Chapter 4
The Impacts of Climate Change on Agricultural, Food, and Public Utility Industries

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Acronyms and Nomenclature

BC	Black carbon
CCS	Carbon capture and sequestration
CFC	Chlorofluorocarbon
CH_4	Methane
CO_2	Carbon dioxide
ENSO	El Niño-Southern Oscillation
ERF	Effective radiative forcing
GHG	Greenhouse gas

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GWP	Global warming potential
HBFC	Hydrobromofluorocarbon
HC	Hydrocarbon
HCFCs	Halogenated fluorocarbons
HFCs	Hydrofluorocarbons
IPCC	Intergovernmental Panel on Climate Change
LFG	Landfill gas
MCL	Maximum contaminant level
N_2O	Nitrous oxide
NPDWR	National Primary Drinking Water Regulations
ODS	Ozone-depleting substance
O_3	Ozone
PFCs	Perfluorinated carbons
PM	Particulate matter
RF	Radiative forcing
USEPA	US Environmental Protection Agency
USGS	US Geological Survey
WMO	World Meteorological Organization
$W\ m^{-2}$	Watts per square meter

4.1 Introduction

Global climate change, also referred to as global warming, is a serious threat to our environment. This chapter will present a summary of scientific facts about climate change and discuss its impacts in particular on water resources and planning. The underlying science of climate change is undisputable. Climate change has become a contentious political issue, which is unfortunate if only because it distracts society and our policymakers from necessary discussions and decisions about how to respond to the impacts of climate change on our communities.

4.1.1 Weather, Climate, and Climate Change

The climate of a region can be thought of as the “average” of that region’s weather. Climate is predictable, or at least enough so that we rely on it for planning. We speak of the sunny, temperate climate of the Mediterranean, or the harsh, cold climate of Siberia (even though there are both cold winter storms in Italy and warm summer days on the taiga), and vacations and population growth projections are adjusted accordingly. In simple modeling terms, if an input that was previously thought to be constant—climate—is found to be variable, or to have become variable, then the model output will also necessarily change from what was previously expected. If the weather we are used to expecting is no longer what can be expected in the future, then what should current and future infrastructure planning be based on? Land use planners and water and wastewater utility operators and regulators need to understand what the impacts of climate change will be on water resources and how to prepare for these changes.

It is well known that the Earth has gone through multiple ice ages in periods of dramatic cooling and dramatic warming. Among the many ice ages the Earth has undergone, we are currently going through a warming trend. Questions we would ask are: "Why is the Earth warming?" "How does the source warm the Earth?" "What are the implications on our water resources, animals, and agriculture?" There are more questions than answers [1–38]. But before we discuss how the Earth's climate is changing, there are some technical terminologies presented below as well as in the "Glossary" section of this chapter [26–30].

Stratospheric ozone plays a decisive role in the stratospheric radiative balance. Since ozone absorbs a band of ultraviolet radiation called UVB that is particularly harmful to living organisms, the ozone layer prevents most UVB from reaching the ground. Depletion of stratospheric ozone, due to chemical reactions that may be enhanced by climate change, results in an increased ground-level flux of ultraviolet (UV) B radiation.

Ozone "Hole" is a large area of the stratosphere with extremely low amounts of ozone.

Ozone-depleting substance (ODS) is a family of man-made compounds that includes, but is not limited to, chlorofluorocarbons (CFCs), bromofluorocarbons (halons), methyl chloroform, carbon tetrachloride, methyl bromide, and hydrochlorofluorocarbons (HCFCs). These compounds have been shown to deplete stratospheric ozone and therefore are typically referred to as ODSs.

Ozone layer depletion means chemical destruction of ozone molecules in the ozone layer. Depletion of this ozone layer by ozone-depleting substances will lead to higher UVB levels (a band of ultraviolet radiation), which in turn will cause increased skin cancers and cataracts and potential damage to some marine organisms, plants, and plastics.

Particulate matter (PM) are very small pieces of solid or liquid matter such as particles of soot, dust, fumes, mists, or aerosols. The physical characteristics of particles, and how they combine with other particles, are part of the feedback mechanisms of the atmosphere.

Photosynthesis is a process by which plants take CO_2 from the air (or bicarbonate in water) to build carbohydrates, releasing O_2 in the process. There are several pathways of photosynthesis with different responses to atmospheric CO_2 concentrations.

Phytoplankton are microscopic plants that live in salt and freshwater environments.

Precession means the wobble over thousands of years of the tilt of the Earth's axis with respect to the plane of the solar system.

Precipitation includes rain, hail, mist, sleet, snow, or any other moisture that falls to the Earth.

Radiation is a type of energy transfer in the form of electromagnetic waves or particles that release energy when absorbed by an object.

Radiative forcing means (a) a change in the balance between incoming solar radiation and outgoing infrared radiation and (b) a measure of the influence of a particular factor (e.g., greenhouse gas (GHG), aerosol, or land use change) on the net change in the Earth's energy balance.

Soil is a complex mixture of inorganic minerals (i.e., mostly clay, silt, and sand), decaying organic matter, water, air, and living organisms.

Soil carbon is a major component of the terrestrial biosphere pool in the carbon cycle. The amount of carbon in the soil is a function of the historical vegetative cover and productivity, which in turn is dependent in part upon climatic variables.

Solar energy is also called solar radiation, energy from the Sun, and also referred to as shortwave radiation. Of importance to the climate system, solar radiation includes ultraviolet radiation, visible radiation, and infrared radiation. It also includes indirect forms of energy such as wind falling or flowing water's hydropower, ocean thermal gradients, and biomass, which are produced when direct solar energy interacts with the Earth.

Solar radiation is a radiation emitted by the Sun. It is also referred to as shortwave radiation. Solar radiation has a distinctive range of wavelengths (spectrum) determined by the temperature of the Sun.

Source means any process or activity that releases a greenhouse gas, an aerosol, or a precursor of greenhouse gas into the atmosphere.

Stratosphere is the region of the atmosphere above the troposphere and between the troposphere and the mesosphere. The stratosphere extends from about 8–50 km (6–31 miles) in altitude. Specifically, it has a lower boundary of approximately 8 km at the poles to 15 km at the equator and an upper boundary of approximately 50 km. Depending upon latitude and season, the temperature in the lower stratosphere can increase, be isothermal, or even decrease with altitude, but the temperature in the upper stratosphere generally increases with height due to absorption of solar radiation by ozone. So the stratosphere gets warmer at higher altitudes. In fact, this warming is caused by ozone absorbing ultraviolet radiation. Warm air remains in the upper stratosphere, and cool air remains lower, so there is much less vertical mixing in this region than in the troposphere. Commercial airlines fly in the lower stratosphere.

Terrestrial radiation means the total infrared radiation emitted by the Earth and its atmosphere in the temperature range of approximately 200–300 Kelvin. Terrestrial radiation provides a major part of the potential energy changes necessary to drive the atmospheric wind system and is responsible for maintaining the surface air temperature within limits of livability.

Troposphere is (a) the region of the atmosphere closest to the Earth. The troposphere extends from the surface up to about 10 km (6 miles) in altitude, although this height varies with latitude. Almost all weather takes place in the troposphere. Mt. Everest, the highest mountain on Earth, is only 8.8 km (5.5 miles) high. Temperatures decrease with altitude in the troposphere. As warm air rises, it cools, falling back to Earth. This process, known as convection, means there are huge air movements that mix the troposphere very efficiently; or (b) the lowest part of the atmosphere from the surface to about 10 km in altitude in midlatitudes (ranging from 9 km in high latitudes to 16 km in the tropics on average) where clouds and "weather" phenomena occur. In the troposphere, temperatures generally decrease with height. All weather processes take place in the troposphere. Ozone that is formed in the troposphere plays a significant role in both the greenhouse gas effect and urban smog. The troposphere contains about 95% of the mass of air in the Earth's atmosphere.

Weather is the specific condition of the atmosphere at a particular place and time. It is measured in terms of such things as wind, temperature, humidity, atmospheric pressure, cloudiness, and precipitation. In most places, weather can change from hour to hour, day to day, and season to season. 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 is 30 years, as defined by the World Meteorological Organization (WMO). These 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. A simple way of remembering the difference is that climate is what you expect (e.g., cold winters) and "weather" is what you get (e.g., a blizzard) [30].

4.1.2 Greenhouse Gases, Greenhouse Effect, Global Warming, Global Warming Potential

A greenhouse gas (GHG) is any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halogenated fluorocarbons (HCFCs), ozone (O_3), perfluorinated carbons (PFCs), hydrofluorocarbons (HFCs), and sulfur hexafluoride. Gases absorb heat in the atmosphere near the Earth's surface, preventing it from escaping into the space. If the atmospheric concentrations of these gases rise, the average temperature of the lower atmosphere will gradually increase, a phenomenon known as the greenhouse effect.

Specifically, greenhouse effect is produced as greenhouse gases allow incoming solar radiation to pass through the Earth's atmosphere, but prevent most of the outgoing infrared radiation from the surface and lower atmosphere from escaping into the outer space. This process occurs naturally and has kept the Earth's temperature about 60 °F warmer than it would otherwise be. Current life on Earth could not be sustained without the natural greenhouse effect. The greenhouse effect is trapping heat and build-up of heat in the atmosphere (troposphere) near the Earth's surface. Some of the heat flowing back toward the space from the Earth's surface is absorbed by water vapor, carbon dioxide, ozone, and several other gases in the atmosphere and then reradiated back toward the Earth's surface [2, 30].

Global warming is known due to the recent and ongoing global average increase in temperature near the Earth's surface. It is the observed increase in average temperature near the Earth's surface and in the lowest layer of the atmosphere. In common usage, "global warming" often refers to the warming that has occurred as a result of increased emissions of greenhouse gases from human activities. Global warming is a type of climate change; it can also lead to other changes in climate conditions, such as changes in precipitation patterns.

