Chapter 1

Climate Change and Variability

"The Vedas describe the atmosphere as a sacred and dynamic realm, a crucial intermediary between Earth and the celestial heavens. It is a domain permeated by divine energies, influencing both nature and human existence. Through hymns and rituals, the Vedic sages acknowledged its profound significance, viewing it as essential for life, well-being, and spiritual endeavors".

1.1 Introduction to Climate Change

- Climate change is the widely accepted single largest pressing issue facing society
- Climate change has been and continues to be the principal source of fluctuations in agriculture, food production, and food security
- Throughout history, extreme events such as droughts, floods, cyclones, heat and cold waves, and various forms of extreme weather and climate caused enormous damage to the agricultural systems
- In conjunction with other physical, social, political, and economic factors, climate change contributes vulnerability to hunger, famine, dislocation, and economic losses
- Hence, it is imperative that climate change aspects are well understood to formulate more sustainable policies and strategies to promote agriculture and food production, thereby food security

- Increased emissions of Green House Gases (GHGs) through anthropogenic activities are causing climate change
- ***The Earth System***
  - The Earth system comprises interconnected components, each influencing the others. This includes the biosphere (living organisms, including crops), the atmosphere (air and gases) the pedosphere (soil) and climate change impacts these elements that interact among themselves **(Fig.1.1)**

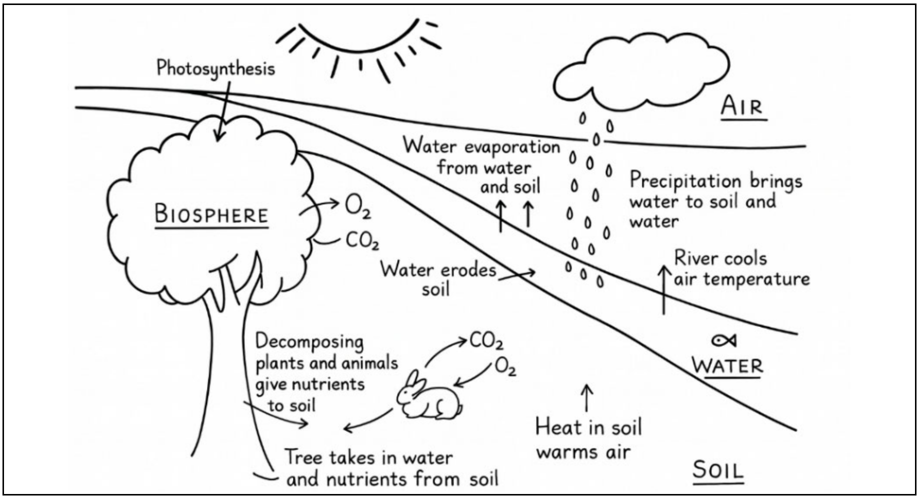

Fig. 1.1 The earth system.

Source: Unknown. Class lecture notes collection.

  - Biosphere and atmosphere: Trees/ crop plants (biosphere) absorb carbon dioxide from the atmosphere during photosynthesis, converting it into biomass and oxygen. Animals respire oxygen and release carbon dioxide. This exchange helps regulate climate and support life. Human activities, like burning fossil fuels and land-use change, disrupt this balance by increasing greenhouse gases in the atmosphere, leading to climate change
  - Soil and atmosphere: Soil and atmosphere interact through various biogeochemical cycles. Soil absorbs solar energy and transfers it to the atmosphere, influencing climate patterns. Soil also plays a vital role in the carbon cycle,

storing a significant amount of carbon. Climate change, particularly increased temperatures, can accelerate carbon loss from soils into the atmosphere, creating a feedback loop that exacerbates warming

  - Trees/crops, biosphere, and soil: Trees, crops, as part of the biosphere, depend on healthy soil for essential ecosystem services like nutrient cycling and water retention. However, agricultural practices significantly influence soil health and the weather health

- ***Climate of the Earth***
  - The climate is a complex, interactive system consisting of (a) atmosphere, (b) land surface (living things, snow, and ice), and (c) oceans and other bodies of water
  - The atmospheric component of the climate system characterizes climate
  - Climate is described in terms of the mean and variability of temperature, rainfall/precipitation, and wind over a period ranging from months to millions of years (the classical period is 30 years)
  - The climate system evolves under the influence of its own internal dynamics and due to changes in external factors that affect climate (forcings)
  - Solar radiation powers the climate system
  - Climate is renewable source of energy
  - Weather and climate information is non- monetary input in agriculture

- Definition: Climate change is a change in the state of the climate that can be identified (using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer
  - *The climate change is due to*
    - Natural internal processes
    - External forcings
    - Persistent anthropogenic changes
    - Anyone or combination of the above processes cause changes in the composition of atmosphere and land use

