18CEO406T - GLOBAL WARMING AND CLIMATE CHANGE

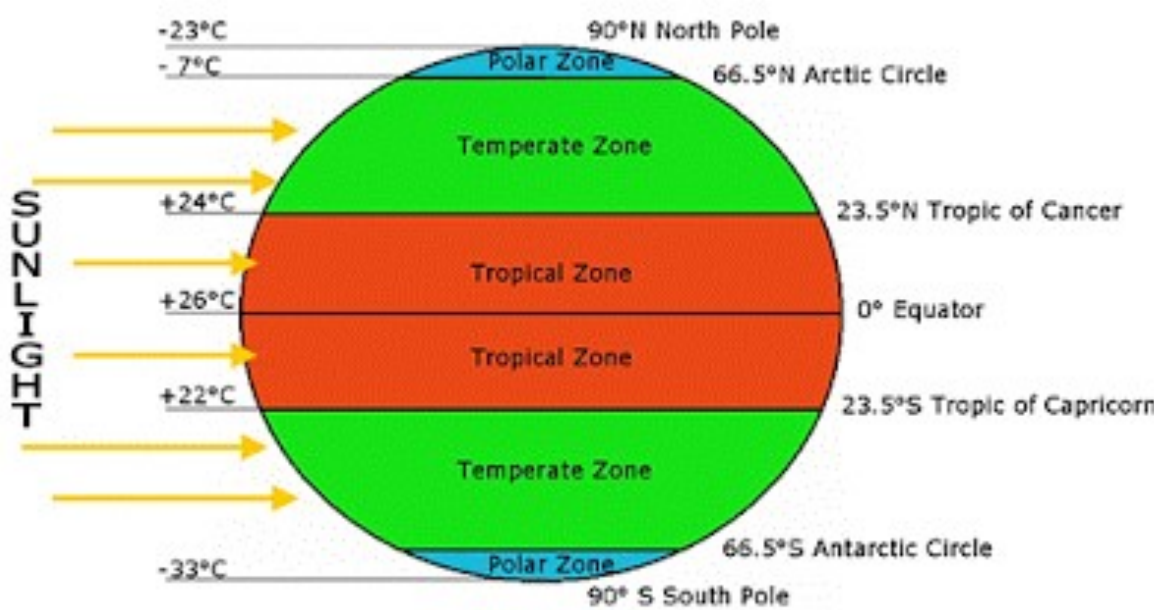
UNIT – 1 [S1 to S3]

S1 : Introduction to earth system – Hydrosphere, lithosphere, cryosphere, atmosphere and biosphere

Introduction to earth Climate

The climate of a place may be defined as a "composite" of the long-term prevailing weather that occurs at that location. In a sense, climate is "average weather". Climate can be measured quantitatively by calculating the long term averages of different climate elements such as temperature and rainfall. Extremes in the weather however, also help us define the climate of a particular area.

We can study climate on a range of geographical scales.



1. Local climate
2. Regional climate
3. Global climate

Local climate:

At the smallest scale, local climates influence areas maybe only a few miles or tens of miles across. Examples of local climatic phenomena include sea breezes and urban heating.

Regional climate:

At larger scales, regional climates provide a picture of particular patterns of weather within individual countries, or within climate zones that exist at different latitudes on the Earth. Climate zones include tropical, subtropical, desert, Savannah, temperate and polar climates. Different climate zones reveal variable patterns of temperature and rainfall

Global climate

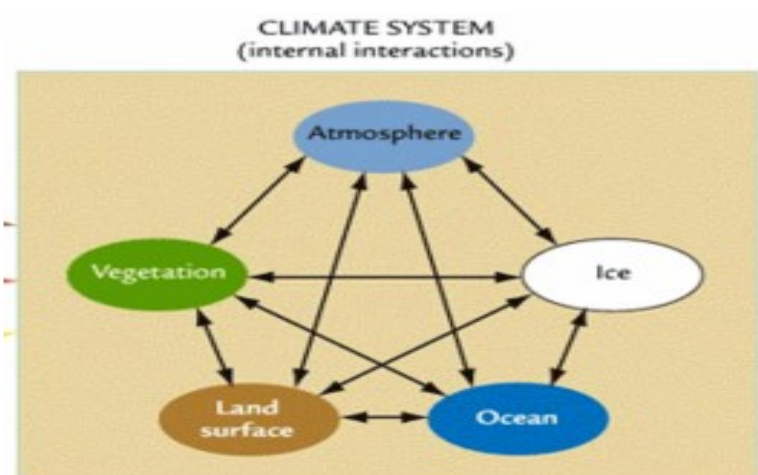
The term "global climate" is used to refer to the general state of the world's climate. Whilst different climate zones may be identified, with different types of weather in different parts of the world, climatologists sometimes like to study the general climate of the whole Earth, for example when investigating evidence for climate change.

The simplest means of assessing the state of the global climate is to measure the global average temperature of the Earth's surface and atmosphere in contact with it

Climate system

The **climate system** is a complex, interactive **system** consisting of the atmosphere, land surface, snow and ice, oceans and other bodies of water, and living things. The atmospheric component of the **climate system** most obviously characterises **climate**; **climate** is often defined as 'average weather'.

The key to understanding global climate change is to first understand what global climate is, and how it operates. At the planetary scale, the global climate is regulated by how much energy the Earth receives from the Sun. However, the global climate is also affected by other flows of energy which take place within the climate system itself. This global climate system is made up of the atmosphere, the oceans, the ice sheets (cryosphere), living organisms (biosphere) and the soils, sediments and rocks (geosphere), which all affect, to a greater or less extent, the movement of heat around the Earth's surface.



Earth's climate arises from the interaction of five major climate system components:

1. Atmosphere (air),
2. Hydrosphere (water),
3. Cryosphere (ice and permafrost),
4. Lithosphere (earth's upper rocky layer) and
5. Biosphere (living things)

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Atmosphere:

The atmosphere plays a crucial role in the regulation of Earth's climate. The atmosphere is a mixture of different gases and aerosols (suspended liquid and solid particles) collectively known as air. Air consists mostly of nitrogen (78%) and oxygen (21%). However, despite their relative scarcity, the so-called greenhouse gases, including carbon dioxide and methane, have a dramatic effect on the amount of energy that is stored within the atmosphere, and consequently the Earth's climate. These greenhouse gases trap heat within the lower atmosphere that is trying to escape to space, and in doing so, make the surface of the Earth hotter. This heat trapping is called the natural greenhouse effect, and keeps the Earth 33°C warmer than it would otherwise be. In the last 200 years, man-made emissions of greenhouse gases have enhanced the natural greenhouse effect, which may be causing global warming.

The atmosphere however, does not operate as an isolated system. Flows of energy take place between the atmosphere and the other parts of the climate system, most significantly the world's oceans. For example, ocean currents move heat from warm equatorial latitudes to colder polar latitudes.

Heat is also transferred via moisture. Water evaporating from the surface of the oceans stores heat which is subsequently released when the vapour condenses to form clouds and rain. The significance of the oceans is that they store a much greater quantity of heat than the atmosphere. The top 200 metres of the world's oceans store 30 times as much heat as the atmosphere. Therefore, flows of energy between the oceans and the atmosphere can have dramatic effects on the global climate.

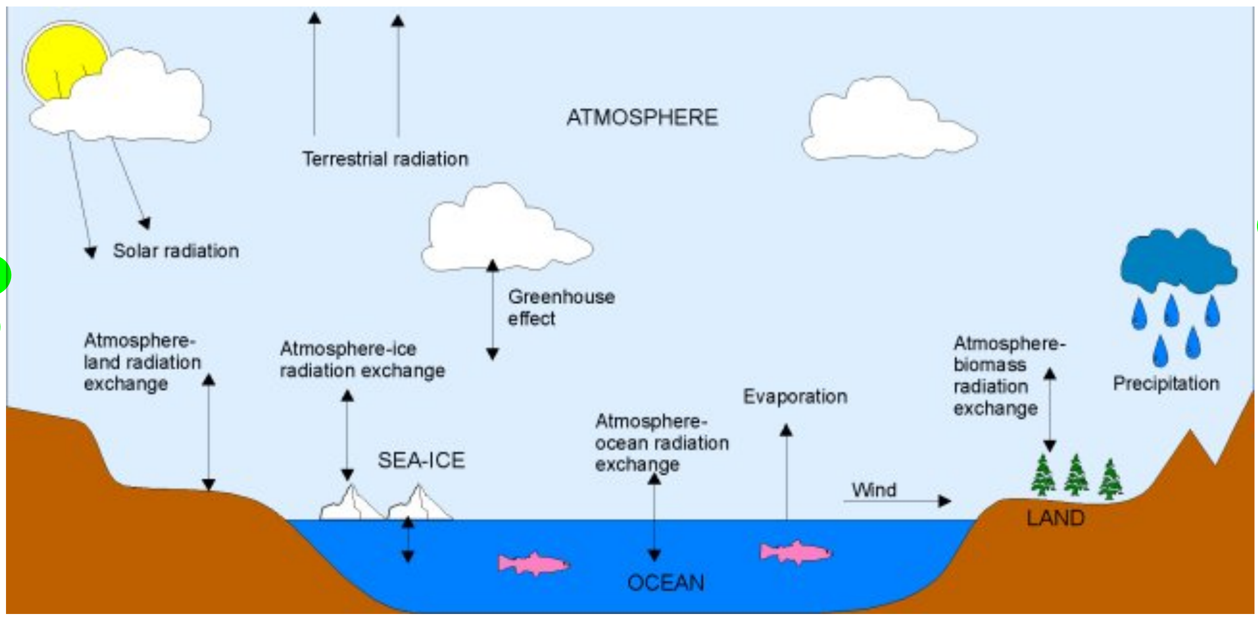

Fig: Earth climate (Atmosphere)

Cryosphere:

The world's ice sheets, glaciers and sea ice, collectively known as the cryosphere, have a significant impact on the Earth's climate. The cryosphere includes Antarctica, the Arctic Ocean, Greenland, Northern Canada, Northern Siberia and most of the high mountain ranges throughout the world, where sub-zero temperatures persist throughout the year. Snow and ice, being white, reflect a lot of sunlight, instead of absorbing it. Without the cryosphere, more energy would be absorbed at the Earth's surface rather than reflected, and consequently the temperature of the atmosphere would be much higher.

Biosphere:

All land plants make food from the photosynthesis of carbon dioxide and water in the presence of sunlight. Through this utilisation of carbon dioxide in the atmosphere, plants have the ability to regulate the global climate. In the oceans, microscopic plankton utilise carbon dioxide dissolved in seawater for photosynthesis and the manufacture of their tiny carbonate shells. The oceans replace the utilised carbon dioxide by "sucking" down the gas from the atmosphere.