Global warming potential (GWP) is a measure of the total energy that a gas absorbs over a particular period of time (usually 100 years), compared to carbon dioxide. GWP is a number that refers to the amount of global warming caused by a substance. The GWP is also the ratio of the warming caused by a substance to the warming caused by a similar mass of carbon dioxide (CO_2). Thus, the GWP of CO_2 is 1.0. Chlorofluorocarbon (CFC)-12 has a GWP of 8500; CFC-11 has a GWP of 5000; hydrochlorofluorocarbons and hydrofluorocarbons have GWPs ranging from 93 to 12,100; and water has a GWP of 0 [2, 30].

4.2 Main Contributors to Greenhouse Gases

The main reason for the Earth's warming is due to the greenhouse effect (Figs. 4.1 and 4.2). Before human activity, natural activities such as volcanic activity and natural forest fires would emit greenhouse gases in the atmosphere. As greenhouse gases absorb heat and solar radiation, the concentrations of gases get trapped near the Earth's surface and sustain life [2]. A microcosm of this balance can be seen in the relationship between humans and trees. Humans take in oxygen and release carbon

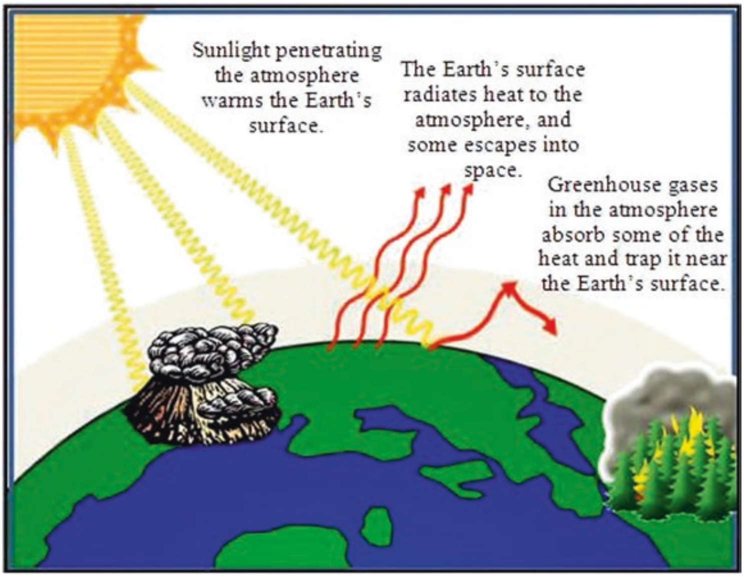


Fig. 4.1 The natural greenhouse effect before human activity ([2], Permission to use)

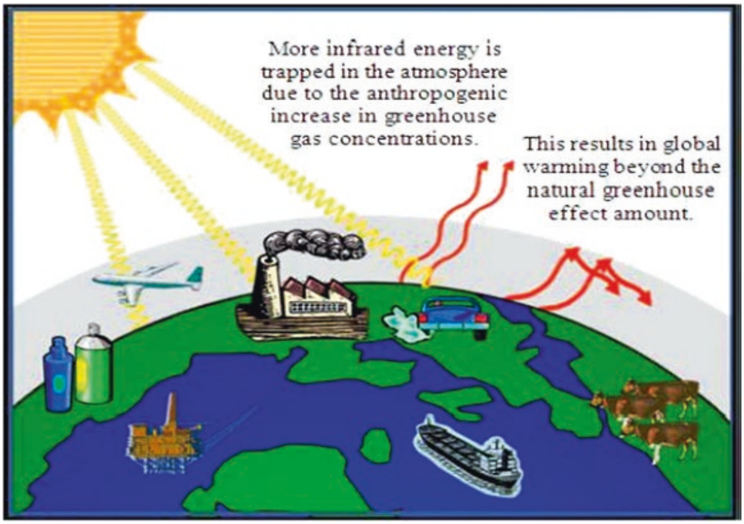


Fig. 4.2 The greenhouse effect after human activity ([2], Permission to use)

dioxide (CO_2), while trees take in carbon dioxide and release oxygen, thereby creating a balance in nature.

However, due to increased human activity (from electricity, transportation, industry, and population increase) [3], large amounts of CO_2 and other greenhouse gases have been released to the atmosphere. Also, as trees get cut down and deforested, there are less resources using up the CO_2, causing levels to rise beyond natural levels. So, what happens to the additional greenhouse gases floating in the air? The excess CO_2 and other greenhouse gases trap the extra radiation near the Earth's surface, causing global temperatures to rise, or global warming [2, 30].

The definitions of greenhouse gases and other technical terms have been introduced in Sect. 4.1. The main contributor to the greenhouse effect is carbon dioxide. Following carbon dioxide are methane gas (CH_4) and nitrous oxide (N_2O), and the halocarbons as the leading greenhouse gases. Figure 4.3 below shows the major climate changing agents of greenhouse gases and their radiative forcing (W m^{-2}), showing their emission ability to retain heat, and their great amounts on the Earth's surface [4]. As seen in Fig. 4.3, carbon dioxide has the greatest amount where it absorbs heat at a radiative forcing above 1.5 W m^{-2} of increased and retained solar radiation at the Earth's surface. Although halocarbons, methane, and nitrous oxide have a greater warming potential than carbon dioxide, the larger quantity of carbon dioxide has a greater impact [28, 30]. Ozone depends on the location. In the troposphere where people live, ozone is a greenhouse gas where it absorbs heat; however, ozone in the stratosphere actually absorbs UV radiation and holds back the radiation from hitting the Earth's surface, thereby keeping the Earth cooler. Water does not affect the warming of the Earth too much since the concentration levels are fairly constant. Land use goes both ways where dark forested areas or black carbon on snow or from diesel engines in the troposphere would absorb heat, whereas planting

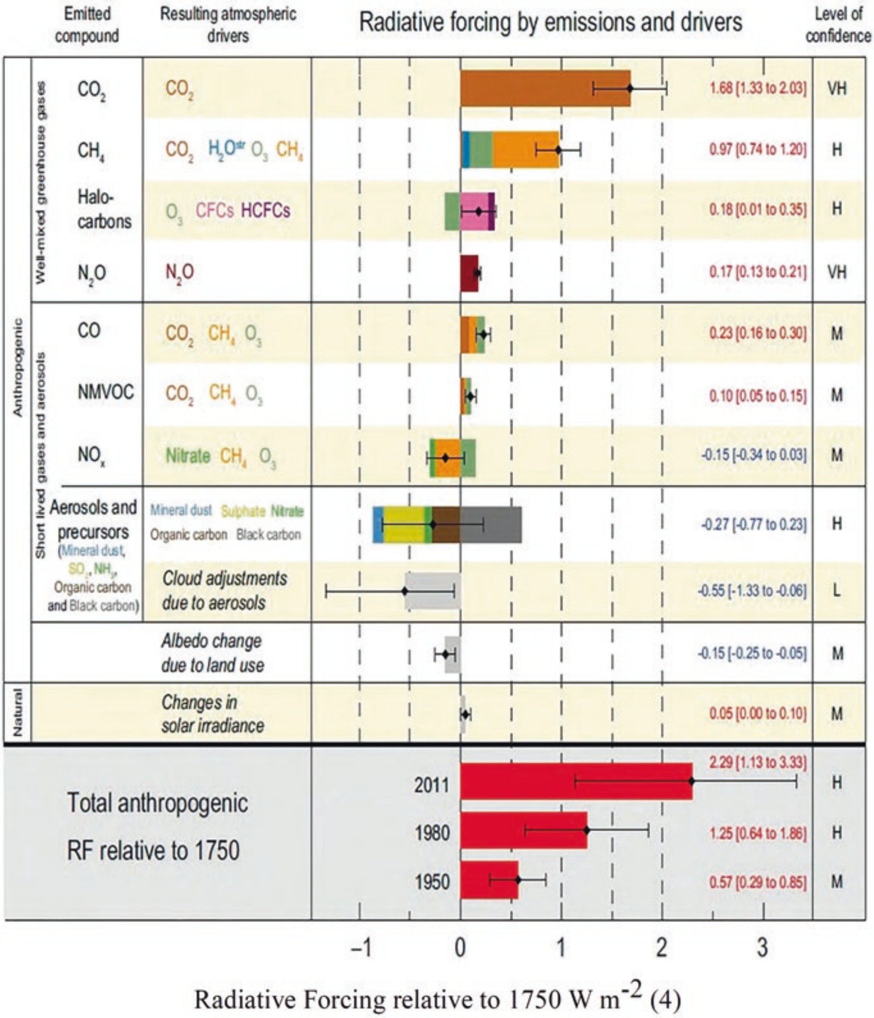


Fig. 4.3 Radiative forcing estimates in 2011 relative to 1750 and aggregated uncertainties for the main drivers of climate change [4]

lighter colored plants on arid regions where light reflects back to the space would actually cool the Earth. Aerosols' effects are uncertain; the concentration of aerosols can be monitored based on the brightness of clouds; the higher the concentration of aerosols, the brighter the clouds are. The reason is the aerosols feed the water droplets that contribute to the clouds, and the more water droplets there are, the more the droplets reflect light more. Aerosols in the stratosphere from volcanic activity block the radiation to help cool the Earth. There is still much to investigate and discover about aerosols [2, 4].

Figure 4.3 shows the total weighted average of all the climate changing agents; there is a total of 2.29 W m^{-2} increase in the amount of solar energy absorbed at the surface of the Earth [2, 4]. Because carbon dioxide shows the greatest quantity and has the greatest impact, carbon dioxide will be the main focus and should often be a reference point to compare to other greenhouse gases. Values in Fig. 4.3 are global average radiative forcing (RF), partitioned according to the emitted compounds or processes that result in a combination of drivers. The best estimates of the net radiative forcing are shown as black diamonds with corresponding uncertainty intervals; the numerical values are provided on the right of the figure, together with the confidence level in the net forcing (VH, very high; H, high; M, medium; L, low; VL, very low). Albedo forcing due to black carbon on snow and ice is included in the black carbon aerosol bar. Small forcings due to contrails (0.05 W m^{-2}, including contrail-induced cirrus) and HFCs, PFCs, and SF_6 (total 0.03 W m^{-2}) are not shown. Concentration-based RFs for gases can be obtained by summing the like-colored bars. Volcanic forcing is not included as its episodic nature makes it difficult to compare to other forcing mechanisms. Total anthropogenic radiative forcing is provided for three different years relative to 1750.