- Relationship between Climate Change and Weather
  - Climate change and weather are intertwined (average weather is climate)
  - Observations show that there have been changes in weather and it is the statistics of changes in weather over time that identify climate change
  - The chaotic nature of weather makes it unpredictable beyond a few days
  - Predicting climate change due to changes in atmospheric composition and other factors is much more meaningful issue than weather prediction which is a very different issue
  - While many factors continue to influence climate, scientists have determined that human activities have become a dominant force, and are responsible for most of the warming observed over the past fifty years
  - Human-caused climate change has resulted primarily not only from increases in the amounts of greenhouse gases in the atmosphere but also from changes in small particles (aerosols) as well as from changes in land use
  - As climate changes, certain types of weather events are affected. Example: As earth's average temperature increased, the weather phenomena like heat waves, heavy rainfall/ precipitation, etc., have become more frequent and intense, while others like extreme cold events have become less frequent and intense

1.2 Significance of Climate Change for Agriculture

- Climate change presents a complex and significant challenge to agriculture. Its influence ranges from crop yields and livestock health to weather health, water resources, soil health, and pest management. The effects are multi-faceted and vary regionally, making climate change a critical concern for farmers, policymakers, and consumers alike
- Changes in crop yields: Rising temperatures and alterations in rainfall patterns can significantly impact crop growth and

development, potentially leading to changes in yields for many major crops like maize, rice, wheat, soybean, cassava, and oats. Some regions may experience slight yield gains for crops like wheat, especially in higher latitudes with cooler temperatures that could become more suitable for agriculture. However, even in areas with potential benefits, those gains may be offset by the increased frequency of extreme events like heat waves and droughts

- Heat stress: Dairy cows, for example, are particularly vulnerable to heat stress, which can negatively affect their appetite, milk production, and overall health
- Pests and diseases: Warmer temperatures and changing precipitation patterns can create conditions favorable for the expansion and increased virulence of agricultural pests and diseases, necessitating greater pesticide use and potentially reducing yields
- Water resources: Climate change is disrupting the water cycle, leading to shifts in precipitation patterns and increased evaporation rates. This can result in increased water scarcity in some areas, potentially limiting the availability of water for irrigation. Conversely, other regions may experience increased runoff and flooding due to heavier rainfall events, which can erode soil and affect crops
- Soil health: Intensified rainfall and increased storm frequency can contribute to soil erosion, potentially depleting vital nutrients and degrading soil quality. Rising temperatures can also affect the ability of soils to store carbon exacerbating climate change through a feedback loop
- Weather health: Injection of GHGs into the atmosphere adversely affect weather health thereby negatively impacting "Soil- Plant- Weather Continuum"
- Economic strain on farmers: Declining yields, increased costs for managing pests and diseases, and investment in mitigation and adaptation measures can strain farmers financially, potentially leading to reduced profits

- Impacts on food security: Reduced agricultural productivity and increased food prices can have severe consequences for food security particularly in vulnerable regions already grappling with poverty and hunger
- The significance of climate change for agriculture cannot be overstated. It is a fundamental force reshaping agricultural landscapes and posing substantial threats to food security, the livelihoods of farmers, and the delicate balance of ecosystems. Understanding these impacts and actively pursuing mitigation and adaptation strategies are essential for building a resilient agricultural sector capable of providing a stable food supply in a changing world

1.3 Basics on Computing and Calculation of Climate Change

- The Intergovernmental Panel on Climate Change (IPCC) provides comprehensive assessments of scientific, technical, and socio-economic information related to climate change. While they do not conduct their own research, they synthesize and assess published scientific literature to inform policymakers and the public
- The IPCC's methods in computing climate change
- Data and observations
  - Reliance on observational datasets: The IPCC assesses global temperature change by analyzing readings from thermometers worldwide, incorporating statistical techniques to account for sparse data areas like the poles. They utilize long-term series of temperature measurements from land-based stations, ships, buoys, and satellites
  - Paleoclimate data: Data from natural archives like ice cores, tree rings, and sediment layers provide information about past climates and help understand the natural variability and long-term trends

- Climate models and scenarios
  - Global climate models (GCMs): These complex computer models simulate Earth's climate system, incorporating atmospheric, oceanic, land, and cryospheric processes. They are crucial for projecting future climate changes under different emission scenarios
  - Climate forcing (radiative forcing): This metric quantifies the impact of various factors (like greenhouse gases, aerosols, and land use changes) on Earth's energy balance and thus its climate system
  - Emission scenarios: The scenarios developed with socioeconomic factors in mind, provide different projections of future greenhouse gas emissions based on assumptions about population growth, technology, and policy choices. They help evaluate the potential consequences of different actions or inaction
  - Climate sensitivity: This refers to the global surface temperature warming at equilibrium in response to a doubling of atmospheric CO_2 concentrations. IPCC reports provide a range for this sensitivity, reflecting the uncertainties in modeling complex feedback mechanisms

- Assessment and reporting
  - Expert assessment: Thousands of volunteer scientists from around the world contribute to the IPCC's assessment reports, evaluating thousands of scientific papers each year
  - Multi-stage review process: IPCC reports undergo a rigorous, multi-stage review process by experts and governments to ensure objectivity, completeness, and a diverse range of views and expertise
  - Key findings and uncertainty language: The IPCC identifies the strength of scientific agreement in different areas and uses calibrated uncertainty language to communicate the degree of certainty in its findings
  - The IPCC's work is crucial for understanding the science of climate change, informing policy decisions, and guiding global efforts to address this critical challenge

