Study Session 9  Introduction to Climate Change
Introduction

This is the first of three study sessions on the rapid changes in the world’s climate since the start of the 20th century, which scientists have detected. Climate change is a global problem that is having widespread effects on the weather on every continent and in every nation. It is altering environments and impacting on biodiversity, human health and sustainable economic and social development. We begin this study session by introducing some key terms and concepts in climate science, and describing the main features of current and future projections of how the global climate is changing. You will then learn about the causes of climate change, both naturally occurring and resulting from human activity. Finally we discuss Ethiopia’s climate and some reasons for concern about Ethiopia’s vulnerability to climate change. In Study Sessions 10 and 11 you will focus on Ethiopia in greater detail as we review the frequency and severity of extreme weather events that are due to climate change, and describe the impacts on health, agriculture and the Ethiopian economy.

Learning Outcomes for Study Session 9

When you have studied this session, you should be able to:

9.1 Define and use correctly each of the key words printed in bold. (SAQs 9.1, 9.2 and 9.3)
9.2 Summarise how the global surface temperature of the land and oceans has changed since the start of the 20th century and describe the effect on sea levels. (SAQ 9.2)
9.3 Describe the naturally occurring and human-generated causes of climate change. (SAQ 9.3)
9.4 Explain how the emission of greenhouse gases into the atmosphere leads to global warming. (SAQ 9.4)
9.5 Identify the observed and predicted changes in climate in Ethiopia. (SAQ 9.5)

9.1 Weather, climate variability and climate change

Everyone is familiar with what is meant by the weather – the temperature, rainfall, wind strength, sunshine, cloud cover, etc. that we experience from hour to hour and from day to day in our local environment. For example, the weather in Addis Ababa on Wednesday 11 March 2015 was light winds (wind speed 10 km/hour), humidity 28%, pleasantly warm (a maximum temperature of 22 °C) and sunny with some clouds.

By contrast, the climate refers to a general description of longer-term features of the weather in a particular location, such as the average temperature or rainfall for each month of the year, calculated over a period of 30 years or more (Pollution Probe, 2004). You can think of the weather as being a daily expression of the fluctuations of climate around the long-term average pattern.
Climates vary widely around the world – from the hot, rainy climates of tropical regions near the equator, to the cold, icy climates near the poles, both of which experience much the same temperature all year round. There are hot, dry deserts and milder ‘temperate’ regions where there is a large difference in temperature between summer and winter. Some regions can have rain in any month, others have a well-defined wet or dry season, and some receive little rain or snow throughout the year.

Although climate is the average weather over a period of a few decades, the climate in a particular country or region isn’t exactly the same every year – it varies around the average climate for that location. You probably remember a year that was hotter or cooler than this year, but the difference was probably not outside the normal range you would expect in your region of Ethiopia. These fluctuations around the average climate are termed climate variability. They are mainly due to fluctuations in natural conditions in the environment such as changes in the patterns of ocean currents or atmospheric pressure (Pollution Probe, 2004).

The global climate has undergone many long-term cyclical variations during millions of years of Earth's history, owing to shifts in natural environmental factors (described in Section 9.3). But from about the beginning of the 20th century, climate scientists began to detect changes in the global climate over time that were happening at a much faster rate than could be explained by normal climate variability. As the evidence for widespread, rapid changes in the world’s climate increased, scientists began using the term climate change to distinguish these trends from normal climate variation.

A frequently mentioned feature of climate change is global warming – a sustained increase in the Earth's average surface temperature, which is predicted to continue rising during the 21st century. However, climate change has other important features, including changes in ocean currents, sea surface temperature, wind strength and direction, and the distribution and extent of rainfall. Many scientists from all over the world agree that climate change is a reality (IPCC, 2013). In the next section, we describe what climate scientists have observed; then in Section 9.3 we examine what is causing the climate to change.

