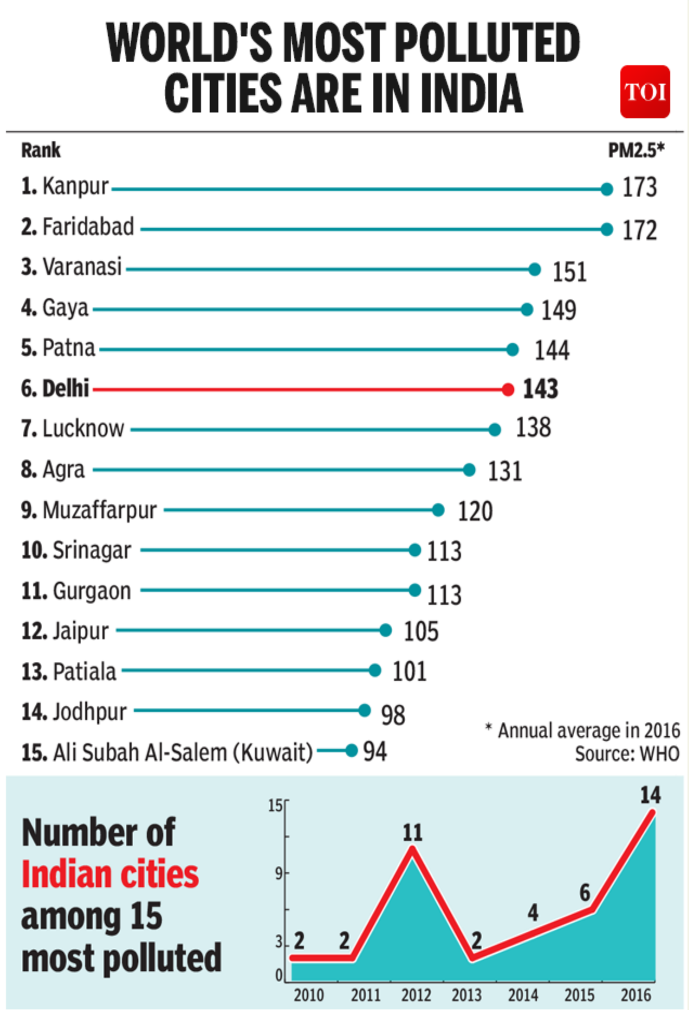
Urban heat Island effect



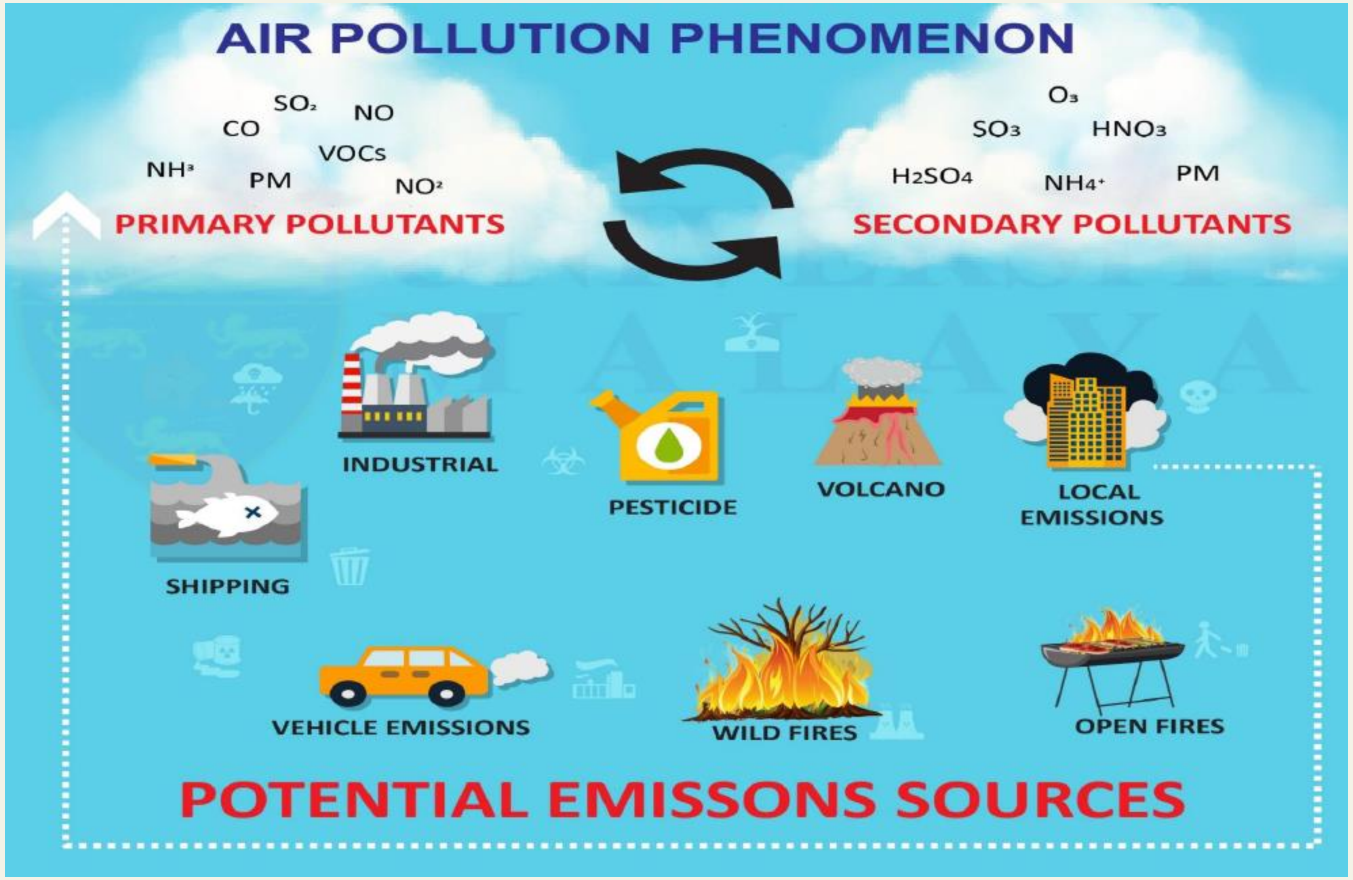
Traffic and Pollution

Urbanization leads to ever larger cities and increased rates of motorization.





Air Pollution: Components and Sources

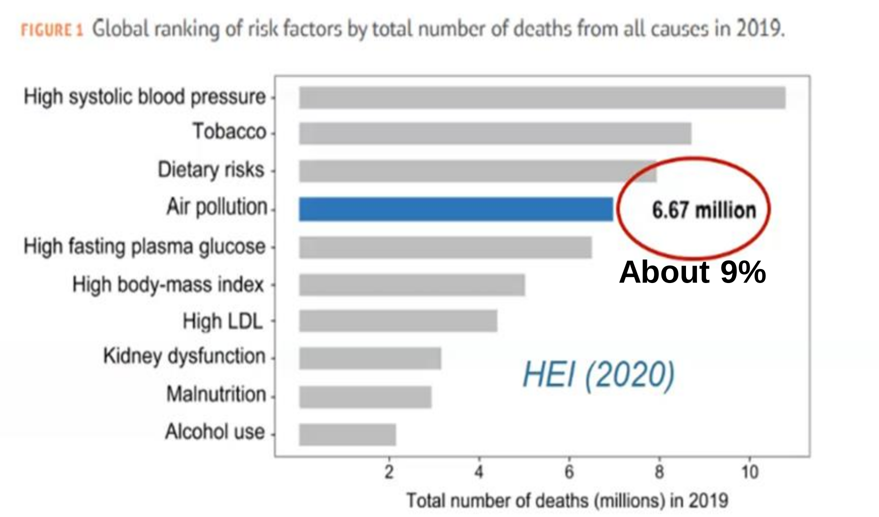


Definition of Air Pollution

Chemicals added to the atmosphere by natural events or human activities **in high enough concentrations to be harmful to ecosystem and humans and climate**

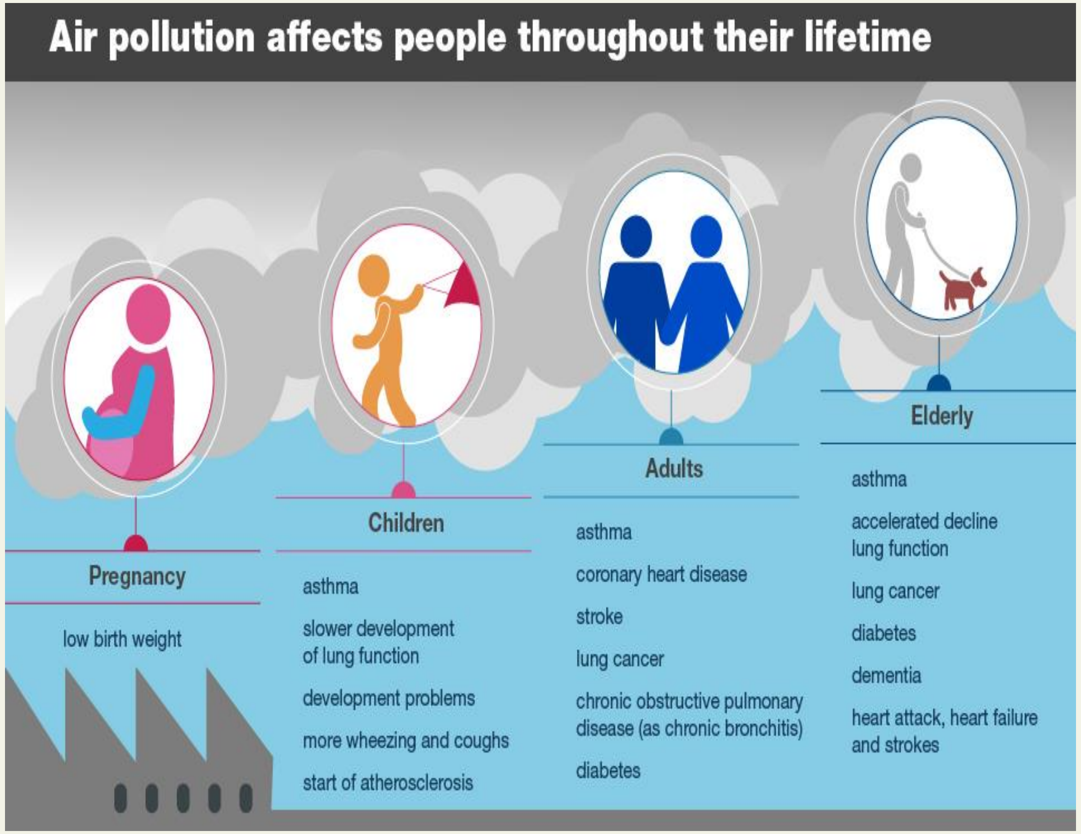
- Air Pollutants include gaseous (SO_2, NOx, O_3..) and particulate matter (PM).
- Categorised as
  - Primary Pollutant are directly released into the atmosphere
  - Secondary Pollutant are formed from chemical reactions between primary pollutants. Meteorological factors like solar radiation, moisture, temperature, play critical role in the formation of secondary pollutants
- Units :
  - ug/m^3 (mass of pollutant per volume of air)
  - Ppm (mg/kg)

Burden of Death from Air Pollution

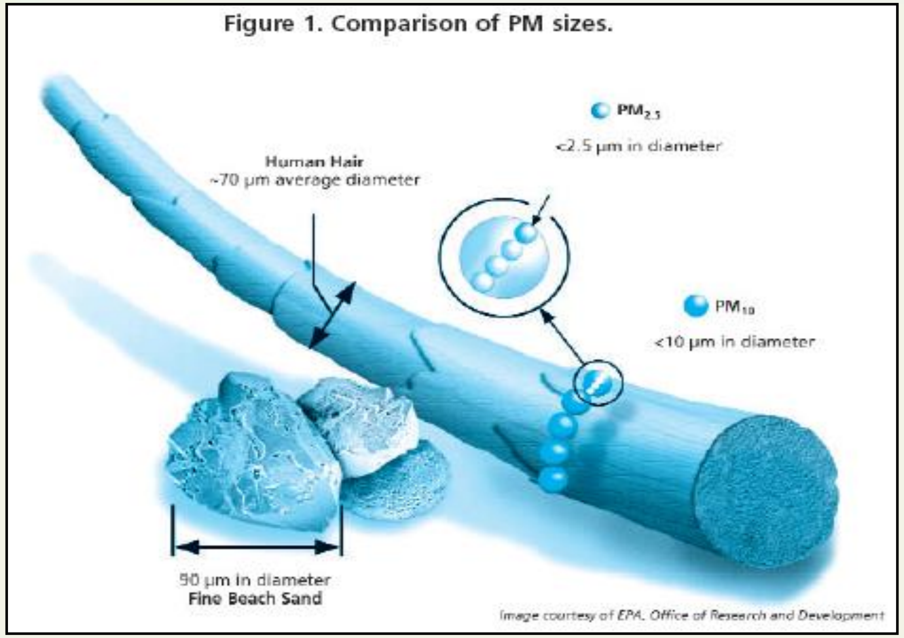


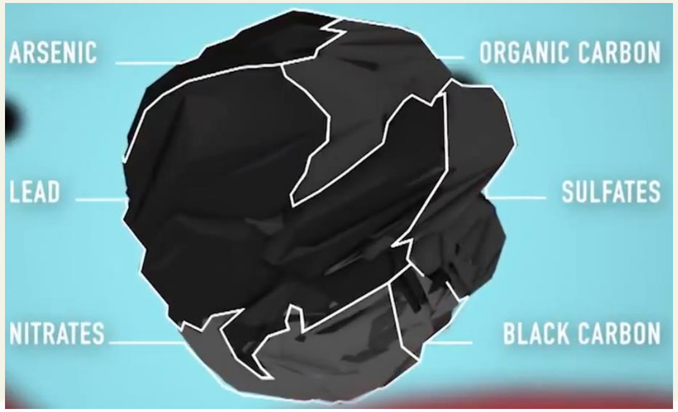
2019: air pollution caused 6.67 mil deaths

- Ambient $PM_{2.5}$: 4.14 mil
- Household ($PM_{2.5}$): 2.31 mil
- Surface ozone: 365,000 to ozone



Particulate Matter (PM) or Aerosol





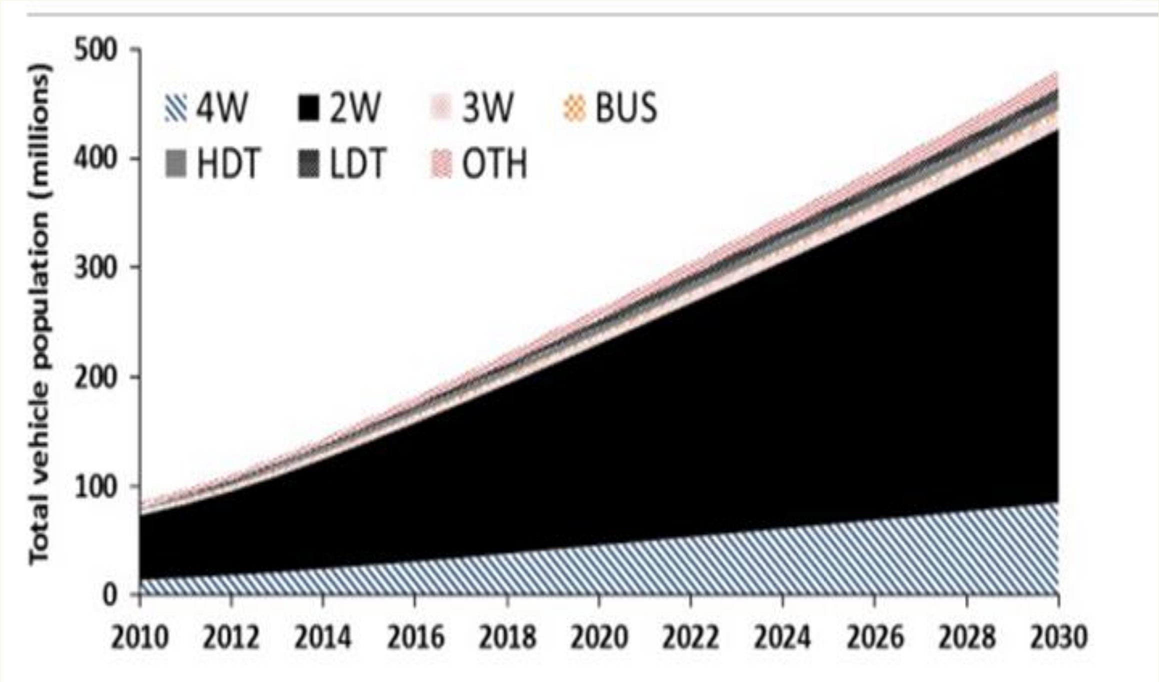
- Aerosols are solid or liquid particles that remain suspended in air
- Particulate matter is amalgamation of numerous chemical components including inorganic species (sulfate, nitrate, ammonium etc), carbonaceous species (organic carbon, elemental carbon), metals and atmospheric water.
- Particulate matter size can vary from few nanometres to hundreds of micrometres.
- Smaller the particle size, deeper penetration and higher chances of adverse health effects
- PM2.5 is a major concern among air pollutants, which is basically particles of size less than 2.5 micrometre in diameter and can penetrate to lungs and enter blood stream
- The mass concentration is expressed in µg/m^3.

