Climate change and its implications

Dr. Raji P

Lecture-1

Course outline: 2 credit

- Introduction to climate & climate change
- Evidence of climate change
- Global climate models & future climate projections
- Implications to
  : Biodiversity, mitigation practices
  : Agriculture, mitigation practices
  : Water resources, mitigation practices

QGIS-Quantum GIS

https://qgis.org/en/site/

Class outline: Introduction

Characteristics of Earth's atmosphere

- Optical properties
- Mass
- Composition
- Vertical structure: temperature, general circulations

Optical properties

- Earth's atmosphere is transparent to incoming solar radiation
- The outgoing radiation emitted by Earth is absorbed by the atmosphere (green house effect), and this makes the Earth's atmosphere warm
- The blue colour: preferential scattering of short wave rad by air molecules
- White colour: scattering from cloud and aerosols (particles)
- About 22% of incoming solar rad is backscattered to space without absorption

Mass of the atmosphere

- At any point on the earth's surface, the atmosphere exerts a downward force on the underlying surface due to earth's gravitational attraction.
- The downward force (i.e., the weight) of a unit volume of air with density ρ is given by,

  $F = \rho g$

  Where g is the acceleration due to gravity.
- Integrating the equ from earth's surface to the top of the atmosphere, we obtain the atmospheric pressure on the earth's surface (Ps) due to the weight (per unit area) of the air in the overlying column.

  i.e., $Ps = \int_0^{\infty} \rho g \, dz$
- Neglect the small variation of g with lat, long, and height, we can take the mean value g, which is equal to 9.807 m^2/s, we can take it outside the integral.

Then Ps= g $\int_0^\infty \rho \, dz$,

which is again equal to = g m

where m is the vertically integrated **mass per unit area of the overlying air**

Exercise 1

- The globally averaged surface pressure is 985 hPa. Estimate the mass of the atmosphere.

Earth's radius=6.37×10^6 m

Ps = mg

$M=Ps/g=985 \times 100/9.807=1.004 \times 10^4$ kg/m2

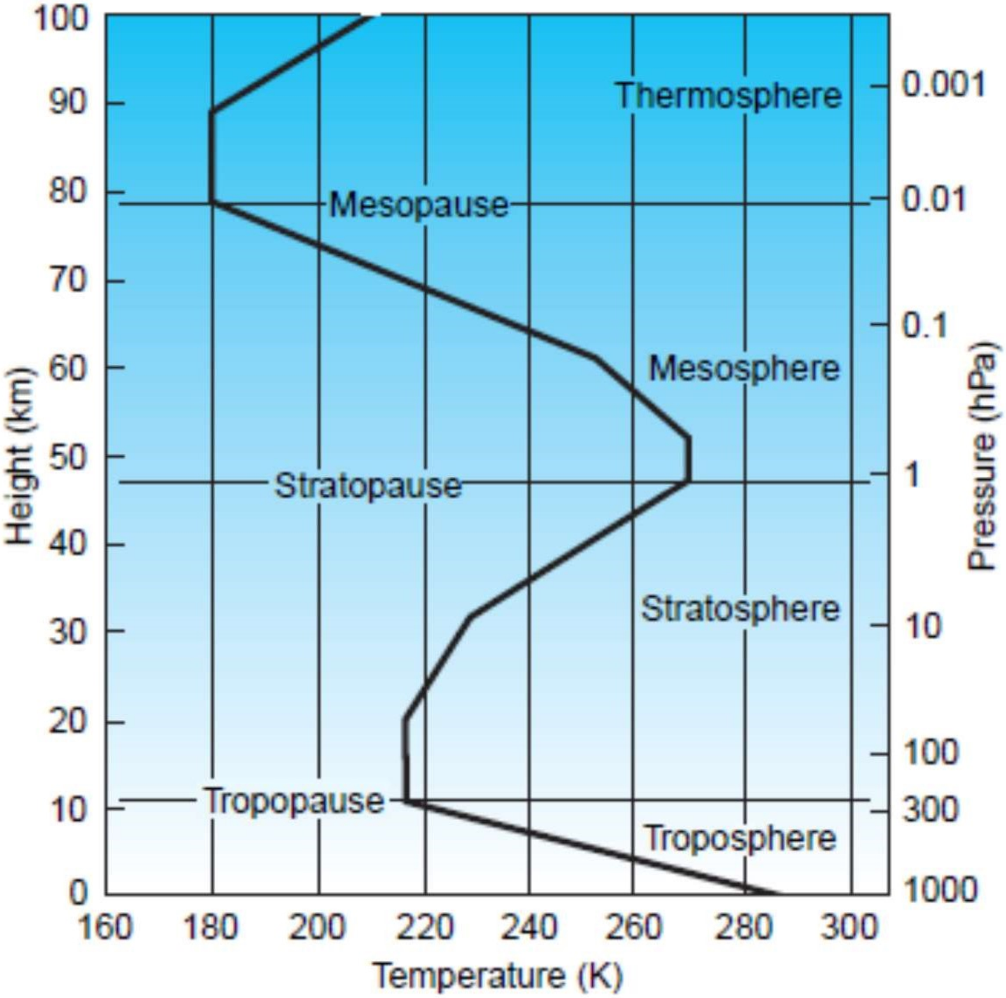
Chemical composition

Constituent[a]	Molecular weight	Fractional concentration by volume
Nitrogen (N_2)	28.013	78.08%
Oxygen (O_2)	32.000	20.95%
Argon (Ar)	39.95	0.93%
Water vapor (H_2O)	18.02	0–5%
Carbon dioxide (CO_2)	44.01	380 ppm
Neon (Ne)	20.18	18 ppm
Helium (He)	4.00	5 ppm
Methane (CH_4)	16.04	1.75 ppm
Krypton (Kr)	83.80	1 ppm
Hydrogen (H_2)	2.02	0.5 ppm
Nitrous oxide (N_2O)	56.03	0.3 ppm
Ozone (O_3)	48.00	0–0.1 ppm

- Water vapour accounts for 0.25% of the mass of the atmosphere
- Exposure to ozone concentration>0.1 ppmv is considered hazardous to human health
- Gas molecules with certain structures are highly effective in trapping outgoing radiation and are called green house gases

eg. CH4, N_2O, CO, and chloroflurocarbons (CFCs) – enter into the atmosphere via burning of plant matter, fossil fuels, emission from plants, decay of plants and animals etc.

Vertical structure



- Tropo-(turning or changing/vertical mixing) -sphere
- Temperature decreases with height (~6.5˚C)
- Troposheric air accounts for the 80% of the mass of the atmosphere

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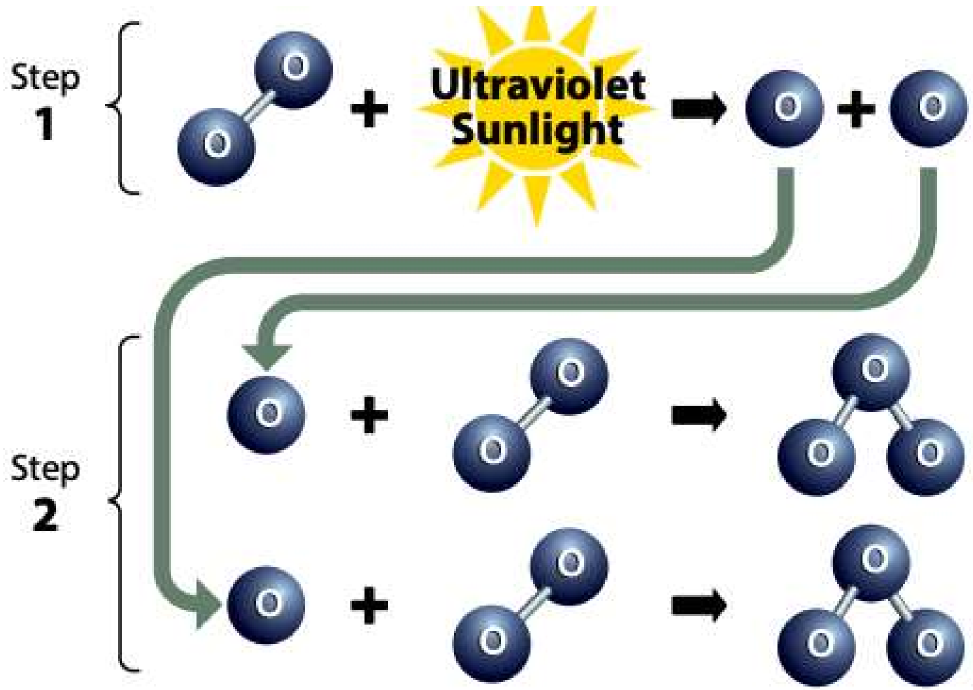
- Strato-(layered)-sphere, vertical mixing is prohibited due to the increase of temp with height
- Residence time of particles are longer
- Air is extremely dry and ozone rich
- They absorb the UV from the spectrum
- This increases the temperature

- Meso-(inbetween)-sphere: temperature decreases with height

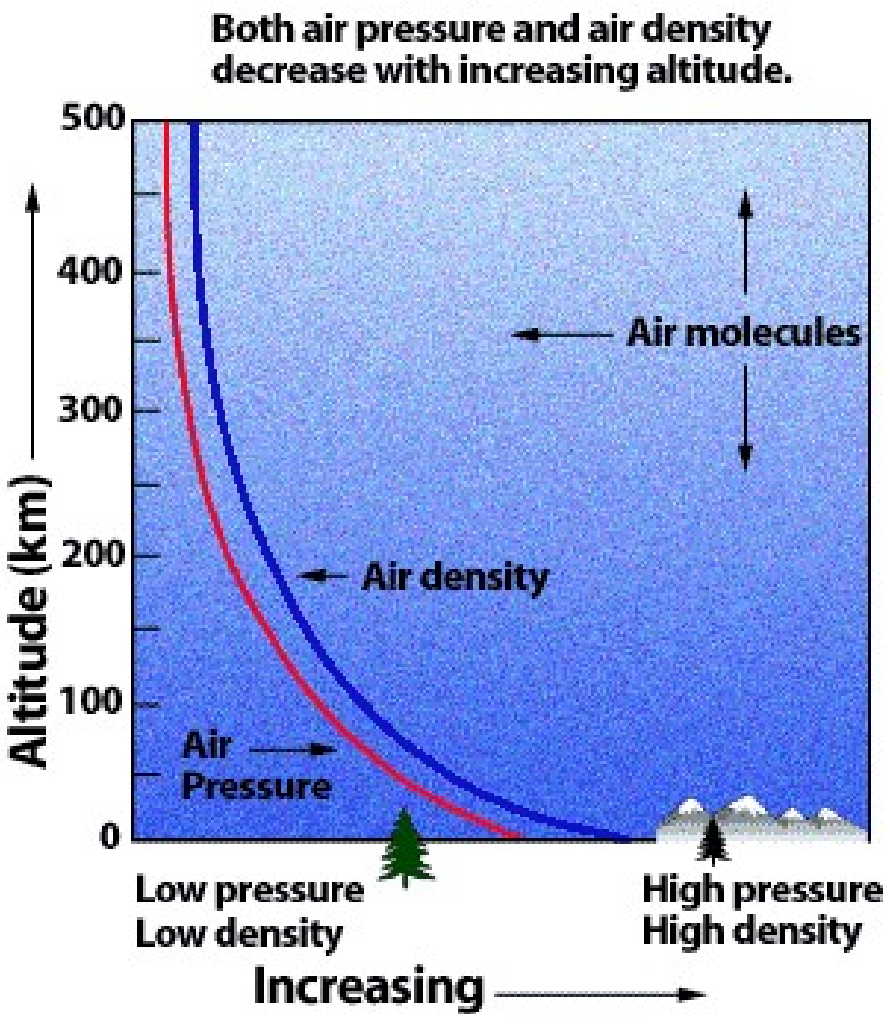
- Thermosphere-temp increases with height due to the absorption of solar rad, and lots of ionization processes occurs

Anvil cloud (Cloud flattening) at the tropopause

- All the weather and climate activities are under the tropopause



Ozone formation in stratosphere



Density of air @ sea level is 1.25 kg/m^3

Pressure at any height:

$$\boxed{p \simeq p_0 e^{-z/H}}$$

P_0 is the pressure @ sea level (reference level)

H- scale height; e-folding depth (height at which pressure becomes 1/e times p_0), 7 to 8 Km

$$\boxed{\ln \frac{p}{p_0} \simeq -\frac{z}{H}}$$

$$\boxed{z = H \ln(p_0/p)}$$

Exercise 2

- At approximately what height above sea level does half the mass of the atmosphere lie above and other half lie below?

Assume an exponential pressure dependence with H=8 km.

Exercise 3

- Assuming an exponential pressure and density dependence with H=7.5 km, estimate the heights in the atmosphere at which (a) the air density is equal to 1 kg/m^3 and (b) the height at which the pressure is equal to 1 hPa.

Climate change and its implications

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Lecture-2

1st lecture:

- Optical properties of Earth's atmosphere
- Mass of Earth's atmosphere
- Vertical structure of the atmosphere: troposphere, stratosphere, mesosphere, thermosphere
- Temperature, pressure, density variations in the atmosphere

Class outline: Introduction (Conti…)

Earth system - components that play a role in climate

- Oceans
- Cryosphere
- Biosphere
- Earth's crust and mantle

Components of Earth System

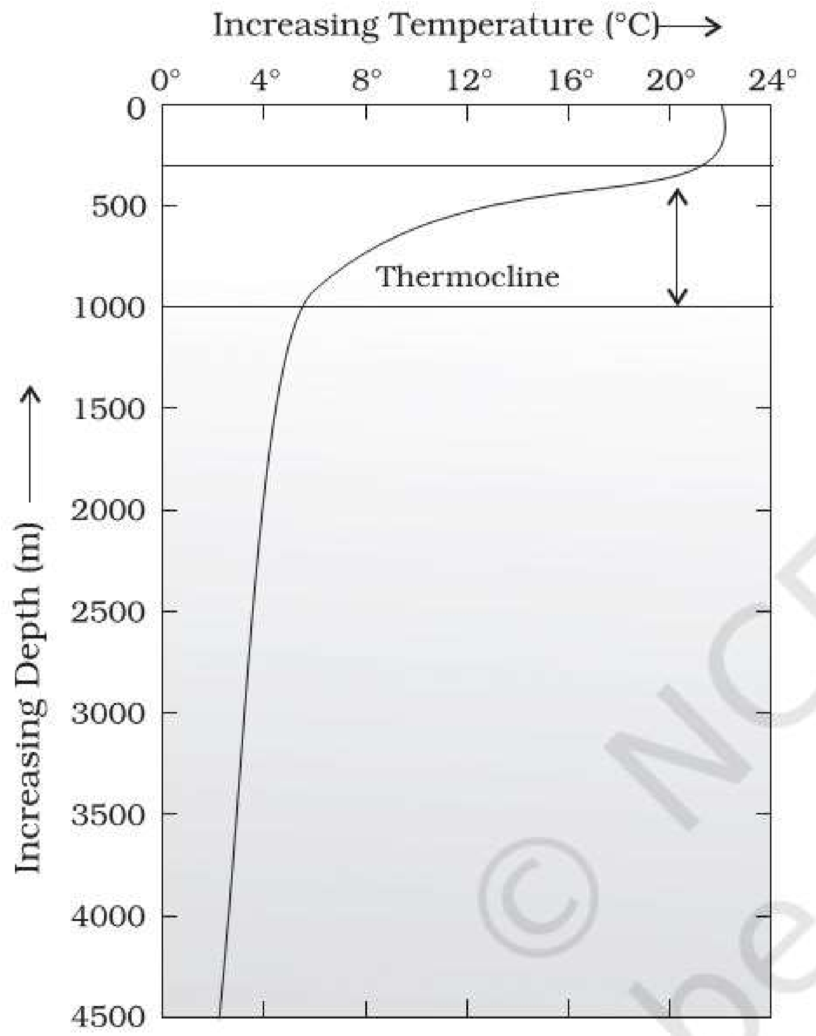
- Climate depends on atmosphere as well as physical, chemical, and biological processes involving other components of earth system.

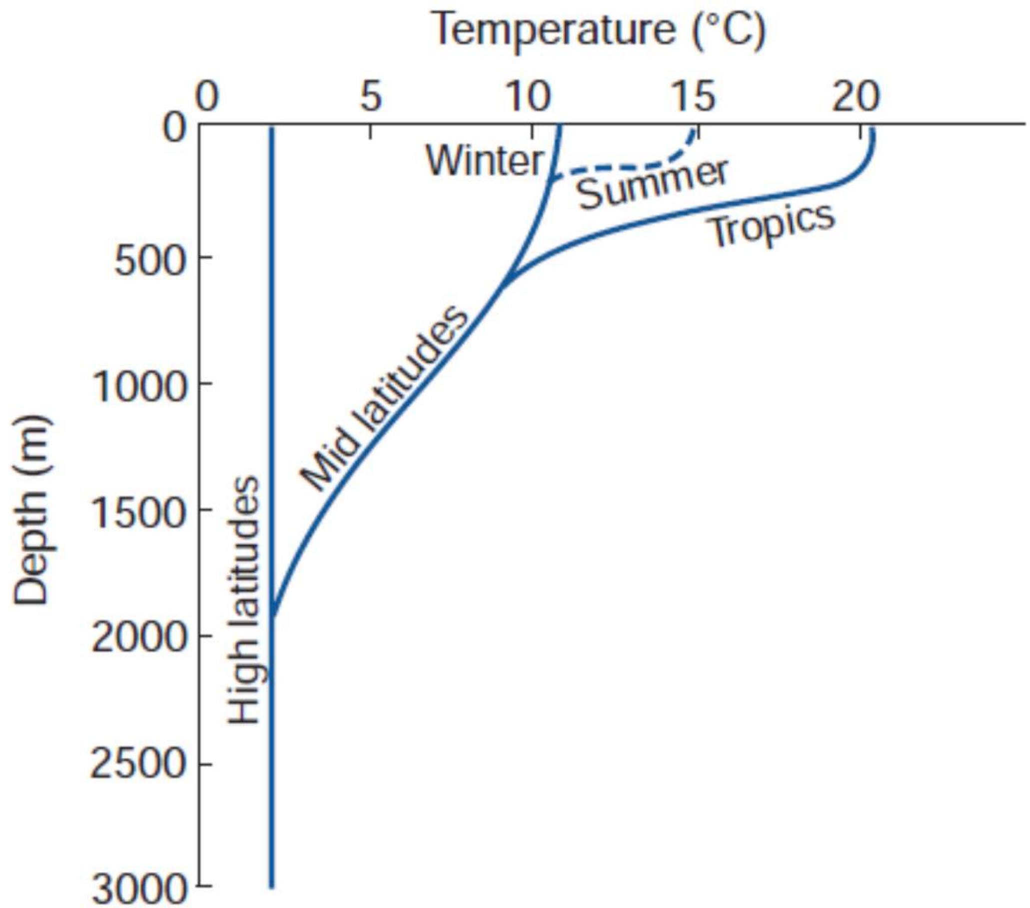
1. **The Oceans**

- Oceans cover 72% of the area of the earth's surface
- Reaches to an extreme depth of 11 km
- Mass of the ocean is approx. 250 times as that of atmosphere

Composition and vertical structure of ocean:

- Density of sea water linearly proportional to the concentration of dissolved salt
- Sea water contains salt ~34 -36 g/kg of fresh water
- Sea water is ~ 2.4% denser than fresh water @ same temperature


Increasing Temperature (°C)
0° 4° 8° 12° 16° 20° 24°
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Thermocline
Increasing Depth (m)


Temperature (°C)
0
5
10
15
20
0
500
1000
1500
2000
2500
3000
Depth (m)
Winter
Summer
Tropics
Mid latitudes
High latitudes

- The density of sea water ranges from 1.02 to 1.03 kg/m^3

- Density of water in the wind-stirred layer (mixed layer) is smaller by a few tenths of a percent than density of water below it

- Thermocline: Layer in which there is a strong temperature gradient exist with respect to depth

- Precipitation lowers the salinity by diluting the salts that are present in the oceanic mixed layer

- But evaporation increases the salinity by removing fresh water and thereby concentrating the residual salts

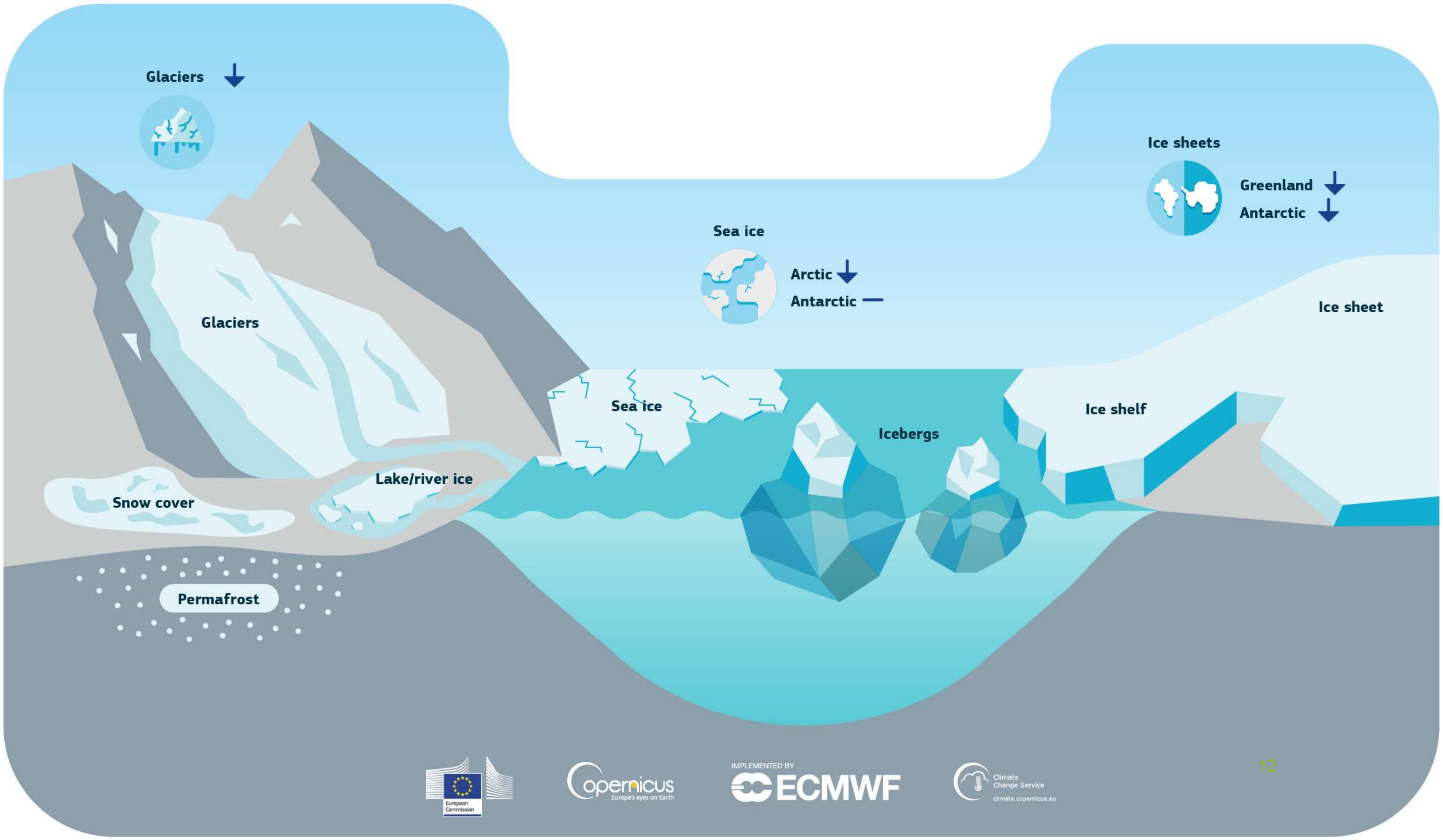
Exercise-1

- A heavy tropical storm dumps 20 cm of rainfall in a region of the ocean in which the salinity is 35 g kg-1 and the mixed layer depth is 50 m. Assuming that the water is well mixed, by how much does the salinity decrease?

