Arbaminch Water Technology Institute
Faculty of Meteorology and Hydrology

Climate change: Impact, adaptation &Mitigation

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Coupling between Changes in the Climate System and Biochemistry

Lecture Note 4:

- Terrestrial Ecosystems and Climate
- Ocean Ecosystems and Climate
- Atmospheric Chemistry and Climate
- Aerosol Particles and Climate
- Coupling the Biogeochemical Cycles with the Climate System
- The Changing Land Climate System
- Dependence of Land Processes and Climate on Scale
- Aspects of climate change

Introduction

- The Earth's climate is determined by a number of complex connected physical, chemical and biological processes occurring in the atmosphere, land and ocean

- The radiative properties of the atmosphere, a major controlling factor of the Earth's climate,

- are strongly affected by the biophysical state of the Earth's surface and by the atmospheric abundance of a variety of trace constituents.

- These constituents include long-lived greenhouse gases (LLGHGs) such as carbon dioxide (Co_2),
- methane (CH_4) and nitrous oxide (N_2o),
- as well as other radiatively active constituents such as ozone and different types of aerosol particles.
- The composition of the atmosphere is determined by processes such as natural and anthropogenic emissions of gases and aerosols,
- transport at a variety of scales, chemical and microphysical transformations,

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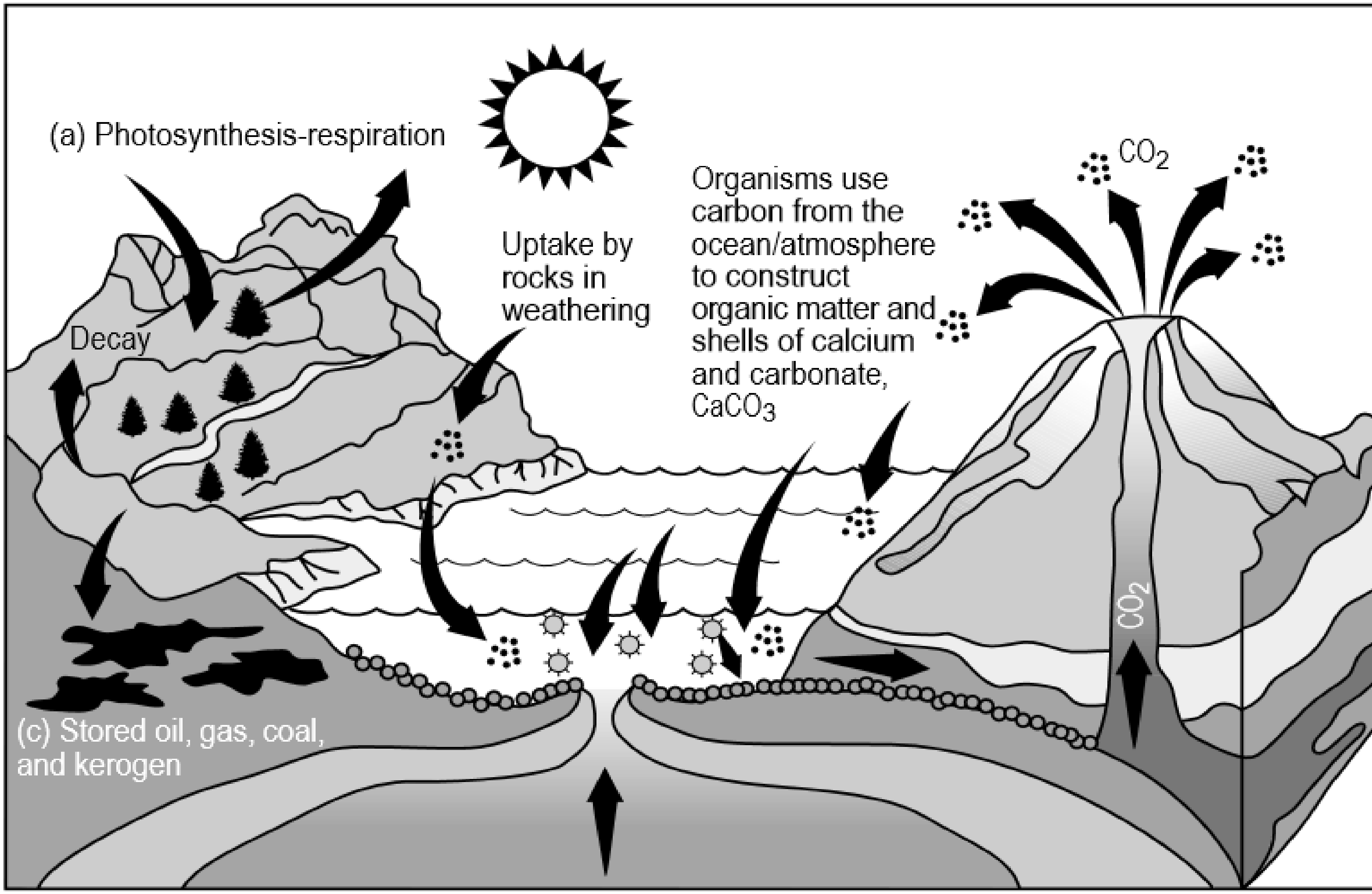
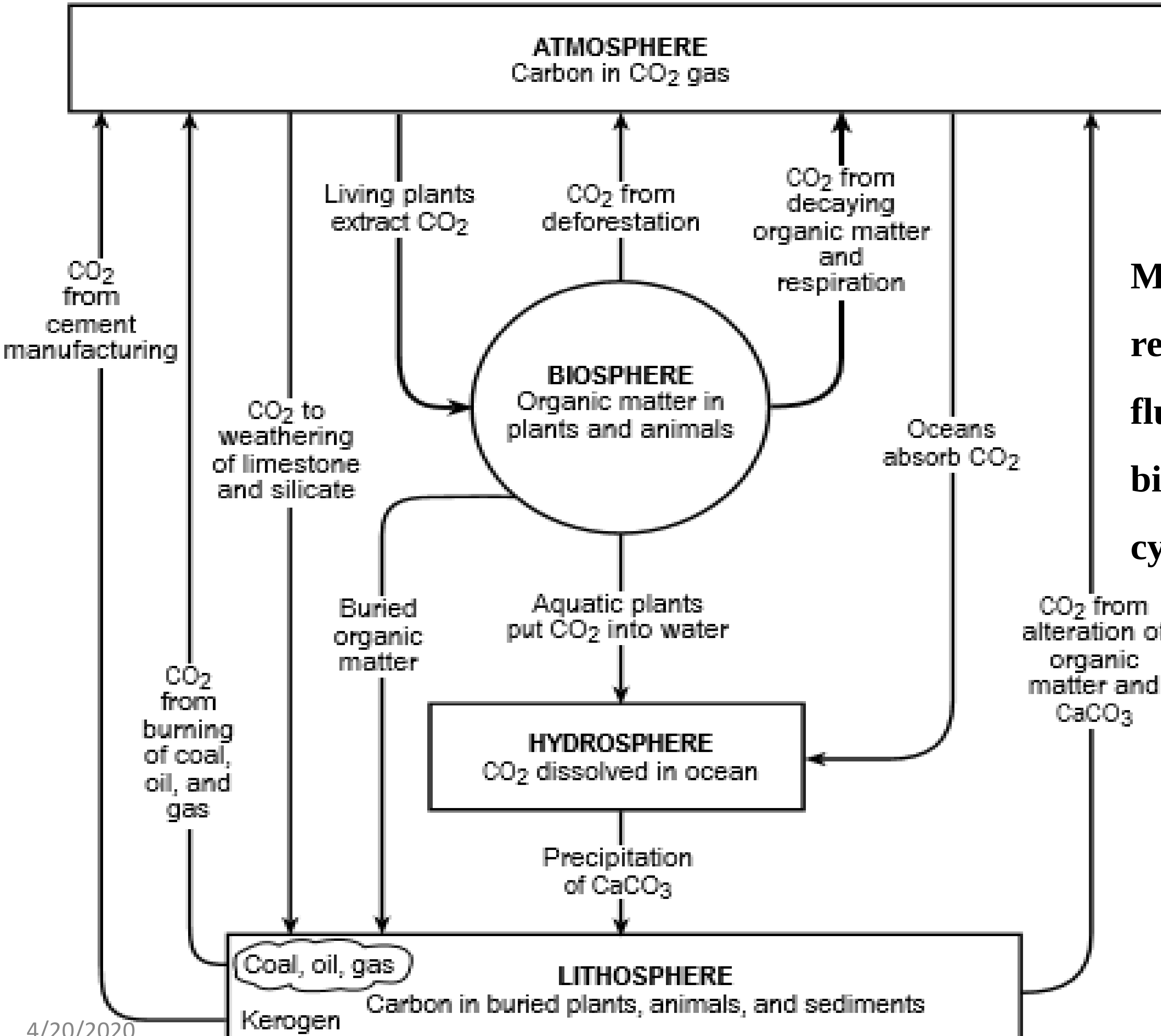
- wet scavenging and surface uptake by the land and terrestrial ecosystems, and by the ocean and its ecosystems.