The strength of drivers in Fig. 4.3 is quantified as radiative forcing (RF) in units watts per square meter (W m^{-2}) as in previous IPCC assessments. RF is the change in energy flux caused by a driver and is calculated at the tropopause or at the top of the atmosphere. In the traditional RF concept employed in previous IPCC reports, all surface and tropospheric conditions are kept fixed. In calculations of RF for well-mixed greenhouse gases and aerosols in this report, physical variables, except for the ocean and sea ice, are allowed to respond to perturbations with rapid adjustments. The resulting forcing is called effective radiative forcing (ERF) in the underlying report. This change reflects the scientific progress from previous assessments and results in a better indication of the eventual temperature response for these drivers. For all drivers other than well-mixed greenhouse gases and aerosols, rapid adjustments are less well characterized and assumed to be small, and thus the traditional RF is used [4].

4.3 Global Warming Potential and Its Limitations

In the earlier sections of this chapter, global warming potential (GWP) is a measurement of how well heat is absorbed by greenhouse gases. The IPCC defines global warming potential (GWP) as "the ratio of the time integrated radiative forcing from a pulse emission of 1 kg of a substance, relative to that of 1 kg of carbon dioxide, over a fixed horizon period. GWP is a relative index used to compare the climate impact of an emitted greenhouse gas, relative to an equal amount of Carbon Dioxide" [10]. Also, the IPCC examines the GWP for 1 g of carbon dioxide at a 20-, 100-, and 500-year time horizon in comparison to other greenhouse gases [9]. The six major greenhouse gases are determined by the Kyoto Protocol. The Kyoto Protocol is an international treaty that sets obligations on industrialized countries to lower the

Table 4.1 IPCC global warming potential consensus [2, 8, 9]

Six greenhouse gases listed designated by the Kyoto Protocol	Lifetime (years)	Global warming potential for the given time horizon		
		20 years	100 years	500 years
Carbon dioxide, CO_2	~150	1	1	1
Methane, CH_4	12	72	25	7.6
Nitrous oxide, N_2O	114	289	298	153
HFC-23	270	12,000	14,800	12,200
PFC-116	10,000	8630	12,200	18,200
Sulfur hexafluoride, SF_6	3200	5210	7390	11,200

emissions of greenhouse gases. The GWP values can be seen in Table 4.1; the table shows the six major greenhouse gases from the Kyoto Protocol: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), HFCs, PFCs, and sulfur hexafluoride (SF_6). The Intergovernmental Panel on Climate Change (IPCC) includes many greenhouse gases in their consensus and a list of HFCs and PFCs. The HFC and PFC chosen in Table 4.1 are for the greatest GWP values within the consensus list. The lifetime among the six gases ranges from 12 to 10,000 years. The value closest to the median is sulfur hexafluoride, with a lifetime of 3200 years. At a time horizon of 500 years, while carbon dioxide releases 1 g, sulfur hexafluoride releases 11,200 g of carbon dioxide (11,200 times more) for the same time horizon. A stronger greenhouse gas can easily leak and create a major impact.

The global warming potential has limitations where radiative properties are uncertain and nonlinear (CO_2, CH_4, N_2O); the actual resident life of greenhouse gases and how long it actually stays in the atmosphere vary and some are unknown (CO_2, ozone precursors, diesel PM, and PM); if the resident lifetimes are short-lived in the atmosphere, the GWP is not useful; there are not only direct radiative forcings but also indirect radiative forcings with uncertainties (i.e., ozone precursors are not only a gas, but they also form ozone) [2]. While the graphs and data interpretations are accepted, people have challenged methodologies and how data is used and interpreted; however, in this case, the US Environmental Protection Agency (USEPA), the United Nations (UN), and the Intergovernmental Panel Data Analysis reports and technical books [3–6, 8–11, 16–17, 19–25] are widely accepted. Comparing global warming potentials to carbon dioxide, greenhouse gases are better understood when examining why carbon dioxide absorbs heat on a molecular level.

4.4 Heat Absorption by Carbon Dioxide

Carbon dioxide's ability to absorb heat is characterized by the molecular structure, the wavelength, and radiative properties. Visible light from the Sun is able to pass the carbon dioxide molecules without its energy being absorbed since the frequency of visible light does induce a dipole moment on the atmospheric CO_2 molecules.

Carbon dioxide does however absorb "infrared" radiation (heat from the Earth's surface) and also re-emits that energy at the same wavelength as what was absorbed (also as heat) [6]. As for its molecular structure, "Carbon dioxide doesn't have a molecular dipole in its ground state. However, some CO_2 vibrations produce a structure with a molecular dipole. Because of this, CO_2 strongly absorbs infrared radiation" [7].

The energy of a molecule can change due to a change in the energy state of the electrons of which it is composed. Thus, the molecule also has electronic energy. The energy levels are quantized and take discrete values only. Absorption and emission of radiation take place when the atoms or molecules undergo transitions from one energy state to another. In general, these transitions are governed by selection rules. Atoms exhibit line spectra associated with electronic energy levels.

The dipole moment is determined by the magnitude of the charge difference and the distance between the two centers of charge. If there is a match in frequency of the radiation and the natural vibration of the molecule, absorption occurs and this alters the amplitude of the molecular vibration. This also occurs when the rotation of asymmetric molecules around their centers results in a dipole moment change, which permits interaction with the radiation field. Dipole moment is a vector quantity and depends on the orientation of the molecule and the photon electric vector [12].

In accordance with Kirchhoff's laws, the following are noted:

1. Materials that are strong absorbers at a given wavelength are also strong emitters at that wavelength; similarly weak absorbers are weak emitters.
2. Emission, reflection, and transmission account for all the incident radiation for media in thermodynamic equilibrium [2, 6].

4.5 Rising Temperature Trend in the Environment

4.5.1 Atmosphere Temperature Increase

As a result of increased human activity, more greenhouse gases are warming the Earth, resulting in an increased temperature trend around the world. The following graphs suggest the increase in emissions has led to the increase in CO_2 in the atmosphere, thereby increasing the temperature of the Earth's surface on land. Figure 4.4 shows the global per capita carbon emission estimates versus years. It appears that the global per capita carbon emission increases significantly after the year 2000 [15].

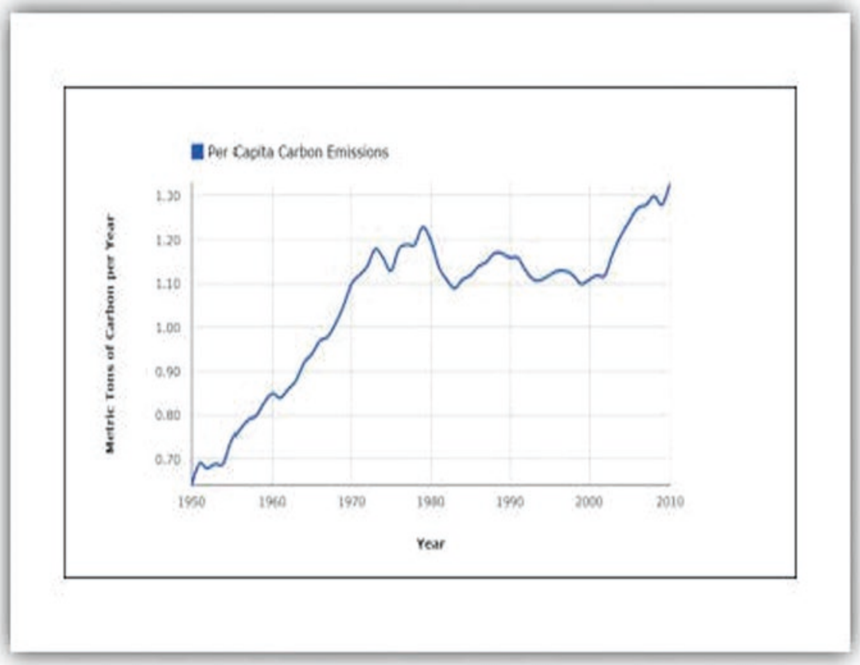


Fig. 4.4 Global per capita carbon emission estimates versus years [15]

4.5.2 Land and Ocean Temperature Increase

As land temperatures rise, we find ocean temperatures rise as well. "The globally averaged combined land and ocean surface temperature data as calculated by a linear trend, show a warming of 0.85 [0.65–1.06] °C, over the period 1880–2012, when multiple independently produced datasets exist. The total increase between the average of the 1850–1900 period and the 2003–2012 period is 0.78 [0.72–0.85] °C, based on the single longest dataset available. There are two methods: The first calculates the difference using a best fit linear trend of all points between 1880 and 2012. The second calculates the difference between averages for the two periods 1850–1900 and 2003–2012 [4].

Figure 4.5 shows an increase of carbon dioxide in the atmosphere from 1958 to 2012 [4], while Fig. 4.6 shows the annual temperature anomalies from land ocean in the period of 1880–2012 [16]. Based on the presented figures, an increase of global carbon emissions shown in Fig. 4.4 leads to an increase of carbon dioxide in the atmosphere shown in Fig. 4.5 and finally results in a temperature increase on land and ocean shown in Fig. 4.6.