New WHO Global Air Quality Guidelines

Units in µg/m³

Pollutant		Time	2005 levels	New 2021 levels
$PM_{2.5}$	Particulate matter < 2,5 microns	Annual	10	5
		24-hour	25	15
PM_{10}	Particulate matter < 10 microns	Annual	20	15
		24-hour	50	45
O_3	Ozone	Peak season	-	60
		8-hour	100	100
NO_2	Nitrogen dioxide	Annual	40	10
		24-hour	-	25
SO_2	Sulfur dioxide	24-hour	20	40
CO	Carbon monoxide	24-hour	-	4

Air Pollution due to Vehicular Emissions



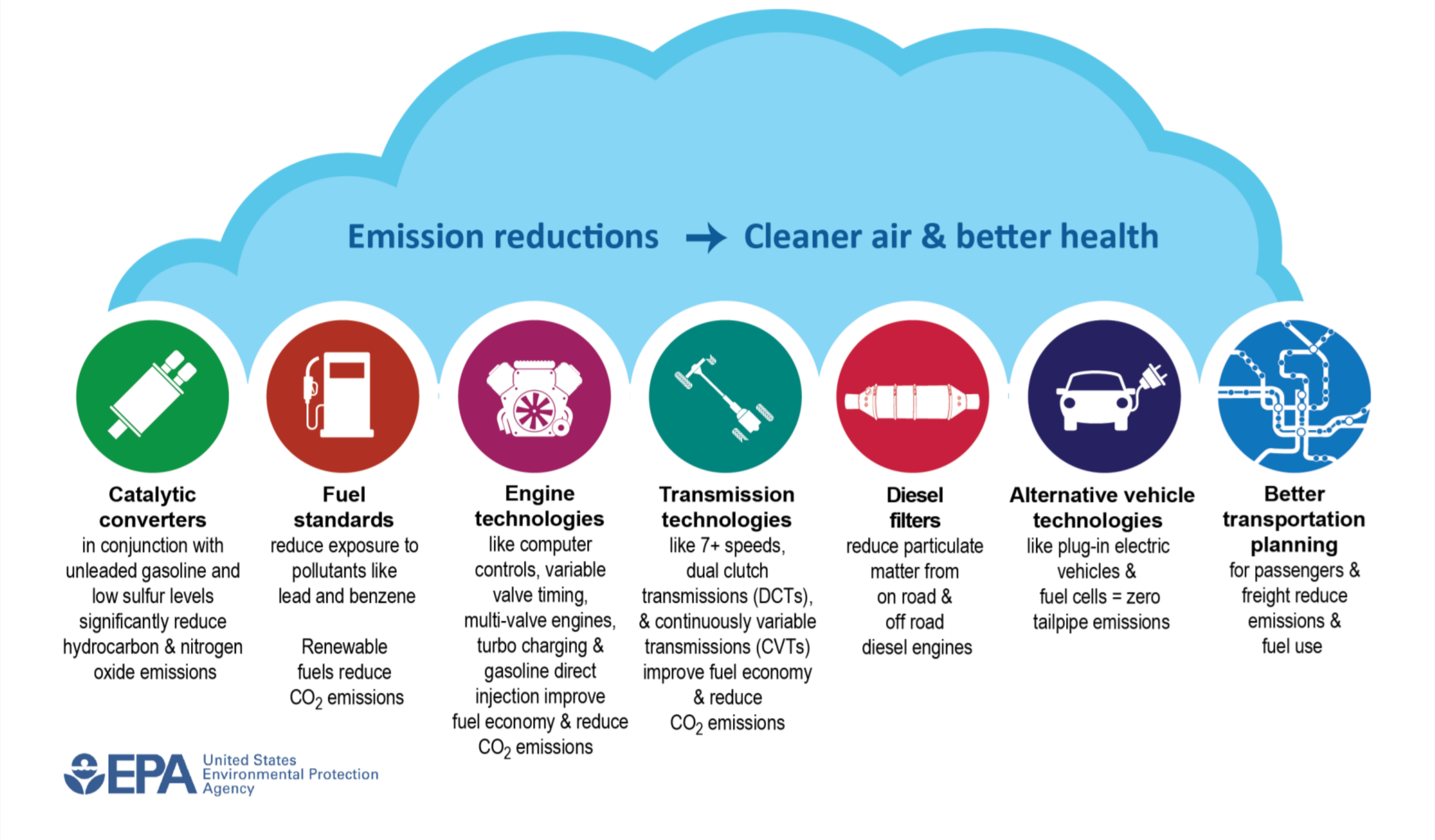
Petrol or Gasoline vehicle = Hydrocarbons and CO
Diesel vehicle = Nitrogen oxides and Particulate matters

Causes of Vehicle Pollution

- growing number of vehicles density
- older vehicles predominant
- inadequate inspection and maintenance facilities
- poor fuel quality and adulteration
- poor road condition
- Poor traffic management system
- old automotive technologies
- absence of effective mass rapid transport system
- increasing number skyrocketing buildings in the urban areas causes stagnation of the vehicular emissions to the ground level and preventing its proper dispersion

Human behavioural change can reduce the vehicular pollution

Technological Interventions



Road for Future – Electric Vehicles

- Electric Vehicles (EVs) are run by electric motors which are powered by energy stored in batteries.
- EVs have an electric motor instead of an Internal Combustion Engine (ICE). As an EV runs on electricity, the vehicle emits no exhaust from a tailpipe i.e. it has zero tail pipe emission and does not contain components, such as a fuel pump, fuel line, or fuel tank and produce much lower noise.
- Adopting EVs will help in reducing local air pollution including aerosols and Greenhouse gas emissions

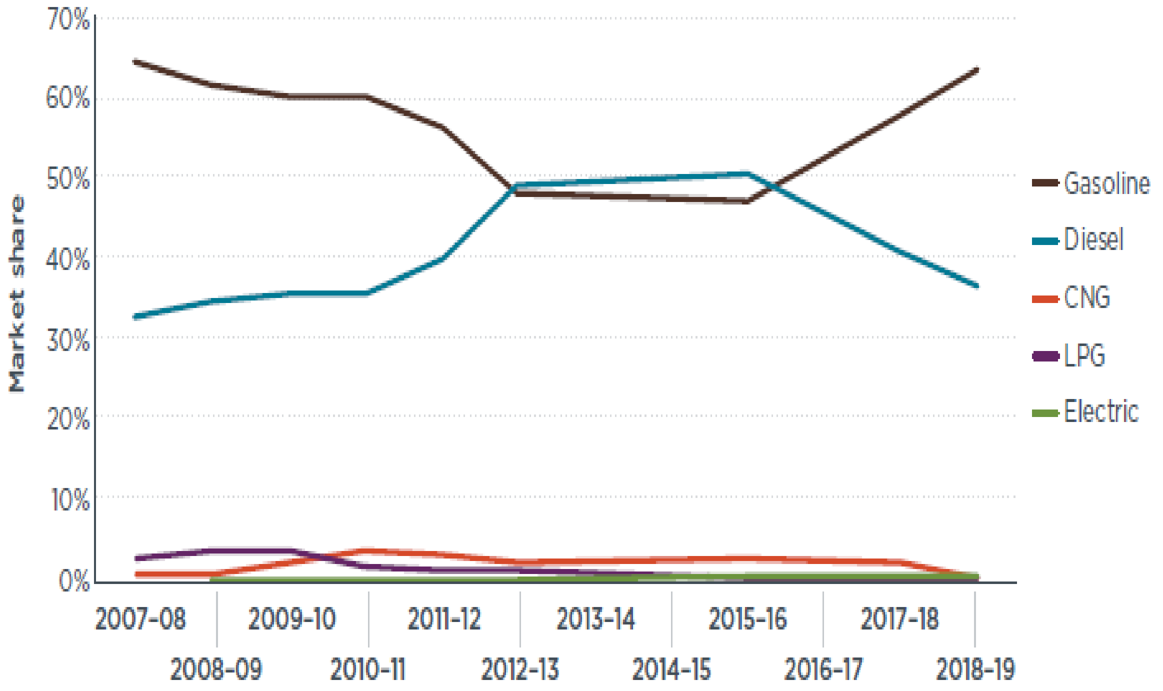
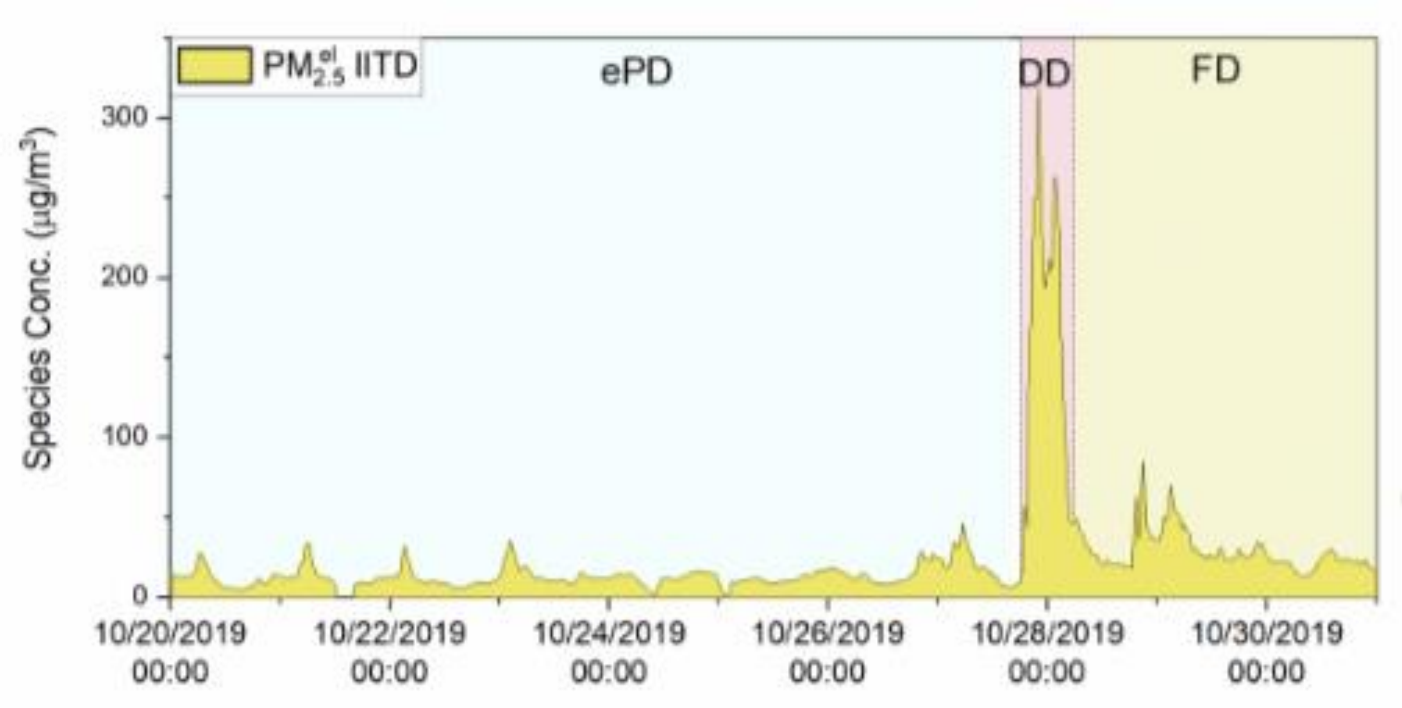


Figure 2. Trends of passenger vehicle sales in India by fuel type

Air Pollution due to Fire Crackers

- Fireworks are seasonal and episodic.
- The conventional firecrackers, when burst, emit oxides of sulfur and nitrogen along with Particulate metals like copper, zinc, sodium, lead, magnesium, cadmium, etc, which have harmful bearing on human as well as environmental health



Mahananda et al., 2021

Case study in Delhi: Diwali Period

A healthy baby girl born in Delhi's Indraprastha Apollo Hospital on October 29. However, on October 31, the baby developed breathing trouble and had to be moved to the ICU.

Doctors said, "The baby had perfectly developed lungs when she was born but is likely to suffer from bronchitis for life,"

Reason - High level of PM 2.5 on 30 and 31 Oct,, reached 837µg/m^3. (Safe limit for humans is 60µg/m^3)

Specific Health Effects by Air Pollutants

Pollutant	Effect on Human Health
Carbon Monoxide	Affects the cardio vascular system, exacerbating cardiovascular disease symptoms, particularly angina; may also particularly affect fetuses, sick, anemic and young children, affects nervous system impairing physical coordination, vision and judgments, creating nausea and headaches, reducing productivity and increasing personal discomfort.
Nitrogen Oxides	Increased susceptibility to infections, pulmonary diseases, impairment of lung function and eye, nose and throat irritations.
Sulphur Dioxide	Affect lung function adversely.
Particulate Matter and Respirable Particulate Matter (SPM and RPM)	Fine particulate matter may be toxic in itself or may carry toxic (including carcinogenic) trace substance, and can alter the immune system. Fine particulates penetrate deep into the respiratory system irritating lung tissue and causing long-term disorders.
Lead	Impairs liver and kidney, causes brain damage in children resulting in lower I.Q., hyperactivity and reduced ability to concentrate.
Benzene	Both toxic and carcinogenic. Excessive incidence of leukemia (blood cancer) in high exposure areas.
Hydrocarbons	Potential to cause cancer

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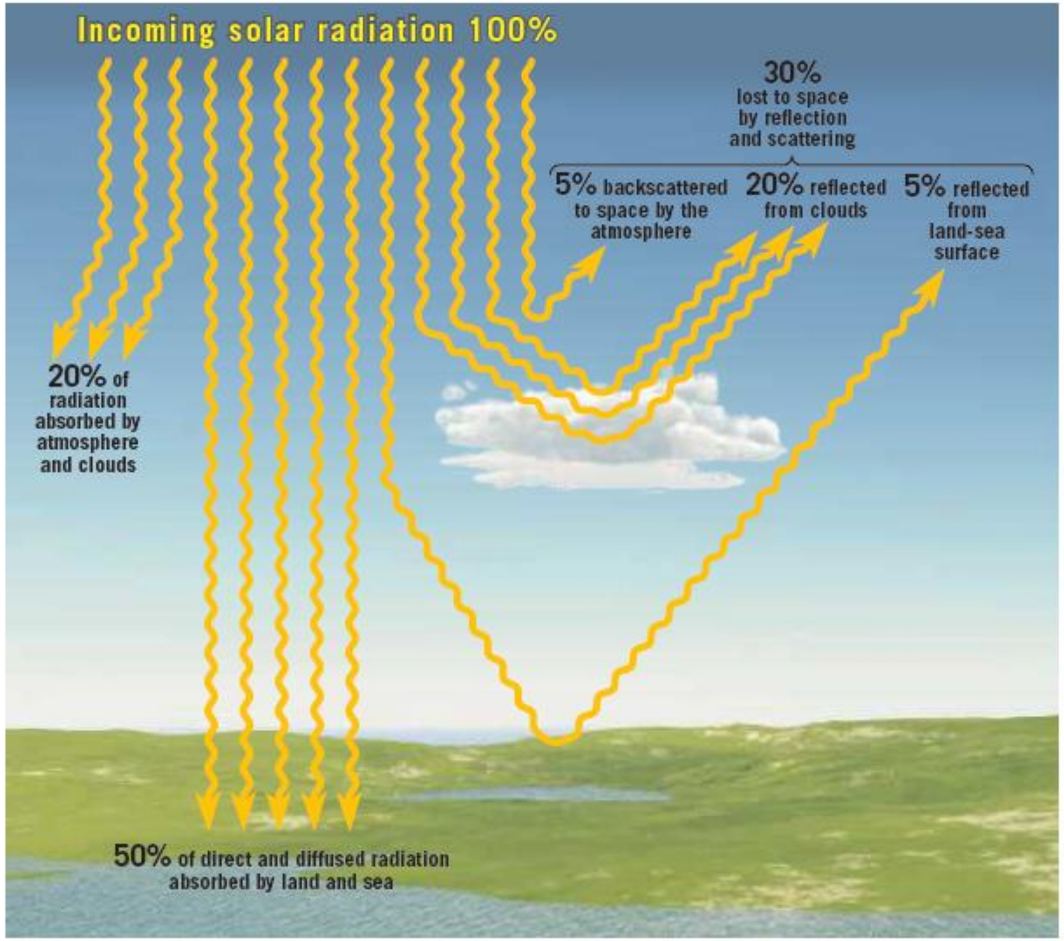
What Happens to Incoming Solar Radiation?