- Calculation of Climate Change
  - Based on the information available through the IPCC (Intergovernmental Panel on Climate Change) and related sources, some related equations are used for calculating temperature and other climate change factors
- Earth's energy budget
  - The Earth's temperature is fundamentally linked to its energy budget, the balance between incoming solar radiation/shortwave radiation and outgoing infrared/longwave radiation
  - Changes in this balance, often caused by the release of greenhouse gases like carbon dioxide and aerosols, lead to changes in global temperature
- Radiative forcing (ΔF)
  - This refers to the change in net radiation at the top of the atmosphere due to a particular factor, like an increase in greenhouse gas concentrations
  - A simplified logarithmic equation, commonly cited in relation to IPCC findings, relates a change in CO_2 concentration to radiative forcing $(\Delta F) = 5.35 \ln (C/C_0)$
  - ΔF: Increase in radiative forcing in Watts per square meter
  - ln: Natural logarithm
  - C: Current concentration of atmospheric CO_2 in parts per million (ppm)
  - C_0: Pre-industrial CO_2 concentration (280 ppm in 1750)
  - 5.35: A scalar value derived from radiative transfer calculations
- Temperature increase (ΔT)
  - The increase in radiative forcing can be translated into a global temperature increase
  - A simplified equation (though acknowledging the complexities of climate feedback mechanisms) can relate radiative forcing to temperature change $= \lambda * \Delta F$
  - ΔT: Temperature increase in degrees Celsius (or Kelvin)

  - λ: Climate sensitivity parameter (often denoted as lambda), indicating the global temperature response to a change in radiative forcing
  - ΔF: Increase in radiative forcing (as calculated above)
- Other variables and complexity
  - Comprehensive climate models used by the IPCC incorporate numerous equations to represent complex interactions within the Earth system, including
    - Navier-Stokes equations for fluid motion (winds, ocean currents)
    - Thermodynamic equations describing heat and moisture transfer
    - Equations for other climate variables such as precipitation, sea level rise, and ice loss
  - These complex models are crucial for capturing the regional and global details of climate change, including feedback (processes that amplify or dampen initial warming) that affect the final temperature response
  - The simplified equations presented above are useful for understanding the fundamental relationships but represent a highly simplified view of the complex calculations involved in detailed climate modeling

1.4 Climate Change, Global Processes, and Effects

- Climate change is the defining issue of the present era. Hardly a day passes without a newspaper, a broadcast or a policy maker, a lawmaker, etc., making at least one statement or reference to the threats climate change poses and the urgency of taking action immediately to limit the effects and in the long term to adapt to the changes that are sure to come. Highly perceptible changes in climate can occur locally even over a few centuries. Anthropogenic activities have brought, within the realm of reality, the possibility of perceptible climate changes even within decades. The climate change, global processes, and effects are as follows

- **Human activities**
  - Land Use Change
    - *Urbanization*
    - *Deforestation*
    - *Land conversion to agriculture*
    - *Increase in impermeable surface*
  - Fossil fuel burning
    - *Industry*
      - Chemicals
      - Cement
    - *Energy production*
      - Heating
      - Electricity
      - Power
    - *Transport*
      - Plane traffic
      - Shipping
      - Road
      - Rail
    - *Agriculture*
      - Fertilizers
      - Chemicals
- **Climate Change Processes**
  - Enhanced Greenhouse effect
    - *Carbon cycle disturbances*
    - CO_2
    - CH_4
    - N_2O
  - Global Warming (average temperature rise)
    - *Ice Caps melting (sea level rise)*
    - *Precipitation changes*
    - *Cloud cover changes*
    - *Ocean circulation upheaval*

        - Salinity
        - Water temperature
      - *Gulf stream modification*
      - *Monsoon disturbances*
- **Disasters**
  - *Environmental refugees*
      - *Droughts*
      - *Cyclones*
      - *Floods*
      - *Tsunami*
      - *Wildfire*
  - *Biodiversity losses*
      - *Coastal wetlands disappearing*
      - *Coral bleaching*
  - Casualties
  - Economic losses
  - Diseases spread
      - *Infectious diseases* (*vector change*)
      - *Diarrhea*
      - *Cardio-respiratory diseases*
  - Subsistence farming and fishing at stake
  - Malnutrition
  - Traditional lifestyles
  - Coastal wetlands disappearing

1.5 The Greenhouse Effect

- The glass walls in a greenhouse reduce airflow and increase the temperature of the air by trapping large quantities of energy inside. Analogously, but through a different physical process, the earth's greenhouse effect warms the surface of the planet
- Global budget of incoming solar radiation and “Natural greenhouse effect”

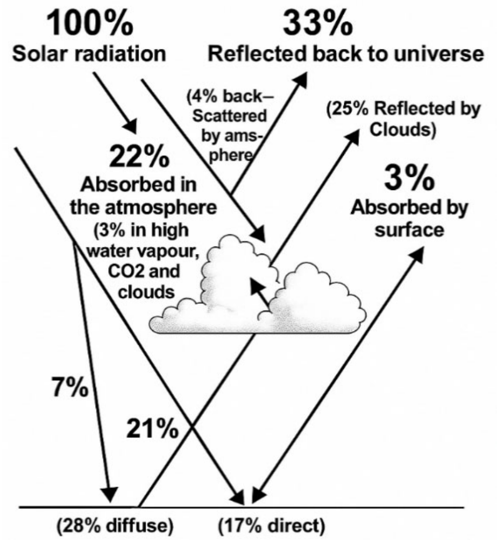

Fig. 1.2 Global budget of incoming solar radiation.