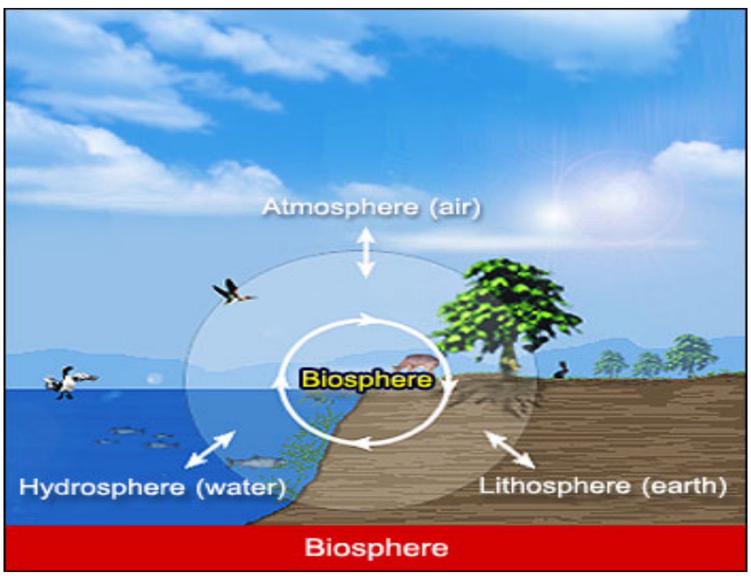

Fig: Earth climate (Biosphere)

LITHOSPHERE

It is believed the lithosphere evolved about 4.6 billion years ago. The lithosphere refers to the solid, rocky crust that covers the entire planet. This solid, rocky crust is composed of a number of different rocks that have been hrouped into three categories based on how they are formed. These three groups include:

- Metamorphic rocks – Metamorphic rocks are formed by heat and / or pressure from pre-existing rocks.
- Igneous rocks – igneous rocks are formed by the cooling of hot molten rock also known as magma. When the hot magma cools it begins to harden meaning once it had fully cooled it create what is known to be an igneous rock.
- Sedimentary rocks – sedimentary rocks are formed from pre-existing rocks. When rocks erode and mix with other dirt, clay and particles then settle together the mix together to form a sedimentary rock.

The lithosphere includes a various number of different landforms such as mountains, valleys, rocks, minerals and soil. The lithosphere is constantly changing due to forces and pressures such as the sun, wind, ice, water and chemical changes.

The earth's surface is composed into two types of lithospheres. There are known as the **oceanic and continental lithospheres.**

The oceanic lithosphere includes the uppermost layers of mantle which is topped with a thin yet heavy oceanic crust. This is where the hydrosphere and lithosphere meet.

The continental lithosphere include the uppermost layers of mantle which is topped with a thick yet light continental crust. This is where the atmosphere, biosphere and hydrosphere meet the lithosphere.

HYDROSPHERE -

The hydrosphere refers to the most important resource which I water. The hydrosphere includes all forms of water in the Earth's environment. The forms of water include things such as the ocean, lakes, rivers, snow and glaciers, water underneath the earth's surface and even the water vapour that is found in the atmosphere. The hydrosphere is always in motion as seen through the movement and flow of water in rivers, streams and the ocean (beach). Plant and animal organisms rely on the hydrosphere for their survival as water is essential. The hydrosphere is also home to many plants and animals and it believed that the hydrosphere covers approximately 70% of the earth's surface

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S1 : Earth system-hydrological cycle and carbon cycle

Hydrologic cycle

The water cycle, also known as the hydrologic cycle or the hydrological cycle, is a biogeochemical cycle that describes the continuous movement of water on, above and below the surface of the Earth.

EXPLAIN WATER CYCLE

- Water exists on earth in all three states, liquid, solid and gaseous state and various degrees of motion. The various aspects of water related to the earth can be explained in terms of cycle known as hydrologic cycle.

- Except for deep ground water, the total water supply of earth is in constant circulation from earth tot atmosphere and back to the earth.

- The earth' water circulatory system is known as hydrologic cycle. It is the process of transfer of moisture from atmosphere to earth in the form of precipitation, conveyance of precipitated water by streams and rivers to oceans and lakes and evaporation of water back to the atmosphere.

- The group of numerous arcs which represents the different path through which water in nature circulates and is transformed is known as hydrological cycle.
- These arcs penetrates into three parts of total earth system, Atmosphere, Hydrosphere and lithosphere.
- Hydrological cycle can be represented in many different ways in pictorial or diagrammatic forms.
- The hydrological cycle has no beginning or end as the water in nature is continuously kept in cyclic motion.

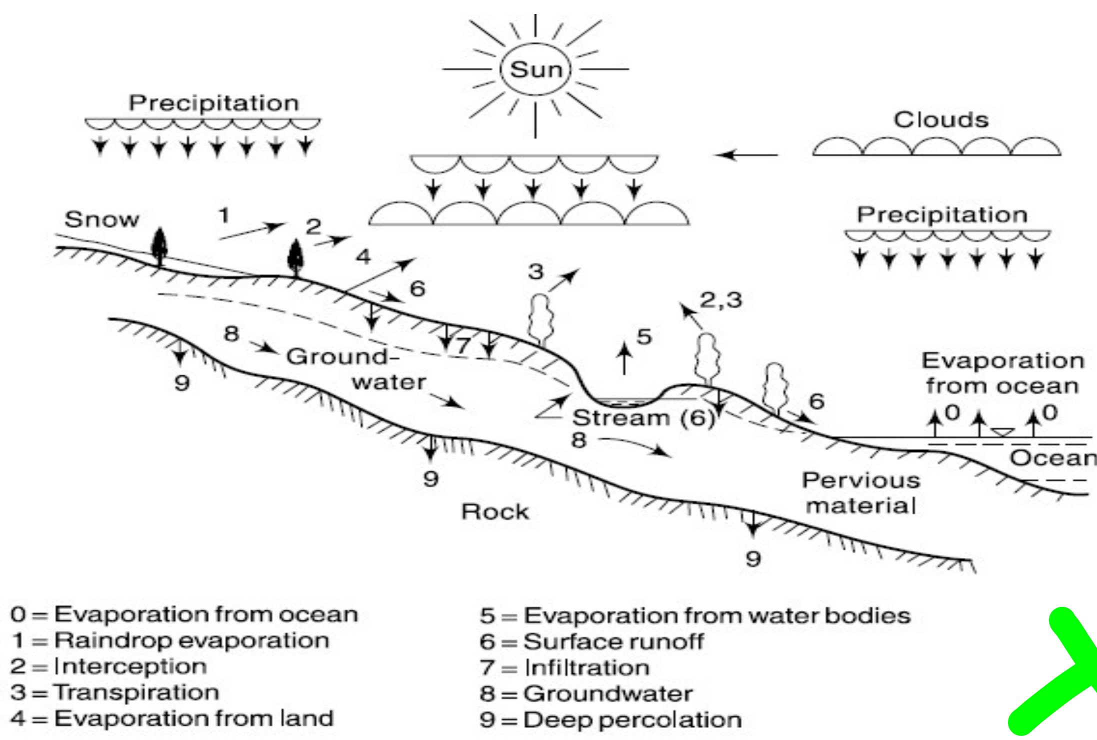

Fig. 1.1 The Hydrologic Cycle

Thus the hydrologic cycle may expressed by the following equation as

Precipitation [P] = Evaporation [E] + Runoff [R]

Provided adjustment is made for the moisture held in storage at the beginning and end of the period.

Precipitation [P]

- Precipitation may be defined as **fall of moisture from atmosphere to the earth surface in any form.**
- The precipitation reaching the ground surface after meeting the needs of infiltration and evaporation moves down the natural slope over the surface and through rivers and streams to reach the oceans.
- Precipitation may be **two forms**

i. Liquid Precipitation – Rainfall

ii. Frozen Precipitation – Snow, Hail, sleet, freezing rain

Measurement of Precipitation

It can be measured by rain gauge. The rain gauge may be

i) Recording type rain gauge [Weighing bucket, Tipping bucket, Floating type]

ii) Non- recording type rain gauge[Symon's Raingauge]

Evaporation [E]

- **Evaporation** from the surfaces of ponds, lakes, reservoirs. ocean surfaces, etc. and transpiration from surface vegetation i.e., from plant leaves of cropped land and forests, etc. take place. These vapours rise to the sky and are condensed at higher altitudes by condensation nuclei and form clouds, resulting in droplet growth.

- It is the process by which water from liquid state passes into vapour state under the action of sunrays.
- Transpiration is the process of water being lost from the leaves of plants from their pores.

Thus **total evaporation inclusive of transpiration** consists of

i. Surface evaporation
ii. Water Surface evaporation [Rivers, oceans]
iii. Evaporation from plants and leaves [Transpiration]
iv. Atmospheric evaporation

A portion of water that reaches the ground enters the earth surface through infiltration, enhance the moisture content of soil and reach the ground water body.

Runoff [R]

- Runoff is the portion of precipitation that is not evaporated.
- When moisture falls to the earth surface as precipitation, a part of it is evaporated from the water surface, soil and vegetation and through transpiration by plants and remainder precipitation is available as runoff which ultimately runs to the oceans through surface or sub-surface streams.

Classification of run off

i. Surface run off
ii. Sub surface runoff
iii. Ground water flow or base flow

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Carbon cycle

The carbon cycle is most easily studied as two interconnected subcycles:

- One dealing with rapid carbon exchange among living organisms.[**Biological carbon cycle]**
- One dealing with long-term cycling of carbon through geologic processes.[**Geological carbon cycle]**

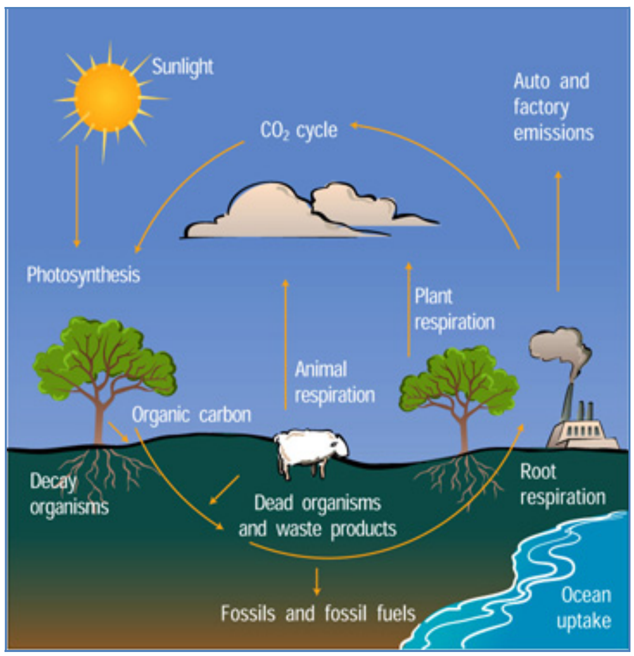

Fig: Carbon cycle

Biological carbon cycle

Carbon enters all food webs, both terrestrial and aquatic, through **autotrophs**, or self-feeders. Almost all of these autotrophs are photosynthesizers, such as plants or algae.