- The incoming solar radiation to the Earth's atmosphere can undergo three pathways:
- **Transmission** is the process by which energy passes though the atmosphere without interacting (no absorption or scattering) with the gases or other particles in the atmosphere. (About 50%)
- **Absorption** is the process by which energy passing through atmosphere is absorbed via Gases and particles. (About 20%)
- **Scattering or reflection** constitutes the remaining radiation which are bounced back by gas molecules or dust particles in the atmosphere. (About 30%)



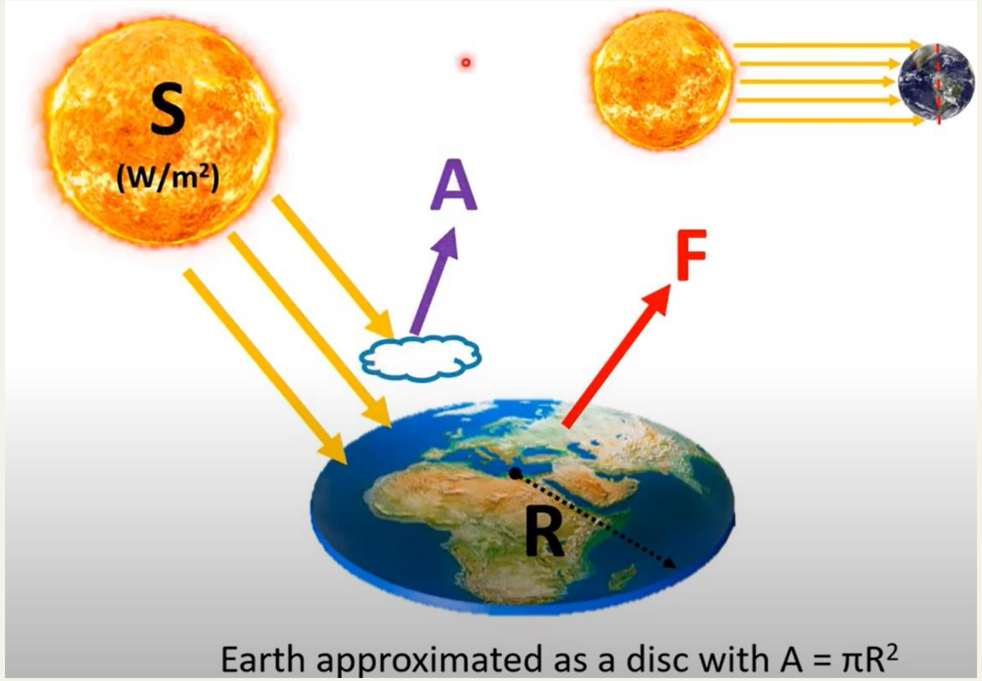
Earth Temperature should increase only?

The Atmosphere Energy Balance

- The atmosphere energy balance of the Earth is essentially zero.

- The Earth radiates the same amount of energy into space as the amount of energy absorbed from the Sun. In this way, the Earth maintains a stable average temperature and therefore a stable climate.

- The amount of electromagnetic radiation from the Sun is primarily in the visible range, and this is absorbed and then converted primarily to thermal energy, which has a lower temperature, around 290 K, that radiates at longer or infrared wavelengths (peak at $1 * 10^{-5}$ m).



S = Solar Irradiance or "Solar Constant"

A = Albedo = the fraction of solar radiation reflected by the Earth (includes clouds, aerosols, and snow)

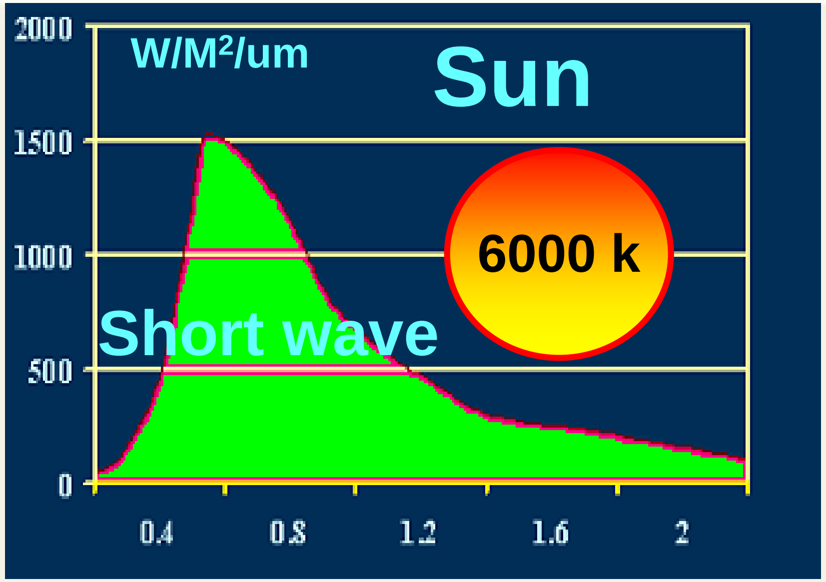
F = Flux of Longwave Energy emitted by the planet

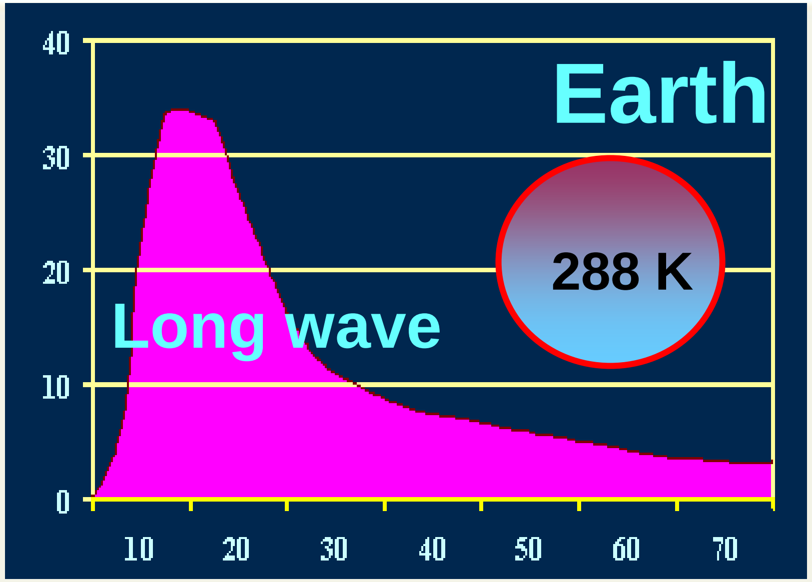
R = radius of the planet

Laws of Radiation – Energy Spectrum

- Hotter objects radiate more total energy per unit area than do colder objects. (The Sun, emits about 160,000 times more energy per unit area than does Earth).

- Hotter objects radiate more energy in the form of shorter wavelength radiation than do cooler objects. (The Sun radiates its peak energy at 0.5 µm, which is in the visible range. While Earth radiates its peak energy at a wavelength of 10 µm (infrared range)

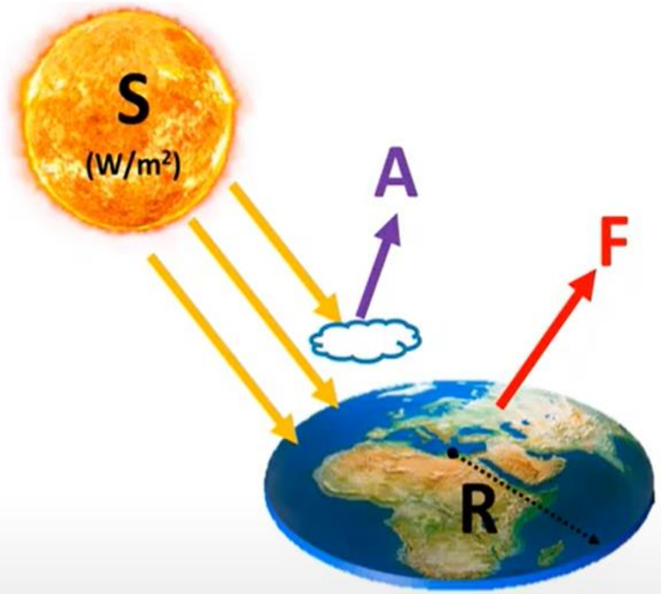




Wien's law

$$\underset{\text{(mm)}}{\lambda_{max}} = \frac{2.897 \; x \, 10^6}{T \;\; \text{(K)}}$$

The energy balance of the Earth is essentially zero



Energy balance: Energy In = Energy Out

$$\underbrace{\pi R^2 S(1 - A)}_{\text{Solar in}} = \underbrace{4\pi R^2 F}_{\text{Terrestrial out}}$$

Assume the Earth is a black body: $F = \sigma T_E^4$

Gives the global energy balance equation:

$$\boxed{\pi R^2 S(1 - A) = 4\pi R^2 \sigma T_E^4}$$

Solar energy incident = $\pi R^2 S$

Solar energy absorbed = $\pi R^2 S(1-A)$

Energy emitted by the planet = $4\ \pi R^2 F$

T_E = Effective Temperature, σ = Boltzmann constant

Global energy balance equation:

$$\cancel{\pi\mathbf{R}^2}\,\mathbf{S}(1-\mathbf{A}) = 4\cancel{\pi\mathbf{R}^2}\,\sigma\mathbf{T}_E^4$$

Solve for T_E:

$$\mathbf{T}_E = \sqrt[4]{\frac{\mathbf{S}(1-\mathbf{A})}{4\sigma}}$$

S = 1361 $W \cdot m^{-2}$

A = 0.30

$\sigma = 5.67 * 10^{-8} W \cdot m^{-2} K^{-4}$

T_E = 255K

Observed Surface Temperature:

T_S = 288K

Why is the observed temperature higher than the calculated temperature?

Case b: When Earth is not blackbody

The Earth isn't a perfect black body. Some emitted energy is re-absorbed by the atmosphere.

Adding a "tuning knob": $F = \sigma \varepsilon T_E^4$

ε = Emissivity factor

Gives us:

$$T_E = \sqrt[4]{\frac{S(1 - A)}{4\varepsilon\sigma}}$$

- Emissivity is defined as the ratio of the energy radiated from a material's surface to that radiated from a perfect emitter, known as a blackbody

- It is a dimensionless number between 0 (for a perfect reflector) and 1 (for a perfect emitter).

- Earth emissivity is 0.61

$$T_E = \sqrt[4]{\frac{S(1 - A)}{4\varepsilon\sigma}}$$

With an emissivity of 0.61, we get:

$$T_E = \sim 288K$$

Observed Surface Temperature:

$$T_S = 288K$$

$S = 1361\ W \cdot m^{-2}$

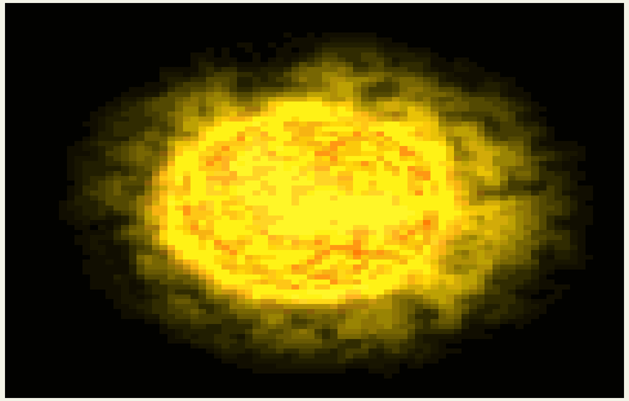
$A = 0.30$

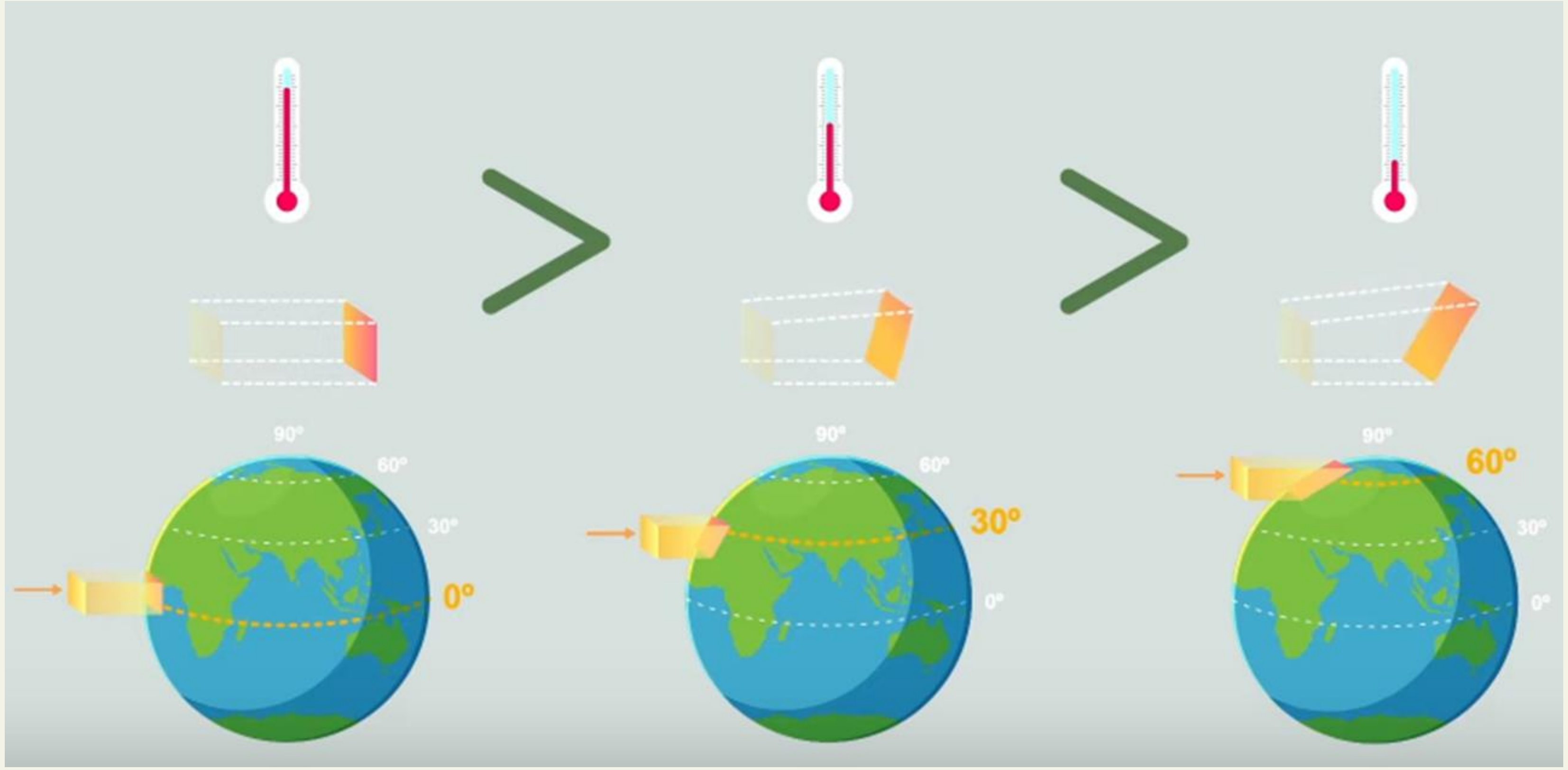
$\sigma = 5.67 * 10^{-8} W \cdot m^{-2} K^{-4}$

$\varepsilon = 0.61$

Interaction of Sun and Earth- Differential Heating

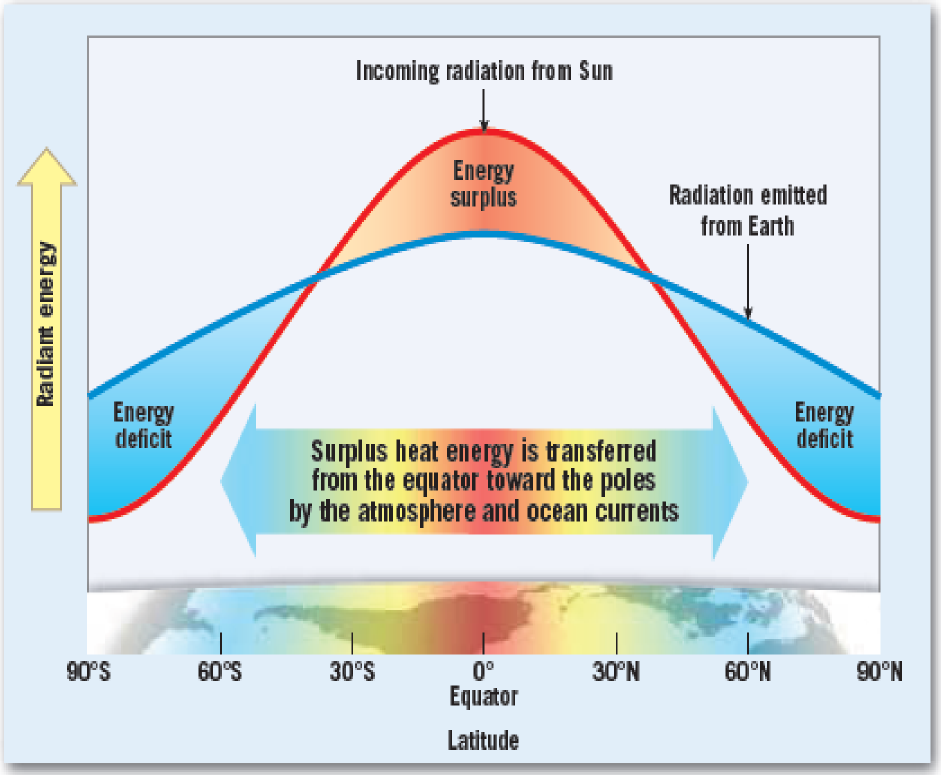
Solar Energy- source of HEAT for our planet





Latitudinal Energy Budget

Coriolis Force



▲ **Figure 2.24 Latitudinal heat balance, averaged over an entire year** The global wind system and, to a lesser extent, the oceans act as giant thermal engines, transferring surplus heat from the tropics poleward.