Source: Unknown. Class lecture notes collection.

- o Global budget of incoming solar radiation refers to "The balance between incoming solar radiation and outgoing terrestrial radiation" **(Fig:1.2).** It also refers to "The equilibrium between incoming solar radiation and outgoing terrestrial radiation ensuring a relatively stable global temperature"
- o Incoming solar radiation is the primary energy source for the Earth's climate system, in the form of shortwave radiation (UV, visible light, and a portion of infrared)
- o Roughly 33% of this incoming radiation is reflected to space by clouds, the atmosphere, and Earth's surface (snow, ice). This reflectivity is called "Albedo"
- o The remaining 67% is absorbed
  - ▪ 22% absorbed by the atmosphere i.e., 19 per cent by water vapor, carbon dioxide, clouds and 3 per cent in high atmosphere
  - ▪ 45% absorbed by the Earth's surface (land and oceans)
- The absorbed energy is re-radiated as longwave radiation (infrared energy)

- Greenhouse gases (carbon dioxide and water vapor) absorb much of this re-radiated longwave radiation, trapping heat and warming the Earth's atmosphere and surface
- This is known as "Natural greenhouse effect" without which the Earth would be significantly colder, making it uninhabitable
- Therefore, the "Earth's energy balance" which ensures "Natural greenhouse effect "is crucial for maintaining a habitable temperature

1.5.1 Greenhouse Gases and "Enhanced Greenhouse Effect"

- Human activities are increasing the concentration of greenhouse gases leading to "Enhanced greenhouse effect" **(Fig:1.3)**
- Enhanced Greenhouse Effect: The two most abundant gases in the atmosphere, nitrogen (comprising 78 per cent of the dry atmosphere) and oxygen (comprising 21 per cent) exert almost no greenhouse effect. However, human activities, such as land use change, burning fossil fuels, etc., release large amounts of greenhouse gases into the atmosphere intensifying the greenhouse effect, which is known as "Enhanced greenhouse effect"

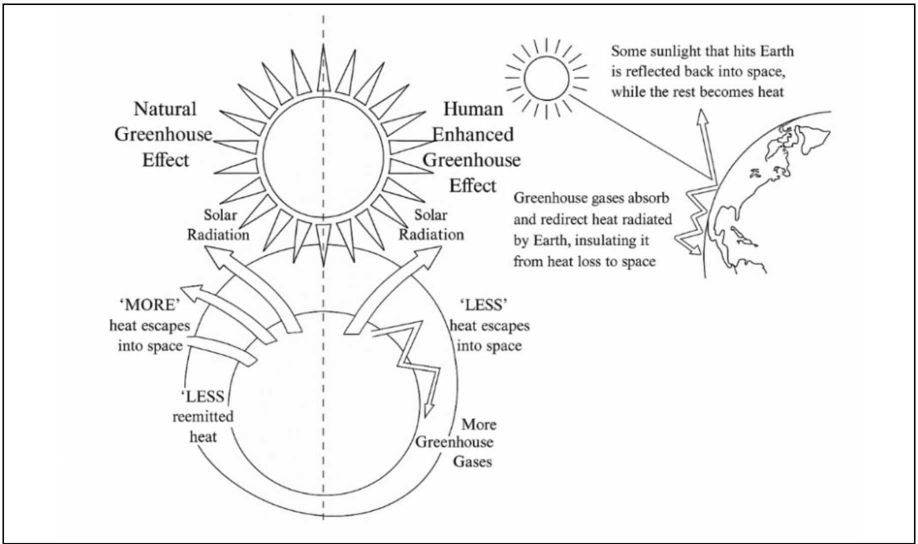

Fig. 1.3 Greenhouse effect.

Source: Unknown. Class lecture notes collection.

- In the natural greenhouse effect more heat escapes into the space and less re-emitted heat is present in the atmosphere
- In the human enhanced greenhouse effect less heat escapes into the space and more re emitted heat enters into the atmosphere
- The “Enhanced greenhouse effect” leads to an imbalance in the Earth's energy budget causing “Global warming” which results in “Climate change”
- In turn, the “Climate change” results in “Changes in weather patterns”
- In essence, the “Natural greenhouse effect” is a natural phenomenon that keeps Earth warm enough for life. However, human activities are amplifying this effect, resulting in “Enhanced greenhouse effect” leading to a shift in the planet's energy balance, global warming, and climate change which have potentially harmful consequences.