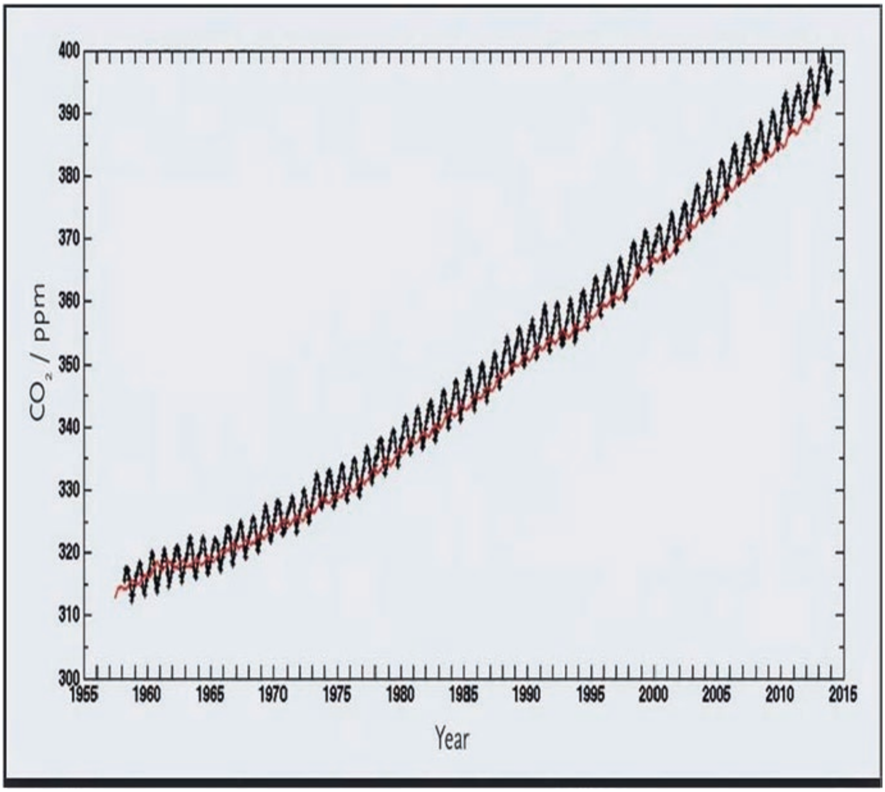


Fig. 4.5 Increase of carbon dioxide in the atmosphere [4]

4.5.3 Rising Temperatures of Land, Air, Sea, and Ice

Figure 4.7 summarizes the temperatures of land, air, and sea, with a dramatic increase beginning in 1980. Similarly, 1920–1940 also experienced an upward trend; however, from 1940 approaching 1980, the temperatures slightly decreased. The reason the temperatures dropped is due to the industrial revolution's emissions, where manufacturers and factories sent a layer of soot in the atmosphere. The layer of soot became a barrier and blocked solar radiation from hitting the Earth's surface, causing a cooling effect. However, when the Clean Air Act of 1970 was enforced, the layer of soot moved out of the atmosphere and so began the true and actual warming trend [2, 18, 19].

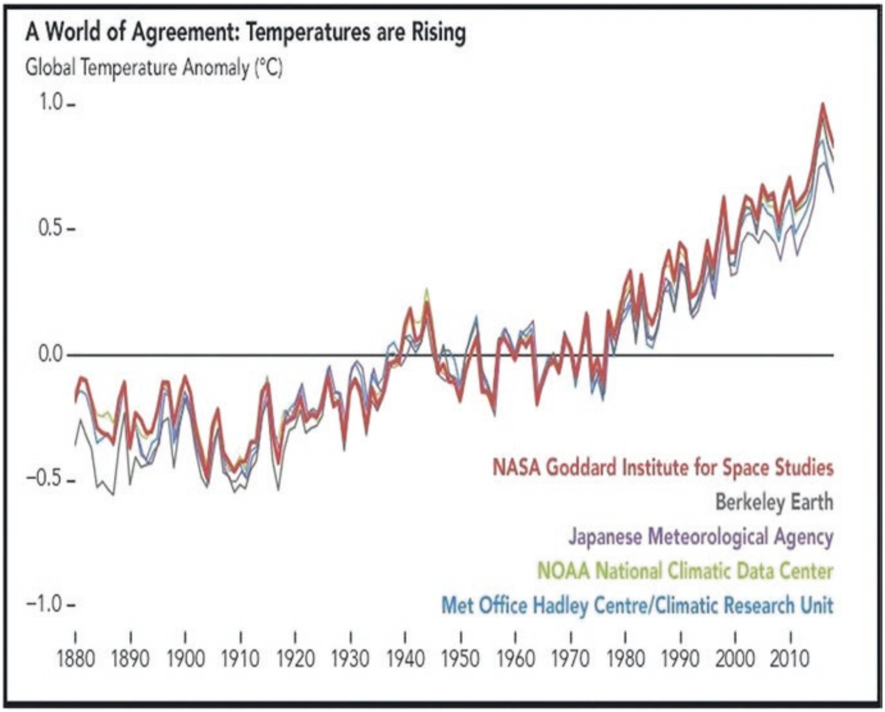


Fig. 4.6 Land and ocean temperature increase: annual temperature anomalies from land and ocean 1880–2012 [16]

4.6 Increased Temperatures on Land and Its Impacts on Agriculture

As discussed previously, climate change results in increased temperatures in the atmosphere, land, and sea. Weather patterns will become more extreme and forceful where storms become cyclones such as Hurricanes Katrina, Irene, and Sandy in the United States. Winters will reach record cooling temperatures, and summers will reach record hotter temperatures. Dry land will become more dry, and droughts will become so severe, agriculture and food shortages may eventually lead to famine. Arid regions will be impacted where there once was water, will be no more water at all, or will experience significantly lower water levels. Agriculture will become a great challenge as soil becomes too dry or arid to harvest food [34].

Table 4.2 demonstrates the impacts of increased temperatures to our food supply. Table 4.2 illustrates the types of impacts that could be experienced as the world comes into equilibrium with more greenhouse gases. The top panel shows the range of temperatures projected at stabilization levels between 400 ppm and 750 ppm CO_2 at equilibrium. The solid horizontal lines indicate the 5–95% range based on climate

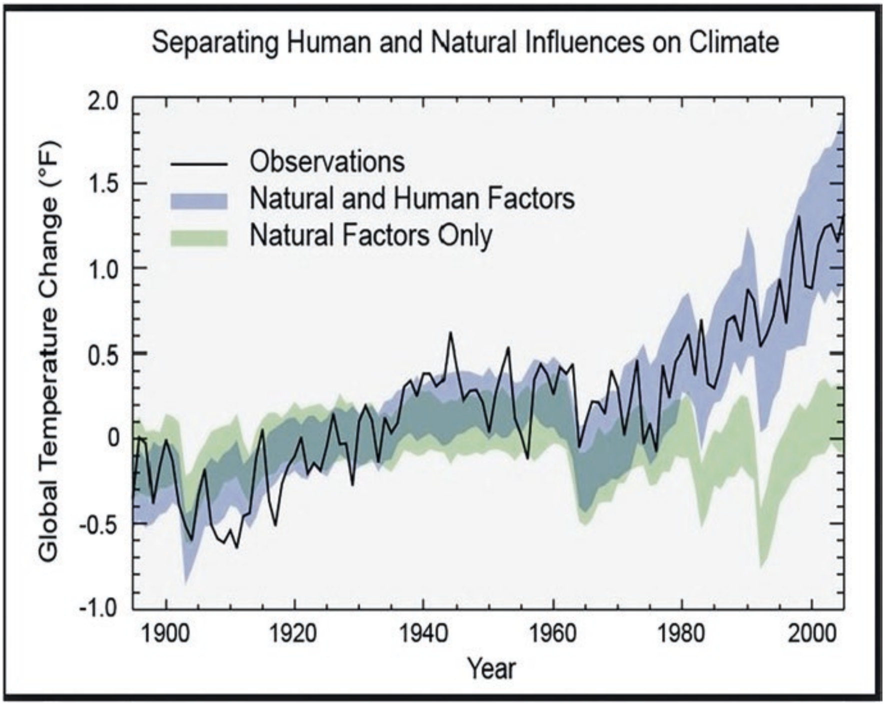


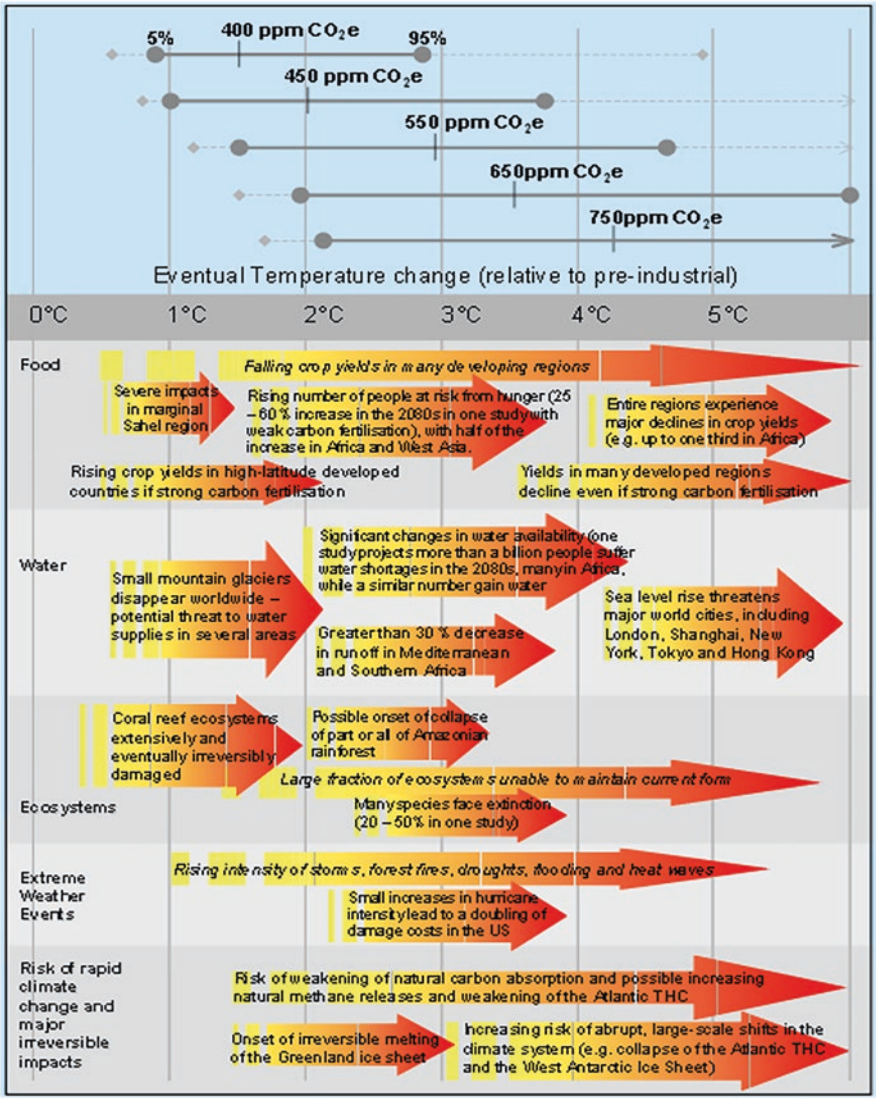
Fig. 4.7 Observed globally averaged combined land and ocean surface temperature anomaly 1895–2012

sensitivity estimates from the IPCC 20012 and a recent Hadley Centre ensemble study. The vertical line indicates the mean of the 50th percentile point. The dashed lines show the 5–95% range based on 11 recent studies. The bottom panel illustrates the range of impacts expected at different levels of warming. The relationship between global average temperature changes and regional climate changes is very uncertain, especially with regard to changes in precipitation. This figure shows potential changes based on current scientific literature [34].