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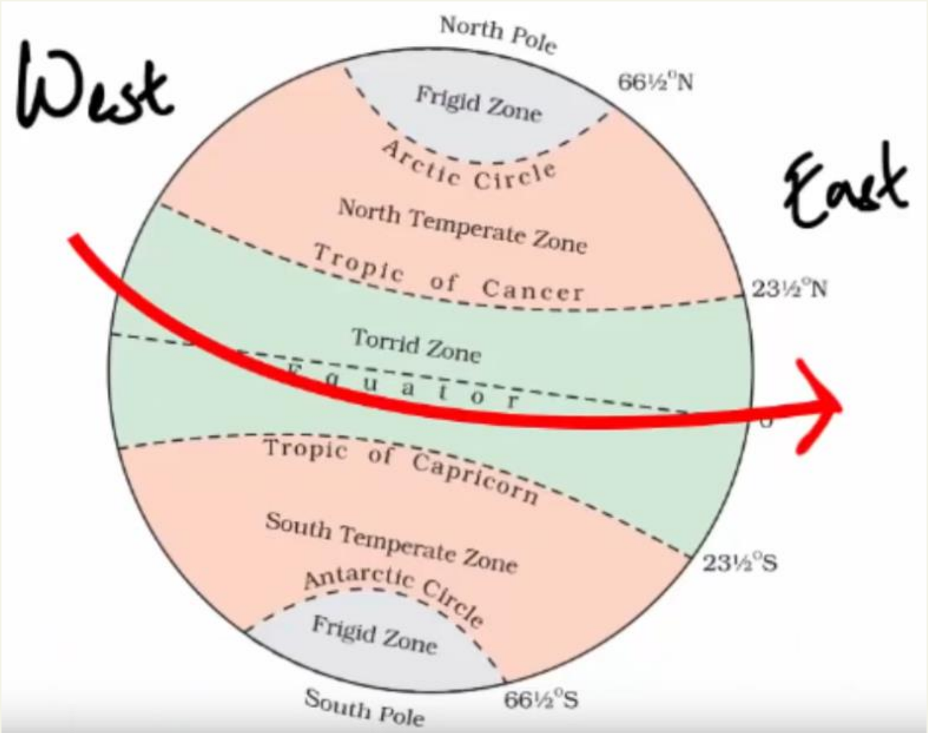
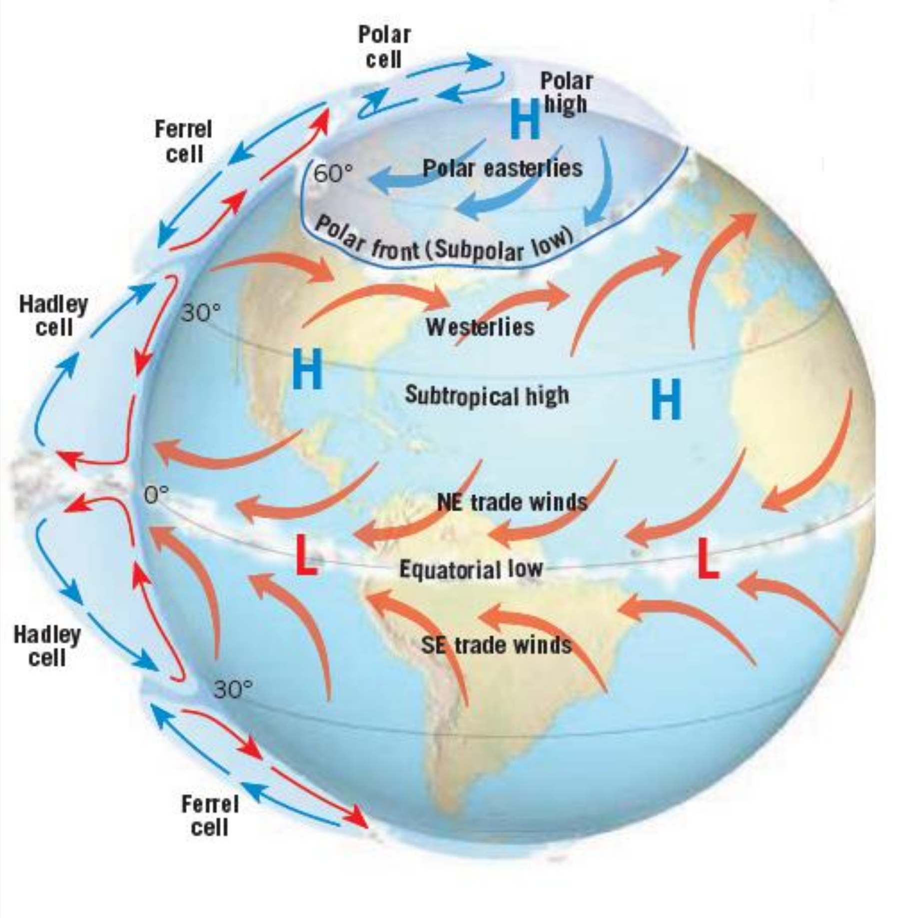


The transfer of surplus heat between the tropics and the poles drives Earth's weather system including winds and ocean currents.

Atmospheric Circulation Model
on rotating Earth

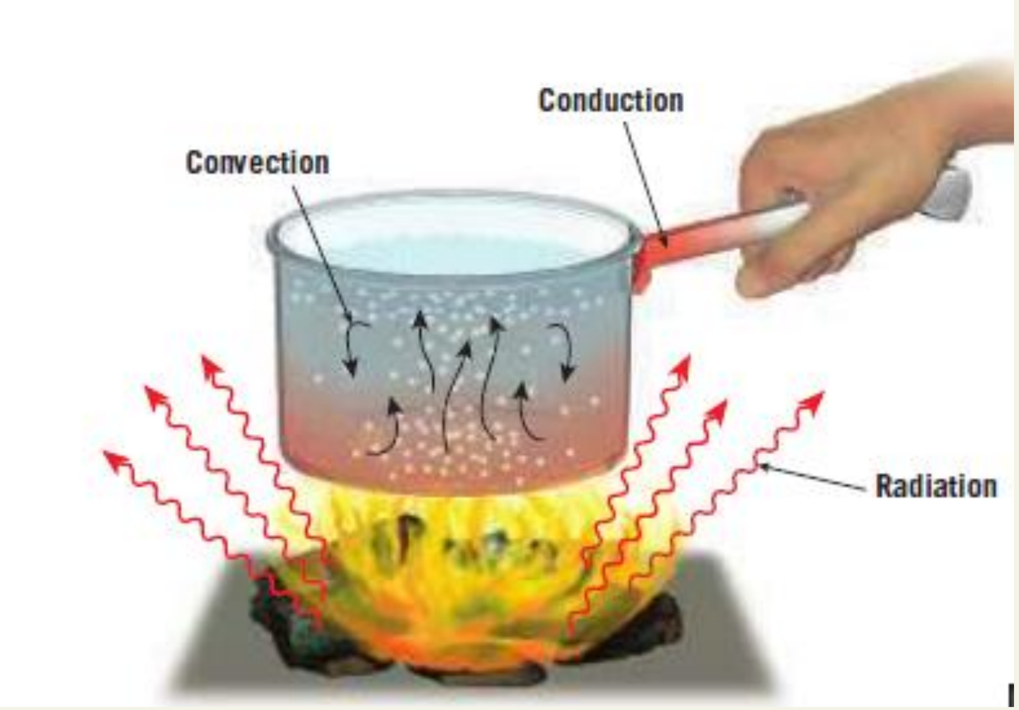


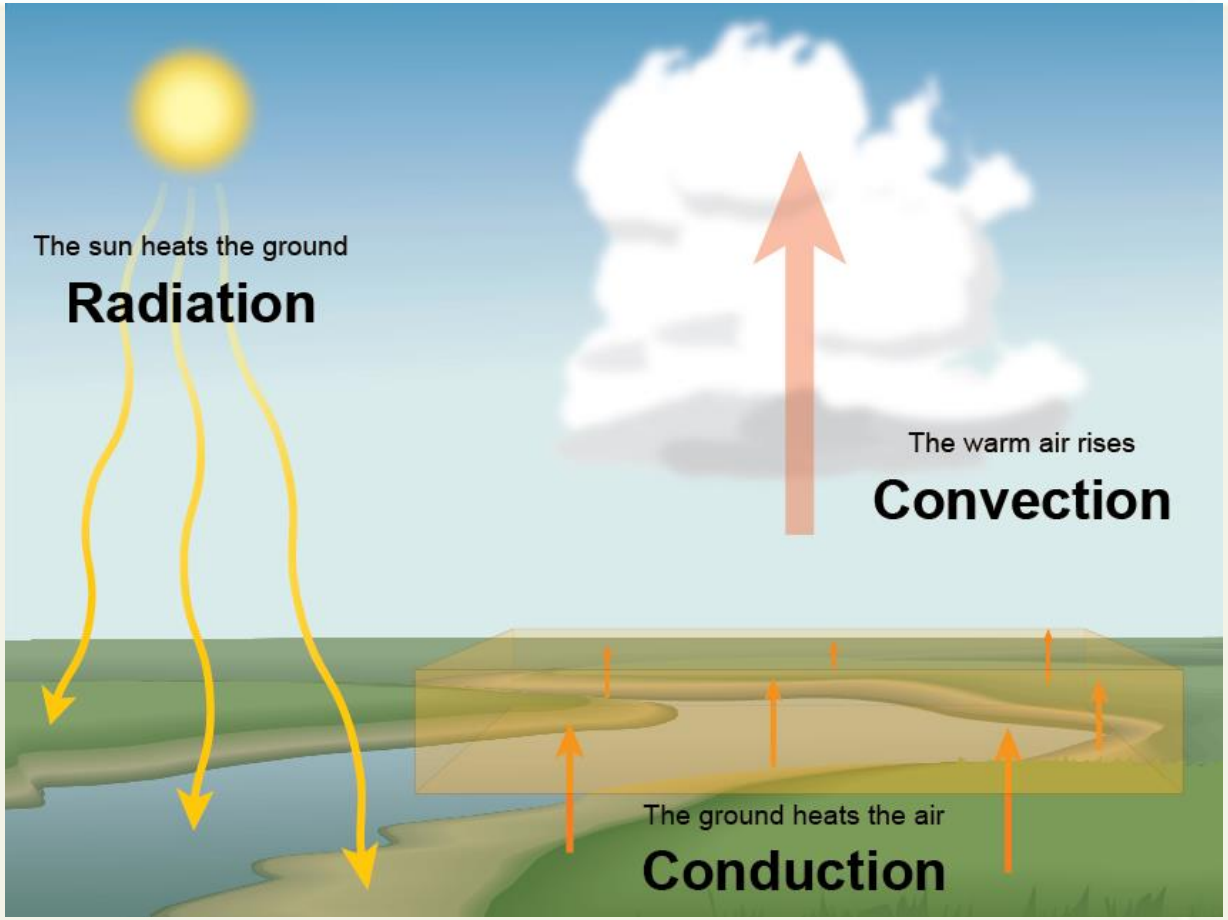
Due to dissimilar solar radiation and coriolis force as a result of earth own rotation, three convection cells are formed

1. Hadley Cell (George Hadley (1735))
2. Ferrel Cell (William Ferrel (1856))
3. Polar Cell

- Hadley Cell and Polar Cell are created based on thermal difference - Thermal Cell
- Ferrel Cell – Mechanical cell

Mechanisms of Heat Transfer





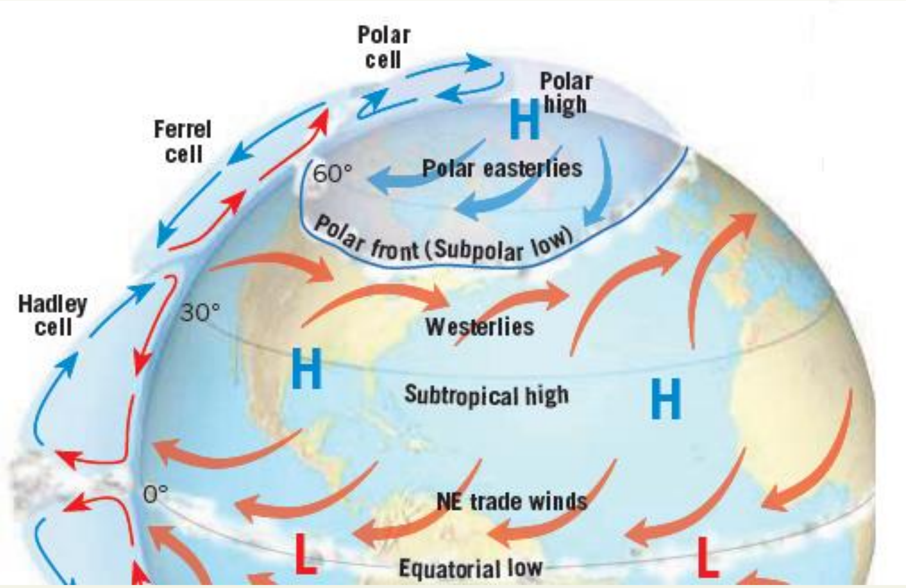
Energy from the sun is transferred through space and through the earth's atmosphere to the earth's surface. There are three ways heat is transferred into and through the atmosphere: Radiation, Conduction, Convection

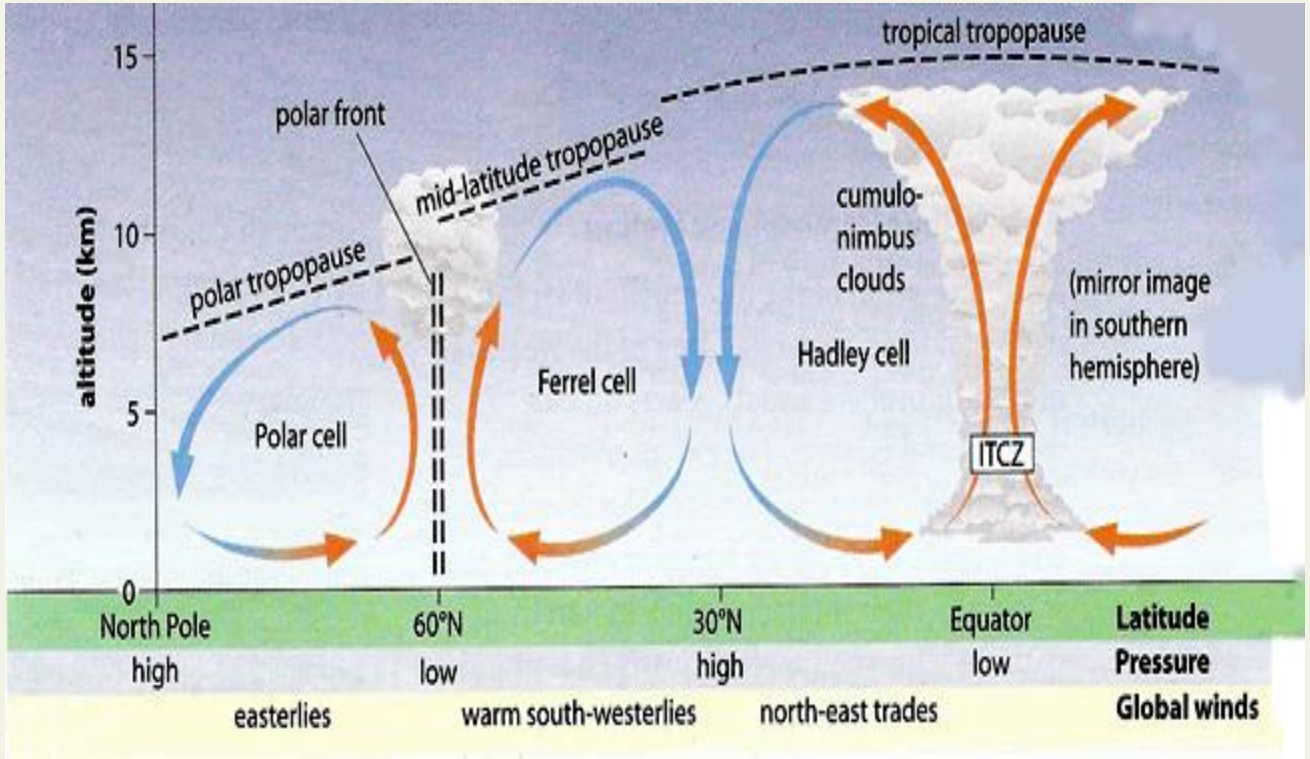
Global atmospheric circulation

Important points to understand global circulation system

- The global atmospheric circulation is mainly dependent on Temperature difference and Coriolis force
- Surface Wind blows horizontally from High to Low Pressure region
- Pressure region changes approximately every 30° Latitude
- The wind flow pattern is to be noted down with respect to Earth surface or top of atmosphere
- Cold air sinks down while hot air rises up
- When surface air comes in contact from different direction then it rises up as a result of convection
- Earth moves around its axis (west to east) lead to Coriolis force
- Coriolis force deflects wind towards the Clockwise direction in Northern hemisphere while Anticlockwise direction in Southern hemisphere
- The northern and southern hemisphere have mirror image for the global circulation pattern

Atmospheric Circulation Model
on rotating Earth





Coriolis force deflects to Clockwise direction in Northern hemisphere and left in Southern hemisphere (Anti-Clockwise)

Usually, fair and dry/hot weather is associated with high pressure, with rainy and stormy weather associated with low pressure

