Chapter
01

Introduction to Climate Change

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Introduction

Global Warming

Global warming is a long-term rise in the average temperature of the Earth's climate system, an aspect of climate change shown by temperature measurements and by multiple effects of the warming. The term commonly refers to the mainly human-caused observed warming since pre-industrial times and its projected continuation, though there were also much earlier periods of global warming. In the modern context the terms are commonly used interchangeably, but *global warming* more specifically relates to worldwide surface temperature increases; while *climate change* is any regional or global statistically identifiable persistent change in the state of climate which lasts for decades or longer, including warming or cooling. Many of the observed warming changes since the 1950s are unprecedented in the instrumental temperature record and in historical and paleoclimate proxy records of climate change over thousands to millions of years.

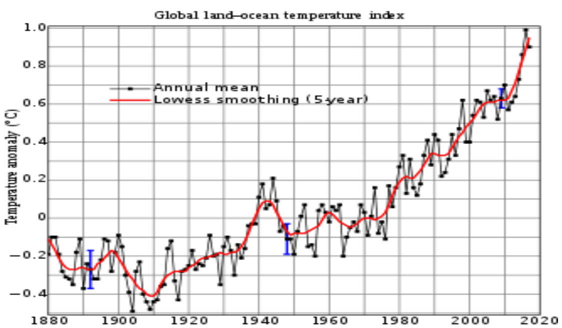

Figure 1: Global mean surface-temperature change from 1880 to 2017, relative to the 1951–1980 mean.

Global mean surface-temperature change from 1880 to 2017, relative to the 1951–1980 mean. The 1951–1980 mean is 14.19 °C (57.54 °F). The black line is the global annual mean, and the red line is the five-year local regression line. The blue uncertainty bars show a 95% confidence interval.

Reasons behind Global Warming

The major cause of present global warming has been attributed to anthropogenic contribution to Greenhouse effect expansion through trapping the radiating heat from atmosphere. Water vapour, carbon dioxide, Methane, Nitrous oxide and Chloroflurocarbons (CFCs) are major gases that contribute to green house effect. Release of these gases to atmosphere happens through natural process such as hydrological cycles, volcanic eruptions and decomposition process or through human activities such as burning of fossil fuels, agricultural practices and industrial process.

Intergovernmental Panel on Climate Change (IPCC) through its Fifth Assessment Report emphasis that probability more than 95 % of earth's warming is through human activities during past five decades. However there are a group of scientists who claims that the climate change could be a result of natural solar process change. But the climate models that include solar irradiance could not reproduce the observed temperature trend over the past century or more without including a rise in greenhouse gases.

Proof for scientific inferences on Climate Change

IPCC states that scientific evidence for warming of climate system is unequivocal. The heat trapping nature of carbon dioxide and other gases were demonstrated in the mid of 19th century. Antropogenic activities since the mid-20th century have been attributed as cause for global warming and were observed to increase thereafter. Indications for climate change have been derived from data collected through earth-orbiting satellites. Ice cores samples from Greenland, Antartica and tropical mountain glaciers indicate earth's climate response to greenhouse gas concentrations. Paleoclimatic evidences found in tree rings, ocean sediments, coral reefs and layers of sedimentary rocks indicates that current warming is occuring around 10 times faster than average rate of ice age recovery warming (NRC, 2006). NASA is an expert in climate and Earth science. While its role is not to set climate policy or prescribe particular responses or solutions to climate change, its purview does include providing the robust scientific data needed to understand climate change and evaluating the impact of efforts to combat it.