4.7 Effect of Global Warming and Climate Change on Sea Level Rise

As global average surface temperatures rise, and global average sea levels increase, the snow cover and ice will decrease and melt. Figure 4.8 reports the changes of temperature, sea level, and Northern Hemisphere snow cover. Specifically observed changes in Fig. 4.8(a) show global average surface temperature versus years. Figure 4.8(b) shows global average sea level from tide gauge (blue) and satellite (red) data versus years. Figure 4.8(c) shows Northern Hemisphere snow cover for

Table 4.2 Stabilization levels and probability ranges for temperature increases



March–April versus years. All differences are relative to corresponding averages for the period 1961–2000. The smoothed curves represent decadal averaged values, while the circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties shown in the figures.

The impacts of sea level rise include increased flood risk, infrastructure investment implications around the world as seen in other countries like Italy, Netherlands,

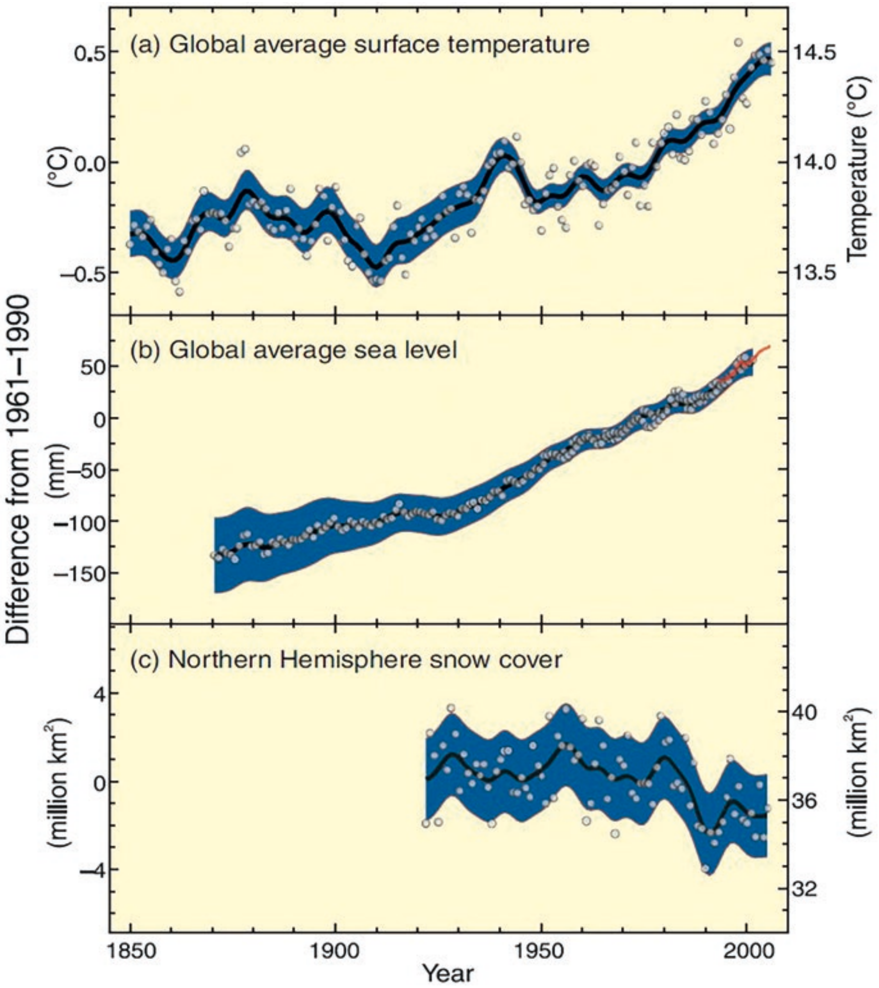


Fig. 4.8 Changes in temperature, sea level, and Northern Hemisphere snow cover

and the South Pacific Island. Sea level rise will also contribute to increases in salinity of rivers and estuaries, saltwater intrusion, as seen in the United States and all around the world. Saltwater intrusion can affect the water supplies for drinking and irrigation water and depletes the available freshwater habitat, as seen in the United States.

The Asia-Pacific Region's climate change adaptation involves the risk insurance scheme as a social safety net through risk transfer and creates resilient societies. The advantages of risk transfer are that it promotes risk mitigation compared to current response-driven mechanisms, provides a cost-effective way to deal with expensive impacts from the effects of climate change, "supports climate change adaptation by covering the residual risks uncovered by other risk reduction mechanisms such as building regulations, landuse planning and disaster risk management plans," stabilizes incomes in rural areas and minimizes the gap in income fluctuation and socio-economic development, provides partnerships between public and private sectors, reduces government dependence after a disaster to reconstruct, helps people and communities to recover and get back to everyday life quickly, and addresses various risks from climatic and non-climatic origin, depending on how insurance is set up.

One of the greatest challenges to sea level rise impacts is increased salinity intrusion in rivers and estuaries, putting our water supply at risk.

4.8 Increased Salinity Intrusion in Rivers and Estuaries

According to the IPCC, studies have shown freshwaters to become more saline over time and seawater has become fresher. This has affected rivers and estuaries, drinking water supplies, irrigation, sea levels, and ecosystems.

4.8.1 Salinity Intrusion in Rivers and Estuaries

Saltwater intrusion (or salinity intrusion) is the movement of saline water into freshwater aquifers, which can become contaminated and undrinkable. Freshwater aquifers can experience saline intrusion due to the hydraulic connection between groundwater and seawater. Because saltwater is more mineral rich than freshwater, it is denser and has higher water pressure. And so the heavier saltwater is able to push inland beneath the freshwater.

Sources of saltwater intrusion include, but are not limited to, (a) activities like groundwater pumping from coastal freshwater wells as seen in coastal areas; (b) water extraction which drops the level of fresh groundwater, reducing its water pressure and allowing saltwater to flow inland; and (c) water channels or agricultural and drainage channels, carrying saltwater inland, and causing sea level rise. Saltwater intrusion can also be worsened by extreme weather events like tropical cyclones and hurricane storm surges. All over the world, rivers and estuaries experience salinity intrusion as a result of rising sea levels.

A case study to consider is California's Sacramento-San Joaquin Delta. The Sacramento-San Joaquin Delta is at the heart of most discussions about water in California. The 1153 square mile of twist-and-turn islands and interconnected waterways is located where the Sacramento and San Joaquin Rivers converge and flow into San Francisco Bay through the Golden Gate Bridge. About 42% of the state's annual runoff flows through the Delta serving more than 23 million Californians and irrigating millions of acres in the Central Valley. Two-thirds of Californians get all or part of their drinking water from the Delta by government water projects that export water to the San Francisco Bay Area and Central and Southern California. The Delta is also the largest estuary on the West Coast with hundreds of species of birds that travel along the Pacific Flyway and dozens of fish species including salmon and steelhead that migrate through the Delta on their journey to and from the ocean. The Delta is strongly influenced by freshwater inflow from tributary rivers, by tides in the SF Bay, and by salinity upstream. Since 1860, the Delta waters have seen an increase in salinity [1, 2].

Plant pollen revealed the Delta was mainly a freshwater marsh for the past 2500 years; however, in the past 100 years, because of human activity, the Delta has become more saline. Today, salinity intrusion is approximately 3–15 miles deeper into the Delta than the early twentieth century. Between 1860 and 1920, human activity modified the Delta when marshland was reclaimed, hydraulic mining caused increased deposition and erosion sediment, and the expansion of the Delta channel's width, depth, and connections took place.

Before freshwater diversions increased in the 1940s, the Delta and Suisun Bay would freshen every winter, even during extreme droughts as seen in the 1930s. However, the Delta did not freshen during recent droughts (1976–1977, 1987–1994, 2007–2009, and 2014–2015), resulting in contaminants and toxins accumulating in the system. The past 25 years have been relatively wet; the Delta's autumn salinity levels have shown to be in drought-like conditions due to human activity and water diversions.

The historical record and published studies demonstrate that the Delta is far saltier now due to human interference. Starting in 1917, local industries and residents observed unprecedented salinity levels, causing a local sugar refinery to find a new water supply, the Town of Antioch to file a lawsuit against upstream water users, and the State of California to start a salinity monitoring program and investigation (Fig. 4.9).

The colored portion on each chart represents the amount of freshwater available within Suisun Bay downstream of the Delta boundary (approximately 18 miles above Crockett). From 2001 to 2005, freshwater was seldom available below the Delta boundary, indicating that the Delta did not "flush" as it used to. Without the seasonal freshening of the Delta, contaminants and toxics can accumulate in the system; and in this case, toxics were found to be a factor in the decline of the Delta ecosystem. Note: While hydrological conditions were similar in the three time periods shown in the table, the sequence of wet and dry periods differs.

4.8.2 Water Quality and Water Supply Impacted by Climate Change and Salinity Intrusion

Because of salinity intrusion, water quality impacts to the water supply are affected. Many coastal cities in the United States have experienced saltwater intrusion through water supply wells. Impacts of saltwater intrusion depend on how far the intrusion extends, the plans for the water use, and how concentrations exceed the standard of dissolved ions for its intended use.