9.2 Observed and projected patterns of global climate change

We begin by considering the long-term rising trend referred to as global warming, and then consider the effect of rising surface temperatures on sea levels and patterns of rainfall.

9.2.1 Global land and sea surface temperatures are rising

In the 100 years between 1905 and 2005, the average global surface temperature has increased by 0.74 °C. Most of this increase has occurred since 1950 and the upward trend is continuing (Bates et al., 2008). The first decade of the 21st century was the warmest since humans began recording surface temperature (IPCC, 2013). If present
trends continue, the average global surface temperature is projected to increase by between 0.3 °C and 4.8 °C by the end of the 21st century (IPCC, 2013). The surface temperature of the oceans has also been rising and the increase is expected to accelerate during the 21st century. Figure 9.1 shows global averages for the annual combined land and ocean surface temperature and the average in each decade from 1850 to 2012.

Figure 9.1  The global annual mean atmospheric surface temperature change from 1880 to 2010. 0 °C on the vertical axis is the mean global atmospheric surface temperature minus the mean global temperature from 1951 to 1980. The black line is the annual mean and the solid red line is a smoothed line through the annual mean. The blue bars show uncertainty estimates.

- Look at the general pattern of surface temperatures shown in Figure 9.1. How would you describe the trend during this period?
- The global surface temperature fluctuated around a relatively stable average from 1880 to about 1920, but after that date it began to rise. Around 1950, the temperature increase seems to have levelled for about 30 years, but it has been increasing rapidly in the decades since 1970.
9.2.2 Effects of rising global temperature on sea levels

Increased global temperature affects the amounts of snow, ice and glaciers that remain frozen. Several reports indicate that the frozen water in the northern hemisphere is melting faster than expected, particularly in the last two decades (IPCC, 2013). As you can see from Figure 9.2, there has been a sharp decrease since about 1960 in the extent of Arctic sea ice during the summer months and in the spring snow cover in the northern hemisphere. About 60–70% of Africa’s glaciers have also been lost since the early 1900s (UNEP, 2012).

![Figure 9.2](image-url) (a) Decrease in Arctic summer sea ice and (b) Northern hemisphere spring snow cover from 1900 to 2010. The coloured lines indicate different original sources of data that have been combined in one graph. (IPCC, 2013)

When there is increased melting of polar ice sheets and snow cover, the melted water flows into the oceans and contributes to the long-term rising trend in global sea levels, shown in Figure 9.3. The global sea level has risen by an estimated 190 millimetres (mm) since the start of the 19th century.
Rising sea levels erode coastlines and allow seawater to flood inland, damaging coastal towns and cities.

- What other effects will seawater flooding have on coastal communities and environments?
- Sea water contaminates fresh water and soils with salt, which reduces the productivity of agricultural land, kills trees and destroys habitats for animals and plants. Salt damage to the environment causes shortages of food and fresh drinking water, leading to malnutrition, displacement of human populations and loss of biodiversity.

Global warming also increases the evaporation of surface water into the atmosphere, which in turn leads to changes in the patterns and intensity of rainfall in different parts of the world. Changes in rainfall cause an increase in floods in some regions and more frequent droughts in others. You will learn more about these changes and their effects on humans and the environment in Study Sessions 10 and 11. Next we discuss the causes of the global climate changes we have just described.

9.3 What are the causes of climate change?

We mentioned earlier that cyclical variations in the global climate have been occurring for millions of years because of shifts in natural environmental factors. We briefly describe
two of the main natural causes of climate change before turning to those that can be attributed to human activity.

9.3.1 Natural causes of climate change

The amount of energy reaching the Earth as heat from the sun has varied over millennia due to changes in the intensity of activity in the sun’s magnetic core. The average temperature of the Earth’s surface increases when solar activity is high and decreases when solar activity is reduced. These changes in the intensity of solar activity take place in cycles lasting hundreds of years, with profound effects on the Earth’s climate. For example, between the 17th and 19th centuries, winters in the northern hemisphere were unusually long and cold, leading to reduced growing seasons, widespread crop failure and famine. This period has become known as the ‘Little Ice Age’ and is thought to have been caused partly by low solar activity.