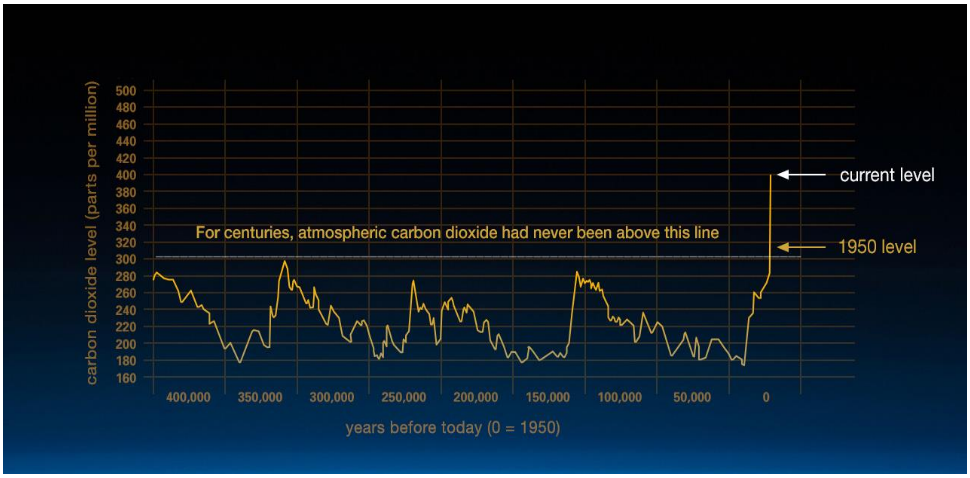

Figure 2.This graph, based on the comparison of atmospheric samples contained in ice cores and more recent direct measurements, provides evidence that atmospheric CO_2 has increased since the Industrial Revolution. (Credit: Vostok ice core data/J.R. Petit et al.; NOAA Mauna Loa CO_2 record.)

NASA then makes this information available to the global community – the public, policy- and decision-makers and scientific and planning agencies around the world. The compelling evidences for rapid climate change as per NASA are as listed below.

- Global temperature rise since late 19th century
- Ocean warming since 1926
- Sea level rise (8 inches in last century)
- Declining Artic sea ice (extend and thickness over last several decades)
- Shrinking ice sheets (loss around 281 billion tons of ice per year at Greenland and loss around 119 billion tons at Antartica between 1993 and 2016)
- Glacial retreats (Alps, Himalayas, Andes, Rockies, Alaska and Africa)
- Decrease in snow cover (Northern hemisphere in past five decades)
- Extreme events (Increase in high temperature events, decrease in low temperature events since 1950 and increase in intense rainfall events)

NASA reports future climate change effects as listed below:

- Change will continue through this century and beyond
- Temperatures will continue to rise
- Frost-free season (and growing season) will lengthen
- Changes in precipitation patterns

- More droughts and heat waves
- Arctic likely to become ice-free
- Hurricanes will become stronger and more intense
- Sea level will rise 1-4 feet by 2100

The following selected resources from U.S. government organizations provide information about options for responding to climate change.

- Climate Data Initiative
- U.S. Climate Resilience Toolkit
- National Oceanic and Atmospheric Administration
- National Climate Assessment 2014
- U.S. Department of Energy
- Environmental Protection Agency
- State of California's Climate Change Portal
- U.N. Framework on Climate Change

The Intergovernmental Panel on Climate Change (IPCC)

IPCC was established by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) in 1988 to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts. 195 countries are now Members of the IPCC. IPCC reviews and assesses the most recent scientific, technical and socio-economic information produced worldwide relevant to the understanding of climate change. So far significant Assessment Reports (AR) were published as 1st AR on 1990 (lead to UNFCC formation), 2nd AR on 1995 (lead to adoption of Kyoto protocol), 3rd AR on 2001, **4th AR on 2007 (led to Nobel Peace Prize)**, 5th AR as 4 parts in 2013 and 2014, while 6th AR is expected on 2022.

IPCC also prepares and publishes Special Reports, Methodology Reports, Technical papers and Supporting Material.The Nobel Peace Prize 2007 was awarded jointly to Intergovernmental Panel on Climate Change (IPCC) and Albert Arnold (Al) Gore Jr. "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". The COP of UNFCC receives the outputs of the IPCC and uses IPCC data and information as a baseline on the state of knowledge on climate change in making science based decisions.

Special Report on the Ocean and Cryosphere in a Changing Climate (SROCC)

IPCC decided to prepare a special report on climate change and the oceans and the cryosphere. During its 45th Session, the Panel approved the outline of the *Special Report on the Ocean and Cryosphere in a Changing Climate* to be finalized in September 2019.

COP21 of the United Nations Framework Convention on Climate Change held in Paris on 2015 featured the role of oceans, inland waters and aquatic ecosystems for temperature regulation and carbon sequestration, and highlighted the urgency of reversing the current trend of overexploitation and pollution to restore aquatic ecosystem services and the productive capacity of the oceans. Consequently Food and Agriculture Organization of the United Nations released the much esteemed publication 'State of world fisheries and aquaculture, 2016 which acknowledges India as among the major producers of aquatic animals from aquaculture.