Ocean circulation

- The ocean circulation is composed of a wind-driven component and a thermohaline (density-dependent) component
- The wind driven circulation dominates the surface currents, and it is restricted to the topmost few hundred meters
- The circulation deeper in the oceans is dominated by the slower thermohaline circulation
- Velocities in wind driven currents are on the order of 10 cm/s
- The timescale in which a parcel completes a circuit of this thermohaline circulation is on the order of hundreds of years

2. Cryosphere



- Cryo (frozen)-sphere refers to the components of the earth system comprised of water in its solid state
- Taking up and releasing fresh water in the polar regions and influences oceanic thermohaline circulation
- It stores enough water to significantly influence global sea level
- The continental ice sheets dominated by Antartica and Greenland are the most massive elements of the cryosphere
- Ice sheets are replenished by snowfall

Cryospheric component	Area	Mass
Antarctic ice sheet	2.7	53
Greenland ice sheet	0.35	5
Alpine glaciers	0.1	0.2
Arctic sea ice (March)	3	0.04
Antarctic sea ice (September)	4	0.04
Seasonal snow cover	9	<0.01
Permafrost	5	1

Area is expressed in percentage (%) of the area of the surface of Earth; Mass is expressed in 10^3 kg/m^2

Total surface area of Earth (m^2)=5.12×10^{14}

Land area (m^2)=1.45×10^{14}

- Permafrost is any ground that remains completely frozen (0°C) or colder—for at least two years straight
- These permanently frozen grounds are most common in regions with high mountains and in Earth's higher latitudes—near the North and South Poles

Exercise-2

- Based on data provided in the table (please see slide 14), estimate how much the sea level would rise if the entire Greenland ice sheet were to melt

Mass of the Greenland ice sheet=0.0035xEarth's area x (mass of Greenland ice sheet/m^2)

(Greenland ice area is 0.35% of the surface area of the Earth, please see the Table in slide No.14)

Earth's area =$4\pi R^2$, (substitute Earth's radius)

If the ice sheet melts, it would be distributed uniformly over the ocean-covered area;

Let rise in sea level be X,

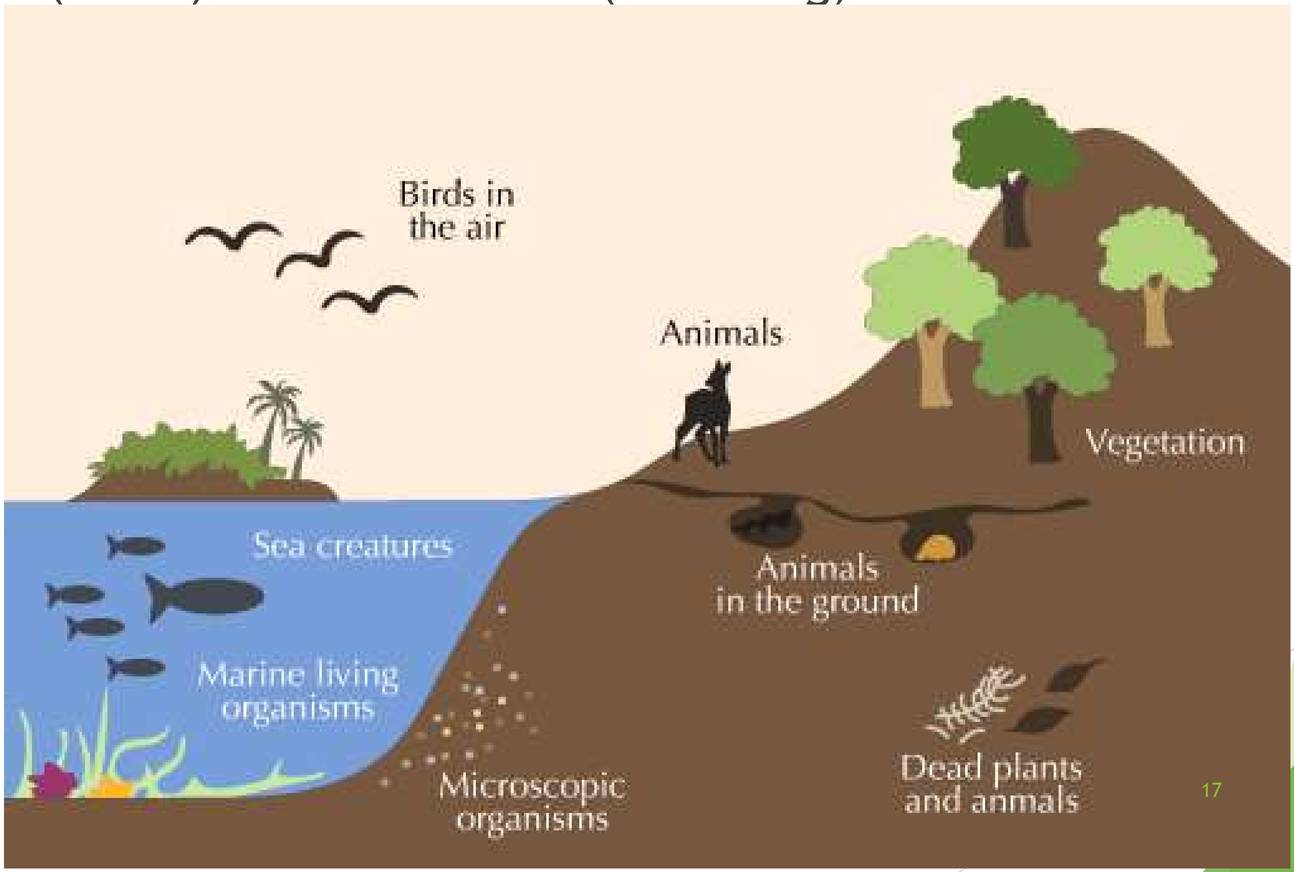
Then, the mass of the Greenland ice sheet=area of ocean x density of water x (X)

Substitute the given values in this equation, and find out the value of X

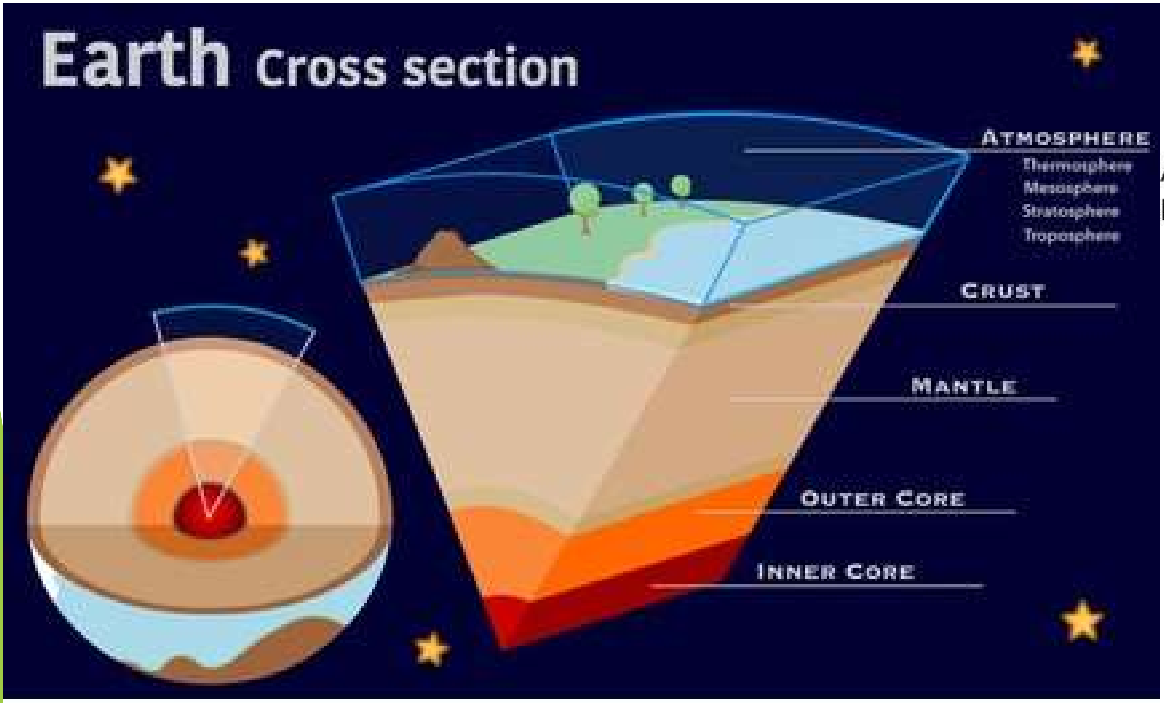
(Area of ocean surface=$(5.10-1.45)\times10^{14}$ m^2

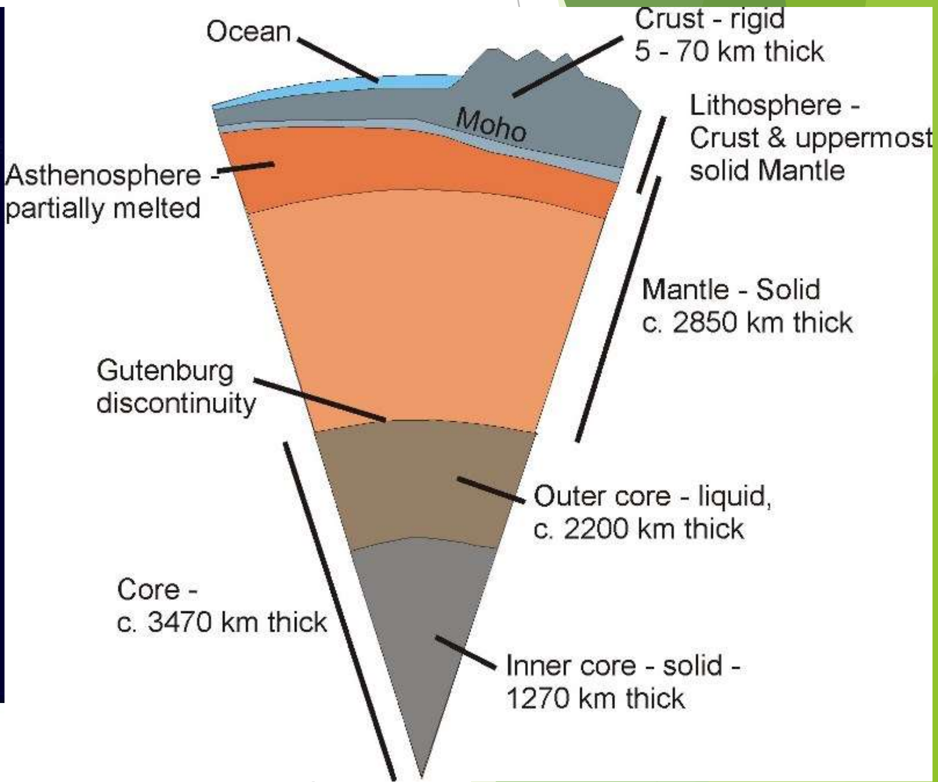
3. **Biosphere**

- The biosphere is a global ecosystem composed of living organisms (biota) and the abiotic (nonliving) factors



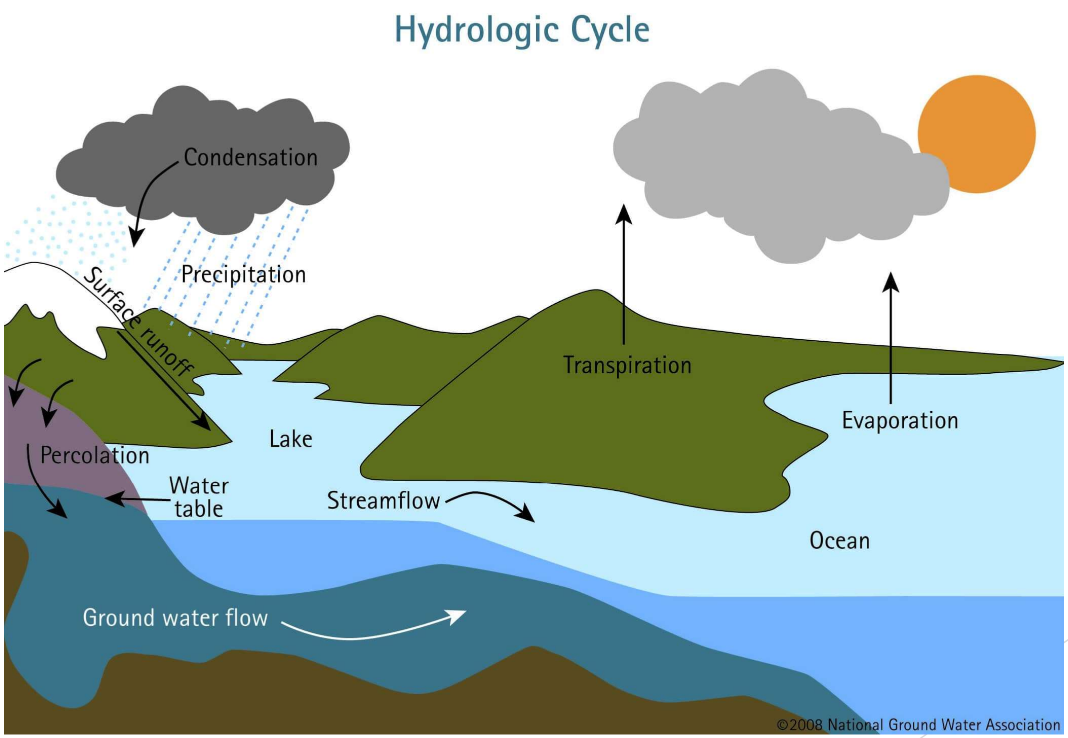
4. Earth's crust and mantle





Hydrologic cycle –water cycle

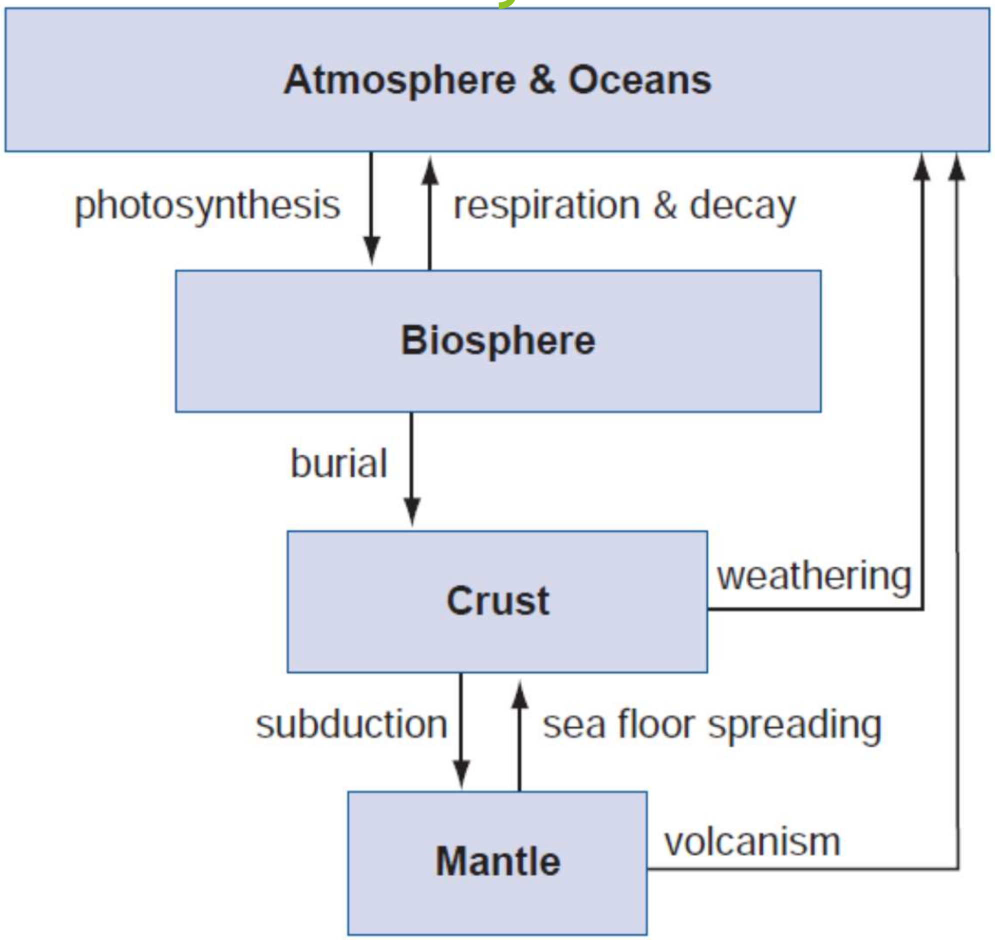
- Life on Earth is dependent on the cycling of water back and forth among various reservoirs in the Earth system, and are hydrosphere



Reservoirs of water	Mass	Residence time
Atmosphere	0.01	Days
Fresh water (lakes and rivers)	0.6	Days to years
Fresh water (underground)	15	Up to hundreds of years
Alpine glaciers	0.2	Up to hundreds of years[a]
Greenland ice sheet	5	10,000 years[b]
Antarctic ice sheet	53	100,000 years
Oceans	2,700	
Crust and mantle	20,000	10^{11} years

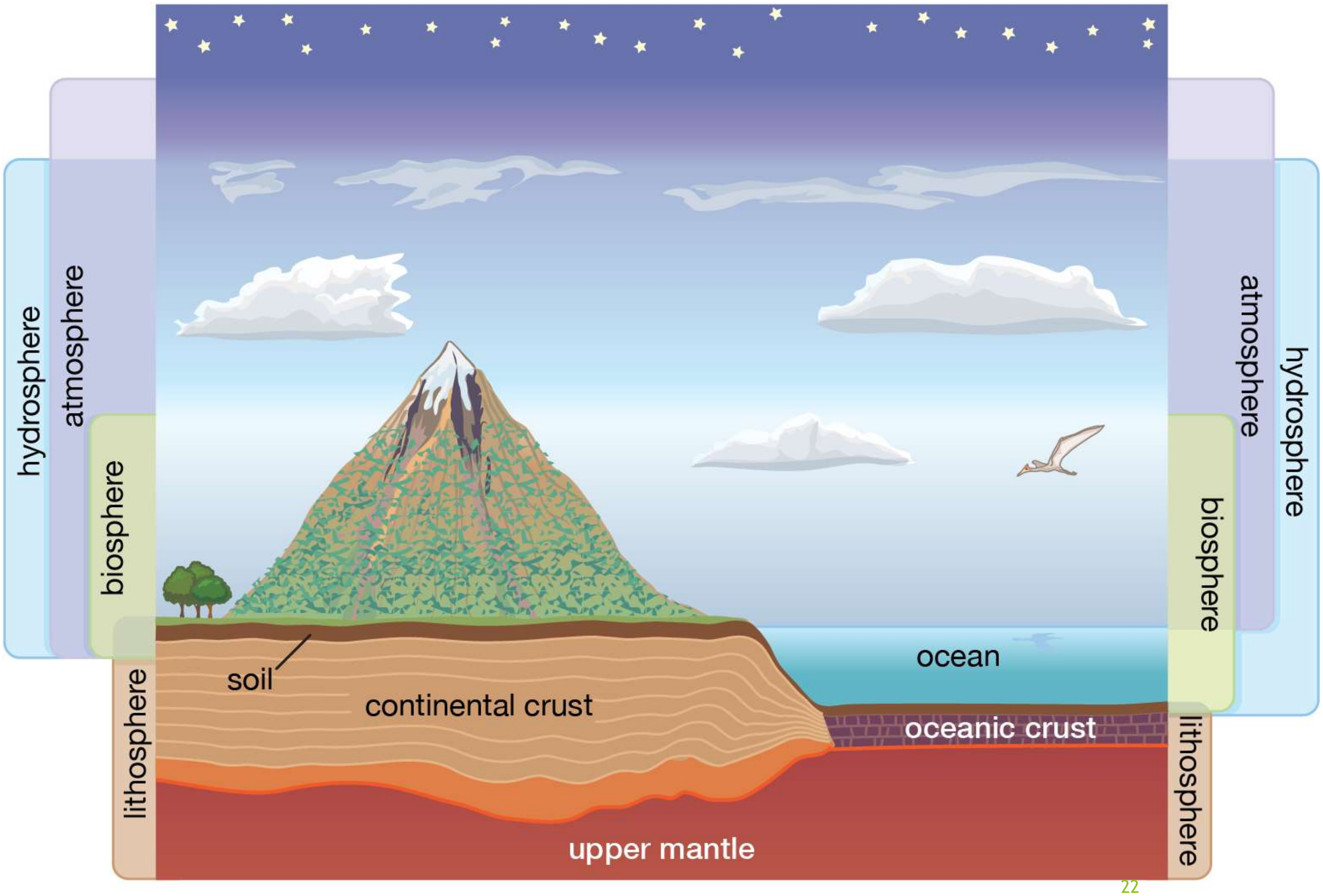
Mass in 10^3 kg/m^2

Carbon cycle



- Carbon cycle is important because it regulates two important green house gases CO_2 and CH_4

Earth's environmental sphere



Climate Change And Its Implications (CCI)

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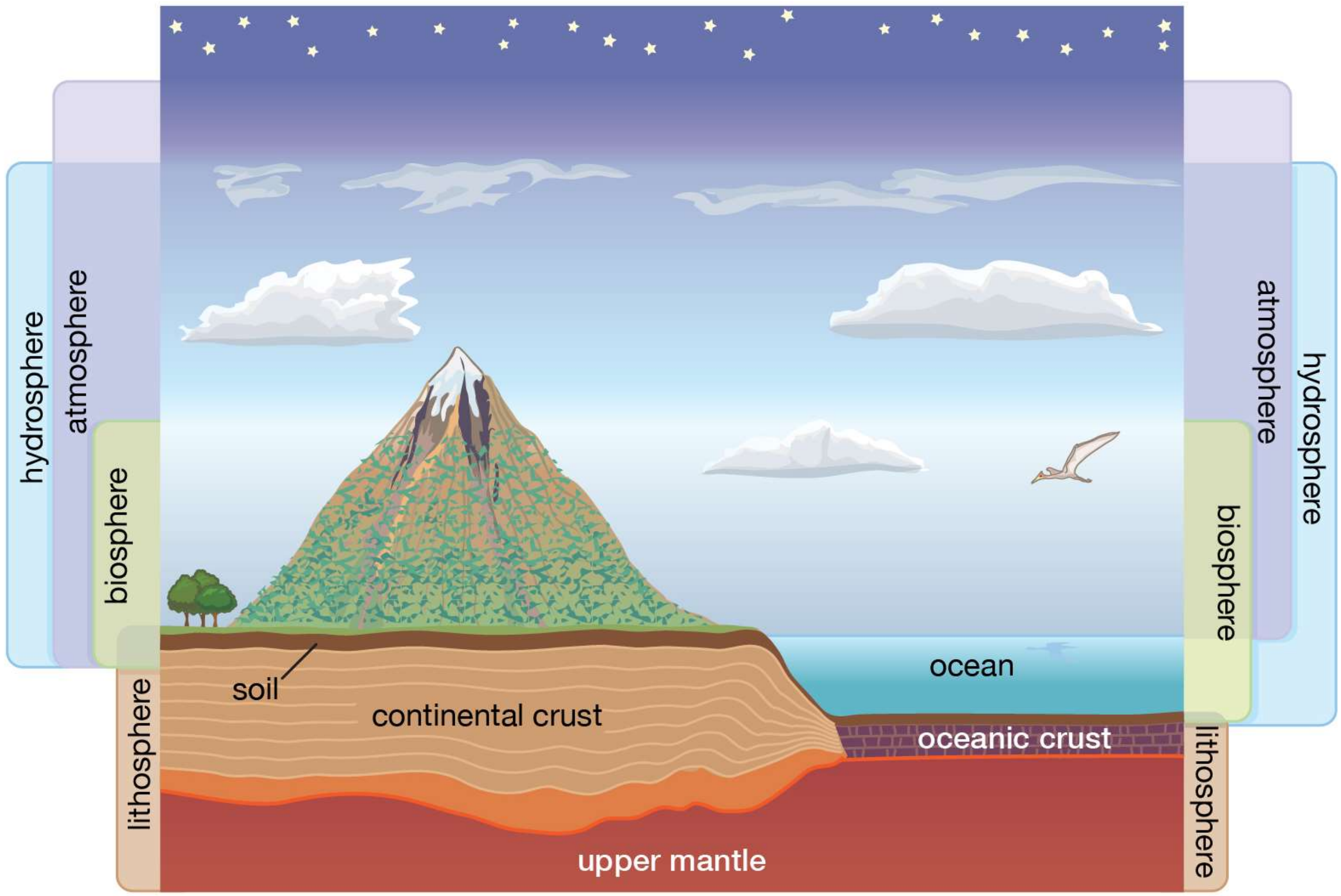
Lecture-3

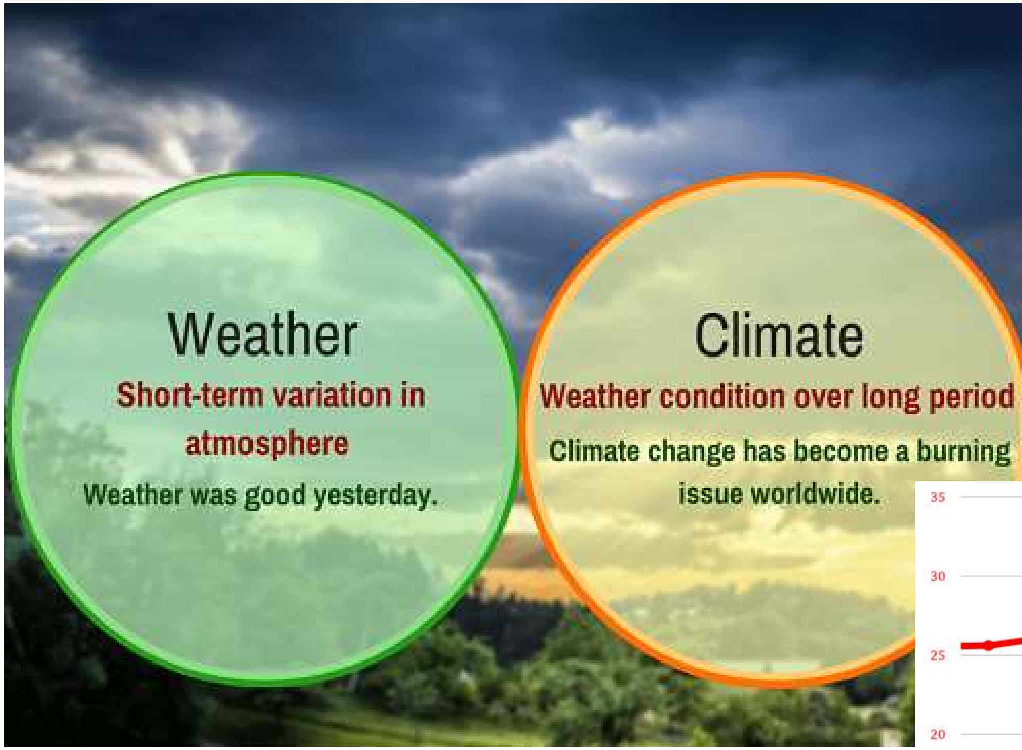
Lecture-1&2

- Earth's atmosphere
- Oceans
- Cryosphere
- Biosphere



Class outline

- Introduction to weather & climate
- Weather parameters
- Measurements and analysis of weather parameters -interpretation


Weather
Short-term variation in atmosphere
Weather was good yesterday.
Climate
Weather condition over long period
Climate change has become a burning issue worldwide.