1.6 Climate Change and Global Warming

- “Global warming” is a major contributor to “Climate change” which encompasses a broader range of changes in weather patterns, sea levels, and other climate-related phenomena. Global warming refers to the increase in global surface temperature relative to a baseline reference period, averaging over a period sufficient to remove interannual variations (20 or 30 years). A common choice for the baseline is 1850–1900 (the earliest period of reliable observations with sufficient geographic coverage) with more modern baselines used depending upon the application

1.7 Climate Change and Air Pollution

- Climate change and air pollution, while distinct, are interconnected to some extent
- Air pollution is primarily caused by the release of harmful substances into the atmosphere which can contribute to climate change locally by releasing greenhouse gases like carbon dioxide and methane

- Conversely, climate change can exacerbate air pollution
- Air pollution represents a significant global environmental challenge with profound implications for agricultural productivity and sustainability
- Increased temperatures and wind speeds decrease pollutants
- Particulate matter reduces photosynthetic efficiency through physical blockage for gases exchange and stomatal conductance
- Sulphur dioxide and nitrogen oxides cause direct foliar damage and soil acidification mechanisms
- There is a critical need for integrated air quality monitoring in agroecosystems

1.8 Global Sector Wise Greenhouse Gases Contributions to Climate Change

- The combustion of coal, oil, and natural gas for electricity generation, transportation, and industrial processes emit substantial quantities of carbon dioxide, constituting the foremost Green House Gases (GHGs) and account for large portion of global GHG emissions. Agriculture and land use changes including rice cultivation, livestock rearing, and fertilizer application emit methane and nitrous oxide add further and account for second largest contribution to global emissions. Deforestation and land use alterations, which include the clearance of forests for agriculture, urban expansion, and other human endeavors liberate stored carbon into the air and release GHGs to Earth's Climate also substantially account for global emissions
- Energy supply: 34%
    - This sector is the largest contributor to global greenhouse gas emissions. It includes the burning of fossil fuels (coal, natural gas, and oil) for electricity and heat production. In 2023, the global power industry alone produced 15.1 gigatons of carbon dioxide equivalent ($GtCO_2e$) accounting for 28% of global emissions

- Industry: 24%
    - This includes emissions from industrial processes like those involved in producing chemicals and cement and emissions from burning fossil fuels on-site at facilities for energy. Emissions from industrial processes have seen the fastest growth since 1990 increasing by 225%
- Agriculture, Forestry, and Other Land Use (AFOLU): 22%
    - Emissions from this sector mainly stem from agricultural activities (cultivation of crops and livestock) and deforestation. AFOLU emissions are subject to higher uncertainty and annual variability compared to other sectors, making their long-term trend harder to determine
- Transportation: 15%
    - This sector is primarily driven by burning fossil fuels for various forms of transport. Road travel makes up most of these emissions
- Other sectors including buildings: 5%
    - Emissions from this sector come from onsite energy generation and fuel burning for heating and cooking. When electricity use is included this sector's contribution increases significantly

1.9 Global Transport Sector Contributions to Climate Change (2019 Data)

- The transportation sector is a major contributor to climate change, and its emissions by mode of transport are
- Road Transport
    - Dominant Source: Road vehicles are by far the largest source of transport emissions, accounting for approximately 70% of global transport-related CO_2 emissions

- Shipping (maritime transport)
  - Significant Contributor: International shipping is the second largest source of transport emissions, contributing around 11% of global transport-related CO_2 emissions
- Aviation (air transport)
  - Growing Emissions: Aviation accounts for roughly 12% of global transport-related CO_2 emissions and is experiencing rapid growth
- Rail and other Transport
  - Lowest emissions: Rail transport is a relatively minor contributor to global transport emissions, accounting for around 1% of the sector's total. Other Transport: (pipelines, etc.) approximately 6%
- In Summary
  - Road: 70%; Shipping: 11%; Aviation: 12%; Rail: 1%; Other Transport: (pipelines, etc.) approximately 6%

1.10 Global Agriculture Sector Contributions to Climate Change

- Globally, the food system is estimated to contribute a significant portion of greenhouse gas emissions, with figures ranging from 25% to 37% and is expected to increase further due to population growth and changing dietary patterns. The main contributors to greenhouse gas emissions from agriculture are
- Livestock and Fisheries
  - These activities are responsible for roughly 31% of emissions from the food system, primarily due to methane from livestock (especially ruminants like cattle), manure management, and fuel consumption from fishing vessels
- Crop production
  - Emissions from crop production for human consumption and animal feed (including fertilizer use and other on-farm processes) account for about 27% of food system emissions

- Land use change
    - This category, including deforestation for agricultural expansion and emissions from cultivated organic soils constitutes approximately 24% of the food system's emissions
- Supply chains
    - Post-farm activities like processing, transportation, and retail account for roughly 18% of emissions