Findings of the Fifth Assessment Report

In 2013, the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report concluded, "It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century." The largest human influence has been the emission of greenhouse gases such as carbon dioxide, methane, and nitrous oxide. In view of the dominant role of human activity in causing it, the phenomenon is sometimes called "*anthropogenic* global warming" or "*anthropogenic* climate change".

Climate model projections summarized in the report indicated that during the 21st century, the global surface temperature is likely to rise a further 0.3 to 1.7 °C to 2.6 to 4.8 °C depending on the rate of greenhouse gas emissions.

Future climate change and associated impacts will differ from region to region. Anticipated effects include rising sea levels, changing precipitation, and expansion of deserts in the subtropics. Warming is expected to be greater over land than over the oceans and greatest in the Arctic, with the continuing retreat of glaciers, permafrost, and sea ice.

Other likely changes include more frequent extreme weather events such as heat waves, droughts, wildfires, heavy rainfall with floods, and heavy snowfall; ocean acidification; and species extinctions due to shifting temperature regimes. Effects significant to humans include the threat to food security from decreasing crop yields and the abandonment of populated areas due to rising sea levels. Because the climate system has a large "inertia" and greenhouse gases will remain in the atmosphere for a long time, many of these effects will persist for not only decades or centuries, but tens of thousands of years. Possible societal responses to global warming include mitigation by emissions reduction, adaptation to its effects, building systems resilient to its effects, and possible future climate engineering.

Most countries are parties to the United Nations Framework Convention on Climate Change (UNFCCC), whose ultimate objective is to prevent dangerous anthropogenic climate change. Parties to the UNFCCC have agreed that deep cuts in emissions are required and that global warming should be limited to well below 2.0 °C compared to pre-industrial levels, with efforts made to limit warming to 1.5 °C. Some scientists call into question climate adaptation feasibility, with higher emissions scenarios, or the two degree temperature target.

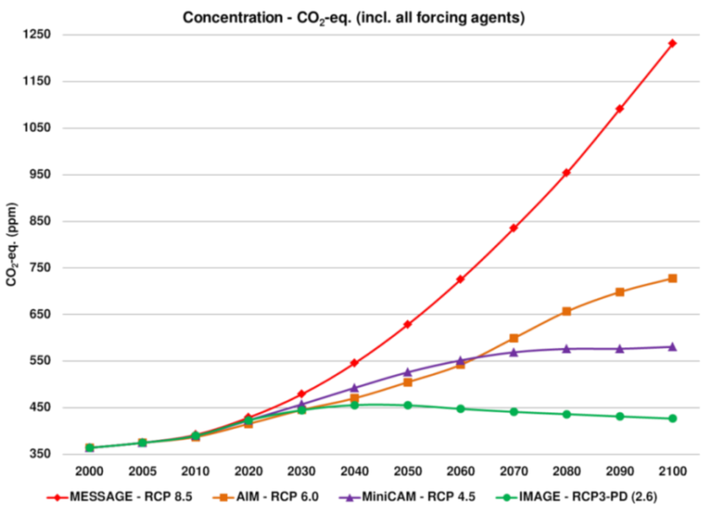

Figure 3. Future CO_2 projections, including all forcing agents' atmospheric CO2-equivalent concentrations (in parts-per-million-by-volume (ppmv)) according to four RCPs (Representative Concentration Pathways)

History of climate change

The history of climate change science began in the early 19th century when ice ages and other natural changes in paleoclimate were first suspected and the natural greenhouse effect first identified. In the late 19th century, scientists first argued that human emissions of greenhouse gases could change the climate. In the 1960s, the warming effect of carbon dioxide gas became increasingly convincing. By the 1990s, greenhouse gases were acknowledged to be deeply involved in most climate changes and human caused emissions were bringing discernible global warming.

Since the 1990s, scientific research on climate change has included multiple disciplines and has expanded. Research during this period has been summarized in the Assessment Reports by the Intergovernmental Panel on Climate Change.

Observed Temperature Changes

By itself, the climate system may generate random changes in global temperatures for years to decades at a time, but long-term changes emanate only from so-called *external forcings.* Examples of external forcings include changes in the composition of the atmosphere (e.g., increased concentrations of greenhouse gases), solar luminosity, volcanic eruptions, and variations in Earth's orbit around the Sun.