➢ These processes and, more generally the rates of biogeochemical cycling, are affected by climate change,

- and involve interactions between and within the different components of the Earth system.
- These interactions are generally nonlinear and may produce negative or positive feedbacks to the climate system.



- Figure. The global biogeochemical cycle of carbon prior to human interference



Major reservoirs & fluxes in the biogeochemical cycle of carbon

1.Terrestrial Ecosystems and Climate

- The terrestrial biosphere interacts strongly with the climate, providing both positive and negative feedbacks due to biogeophysical and biogeochemical processes.

- Some of these feedbacks, at least on a regional basis, can be large.

- Surface climate is determined by the balance of fluxes, which can be changed by radiative (e.g., albedo) or non-radiative (e.g., water cycle related processes) terms.

- Both radiative and non-radiative terms are controlled by details of vegetation.
- High-latitude climate is strongly influenced by snow albedo feedback, which is drastically reduced by the darkening effect of vegetation.
- In semi-arid tropical systems, such as the Sahel or northeast Brazil, vegetation exerts both radiative and hydrological feedbacks.
- Surface climate interacts with vegetation cover, biomes, productivity, respiration of vegetation and soil, and fires, all of which are important for the carbon cycle.

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- Terrestrial ecosystem photosynthetic productivity changes in response to changes in temperature, precipitation, Co_2 and nutrients.
- If climate becomes more favorable for growth (e.g., increased rainfall in a semi-arid system),
- productivity increases, and carbon uptake from the atmosphere is enhanced.

2.Ocean Ecosystems and Climate

- The functioning of ocean ecosystems depends strongly on climatic conditions including
- near-surface density stratification,
- ocean circulation, temperature, salinity, the wind field and sea ice cover.
- In turn, ocean ecosystems affect the chemical composition of the atmosphere (e.g. Co_2, N_2o, oxygen (o_2), dimethyl sulphide (DMS) and sulphate aerosol).

- Most of these components are expected to change with a changing climate and high atmospheric Co_2 conditions.
- Marine biota also influence the near-surface radiation budget through changes in the marine albedo and absorption of solar radiation (biooptical heating).
- Feedbacks between marine ecosystems and climate change are complex because most involve the ocean's physical responses and feedbacks to climate change.

- Increased surface temperatures and stratification should lead to increased photosynthetic fixation of Co_2,
- but associated reductions in vertical mixing and overturning circulation may decrease the return of required nutrients to the surface ocean and
- alter the vertical export of carbon to the deeper ocean.

3.Atmospheric Chemistry and Climate

- Interactions between climate and atmospheric oxidants, including ozone, provide important coupling mechanisms in the Earth system.

- The concentration of tropospheric ozone has increased substantially since the pre-industrial era,
- especially in polluted areas of the world, and has contributed to radiative warming.