Autotrophs capture carbon dioxide from the air or bicarbonate ions from the water and use them to make organic compounds such as glucose.

Heterotrophs, or other-feeders, such as humans, consume the organic molecules, and the organic carbon is passed through food chains and webs. Carbon can cycle quickly through this biological pathway, especially in aquatic ecosystems. Overall, an estimated 1,000 to 100,000 million metric tons of carbon move through the biological pathway each year.

In the first step, through photosynthesis (the process by which plants capture the sun's energy and use it to grow), plants take carbon dioxide out of the atmosphere and release oxygen. The carbon dioxide is converted into carbon compounds that make up the body of theplant, which are stored in both the aboveground parts of the plants (shoots and leaves), and the below ground parts (roots).

Photosynthesis: Energy (sunlight) + $6CO_2$ + $H_2O \rightarrow C_6H_{12}O_6 + 6O_2$

In the next step, animals eat the plants, breath in the oxygen, and exhale carbon dioxide. The carbon dioxide created by animals is then available for plants to use in photosynthesis. Carbon stored in plants that are not eaten by animals eventually decomposes after the plants die, and is either released into the atmosphere or stored in the soil.

Respiration: $C_6H_{12}O_6$ (organic matter) + $6O_2 \rightarrow 6CO_2 + 6\ H_2O$ + Energy

Large quantities of carbon can be released to the atmosphere through geologic processes like volcanic eruptions and other natural changes that destabilize carbon sinks. For example, increasing temperatures can cause carbon dioxide to be released from the ocean.

Geological Process of carbon cycle

The geological pathway of the carbon cycle takes much longer than the biological pathway described above. In fact, it usually takes millions of years for carbon to cycle through the geological pathway. Carbon may be stored for long periods of time in the atmosphere, bodies of liquid water—mostly **oceans— ocean sediment, soil, rocks, fossil fuels, and Earth's interior.**

The level of carbon dioxide in the atmosphere is influenced by the reservoir of carbon in the oceans and vice versa. Carbon dioxide from the atmosphere dissolves in water and reacts with water molecules in the following reactions:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+ \rightleftharpoons CO_3^{2-} + 2H^+$$

The carbonate—CO_3^{2-}—released in this process combines with Ca^{2+} ions to make calcium carbonate $CaCO_3$ a key component of the shells of marine organisms. When the organisms die, their remains may sink and eventually become part of the sediment on the ocean floor. Over geologic time, the sediment turns into limestone, which is the largest carbon reservoir on Earth.

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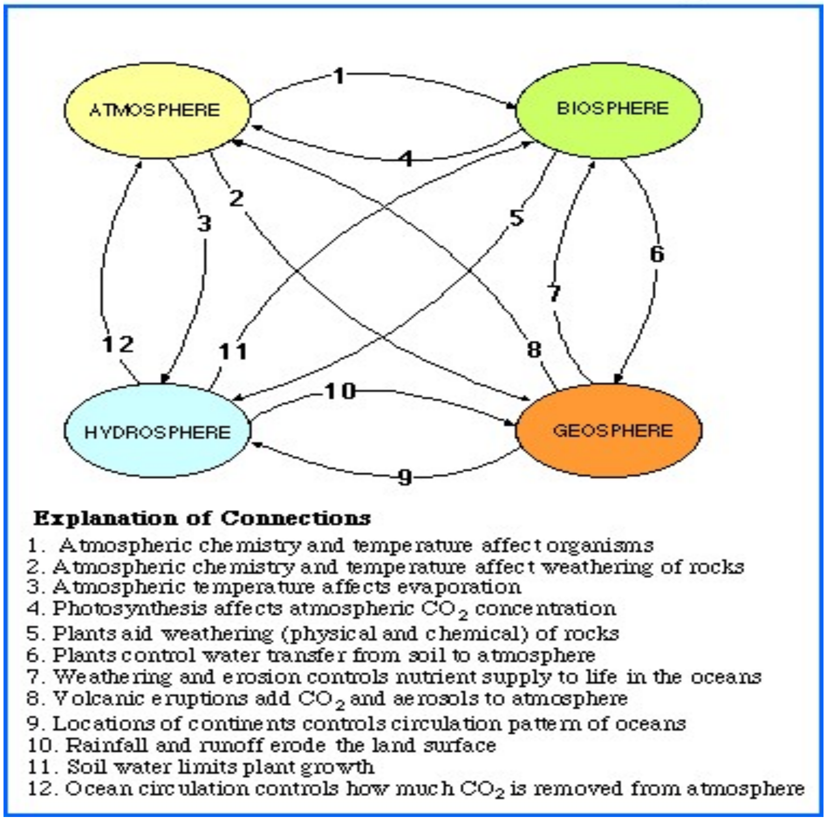
S2: Importance of earth system and climate

Earth System Science is a relatively new field of study that focuses on the operation of the whole Earth, including the **atmosphere, hydrosphere, biosphere, and geosphere.** These four spheres can be thought of as four machines or systems that are connected together to make one larger machine -- the whole Earth system. Earth System Science is especially concerned with the interactions between these different spheres and how these interactions control the global climate. This field of study incorporates and integrates material from traditional geology, meteorology, oceanography, ecology, atmospheric chemistry, and other fields.

	Major Influences on the Global Climate
Atmosphere	CO_2 and H_2O control greenhouse; clouds and aerosols control amount of sunlight reaching surface; global circulation determines climatic zones
Biosphere	Land plants transfer CO_2 from atmosphere and soil; oceanic plants transfer CO_2 from atmosphere to ocean floor; plants affect albedo of surface; land plants transfer H_2O from the soil to the atmosphere; plants and microbes enhance weathering of rocks, which consumes atmospheric CO_2
Hydrosphere	Atmospheric H_2O controls greenhouse and cloud cover and transfers heat energy; surface water controls plant growth and thus albedo and CO_2 transfer; oceans transfer heat and regulate atmospheric CO_2; glaciers control albedo, sea level, and deep ocean circulation patterns
Geosphere	Locations of continents controls ocean circulation, global weather patterns; mountains affect regional weather and are main locations of weathering which removes atmospheric CO_2; volcanoes return CO_2 to the atmosphere; volcanic aerosols block sunlight; sea-floor spreading rates control sea level

In addition to understanding how different parts of the Earth System affect the global climate, it is important to understand how these different parts are linked together &emdash; how they are interconnected. The graph below represents these interconnections in the form of connecting arrows; each arrow represents some set of processes that operate within one of the Earth's four "spheres" that influences the "sphere" that the arrow points to

Connections Within The Earth System



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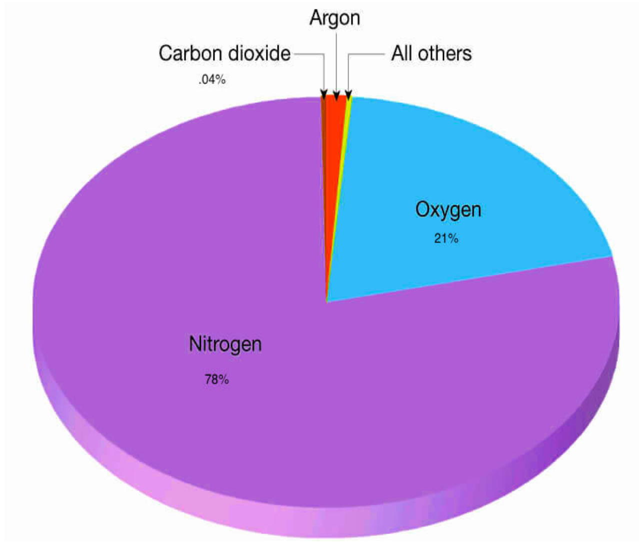
S3: Atmosphere and its composition, different strata of atmosphere and temperature profile

Atmosphere and its composition

The earth's atmosphere is a very thin layer wrapped around a very large planet. The three major constituents of dry air are **nitrogen (N_2) oxygen (O_2) and argon (Ar), which account respectively for 79 percent, 21 percent and 1 percent of the molecules.**



Composition of the Atmosphere	Other Components of the Atmosphere
• Nitrogen 78.08% • Oxygen 20.95% • Argon 0.93% (9300 ppm) • Carbon Dioxide 0.035% (350 ppm) • Neon 18 ppm • Helium 5.2 ppm • Methane 1.4 ppm • Ozone 0.07 ppm	• Water Droplets • Ice Crystals • Sulfuric Acid Aerosols • Volcanic Ash • Windblown Dust • Sea Salt • Human Pollutants

Different strata of atmosphere

Based on temperature, the atmosphere is divided into five layers:

i) Troposphere
ii) Stratosphere
iii) Mesosphere and
iv) Thermosphere
v) Exosphere