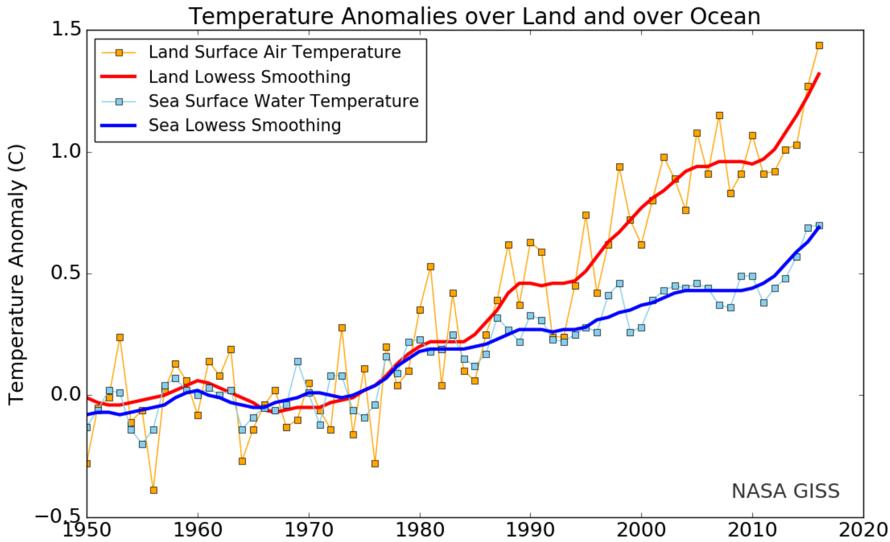

Figure 4. Annual (thin lines) and five-year lowess smooth (thick lines) for the temperature anomalies averaged over the Earth's land area (red line) and sea surface temperature anomalies (blue line) averaged over the part of the ocean that is free of ice at all times (open ocean).

Greenhouse gases

On Earth, an atmosphere containing naturally occurring amounts of greenhouse gases causes air temperature near the surface to be warmer by about 33 °C than it would be in their absence. Without the Earth's atmosphere, the Earth's average temperature would be well below the freezing temperature of water. The major greenhouse gases are water vapour, which causes about 36–70% of the greenhouse effect; carbon dioxide (CO_2), which causes 9–26%; methane (CH_4), which causes 4–9%; and ozone (O_3), which causes 3–7%.

The greenhouse effect is the process by which absorption and emission of infrared radiation by gases in a planet's atmosphere warm its lower atmosphere and surface. It was proposed by Joseph Fourier in 1824, discovered in 1860 by John Tyndall, was first investigated quantitatively by Svante Arrhenius in 1896, and the hypothesis was reported in the popular press as early as 1912.

Human activity since the Industrial Revolution has increased the amount of greenhouse gases in the atmosphere, leading to increased radiative forcing from CO_2, methane, tropospheric ozone, CFCs, and nitrous oxide. According to work published in 2007, the concentrations of CO_2 and methane had increased by 36% and 148% respectively since 1750. These levels are much higher than at any time during the last 800,000 years, the period for which reliable data has been extracted from ice cores. Less direct geological evidence indicates that CO_2 values higher than this were last seen about 20 million years ago.

Fossil fuel burning has produced about three-quarters of the increase in CO_2 from human activity over the past 20 years. The rest of this increase is caused mostly by changes in land-use, particularly deforestation. Estimates of global CO_2 emissions in 2011 from fossil fuel combustion, including cement production and gas flaring, was 34.8 billion tonnes (9.5 ± 0.5 PgC), an increase of 54% above emissions in 1990. Coal burning was responsible for 43% of the total emissions, oil 34%, gas 18%, cement 4.9% and gas flaring 0.7%.

In May 2013, it was reported that readings for CO_2 taken at the world's primary benchmark site in Mauna Loa surpassed 400 ppm. Monthly global CO_2 concentrations exceeded 400 ppm in March 2015, probably for the first time in several million years. On 12 November 2015, NASA scientists reported that human-made carbon dioxide continues to increase above levels not seen in hundreds of thousands of years; currently, about half of the carbon dioxide released from the burning of fossil fuels is not absorbed by vegetation and the oceans and remains in the atmosphere.

Emissions scenarios, estimates of changes in future emission levels of greenhouse gases, have been projected that depend upon uncertain economic, sociological, technological, and natural developments. In most scenarios, emissions continue to rise over the century, while in a few, emissions are reduced. Fossil fuel reserves are abundant, and will not limit carbon emissions in the 21st century. Emission scenarios, combined with modelling of the carbon cycle, have been used to produce estimates of how atmospheric concentrations of greenhouse gases might change in the future.