- Emissions of chemical ozone precursors (carbon monoxide, CH_4, non-methane hydrocarbons, nitrogen oxides)
- have increased as a result of larger use of fossil fuel, more frequent biomass burning and more intense agricultural practices.
- The atmospheric concentration of pre-industrial tropospheric ozone is not accurately known, so that the resulting radiative forcing cannot be accurately determined, and must be estimated from models.

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- Changes in atmospheric chemical composition that could result from climate changes are even less well quantified.
- Photochemical production of the hydroxyl radical (OH),
- which efficiently destroys many atmospheric compounds,
- occurs in the presence of ozone and water vapour, and
- should be enhanced in an atmosphere with increased water vapour, as projected under future global warming.

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- Other chemistry-related processes affected by climate change include the frequency of
- lightning flashes in thunderstorms (which produce nitrogen oxides),
- scavenging mechanisms that remove soluble species from the atmosphere, the intensity and frequency of convective transport events,
- the natural emissions of chemical compounds
- (e.g., biogenic hydrocarbons by the vegetation, nitrous and nitric oxide by soils).

4.Aerosol Particles and Climate

- Atmospheric aerosol particles modify Earth's radiation budget by

- absorbing and scattering incoming solar radiation.
- Even though some particle types may have a warming effect, most aerosol particles,
- such as sulphate (SO4) aerosol particles, tend to cool the Earth surface by scattering some of the incoming solar radiation back to space.

- In addition, by acting as cloud condensation nuclei, aerosol particles affect radiative properties of clouds and their lifetimes,
- which contribute to additional surface cooling.
- A significant natural source of sulphate is DMS, an organic compound whose production by phytoplankton and release to the atmosphere depends on climatic factors.
- In many areas of the Earth, large amounts of SO4 particles are produced as a result of human activities (e.g., coal burning).

- Other indirect effects of aerosols on climate include the evaporation of cloud particles through absorption of solar radiation by soot,
- which in this case provides a positive warming effect.
- Aerosols (i.e., dust) also deliver nitrogen (N), phosphorus and iron to the Earth's surface;
- these nutrients could increase uptake of Co_2 by marine and terrestrial ecosystems.

5.Coupling the Biogeochemical Cycles with the Climate System

- Models that attempt to perform reliable projections of future climate changes should account explicitly for the feedbacks between climate and

- the processes that determine the atmospheric concentrations of greenhouse gases, reactive gases and aerosol particles.

- An example is provided by the interaction between the carbon cycle and climate.

- It is well established that the level of atmospheric Co_2, which directly influences the Earth's temperature,
- depends critically on the rates of carbon uptake by the ocean and the land,which are also dependent on climate.
- Climate models that include the dynamics of the carbon cycle suggest that
- the overall effect of carbon-climate interactions is a positive feedback.

6. The Changing Land Climate System

Introduction to Land Climate

- The land surface *relevant* to climate consists of
- the terrestrial biosphere, that is the fabric of soils, vegetation and other biological components,
- the processes that connect them and the carbon, water and energy they store.

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❖ The land climate consists of

- ‘internal’ variables and ‘external’ drivers,
- including the various surface energy,
- carbon and moisture stores, and
- their response to precipitation, incoming radiation and near surface atmospheric variables.

▪ The drivers and response variables change over various temporal and spatial scales.

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- This variation in time and space can be at least as important as averaged quantities.
- The response variables and drivers for the terrestrial system can be divided into biophysical, biological,
- biogeochemical and human processes

Dependence of Land Processes and Climate on Scale

- **Multiple Scales are Important**

- Temporal variability ranges from the daily and weather time scales to annual, inter annual, and decadal or longer scales:
- the amplitudes of shorter time scales change with long-term changes from global warming.
- The land climate system has controls on amplitudes of variables on all these time scales, varying with season and geography

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- On scales large enough that surface temperatures control atmospheric temperatures,
- the atmosphere will hold more water vapour and may provide more precipitation with warmer temperatures.
- Low clouds strongly control surface temperatures, especially in cold regions where they make the surface warmer.

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- In warm regions without precipitation,
- the land surface can become warmer because of lack of evaporation, or lack of clouds.
- Although a drier surface will become warmer from lack of evaporative cooling,
- more water can evaporate from a moist surface if the temperature is warmer.