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https://www.youtube.com/watch?v=1nKanfN1Jlc&list=PL4ICDLZy58XG47QgyMeL4Y3cYLCS3xMQ9&index=1
https://www.youtube.com/watch?v=Tcugv5zNI9w

Thanks

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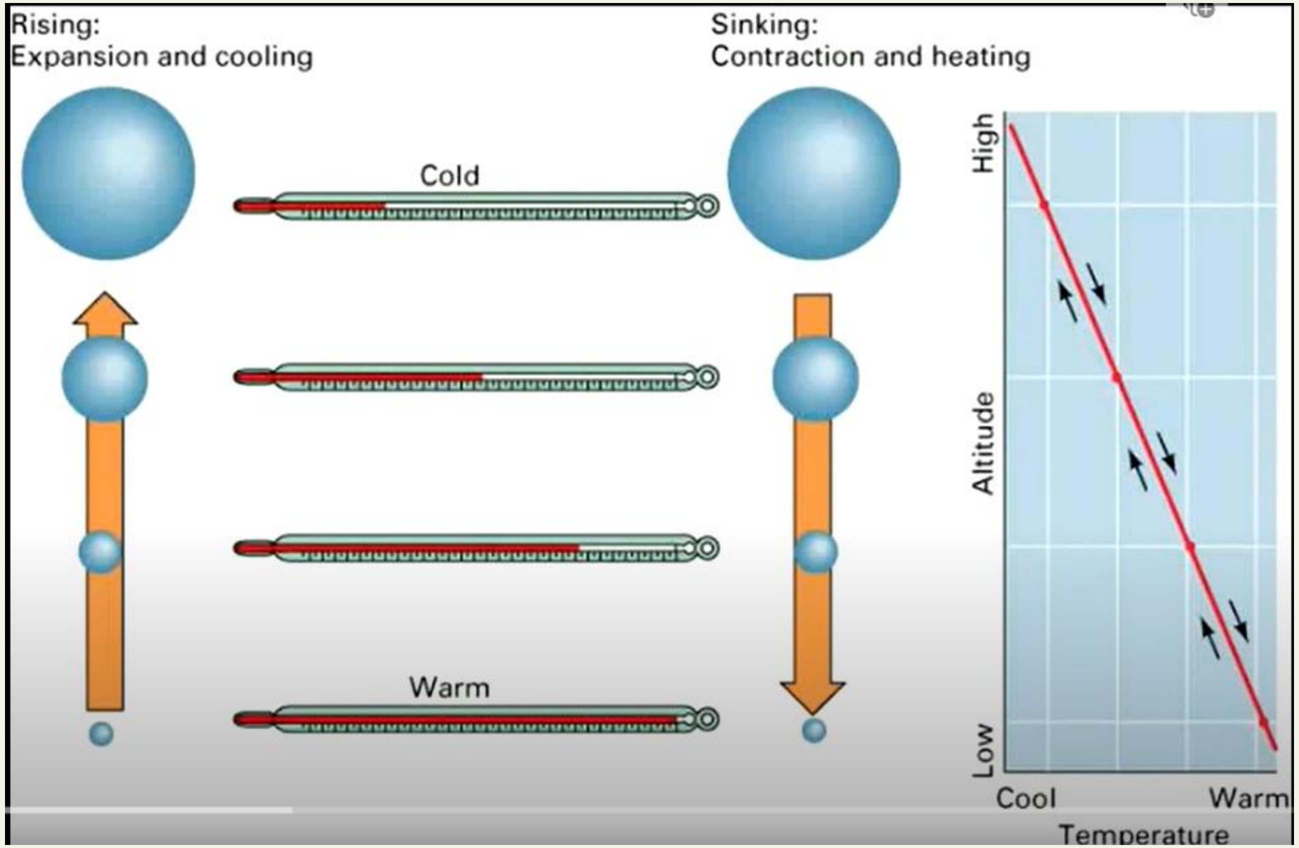
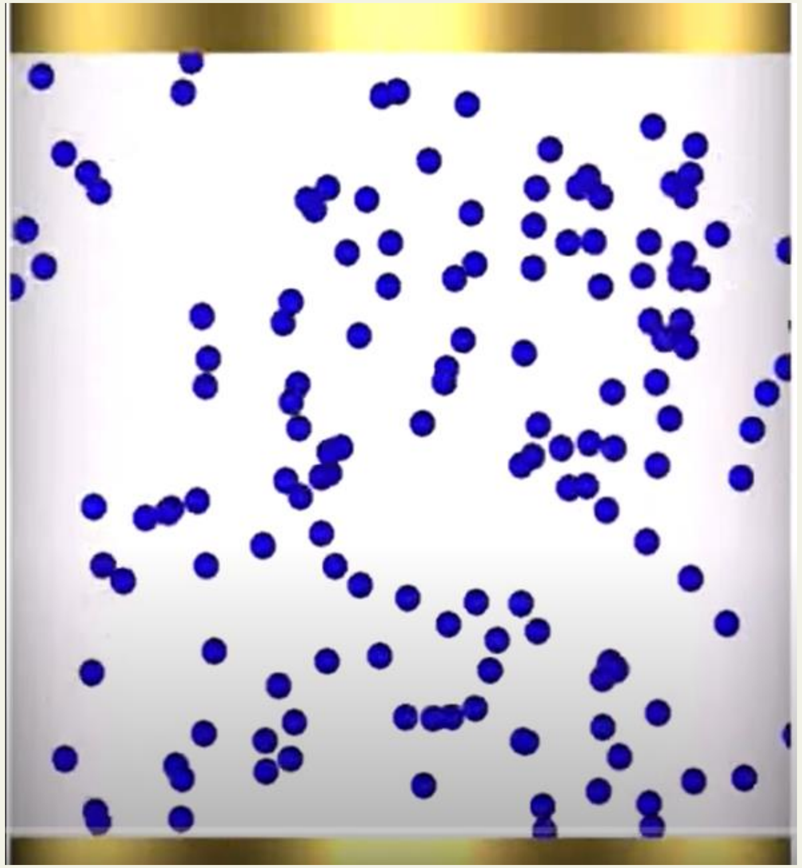
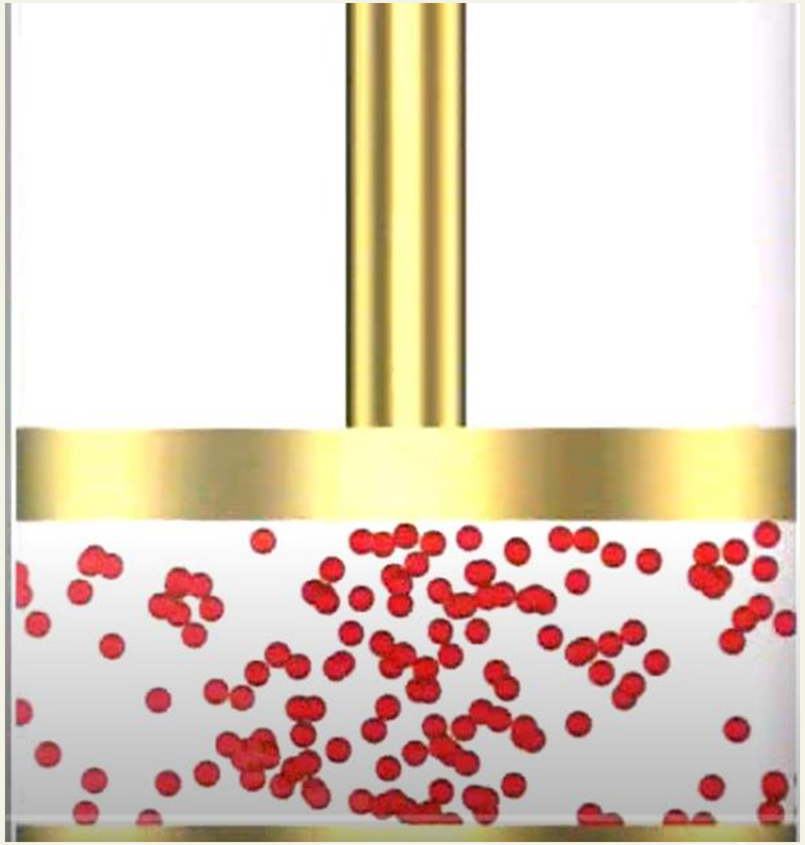
Temperature of an Air Parcel in the atmosphere changes via. Adiabatic expansion/contraction





Adiabatic Processes = heating by compression or cooling by expansion

Pressure increase results in more Kinetic energy that results in more temperature

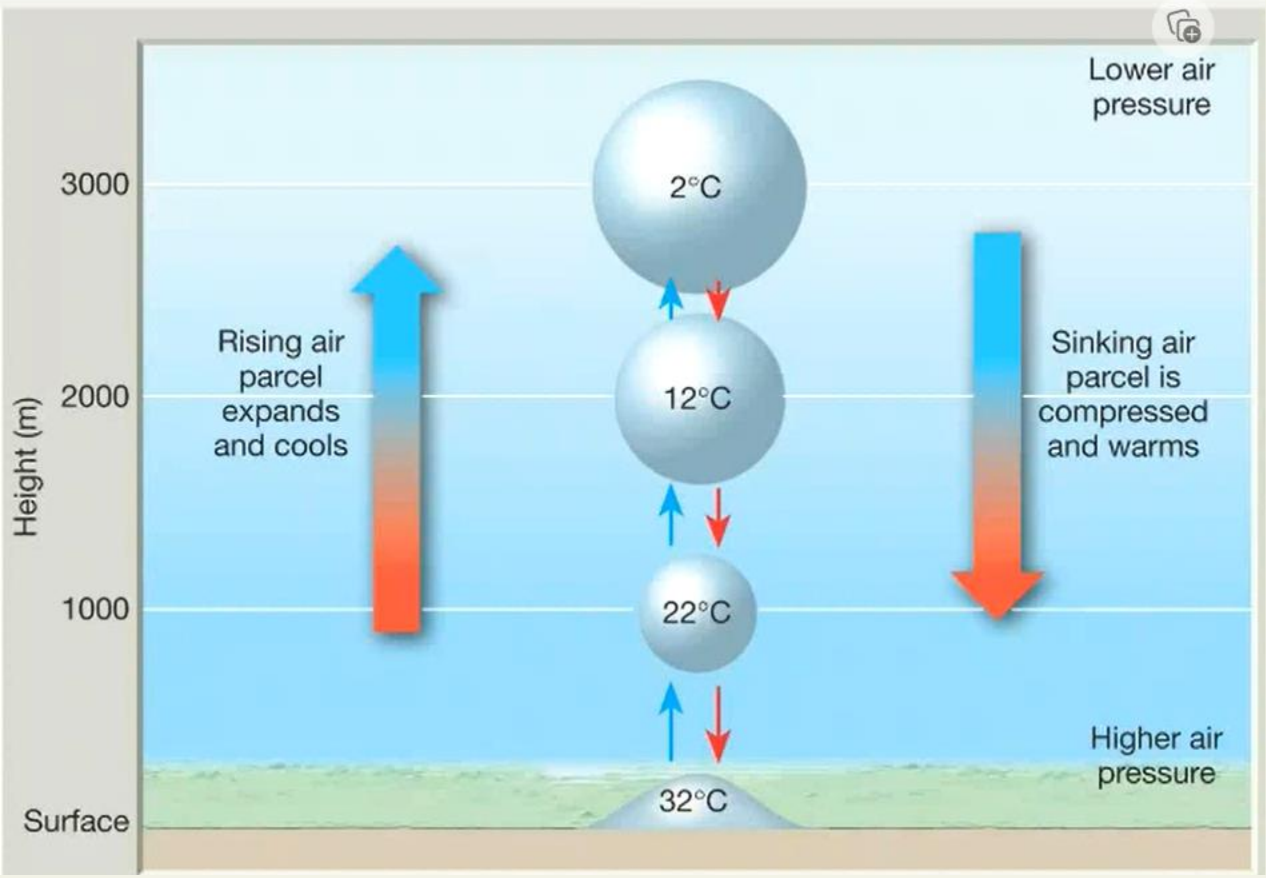


Dry Adiabatic Lapse Rate

Lapse rate means how much gases expand as a function of temperature (or can be said how temperature changes with altitude)

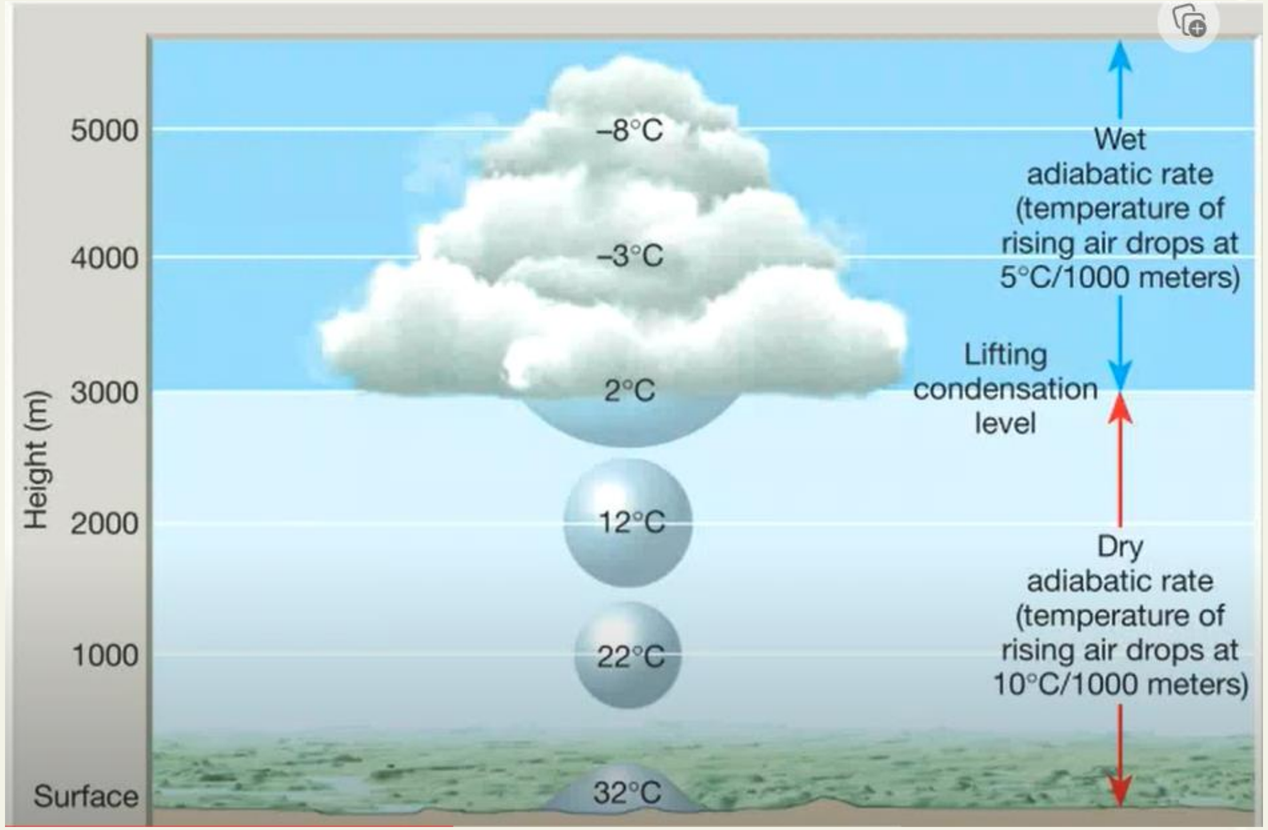
Units of lapse rate °C per 1 km

Dry Adiabatic Lapse Rate = 10°/1,000 m



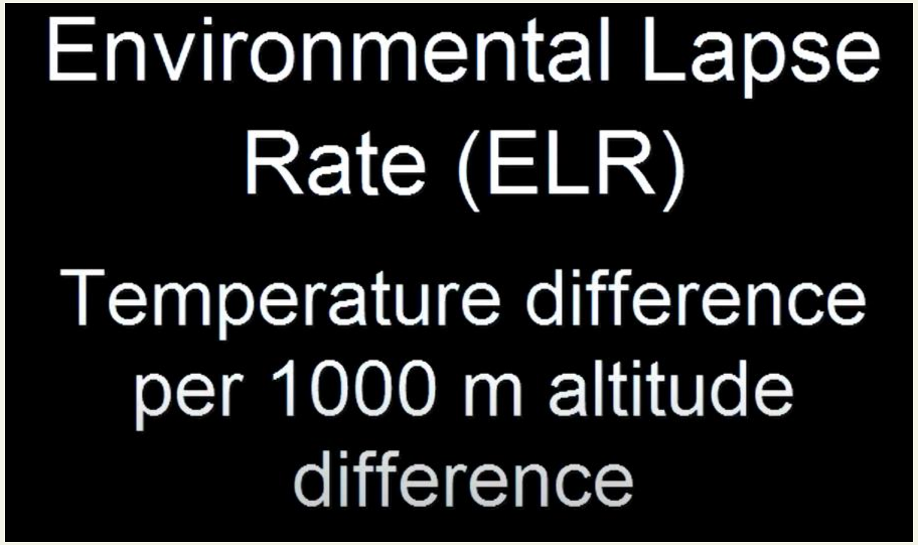
MOIST/WET/SATURATED Adiabatic lapse rate