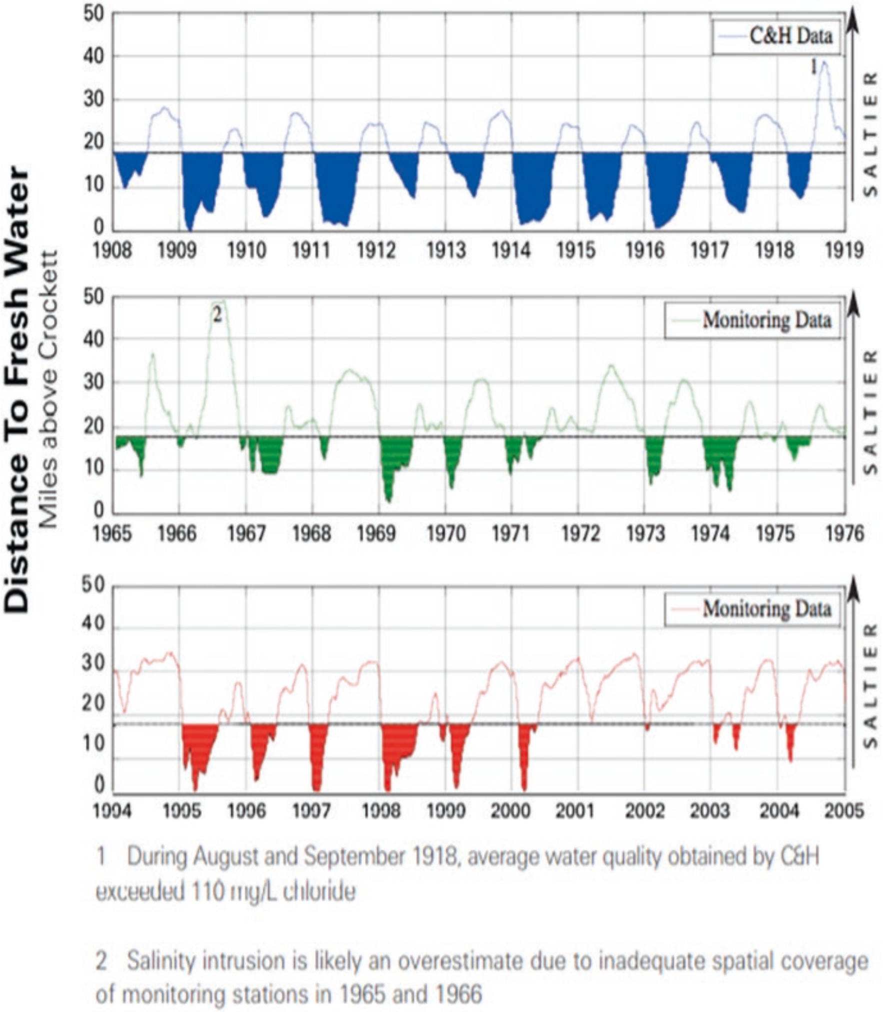


Fig. 4.9 Freshwater was available within Suisun Bay for a longer time period each year during the early 1900s

For example, a coastal state such as Washington State and Southern California reaches portions of the aquifer, affecting only certain water supply wells, whereas Cape May, New Jersey, United States, experienced saltwater encroachment laterally within each aquifer; it led to closing 20 or more public and industrial supply wells.

Not only in the United States, but salinity intrusion is a threat to water quality and water supply all over the world. Since the autumn of 2003, a strong salinity intrusion has caused a serious threat to the water supply in the Pearl River Delta, in Macau and Zhuhai, cities in China. The salinity intrusion is caused by rapid industrialization and urbanization, leading to greater water demand in the middle and upper stream of the river basin. When the flow runs low, either by water demand or during a dry season, salinity intrusion often occurs. Other sources of salinity intrusion include the rise of temperatures and sea levels, thereby affecting the water supply and quality.

Also, in Bangladesh, drinking water from natural sources by the coast has become contaminated by varying degrees of salinity due to saltwater intrusion from rising sea levels, cyclone and storm surges, and upstream withdrawal of freshwater. Not only in Asia, but also in Africa, the Ada peninsular in Ghana has suffered rapid coastal erosion and inundation for over 50 years. As a result, it has led to loss of property and livelihoods, economic stagnation, and saltwater intrusion. While property loss and economic opportunities are addressed, the solutions do not benefit increasing salinity intrusion in the Volta River. In fact, it aggravates the salinity intrusion, increasing salt in the Volta Estuary. The government intervened to implement a sea defense project to keep seawater from intruding and is concerned about the water supply and water quality due to saltwater intrusion.

Ada, situated at the mouth of the Volta Estuary, the Impact Assessment Report writes there is a likely significant impact on the physicochemical water characteristic of the estuary: "The most significant change will be an increased salinity in this zone, whereby the salinity gradient will shift to the north… The intrusion of salt water further into the estuary will probably lead to local changes in water quality. In places where the fresh water is high in particulate organic matter content comes in contact with salty coastal water, the organic matter starts to flocculate creating depositions of dark material in which toxins and nutrients tend to accumulate. This compromises the quality of water in the far southern part of the estuary, even more so because it creates nutrient rich conditions in which many bacterial and viral organisms, capable of causing diseases thrive. Hence, by opening up the estuary, this zone could be drawn into the estuary, negatively affecting water quality. However, the spatial extent of salinity shift is uncertain, and rated low to moderate compared to some natural phases in the estuary dynamics where openings have been created naturally that are far larger than the planned access channel."

In the case of Australia's dry weather challenges, droughts and extreme low flows in the water systems reduce ecosystem capacity to absorb and process contaminated water. As sea levels rise, the estuaries in the Murray-Darling Basin experience an increase in saltwater intrusion, affecting major urban water supplies, as well as freshwater ecosystem stability and productivity.

According to a case study of salinity of Israel's Lake Kinneret, the conclusion was made that increased salinity did not show obvious signs to effects on the lake ecology; however, the study showed a reduced water quality; this brought attention to implement changes in the Israeli water supply system.

All around the world, water quality impacts to water supply are affected by increased salinity in drinking water, such as well water, aquifers, and other sources, where the salt concentrations exceed the allowable. In the United States, a secondary maximum contaminant level is applied to 15 contaminants as a nonmandatory measure.

Water naturally accumulates a variety of dissolved solids, or salts, as it passes through soils and rocks on its way to the sea. These salts typically include such cations as sodium, calcium, magnesium, and potassium and anions such as chloride, sulfate, and bicarbonate. A careful analysis of salinity would result in a list of the concentrations of the primary cations and anions, but a simpler, more commonly used measure of salinity is the concentration of total dissolved solids (TDS). As a rough approximation, freshwater can be considered to be water with less than rough approximation, freshwater can be considered to be water with less than 1500 mg/L TDS, brackish waters may have TDS values up to 5000 mg/L, and saline waters are those with concentrations above 5000 mg/L, whereas seawater contains 30,000–34,000 mg/L TDS.

In some parts of the country, salty water may be encountered. Since the saltwater generally is overlain by freshwater, the lower part of the well in the saltwater zone can be sealed off. But when this is done, the yield of the well is decreased.

Sometimes, waste saltwater resulting from the backwashing of a home ion exchange water softener is discharged close to the well. Since saltwater is not filtered out in seeping through the soil, it may find its way into the well. The best thing to do is to discharge the wastewater as far as possible and downgrade from the well or utilize a commercial water softener service. Saltwater is corrosive; it will damage grass and plants and sterilize soil. Road salting or salt storage areas may also contribute to well pollution.

Special desalting units (using distillation, deionization, and reverse osmosis) are available for residential use, but they are of limited capacity and are relatively expensive, and pretreatment of the water may be needed. Complete information, including effectiveness with the water in question and annual cost, should be obtained before purchase.

The US Environmental Protection Agency (USEPA) has established National Primary Drinking Water Regulations (NPDWR) that set mandatory water quality standards for drinking water contaminants. One enforceable standard is the measurement of MCL (maximum contaminant levels), which were established to protect the public against consumption of drinking water contaminants that present a risk to human health. An MCL is the maximum allowable amount of a contaminant in drinking water, which is delivered to the consumer.

4.8.3 Agricultural Irrigation and Operations Impacted by Climate Change and Salinity Intrusion

According to Hung and Forrider [37], the impacts of global warming and climate change include degradation of natural resources, reduced agricultural production, and human dislocation, and these impacts as a driver of future forced migration depend on several factors:

1. Quantity of future GHG emissions

2. Rate of future population growth and distribution
3. Meteorological evolution of climate change
4. Effectiveness of local and national adaption strategies

Climate change has affected the food security either directly or indirectly causing stress on the production of food [39]. Climate change has also created pressures on the hydrological cycle and impacts water availability, which strongly influences agriculture. Effects on crop production are hard to predict as it depends on the frequency or intensity of extreme weather events. Global aridity has increased since the 1970s due to desertification. The areas under aridity have increased from 17 to 27% from the 1950s until now. This has notable effect on crop production and decreasing crop yields. For example, maize yields diminish up to 1.7% under drought conditions [39].

Higher CO_2 levels can positively affect food crop growth. However, other factors such as temperature, ozone, water availability, and nutrient constraints may counteract potential increases in yield. Many weeds, pests, and fungi thrive under warmer temperatures and wetter climates. Currently, farms spend more than $11 billion per year to fight weeds which compete with crops.

Drought may threaten livestock yield. In 2011, exposure to temperature events caused over $1 billion in heat-related losses. Heat stress affects animals directly and indirectly, making them vulnerable to disease and infertility. The prevalence of parasites increases, and the productivity of pastures is affected. The quality of the forage found in pastureland decreases with higher GHG; as a result, the cattle would need to eat more to get the same nutritional value. This can lead to overgrazing and misuse of land management [40].

Fisheries are also impacted [30]. American anglers catch or harvest five million metric tons of seafood each year and contribute $1.5 billion to the US economy annually. Aquatic species migrate to colder waters, and shell-building animals decrease in number. Fishermen experience decreases in harvest, which increase the price and availability of seafood. American fisheries are analogous to the global fishing economy.

Salt affects plant growth in three ways: (a) osmotic effects, caused by the total dissolved salt concentration in the soil water; (b) specific ion toxicity, caused by the concentration of individual ions; and (c) soil particle dispersion, caused by high sodium and low salinity. With increasing soil salinity in the root zone, plants expend more of their available energy on adjusting the salt concentration within the tissue (osmotic adjustment) to obtain needed water from the soil. The consequence is less energy is available for plant growth.