- **Spatial Dependence**

- Drivers of the land climate system have larger effects at regional and local scales than on global climate, which is controlled primarily by processes of global radiation balance.

- The albedo of agricultural systems may be only slightly higher than that of forests and
- estimate that the impact since pre-agricultural times of land use conversion to agriculture on
- global radiative forcing has been only –0.09 W m^2,

- that is, about 5% of the warming contributed by Co_2 since pre-industrial times.
- Land comprises only about 30% of the Earth's surface,
- but it can have the largest effects on the reflection of global solar radiation in conjunction with changes in ice and snow cover,
- and the shading of the latter by vegetation

- The consequences of changes in atmospheric heating from land changes at a regional scale are
- similar to those from ocean temperature changes such as from El Niño,
- potentially producing patterns of reduced or
- increased cloudiness and precipitation elsewhere to maintain global energy balance.

Aspects of climate change where there is a wide consensus but continuing debate and discussion

- **The Carbon cycle and climate**

- Once atmospheric CO_2 concentrations are increased, carbon cycle models (which simulate the exchange of carbon between the atmosphere, oceans, soils and plants)
- indicate that it would take a very longtime for that increased CO_2 to disappear;
- this is mainly due to well-known chemical reactions in the ocean.

- **Natural Source and Sink of Carbon Dioxide**

(Atm. Lifetime ~ 50-200 yrs.)

✓ **Source:**

- Lithosphere: C + $O_2 \rightarrow CO_2$
- Other chemical reactions in the atmosphere.

✓ **Sink**:

- CO_2 dissolves into the oceans (and returns to the atmosphere by a reverse process)
- Photosynthesis (land biota):

$$CO_2 + H_2O + \text{sunlight} \rightarrow CH_2O + O_2.$$

- The main way anthropogenic CO_2 is removed from the atmosphere is through **oceanic uptake**.
- This occurs because CO_2 dissolves in seawater.
- The excess carbon is eventually incorporated into the skeletons of marine organisms and buried in deep sea sediments as the organisms die and fall to the bottom of the ocean.
- This process is thought to remove about 2.4 giga tons of carbon per year from the atmosphere.

- Human activity is also adding CO_2 to the atmosphere through deforestation.
- When tropical forests are clear cut, the land is typically converted to pasture.
- The original forest and its soil have much higher carbon content than the pasture land,
- so the process of burning the forest must result in a significant release of carbon to the atmosphere.