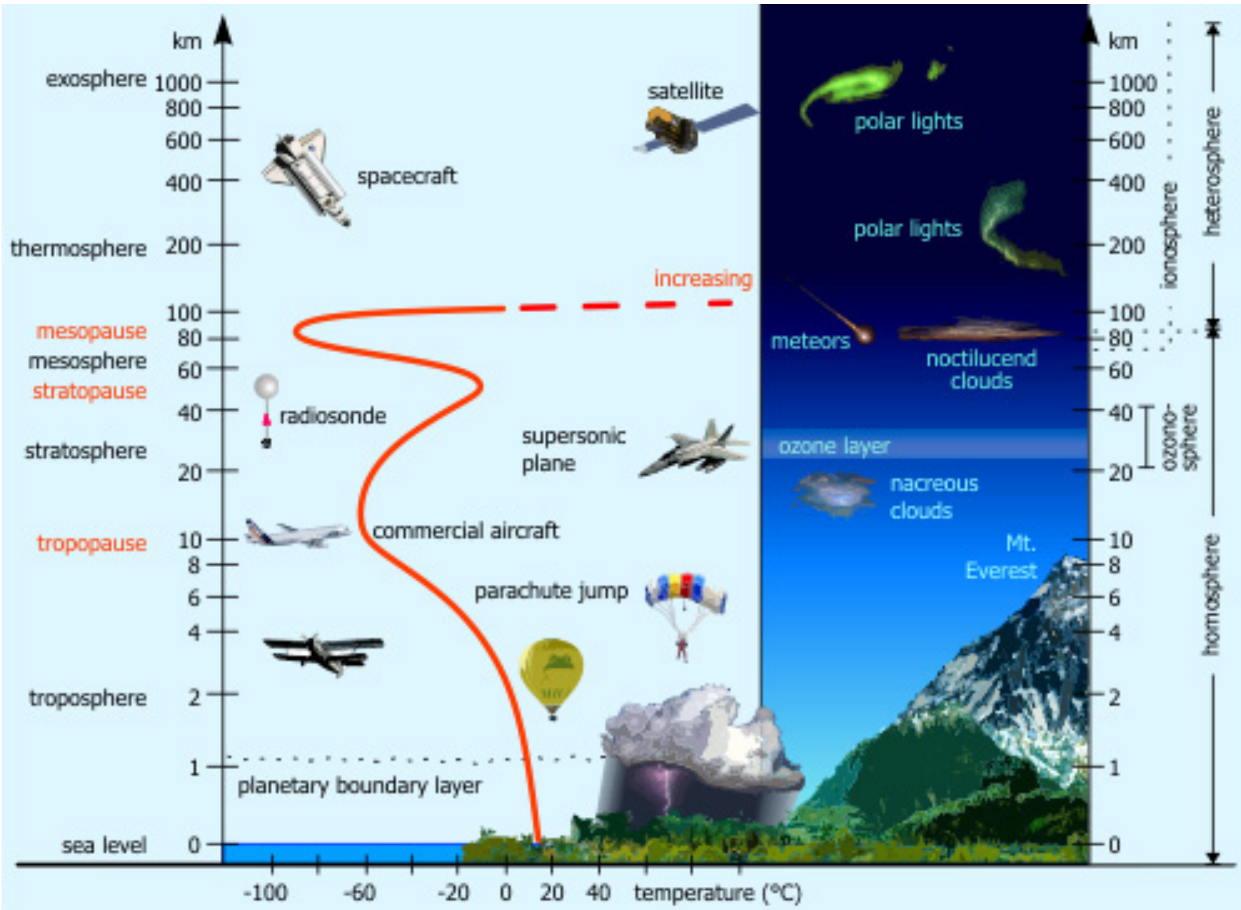


Fig: Different layers of Atmosphere

i) Troposphere

"**Tropos**" means change.

This layer gets its name from the weather that is constantly changing and mixing up the gases, in this part of our atmosphere.This layer is the closest to Earth's surface.

On average the troposphere extends, from the ground to about 12 kilometers or 7.5 miles high.The troposphere contains, about 75% of all of the air in the atmosphere, and, almost all of the water vapor, which forms clouds and rain. In this layer, air is made up of approximately 78% nitrogen, 21% oxygen, and 1% argon with small amounts of additional gases, including water vapor and, carbon dioxide.

(ii) Stratosphere

"**Strat**" means layer.

This layer of our atmosphere has its own set of layers. The boundary between the stratosphere and the troposphere is called the tropopause. It is the region where airplanes fly.

The Stratosphere layer, extends from the tropopause to about 50 kilometers (32 miles) above the Earth's surface.This layer contains a thin layer of ozone molecules which forms a protective layer and absorbs harmful ultraviolet radiation, from the Sun. The high-altitude weather balloons flying into the stratosphere for monitoring atmospheric conditions and climate research.

(iii) Mesosphere

"**Meso**" means middle.

This layer is located above the stratosphere and below the thermosphere. It is the third layer in our atmosphere which is 35 kilometers (22 miles) thick. The transition boundary which separates the mesosphere, from the stratosphere is called the stratopause. In the mesosphere fewer air molecules to absorb incoming electromagnetic radiation from the Sun. Most meteors burn up in this atmospheric layer.

(iv) Mesosphere

"**Thermo**" means heat.

This layer has extremely high temperatures, and located above the mesosphere, and below the exosphere. The boundary between the mesosphere, and the thermosphere atmospheric regions, is called Mesopause. It is the coldest part of Earth's atmosphere. The thermosphere, extends from the mesopause to 700 kilometers (435 miles) above the surface of the Earth. The thermosphere is the thickest layer, in the atmosphere. Only the lightest gases, mostly oxygen, helium, and, hydrogen are found here. The aurora, and satellites mostly occur in this layer.

(V) EXOSPHERE

"**Exo**" means outside.

The exosphere, represents the outermost layer of Earth's atmosphere. It extends, from the top of the thermosphere to 10,000 kilometers (6,214 miles) above Earth's surface.

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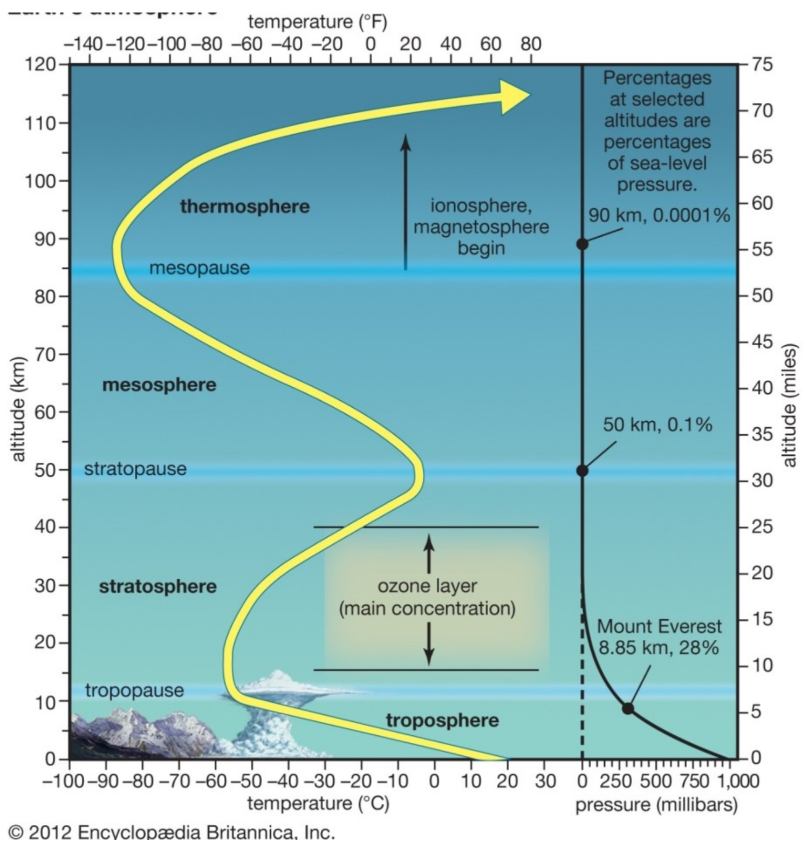
Temperature profile



Atmospheric Composition - affects Air Temperature:

Air temperature also changes as altitude increases. The temperature differences result mainly from the way solar energy is absorbed as it moves through the atmosphere.Some parts of the atmosphere are warmer because they contain a high percentage of gases that absorb solar energy. Other parts of the atmosphere contain less of these gases and are cooler

Heat and Temperture:

Temperature: Average energy of molecules or atoms in a material.
Heat: Total energy of molecules or atoms in a material.
It’s possible to have large amount of heat but low temperatures and high temperatures but little heat.
The Arctic Ocean has a large amount of heat (because of large mass) even though the temperature is low. Air in an oven at 500ºF has high temperature but little heat.
However if you touch anything solid in the oven you’ll get burned. Same temperature but much larger amount of heat. The earth’s outermost atmosphere is extremely “hot” but its heat content is negligible.
It takes time for things to warm up and cool off.

Temperature Scales	**Absolute Temperature**
1) Fahrenheit a) Water Freezes at 32 F b) Water Boils at 212 F 2) Centigrade or Celsius a) Water Freezes at 0 C b) Water Boils at 100 C 3) Two scales exactly equal at -40	Kelvin scale uses Celsius degrees and starts at absolute zero Absolute Zero specify - 273ºC / - 459ºF.

18CEO406T - GLOBAL WARMING AND CLIMATE CHANGE

UNIT – 1 [S4 to S6]

S4: Weather and Climate Climate parameter- temperature, atmospheric pressure

WEATHER

What is weather?

Weather is the day-to-day state of the atmosphere, and its short-term variation in minutes to weeks. People generally think of weather as the combination of temperature, humidity, precipitation, cloudiness, visibility, and wind

What is Climate?

Climate describes the average weather of a particular part of the world at different times of the year. The climate of a place may be defined as a "composite" of the long-term prevailing weather that occurs at that location.

Climate is the weather of a place averaged over a period of time, often 30 years

In a sense, climate is "average weather". Climate can be measured quantitatively by calculating the long term averages of different climate elements such as temperature and rainfall. ..

Atmospheric Pressure

Atmospheric pressure is the force per unit area exerted on a surface by the weight of air above that surface in the atmosphere of earth (or that another planet).

In most circumstances atmospheric pressure is closely approximated by the hydrostatic pressure caused by the weight of air above the measurement point.

On a given plane, low-pressure areas have less atmospheric mass above their location, whereas high-pressure areas have more atmospheric mass above their location. Likewise, as elevation increases, there is less overlying atmospheric mass, so that atmospheric pressure decreases with increasing elevation.

Atmospheric Temperature

Atmospheric temperature is a measure of temperature at different levels of the Earth’s atmosphere. It is governed by many factors, including incoming solar radiation, humidity and altitude.

In the Earth's atmosphere, temperature varies greatly at different heights relative to the Earth’s surface. The coldest temperatures lie near the mesopause, an area approximately 85 km to 100 km above the surface. In contrast, some of the warmest temperatures can be found in the thermosphere, which receives strong ionizing radiation.

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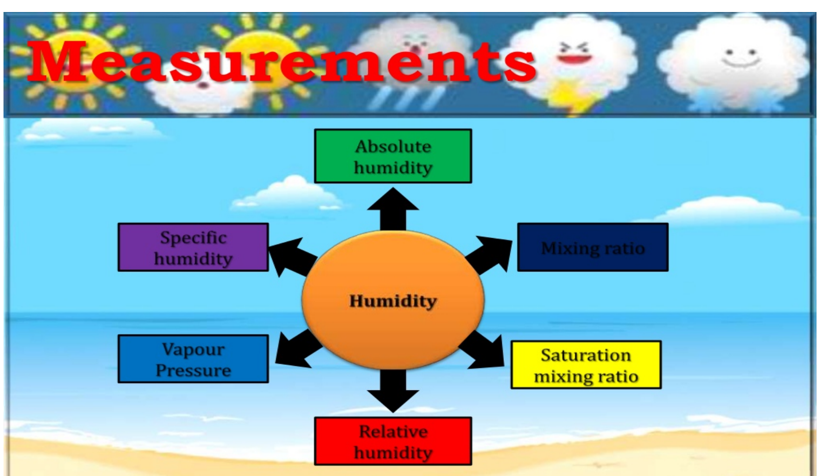
S5: Atmospheric humidity and rainfall, Wind circulation

Atmospheric humidity

Atmospheric humidity is the amount of water vapour carried in the air. It can be measured as vapour pressure, mixing ratio or specific humidity. ... Atmospheric water vapour is also the most important greenhouse gas in the atmosphere.