28
29
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26
11 am
2 pm
5 pm
8 pm
11 pm
2 am
5 am
8 am
Wed
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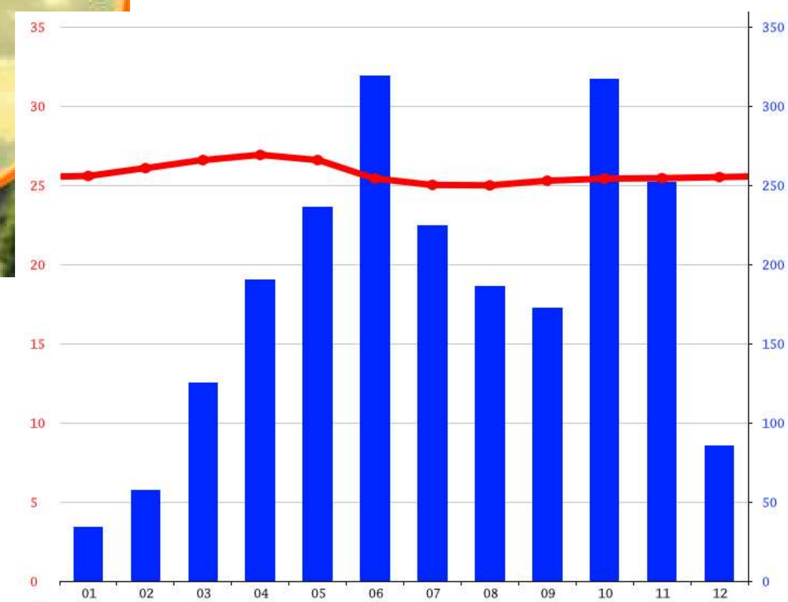
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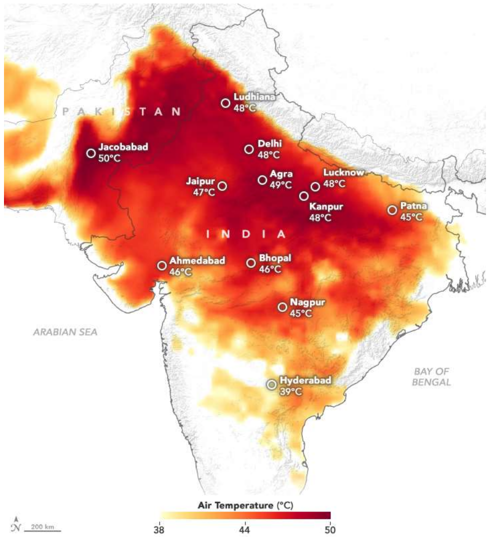
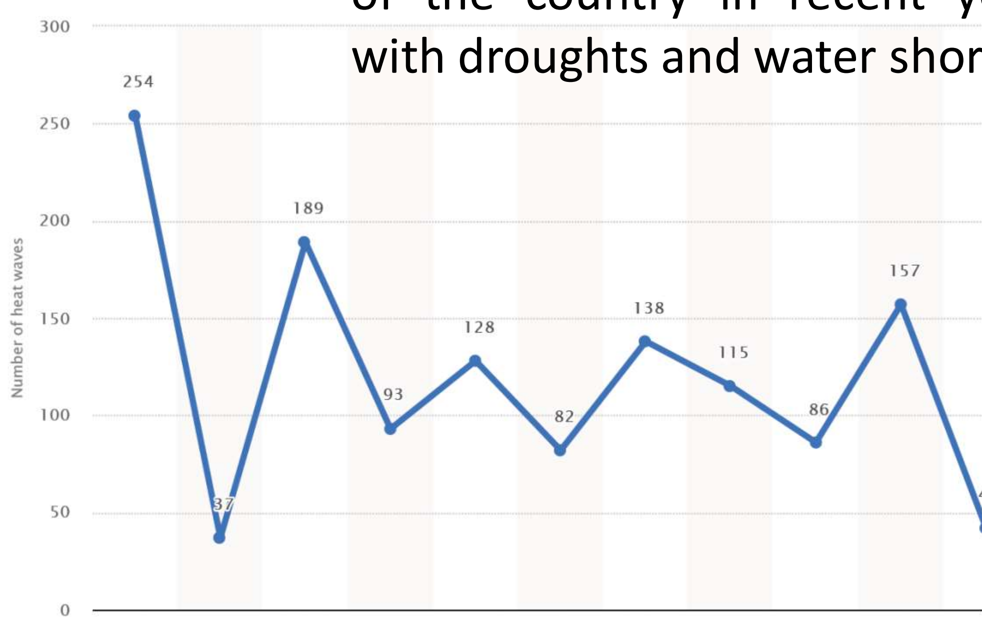
12

Where do we use weather information?

Heat waves

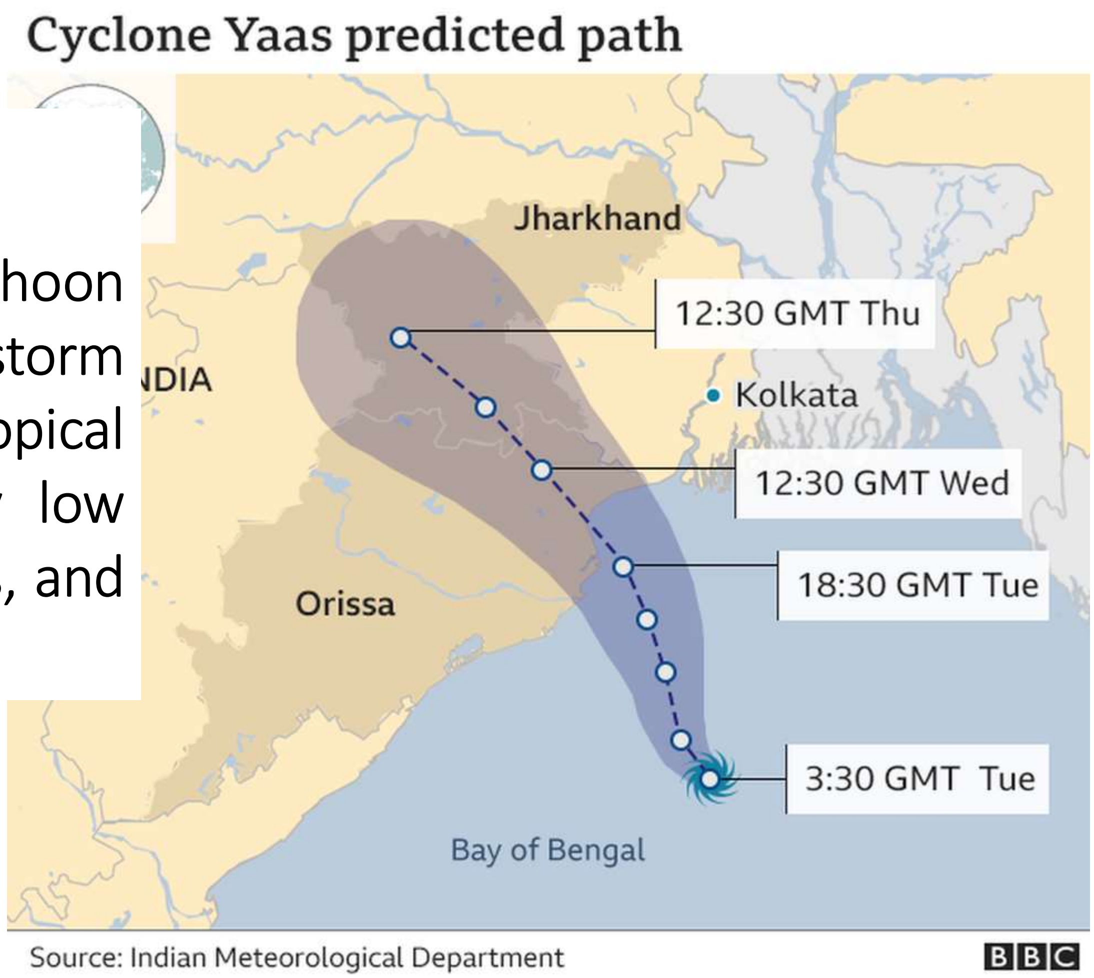


- Heat wave is considered if maximum temperature of a station reaches at least 40^0C or more for Plains and at least 30^0C or more for Hilly regions.
- About 42 heat wave days are reported in India in 2020
- These are more intense in northern regions of the country in recent years, coinciding with droughts and water shortage



Tropical cyclones

- Tropical cyclone, also called typhoon or hurricane, an intense circular storm that originates over warm tropical oceans and is characterized by low atmospheric pressure, high winds, and heavy rain



Extreme rainfall

Tornadoes

- A tornado is a narrow, violently rotating column of air that extends from a thunderstorm to the ground


USAF
DELTA

Weather & Climate

- Weather is the state of the atmosphere experienced at a given time
- It is defined by variables such as temperature, wind, rainfall, pressure, and other dynamical variables -Meteorology
- Climate is the averages of weather elements obtained from their time series for a location or any region
- Climate refers to the monthly, seasonal or annual mean distributions of temperature, rainfall or any other weather parameter
- Climate could refer to the probability of occurrence of event
- Any change in the incoming and outgoing radiations would affect its climate

Weather Parameters

Temperature

- Maximum and minimum temperatures (most important for agriculture)
- Average temperature
- Diurnal temperature

Measurements: Thermometers

Stevenson's screen

Satellite measurements

- Satellite measures the atmosphere in radiance (W/m^2), and then using mathematical and statistical equations, temperature is derived from this

INSAT-3D is a meteorological, data relay and satellite aided search and rescue satellite developed by the Indian Space Research Organisation (in 2013)

Precipitation


Hail


Sleet


Rain


Glaze

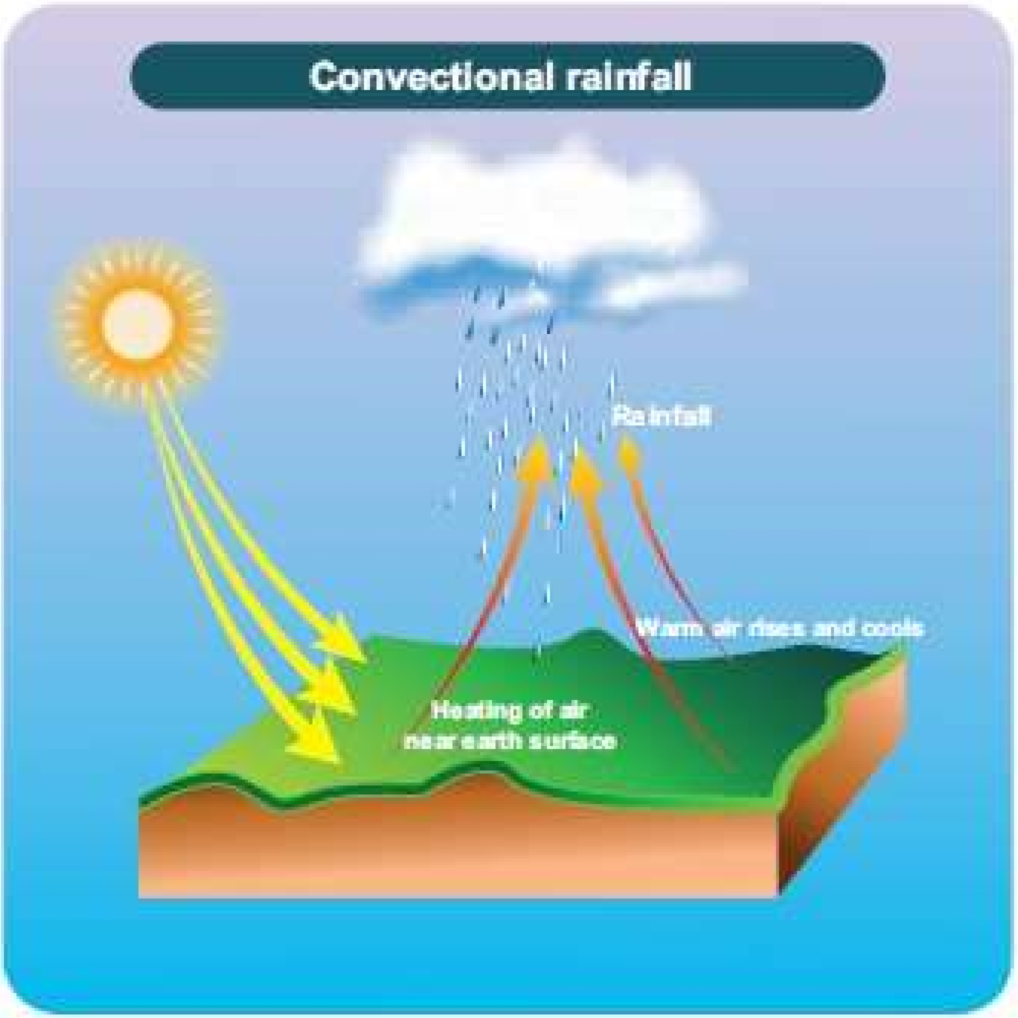

Snow

Forms of precipitation

- Rain – It is the main form of precipitation with water drop size >0.5 mm
- Snow – Ice crystals, which combines to form flakes
- Drizzle-Fine sprinkle of numerous water droplets of size <0.5 mm
- Glaze- when rain or drizzle comes in contact with cold ground at 0°C, the water drops freeze to form an ice coating called freezing rain
- Sleet – frozen raindrops forms when rain falls through air at subfreezing temperature
- Hail – precipitation in the form of ice crystals of size >8 mm

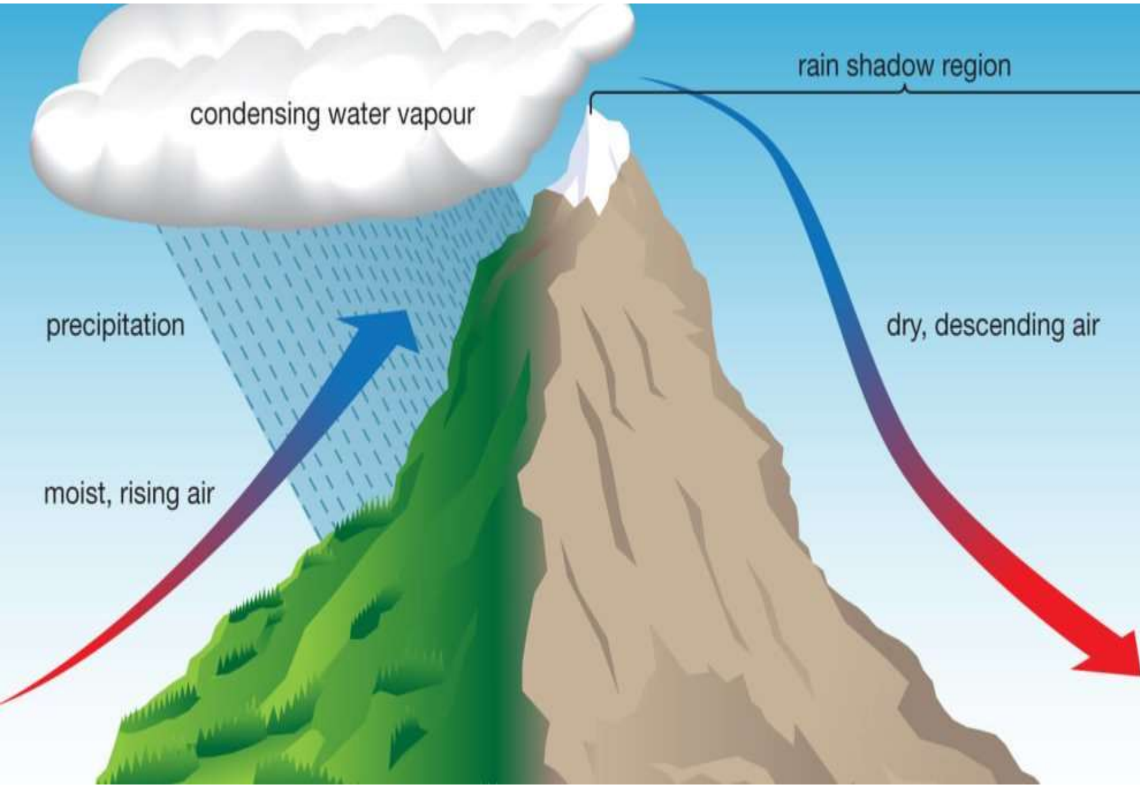
Weather systems for precipitation

Convective precipitation



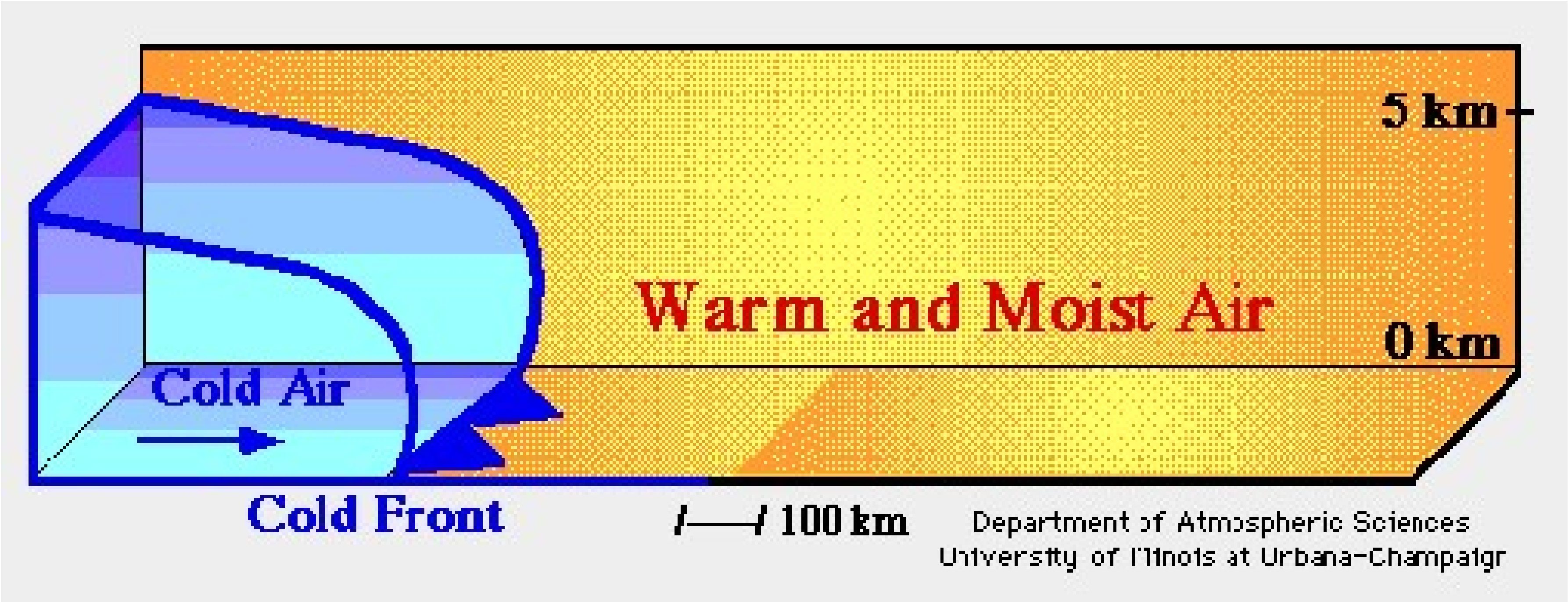
- On a hot day the ground surface becomes heated, as does the air in contact with it
- This causes the air to rise, expand, and cool dynamically, causing condensation and precipitation

Orographic precipitation



- Lifting an air mass occurs when air flows up and over a topographic feature such as a mountain barrier
- Orographic barriers often supply the lift to set off precipitation
- For this reason, precipitation is heavier on windward slopes, with rain shadows (areas of lighter precipitation) on leeward slopes
- Orographic precipitation is associated with low intensity with relatively long durations

Precipitation along cold front: A cold front is defined as the transition zone where a cold air mass is replacing a warmer air mass



Characteristics of precipitation in India

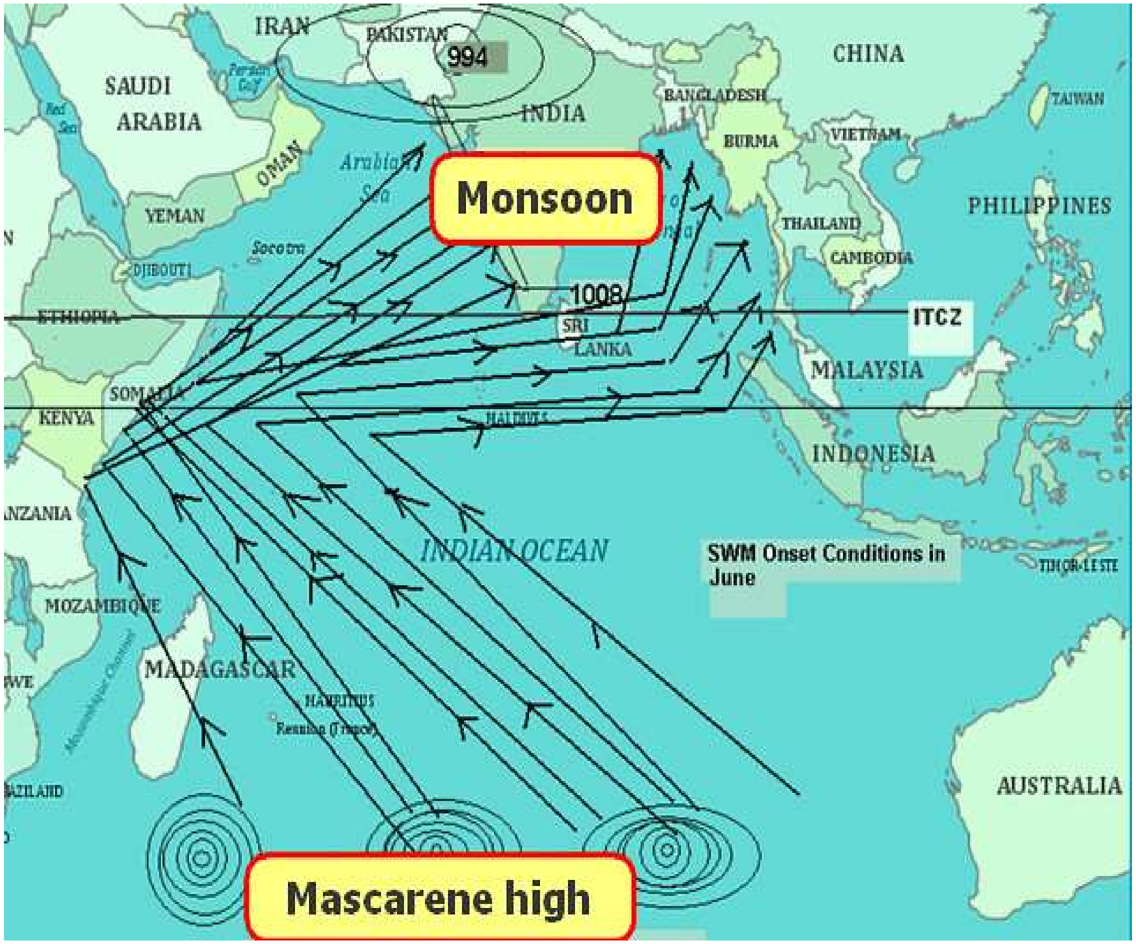
1) **<u>South-West Monsoon (June-September)</u>**

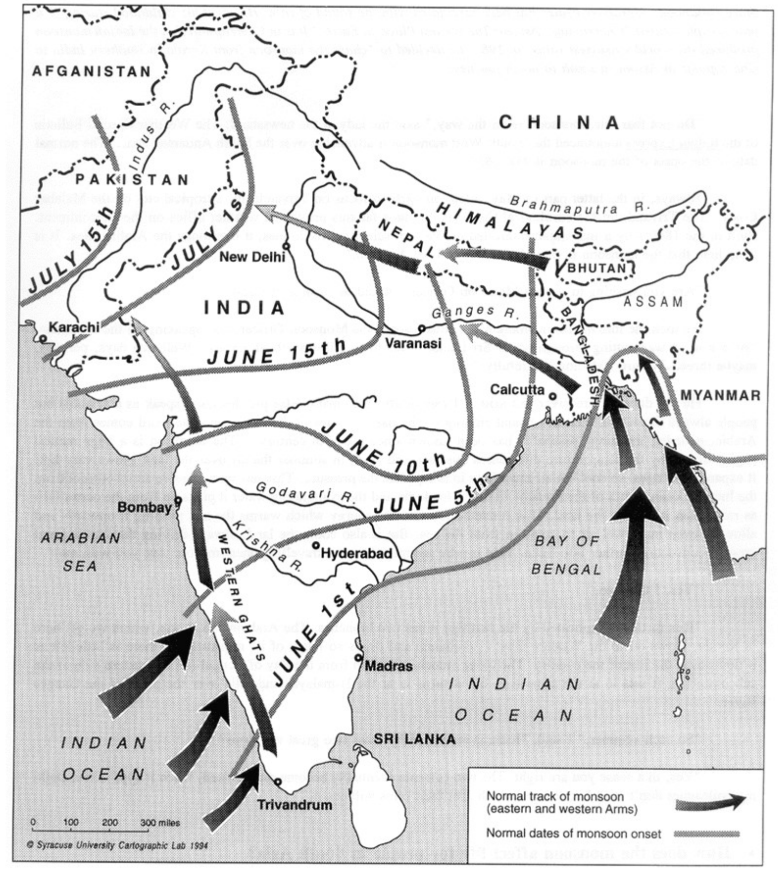
- It originates in Indian ocean
- Receives 75% of annual rainfall
- Starts from Kerala, and extends towards all states except Tamil Nadu and Jammu & Kashmir

<u>2) Post-Monsoon or NE Monsoon (October-November)</u>

- It mainly strikes the east coast of Southern Peninsula (Tamil Nadu)

<u>3) Pre-Monsoon (March-May)</u>





ITCZ-Inter Tropical Convergence Zone: The region that circles the Earth, near the equator, where the trade winds of the Northern and Southern Hemispheres come together

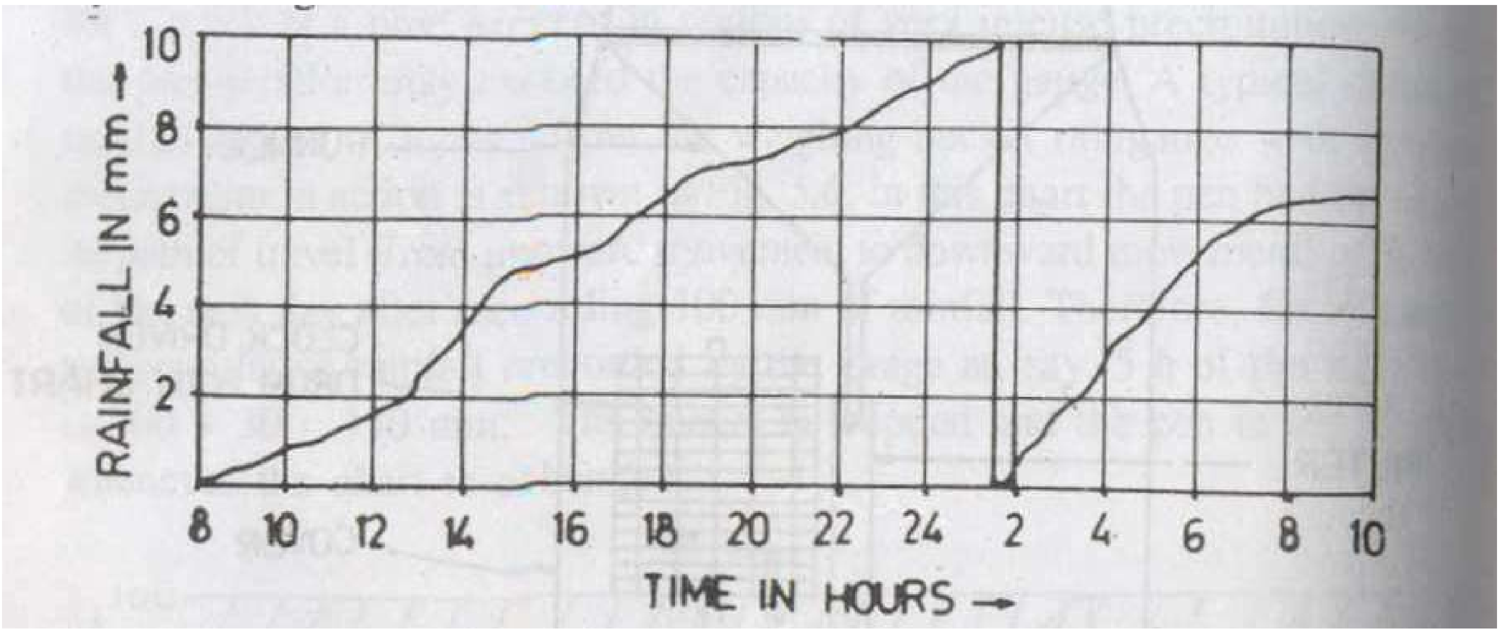
- The **Mascarene High** (MH) is a semi-permanent subtropical high-pressure zone in the South Indian Ocean
- A trough extends from this low over Pakistan (994 hPa) to Head Bay with strong pressure gradient to the south. This trough is often referred to as the 'monsoon trough'.