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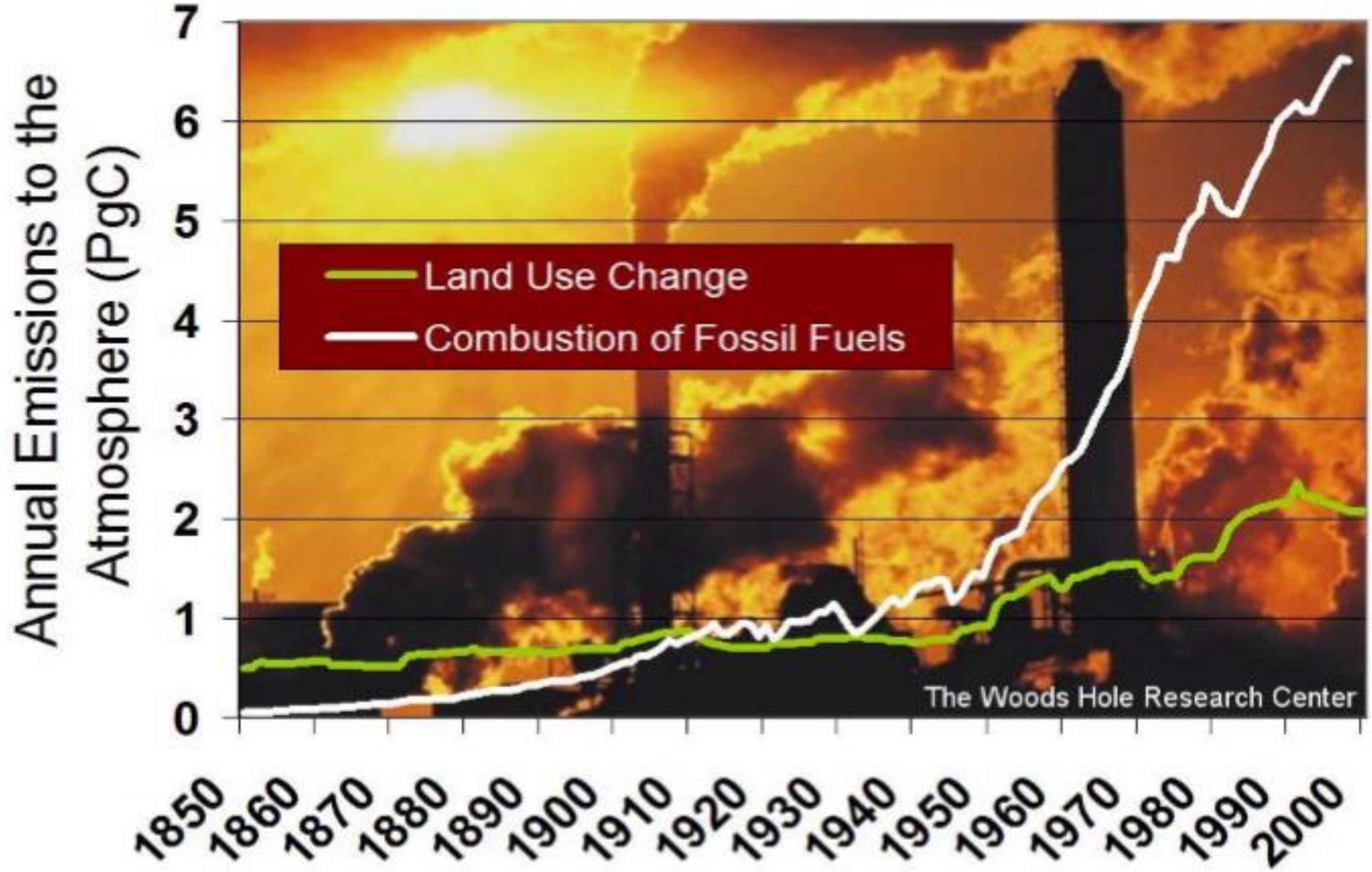
- Global carbon cycle: The burning of the forests releases carbon dioxide into the atmosphere, contributing to the increase in greenhouse gas concentrations.
- Local climate change: The loss of rain forest alters precipitation and cloud patterns.



- Deforestation is thought to be releasing about 2.2 giga tons of carbon every year into the atmosphere.

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- CO_2 fertilization

- Plants need CO_2 for photosynthesis.
- They generally obtain this CO_2 through stomata, small openings on their leaves.
- But plants also lose water, another critical substance for their survival, through their stomata.
- This makes it essential that they be able to control the size of the stomata.

Aspects of climate change on which there is wide agreement

- **Changes in global-average surface temperature**

- Measurements suitable for showing how surface temperature has changed with time across the world became available around 1850.
- Analyses of these data, in a number of institutes, try to take into account changing distributions of measurements, changing observation techniques, and changing surroundings of observing stations (e.g. some stations become more urban with time, which can make measurements from them less representative of wider areas).

- Measurements show that averaged over the globe, the surface has warmed by about 0.8^{o}C (with an uncertainty of about ±0.2^{o}C) since 1850.
- This warming has not been gradual, but has been largely concentrated in two periods,
- From around 1910 to around 1940 and from around 1975 to around 2000.
- The warming periods are found in three independent temperature records over land, over sea and in ocean surface water.

Developments in climate science

- Climate change science has advanced markedly over the past years, as a result of many factors.
- These include improved methods for handling long-term climate data sets,
- The ever-lengthening record of climate observations, improved measurement techniques, including those from satellites, better understanding of the climate system, improved methods for simulating the climate system, and increased computer power.

Thank You !!! Do it !!!