Various ways of expressing humidity

Types of Humidity

(i) Relative humidity,

(ii) Specific humidity,

(iii) Mixing ratio, and

(iv) Absolute humidity.

Relative humidity

Relative humidity may also be defined as the ratio of actual vapour pressure to that required for saturation at the same temperature.

$$RH = \frac{\text{Actual vapour pressure}}{\text{Saturation vapour pressure}} \times 100$$

Specific humidity

- It is the ratio of mass of water vapours actually present in the air to a unit mass of air including the water vapour (dry air + moisture). It is expressed as grams of water vapour per kg of moist air mass. The amount of water vapour that air can hold depends upon temperature. Specific humidity at 20°C is 15g per kg. At 30°C, it is 26 g per kg and at -10°C, it is 2 g per kg.
- Suppose, 1kg of air contains 12 grams of water vapours, then the specific humidity of air is 12 g per kg.

Mixing ratio

It is defined as the ratio of mass of water vapours per unit mass of dry air. It is also defined as the ratio of density of water vapours to the density of dry air. It varies from 1 g per kg in arctic zone to 40 g per kg in humid equatorial zone.

Absolute Humidity:

- It is defined as the weight of water vapours in a given volume of air. It is expressed as grams of water vapours per cubic meter of air (g m^{-3}). Absolute humidity is rarely used because it varies with the expansion and contraction of air. It varies with temperature, even though the amount of water vapours remains constant.

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RAINFALL

- Rainfall is a form of Precipitation. The term "rainfall" is used to describe precipitation in the form of water drops of sizes larger than 0.5 mm. Other forms are snow, drizzle, glaze, sleet and hail. ... Sleet is frozen raindrops of transparent grains which form when rain falls through air at subfreezing temperature.

Convectional Rainfall

- Suppose we are enjoying the rays of sunshine and suddenly, the sky gets darker with the grey cloud. Without any warning the heavens open and it begins to rain, with a thundery feel. This is the convectional rain. It occurs frequently on hot days usually giving cumulus cloud and thundery showers.
- The sun heats the ground which causes the air to warm and become very hot. Then the air rises upwards and becomes cool. Then it condenses to form cumulus cloud.
- When this cloud is saturated, it begins to precipitate giving heavy and thundery showers. Due to this, we get thundershowers on a hot day, as the Sun warms the air and it rises, cools and begins to rain.

Frontal Rainfall

- This rainfall occurs when a warm, tropical air mass comes in contact with a cold, polar air mass. It is very common in Britain and Ireland. Because the air is in the warm front, then it rises over the cold front. The air is cooled and so condenses to form a stratus cloud. Thus when the stratus cloud becomes saturated, it begins to precipitate.

Relief Rainfall

- This type of rainfall is common in places with mountains and sea. Relief rainfall frequently occurs near mountains beside the sea. The moisture-laden wind blows in from the sea because the wind meets a high mountain and hence it is forced to rise upwards. At the height, it is cooled and then the cloud is formed.
- This saturated cloud with water vapor begins to precipitate on the side of the mountain facing the sea. This front side of the mountain is called the windward side.
- The cloud mostly precipitates on the windward side of the mountain. Meanwhile, the cloud meets the other side, which is called the leeward side. Since the cloud has already lost most of its moisture so it rains very little there.
- This makes leeward sides of a mountain very little rains. There is a much more moist climate on the windward sides of slopes. On the other hand, there is a more dry, sheltered climate on the leeward side. This rainfall is common in Hawaii, Sierra Nevada, and the Andes.

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Wind circulation

Winds are produced in response to radiative heating of the atmosphere. These winds constitute an important forcing for ocean currents, which are generated due to momentum transferinto the ocean bywinds. The pressure gradients generated by radiative heatingcould produce wind speeds of about10ms−1in the atmospherejust above the ocean.Yet,there willbeno momentum transfer by winds to ocean layersif there were no friction at the surface.Becauseof the frictional contact,no slipconditionwill be satisfied by the airflow at solid surface boundary; that is, the air in immediate contact with the boundary attains zero velocity.

This will set up a velocity gradient (or shear) near the solid boundary. The shear flowset upin this manneris not stable at higher windspeeds because small disturbances can grow at the expense of mean motion to turnthe flow turbulent. The turbulent eddiesare responsible for the gusty nature of the flow, modify shear fora well-defined mean velocity structure to developafter sufficiently long time. The flow velocity is a function of z, i.e. the distance from the surface inverticaldirection. The shear depends on mean stress τ, density ρand distance z from the ground, and one obtains a logarithmic mean velocity profile.

For the same solar heating rate, land temperaturesrise faster in summer than the sea temperatures and also land coolsrapidly during winter with the diminishing radiative heating. As a result of this contrast, low-pressuresystems during summers and high pressures during winters develop over land areas. Such a flip-flop in atmospheric pressures over land will result in the alteration of pressure systems over the oceans as well.

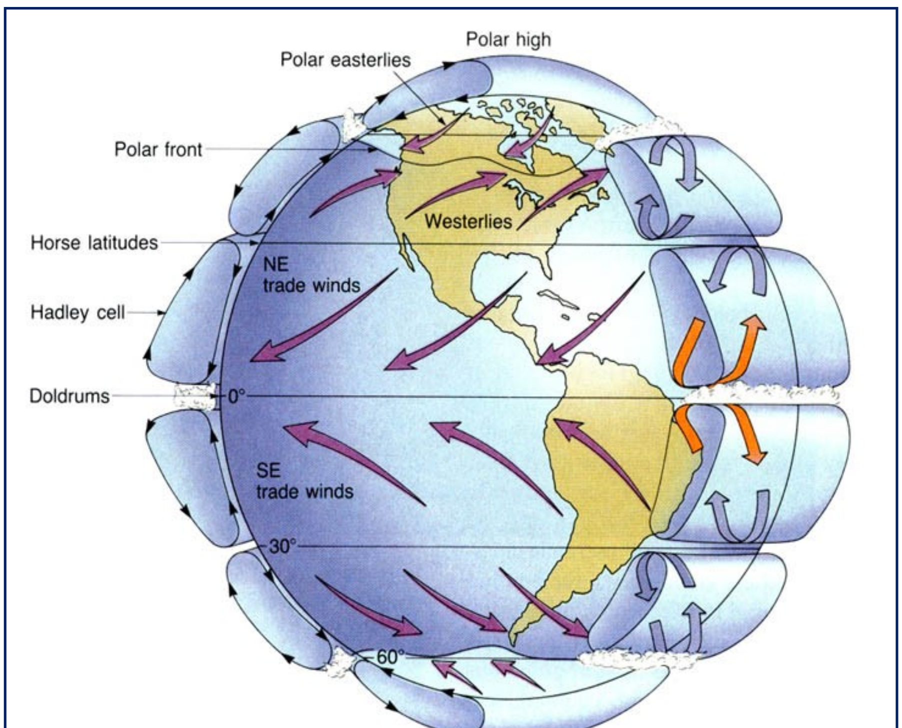
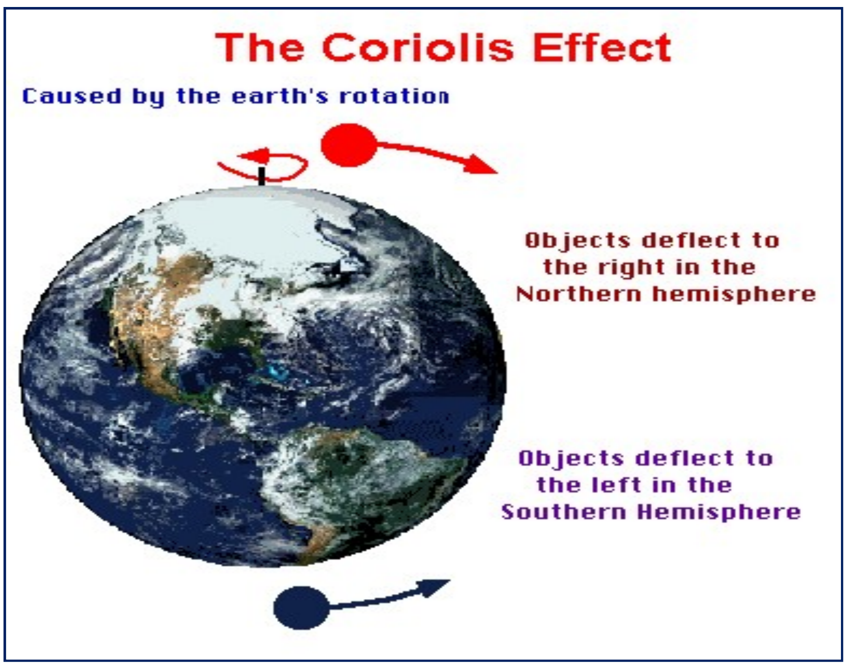


Fig: Global wind pattern

Coriolis force

- Due to the rotation of the earth, wind and ocean currents are deflected to the right in the northern hemisphere and to the left in the southern hemisphere. This effect is known as the "Coriolis force."
- The deflection leads to highs and lows of sea level directly proportional to the speed of the surface currents
- The Earth would have two large Hadley cells, if it did not rotate.
- Rotation of the Earth leads to the Coriolis Effect
- This causes winds (and all moving objects) to be deflected:
- To the right in the Northern Hemisphere
- To the left in the Southern Hemisphere



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S6: Ocean circulation, Atmospheric stability and lapse rate

Ocean circulation

Ocean circulation is the large scale movement of waters in the ocean basins.

There are two main types of ocean currents: currents driven mainly by wind and currents mainly driven by density differences. Density depends on temperature and salinity of the water.

1. Horizontal circulation
    1. Surface currents
    2. Deep currents

    (Cold and salty water is dense and will sink. Warm and less salty water will float)

2. Vertical circulation
    1. Upwelling
    2. Downwelling

Horizontal currents:

Winds drive surface circulation, and the cooling and sinking of waters in the polar regions drive deep circulation.