The global climate can also be influenced by volcanic eruptions. The explosion of dust particles, ash, water vapour and gases such as sulphur dioxide into the atmosphere is dispersed around the globe and reflects sunlight back into space.

- What effect do you think volcanic eruptions could have on the Earth’s surface temperature?
- If some of the energy from sunlight is reflected back into space by the dust in the atmosphere, the average surface temperature of the Earth is likely to be reduced.

Even though the volcanic eruption may last only a few days, the effect on the global climate may last for several years. For example, the average surface temperature in the northern hemisphere was reduced by about 0.5 °C for a few years after the eruption of Mount Pinatubo in the Philippines in June 1991 (Figure 9.4).

Figure 9.4 The eruption of Mount Pinatubo, Philippines, released huge amounts of dust particles and gas into the atmosphere.
Solar activity and volcanic eruptions cannot be modified by human interventions. However, human activity is increasingly seen as a direct cause of climate change from the 20th century onwards.

9.3.2 How do greenhouse gases contribute to climate change?

Climate change has been accelerating in recent decades in part due to increasing emissions into the atmosphere of so-called greenhouse gases generated by a range of human activities. We will explain why they have been given this name in a moment, but first note from Figure 9.5 how the atmospheric concentration of the major greenhouse gases – carbon dioxide, methane and nitrous oxide – has changed over the past 2000 years. It remained constant until about 1750, but then began rising, with dramatic increases since about 1900. These recent increases are attributed to human industrial and domestic activity.

![Figure 9.5 Changes in the atmospheric concentration of carbon dioxide, methane and nitrous oxide over the last 2000 years, measured in parts per million (ppm) or parts per billion (ppb). (IPCC, 2007a)](image)

These gases have been called ‘greenhouse’ gases because they act like the glass or plastic sheeting in a greenhouse (see Figure 9.6). Sunlight has a short wavelength and high energy, which enables it to pass through the glass into the greenhouse. Sunlight
energy heats the air, plants, soil and structures in the greenhouse, and some of this heat energy is radiated back towards the glass in the form of infra-red radiation. However, infra-red radiation has a long wavelength and low energy, which means it is not able to pass back out through the glass, so the radiated heat remains in the greenhouse causing it to heat up very quickly. This phenomenon increases the productivity of greenhouse crops because plants grow faster in the higher temperature.
Figure 9.6 (a) Plastic greenhouses used for flower growing in Ethiopia and (b) the greenhouse effect.

A similar process happens at a global scale. Global warming is partly due to the effect of greenhouse gases in the atmosphere. Sunlight has enough energy to pass through these gases in the Earth’s atmosphere, so it reaches the Earth's surface and transmits heat energy. Some of this heat energy is radiated back from the Earth's surface into the atmosphere as lower-energy infra-red radiation. The greenhouse gases in the atmosphere absorb some of this infra-red radiation and reflect it back towards the Earth, causing the Earth's temperature to heat up a bit more (Cunningham and Cunningham, 2006).

This greenhouse effect is a natural phenomenon. It is crucial for the survival of life on Earth because it maintains a global average temperature of about 15 °C. Without the greenhouse effect our global average temperature would be much colder: about −18 °C. However, human industrial and domestic activity since the start of the 20th century has released rapidly increasing amounts of greenhouse gases into the atmosphere. As a consequence, more sunlight energy is trapped close to the Earth because even less of the radiated heat can escape through the thicker shield of greenhouse gases surrounding the Earth.