In irrigated areas, salts originate from the local groundwater or from salts in the applied water. Salts tend to concentrate in the root zone due to evapotranspiration, and plant damage is tied closely to an increase in soil salinity. Establishing a net downward flux of water and salt through the root zone is the only practical way to manage a salinity problem. Under such conditions, good drainage is essential to allow a continuous movement of water and salt below the root zone. Long-term use of reclaimed water for irrigation in which only the conventional constituents have been removed is not possible without adequate drainage.

Specific ion toxicity is another factor to be studied. If the decline of crop growth is due to excessive concentrations of specific ions, rather than osmotic effects alone, it is referred to as "specific ion toxicity." The ions of most concern in wastewater are sodium, chloride, and boron. The most prevalent toxicity from the use of reclaimed water is boron. The source of boron is usually household detergents or discharges from industrial plants. The quantities of chloride and sodium also increase as a result of domestic usage, especially where water softeners are used.

For sensitive crops, specific ion toxicity is difficult to correct without changing the crop or the water source. The problem is also accentuated by hot and dry climatic conditions due to high evapotranspiration rates. Regulations for maximum trace element concentrations for irrigation water are reported. In severe cases, these elements tend to accumulate in plants and soils, which could result in human and animal health hazards or cause phytotoxicity in plants.

The concentration of dissolved solids is an important indicator of the usefulness of water for various applications. Drinking water, for example, has a recommended maximum total dissolved solids (TDS) concentration of 500 mg/L. Many people will begin to notice water tastes salty at about 1000 mg/L of TDS, although this is very dependent on the particular dissolved constituents. Livestock can tolerate higher concentrations. Upper limits for stock water concentrations quoted by the US Geological Survey (1985) include poultry at 2860 mg/L, pigs at 4290 mg/L, and beef cattle at 10,100 mg/L. Of greater importance, however, is the salt tolerance of crops. As the concentration of salts in irrigation water increases above 500 mg/L, the need for careful water management to maintain crop yields becomes increasingly important. With sufficient drainage to keep salts from accumulating in the soil, up to 1500 mg/L TDS can be tolerated by most crops with little loss of yield, but at concentrations above 2100 mg/L, water is generally unsuitable for irrigation except for the most salt-tolerant crops. All naturally occurring water has some amount of salt in it. In addition, many industries discharge high concentrations of salts, and urban runoff may contain large amounts in areas where salt is used to keep ice from forming on roads in the winter. Although such human activities may increase salinity by adding salts to a given volume of water, it is more often the opposite process, the removal of freshwater by evaporation, that causes salinity problems. When water evaporates, the salts are left behind, and since there is less remaining freshwater to dilute them, their concentration increases.

Irrigated agriculture, especially in arid areas, is always vulnerable to an accumulation of salts due to this evapotranspiration on the cropland itself. The salinity is enhanced by the increased evaporation in reservoirs that typically accompany irrigation projects. In addition, irrigation drainage water may pick up additional salt as it passes over and through soils. As a result, irrigation drainage water is always higher in salinity than the supply water and, with every reuse, its salt concentration increases even more. In rivers that are heavily used for irrigation, the salt concentration progressively increases downstream as the volume of water available to dilute salts decreases due to evaporation and as the salt load increases due to salty drainage water returning from irrigated lands. It has been estimated that roughly one-third of the irrigated lands in the western part of the United States have a salinity problem that is increasing with time, including regions in the Lower Colorado River Basin and the west side of the San Joaquin Valley in California, United States. An estimated 100,000 tons of salt are imported annually into Southern Arizona through its consumption of Colorado River water via the 300 mile long, Central Arizona Project canal. Salinity problems are also having major impacts on irrigated lands in Iraq, Pakistan, India, Mexico, Argentina, Mali, and North Africa, among others. The collapse of ancient civilizations, once known as the Fertile Crescent, and is now Iraq, is thought to have formed by accumulating salt from irrigated agriculture. Agriculture that depends on irrigation from affected rivers would be directly impacted by sea level rise. Crops do not grow as well with salty water, as seen in the resulting smaller leaves, shorter stature, and sometimes fewer leaves. The severity of salinity on crops is based on the environment's humidity, temperature, radiation, and air pollution. Some of the agricultural production could be shifted to salt-tolerant crops. Irrigation with salty water tends to accumulate salt in the soil, decreasing soil productivity. Note that this is not the only way that climate change can disrupt food production.

4.8.4 Food Production Impacted by Climate Change and Salinity Intrusion

Drought and other climate extremes have a direct impact on food crop, food supply, and economics. During a dry spell, there will be excessive water loss from the plants; thus, the process of photosynthesis is greatly reduced and it is difficult for the plants to survive [36]. On the contrary, during a flooding event, plants will be inundated and damaged due to depleted oxygen (approaches zero after 24 h flooding event) and nitrogen levels in the flooded soils. In addition, the affected plant's stomata will be closed for a period of time which will subsequently reduce the respiration, transpiration. Loss in crop yield may lead to economic collapse (as the price of staple crops could rapidly escalate causing major inflation) and food shortage, where hunger will be the biggest battle and create conflicts in some countries.

Coming out of the last ice age, the climate change was maintained and steady and the human population was small and nomadic, whereas now, large communities of an increasing population live away from agriculture that naturally gets rain, but instead relies on irrigation. Demand for water is greater than the renewable supply of freshwater for a community's demand and supply needs. Irrigation demand is of poor water quality containing dissolved salts that collect in the soil. Irrigation and removing native perennial vegetation have led to rising water tables—some rise into the root zone and soak the land. Over 50% of groundwater is saline, especially in dry and semiarid regions, so as water tables rise, the saltwater gets brought into root zone areas. How sustainable are irrigated systems as we work through issues of water resource availability and allocation? The changes in climate and population are projected to increase, and so irrigation and water supply would follow. Unless dramatic changes are made, continued increasing salinity will be found in agriculture.

4.8.5 Ecosystem Impacts Due to Loss of Freshwater Habitat (Recreation, Fishing)

Salt accumulation in soils is often controlled by flushing the salts away with additional amounts of irrigation water. This increases costs; wastes water, which may not be abundantly available in the first place; and unless adequate drainage is available, increases the likelihood that a rising water table will drown plant roots in salt-laden water. Providing adequate drainage can be an expensive and challenging task involving extensive on-farm subsurface drainage systems coupled with a central drain and disposal system. Even when salt is removed from the agricultural land by good drainage, it can have later repercussions. In the mid-1980s, it was found that birdlife in the natural freshwater marshes of the Kesterson National Wildlife Refuge in Central California was being poisoned by selenium draining from the region's agricultural fields. Since irrigation return water contains not only salts but also fertilizers and pesticides, finding an acceptable method of disposal is difficult. These issues with salts highlight how important it is to not only deal with the immediate impacts of pollution but to develop the remedies so that further downstream impacts are not created.

4.9 Impacts of Solid Waste Landfill Gas on Sanitary Landfill Utility, Ecosystem, and Human

4.9.1 Impacts on Sanitary Landfill Operations and Surrounding Environment

Shammas, Wang, Wang, and Chen [35] have discussed the ecological impact of sanitary landfill gas (LFG) on the landfill utility's operation as well as LFG collection, control, and utilization. The result of a 214-year study of the time phase evolution of various gases in a landfill has shown the following [38]:

1. Hydrogen, oxygen, nitrogen, carbon dioxide, and methane constitute the major gases.
2. Hydrogen in great quantities appears during the first 3 weeks (20% during the first and second weeks).
3. Hydrogen sulfide appears in a trace form during the first 2 years.
4. Carbon dioxide reaches 35% after 2 weeks (40% after 2 months).

5. Methane reaches 2.7% after 2 months, 6% in 6 months, 13% after 1 year, and 20% after 2 years.
6. Composition of gas is dependent on compaction densities. Higher compaction densities yield more gas per unit volume.
7. The most pronounced changes in the organic materials occur within the first 2 months.
8. A landfill is still far from being stabilized at the end of 2 years.
9. Dry refuse and saturated refuse produce 0.0022 and 0.0131 m^3 gas/kg refuse, respectively, on a dry basis.
10. Carbon dioxide increases the hardness and level of bicarbonates in groundwater. Depending on the pH, the water may become acidic and corrosive.

Aziz, Rosli, and Hung [36] have reported that methane is a shorter lifetime potent gas (9–15 years) with a high global warming potential due to a strong molar absorption coefficient. As the concentrations in the atmosphere increased due to uncontrolled anthropogenic methane production, it has become more long-lived and causes damages by creating an imbalance between methane emissions and removals. Their publication [36] discusses about methane generation in landfills (anaerobic decomposition process, source of methane in landfills, and methane reduction), methane emissions (mechanisms and factors influencing the mechanisms), methane in the atmosphere (methane sink and removal), and the impact of landfill methane emissions.

The migration and emission of LFG may potentially lead to negative effects in the surroundings, for example, fire and explosion hazards, health risks, damage to vegetation, groundwater contamination, and global climate effects. The main environmental hazards related to methane emissions are believed to be explosion hazards and global climate effects.

The potential for methane gas to explode is determined by its lower explosive limit (LEL) and upper explosive limit (UEL), which lies between 5 and 15% in air at ambient temperature and atmospheric pressure. Even though explosion will not occur if the concentration is above the UEL, methane concentrations equal to or greater than LEL will be considered hazardous as it exceeds the LEL. Thus, it is essential to monitor and keep the methane concentration below the LEL.

4.9.2 Impacts on Human Health

Extreme climate affects human health with exposure to both extreme hot and cold weather being associated with cardiovascular disease (CVD) and mortality [36]. The Europe episode in summer 2013 is one example of mortality effect, when the temperature increased to 3.5 °C above normal and caused 22,000–45,000 heat-related deaths within 2 weeks in August 2003. In addition, changes in the rainfall pattern in many areas affect the distribution of infectious diseases/vector-borne diseases (malaria, dengue, plague, elephantiasis, and bluetongue disease) due to the nature of the infectious agents (bacteria, virus, and protozoa) and their vector organisms (mosquitoes, snails, and other insects) that are temperature dependent, with a warm environment boosting their rate of reproduction. This was seen during an El Niño episode in Peru (1997–1998) when the ambient temperature increased more than 5 °C above normal and caused the number of daily admissions for diarrhea to increase by twofold from the previous rate.