INDIA
BLANK MAP
North East
Trade winds
Arabian
Sea
Bay
of
Bengal
INDIAN OCEAN
International Boundary

Measurement of rainfall

- Rainfall is expressed in terms of depth (mm)
- Rainfall is measured using rain gauges: Recording & non-recording gauges
- Radar/satellite measurement

Rain gauges



Rain gauge chart

Tropical Rainfall Measuring Mission (TRMM)-1997

- A joint space mission between NASA and the Japan Aerospace Exploration Agency JAXA designed to monitor and study tropical rainfall

Solar radiation

Meaurement (W/m^2)

- **<u>Pyranometer</u>**: It is designed to measure the solar radiation flux density (W/m^2) from the hemisphere above within a wavelength range 0.3 µm to 3 µm

- **Satellite**

Meteorological observatories

IMD (Indian Meteorological Department)

http://weather.uwyo.edu/upperair/sounding.html- University of Wyoming

https://power.larc.nasa.gov/data-access-viewer/- NASA Power data

Climate Change And Its Implications (CCI)

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Lecture-4

Class outline

- Probability of occurrence of an event –rainfall
- Climate, climate variability and climate change
- Evidences of climate change
- Reasons for climate change

Probability of occurrence of an event-Rainfall

- Design of hydraulic structures, flood control structures, soil conservation structures, drains, culverts etc. are based on probability of occurrence of extreme rainfall events

Weibulls' formula

- Probability of occurrence (plotting position) of a rainfall event,

P= 100*M/(N+1)

M is the ranking of the event (after arranging it in descending order)

N is the total number of events

and its recurrence interval or return period, T =1/P

There are many formulas to calculate P (Gumbel, Hazen, Blom etc.)

Exercise-1 - HW

For a station A, the recorded annual 24 h maximum rainfall are given below.(a) estimate the 24 h maximum rainfall with a return period of 13 and 50 years.(b) what would be the probability of a rainfall magnitude equal to or exceeding 10 cm occurring in 24 h at station A.

1950	1951	1952	1953	1954	1955	1956	1957	1958	1959
13	12	7.6	14.3	16	9.6	8	12.5	11.2	8.9

1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
8.2	7.8	9	10.2	8.5	7.5	6	8.4	10.8	10.6

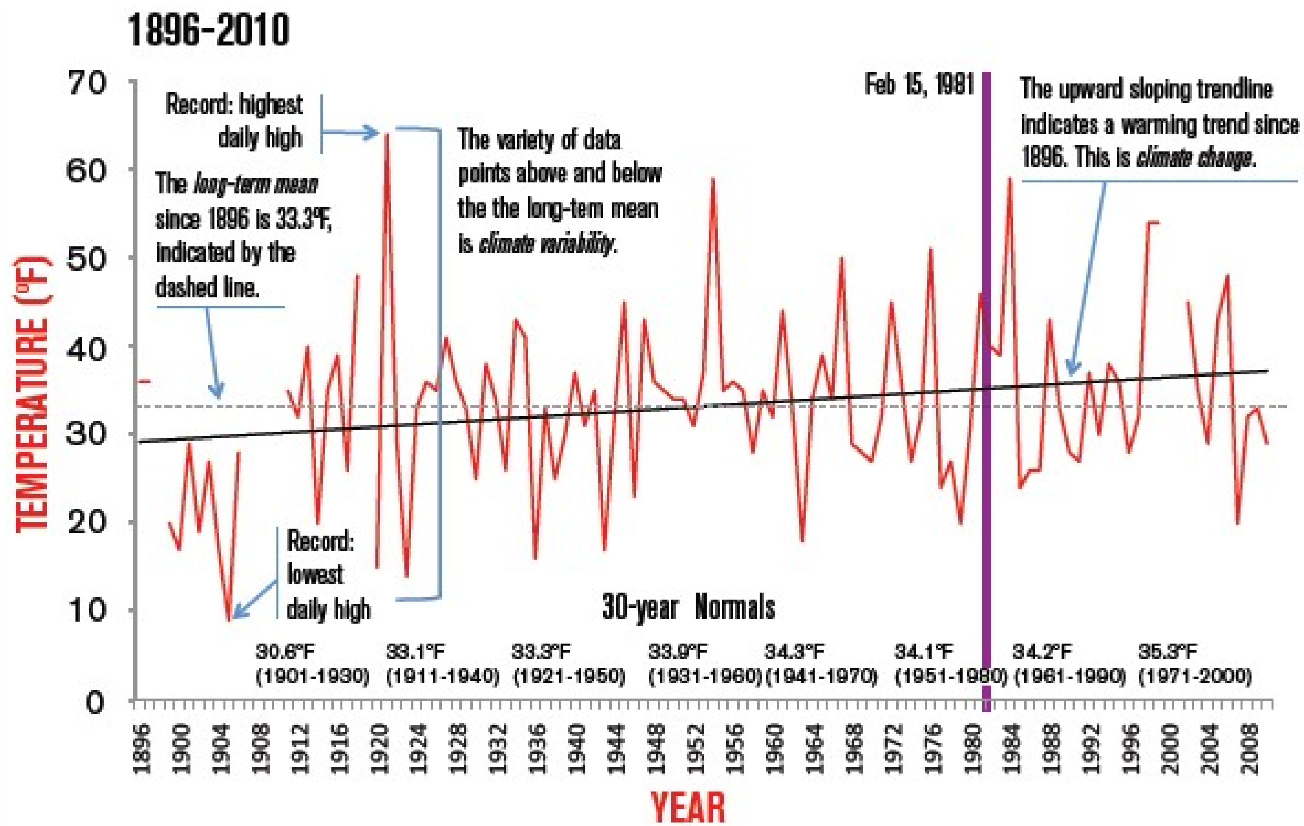
1970	1971
8.3	9.4

Steps

- Arrange data in descending order, and rank the events starting from 1 (i.e., M=1,2,3…)
- Calculate P value for each event using the equation $P=M/(N+1)$
- Then estimate recurrence interval or return period, $T=1/P$
- Make a plot using excel or graph paper
- From the plot (event vs. T), you will be able to derive the return period of any event
- Similarly, you can derive the magnitude of rainfall (event) for any return period.

Climate variability and climate change

Climate Variability & Climate Change



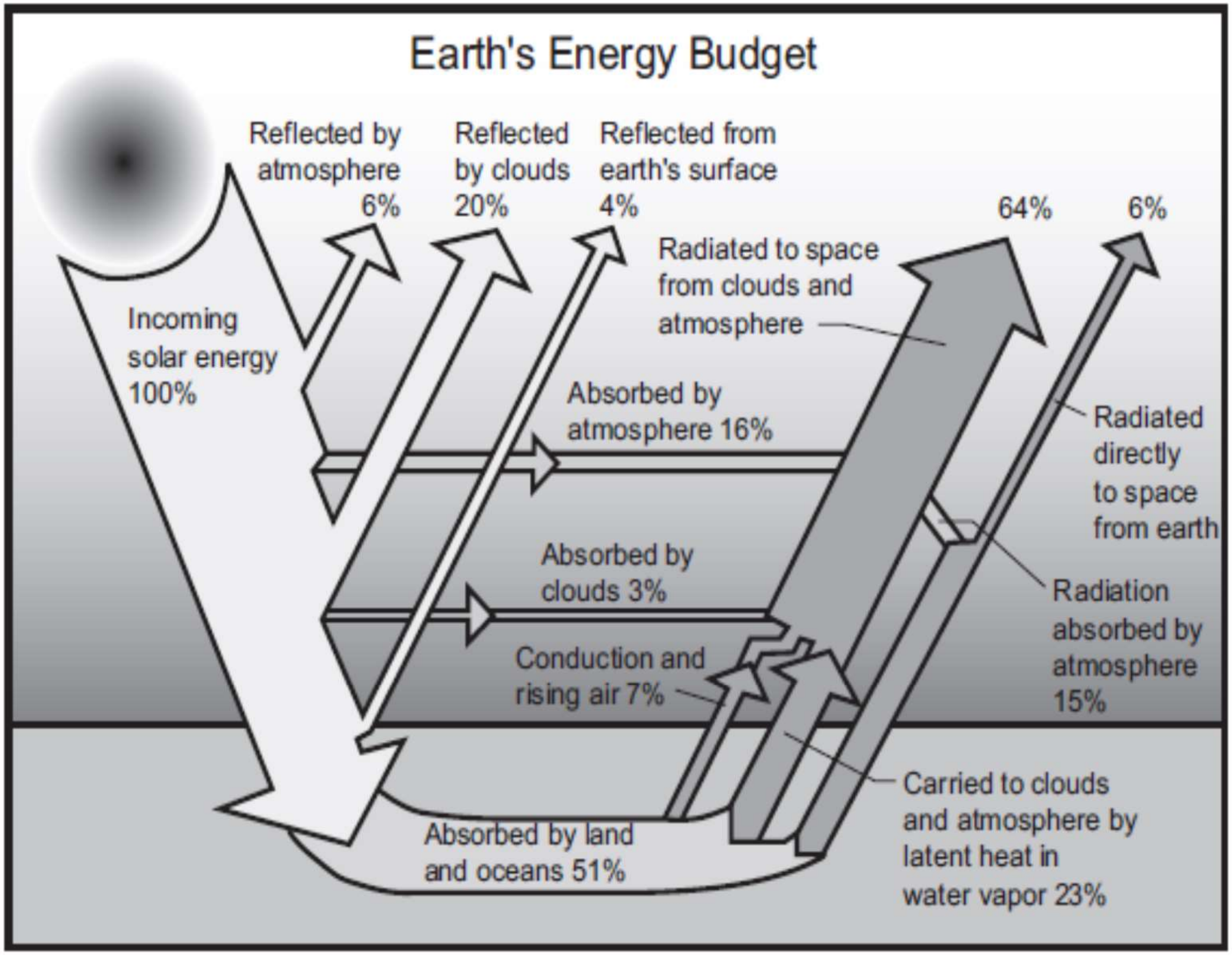
- Climate varies over seasons and years instead of day to day like weather
- Some summers are colder than others and some years precipitations are higher than others

- Climate variability: The way the climate fluctuates yearly above or below a long term average

- Climate change: Long term continuous change to average weather conditions

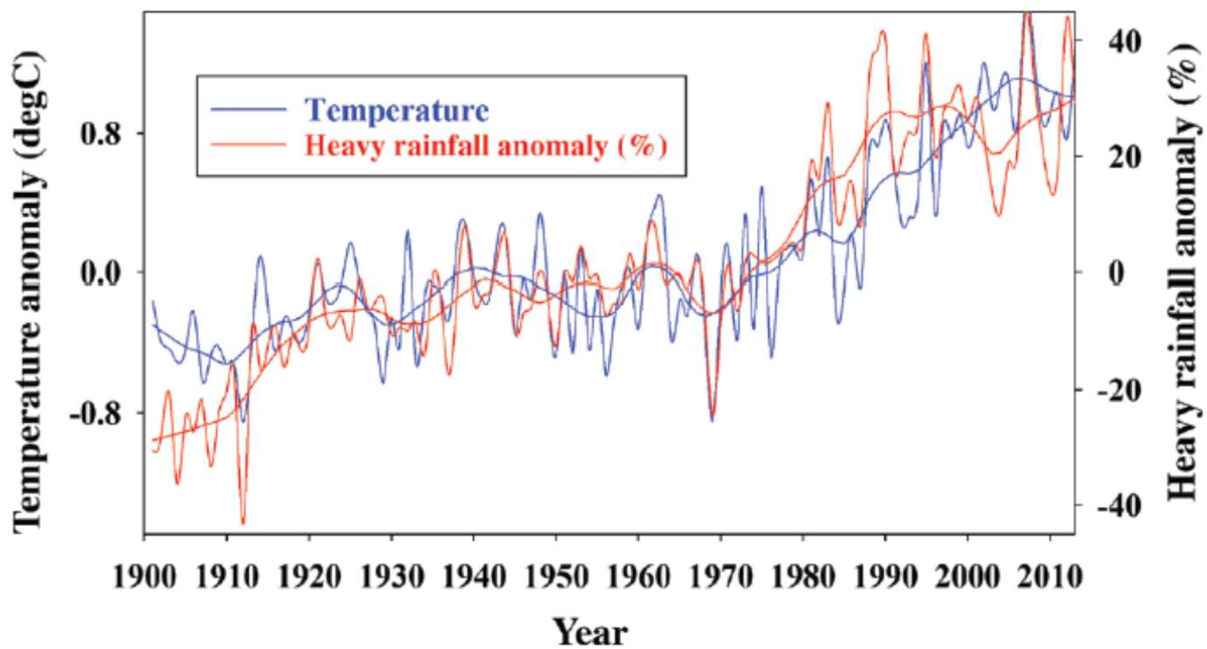
- Climate change is slow and continuous unlike variability

How the climate is changing?



Atmosphere is responsible for radiating ~90% of total absorbed solar energy back to space!!

Climate Change: Is it real ?



Earth is getting warmer and the temperature has been well above normal for more than 25 years.

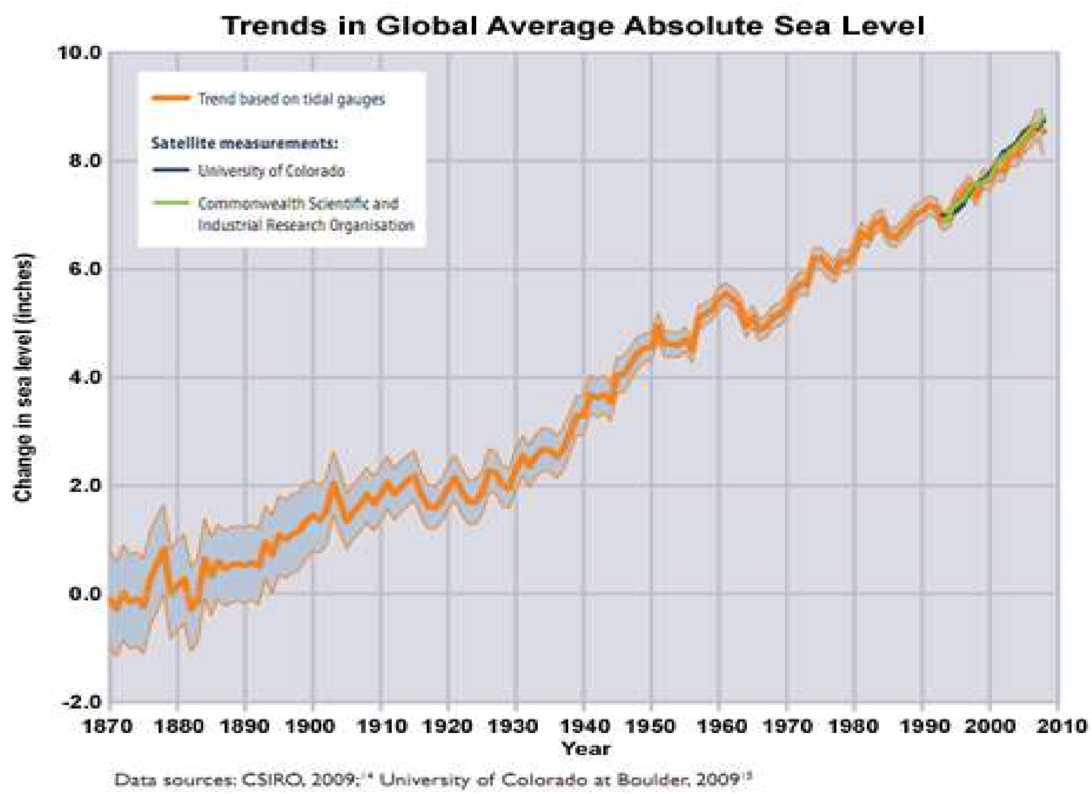
Assignment-1

- Identify the trend in Temperature in your location from the historical data.

Download the data from 1985 to 2015 (15 years daily data) from NASA Power data (https://power.larc.nasa.gov/data-access-viewer/)

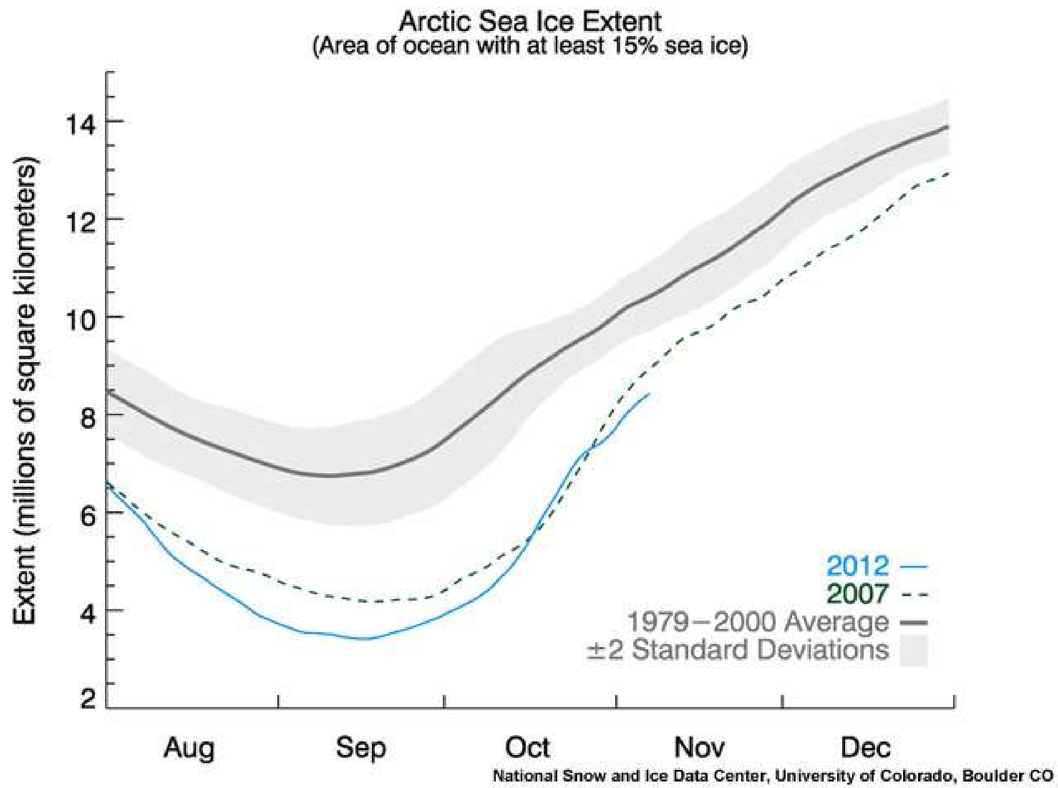
Submission due date: 17.09.2021

Evidence of change: Oceans



The IPCC estimates that the oceans rose 4 to 10 inches (10-25 cm) in the 20th century from melting ice and snow and the physical expansion of warmer water.

Evidence of change: Sea Ice



Sea ice is diminishing in the Arctic. Satellites have observed winter Arctic sea ice shrink by about 3-4% per decade from 1979, and an even higher rate in summer.

Reasons for climate change

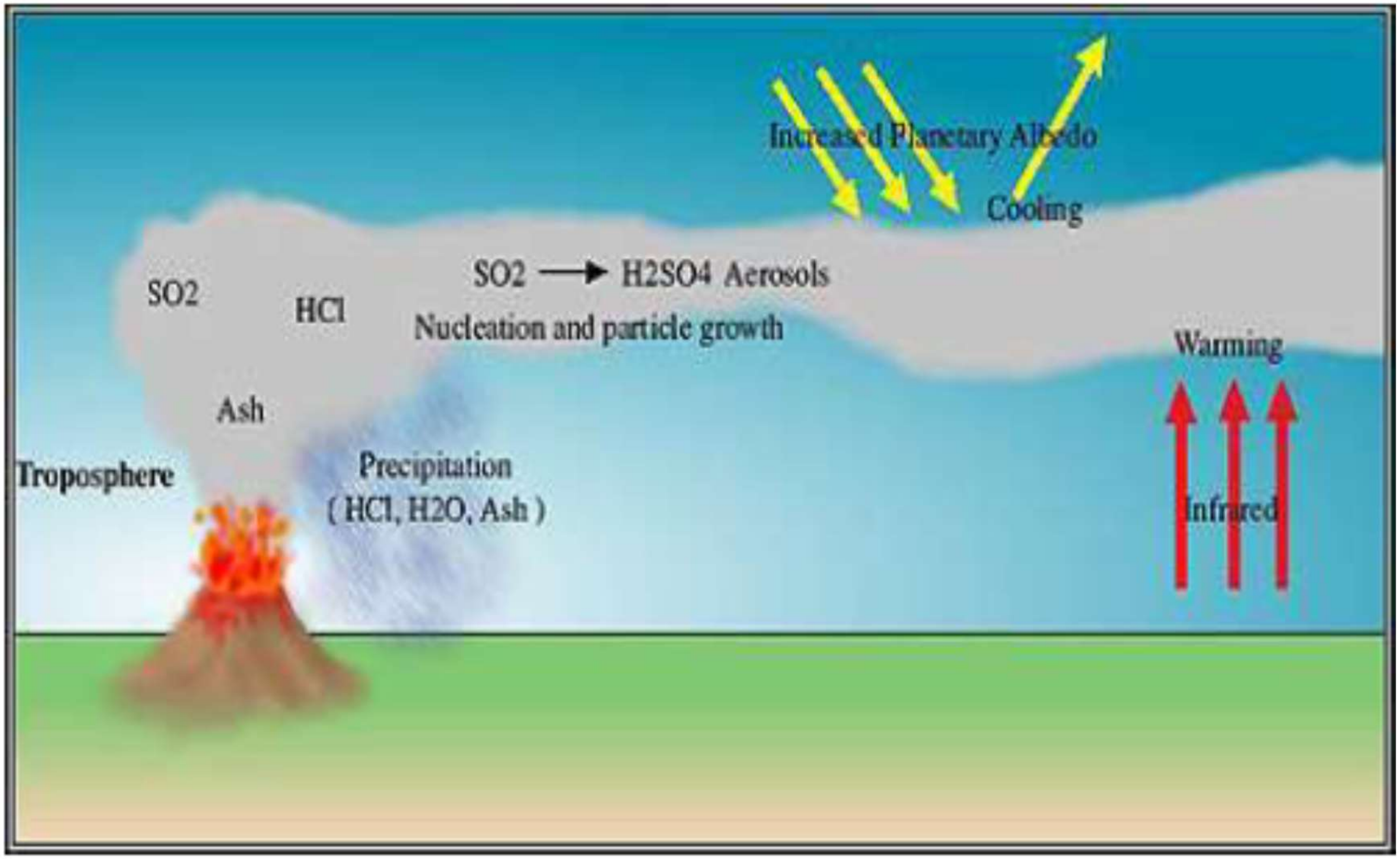
<u>Natural & human made reasons</u>

<u>1. Natural:</u>

- The earth's climate is influenced and changed through natural causes like volcanic eruptions, ocean currents, the Earth's orbital changes, solar variations and internal variability

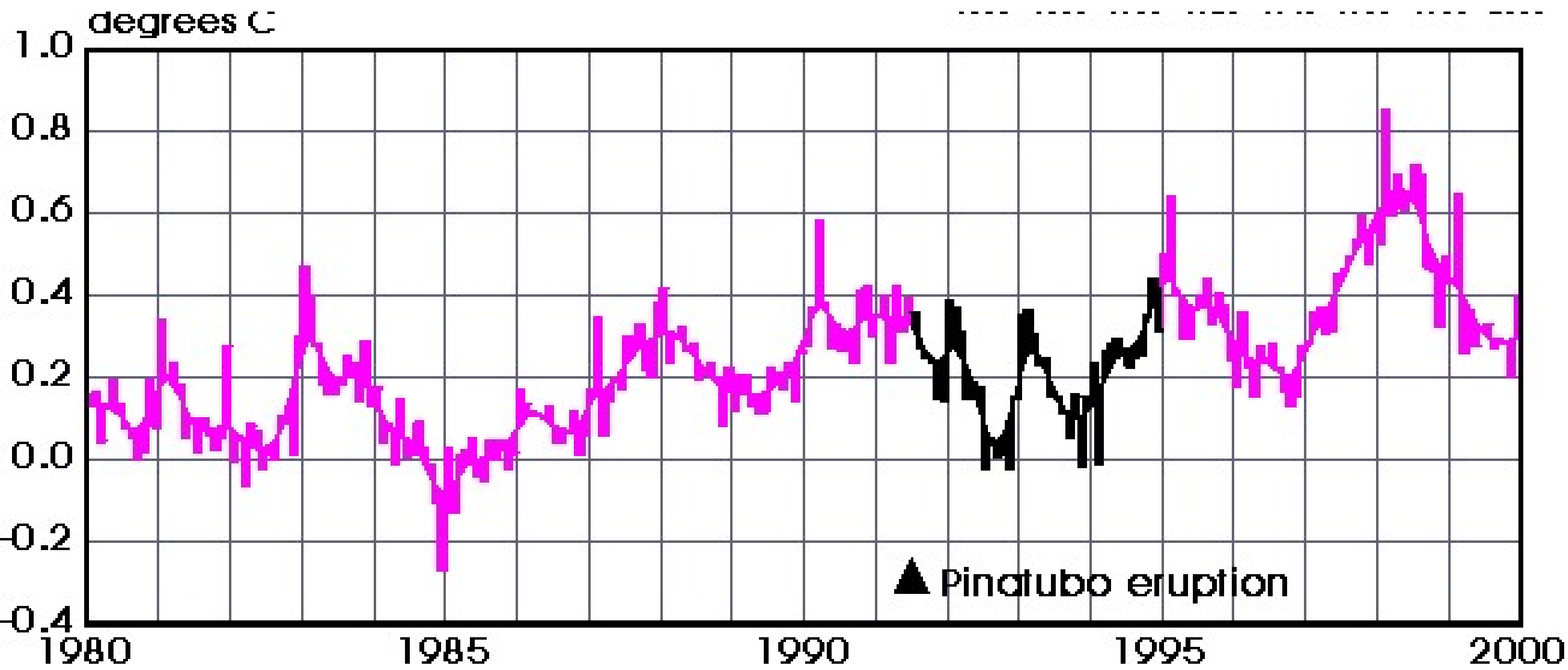
➢Volcanic eruptions:

- Volcanic eruptions pump out clouds of dust and ash, which block out some sunlight
- The ash particles are relatively heavy, they fall to the ground within about three months, so their cooling effect is very short-lived
- But volcanic debris also includes sulfur dioxide. This gas combines with water vapor and dust in the atmosphere to form sulphate aerosols, which reflect sunlight away from the Earth's surface- can lead cooling of Earth's surface
- These aerosols are lighter than ash particles and can remain in the atmosphere for a year or more



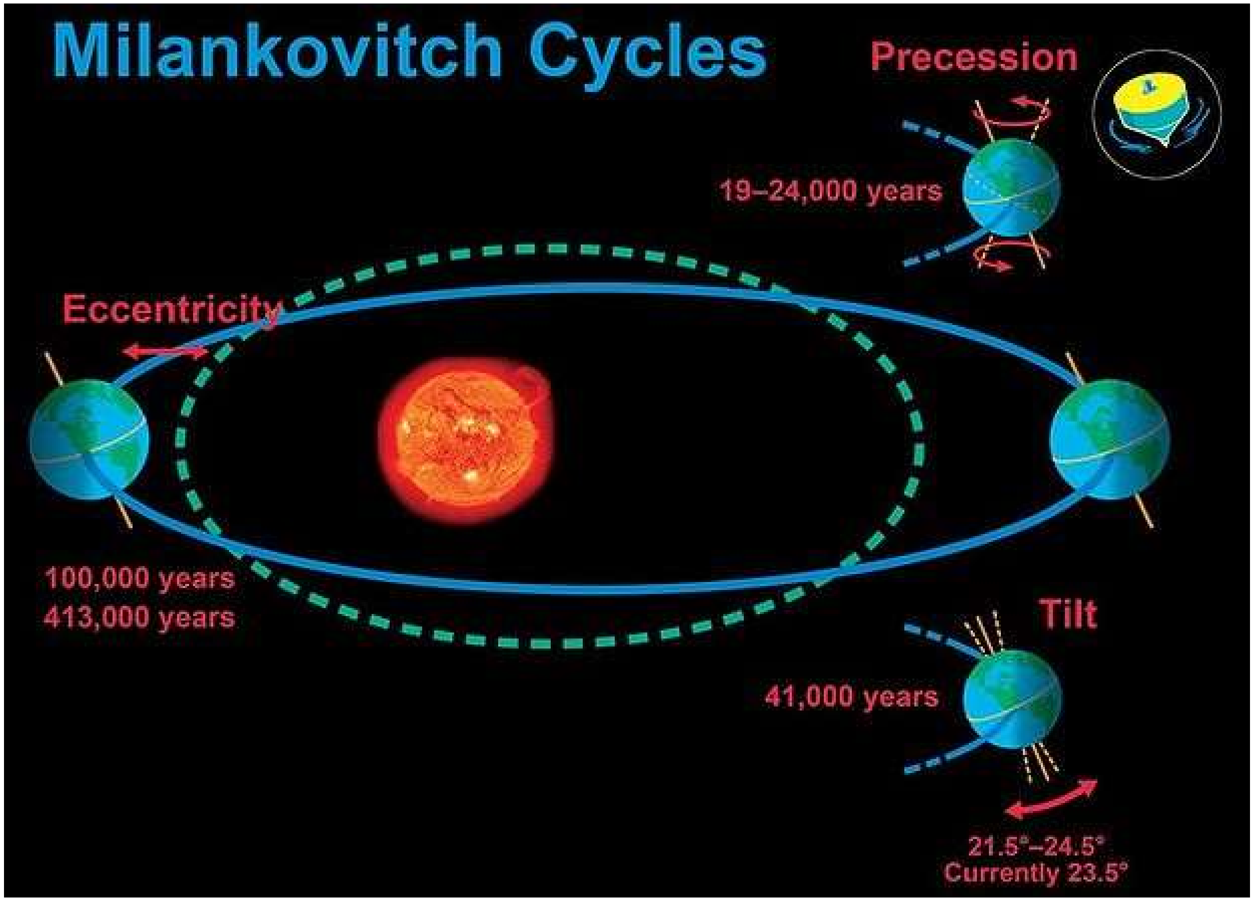
Increased Planetary Albedo
Cooling
SO2 → H2SO4 Aerosols
SO2
HCl
Nucleation and particle growth
Warming
Ash
Troposphere
Precipitation
(HCl, H2O, Ash)
Infrared

Mount Pinatubo-1991



- Large volumes of gases and ash can influence climatic patterns for years by increasing planetary reflectivity causing atmospheric cooling
- The eruption of Mount Pinatubo in 1991 caused a 0.5 °C drop in global temperature

➢Earth's orbital changes:



- Milankovitch cycles describe the collective effects of changes in the Earth's movements on its climate over thousands of years

Cycle includes:

- shape of Earth's orbit, known as **eccentricity**
- angle Earth's axis is tilted with respect to Earth's orbital plane, known as **obliquity**
- direction Earth's axis of rotation is pointed, known as **precession**

Ice Age: Did it exist ?

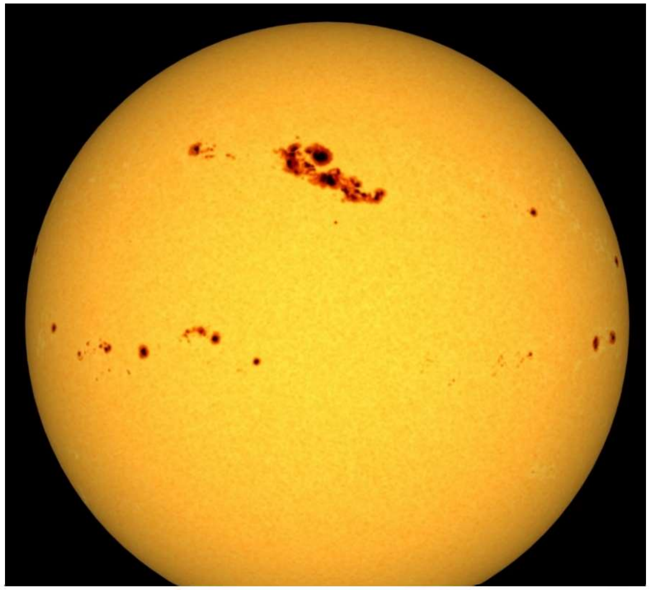
- The last ice age ended about 12,000 years ago and the next cooling cycle may begin in about 30,000 years

- An **ice age** is a long period of reduction in the temperature of Earth's surface and atmosphere, resulting in the presence or expansion of continental and polar ice sheets and alpine glaciers

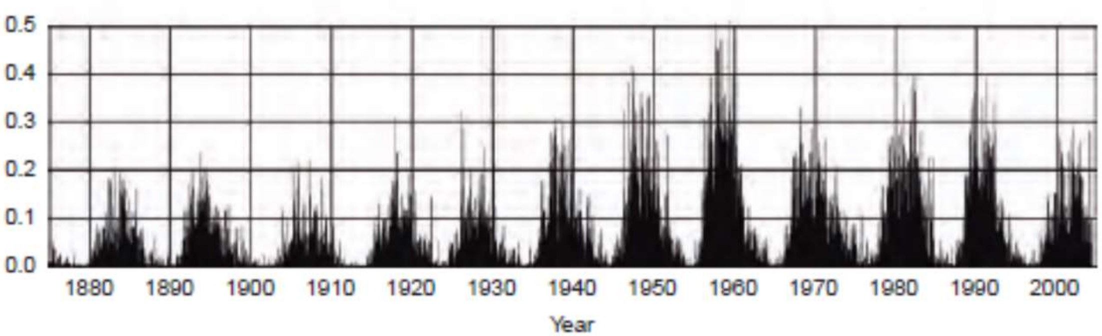
- *Ice age* implies the presence of extensive ice sheets in both northern and southern hemispheres – 5 major ice ages
- Earth is currently in an interglacial period

- Orbital changes are so gradual they're only noticeable over thousands of years – not decades or centuries
- The earth makes one full orbit around the sun each year, it is tilted at an angle of 23.5° to the perpendicular plane of its orbital path
- Changes in the tilt of the earth can lead to small but climatically important changes in the strength of the seasons, more tilt means warmer summers and colder winters; less tilt means cooler summers and milder winters
- Slow changes in the Earth's orbit lead to small but climatically important changes in the strength of the seasons over tens of thousands of years

➢ Solar variations:



- Sunspots are temporary phenomena on the Sun's photosphere that appear as spots darker than the surrounding areas
- They are regions of reduced surface temperature caused by concentrations of magnetic field flux that inhibit convection



The fractional area of the surface of the entire solar photosphere (in %) covered by sunspots as a function of time

- That could lead to **fewer solar storms**, as well as a cooler climate on Earth

Little Ice Age (François E. Matthes in 1939)

- The **Little Ice Age** (**LIA**) was a period of regional cooling that occurred after the Medieval Warm Period (The time period has been conventionally defined as extending from the 16th to the 19th centuries)

- The Intergovernmental Panel on Climate Change (IPCC) 3rd Assessment Report: timing and the areas affected by the Little Ice Age suggested largely-independent regional climate changes, rather than a globally-synchronous increased glaciation

Climate Change And Its Implications (CCI)

Dr. Raji P

Lecture-5 & 6

Class outline

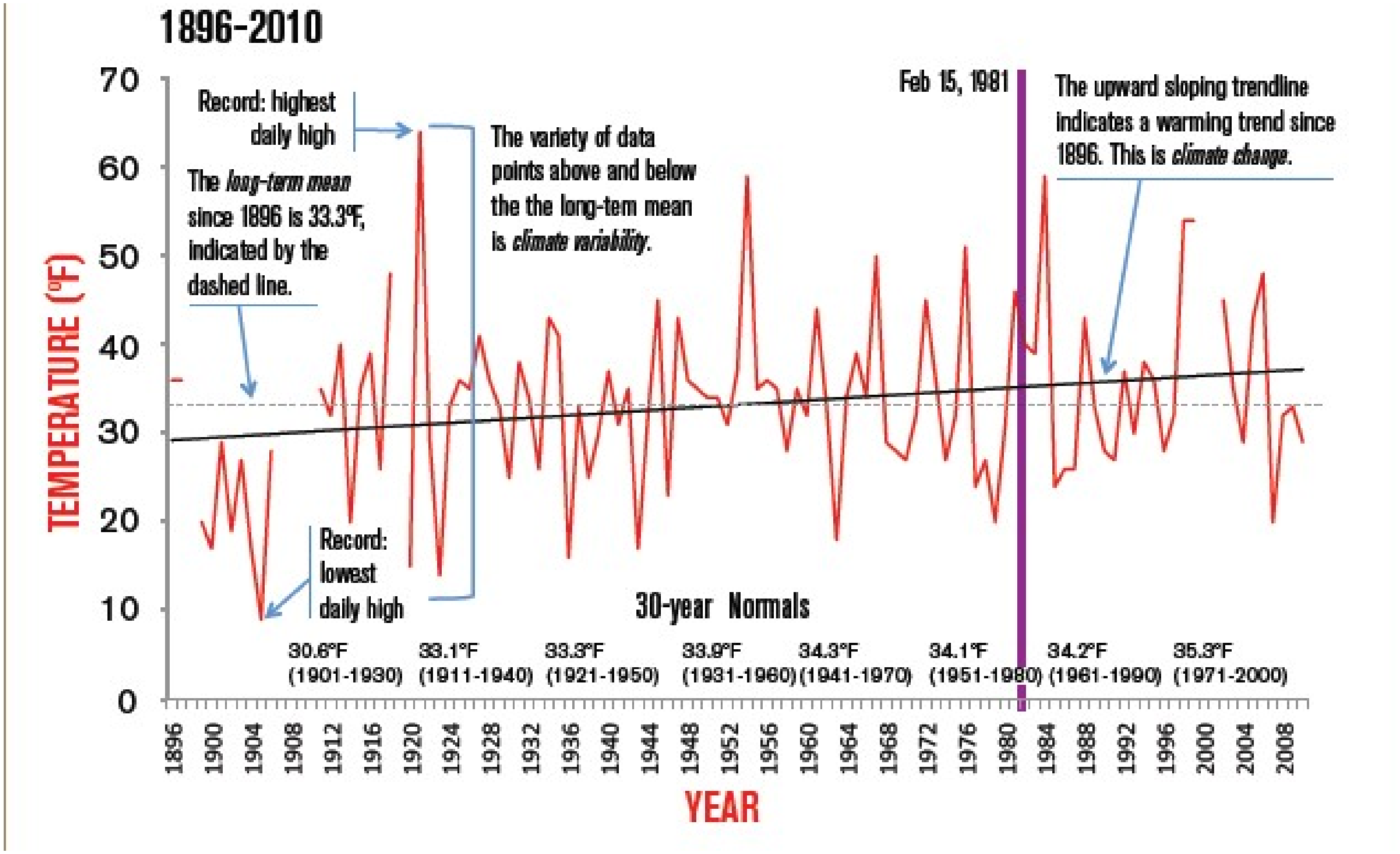
- Natural reasons for climate variability

Anthropogenic influences

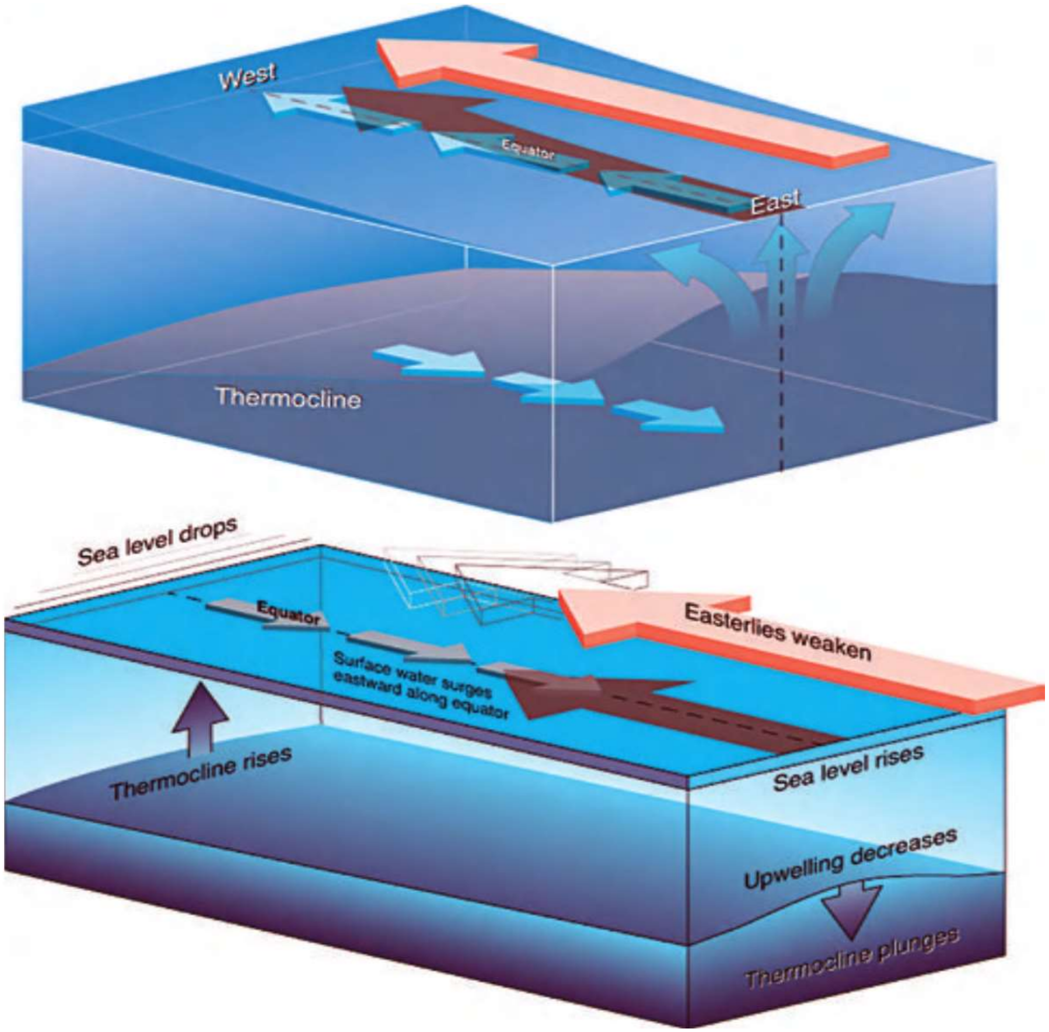
- Greenhouse gases

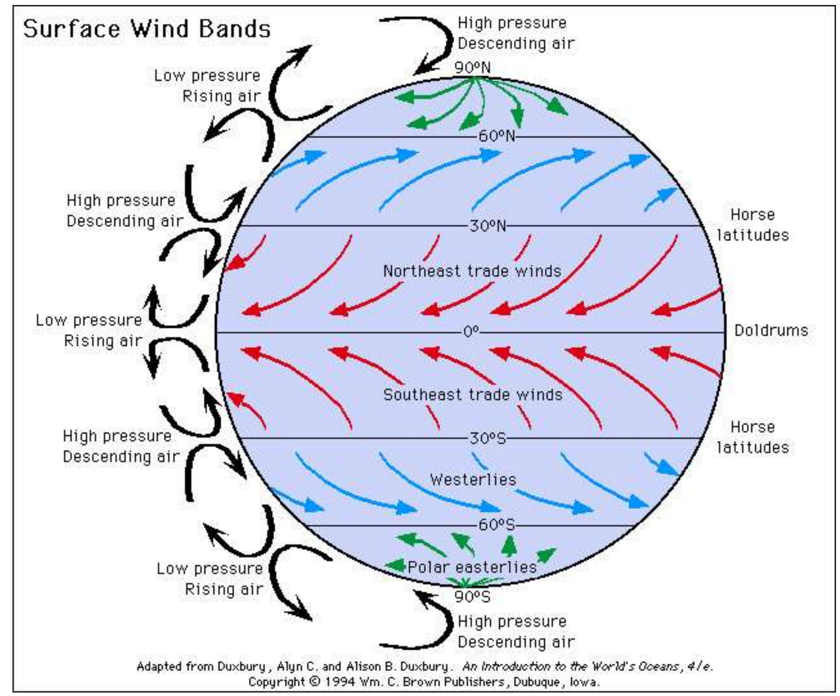
- Sources of greenhouse gases

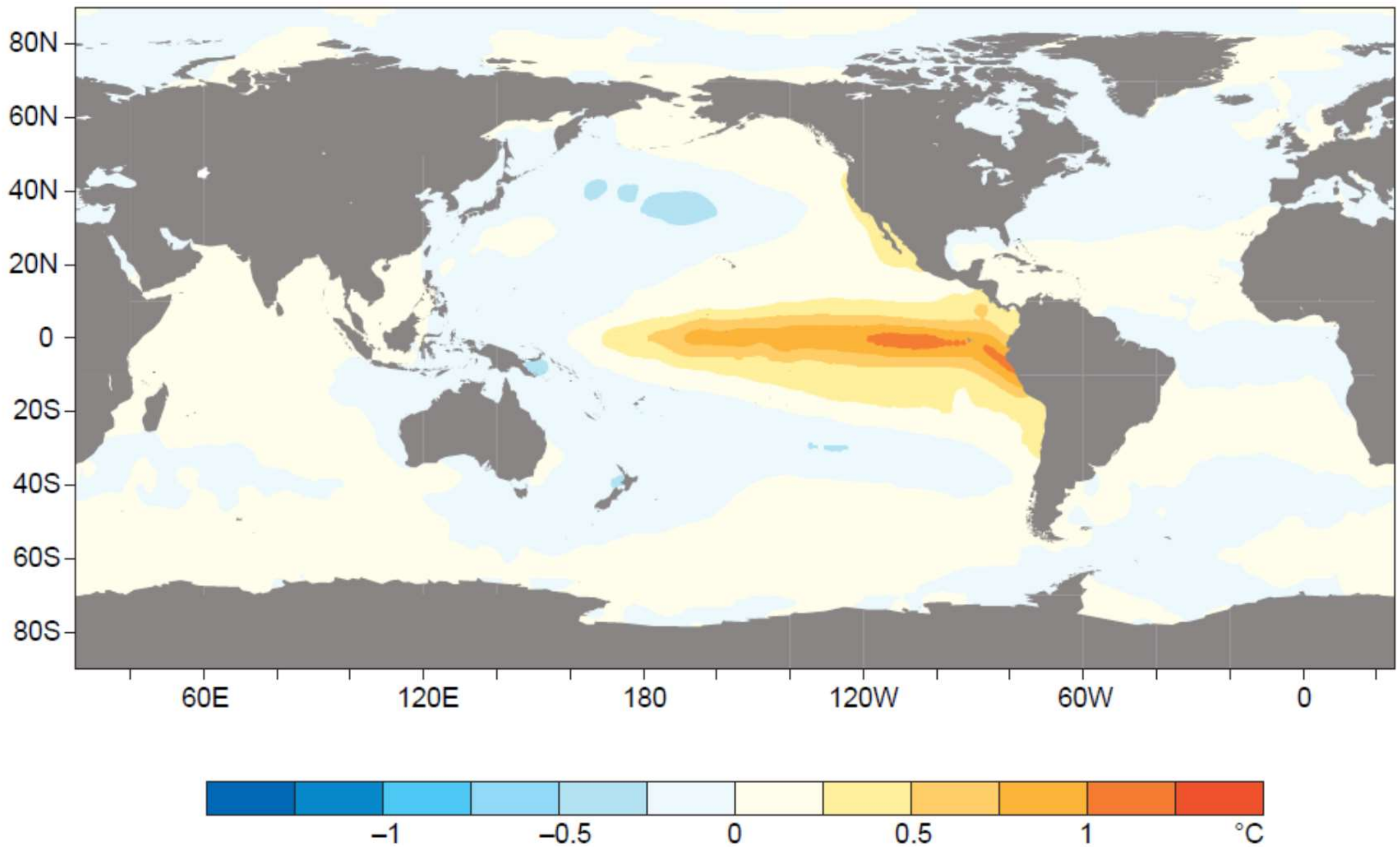
Natural reasons for climate variability


1896-2010
Record: highest daily high
The *long-term mean* since 1896 is 33.3°F, indicated by the dashed line.
The variety of data points above and below the the long-tem mean is *climate variability*.
Feb 15, 1981
The upward sloping trendline indicates a warming trend since 1896. This is *climate change*.
Record: lowest daily high
30-year Normals
30.6°F (1901-1930)
33.1°F (1911-1940)
33.3°F (1921-1950)
33.9°F (1931-1960)
34.3°F (1941-1970)
34.1°F (1951-1980)
34.2°F (1961-1990)
35.3°F (1971-2000)
TEMPERATURE (°F)
YEAR

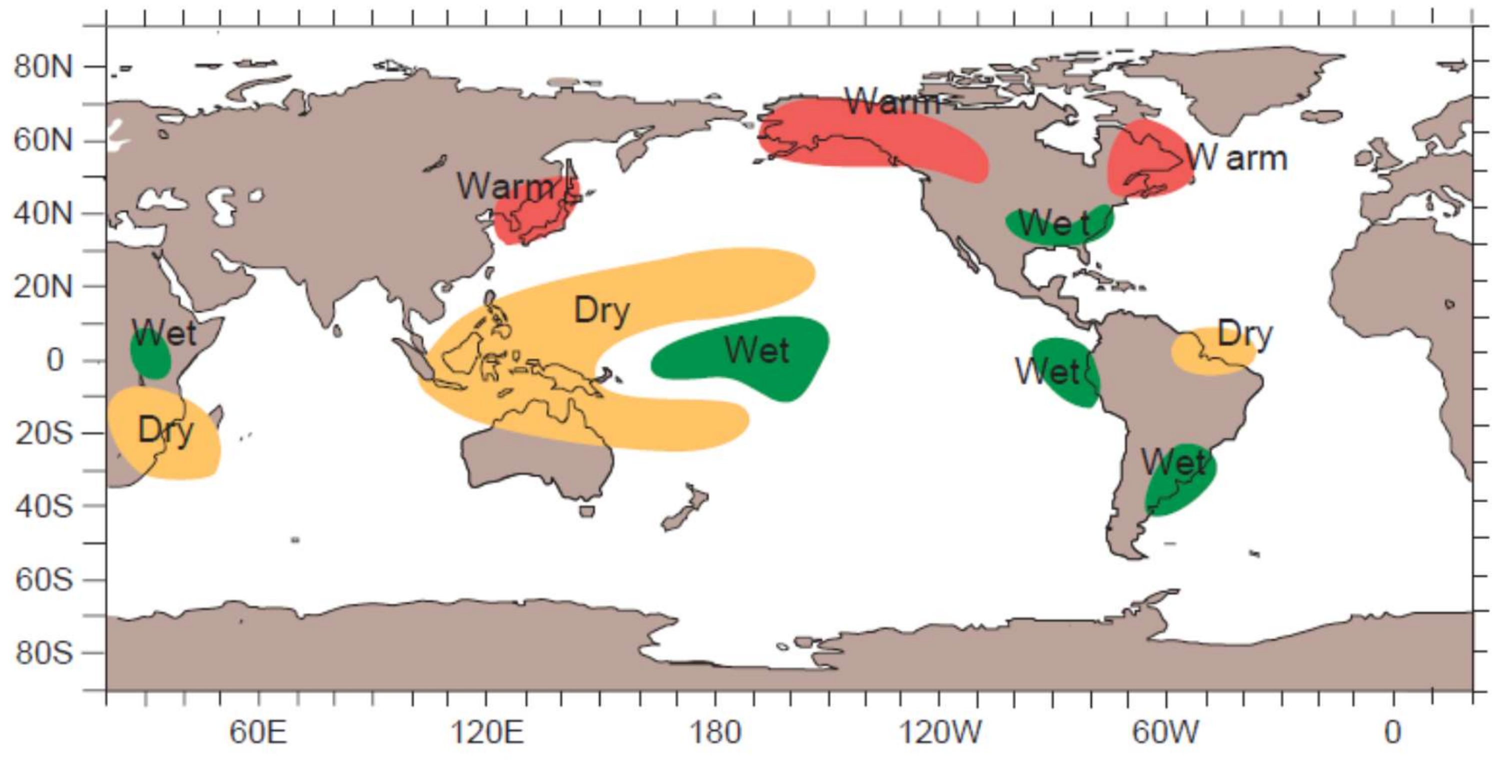
General circulation of the atmosphere



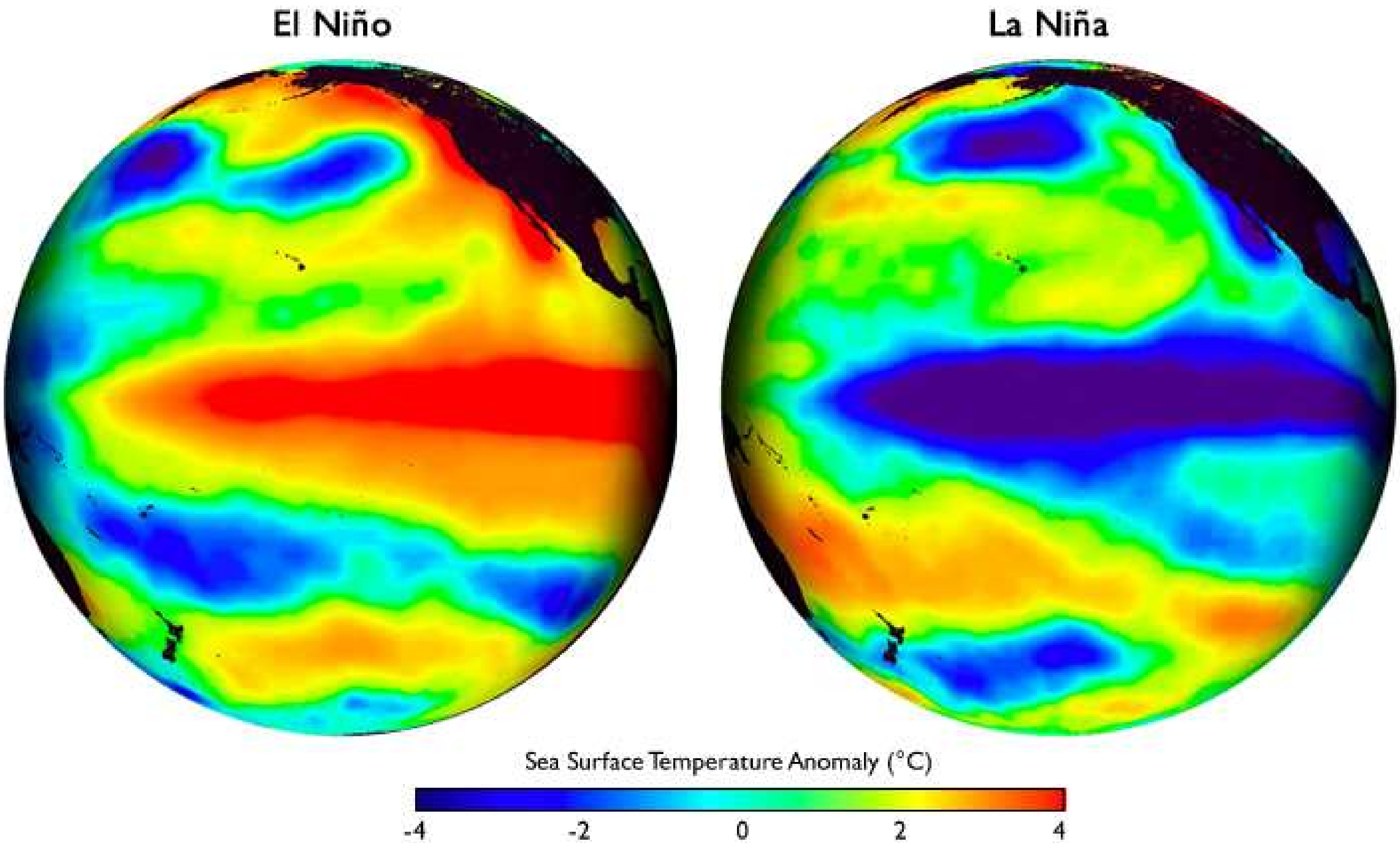




Global pattern of sea surface temperature (°C) anomalies observed during El Niño years