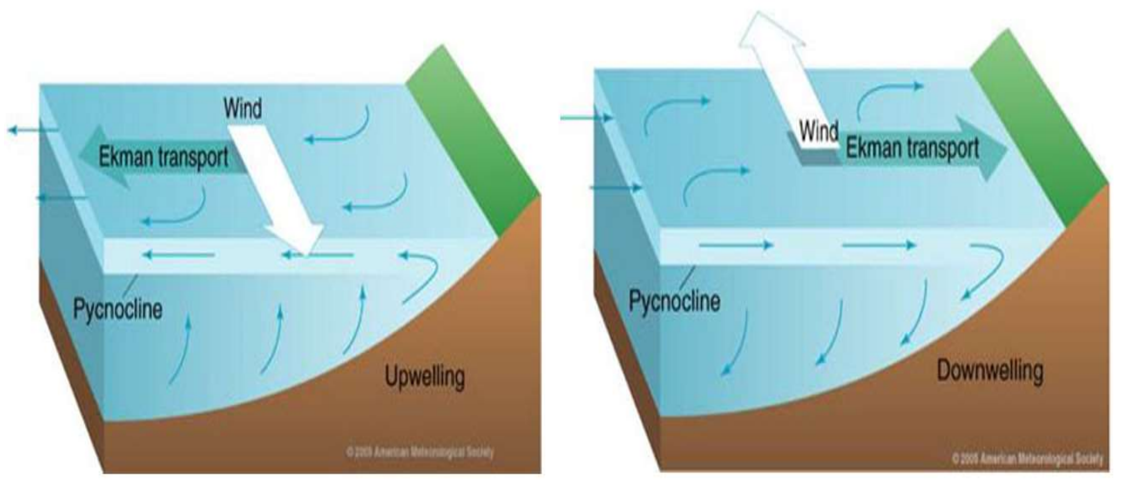
Surface circulation carries the warm upper waters poleward from the tropics.

Heat is disbursed along the way from the waters to the atmosphere. At the poles, the water is further cooled during winter, and sinks to the deep ocean. This is especially true in the North Atlantic and along Antarctica.

Deep ocean water gradually returns to the surface nearly everywhere in the ocean. Once at the surface it is carried back to the tropics, and the cycle begins again. The more efficient the cycle, the more heat is transferred, and the warmer the climate.

Winds blowing across the ocean surface push water away. Water then rises up from beneath the surface to replace the water that was pushed away. This process is known as "upwelling."

Upwelling occurs in the open ocean and along coastlines. The reverse process, called "downwelling,"



Importance of ocean circulation

- ocean currents have a major impact on the global climate. They cause the relative mildness of the Western European climate, for example.
- Ocean and atmospheric currents form a coupled dynamic system. Instabilities of this system, the El Nino Southern Oscillation (ENSO) in particular, produce important climate fluctuations.
- Ocean currents not only distribute heat, but they also play a crucial role in the global ecosystem by storing CO_2 and recycling nutrients.

Atmospheric stability

- Atmospheric stability is a term used to qualitatively describe the amount of vertical motion of the air in the lower atmosphere (the troposphere). In broad general terms, the atmospheric stability can be characterized by these four categories:
- A *very stable* atmosphere is one that has very little vertical motion of the air.
- A *stable* atmosphere is one that discourages vertical motion but does have some motion of the air.
- An *unstable* atmosphere is one that encourages continual vertical motion of the air, upwards or downwards.
- A *neutral* atmosphere is one that neither discourages nor encourages vertical motion of the air and is often referred to as *conditionally stable*.

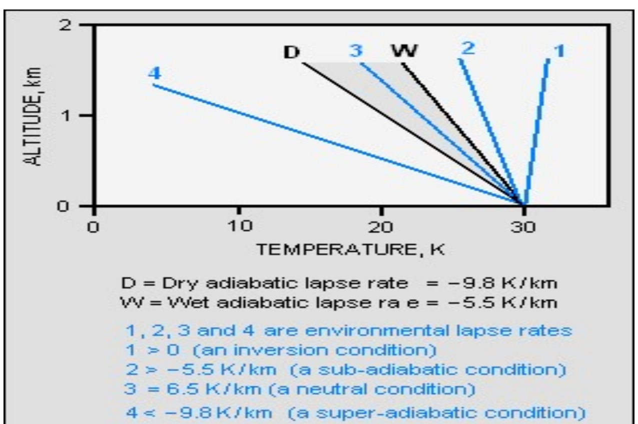
Importance of understanding atmospheric stability

- An understanding and knowledge of atmospheric stability is important for many reasons. What follows is a brief discussion of some of those reasons:
- Probably one of the most important reasons is that atmospheric turbulence and mixing plays a major role in air pollution dispersion modeling. Turbulence and mixing is provided by an unstable atmosphere and thus enhances the dispersion of air pollutant, while a stable atmosphere inhibits turbulence and results in very poor dispersion of air pollutants.
- A stable atmosphere inhibits rain fall, while an unstable atmosphere encourages rainfall and thunderstorms.
- A stable atmosphere also inhibits forest fire activity and an understanding of atmospheric stability helps explain certain aspects of forest fire behavior.

- A certain amount of atmospheric instability is important for glider pilots, since without it the thermals needed for glider flight would not form. Understanding of atmospheric stability is also important for the safety of glider pilots because high atmospheric instability may lead to thunderstorms.
- The atmospheric stability has a large impact on the deposition and drift of aerially applied sprays of various farm crop protection materials.

Atmospheric lapse rate

- The **atmospheric lapse rate** refers to the change of an atmospheric variable with a change of altitude, the variable being temperature unless specified otherwise (such as pressure, density or humidity).
- Lapse rates are usually expressed as the amount of temperature change associated with a specified amount of altitude change, such as 9.8 K per kilometre, 0.0098 K per metre or the equivalent 5.4 °F per 1000 feet.
- If the atmospheric air cools with increasing altitude, the lapse rate may be expressed as a negative number. If the air heats with increasing altitude, the lapse rate may be expressed as a positive number.



Source: Milton Beychok

Various lapse rates defining the change of atmospheric temperature with altitude.

18CEO406T - GLOBAL WARMING AND CLIMATE CHANGE

UNIT – 1 [S7 to S9]

S7: Atmospheric stability continuation, Pollutant dispersion

Pollutant Dispersion

The stream of polluted air downwind of a smoke stack is called a smoke plume. If the plume is buoyant, or if there is a large effluent velocity out of the top of the smoke stack, the center of the plume can rise above the initial emission height. This is called plume rise. The word "plume" in air pollution work means a long, slender, nearly-horizontal region of polluted air. However, the word "plume" in atmospheric bound-ary-layer (ABL) studies refers to the relatively wide, nearly vertical updraft portion of buoyant air that is convectively overturning. Because smoke plumes emitted into the boundary layer can be dispersed by convective plumes, one must take great care to not confuse the two usages of the word "plume".

Dispersion is the name given to the spread and movement of pollutants. Pollution dispersion de-pends on

- wind speed and direction,
- plume rise, and
- atmospheric turbulence.

Pollutants disperse with time by mixing with the surrounding cleaner air, resulting in an increasingly dilute mixture within a spreading smoke plume.

Wind and turbulence are characteristics of the ambient atmosphere, as were described in earlier chapters. While emissions out of the top of the stack often have strong internal turbulence, this quickly decays, leaving the ambient atmosphere to do the majority of the dispersing.

The amount of a pollutant in the air can be given as a fraction or ratio, q. This is the amount (moles) of pollution divided by the total amount (moles) of all constituents in the air. For air quality, the ratios are typically reported in parts per million (ppm). For example, 10 ppm means

10 parts of pollutant are contained within 106 parts of air. For smaller amounts, parts per billion (ppb) are used.

For a standard atmosphere at sea level, where temperature is 15°C and pressure is 101.325 kPa, the equation above reduces to

$$q(\text{ppmv}) = \frac{b}{M_s} \cdot c(\mu\text{g/m}^3)$$

where $b = 0.02363$ (ppmv) / (µg m^{-3}).

For example, nitrogen dioxide (NO_2) has a molecular weight of $M_s = 46.01$ g/mole (see Table 1-2 in Chapter 1). If concentration $c = 100$ µg m^{-3} for this pollutant, then the equation above gives a volume fraction of $q = (0.02363/46.01) \cdot (100) = 0.051$ ppmv.

Table 19-1. Air quality concentration standards for the USA (US), Canada (CAN), and The European Union (EU) for some of the commonly-regulated chemicals, as of Sep 2017. Concentrations represent averages over the time periods listed. For Canada, the CAAQS are changing over years 2015 -> 2020. Older Canadian National Ambient Air Quality Objectives (acceptable levels) are in grey.

Avg. Time	US	CAN	EU
Sulfur Dioxide (SO_2)			
1 yr		->5 ppb	
1 day			125 µg m^{-3}
3 h	1300 µg m^{-3} or 0.5 ppm		
1 h	75 ppb	->70 ppb	350 µg m^{-3}
Nitrogen Dioxide (NO_2)			
1 yr	100 µg m^{-3} or 53 ppb	53 ppb	40 µg m^{-3}
1 h	100 ppb	213 ppb	200 µg m^{-3}
Carbon Monoxide (CO)			
8 h	10,000 µg m^{-3} or 9 ppm	13 ppm	10,000 µg m^{-3}
1 h	40,000 µg m^{-3} or 35 ppm	31 ppm	
Ozone (O_3)			
8 h	0.070 ppm	63 -> 62 ppb	120 µg m^{-3}
Particulates, diameter < 10 µm (PM_{10})			
1 yr		70 µg m^{-3}	40 µg m^{-3}
1 day	150 µg m^{-3}	120 µg m^{-3}	50 µg m^{-3}
Fine Particulates, diam. < 2.5 µm ($PM_{2.5}$)			
1 yr	12 µg m^{-3}	10->8.8 µg m^{-3}	25 µg m^{-3}
1 day	35 µg m^{-3}	28->27 µg m^{-3}	
Lead (Pb)			
1 yr			0.5 µg m^{-3}
3 mo	0.15 µg m^{-3}		
Benzene (C_6H_6)			
1 yr			5 µg m^{-3}
Arsenic (As)			
1 yr			6 ng m^{-3}

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S8; Introduction to greenhouse gases and global warming, Photo chemical smog