By itself, the climate system may generate random changes in global temperatures for years to decades at a time, but long-term changes emanate only from so-called *external forcings.* These forcings are "external" to the climate system, but not necessarily external to Earth. Examples of external forcings include changes in the composition of the atmosphere (e.g., increased concentrations of greenhouse gases), solar luminosity, volcanic eruptions, and variations in Earth's orbit around the Sun.

Environmental Effects

The environmental effects of global warming are broad and far reaching, including:

- Arctic sea ice decline, sea level rise, retreat of glaciers: Global warming has led to decades of shrinking and thinning in a warm climate that has put the Arctic sea ice in a precarious position, it is now vulnerable to atmospheric anomalies. Recent projections suggest that Arctic summers could be ice-free (defined as ice extent less than 1 million square km) as early as 2025–2030. The sea level rise since 1993 has been estimated to have been on average 2.6 mm and 2.9 mm per year ± 0.4 mm. Additionally, sea level rise has accelerated from 1995 to 2015. Over the 21st century, the IPCC projects for a high emissions scenario, that global mean sea level could rise by 52–98 cm.
- Extreme weather, extreme events, tropical cyclones: Data analysis of extreme events from 1960 until 2010 suggests that droughts and heat waves appear simultaneously with increased frequency. Extremely wet or dry events within the monsoon period have increased since 1980. Projections suggest a probable increase in the frequency and severity of some extreme weather events, such as heat waves.
- Ecosystem changes, changes in ocean properties: In terrestrial ecosystems, the earlier timing of spring events, as well as poleward and upward shifts in plant and animal ranges, have been linked with high confidence to recent

warming. It is expected that most ecosystems will be affected by higher atmospheric CO_2 levels, combined with higher global temperatures. The physical effects of global warming on oceans include an increase in acidity, and a reduction of oxygen levels (ocean deoxygenation). Increases in atmospheric CO_2concentrations have led to an increase in dissolved CO_2 and thus ocean acidity, measured by lower pH values. Ocean acidification threatens damage to coral reefs, fisheries, protected species, and other natural resources of value to society.

- Long-term effects of global warming, runaway climate change: On the timescale of centuries to millennia, the magnitude of global warming will be determined primarily by anthropogenic CO_2 emissions. This is due to carbon dioxide's very long lifetime in the atmosphere.
- Abrupt climate change: Climate change could result in global, large-scale changes in natural and social systems. Examples include ocean acidification caused by increased atmospheric concentrations of carbon dioxide, and the long-term melting of ice sheets, which contributes to sea level rise. Some large-scale changes could occur abruptly, i.e., over a short time period, and might also be irreversible. Examples of abrupt climate change are the rapid release of methane and carbon dioxide from permafrost, which would lead to amplified global warming.

Mitigation

Mitigation of climate change refers to actions taken to reduce greenhouse gas emissions, or enhance the capacity of carbon sinks to absorb greenhouse gases from the atmosphere. There is a large potential for future reductions in emissions by a combination of activities, including energy conservation and increased energy efficiency; the use of low-carbon energy technologies, such as renewable energy, nuclear energy, and carbon capture and storage. Near- and long-term trends in the global energy system are inconsistent with limiting global warming at below 1.5 or 2 °C, relative to pre-industrial levels.

In limiting warming at below 2 °C, more stringent emission reductions in the near-term would allow for less rapid reductions after 2030. Many integrated models are unable to meet the 2 °C target if pessimistic assumptions are made about the availability of mitigation technologies.

Adaptation

Climate change adaptation is another policy response. The adaptation may be planned, either in reaction to or anticipation of global warming, or spontaneous, i.e., without government intervention. Planned adaptation is already occurring on a limited basis. The barriers, limits, and costs of future adaptation are not fully understood. Environmental organizations and public figures have emphasized changes in the climate and the risks they entail, while promoting adaptation to changes in infrastructural needs and emissions reductions.

Adaptation is especially important in developing countries since those countries are predicted to bear the brunt of the effects of global warming. That is, the capacity and potential for humans to adapt (called adaptive capacity) is unevenly distributed across different regions and populations, and developing countries generally have less capacity to adapt.

Glossary of related technical terms

(Source: IPCC)

Climate: Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system. WGIII

Climate variability: Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate at all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

Climate change: Climate change refers to a change in the state of the climate that can be identified (e.g., by 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. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes. WGIII.