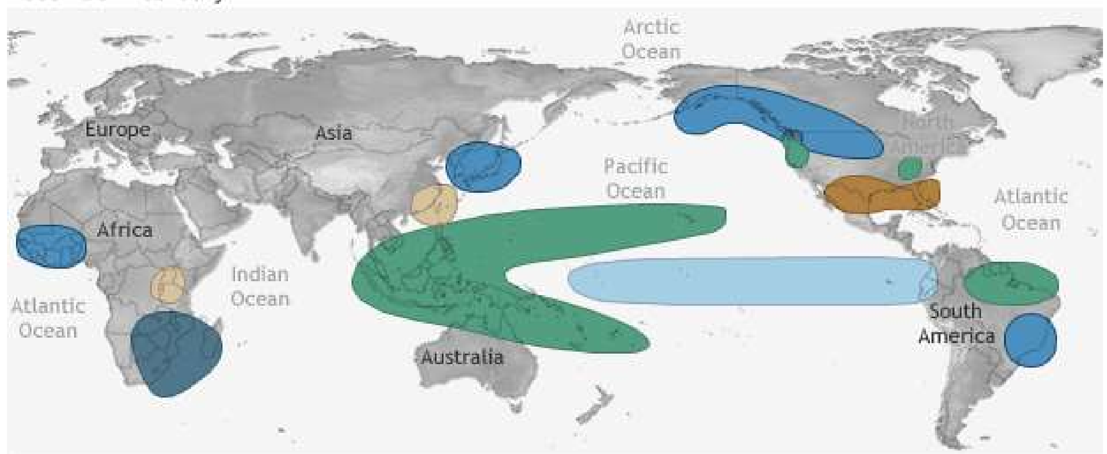


Impacts of El Niño on weather and climate


El Niño
La Niña
Sea Surface Temperature Anomaly (°C)
-4
-2
0
2
4

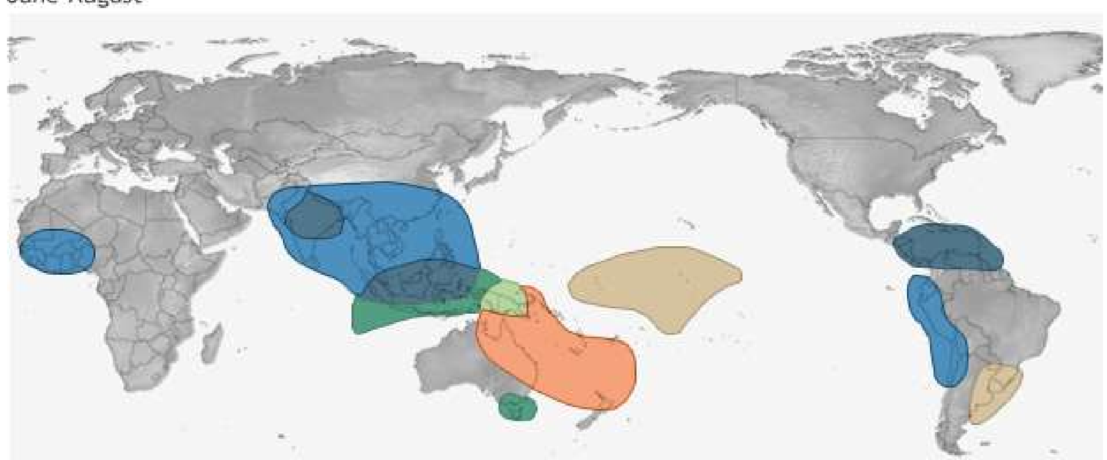
LA NIÑA CLIMATE IMPACTS

December-February



Cool | Wet | Cool and dry | Cool and Wet
Warm | Dry | Warm and dry | Warm and wet

June-August



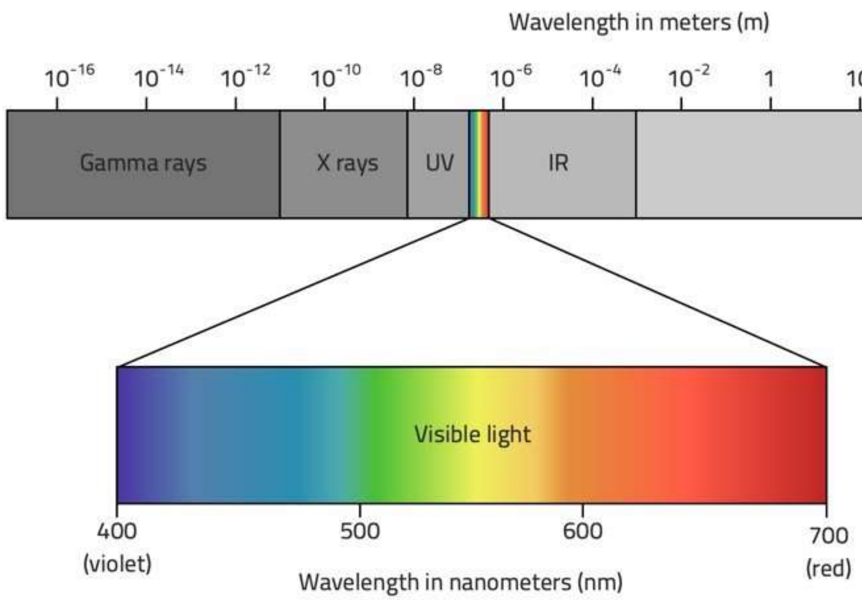
NOAA Climate.gov

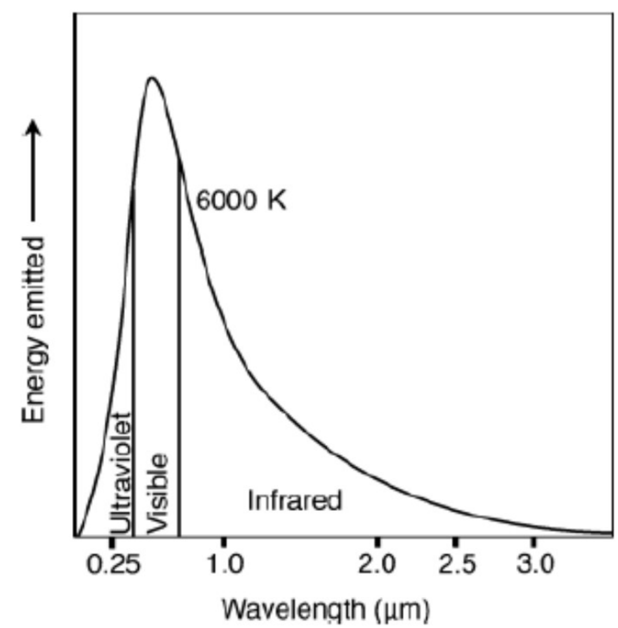
- El Niño and La Niña are opposite phases of a natural climate pattern across the tropical Pacific Ocean that swings back and forth every 3-7 years on average
- Together, they are called ENSO (pronounced "en-so"), which is short for **E**l **N**iño-**S**outhern **O**scillation
- El Niño (the warm phase) and La Niña (the cool phase) lead to significant differences from the average ocean temperatures, winds, surface pressure, and rainfall across parts of the tropical Pacific
- Climate Change is making El Niños more intense, leading to intensifying droughts, worsening floods, and shifting hurricane patterns
- Strong El Niños can cause severe drought in dry climates such as Australia and India, intense flooding in wetter climates such as the Pacific Northwest and Peru, and causes more hurricanes to form in the Pacific and fewer in the Atlantic

Anthropogenic influences- Climate Change

Radiative equilibrium temperature of Earth

Electromagnetic spectrum

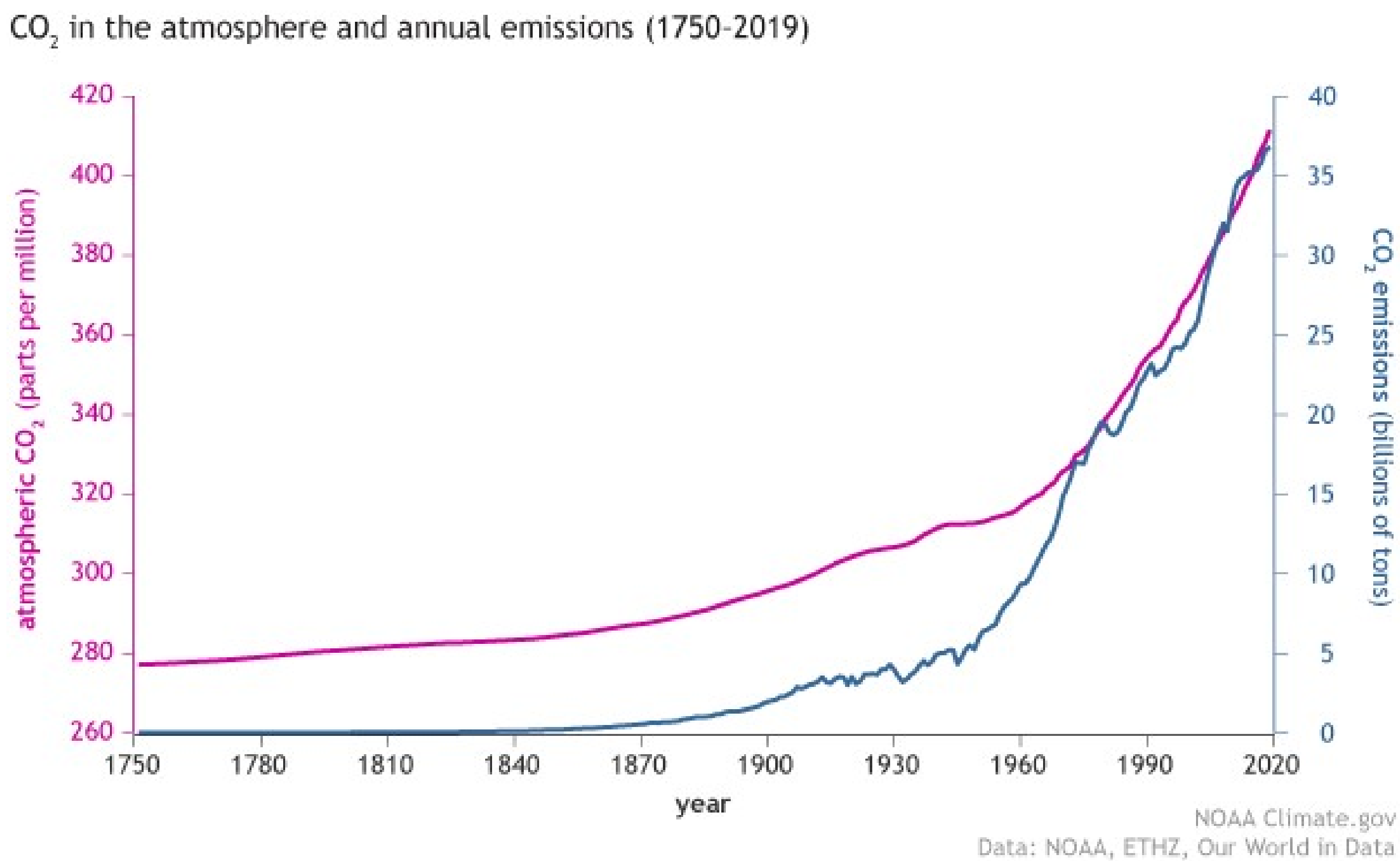




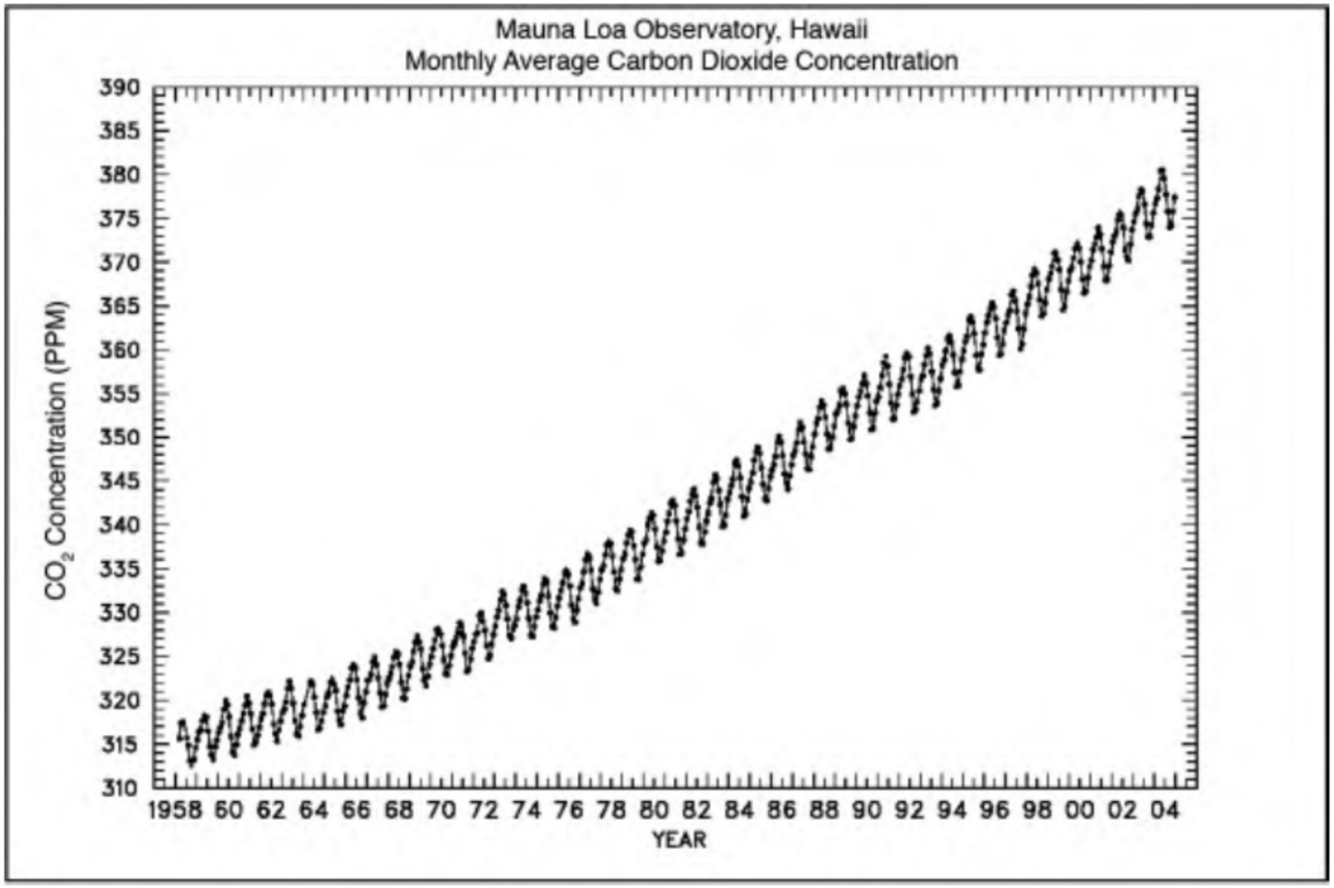
Energy emitted from the sun against the wavelength

Atmospheric composition

CO_2 in the atmosphere and emission

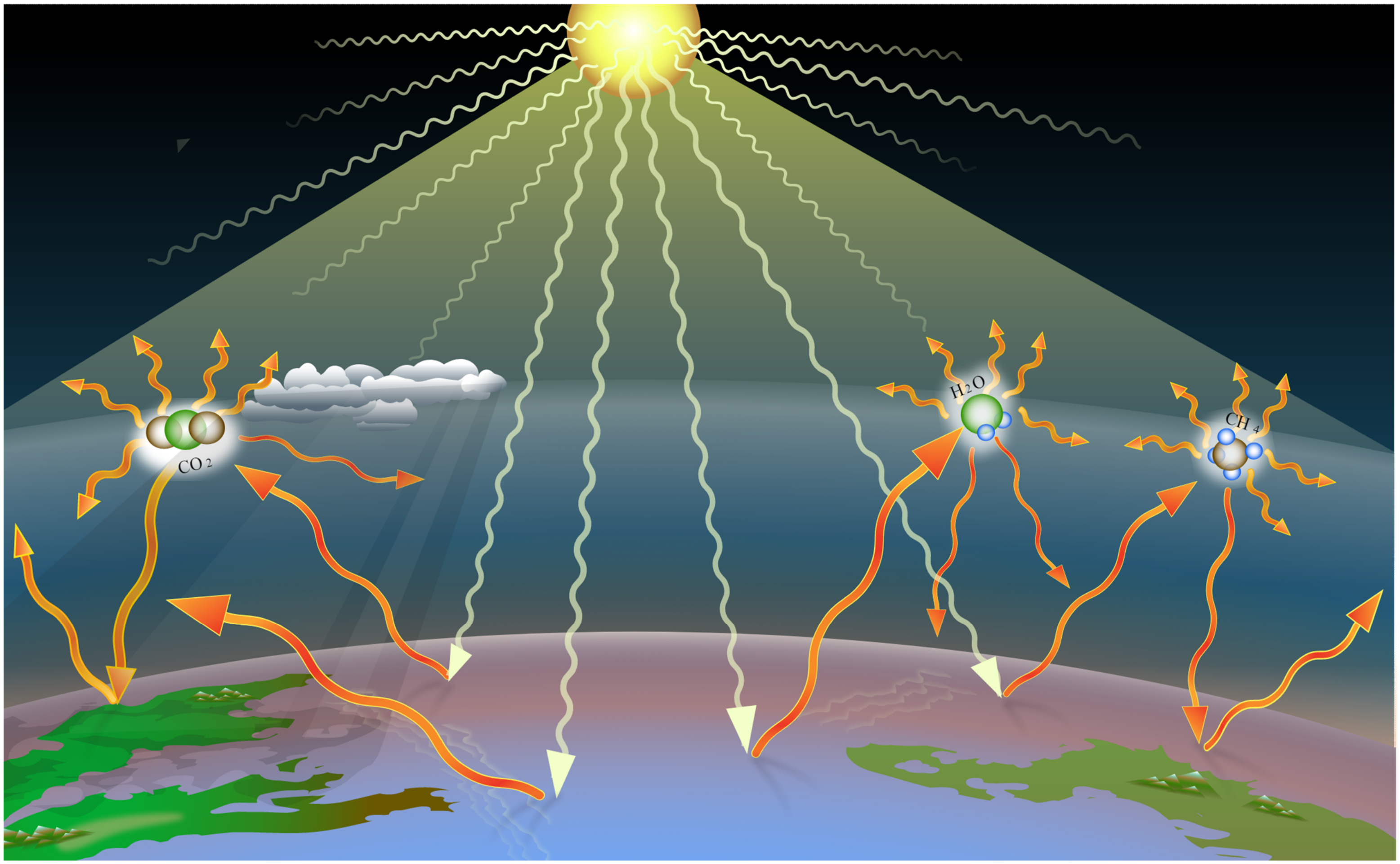


Atmospheric CO_2 concentrations observed at Mauna Loa, Hawaii



- The trend is due to anthropogenic emissions
- The seasonal cycle is thought to be driven by the terrestrial biosphere: net consumption of CO_2 by biomass in the summertime (due to abundance of light and heat) and net respiration in wintertime

Greenhouse effect

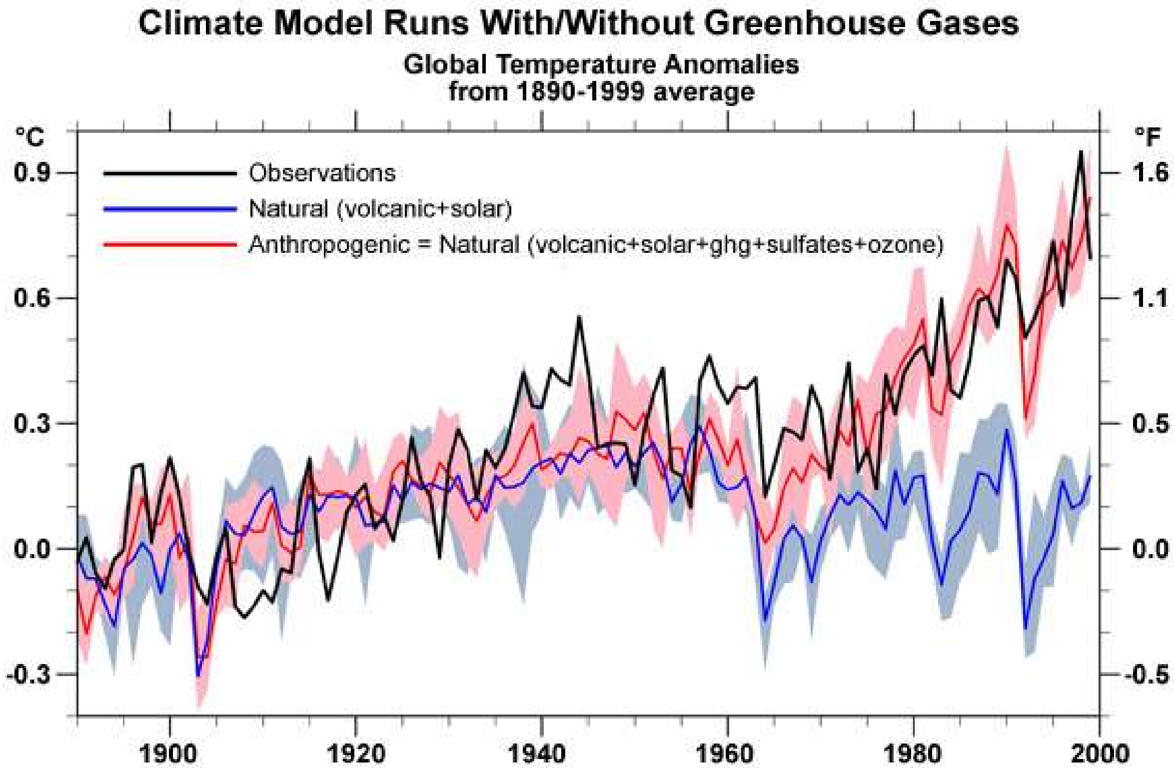


- The incoming solar radiation peaks at shorter wavelengths, in the visible spectrum

- The outgoing terrestrial radiation peaks in the infrared (IR) spectrum

- But the atmosphere is strongly absorbing these wavelengths (IR) due to the presence of trace gases—principally the triatomic molecules H_2O and CO_2—which absorb and emit in the infrared, thus raising the surface temperature, and is known as the *greenhouse effect*

How much do we contribute ?