9.3.3 How are greenhouse gases generated?

Human civilisation is highly dependent for its sources of energy on burning fossil fuels such as coal, oil and natural gas. Fossil fuels are formed over millions of years from the decayed remains of living organisms buried underground. The burning of fossil fuels, wood and compressed animal dung generates large amounts of carbon dioxide (CO₂), one of the major greenhouse gases. Carbon dioxide remains in the atmosphere for many years and causes the Earth’s surface temperature to rise as a result of the greenhouse
effect. Figure 9.7 shows that the concentration of atmospheric CO\textsubscript{2} increased from 280 ppm in 1958, to more than 380 ppm in 2010 (IPCC, 2013).

![Figure 9.7 The concentration of carbon dioxide in the atmosphere from 1958 to 2010 measured in ppm at Mauna Loa, Hawaii. (Scripps, 2007)](image)

There are natural processes on Earth that, to some extent, balance the generation of carbon dioxide. For example, all green plants remove CO\textsubscript{2} from the atmosphere in the process of photosynthesis. Plants, especially forests, oceans and wetlands are all important carbon sinks. **Carbon sink** is the term used to describe natural systems that absorb and store carbon dioxide from the atmosphere. However, as Figure 9.7 shows these balancing processes are not able to keep up with the rate of CO\textsubscript{2} generation.

Another important greenhouse gas is methane (CH\textsubscript{4}), which is increasing in the atmosphere as a result of two main aspects of human activity: the decomposition of organic solid waste, and livestock farming. The digestive processes of ruminant animals such as cows (Figure 9.8), sheep and goats produce and release large amounts of methane gas (USEPA, n.d.; NASA, n.d.).

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**Figure 9.7** The concentration of carbon dioxide in the atmosphere from 1958 to 2010 measured in ppm at Mauna Loa, Hawaii. (Scripps, 2007)

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Nitrous oxide (N\textsubscript{2}O) is another major greenhouse gas. It is generated from human activities such as burning organic materials, vehicle exhaust emissions and the production and use of organic fertilisers (USEPA, n.d.; NASA, n.d.). The concentration of N\textsubscript{2}O in the atmosphere has increased from the pre-industrial level of 270 parts per billion (ppb) to about 324 ppb in 2011 (IPCC, 2013).

Now that you know about the pattern of climate change at a global level and how it is affected by human activities, we can turn our attention to the effects in Ethiopia in the final section of this study session.

9.4 Observed and projected climate change in Ethiopia

The wide variation in elevation (the height of land above sea level) in Ethiopia produces three types of climate, illustrated in Figure 9.9:

- The hot Kolla climate occurs in regions below 1500 m and has an average annual temperature of about 30–33°C with an average annual rainfall of 300–1000 mm.
- The temperate *Woina dega* climate occurs in regions between 1500 and 2500 m and has an average annual temperature of 16–29°C with an average annual rainfall of 400–2400 mm.
- The cool *Dega* climate occurs in regions above 2500 m and has an average annual temperature of 10–16°C with an average annual rainfall of 1000–1600 mm.

*Figure 9.9 Maps of the average annual temperature and rainfall across Ethiopia.*
*(Hopping and Wann, 2009)*
Based on Figure 9.9, what type of climate and how much rain would you expect in the lowlands of Ethiopia like Asayat, Afar Region?

- You would expect a very hot climate and very little rainfall.

If you lived in the highlands, for example in the Simien Mountains, what type of climate would you have and how much rain would you expect?

- You would expect a very cold climate and high rainfall.

Like many other countries in the world, climate change has been observed in Ethiopia. Since 1950 the average minimum temperature has been rising by about 0.37 °C per decade the average temperature is expected to increase substantially if global greenhouse gas emissions continue at the present rate (MoWR/NMA, 2007). The projected increases in Ethiopia’s average temperature in the future are: 0.9–1.1 °C by 2030, 1.7–2.1 °C by 2050 and 2.7–3.4 °C by 2080.