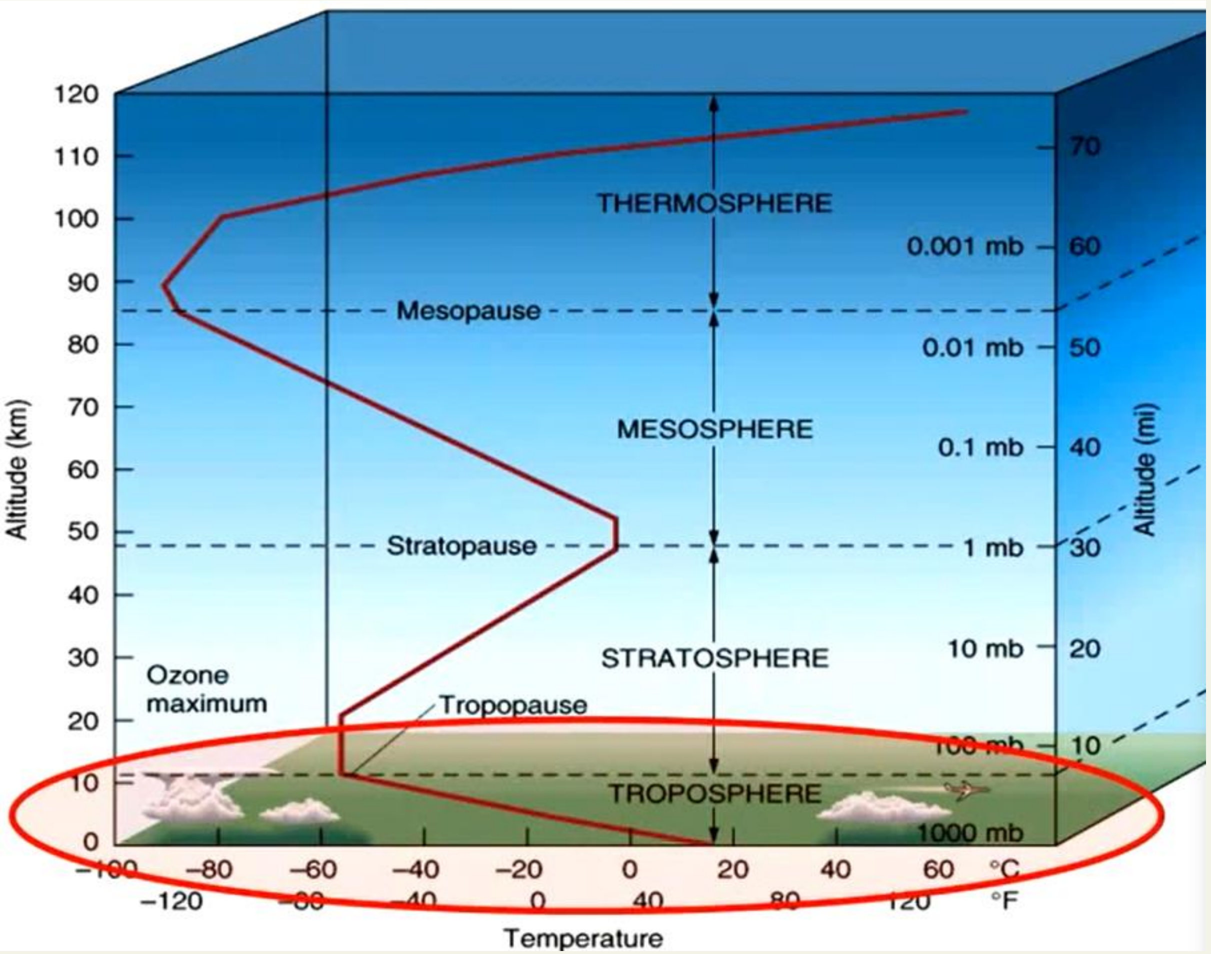
- If the air parcel is lifted high enough it gets colder and reaches a saturation level meaning no longer it can hold the water vapor in gaseous state and thus condensation happens (gaseous water vapor to liquid)
- The process of condensation happens when temperature reaches to dew point temperature
- The condensation mechanism releases energy, therefore the rate of cooling decreases (4 to 9 ℃ per Km, depending on water vapor content of air parcel)



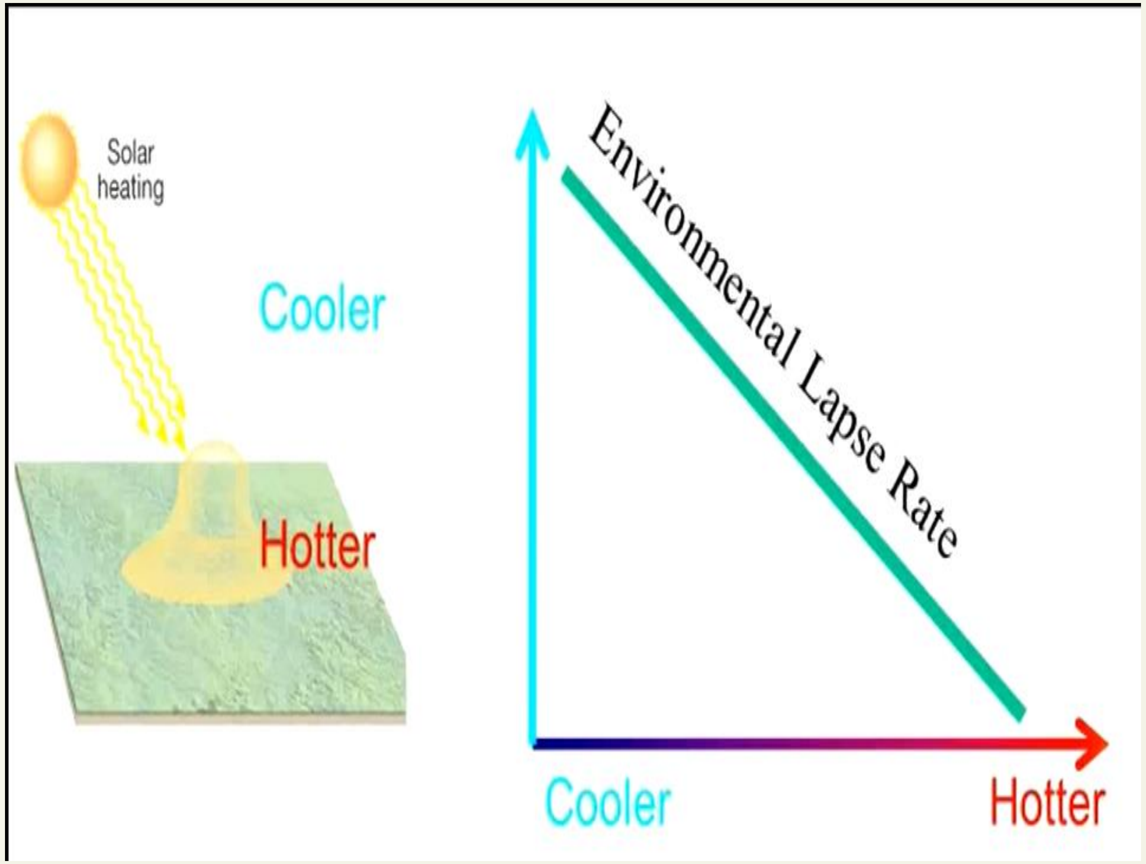
Adiabatic lapse rate is different than Environmental Lapse Rate

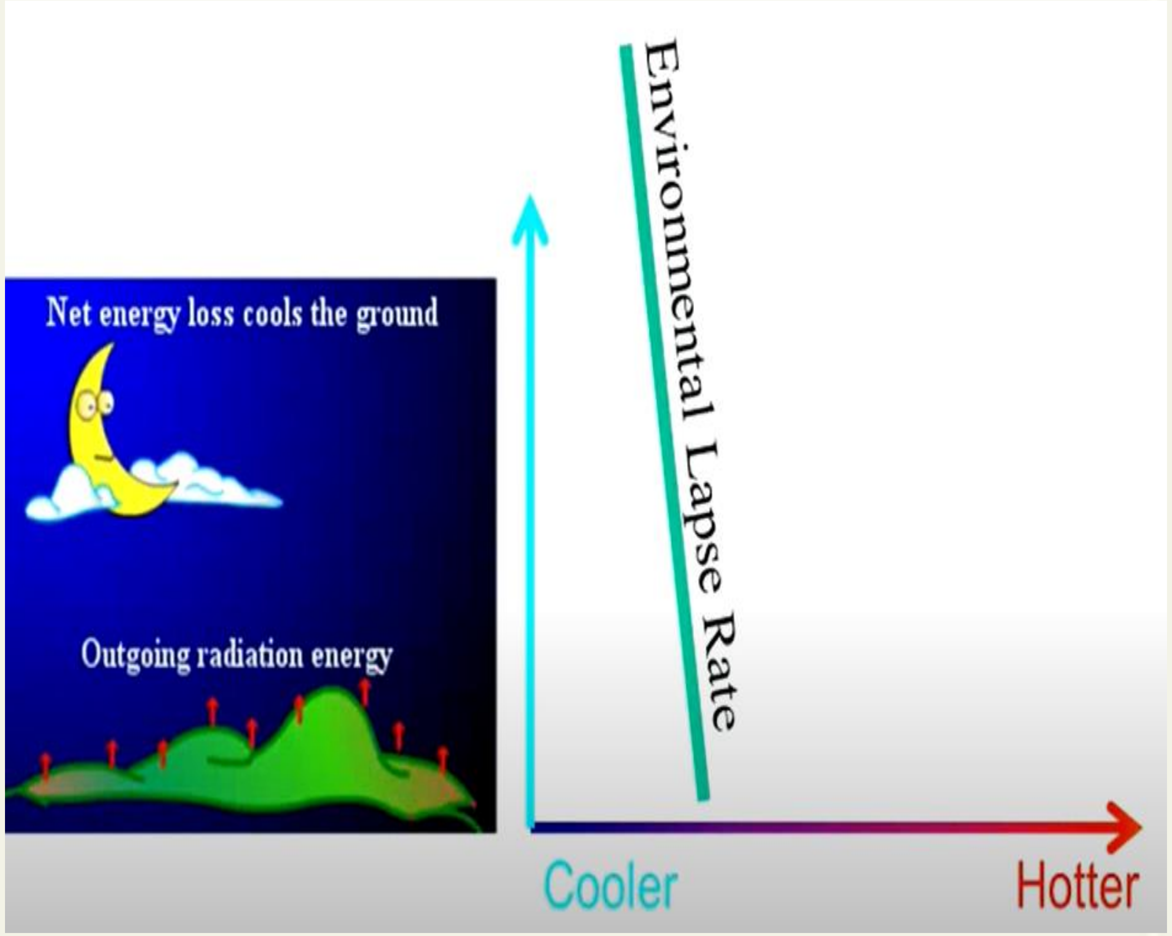
The change in atmospheric temperature with altitude is termed as Environmental Lapse Rate (ELR)





Factors affecting ELR





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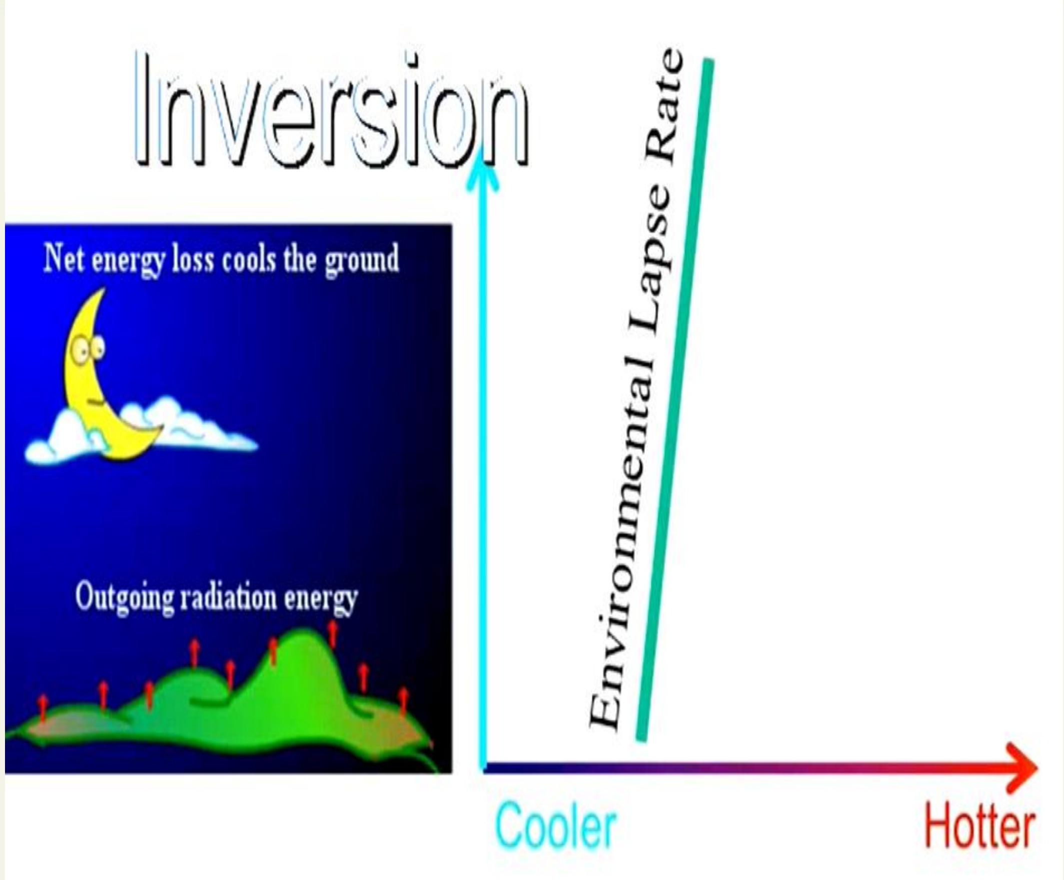
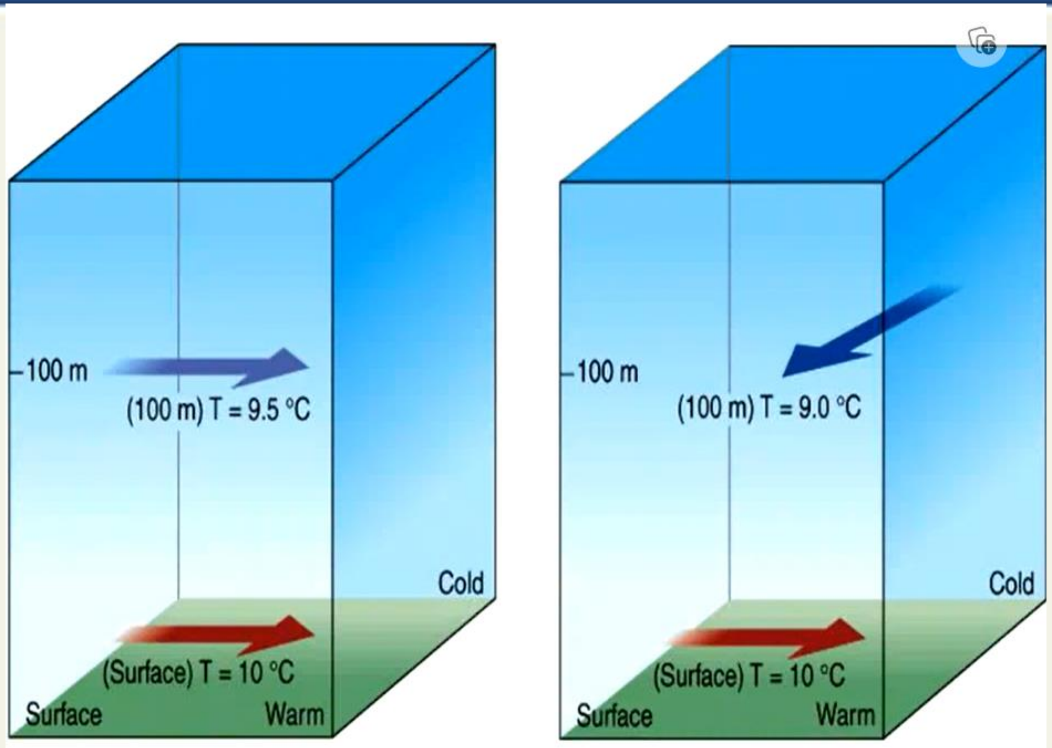
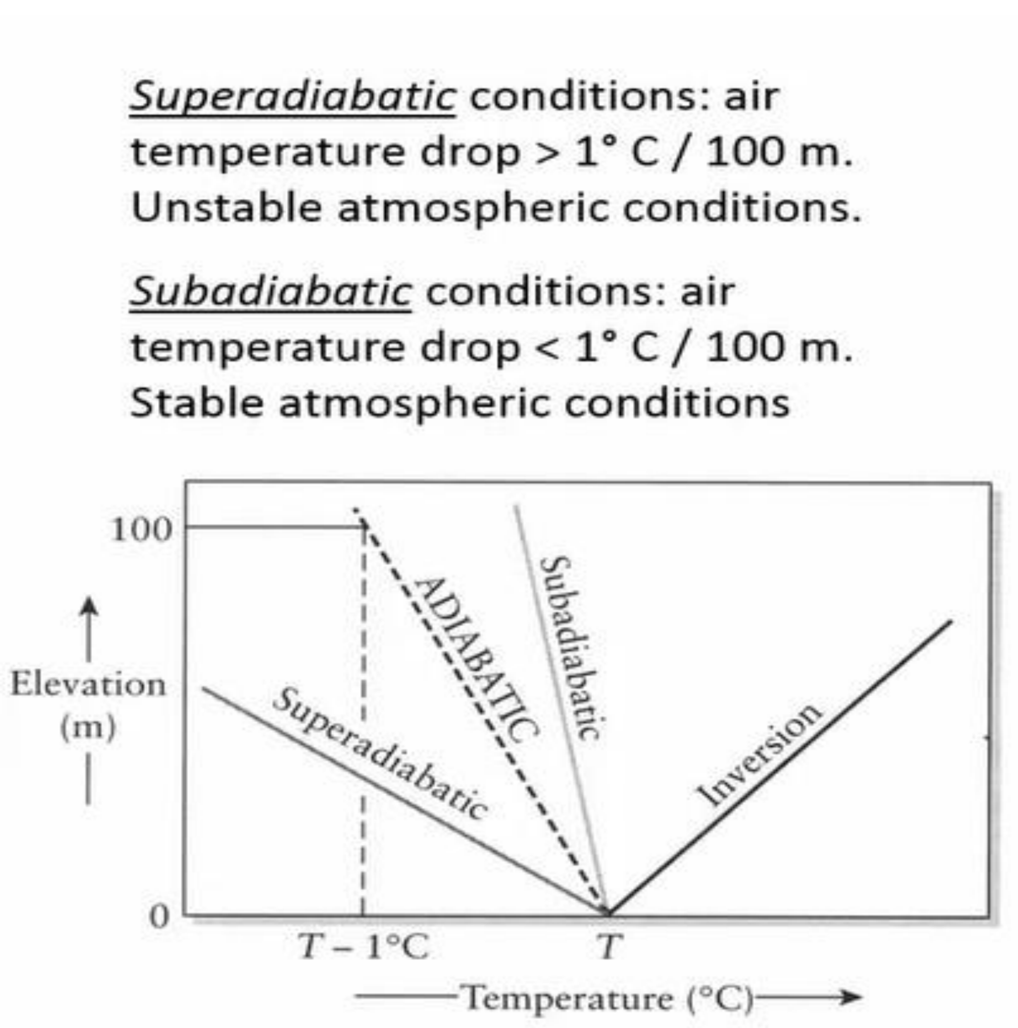