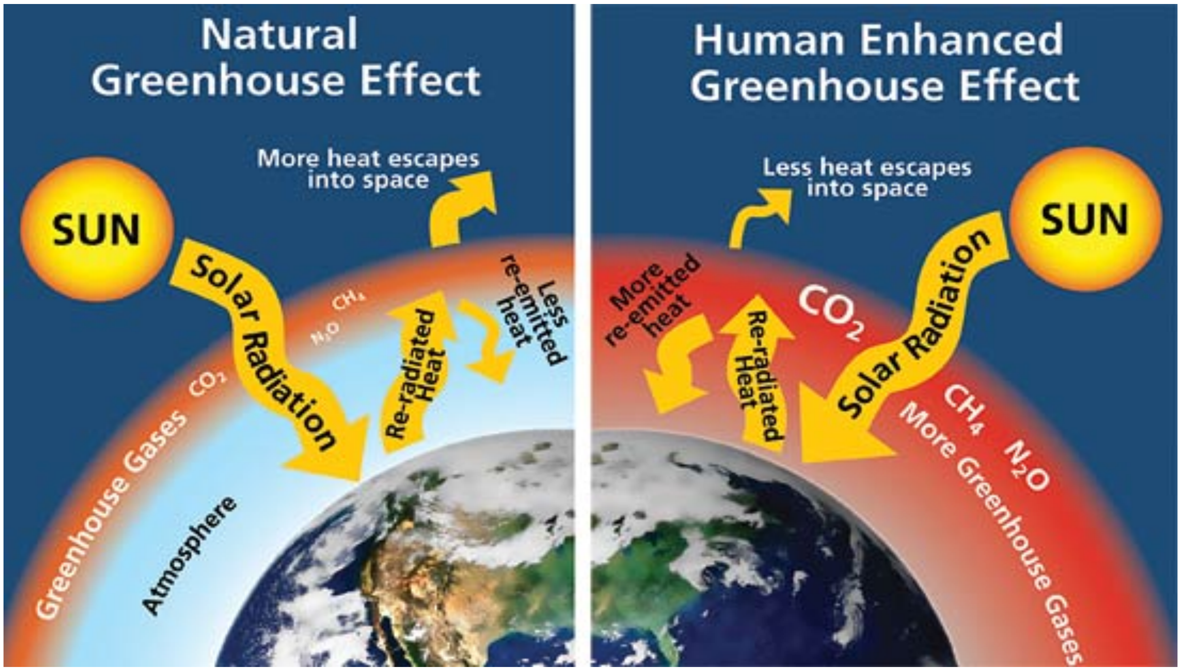
GREEN HOUSE GASES

Allowing short wave solar radiation into earth's surface and retaining the long wave infrared radiation reflected by the earth's surface by greenhouse gases in the atmosphere is termed as greenhouse effect.

Greenhouse gases include any gas in the atmosphere that is capable, as a result of its particular molecular structure, of absorbing infrared radiation or heat. They are called greenhouse gases because they behave like glass in a greenhouse gas, allowing sunlight to pass through but trapping the heat formed and preventing it from escaping, thereby causing a rise in temperature.

Greenhouse gases cause the **greenhouse** effect on planets. The primary **greenhouse gases** in Earth's atmosphere are

1. CO_2 Carbon dioxide
2. CH_4 Methane
3. N_2O Nitrous Oxide
4. SF_6 Sulphur hexafluoride
5. PFCs Perfluorocarbones
6. HFCs Hydrofluorocarbons



Energy from the sun drives the earth's weather and climate, and heats the earth's surface.

In turn, the earth radiates energy back into space.

Some atmospheric gases (water vapor, carbon dioxide, and other gases) trap some of the outgoing energy, retaining heat (like the glass panels of a greenhouse).

These gases are therefore known as greenhouse gases. The greenhouse effect is the rise in temperature on Earth as certain gases in the atmosphere trap energy.

Sources of Green house gases:

- **Carbon dioxide**, which is emitted whenever coal, oil, natural gas and other carbon-rich fossil fuels are burned. Although carbon dioxide is not the most powerful greenhouse gas, it is the largest contributor to climate change because it is so common. In order to reduce carbon dioxide emissions, we need to reduce the amount of fuel we use in our cars, homes, and lives.

- **Methane** is caused by the decomposition of plant matter, and is released from landfills, swamps, rice paddies. Cattle also release methane. Although methane emissions are lower than carbon dioxide emissions, it is considered a major greenhouse gas because each methane molecule has 25 times the global warming potential of a carbon dioxide molecule.
- **Nitrous oxide** is released from bacteria in soil. Modern agricultural practices — tilling and soil cultivation, livestock waste management, and the use of nitrogen-rich fertilizers — contribute significantly to nitrous oxide emissions. A single nitrous oxide molecule has 298 times the global warming potential of a carbon dioxide molecule.
- Additional greenhouse gases include **hydrofluorocarbons** (1,430-14,800 time the global warming potential of carbon dioxide), **sulfur hexafluoride** (22,800 times the global warming potential of carbon dioxide), and water vapor.

Causes of Greenhouse Effect

The major causes of the greenhouse effect are:

Burning of Fossil Fuels

Fossil fuels are an important part of our lives. They are widely used in transportation and to produce electricity. Burning of fossil fuels releases carbon dioxide. With the increase in population, the utilization of fossil fuels had increased. This has led to an increase in the release of greenhouse gases in the atmosphere.

Deforestation

Plants and trees take in carbon dioxide and release oxygen. Due to the cutting of trees, there is an inconsiderable increase in the greenhouse gases which increases the earth's temperature.

Farming

Nitrous oxide used in fertilizers is one of the contributors to greenhouse effect in the atmosphere.

Industrial Waste and Landfills

The industries and factories produce harmful gases which are released in the atmosphere.

Landfills also release carbon dioxide and methane that adds to the greenhouse gases.

Effects of Greenhouse Effect

The main effects of increased greenhouse gases are:

Global Warming

It is the phenomenon of a gradual increase in the average temperature of the Earth's atmosphere. The main cause for this environmental issue is the increased volumes of greenhouse gases such as carbon dioxide and methane released by the burning of fossil fuels, emissions from the vehicles, industries and other human activities.

Depletion of Ozone Layer

Ozone Layer protects the earth from harmful ultraviolet rays from the sun. It is found in the upper regions of the stratosphere. The depletion of the ozone layer results in the entry of the harmful UV rays to the earth's surface that might lead to skin cancer and can also change the climate drastically.

The major cause of this phenomenon is the accumulation of natural greenhouse gases including chlorofluorocarbons, carbon dioxide, methane, etc.

Runaway Greenhouse Effect

This phenomenon occurs when the planet absorbs more radiations than it can radiate back. Thus, the heat lost from the earth's surface is less and the temperature of the planet keeps rising. Scientists believe that this phenomenon took place on the surface of Venus billions of years ago.

This phenomenon is believed to have occurred in the following manner:

- A runaway greenhouse effect arises when the temperature of a planet rises to a level of the boiling point of water. As a result, all the water from the oceans converts into water vapour, which traps more heat coming from the sun and further increases the planet's temperature. This eventually accelerates the greenhouse effect. This is also called the "positive feedback loop".
- There is another scenario giving way to the runaway greenhouse effect. Suppose the temperature rise due to the above causes reaches such a high level that the chemical reactions begin to occur. These chemical reactions drive carbon dioxide from the rocks into the atmosphere. This would heat the surface of the planet which would further accelerate the transfer of carbon dioxide from the rocks to the atmosphere, giving rise to the runaway greenhouse effect.

In simple words, increasing greenhouse effect gives rise to a runaway greenhouse effect which would increase the temperature of the earth to such an extent that no life will exist in the near future.

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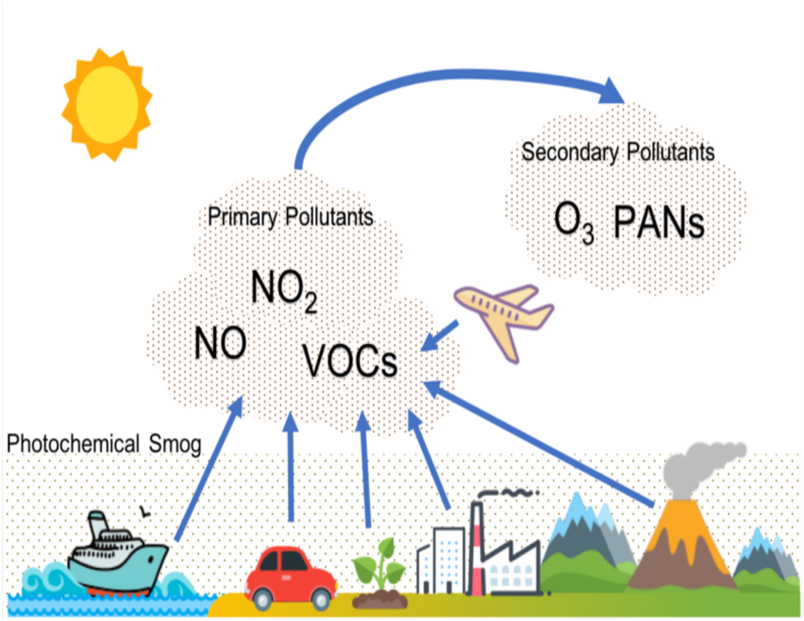
Photochemical smog:

Photochemical smog is a mixture of pollutants that are formed when nitrogen oxides and volatile organic compounds (VOCs) react to sunlight, creating a brown haze above cities. It tends to occur more often in summer, during more sunlight.



Photochenical smog is a major contributor to air pollution. The word "smog" was originally coined as a mixture of "**smoke" and "fog".** This type of air pollution is formed through the reaction of solar radiation with airborne pollutants like nitrogen oxides and volatile organic Compounds.

These compounds, which are called primary pollutants, are often introduced into the atmosphere through automobile emissions and industrial processes. Products like ozone, aldehydes, and peroxyacetyl nitrates are called secondary pollutants. The misture of these primary and secondary pollutant forms photochemical smog. Both primary and secondary pollutants in photochemical smog are highly reactive.

Photochemical smog, which is also known as **"Los Angeles smog,"** occurs most prominently in urban areas that have large numbers of automobiles. It requires neither smoke nor fog. This type of smog has its origin in the nitrogen oxides and hydrocarbon vapours emitted by automobiles and other sources, which then undergo photochemical reactions in the lower atmosphere. The highly toxic gas ozone arises from the reaction of nitrogen oxides with hydrocarbon vapours in the presence of sunlight, and some nitrogen dioxide is produced from the reaction of nitrogen oxide with sunlight.

Effect of smog:

- causes a light brownish coloration of the atmosphere,
- reduced visibility,
- plant damage,
- irritation of the eyes, and respiratory distress.
- Surface-level ozone concentrations are considered unhealthy if they exceed 70 parts per billion for eight hours or longer; such conditions are fairly common in urban areas prone to photochemical smog.