1.11 Global Agricultural Chemicals Sector contributions to Climate Change

- Agricultural chemicals, particularly fertilizers and pesticides, significantly contribute to greenhouse gas (GHG) emissions throughout their entire life cycle from manufacturing to application and eventual environmental fate
- Fertilizers
    - Nitrous Oxide (N_2O)
        - Direct Emissions: Application of synthetic nitrogen fertilizers on agricultural land leads to the release of N_2O, a powerful GHG, into the atmosphere
        - Indirect Emissions: Excess nitrogen from fertilizer runoff enters waterways, leading to eutrophication and further N_2O emissions from aquatic systems
- Methane (CH_4) and Carbon Dioxide (CO_2)
    - Manufacturing: The industrial process for producing synthetic nitrogen fertilizers, like the Haber-Bosch process, uses fossil fuels (often natural gas, which is mostly methane) and releases both CH_4 and CO_2
    - Eutrophication: Over-fertilization contribute to eutrophication in bodies of water, which also release CH_4 and CO_2 as algae and other aquatic organisms decompose
- Pesticides
    - Manufacturing and transport: Nearly all synthetic pesticides come from fossil fuels. The manufacturing

process is energy-intensive, and their transport and packaging also contribute to GHG emissions. Producing one kilogram of pesticide requires approximately ten times more energy than one kilogram of nitrogen fertilizer

- Volatilization: Some pesticides, such as sulfuryl fluoride, are potent GHGs. Emitting one ton of sulfuryl fluoride equals the emission of nearly 5,000 tons of CO_2
- Ground-level Ozone: Many pesticides contribute to ground-level ozone formation, a harmful GHG and air pollutant
- Impact on soil health: Pesticides disrupt natural soil processes. This affects the soil's ability to store carbon and influences microbial communities that regulate GHGs

1.12 Global Economic Losses due to Climate Change

- Studies indicate that the estimated world economic losses due to climate change could be between 127 and 616 trillion dollars by 2100 with current commitments. Failure to implement current commitments raises economic losses to 150-792 trillion dollars by 2100

1.13 Country wise GHG emissions in GtCO_2e (Gt CO_2 e stands for Gigatons of Carbon Dioxide Equivalent)

- China-15.9; USA- 6.0; India-4.1; European Union-3.2; Russia-2.7; Brazil-1.3; Indonesia-1.2; Japan-1.0; Iran-1.0; Saudi Arabia-0.8; Canada-0.7; Mexico-0.7; South Korea-0.7; Turkiye-0.6

1.14 Global Regions most Vulnerable to Climate Change

- Globally, four (4) regions have been identified as the most vulnerable to climate change. These are as follows

- The Arctic
  - The causes of enhanced vulnerability in the Arctic are due to large regional warming and associated ice melt
  - The habitat of plant and animal species living along the ice margins such as polar bears will alter as the ice melts. The area of ice is already decreasing since 1979, and the Arctic has been losing summer ice at about 9 per cent per decade, and this trend is expected to continue
  - Traditional ways of life of indigenous inhabitants are likely to be affected (those of the Inuit which are based on hunting)
  - Ice melting associated with global warming leads to improved transport links and opportunities to open the Arctic to commercial activities, especially the exploitation of its mineral and oil wealth
  - However, these opportunities must be set against the threat to ecosystems and indigenous livelihoods and the risk of extinction of some iconic species
- Africa
  - Much of Africa is already vulnerable to drought due to high natural variability in the climate and high demand on natural resources from a population which is heavily dependent on agriculture for its livelihood
  - Thus, Africa is vulnerable to any increase in the frequency of occurrence and /or severity of drought due to global warming
  - The IPCC Fourth assessment considered it likely that the area affected by drought would increase during 21^{st} century
  - These risks are compounded by structural problems, the quality of governance, and the health and education levels of the population limiting the capacity to adapt to climate change
- Asian and African mega deltas
  - The Asian and African (principally the Nile) mega deltas are areas of very high population density concentrated in

low- lying areas prone to flooding and exposed to storm surge and tropical storms
  - These areas are vulnerable to rising sea levels related to global warming and the severity of tropical storms and storm surge
  - By 2100 sea level is expected to rise substantially
  - The IPCC Fourth Assessment considered it likely that intense tropical cyclone activity will increase in the future

- Small islands
  - Small islands are also vulnerable to rising sea levels and increasing storm severity
  - In future higher mean sea levels may be sufficient to inundate some small islands
  - In the Caribbean and Pacific islands more than 50 per cent of the population live within 1.5 km of shore
  - Unlike deltas and other coastal areas small islands have no hinterland to move to in case of coastal land loss
  - As the sea level rises, it is not only coastal inundation that poses a threat to small islands but also contamination of freshwater supplies by salinization of the ground water may threaten the settlements
  - Tourism is a major contributor to the economies of many small islands. Beach erosion, degradation of coral reefs, and bleaching make small islands a less attractive destination for tourists

1.15 Evidence for Climate Change

- The following observed changes in the climate system since the late 19th Century reveal an unequivocally warming world
- Air: Increases in atmospheric circulation, air temperature, water vapor, and surface temperature
- Land: Increases in species ranges shift, growing season length, precipitation, and greenness
- Ocean: Increases in sea level, sea surface temperature, species ranges shift, ocean heat content, and ocean acidification

- Ice: Decreases in permafrost extent, ice sheets, Arctic Sea ice, snow cover, and glaciers