Only the addition of the extra greenhouse gases and particles to our computer models can reproduce the pattern of warming we've seen over the past century

Sources of GHG

Greenhouse gas	Major sources	Pre-industrial concentration (ppb)	2011 concentratio
Carbon Dioxide	Fossil fuel combustion; Deforestation; Cement production	278,000	390,000
Methane	Fossil fuel production; Agriculture; Landfills	722	1,803
Nitrous Oxide	Fertilizer application; Fossil fuel and biomass combustion; Industrial processes	271	324
Chlorofluorocarbon-12 (CFC-12)	Refrigerants	0	0.527
Hydrofluorocarbon-23 (HFC-23)	Refrigerants	0	0.024
Sulfur Hexafluoride	Electricity transmission	0	0.0073
Nitrogen Trifluoride	Semiconductor manufacturing	0	0.00086

Climate Change And Its Implications (CCI)

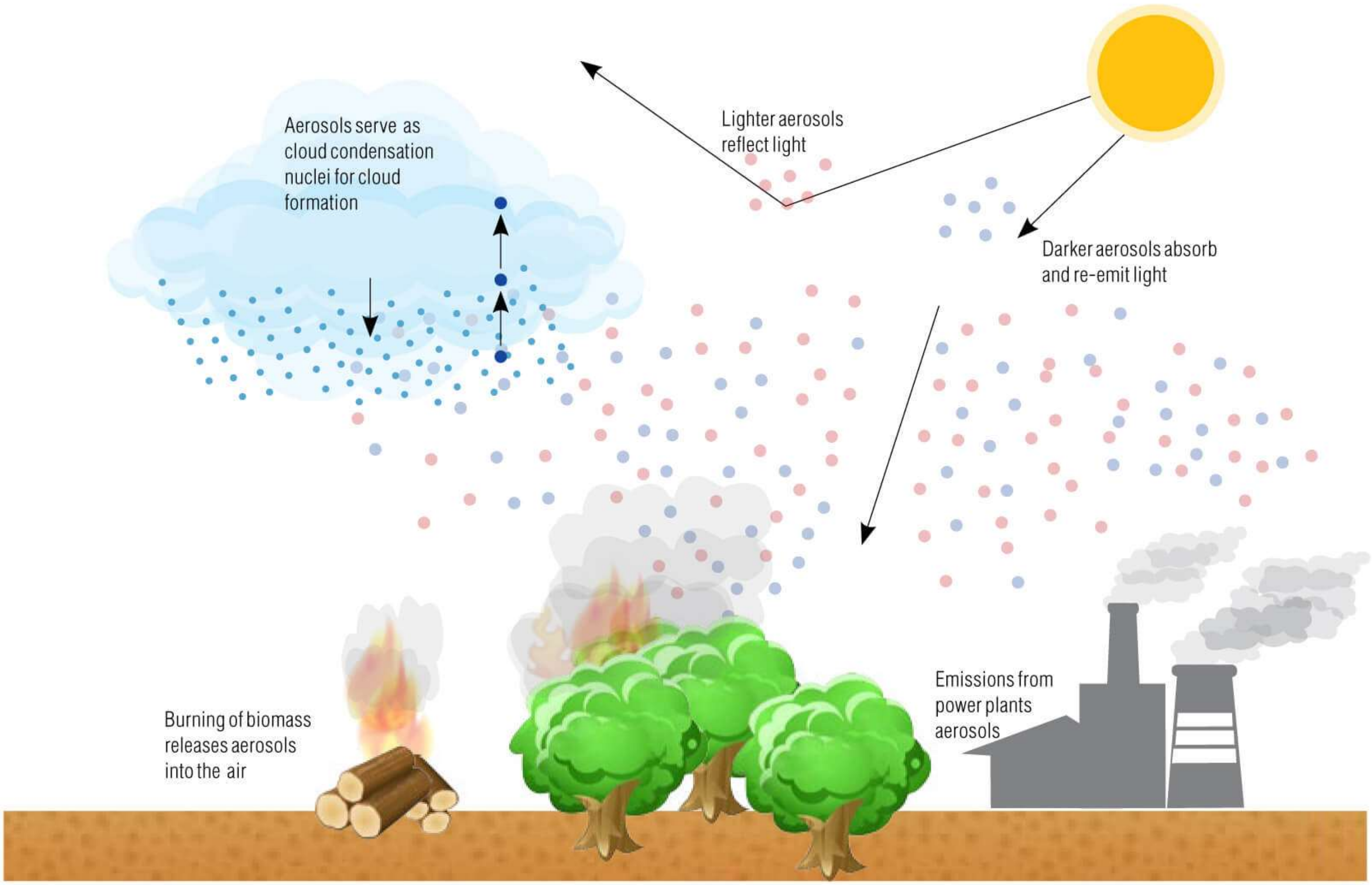
Dr. Raji P

Lecture-7

Class outline

- Aerosols
- Advantages of aerosols
- Forms of aerosols
- Sources of aerosols
- Black carbon & sources of black carbon
- Removal of aerosols
- Influence on Indian Monsoon

Aerosols



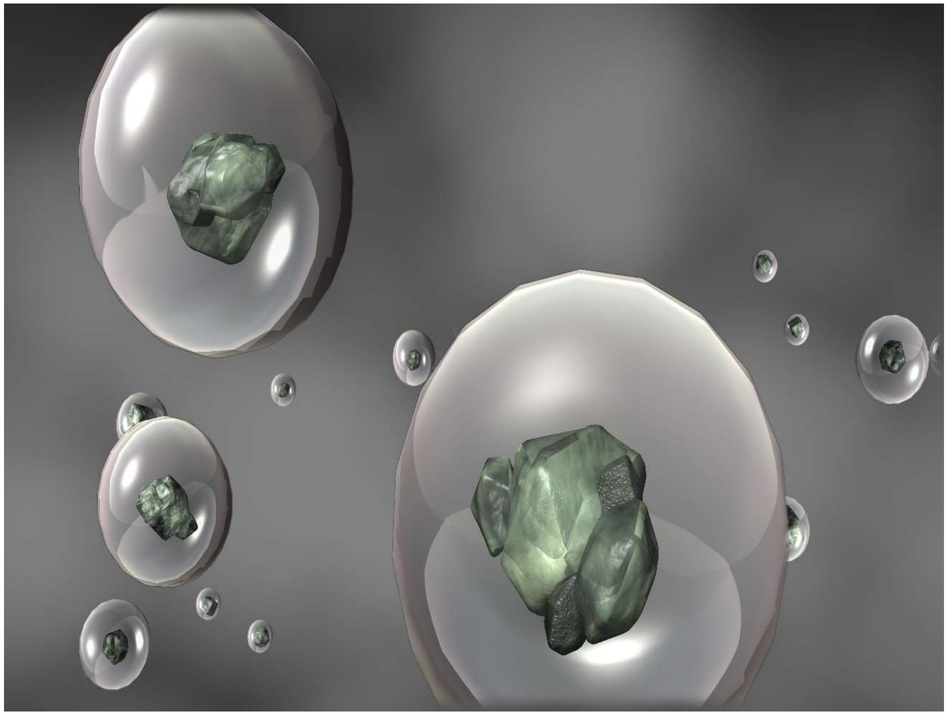
Aerosols serve as cloud condensation nuclei for cloud formation
Lighter aerosols reflect light
Darker aerosols absorb and re-emit light
Burning of biomass releases aerosols into the air
Emissions from power plants aerosols

What are aerosols?

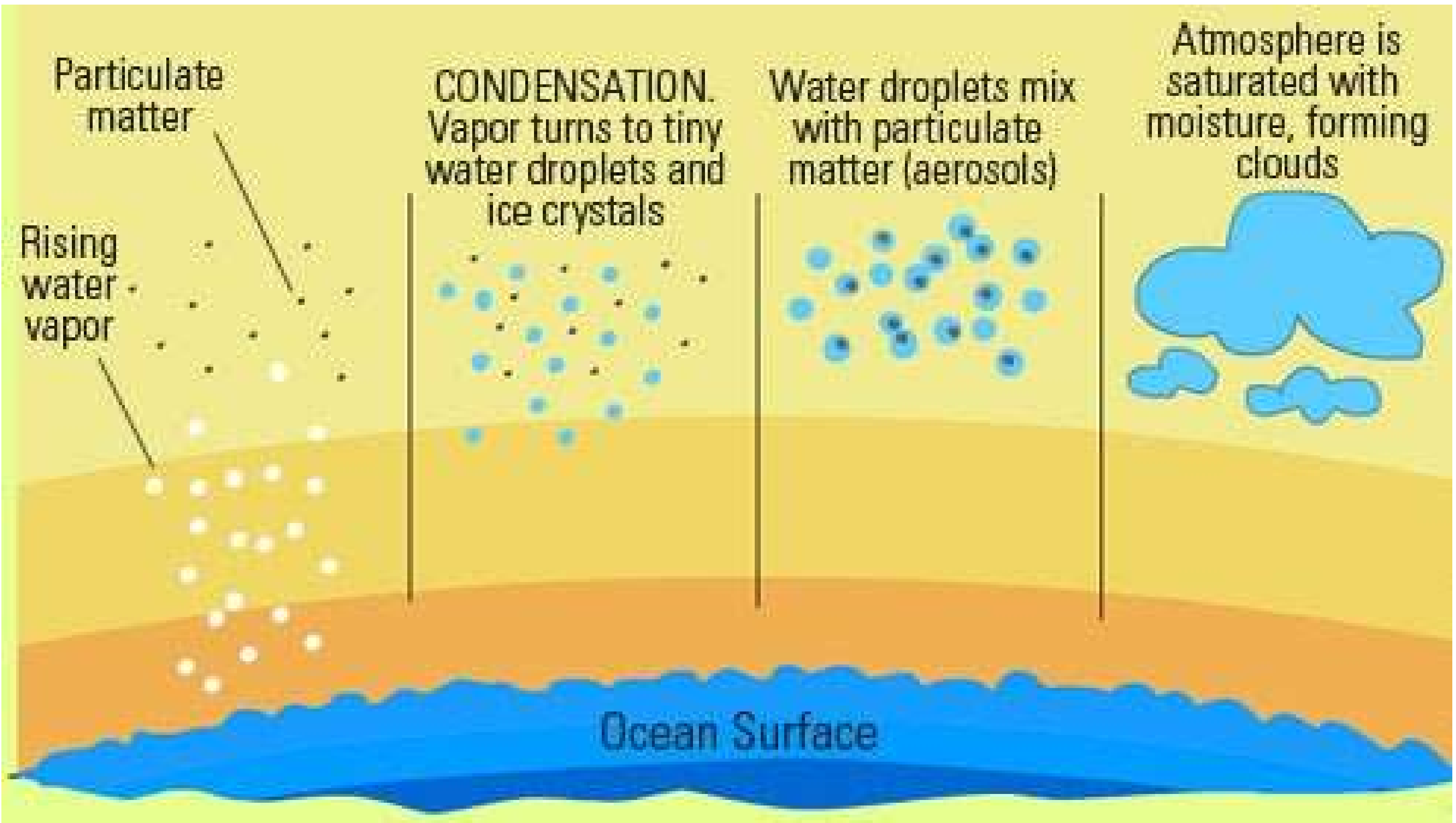
- Aerosols/particulates are microscopic particles of solid or liquid matter suspended in the air/gas
- Aerosols occur in both the troposphere and the stratosphere, but there are considerable differences in the size ranges, chemical nature and sources of the aerosols
- Aerosol is to be stable for few seconds to several months
- Aerosol includes particles size: 0.002 to more than 100µm

How aerosols are useful?

How aerosols help in cloud formation?



Cloud formation



Presence of aerosols in the atmosphere and its consequences

- Aerosols have important consequences for global climate, ecosystem processes, and human health

- Aerosols affect the earth-atmosphere radiation budget and leads to

  - ✓ Direct effects - scattering and absorption of solar radiation

  - ✓ Indirect effects- caused by changes in cloud characteristics

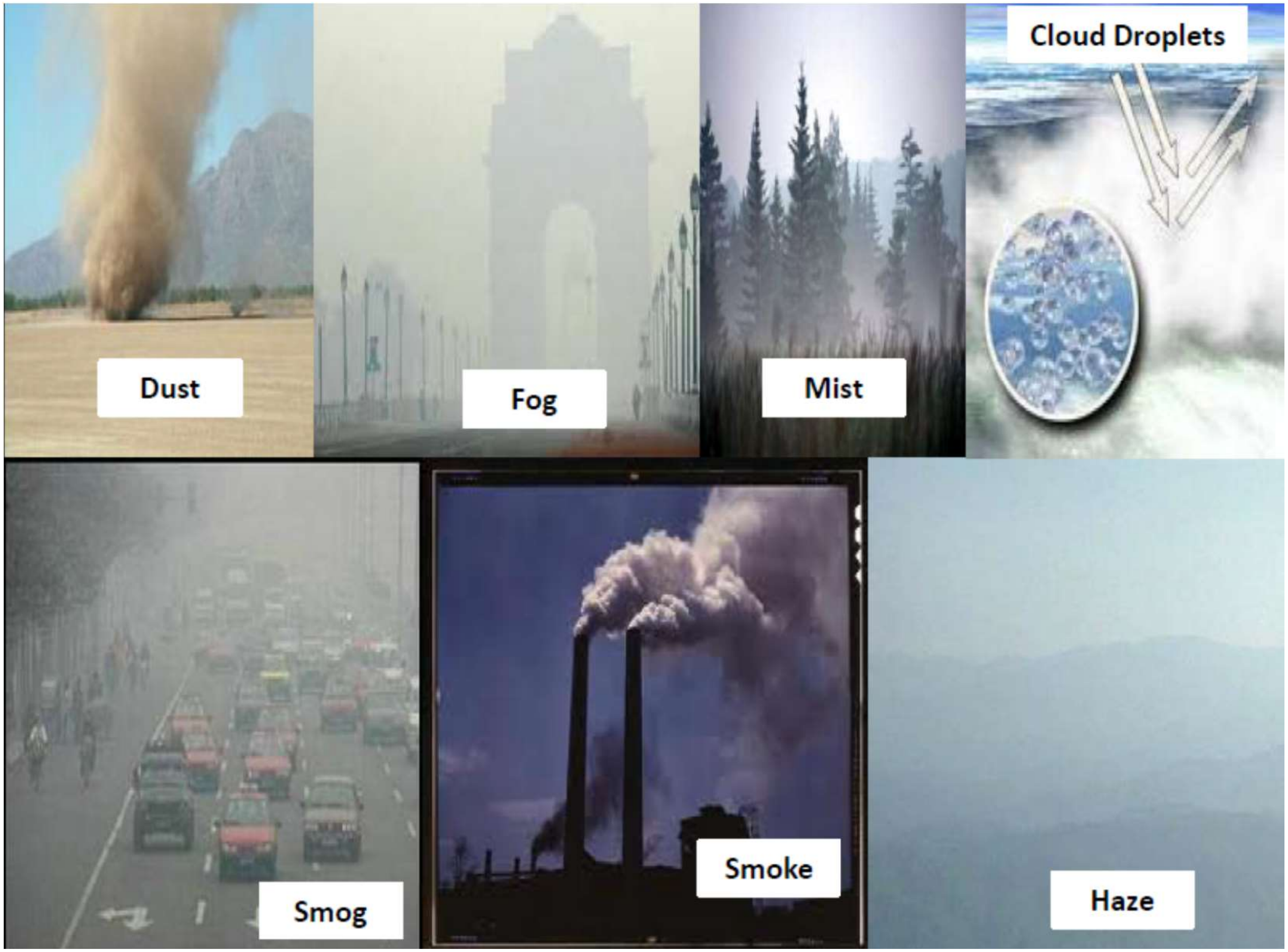
- Dust particles near the surface are usually very large, often about 0.1–1 mm
- They do not stay very long nor can they reach high into the atmosphere
- Aerosol particles present at higher levels are much smaller and are able to stay much longer in the atmosphere to have important impacts

Classifications of aerosols baesd on size:

(1) Aitken particles – radius < 0.1 µm

(2) Large particles – radius $0.1 \leq r \leq 1.0$ µm

(3) Giant particles – radius > 1.0 µm


Dust
Fog
Mist
Cloud Droplets
Smog
Smoke
Haze

Forms of aerosols

Dust: Solid particles formed by mechanical breakage of parent materials or crushing (size>1μm)

Fumes: Particles formed by condensation or chemical reaction (<1μm)

Fog: Suspension of water droplets (2 to 15 μm)

Mist: Suspension of droplets and they affect visibility >1 km (<0.5 μm)

Smog: Consists of solid and liquid particles formed by the presence of sunlight and vapour (0. 3-1.0 µm)

Smoke: Visible aerosol from incomplete combustion (<1µm)

Cloud: Visible aerosol with defined boundaries

Haze: Visibility reducing aerosol with fine suspended particles (0.02 to 0.06 µm)

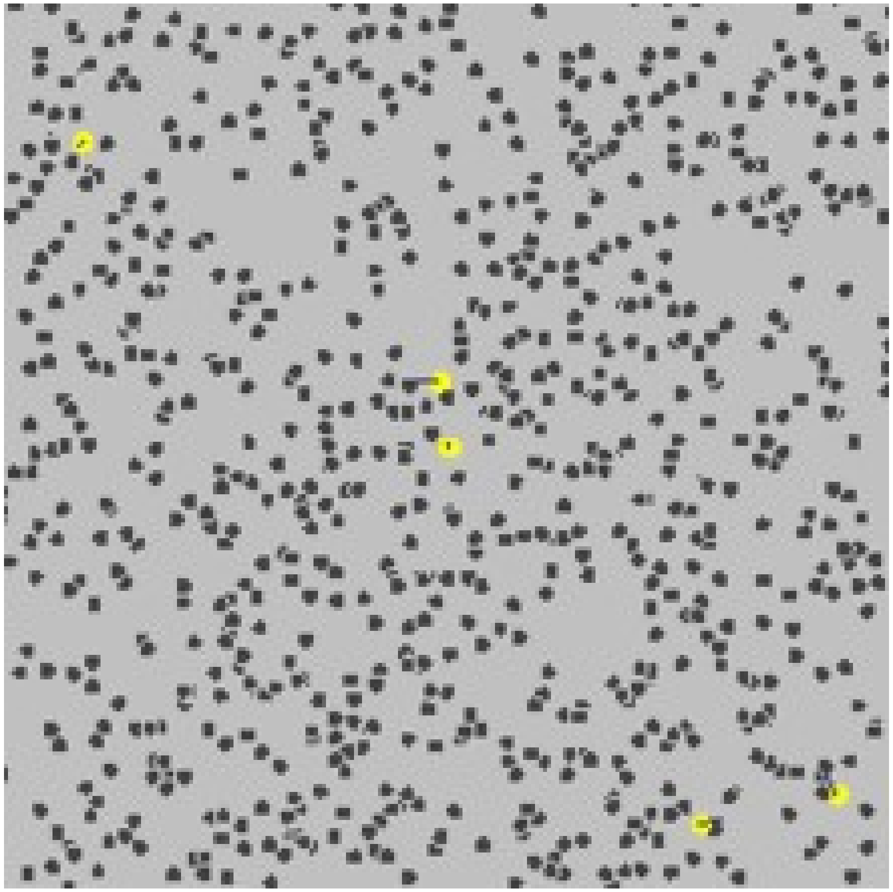
Concentration of aerosols

- Aerosol concentration varies from place to place, and also varies with height

- The total concentration of aerosol particles in the lower atmosphere is maximum near the surface and it decreases with height (altitude)

Movement of aerosols & its concentration

Brownian coagulation



- Most aerosol particles are much smaller than cloud droplets and can be influenced easily by the constant bombardment of air molecules and perform random motions called Brownian motion

- Brownian motion is especially pronounced for particles $<0.5\ \mu m$ because of their small size, and they can collide and coagulate to form larger particles

Aging of aerosols

Types of aerosols based on source

Primary: They directly reaches to the atmosphere (wind action, burning etc)

Secondary: Forms from the atmosphere itself- Gas to particle conversion (GPC) and drop to particle conversion (DPC)

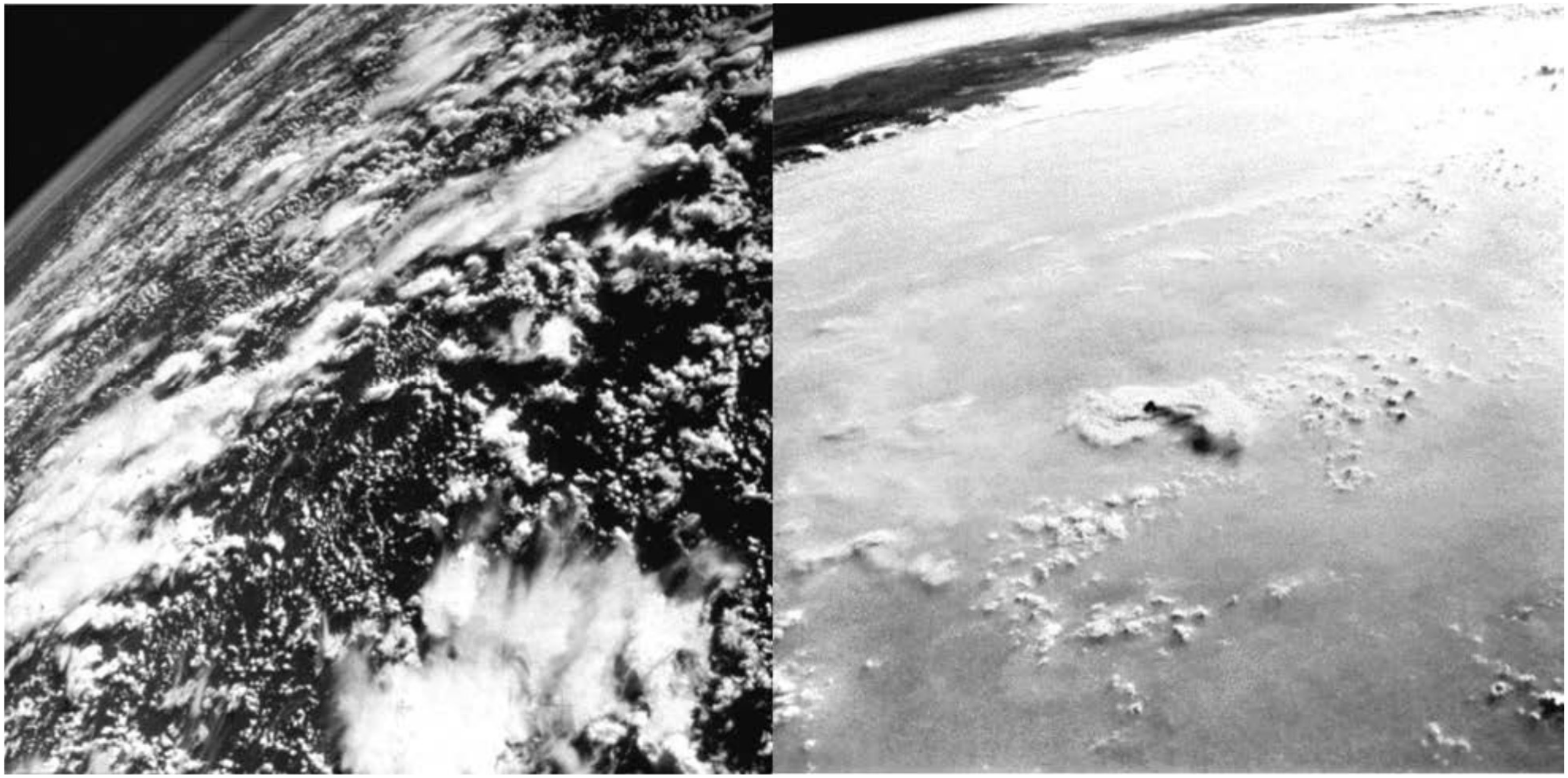
Major sources of aerosols from the Earth surface

Dust storms

- A dust storm (sandstorm) is a meteorological phenomenon common in arid and semi-arid regions
- Dusts can travel thousands of kilometers and inject a huge number of aerosol particles into the atmosphere
- Clay particles such as SiO_2, Al_2O_3, Fe_2O_3, and MgO

Biomass burning

- Natural or man-made fires that destroy large areas of forests and other vegetated surfaces – Biomass burning
- Large-scale biomass burning can cause significant changes in local albedo (will increase)



Satellite images of the Amazon basin area during (left) a day with no biomass burning and (right) a day with massive biomass burning (Source: NASA)

- The air became opaque due to strong reflection of sunlight by fire-produced aerosol particles

- The local albedo will increase dramatically

- Biomass burning particles are efficient cloud condensation nuclei and hence they have great impact on the global climate process through their cloud formation ability

- Biomass burning can combine with deep convective systems to create a new kind of convection system called pyrocumulonimbus (pyroCb), which can carry combustion particles into the upper troposphere and lower stratosphere

- Biomass burning particles can travel a long range, and thus may have a far greater impact on the global climate

Will aerosol travel from tropics to Antarctica?