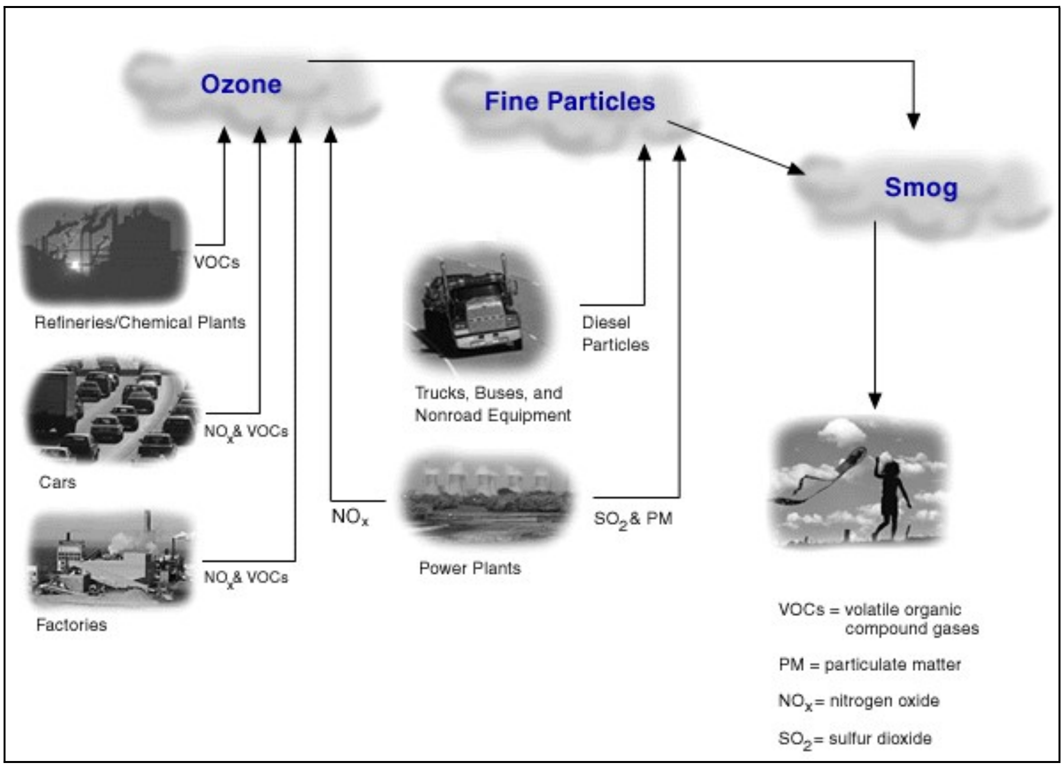


Fig: sources of Smog

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S~~8~~ ; OZONE DEPLETION and El Nino and their impact

OZONE DEPLETION

Ozone layer depletion, is simply the wearing out (reduction) of the amount of ozone in the **stratosphere**. Ozone depletion occurs when destruction of the stratospheric ozone is more than the production of the molecule. The scientists have observed reduction in stratospheric ozone since early 1970s. It is found to be more prominent in Polar Regions.

There are two regions in which the ozone layer has depleted.

In the mid-latitude, for example, over Australia, ozone layer is thinned. This has led to an increase in the UV radiation reaching the earth. It is estimated that about 5-9% thickness of the ozone layer has decreased, increasing the risk of humans to over-exposure to UV radiation owing to outdoor lifestyle.

Since 1928, Chlorofluorocarbons have been produced, originally as nonflammable refrigerants for use in refrigerators, and eventually for use in fire extinguishers, dry cleaning agents, pesticides, degreasers, adhesives, and as propellants for aerosol products.

As these CFCs have been released into the atmosphere, the level of ozone in the stratosphere has decreased.

CFCs have an estimated lifespan of **more than 100 years**

Cause of ozone depletion:

Natural causes of depletion of ozone layer: Ozone layer has been found to be affected by certain natural phenomena such as Sun-spots and stratospheric winds. But this has been found to cause not more than 1-2% depletion of the ozone layer and the effects are also thought to be only temporary. It is also believed that the major volcanic eruptions (mainly El Chichon in 1983 and and Mt. Pinatubo in 1991) has also contributed towards ozone depletion.

Man-made causes of depletion of ozone layer: The main cause for the depletion of ozone is determined as excessive release of chlorine and bromine from man-made compounds such as chlorofluorocarbons (CFCs). CFCs (chlorofluorocarbons), halons, CH_3CCl_3 (Methyl chloroform), CCl_4(Carbon tetrachloride), HCFCs (hydro-chlorofluorocarbons), hydrobromofluorocarbons and methyl bromide are found to have direct impact on the depletion of the ozone layer. These are categorized as ozone-depleting substances (ODS). Chlorofluorocarbons are released into the atmosphere due to:

- Cleaning Agents
- Coolants in refrigerators
- Packing material
- Air conditioning
- Aerosol spray cans etc.

The problem with the Ozone-Depleting Substances (ODS) is that they are not washed back in the form of rain on the earth and in-fact remain in the atmosphere for quite a long time. With so much stability, they are transported into the stratosphere. The emission of ODS account for roughly 90% of total depletion of ozone layer in stratosphere. These gases are carried to the stratosphere layer of atmosphere where ultraviolet radiations from the sun break them to release chlorine (from CFCs) and bromine (from methyl bromide and halons). The chlorine and bromine free radicals react with ozone molecule and destroy their molecular structure, thus depleting the ozone layer. One chlorine atom can break more than 1, 00,000 molecules of ozone. Bromine atom is believed to be 40 times more destructive than chlorine molecules. The chlorine becomes actively involved in the process of destruction of ozone. The net result is that two molecules of ozone are replaced by three of molecular oxygen, leaving the chlorine free to repeat the process:

$$Cl + O_3 \rightarrow ClO + O_2$$

$$ClO + O \rightarrow Cl + O_2$$

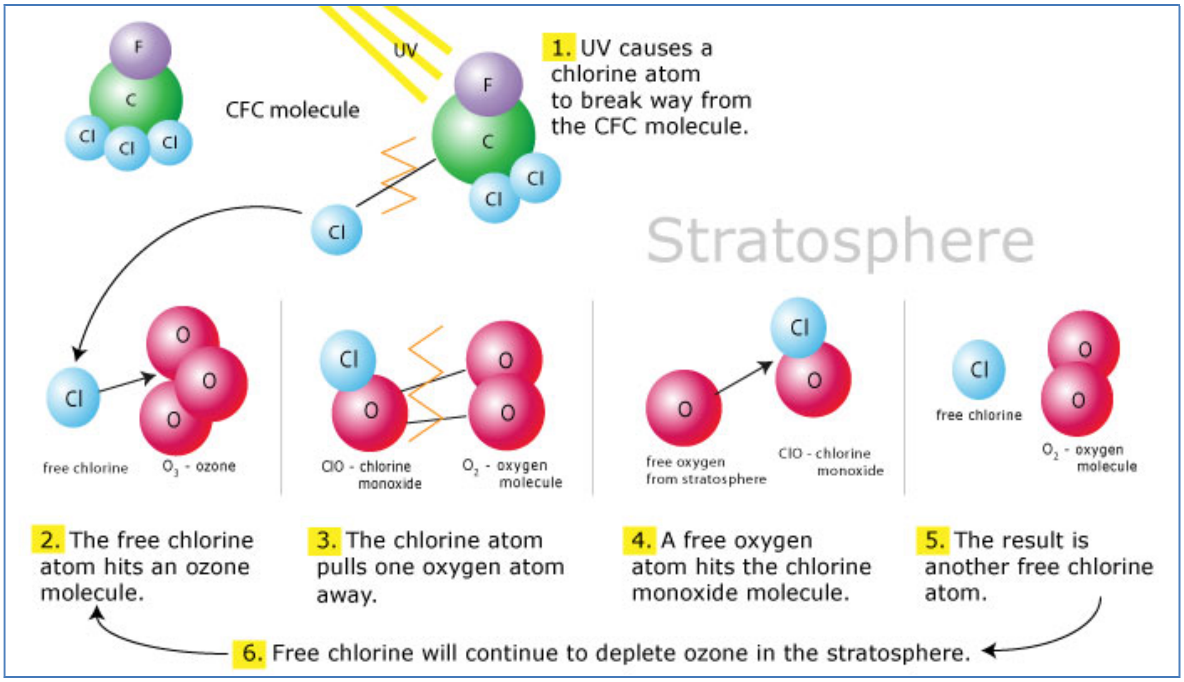

Fig: Ozone depletion by CFCs

Main Ozone Depleting Substances (OCD)

- **Chlorofluorocarbons:** Account for more than 80% of ozone depletion. Used in freezers, air cooling component, dry-cleaning agents, hospital sterilants.
- **Methyl Chloroform:** Used for vapour degreasing, some aerosols, cold cleaning, adhesives and chemical processing.
- **Hydro chlorofluoro carbons:** Substitutes for CFC's but still play a vital role in ozone depletion.
- **Halons**
- **Carbon Tetrachloride:** Mainly used in fire extinguishers

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El Nino and their impact

El Niño and La Niña events are a natural part of the global climate system. They occur when the Pacific Ocean and the atmosphere above it change from their neutral ('normal') state for several seasons.

El Niño events are associated with a warming of the central and eastern tropical Pacific, while La Niña events are the reverse, with a sustained cooling of these same areas.

Impacts of global warming

1) **Rising Seas**--- inundation of fresh water marshlands (the everglades), low-lying cities, and islands with seawater.
2) **Changes in rainfall patterns** --- droughts and fires in some areas, flooding in other areas. See the section above on the recent droughts, for example!
3) **Increased likelihood of extreme events**--- such as flooding, hurricanes, etc.
4) **Melting of the ice caps** --- loss of habitat near the poles. Polar bears are now thought to be greatly endangered by the shortening of their feeding season due to dwindling ice packs.
5) **Melting glaciers** - significant melting of old glaciers is already observed.
6) **Widespread vanishing of animal populations** --- following widespread habitat loss.
7) **Spread of disease** --- migration of diseases such as malaria to new, now warmer, regions.
8) **Bleaching of Coral Reefs due to warming seas and acidification due to carbonic acid formation** --- *One third* of coral reefs now appear to have been severely damaged by warming seas.
9) **Loss of Plankton due to warming seas** --- The enormous (900 mile long) Aleution island ecosystems of orcas (killer whales), sea lions, sea otters, sea urchins, kelp beds, and fish populations, appears to have collapsed due to loss of plankton, leading to loss of sea lions, leading orcas to eat too many sea otters, leading to urchin explosions, leading to loss of kelp beds and their associated fish populations.

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