Ethiopia has experienced both dry and wet years since 1950, but the average annual rainfall has remained more or less constant. However, some regions of the country have experienced more frequent and more widespread floods, whereas other regions have been hit by more frequent and intense droughts. Floods and droughts are categorised as ‘extreme weather events’ and you will learn more about them in Study Session 10. Here are some key points to demonstrate that Ethiopia is experiencing climate change (EM-DAT, n.d.):

- Between 1960 and 1990 there were ten floods in Ethiopia, but between 1990 and 2014 there were 46 reported flood events.
- Between 1960 and 1990 there were six droughts in Ethiopia, but between 1990 and 2014 nine drought events were reported and they are occurring at more frequent intervals, approximately every two years.
- In 1965, about 1.5 million people were affected by droughts, but the number has increased over time; in 2003, about 13 million people in Ethiopia were drought-affected.

Low-income countries like Ethiopia are highly vulnerable to the effects of climate change and extreme weather events. They lack sufficient numbers of people who have been trained in how to respond and they lack the organisational and financial resources to deal with the impacts on environments and communities. Rural areas are particularly vulnerable to loss of agricultural livelihoods, leading to population displacement and food shortages. Ethiopian towns and cities are vulnerable to climate change because they are densely populated (Environmental Protection Authority, 2003). You will learn more about the impacts of climate change in Ethiopia in Study Sessions 10 and 11.

Summary of Study Session 9

In Study Session 9, you have learned that:

1. The climate is the average weather experienced over months or years and climate variability is the short-term fluctuations around the expected average weather.
Climate change refers to widespread, rapid changes in the global climate since the beginning of the 20th century, which have been increasing at a faster rate in recent decades.

One driver of climate change is global warming: the global average surface land and ocean temperature has increased by about 0.74 °C in the century between 1905 and 2005; climate change also includes alterations in wind patterns, ocean currents and the distribution of rainfall.

Natural causes of climate change include fluctuations in solar activity and volcanic eruptions. The major human cause of climate change is the increasing release of greenhouse gases (carbon dioxide, methane and nitrous oxide) into the atmosphere.

Greenhouse gases act like the glass in a greenhouse by reflecting radiated heat back towards the Earth, trapping more of the sun’s energy and causing the surface temperature to rise.

Global warming is causing sea levels to rise as ice and snow cover decreases and melted water runs into the oceans.

Climate change effects have been observed in Ethiopia, especially since 1950; the average minimum temperature and the average annual temperature have been rising; although there has been little change in average rainfall, the number and intensity of floods and droughts have also increased.

Self-Assessment Questions (SAQs) for Study Session 9

Now that you have completed this study session, you can assess how well you have achieved its Learning Outcomes by answering these questions.

SAQ 9.1 (tests Learning Outcome 9.1)
Match the following words to their correct definitions.
weather
a condition of the atmosphere over a short period of time

greenhouse effect
natural process in which heat energy from the sun is trapped by the Earth’s atmosphere so the surface stays warm

climate variability
short-term fluctuations from the expected average weather conditions

climate
the average weather over a relatively long period

climate change
a change in the average climate over a long period of time

carbon sink
process or system that removes carbon dioxide from the atmosphere
SAQ 9.2 (tests Learning Outcome 9.1)
Rewrite the paragraph below using terms from the list provided to fill the gaps.
droughts, floods, global warming, greenhouse gases, rainfall, sea levels.
The rise in the mean global surface temperature referred to as ................. is partly
due to an increase in the concentration of ................. in the atmosphere. This
change in the global climate is expected to melt Arctic sea ice, leading to rising
............... and to alter the pattern of ................., so that there are more severe
............... in wetter regions, and more severe ................. in drier regions.

Answer
The rise in the mean global surface temperature referred to as global warming is partly
due to an increase in the concentration of greenhouse gases in the atmosphere. This
change in the global climate is expected to melt Arctic sea ice, leading to rising sea
levels and to alter the pattern of rainfall, so that there are more severe floods in wetter
regions, and more severe droughts in drier regions.

SAQ 9.3 (tests Learning Outcome 9.3)
Which of the following statements are false? In each case explain why it is incorrect.