Hot air mass sits above the cold air mass (mostly happens in wintertime)



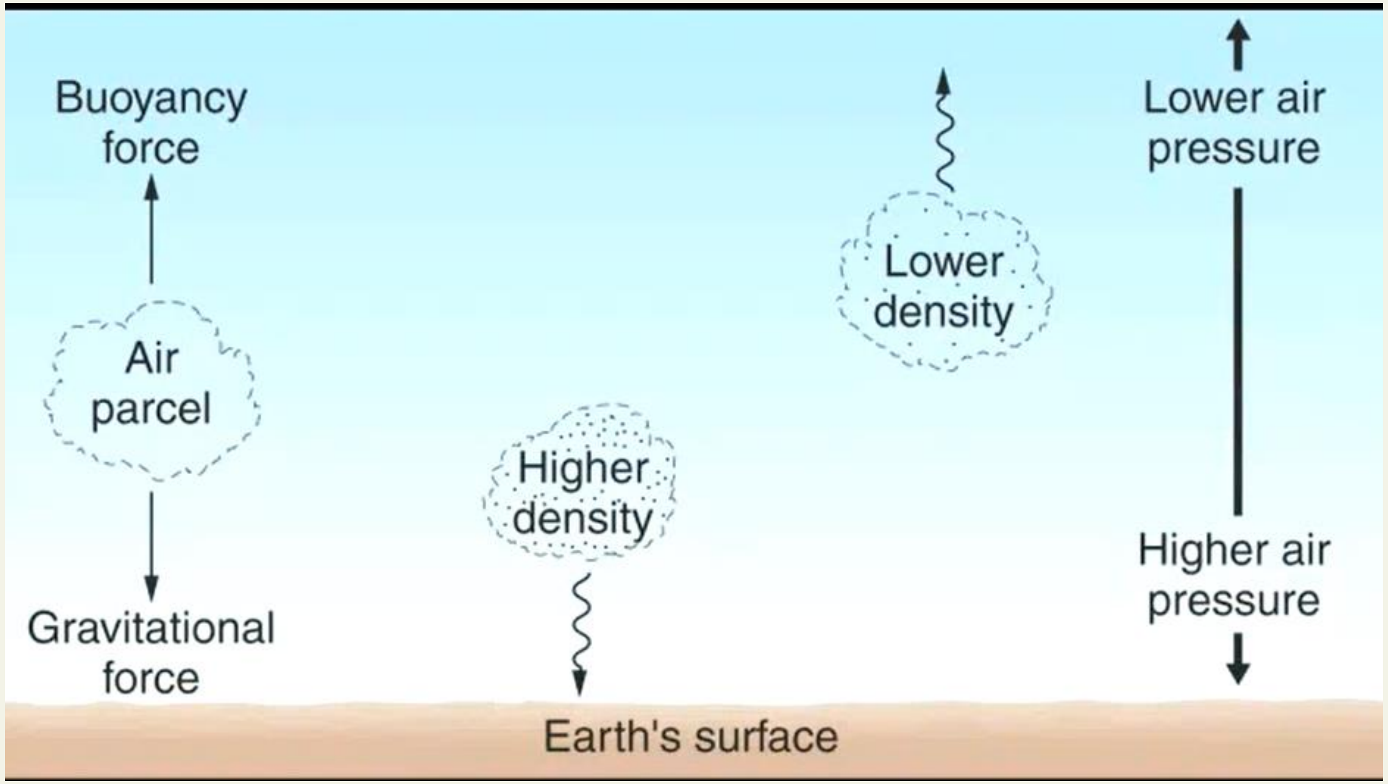
Advection = horizontal transport of air

Environmental Lapse rate classifications



- Superadiabatic refers to cooling more than expected (ELR>ALR)
- Subadiabatic referes to cooling lesser than expected (ELR<ALR)
- Inversion is an opposite phenomenon that refers to increase in temperature with elevation

What makes an Air Parcel rise or sink?



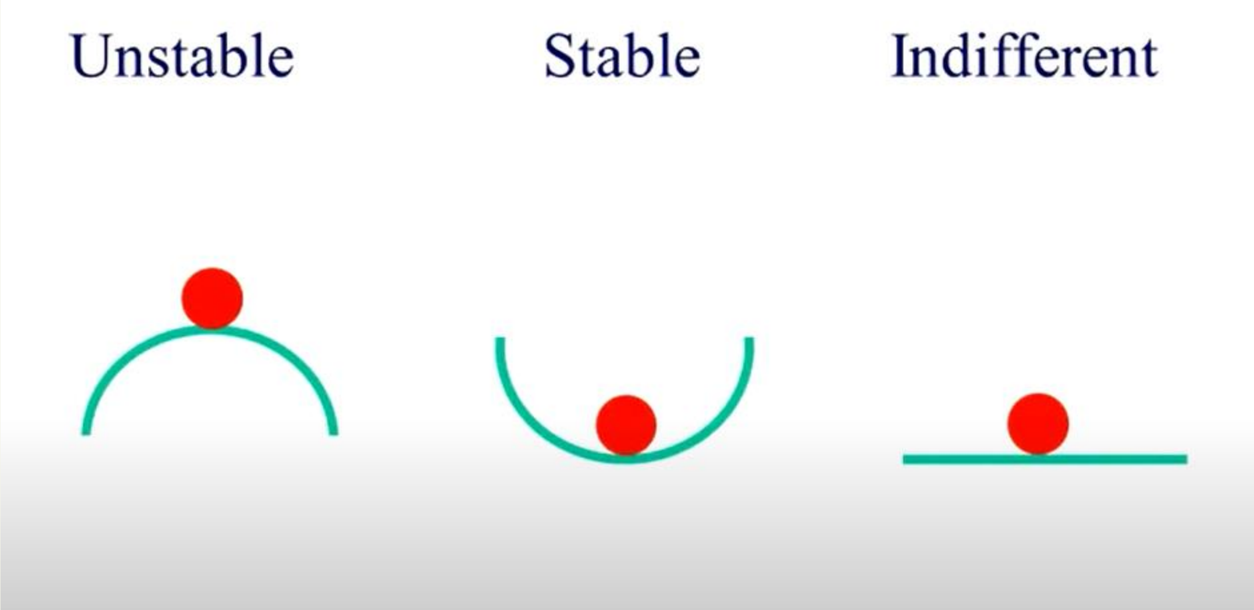
- Density of air parcel determines sinking or rising.
- If density of air parcel is lower then surrounding air it will RISE, while greater then it will SINK.
- Temperature determines the density of air parcel, air parcel cooler than surrounding have higher density while hot air parcel have lower density

Atmospheric Stability

Tendency of atmosphere to resist or enhance further free vertical motion of air parcel which is forced initially is called atmospheric stability

Types of equilibrium :

- **Stable equilibrium** : after a small displacement the body returns to its **original** equilibrium position.
- **Unstable equilibrium** : after a small displacement the body **does not return** to the original equilibrium position and moves to a new equilibrium position.
- **Neutral equilibrium** : after a displacement the body **remains** in the displaced position.



Assessing Atmospheric Stability

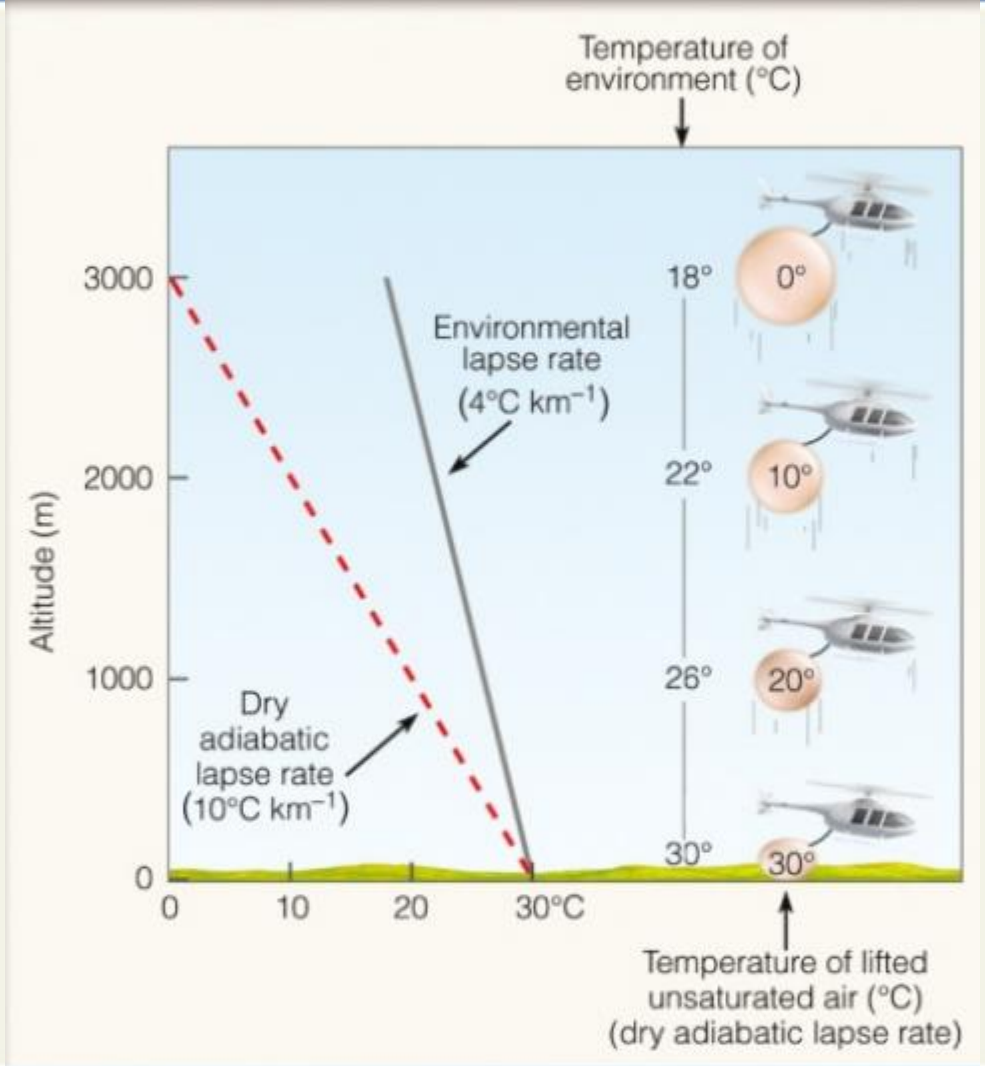
- The bottom line -
  - To determine whether or not a parcel will rise or sink in the atmosphere, one must compare the parcels temperature (T_p) with that of the environment (T_e) at some altitude:
  - if $T_p > T_e$ what will the parcel do?
  - if $T_p = T_e$ what will the parcel do?
  - if $T_p < T_e$ what will the parcel do?

- Cooler air packet released in atmosphere has lower temperature than prevailing conditions (atmosphere) then air packet descends

- Air packet released in atmosphere having higher temperature than surrounding temperature, air packet rises.

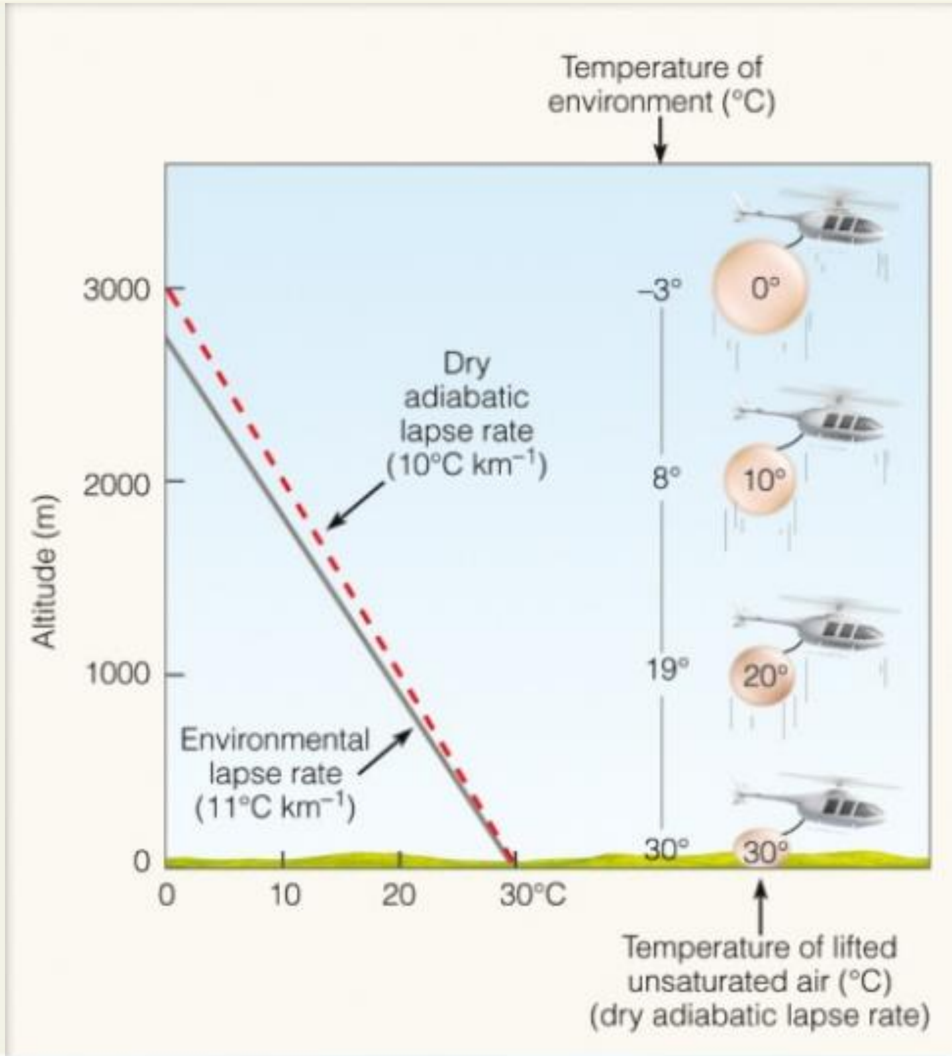
STABLE CONDITIONS

Subadiabatic condition (ELR<ALR)