1.16 Climate Variability

- Definition: Deviations of climate variables from a mean state, including the occurrence of extremes, across all spatial and temporal scales beyond individual weather events
- The climate variability is due to
  - Natural internal processes within the climate system (internal variability)
  - Variations in natural or anthropogenic external forcings (external variability)
- Sources of Climate Variability
  - The sources of climate variability are represented on "Time and spatial scales". Examples: A few days, Intra season, Inter season, A very few years, etc.
  - The day-to-day weather variations which are primarily controlled by internal atmospheric dynamics
  - Climate variations in intra- season, inter -seasonal, a very few years etc., are controlled by boundary conditions at the interface among atmosphere, ocean, and land surface
- Types of climate variability
  - *Short term variability:* In this type, the climate variability is confined to limited time and space. Examples: Cyclones, hurricanes, typhoons, droughts, floods, etc.
  - *Long term variability*: In this type, the variability is extended to relatively longer time and larger areas. Examples: Inter and intra annual variability in rainfall which is the key climatic element that determines the success of agriculture in a region; Variability in temperature during the whole crop season which impacts photosynthesis thereby final crop yield
- Approaches in climate impact assessment
  - Different approaches exist to assess climate impact. The specific terms "Impact Approach" and "Interaction

Approach" are always explicitly used to resonate with common ways to categorize such assessments **(Fig:1.4)**

- o Impact approach (top-down)

- *Focus*: This approach typically starts with projections of climate change (temperature and precipitation changes from climate models) and then assesses the direct consequences or impacts on a specific sector, ecosystem, or region
- *Methodology*: Involves modeling how changes in climatic variables, such as temperature and precipitation, would affect various systems (crop yields, water resources, sea level rise) without necessarily considering the socio-economic context or human responses

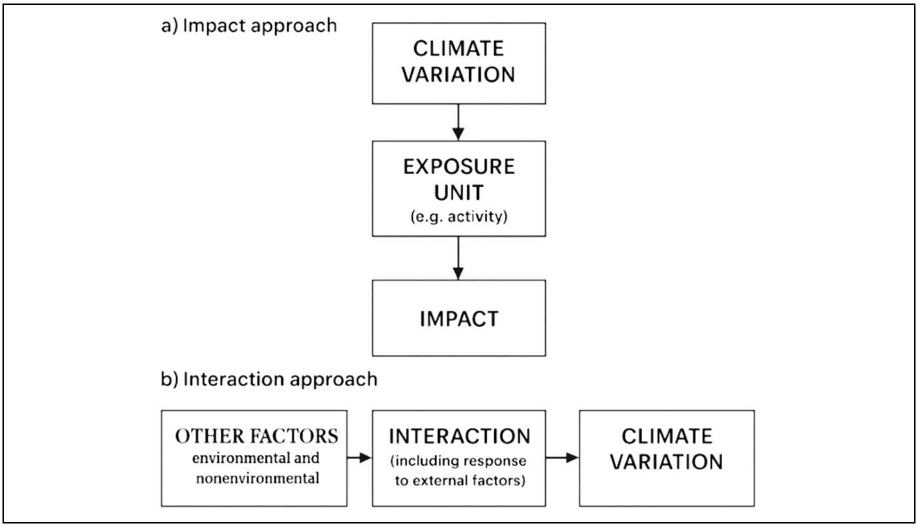

Fig. 1.4 Approaches in climate impact assessment.

Source: Parry and Carter,1989.

- *Strengths*: Allows systematic analysis of potential consequences under different climate scenarios. Can highlight areas of particular vulnerability to climate change
- *Weaknesses*: Can be seen as "Predict-then-act" or "Top-down," often making it difficult to fully integrate with local socio-economic contexts and adaptation strategies. May overlook the

dynamics and resilience of socio-economic systems and their capacity to adapt to changing conditions

- Interaction approach (bottom-up/co-evolutionary)
    - *Focus*: Emphasizes the interplay between climate variation and other factors viz., environmental and non-environmental (socio-economic factors), recognizing that these are not independent but constantly influencing each other. This approach prioritizes understanding system vulnerabilities and adaptive capacities in the context of both climatic and non-climatic stresses
    - *Methodology*: Often starts with identifying current climate risks and system sensitivities and explores adaptation options through participatory and scenario-based methods, working closely with local stakeholders. It considers how societal changes (independent of climate change) influence vulnerability and resilience
    - *Strengths*: More directly relevant for adaptation planning as it focuses on vulnerabilities and local needs. Fosters learning and engagement among stakeholders, promoting a more holistic understanding of climate risks and opportunities for action
    - *Weaknesses*: Can be more complex to implement and may require more intensive data collection and stakeholder engagement. Dealing with the uncertainties in both climate and socio-economic futures can be challenging
    - While the Impact Approach focuses primarily on the direct consequences of climate change, the Interaction Approach recognizes that climate change impacts are mediated and shaped by ongoing societal and environmental processes, necessitating a more integrated and adaptive approach to assessment of pests, diseases, and final crop yield.