At a low concentration in the air, methane and carbon dioxide do not affect the health. Nevertheless, high concentrations of methane and carbon dioxide in the atmosphere will contribute to adverse health effects, not by breathing the gases itself but through the displacement of oxygen, which can reduce the concentration of oxygen (below 16%) in the air [41]. As a result, there is a risk of asphyxiation, which can lead to dizziness, fatigue, vomiting, headache, visual disturbance, faster heartbeat, asthma, reduced lung function, unconsciousness, and even death if the condition is prolonged [42].

4.9.3 Impacts on Vegetation

Methane does not have a direct toxicity effect on the plant or vegetation growth. Nevertheless, a high methane concentration in ambient air will result in a lack of oxygen in the root zone, and the displacement of oxygen by methane can cause anaerobic soil conditions which are detrimental to plants [35].

4.10 Natural Variability

Is it possible that the natural environment could make a small contributing factor toward climate change? When assessing climate change, one must also consider the impacts of the natural environment. Natural contributions to climate can happen through either internal impacts or external forces. Internal impacts are those factors that occur directly within a climate system. These can occur within the atmosphere, through entities within the climate system, or among phenomena that drive climate variations on Earth. The effects of internal impacts can happen almost immediately or incrementally over a long period. On the other hand, external forces are factors outside of the climate system that can result in changes in the climate. For example, ash and sulfuric aerosols from a volcanic eruption may cause temporary changes both locally and thousands of miles away from the eruption. The consequence of these natural particulate emissions is that these emissions create a layer of particulates that keep sunlight from penetrating the atmosphere. As a result, there is an expectation that temperatures will be cooler for a period before recovering back to levels experienced prior to the event [31–32].

The change to climate due to nature can happen over a short or long period of time. Changes that happen over thousands of years are known as millennial climate cycles. These cycles can happen every 10,000–100,000 years and can cause significant periods of warming and cooling. The cause of these changes can be attributed to Milankovitch cycles, or changes in the Earth's orbit around the Sun. While these changes do not directly cause warming and cooling, they can provide a mechanism for these phenomena to take place. For example, a change in solar reflectivity can increase ice melt. Periods where warming and cooling can occur between 250 and 1000 years are known as century-scale climate changes. The shorter periods between events could be attributed to the Sun or ocean circulation patterns. Finally, there are periods where climate can change in as short of a time as year to every 10 years. Most of the time, this is caused by interactions between the ocean and the atmosphere. The most common example is the El Niño-Southern Oscillation (ENSO). This can bring warmer weather to some areas and an increase in precipitation in others.

It is important to quantify if climate change is directly related to the climate system or some external factors. The primary way to determine this is by having an understanding of the physical attributes of the climate. Data based on climatic observations is also beneficial. Models can also be considered because they provide a way to simulate the unpredictable effects of varying phenomena over time. Nevertheless, models must be compared with climatic observations and the known physical attributes of a climate to ensure that the models are put into proper context. This is done by placing proper boundaries around scenarios and outcomes that would not otherwise fit within what has been observed historically through data or by prior knowledge of the climate. This would in turn minimize potential biases that could occur in situations where data was unavailable [32].

So what have the models reported? The following is a summary of key points as described from the IPCC [31–32]:

1. With an exception of a few locals, the models show both model and observed data agree that warming occurs around the world. During the first half of the century, warming was due to a combination of anthropogenic and natural events (volcanic, solar, and internal). Anthropogenic sources caused warming during the second half of the century. The anthropogenic forcing appears to be primarily greenhouse gases (GHGs).
2. An increase in Northern Hemisphere (NH) temperatures has occurred within the last 50 years regardless of methods of reconstruction or external factors employed.
3. It is impossible to see a significant increase in NH temperatures without human influence, but natural variability would play some role since the warming is not consistent.
4. Greenhouse gas, volcanic eruptions, and solar irradiance have played some role in temperature change over the past 1000 years. Volcanic activity during 1675 and 1715 might have led to cooling during this time.
5. Models found that data that only considered natural variability did not match global mean surface temperature data. This data appeared to match better to what is seen in simulations comparing with what was observed.

6. There is uncertainty surrounding the effects from the Sun and volcanoes. This is primarily because of the changes to methods in modeling (e.g., number of sample sizes, scaling factors to account for unknown factors, and internal variability). Therefore, one must consider the assumptions and factors each author makes within a model.
7. Regional climate change may be hard to predict due to internal impacts that are unique to a particular area. These impacts will become more important at the regional level as opposed to considering the larger area. This is also true on shorter time scales of less than 50 years.
8. There has been documented evidence of a change in tropospheric height, ozone-induced stratospheric cooling, and tropospheric warming by GHGs. It appears that natural causes alone are simply unable to explain these changes.
9. Oceans have gained 14.2×10^{22} J of energy from 1961 to 2003. The reason behind such a gain may be attributed to GHGs and sulfur aerosols. Volcanic eruptions can explain some cooling events within an ocean.
10. The sea level rise might be explained by anthropogenic reasons, specifically upper ocean and glacier loss. There have been small changes to sea level pressure changes due to ozone depletion. Anthropogenic impacts have affected Asian monsoon circulation (black carbon aerosols), an increase of tropical cyclones, atmospheric water vapor, and saturated vapor pressure. The combination of both anthropogenic and natural causes has also contributed to an increase in land mass mean precipitation.
11. Greenhouse gases may have also caused changes in precipitation values and glacial retreat. Warming may have altered the movement of water vapor from the tropics to high-altitude regions may have led to changes in the precipitation values.

4.11 Applications to Take Action

To avoid the consequences, solutions begin with us. We can start by [2]:

1. Carpooling.
2. Get a vehicle with better gas mileage
3. Use compact florescent lights
4. Make your home more energy efficient by replacing appliances
5. Turn off your power strip when you are done; it conserves 25%
6. Be a better consumer by buying recycled things, and recycle simple things like the disposable coffee sleeve from your coffee shop
7. Get off junk mail
8. Stop buying bottled water and use a water filter

4.12 Summary

What is certain? It is certain that:

1. The study of climate change begun as early as the 1820s with scientists such as Fourier, Tyndall, and Arrhenius. Therefore, this field of science is older than the first trans-Atlantic flight and was before the invention of the atomic bomb!
2. Contemporary recognition of climate change began in the 1950s and continued to become a staple within the scientific community during the environmental movement of the 1960s and 1970s.
3. The increasing amount of human activity is changing the composition of the atmosphere with overwhelming supporting data.
4. Carbon dioxide, methane, and nitrous oxide are increasing dramatically because of human activities.
5. Greenhouse gases absorb heat and emit heat; since they get trapped in the atmosphere, the heat gets trapped in the atmosphere and warms the Earth.
6. Human activity produces greenhouse gases that remain in the atmosphere for years.
7. It is estimated that the average global temperatures have risen between 1 and 4 °F.
8. During the first half of the twentieth century, increases in temperature have been due to natural causes. During the latter half, temperature increases have been due to anthropogenic activities.
9. Greenhouse gases, global warming, and climate change have negative impacts on agricultural irrigation, agricultural operations, food production, water utility, and sanitary landfill utility.

What is uncertain? It is uncertain that:

1. Forecasting exact impacts to health, agriculture, water resources, forests, wildlife, and coastal areas in regional basis is difficult.
2. There is also uncertainty in quantifying the exact magnitude and extent of adverse effects, projecting the magnitude of sea level rise, and quantifying the indirect effects of aerosol particles to the Earth's energy balance (i.e., cloud formation and its radiative properties, precipitation efficiencies).
3. The negative impacts of greenhouse gases, global warming, and climate change on agricultural irrigation, agricultural operations, food production, water utility, and sanitary landfill utility cannot be quantified at present.

Adaptation/mitigation for the effects of climate change is necessary because evidence shows it is too late for complete prevention. The responsible thing to do is to start preparing now.

Glossary

Agricultural irrigation It is a large-scale agricultural process of applying controlled amounts of water to land to assist in the production of crops, as well as to grow landscape plants. Small-scale irrigation applied to lawn is called watering. There are different types of irrigation, such as sprinkler irrigation, surface irrigation, drip irrigation, subirrigation, and manual irrigation.

Climate (a) 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 of years. The classical period is three decades, as defined by the World Meteorological Organization (WMO). These 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. (b) The average weather (usually taken over a 30-year time period) for a particular region and time period. Climate is not the same as weather, but rather, it is the average pattern of weather for a particular region. Weather describes the short-term state of the atmosphere. Climatic elements include precipitation; temperature; humidity; sunshine; wind velocity; phenomena such as fog, frost, and hailstorms; and other measures of the weather.

Climate change (1) Changes in average weather conditions that persist over multiple decades or longer. Climate change encompasses both increases and decreases in temperature, as well as shifts in precipitation, changing risk of certain types of severe weather events, and changes to other features of the climate system. (2) Climate change refers to any significant change in the measures of climate lasting for an extended period of time. In other words, climate change includes major changes in temperature, precipitation, or wind patterns, among others, that occur over several decades or longer.

Enhanced greenhouse effect The concept that the natural greenhouse effect has been enhanced by increased atmospheric concentrations of greenhouse gases (such as CO_2 and methane) emitted as a result of human activities. These added greenhouse gases cause the Earth to warm.

Environment The complex of physical, chemical, and biotic factors (as climate, soil, and living things) that act upon an organism (a living thing) or an ecological community (a collection of living things) and ultimately determine its form and survival. The circumstances, objects, and conditions that surround each of us.

Public utility (a) A public utility is an organization that maintains the infrastructure for a public service and, therefore, is subject to forms of public control and regulation ranging from local community-based groups to statewide government monopolies. (b) It is an organization supplying the community with electricity, gas, water, solid waste disposal service, or sewerage management service.

Rain-fed agriculture It is an agriculture that does not use irrigation but instead relies only on direct rainfall.

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