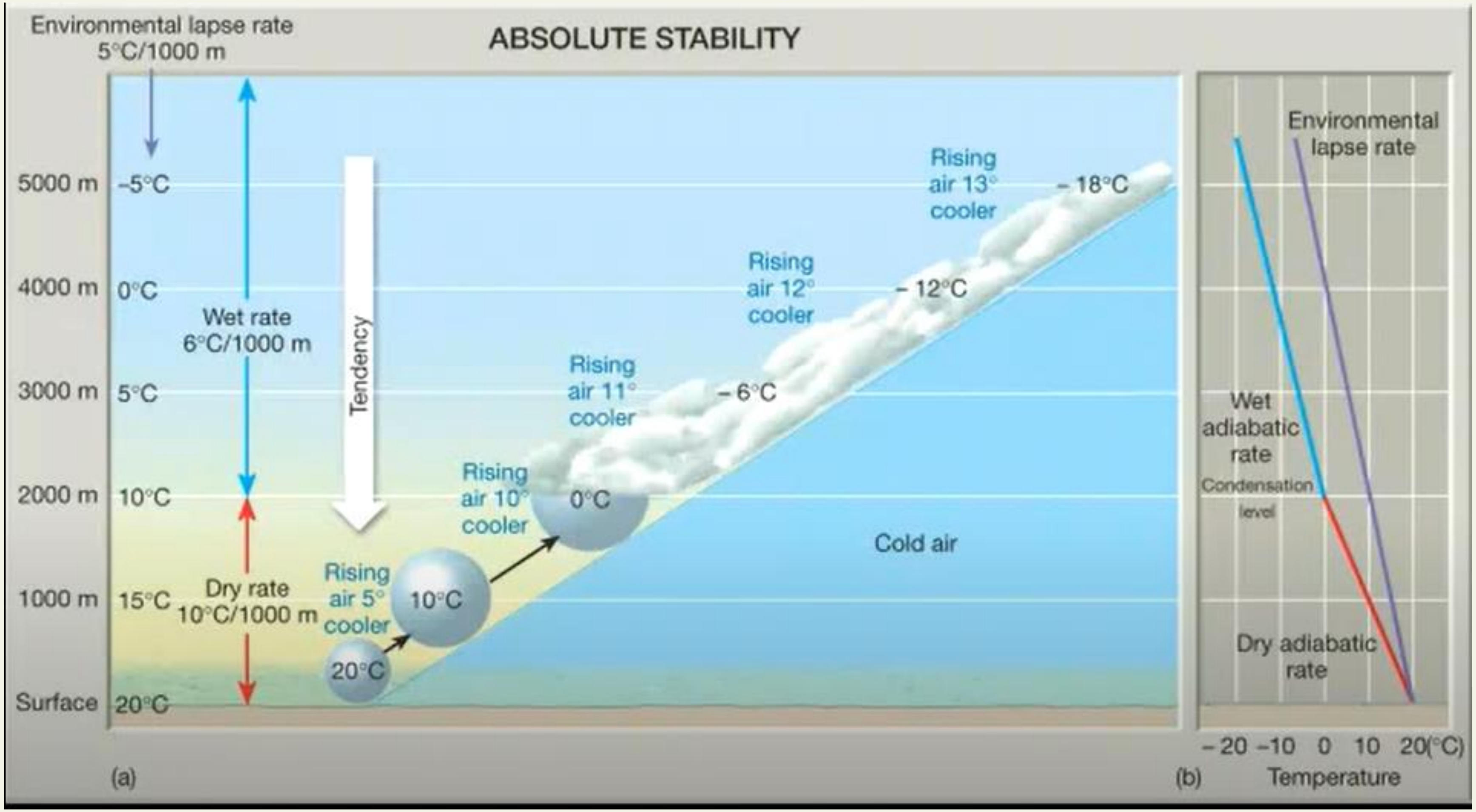


UNSTABLE CONDITIONS

Superadiabtic conditions (ELR>ALR)

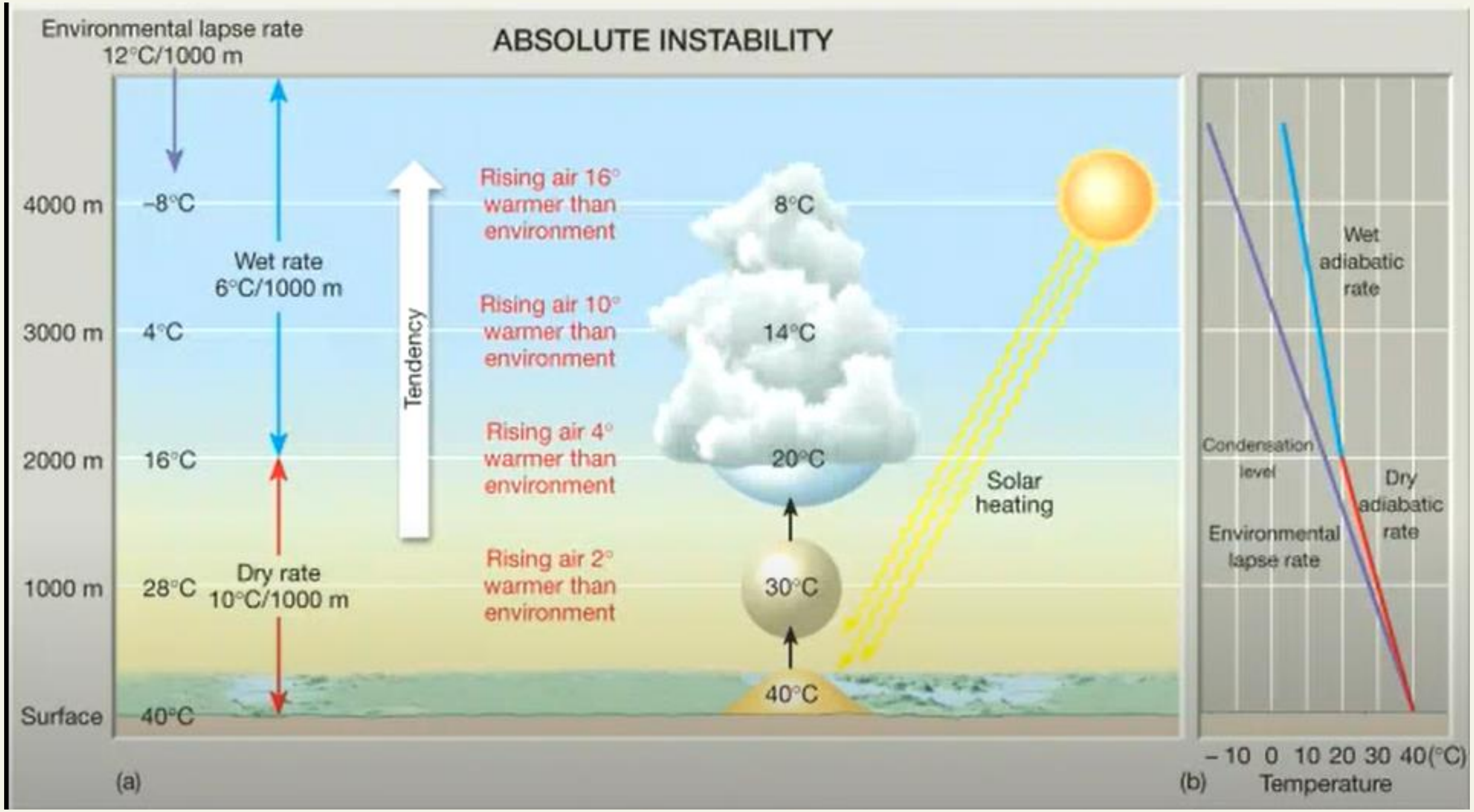


1. ABSOLUTE STABILITY (DALR>MALR>ELR)



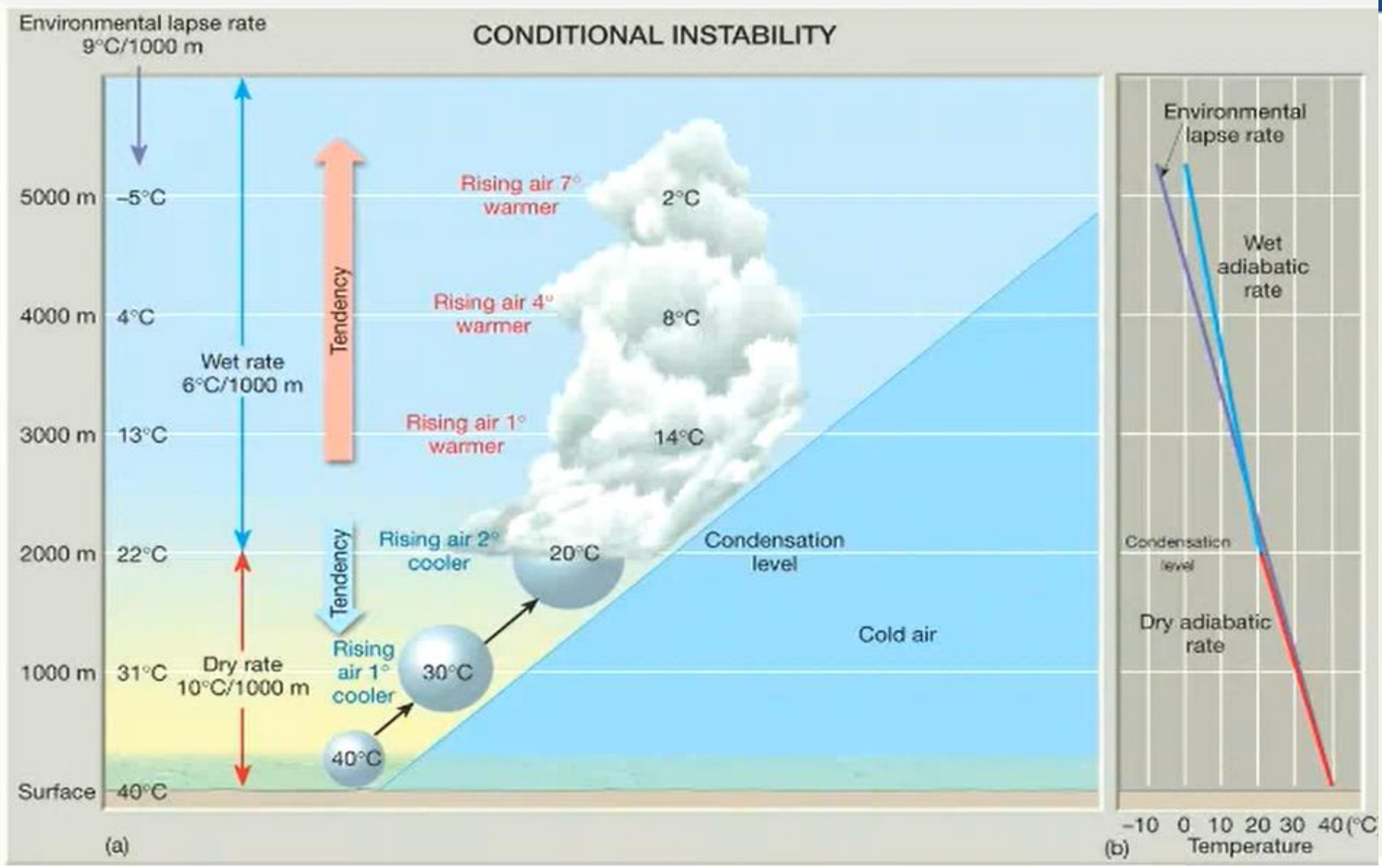
- The natural tendency of air parcel will be to sink downwards if the upward force is discontinued at any elevation.

2. ABSOLUTE INSTABILITY (ELR>DALR>MALR)



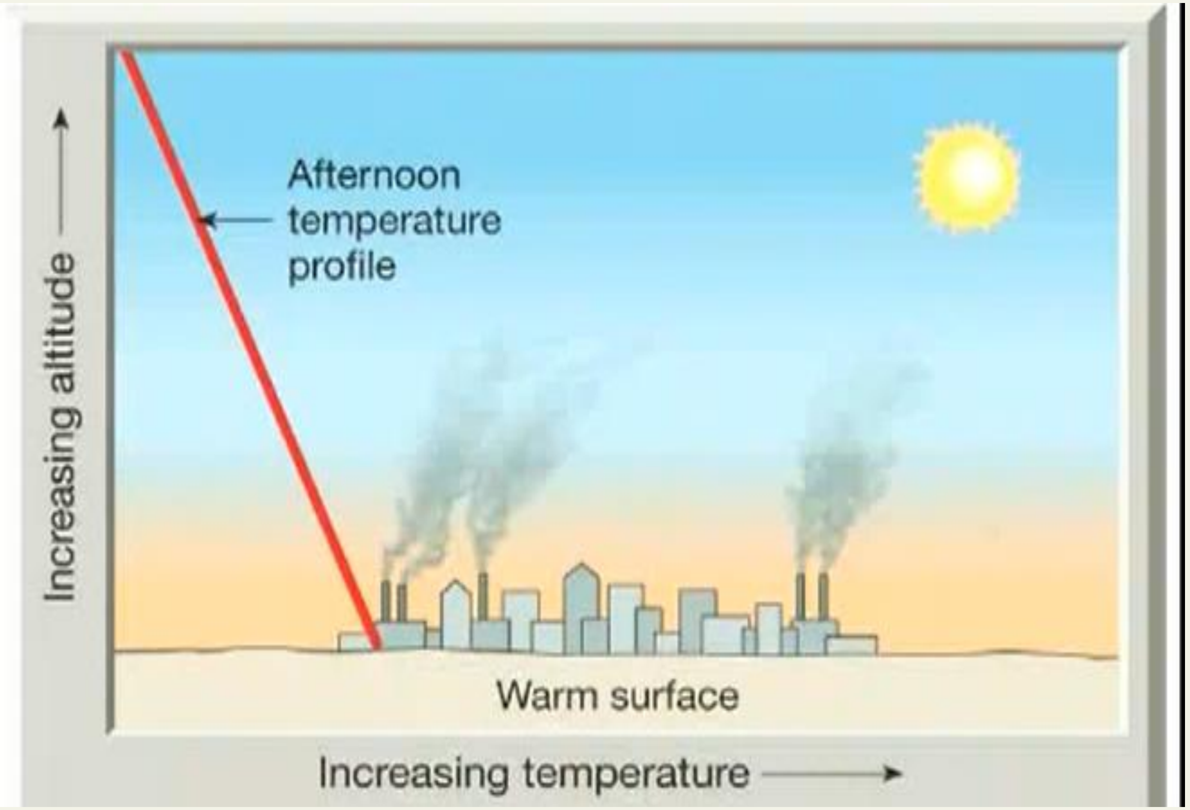
- The natural tendency of air parcel will be to freely RISE upwards if the upward force is discontinued at any elevation.

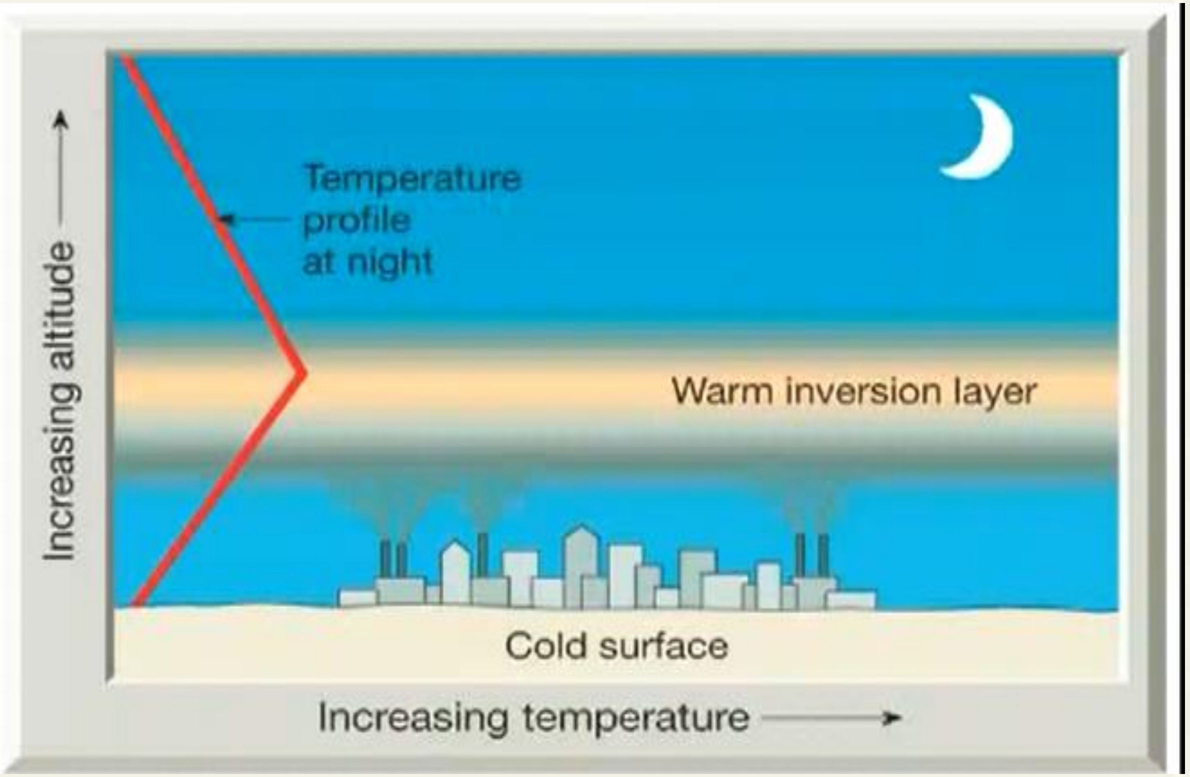
3. Conditional Instability (DALR>ELR>MALR) (Partially stable conditions)



The natural tendency of air parcel will be to sink downwards in dry adiabatic region until the air parcel reaches CONDESATION LEVEL and enters the moist adiabatic region from which it will freely RISE upwards

INVERSION- Extreme case of Stability





Thanks