1.17 Differences between Climate Variability and Climate Change

Table 1.1 Differences between climate variability and climate change.

S.No.	Climate variability	Climate change
1.	Observed short term changes/ trends of day to day, inter and intra seasons, year to year differences, etc. in values of specific climate variables within an averaging period, typically 30 years. Example: Variability in the annual rainfall of India from 1951 to 1990	Long term changes/trends between averaging periods either in the mean values of climate variables or in their variability. Example: Change in the global temperature for a period of 1915-1995 over a base period of 1750-1900
2.	Climate variability is a consequence of global climate change at local and regional levels. A notable consequence of climate variability is "Drought", which sharply increase crop failures, hunger and famine	Global climate change leads to regional climate variabilities. A notable consequence of climate change is "Sea level raising" which causes inundation of coastal areas and dislocation of inhabitants
3.	Ups and downs in day to day, season to season or year to year	Gradual and persistent shift in average climatic conditions
4.	Short term trends associated with natural variations which occur within shorter time frames such as days, weeks, months, seasons, and few years	Long term trends associated with natural forcings, external forces, and human activities or a combination of one or more
5.	The range and frequency of shocks that society can absorb or to which it adjusts	The range and frequency of shocks that society cannot absorb/adjust without external help
6.	Describes short term fluctuations in weather variables	Describes long-term shifts in global or regional climate patterns

Table 1.1 *contd...*

S.No.	Climate variability	Climate change
7.	Temporary variations in weather/climatic conditions for a limited and specific area	Sustained changes in average climatic conditions over large areas
8.	The impacts are local, and regional within the earth's climate system Example: Drought, flood, etc.	Impacts are national and global Example: Raising global temperatures, Changes in global precipitation patterns
9.	Has a limited impact on production of farm and livestock	Has a major impact on production of farm and livestock
10.	Confined to short term affects which temporarily alter existing resource base	Long term effects which permanently alter the resource base
11.	Driven by fluctuations in temperature, precipitation, extreme weather events, etc.	Driven by natural, internal, external, and anthropogenic climate system

1.18 The Intergovernmental Panel on Climate Change (IPCC)

- The United Nations Environment Program (UNEP) and the World Meteorological Organization (WMO), established the Inter-Governmental Panel on Climate Change (IPCC) in 1988 to periodically assess the state of global environment and advise Members through UN agencies. Since then, the subjects of "Global warming" and "Climate Change" have drawn international attention
- The IPCC, brings together more than 2000 scientists and Government representatives to assess the risk posed by human induced changes in climate
- Its job is to assess the latest scientific, technical, and socio-economic literature on understanding the risk of climate change, its observed and projected impacts and options for adaptation and mitigation

- Since the creation of the IPCC, each Assessment Report has fed directly into international climate policymaking
- In 1990, the First IPCC Assessment Report (FAR) underlined the importance of climate change as a challenge with global consequences and requiring international cooperation. It played a decisive role in the creation of the UNFCCC, the key international treaty to reduce global warming and cope with the consequences of climate change
- The Second Assessment Report (SAR) (1995) provided important material for governments to the Kyoto Protocol in 1997
- The Third Assessment Report (TAR) (2001) focused attention on the impacts of climate change and the need for adaptation
- The Fourth Assessment Report (AR4) (2007) laid the groundwork for a post-Kyoto agreement, focusing on limiting warming to 2°C
- The Fifth Assessment Report (AR5) was finalized between 2013 and 2014. It provided scientific input into the Paris Agreement
- The IPCC has completed its sixth assessment cycle where it produces three Special Reports, a Methodology Report and the Sixth Assessment Report. The first of these Special Reports, Global Warming of 1.5°C (SR15), was requested by world governments under the Paris Agreement. In May 2019, the IPCC finalized the 2019 Refinement – an update to the 2006 IPCC Guidelines on National Greenhouse Gas Inventories. The Special Report on Climate Change and Land (SRCCL) was in August 2019 and the Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC) in September 2019. The Sixth Assessment Report (AR6) was finalized in March 2023 in time for the first global stock take at the end of 2023
- In 2007, the IPCC and U.S. Vice-President Al Gore were jointly awarded the Nobel Peace Prize "For their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change"

- In October 2022, the IPCC and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) were declared co-laureates of the 2022 Gulbenkian Prize for Humanity
- The Jury of the Gulbenkian Prize for Humanity led by Dr. Angela Merkel, selected the IPCC and IPBES out of 116 nominations from 41 countries, in recognition of "…the role of science on the front line of tackling climate change and the loss of biodiversity"
- Inter Academy Council (IAC) conducts an independent review of IPCC procedures. The IAC issued a report and recommendations in August 2010. The IPCC considered these at its subsequent sessions, and made several revisions to its procedures as a result

1.19 Addressing Climate Change and Variability Challenges

- To address climate change and variability challenges individuals, families, communities, governments, etc., have the best sciences available to plan for and implement climate-smart and resilient practices. Two critically important approaches which are available to managing climate resilience are mitigation and adaptation. These strategies are interrelated and must be pursued simultaneously as both can potentially improve resilience to the changing climate and variability.