- Biomass burning particles have been collected in Antarctica and their origin is in central Brazil (Amazon basin), a tropical region (Fiebig et al., 2009)

- Detection of aerosols in Antarctica From Long-Range Transport of the Australian Wildfires in 2009 (Jumelet et al., 2020)

- Tropical biomass burning particles, and whatever climatic implications they have, can reach the polar regions in a short time

Volcanic activity

Eruption of Mt. Pinatubo, Philippines on 12 June 1991

- The volcanic eruption was a near-vertical one and the plumes reached the stratosphere (up to 24 km)
- They inject directly into the atmosphere not only aerosol particles but a large amount of other gases as well
- The most abundant volcanic gas turns out to be water vapor, followed by CO_2 and SO_2
- Among these gases, SO_2 is the precursor for the formation of sulfate aerosols

- In the Mt. Pinatubo eruption, SO_2 injection is estimated at more than 2×10^7 tons

- Pure sulfates and nitrates reflect nearly all radiation they encounter, cooling the atmosphere

- Black carbon absorbs radiation readily, warming the atmosphere but also shading the surface

- Sulphates also delay formation of stratospheric ozone

- Sulfate aerosols are believed to survive in the atmosphere for about 3-5 days

Human industrial activity

- Aerosol particles from by burning fuels (wood, coal, etc.) to obtain energy-produces smoke

- The most conspicuous particle sources due to industry are the thick smoke coming out of numerous tall stacks in the world's industrial complexes

- The most common outputs from these stacks are sulfates and black carbon

- SO_2 produced by burning fossil fuels is a common precursor that usually ends up as sulfate particles through DPC or GPC

- Another familiar aerosol production due to human activity is the photochemical smog in big cities

- This is mainly due to high automobile traffic volumes that produce large amounts of nitrogen oxides, which, in the presence of sunlight, produce ozone, several radicals, and some stable products

Ocean surface process

Ocean surface process

- Aerosol particles produced over the ocean surface are largely NaCl particles, smaller amounts of K^+, Mg^{2+},CO_3^{2-} ; and SO_4^{2-}, organic and biological materials
- The production of sea salt particles is due to the bubble burst mechanism (also called sea spray mechanism)

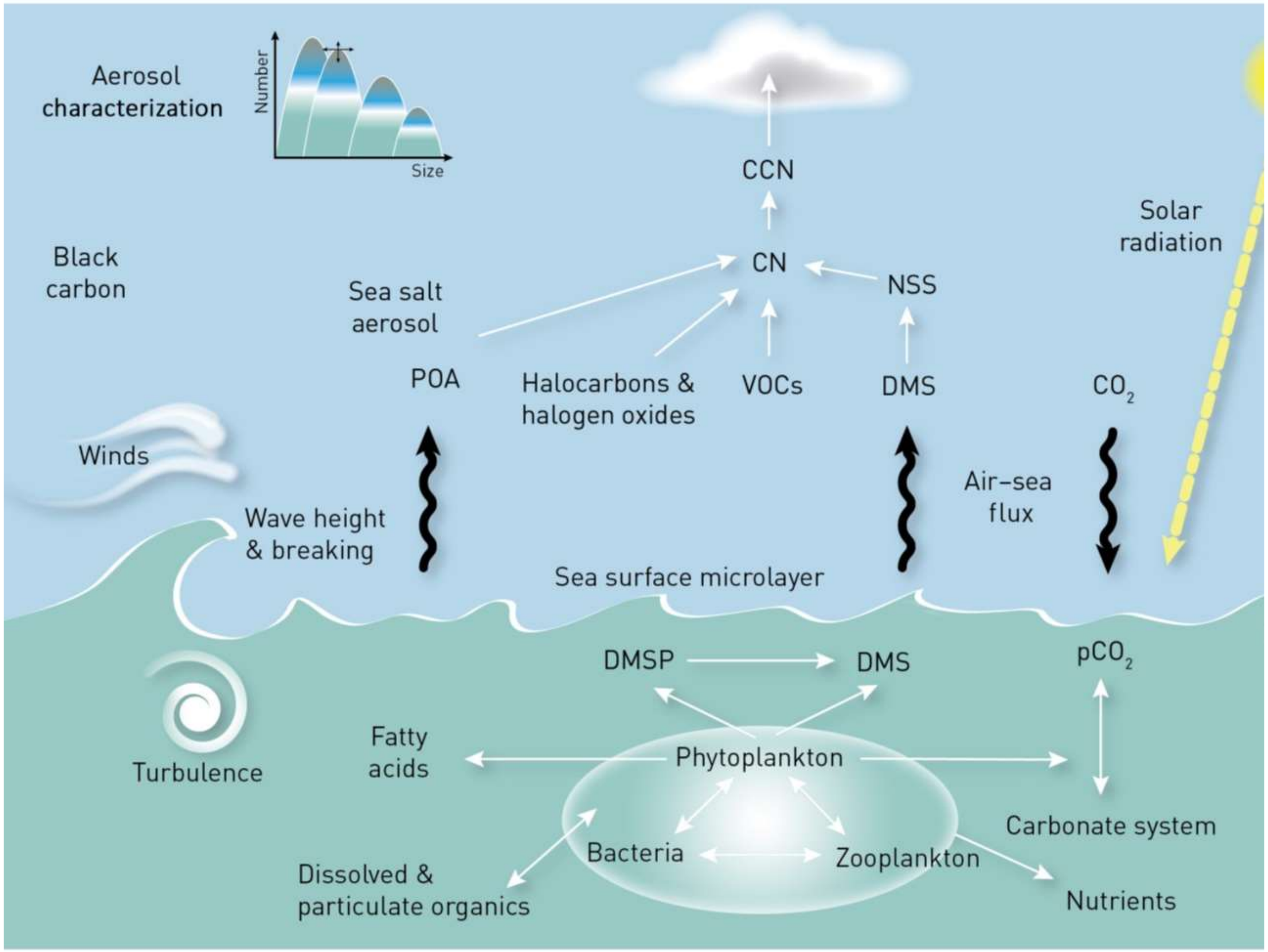
- The sea surface is constantly subject to winds, air is trapped in the surface layer to form bubbles

- Sea salt aerosol particles form in two stages of the burst process

- First, when a bubble rises to the top of the surface, its cap becomes a very thin film

- This eventually ruptures to form numerous mini-droplets that fly into the air

- Some of these film droplets eventually evaporate to leave dry sea salt particles that may be carried up higher by winds



Aerosol characterization
Number
Size
CCN
Solar radiation
Black carbon
CN
NSS
Sea salt aerosol
POA
Halocarbons & halogen oxides
VOCs
DMS
CO_2
Winds
Air–sea flux
Wave height & breaking
Sea surface microlayer
DMSP
DMS
pCO_2
Fatty acids
Phytoplankton
Turbulence
Carbonate system
Bacteria
Zooplankton
Dissolved & particulate organics
Nutrients

Biogenic aerosol

- Aerosol particles are produced by biological systems during their life cycle and plants are the main source of these biogenic aerosols

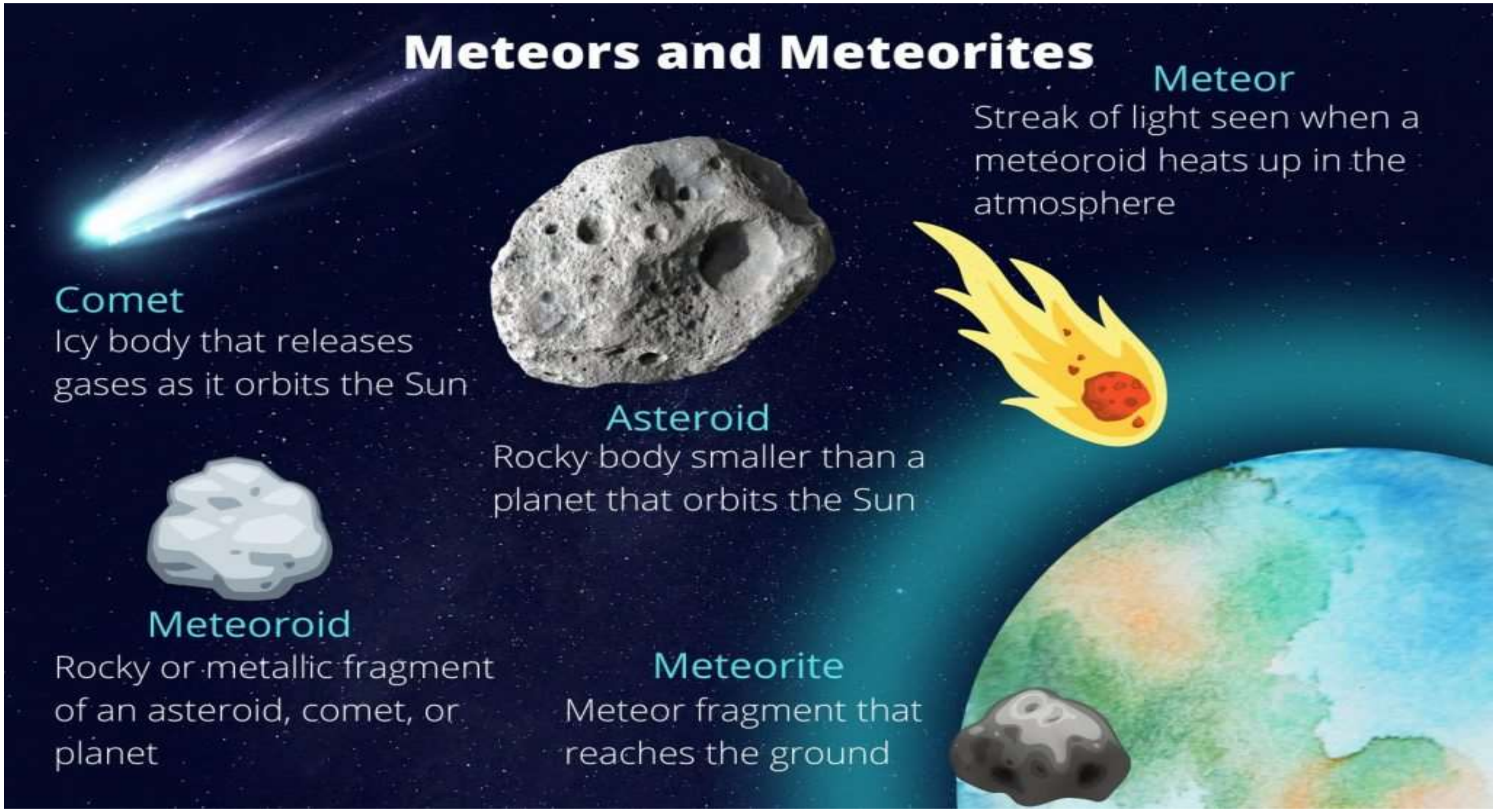
- Pollens released by the flowers of various plants are spread in the air during pollination to become aerosol particles

- They are typically about 10 μm or larger in size

- Some of these biogenic aerosol particles may serve as efficient nuclei for condensation and freezing

- Measurements in the Amazon basin by Pöschl et al. (2010) showed that sub-micrometer biogenic aerosol particles are the main cloud condensation nuclei during the wet season in contrast to the dry season, when the biomass burning particles dominate the condensation

Natural Sources -Extraterrestrial sources



- The Earth’s atmosphere is constantly bombarded by meteoroids, which are basically rocks of various sizes

- Some are larger than a few centimeters but most are probably just of dust particle size

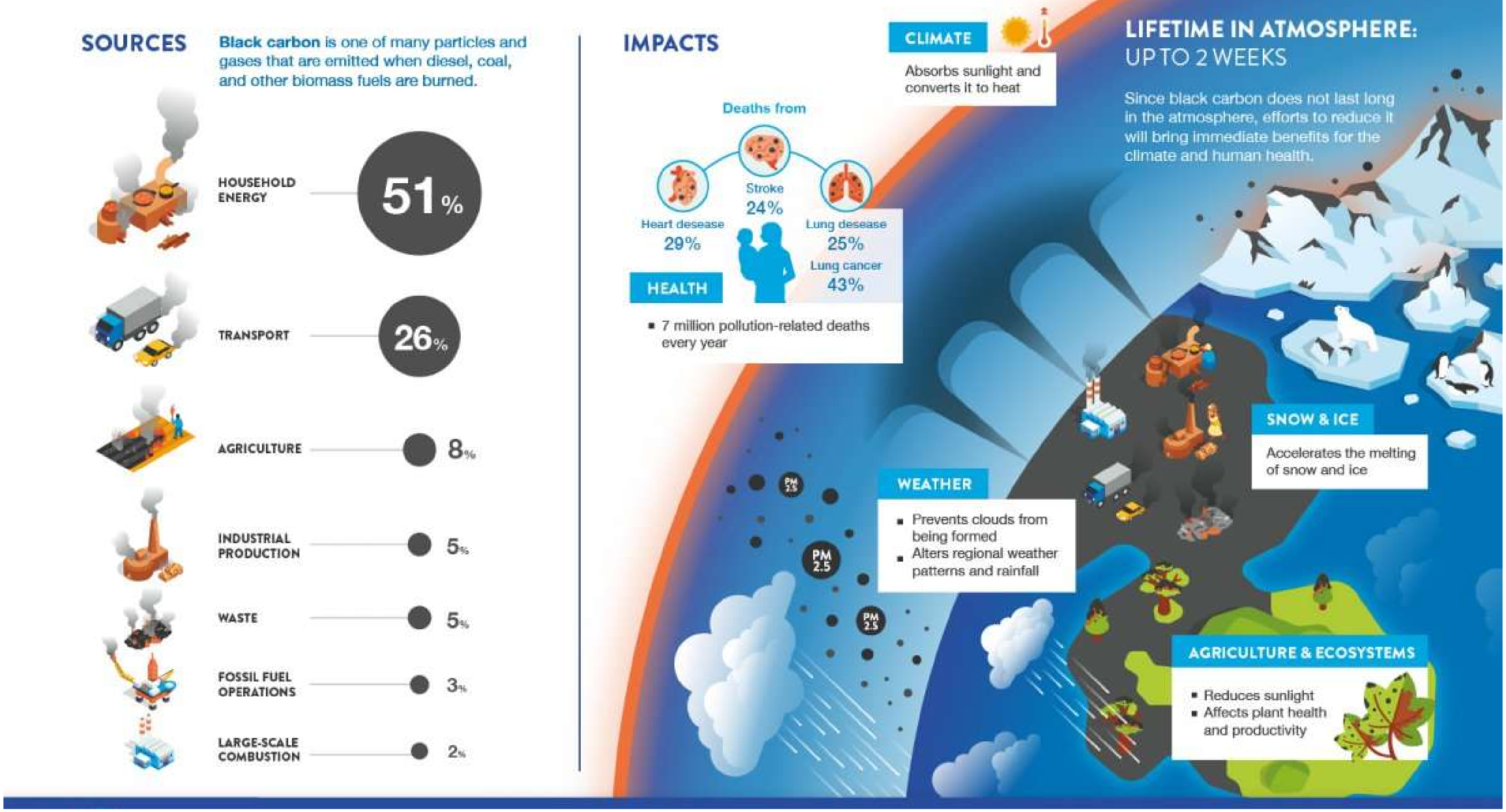
- These rocks are widely distributed in the interplanetary space in the Solar System and are attracted to the Earth by the gravitational force if their orbits happen to intercept that of the Earth

- Meteoric aerosols are known to contain elements such as Fe, Si, Mg, S, Ca, Ni, Al, Cr, Mu, Cl, K, Ti, and Co

Black carbon

BLACK CARBON (BC)

Black carbon, or soot, is part of fine particulate air pollution ($PM_{2.5}$) and contributes to climate climate.



- Aerosol BC is released from the incomplete combustion of fossil fuels, bio-fuels and biomass

- It exerts considerable influence on regional precipitation and surface cooling, northern hemispheric tropical expansion, Arabian Sea tropical cyclones and the hydrological cycle in general

- Among aerosol chemical constituents, black carbon (BC) is the most potent climate forcing agent with a radiatve forcing (RF) estimate of +1.1 (+0.17 to +2.1) W m^{-2} which is around ~65% of that of CO_2

- Its atmospheric residence time: 6-10 days

- India is the 2nd largest emitter of BC in the world, with emissions projected to rise steadily in the coming decades

- Its emission estimate: 400 Gg y^{-1} in 1997 to 901 Gg y^{-1} in 2011

- It is projected that overall BC emissions from India are likely to increase in the future with a projected emission of 1227 Gg y^{-1} in 2030

- Unlike developed economies (USA, UK and Europe) where aerosol BC is predominantly sourced from on-road and off-road diesel engines

- Indian BC emissions are from low efficiency combustion of domestic fuels (425 Gg y^{-1} in 2011; 47% of total) followed by industrial emissions (198 Gg y^{-1} in 2011; 22% of total)

Removal mechanism of aerosol

- The pathways via which aerosol particles are removed from the atmosphere can be divided into two broad categories – dry removal and wet removal

- Dry removal mechanisms are those not involving cloud and precipitation processes, while wet removals are those related to clouds and precipitation

Dry removal

- Aerosol particles can stay afloat by updrafts that are strong enough to support them
- If the updraft weakens or disappears, particles will go down to the surface by the pull of gravity of the Earth –gravitational settling
- The settling velocity of an aerosol particle depends on the density and size of the particle and where it is located in the atmosphere
- Settling time-exercise

Attachment on obstacle surfaces

- Aerosol particles carried by air flow can become attached to the surface of plants, buildings or other obstacles above the ground either by their own Brownian motion, electrostatic forces, interception or inertial impaction

Particle coagulation

- Small particles collide and stick together to become larger particles

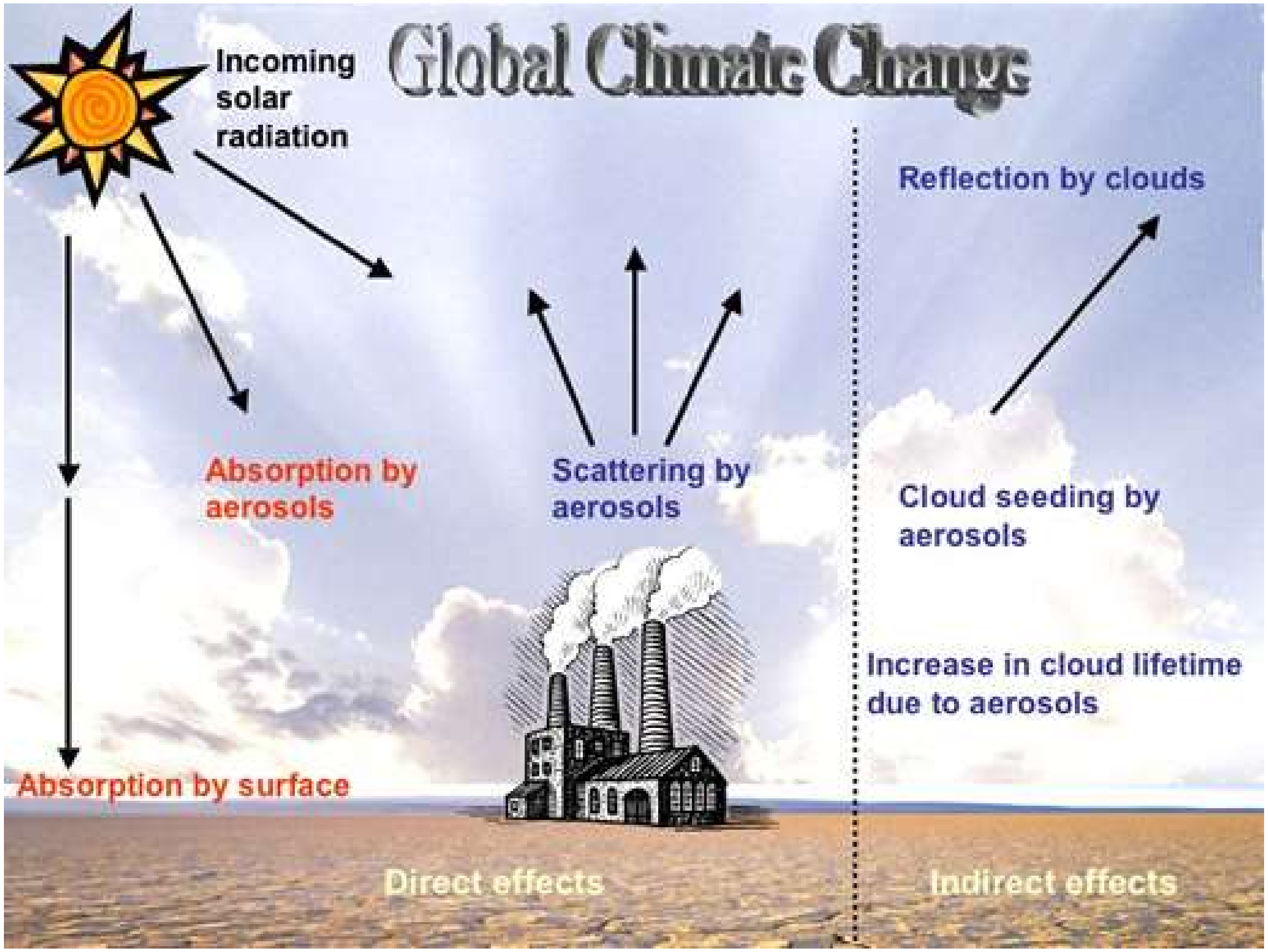
- In accounting for the aerosol budget, coagulation causes particle concentration to decrease and also the coalesced particles are "removed" from their original size categories, so it should be considered as a sink of aerosol particles

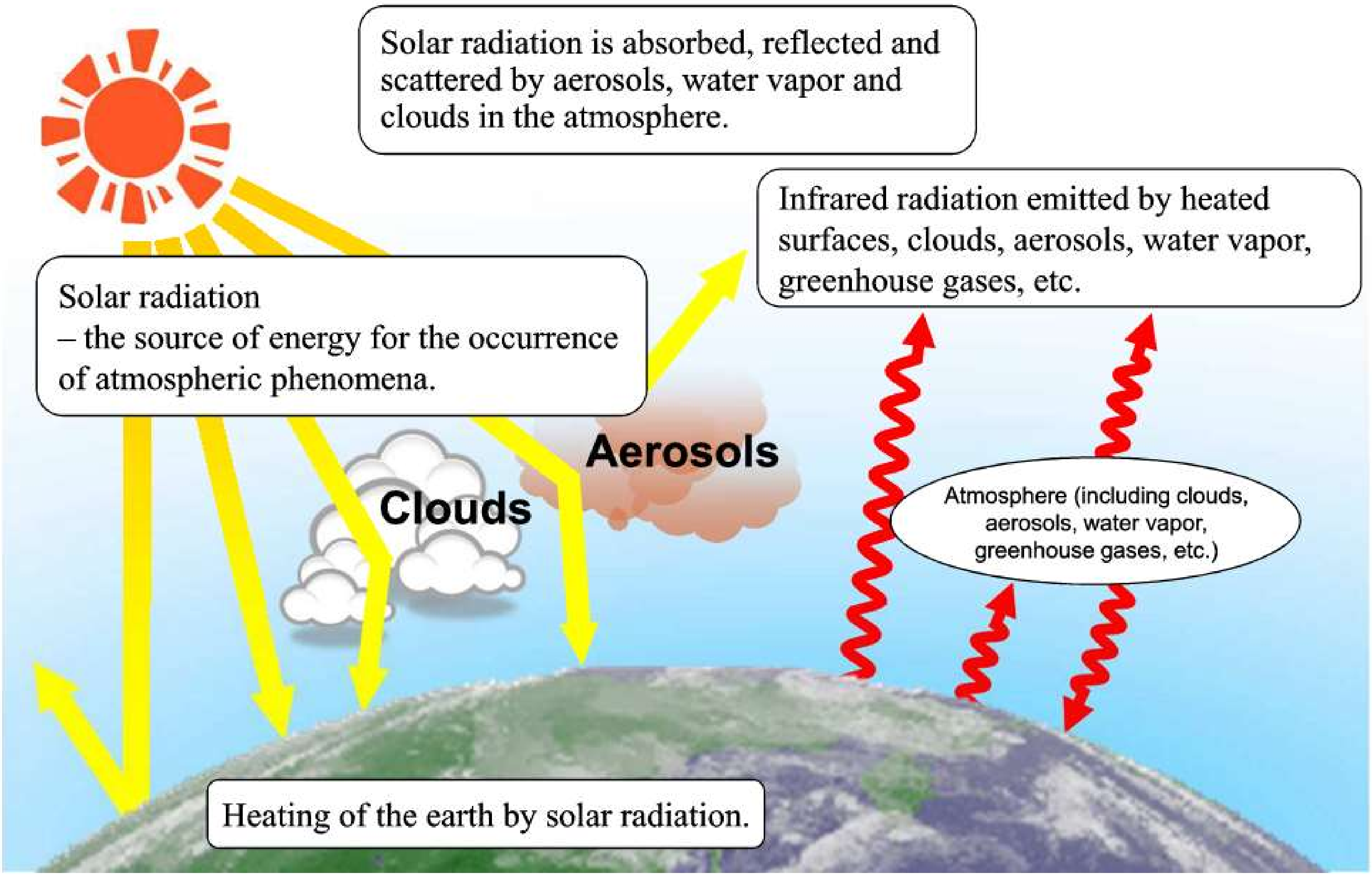
Wet removal

Cloud and precipitation processes are the most efficient way to remove aerosol particles from the atmosphere, and the process that removes aerosol particles is wet removal, also called precipitation scavenging

Aerosol & Climate

How aerosol affect climate?




Solar radiation is absorbed, reflected and scattered by aerosols, water vapor and clouds in the atmosphere.
Solar radiation – the source of energy for the occurrence of atmospheric phenomena.
Infrared radiation emitted by heated surfaces, clouds, aerosols, water vapor, greenhouse gases, etc.
Aerosols
Clouds
Atmosphere (including clouds, aerosols, water vapor, greenhouse gases, etc.)
Heating of the earth by solar radiation.

- All atmospheric aerosols scatter incoming solar radiation, and a few aerosol types can also absorb solar radiation

- BC is the most important of the latter, but mineral dust and some OC components are also sunlight absorbers

- Aerosols that mainly scatter solar radiation have a cooling effect, by enhancing the total reflected solar radiation from the Earth

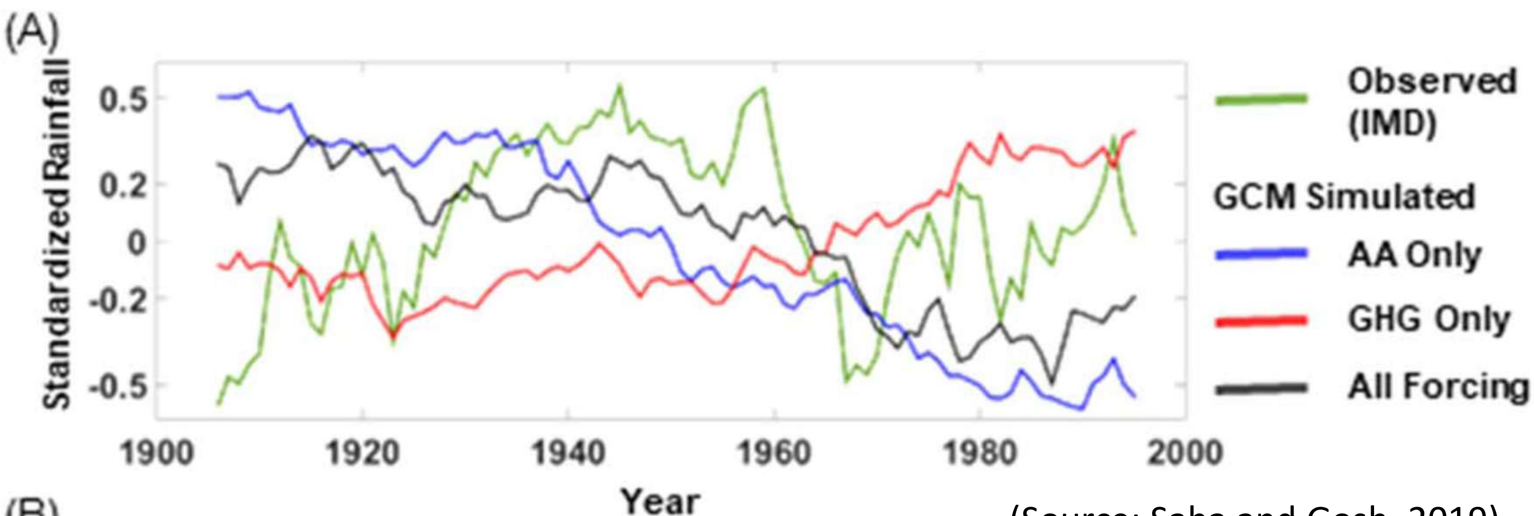
- Strongly absorbing aerosols have a warming effect

- In the atmosphere, there is a mixture of scattering and absorbing aerosols, and their net effect on Earth's energy budget is dependent on surface and cloud characteristics

Aerosol and Indian Monsoon

Can the weakening of Indian Monsoon be attributed to anthropogenic aerosols?

- The greenhouse gas (GHG)-induced warming of the Indian Ocean, as well as the direct and indirect effects of anthropogenic aerosols have been documented as possible reasons for weakening of Indian monsoon



(Source: Saha and Gosh, 2019)

Effects of Black Carbon Aerosols on the Indian Monsoon

- Observed decreases of rainfall over parts of India due to BC aerosols (Meehl et al., 2008)

Aerosols cause intraseasonal short-term suppression of Indian monsoon rainfall

- The causal influence of aerosols on precipitation suppression is relevant to the inter-annual variability of monsoon precipitation and the timing of monsoon break spells

- Prolonged and intense breaks in the monsoon were associated with rainfall deficits, which have been linked to reduced food grain production during latter half of the twentieth century

- Thus, aerosol-induced precipitation suppression and aggravation of break spells, uncovered here, could influence future rainfall deficits and agricultural vulnerability in India

(Source: Dave et al., 2017)