(A) THE GLOBAL CLIMATE IS AFFECTED BY FLUCTUATIONS IN THE AMOUNT
OF ENERGY REACHING THE EARTH FROM THE SUN.
(B) VOLCANIC ERUPTIONS INTO THE ATMOSPHERE INCREASE THE TEM-
PERATURE OF THE AIR AND CONTRIBUTE TO GLOBAL WARMING.
(C) GREENHOUSE GASES ARE ONLY PRODUCED BY HUMAN ACTIVITY.
(D) METHANE RELEASED BY DECOMPOSING SOLID WASTE AND LIVESTOCK
FARMING CONTRIBUTES TO THE GREENHOUSE EFFECT.

Answer
B is false. Dust, ash and gases released during volcanic eruptions create a shield
around the Earth that reflects sunlight energy back into space, so that the Earth’s
atmosphere is cooled – not warmed. The statement would have been correct if it said
that volcanic eruptions contribute to climate change.

C is also false. Greenhouse gases occur naturally in the atmosphere and keep the
global mean surface temperature of the Earth at around 15 ºC. Without these natural
greenhouse gases, the global mean surface temperature would be around –18 ºC.

SAQ 9.4 (tests Learning Outcome 9.4)
Rearrange the following statements into the correct order to produce a coherent
explanation of how the rising emission of greenhouse gases generated by human
activity is contributing to global warming.

- Heat energy is infra-red radiation, which has a long wavelength and low energy,
  and is absorbed by greenhouse gases in the atmosphere.
- Visible sunlight has a short wavelength and high energy, which enables it to pass
  through greenhouse gases in the Earth’s atmosphere.
- Heat is radiated from the surface of the Earth back towards the atmosphere.
- Sunlight energy reaches the Earth and heats the Earth's surface.
- Human activity since the start of the 20th century has increased the emission of greenhouse gases and accelerated the rate of global warming.
- Heat energy trapped in the atmosphere by the greenhouse gases causes the atmosphere to become warmer.

**Answer**

The correct sequence of statements explaining how the rising emission of greenhouse gases in the Earth's atmosphere is leading to global warming is as follows:

1. Visible sunlight has a short wavelength and high energy, which enables it to pass through greenhouse gases in the Earth's atmosphere.
2. Sunlight energy reaches the Earth and heats the Earth's surface.
3. Heat is radiated from the surface of the Earth back towards the atmosphere.
4. Heat energy is infra-red radiation, which has a long wavelength and low energy, and is absorbed by greenhouse gases in the atmosphere.
5. Heat energy trapped in the atmosphere by the greenhouse gases causes the atmosphere to become warmer.
6. Human activity since the start of the 20th century has increased the emission of greenhouse gases and accelerated the rate of global warming.

**SAQ 9.5 (tests Learning Outcome 9.5)**

Complete the following statements of evidence that climate change is occurring in Ethiopia by writing the missing numbers in the spaces provided:

(a) Since 1950 the average minimum temperature in Ethiopia has been rising by about …… °C per decade.
(b) Before 1990 there were 10 floods in Ethiopia, but between 1990 and 2014 there were …… reported flood events.
(c) Before 1990 there were 6 droughts in Ethiopia, but between 1990 and 2014 more than …… drought events were reported.
(d) In 1965, about 1.5 million people were affected by droughts, but in 2003 about …… million people in Ethiopia were drought-affected.

**Answer**

The completed statements of evidence for climate change in Ethiopia are:

(a) Since 1950 the average minimum temperature in Ethiopia has been rising by about 0.37 °C per decade.
(b) Before 1990 there were 10 floods in Ethiopia, but between 1990 and 2014 there were 46 reported flood events.
(c) Before 1990 there were 6 droughts in Ethiopia, but between 1990 and 2014 9 drought events were reported.
(d) In 1965, about 1.5 million people were affected by droughts, but in 2003 about 13 million people in Ethiopia were drought-affected.