Abrupt climate change: The nonlinearity of the climate system may lead to abrupt climate change, sometimes called rapid climate change, abrupt events, or even surprises. The term abrupt often refers to time scales faster than the typical time scale of the responsible forcing.

Climate extreme (extreme weather or climate event): The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. For simplicity, both extreme weather events and extreme climate events are referred to collectively as 'climate extremes.'

Radiative forcing: Radiative forcing is the change in the net, downward minus upward, irradiance (expressed in W m^{-2}) at the tropopause due to a change in an external driver of climate change, such as, for example, a change in the concentration of carbon dioxide or the output of the Sun.

Impacts: Effects on natural and human systems. In this report, the term 'impacts' is used to refer to the effects on natural and human systems of physical events, of disasters, and of climate change.

Mean sea level: Sea level measured by a tide gauge with respect to the land upon which it is situated. Mean sea level is normally defined as the average relative sea level over a period, such as a month or a year, long enough to average out transients such as waves and tides.

Sea level change: Changes in sea level, globally or locally, due to (i) changes in the shape of the ocean basins, (ii) changes in the total mass and distribution of water and land ice, (iii) changes in water density, and (iv) changes in ocean circulation.

Sea surface temperature (SST): The sea surface temperature is the temperature of the subsurface bulk temperature in the top few meters of the ocean, measured by ships, buoys, and drifters.

Vulnerability: The propensity or predisposition to be adversely affected.

Disaster: Severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery.

Disaster management: Social processes for designing, implementing, and evaluating strategies, policies, and measures that promote and improve disaster preparedness, response, and recovery practices at different organizational and societal levels.

Mitigation (of climate change): A human intervention to reduce the sources or enhance the sinks of greenhouse gases.

Adaptation: In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate.

Adaptive capacity: The combination of the strengths, attributes, and resources available to an individual, community, society, or organization that can be used to prepare for and undertake actions to reduce adverse impacts, moderate harm, or exploit beneficial opportunities.

Coping: The use of available skills, resources, and opportunities to address, manage, and overcome adverse conditions, with the aim of achieving basic functioning in the short to medium term.

Resilience: The ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions.

Scenario: A plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a narrative storyline.

Climate scenario: A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships that has been constructed for explicit use in investigating the potential consequences of anthropogenic climate change, often serving as input to impact models. Climate projections often serve as the raw material for constructing climate scenarios, but climate scenarios usually require additional information such as about the observed current climate.

Climate projection: A projection of the response of the climate system to emissions or concentration scenarios of greenhouse gases and aerosols, or radiative forcing scenarios, often based upon simulations by climate models. Climate projections are distinguished from climate predictions in order to emphasize that climate projections depend upon the emission/ concentration/radiative-forcing scenario used, which are based on assumptions concerning, e.g., future socioeconomic and technological developments that may or may not be realized and are therefore subject to substantial uncertainty.

Climate model: A numerical representation of the climate system that is based on the physical, chemical, and biological properties of its components, their interactions, and feedback processes, and that accounts for all or some of its known properties. The climate system can be represented by models of varying complexity, that is, for any one component or combination of components a spectrum or hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical, or biological processes are explicitly represented, or the level at which empirical parameterizations are involved.

Downscaling: Downscaling is a method that derives local- to regional-scale (up to 100 km) information from larger-scale models or data analyses.

Emissions scenario: A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g., greenhouse gases, aerosols), based on a coherent and internally consistent set of assumptions about driving forces (such as technological change, demographic and socioeconomic development) and their key relationships. Concentration scenarios, derived from emissions scenarios, are used as input to a climate model to compute climate projections.

Greenhouse Gas: Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, which absorb and emit radiation at specific wavelengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, by the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapor (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere.

Greenhouse Effect: Greenhouse gases effectively absorb thermal infrared radiation, emitted by the Earth's surface, by the atmosphere itself due to the same gases, and by clouds. Atmospheric radiation is emitted to all sides, including downward to the Earth's surface. Thus, greenhouse gases trap heat within the surface-troposphere system. This is called the greenhouse effect. An increase in the concentration of greenhouse gases leads to an increased infrared opacity of the atmosphere and therefore to an effective radiation into space from a higher altitude at a lower temperature. This causes a radiative forcing that leads to an enhancement of the greenhouse effect, the so-called enhanced greenhouse effect.

(Source: NASA, Wikipedia)

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